ELECTRICIAN

NSQF LEVEL - 5

1^{st} Year (Volume I of II)

TRADE THEORY

SECTOR: Electrical

Directorate General of Training

DIRECTORATE GENERAL OF TRAINING
MINISTRY OF SKILL DEVELOPMENT & ENTREPRENEURSHIP
GOVERNMENT OF INDIA

NATIONAL INSTRUCTIONAL
MEDIA INSTITUTE, CHENNAI

Post Box No. 3142, CTI Campus, Guindy, Chennai - 600 032

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P. B. No.3142, CTI Campus, Guindy Industrial Estate,
Guindy, Chennai - 600 032.
Phone : 044 - 2250 0248, 2250 0657, 2250 2421
Fax : 91 - 44 - 2250 0791
email : nimi_bsnl@dataone.in
chennai-nimi@nic.in
Website: www.nimi.gov.in

FOREWORD

The Government of India has set an ambitious target of imparting skills to 30 crores people, one out of every four Indians, by 2020 to help them secure jobs as part of the National Skills Development Policy. Industrial Training Institutes (ITIs) play a vital role in this process especially in terms of providing skilled manpower. Keeping this in mind, and for providing the current industry relevant skill training to Trainees, ITI syllabus has been recently updated with the help of Mentor Councils comprising of various stakeholder's viz. Industries, Entrepreneurs, Academicians and representatives from ITIs.

National Instructional Media Institute (NIMI), Chennai has come up with instructional material to suit the revised curriculum for **Electrician 1st Year (Volume I of II) Trade Theory NSQF Level - 5** in **Electrical** sector under Semester Pattern required for ITIs and related institutions imparting skill development. The NSQF Level 5 will help the trainees to get an international equivalency standard where their skill proficiency and competency will be duly recognized across the globe and this will also increase the scope of recognition of prior learning. NSQF level 5 trainees will also get the opportunities to promote life long learning and skill development. I have no doubt that with NSQF level 5 the trainers and trainees of ITIs, and all stakeholders will derive maximum benefits from these IMPs and that NIMI's effort will go a long way in improving the quality of Vocational training in the country.

The Executive Director & Staff of NIMI and members of Media Development Committee deserve appreciation for their contribution in bringing out this publication.

Jai Hind

RAJESH AGGARWAL
Director General / Addl. Secretary,
Ministry of Skill Development & Entrepreneurship,
Government of India.

New Delhi - 110 001

PREFACE

The National Instructional Media Institute (NIMI) was established in 1986 at Chennai by then Directorate General of Employment and Training (D.G.E & T), Ministry of Labour and Employment, (now under Directorate General of Training, Ministry of Skill Development and Entrepreneurship) Government of India, with technical assistance from the Govt. of the Federal Republic of Germany. The prime objective of this institute is to develop and provide instructional materials for various trades as per the prescribed syllabi NSQF (Level 5) under the Craftsman and Apprenticeship Training Schemes.

The instructional materials are created keeping in mind, the main objective of Vocational Training under NCVT/NAC in India, which is to help an individual to master skills to do a job. The instructional materials are generated in the form of Instructional Media Packages (IMPs). An IMP consists of Theory book, Practical book, Test and Assignment book, Instructor Guide, Audio Visual Aid (Wall charts and Transparencies) and other support materials.

The trade theory book provides related theoretical knowledge required to enable the trainee to do a job. The test and assignments will enable the instructor to give assignments for the evaluation of the performance of a trainee. The wall charts and transparencies are unique, as they not only help the instructor to effectively present a topic but also help him to assess the trainee's understanding. The instructor guide enables the instructor to plan his schedule of instruction, plan the raw material requirements, day to day lessons and demonstrations.

IMPs also deals with the complex skills required to be developed for effective team work. Necessary care has also been taken to include important skill areas of allied trades as prescribed in the syllabus.

The availability of a complete Instructional Media Package (IMF) in an institute helps both the trainer and management to impart effective training.

The IMPs are the outcome of collective efforts of the staff members of NIMI and the members of the Media Development Committees specially drawn from Public and Private sector industries, various training institutes under the Directorate General of Training (DGT), Government and Private ITIs.

NIMI would like to take this opportunity to convey sincere thanks to the Directors of Employment & Training of various State Governments, Training Departments of Industries both in the Public and Private sectors, Officers of DGT and DGT field institutes, proof readers, individual media developers and coordinators, but for whose active support NIMI would not have been able to bring out this materials.

R. P. DHINGRA
EXECUTIVE DIRECTOR

Chennai - 600 032

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MEDIA DEVELOPMENT COMMITTEE MEMBERS

Shri. T. Muthu	–	Principal (Retd.), MDC Member. NIMI, Chennai
Shri. C.C. Jose	–	Training Officer (Retd.), MDC Member, NIMI, Chennai
Shri. K. Lakshmanan	–	Assistant Training Officer (Retd.), MDC Member, NIMI, Chennai.

NIMI CO-ORDINATORS

Shri. K. Srinivasa Rao	–	Joint Director NIMI, Chennai - 32.
Shri. V. Gopalakrishnan	–	Assitant Manager, NIMI, Chennai - 32

NIMI records its appreciation for the Data Entry, CAD, DTP operators for their excellent and devoted services in the process of development of this Instructional Material.

NIMI also acknowledges with thanks the invaluable efforts rendered by all other NIMI staff who have contributed towards the development of this Instructional Material.

NIMI is also grateful to everyone who has directly or indirectly helped in developing this Instructional Material.

INTRODUCTION

This manual for trade Theory is intended for use in the ITI classoom. It consists of a series of practical exercises that are to be completed by the trainees during the first semester of course is the **Electrician trade under Electrical Sector. It is National Skills Qualifications Framework (NSQF) - (LEVEL 5),** supplemented and supported by instructions/information to assist the trainees in performing the exercises. The syllabus for the1st Semester **Electrician NSQF (LEVEL - 5)** Trade under **Electrical Sector** Trade Practical is divided into Six Modules.The allocation of time for the various modules is given below:

Module 1: Safety Practice and Hand Tools	14 Exercises	75 Hrs
Module 2: Basic Workshop Practice (Allied Trade)	09 Exercises	100 Hrs
Module 3: Wires, Joints - Soldering - U.G. Cables	10 Exercises	125 Hrs
Module 4: Basic Electrical Practice	11 Exercises	75 Hrs
Module 5: Magnetism and Capacitors	08 Exercises	50 Hrs
Module 6: AC Circuits	12 Exercises	100 Hrs
Total	64 Exercises	525 Hrs

The syllabus and the content in the modules are interlinked. As the number of workstations available in the electrical section is limited by the machinery and equipment, it is necessary to interpolate the exercises in the modules to form a proper teaching and learning sequence. The sequence of instruction is given in the schedule of instruction which is incorporated in the Instructor's Guide. With 25 practical hours a week of 5 working days 100 hours of practical per month is available.

The procedure for working through the 64 exercises for the 1st semester with the specific objectives to be achieved as the learning out comes at the end of each exercise is given in this book.

The symbols used in the diagrams comply with the Bureau of Indian Standards (BIS) specifications.

This manual on trade Theory forms part of the Written Instructional Material (WIM). Which includes manual on trade theory and assignment/test.

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ASSESSABLE / LEARNING OUTCOME

On completion of this book you shall be able to

- **Apply safe working practices**
- **Prepare profile with an appropriate accuracy as per drawing**
- **Prepare electrical wire joints, carry out soldering, crimping and measure insulation resistance of underground cable.**
- **Verify characteristics of electrical and magnetic circuits.**

SYLLABUS

1st Year (Volume I of II) **Duration: Six Month**

Week No.	Ref. Learning Outcome	Professional Skills(Trade Practical) with Indicative hours	Professional Knowledge (Trade Theory)
1.	• Apply safe working practices • Install and setup operating system and related software in a computer.	**Safe working practices** 1. Visit various sections of the institutes and location of electrical installations. (05 hrs) 2. Identify safety symbols and hazards. (05 Hrs) 3. Preventive measures for electrical accidents and practice steps to be taken in such accidents. (05 hrs) 4. Practice safe methods of fire fighting in case of electrical fire. (05 hrs) 5. Use of fire extinguishers. (05 Hrs)	Scope of the electrician trade. Safety rules and safety signs. Types and working of fire extinguishers
2.	• Install and setup operating system and related software in a computer.	6. Practice elementary first aid. (05 hrs) 7. Rescue a person and practice artificial respiration. (05 Hrs) 8. Disposal procedure of waste materials. (05 Hrs) 9. Use of personal protective equipments. (05 hrs) 10. Practice on cleanliness and procedure to maintain it. (05 hrs)	First aid safety practice. Hazard identification and prevention. Personal safety and factory safety. Response to emergencies e.g. power failure, system failure and fire etc
3	• Prepare profile with an appropriate accuracy as per drawing	11. Identify trade tools and machineries. (10 Hrs) 12. Practice safe methods of lifting and handling of tools & equipment. (05 Hrs) 13. Select proper tools for operation and precautions in operation. (05 Hrs) 14. Care & maintenance of trade tools	Concept of Standards and advantages of BIS/ISI. Trade tools specifications. Introduction to National Electrical Code-2011

4 - 5	• Prepare profile with an appropriate accuracy as per drawing	15. Operations of allied trade tools. (05 Hrs) 16. Workshop practice on filing and hacksawing. (10 Hrs) 17. Prepare hand coil winding assembly. (5 Hrs) 18. Practice on preparing T-joint, straight joint and dovetail joint on wooden blocks. (15 Hrs) 19. Practice sawing, planing, drilling and assembling for making a wooden switchboard. (15 Hrs)	Allied trades: Introduction to fitting tools, safety precautions. Description of files, hammers, chisels hacksaw frames, blades, their specification and grades. Marking tools description and use. Types of drills, description & drilling machines. Various wooden joints
6 - 7	• Prepare profile with an appropriate accuracy as per drawing	20. Practice in marking and cutting of straight and curved pieces in metal sheets, making holes, securing by screw and riveting. (10 Hrs) 21. Workshop practice on drilling, chipping, internal and external threading of different sizes. (20 Hrs) 22. Practice of making square holes in crank handle. (5 Hrs) 23. Prepare an open box from metal sheet. (15 Hrs)	Marking tools; calipers Dividers, Surface plates, Angle plates, Scribers, punches, surface gauges Types, Uses, Care and maintenance. Sheet metal tools: Description of marking & cutting tools. Types of rivets and riveted joints. Use of thread gauge. Description of carpenter's tools Care and maintenance of tools
8	• Prepare electrical wire joints, carry out soldering, crimping and measure insulation resistance of underground cable	24. Prepare terminations of cable ends (02 hrs) 25. Practice on skinning, twisting and crimping. (15 Hrs) 26. Identify various types of cables and measure conductor size using SWG and micrometer. (8 Hrs)	Fundamentals of electricity, definitions, units & effects of electric current. Conductors and insulators. Conducting materials and their comparison
9 - 10	• Prepare electrical wire joints, carry out soldering, crimping and measure insulation resistance of under ground cable	27. Make simple twist, married, Tee and western union joints. (18 Hrs) 28. Make britannia straight, britannia Tee and rat tailjoints. (18 Hrs) 29. Practice in Soldering of joints / lugs. (14 Hrs)	Joints in electrical conductors. Techniques of soldering. Types of solders and flux

11 - 12	• Prepare electrical wire joints, carry out soldering, crimping and measure insulation resistance of underground cable	30. Identify various parts, skinning and dressing of underground cable. (15 Hrs) 31. Make straight joint of different types of underground cable. (15 Hrs) 32. Test insulation resistance of underground cable using megger. (05 hrs) 33. Test underground cables for faults and remove the fault. (15 Hrs)	Underground cables: Description, types, various joints and testing procedure. Cable insulation & voltage grades Precautions in using various types of cables
13 - 14	• Verify characteristics of electrical and magnetic circuits	34. Practice on measurement of parameters in combinational electrical circuit by applying Ohm's Law for different resistor values and voltage sources and analyse by drawing graphs. (15 Hrs) 35. Measure current and voltage in electrical circuits to verify Kirchhoff's Law (10 Hrs) 36. Verify laws of series and parallel circuits with voltage source in different combinations. (05Hrs) 37. Measure voltage and current against individual resistance in electrical circuit (10 hrs) 38. Measure current and voltage and analyse the effects of shorts and opens in series circuit. (05 Hrs) 39. Measure current and voltage and analyse the effects of shorts and opens in parallel circuit. (05 Hrs)	Ohm's Law; Simple electrical circuits and problems. Kirchoff's Laws and applications. Series and parallel circuits. Open and short circuits in series and parallel networks
15	• Verify characteristics of electrical and magnetic circuits	40. Measure resistance using voltage drop method. (5 Hrs) 41. Measure resistance using wheatstone bridge. (5 Hrs) 42. Determine the thermal effect of electric current. (5Hrs) 43. Determine the change in resistance due to temperature. (5 Hrs) 44. Verify the characteristics of series parallel combination of resistors. (5 Hrs)	Laws of Resistance and various types of resistorsWheatstone bridge; principle and its applications. Effect of variation of temperature on resistance. Different methods of measuring the values of resistance. Series and parallel combinations of resistors

16 - 17	• Verify characteristics of electrical and magnetic circuits	45. Determine the poles and plot the field of a magnet bar. (08 Hrs) 46. Wind a solenoid and determine the magnetic effect of electric current. (06 Hrs) 47. Measure induced emf due to change in magnetic field. (06 hrs) 48. Determine direction of induced emf and current. (06 hrs) 49. Practice on generation of mutually induced emf. (08 hrs) 50. Measure the resistance, impedance and determine inductance of choke coils in different combinations. (06 Hrs) 51. Identify various types of capacitors, charging / discharging and testing. (05 Hrs) 52. Group the given capacitors to get the required capacity and voltage rating. (05 Hrs)	Magnetic terms, magnetic materials and properties of magnet. Principles and laws of electromagnetism. Self and mutually induced EMFs. Electrostatics: Capacitor- Different types, functions, grouping and uses. Inductive and capacitive reactance, their effect on AC circuit and related vector concepts
18 - 19	• Verify characteristics of electrical and magnetic circuits	53. Measure current, voltage and PF and determine the characteristics of RL, RC and RLC in AC series circuits. (08 Hrs) 54. Measure the resonance frequency in AC series circuit and determine its effect on the circuit. (07 hrs) 55. Measure current, voltage and PF and determine the characteristics of RL, RC and RLC in AC parallel circuits. (08 Hrs) 56. Measure the resonance frequency in AC parallel circuit and determine its effects on the circuit. (07 hrs) 57. Measure power, energy for lagging and leading power factors in single phase circuits and compare characteristic graphically. (08 Hrs) 58. Measure Current, voltage, power, energy and power factor in three phase circuits. (07 hrs) 59. Practice improvement of PF by use of capacitor in three phase circuit.(05 Hrs)	Comparison and Advantages of DC and AC systems. Related terms frequency, Instantaneous value, R.M.S. value Average value, Peak factor, form factor, power factor and Impedance etc. Sine wave, phase and phase difference. Active and Reactive power. Single Phase and three-phase system. Problems on A.C. circuits

20 - 21	• Verify characteristics of electrical and magnetic circuits	60. Ascertain use of neutral by identifying wires of a 3-phase 4 wire system and find the phase sequence using phase sequence meter. (10 Hrs) 61. Determine effect of broken neutral wire in three phase four wire system.(05 hrs) 62. Determine the relationship between Line and Phase values for star and delta connections. (10Hrs) 63. Measure the Power of three phase circuit for balanced and unbalanced loads. (15 Hrs) 64. Measure current and voltage of two phases in case of one phase is short-circuited in three phase four wire system and compare with healthy system.(10 hrs)	Advantages of AC poly-phase system. Concept of three-phase Star and Delta connection. Line and phase voltage, current and power in a 3 phase circuits with balanced and unbalanced load. Phase sequence meter
22 - 23	Project work / Industrial visit Broad Areas: a) Prepare and assemble a test board with switches, plug socket, lamp holder etc. b) Temperature controlled system for switching 'ON' and 'OFF' of any circuit using bimetallic strip. c) Series/ parallel combinational circuits		
24 - 25	Revision		
26	Examination		

Organization of ITI's and scope of the electrician trade

Objectives: At the end of this lesson you shall be able to
- **state brief introduction about Industrial Training Institutes (ITI)**
- **state about the organized structure of the Institute.**

Brief Introduction of Industrial Training Institute (ITIs)

Industrial Training Institute plays a vital role in economy of the country, especially interms of providing skilled manpower.

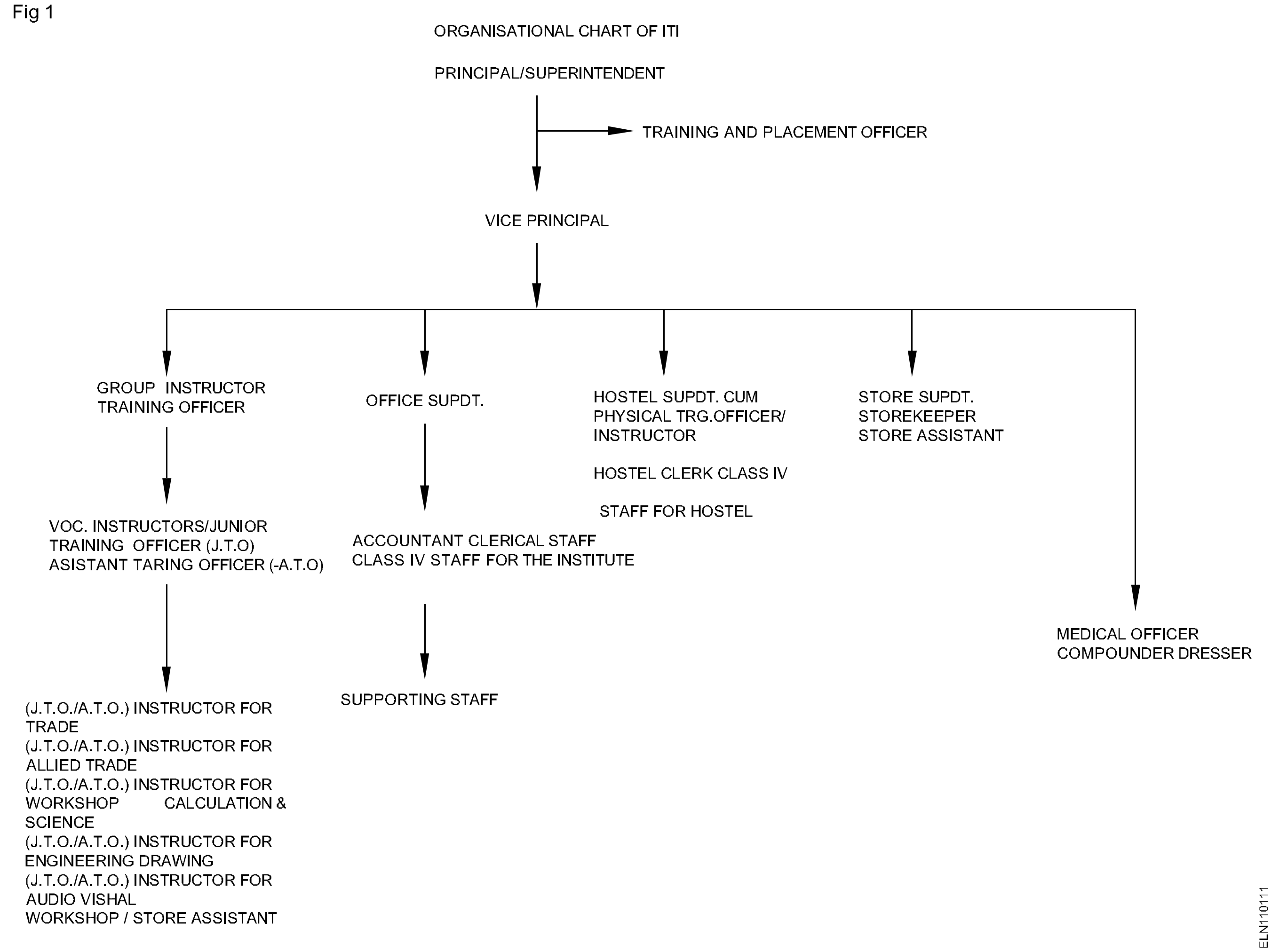
The Directorate General of Training (DGT) comes under **Ministry of Skill Development and Entrepreneurship (MSDE)** offers a range of vocational training trades in different sectors based on economy /labour market. The vocational training programs are delivered under the aegis of **National Council of Vocational Training (NCVT).** Craftsman Training scheme (CTS) and Apprenticeship Training Scheme (ATS) and two pioneer programs of NCVT for Propagatory Vocational Training.

Total number of ITIs in India as on April 2016 is about 13105 (Govt. 2293 + 10812 Private ITIs). They are giving training about 132 trades including Engineering and Non-engineering with the duration of 1 or 2 years. The minimum eligibility for admission in ITIs 8th, 10th and 12th pass with respect to the trades and admission process will be held in every year in July.

From 2013, semester pattern was introduced with 6 months/Semester and revised the syllabus for each semester. Then in 2014, they introduced and implemented "Sector Mentor council (SMC)" re-revised syllabus under 11 sectors of about 80 trades.

At the end of each semester, All India Trade Test (AITT) will be conducted in every July and January, with OMR answer sheet pattern and multiple choice type questions. After passing, National trade certificates (NTC), will be issued by DGT which is authorized and recognized internationally. In 2017, for some trades they have introduced and implemented **National Skill Qualification Frame** work (NSQF) with Level 4 and Level 5.

Fig 1



After finishing instructional training with 'NTC' certificate, they have to undergo Apprenticeship training (ATS) for one or two year in respective trades under the Apprentice ACT 1961, in various government and private establishments with stipend. At the end of the Apprenticeship training, All India Apprentice Test will be conducted and apprentice certificate will be issued. They can get job opportunities in private or government establishment in India/Abroad or they can start small scale industries in manufacturing or in service sector with subsidiary government loan.

Organizational Structure of ITIs

In most of the ITIs, the head of the institute is the principal under him one vice-principal (VP). then Training Officers (TO)/Group Instructors (GI) who are the management and supervisory staff. Then Assistant Training Officers(ATO), Junior Training Officer (JTO), and Vocational Instructors (VI) are under Training officers for each trade and for Workshop calculations, Engineering Drawing, Employability skills etc. Administrative staff, Hostel Superintendent (H.S.) physical Education Trainer (PET), Library incharge, Pharmacist, etc. will be under the head of the Institution.

The typical organizational of ITI chart is shown in Fig 1

Scope of the electrician trade

Objectives: At the end of this lesson you shall be able to
- **explain the duties of electrician general and electrical fitter and their NCO**
- **state the key skills and carrier pathway for electrician**
- **list out the job opportunities and self employment opportunities.**

Welcome to the electrician trade

Electrician trade under craftsman training scheme (CTS) is one of the most popular trade delivered nationwide through the network of ITIs. This trade is of two year (4 semester) duration.

It mainly consists of domain area and core areas. In domain area trade practical and trade theory and core area workshop calculation and science, Engineering drawing and employability skills which imparts soft and life skills. There are two professional classification in electrician trade based on National Code of Occupation (NCO) as

(i) Electrician general (NCO - 2015 reference is 7411.0100)

(ii) Electrical fitter (NCO - 2015 reference is 7412.0200)

Duties of Electrician - General and Electrical - Fitter

Electrician - General installs, maintains and repairs electrical machinery, equipment and fittings in factories, workshops, power houses, business and residential premises, etc. Studies drawings and other specifications to determine electrical circuit, installation etc. Positions and installs electrical motors, transformers, switchboards, microphones, loud-speakers and other electrical equipment, fittings and lighting fixtures. Makes connections and solder terminals. Tests electrical installations and equipment and locates faults using megger, test lamp etc.

Repairs or replaces defective wiring , burnt out fuses and defective parts and keeps fittings and fixtures in working order. may do armature winding, draw wires and cables and do simple cable joining. May operate, attend and maintain electrical motors, pumps etc. NCO - 2015 reference is 7411.0100

Record class of work in which experienced such as factory, power-house, ship etc., whether experienced in electrical repairs or detecting faults, details of experience in electrical equipment such as sound recording apparatus, air purification plant, heating apparatus etc. whether used to working do drawing, whether accustomed to high tension or low tension supply system and if in possession of competency certificate issued under electricity act.

Electrical fitter fits and assembles electrical machinery and equipment such as motors, transformers, generators, switch gears, fans, etc., Studies drawings and wiring diagrams of fittings, wiring and assemblies to be made. Collects prefabricated electrical and mechanical components according to drawing and wiring diagram and checks them with gauges, megger etc. to ensure proper function and accuracy.

Fits mechanical components, resistance, insulators, etc. as per specification doing supplementary tooling where necessary. Follows wiring diagrams, makes electrical connections and solder points as specified. Checks for continuity, resistance, circuit shorting, leakage, earthing etc., at each stage of assembly using megger, ammeter, voltmeter and other appliances and ensures stipulated performance of both mechanical and electrical components filled in assembly.

Erects various equipment such as bus bars, panel board, electrical post, fuse boxes switch gears, meters, relays etc., using non-conductors, insulating and hoisting equipment as necessary for receipt and distribution of electrical current to feeder lines.

Installs motors, generators, transformers, etc. as per drawing using lifting and hoisting equipment as necessary, does prescribed electrical wirings and connects to supply line. Locates faults in case of breakdown and replaces blown out fuses, burnt coils, switches, conductors, etc. as required. Checks dismantles, repairs and overhauls electrical units periodically or as required according to scheduled procedure.

Test electrical equipment and rewind blown out coils. May specialize in repairs of particular type of electrical appliances and machinery, equipment manufacturing, installation or power house work and be designated accordingly NCO - 2015 reference is 7412.0200

Record nature of work done; if specialized in repairing or assembling any particular item such as generator, motor, transformer, relays switchgear, domestic appliance etc. , experience of working in power-house and distribution centre and if in possession of electrician's competency certificate

Key Skills of Electrician

After passing the electrician trade, they are able to

- Read and interpret technical parameter documents, plan and organic work process, identify necessary materials and tools
- Perform tasks with due consideration to safety rules, accident prevention regulation and environment protection.
- Apply professional skill knowledge and employability skills while performing jobs.
- Checking job/assembly as per drawing for functioning, identifying and rectifying errors in job/assembly.
- Document the technical parameters related to the tasks undertaken
- In 2013, semester systems was introduced and the syllabus also revised for semester pattern
- Then in 2014 Sector Mentor Council (SMC) was formed and the syllabus was also re-revised and implemented.

Presently electrician syllabus again revised and sequentially structured by National Skill Qualification Framework NSQF - level 5 and implemented from August 2017

Carrier Progress Pathways

After passing the electrician trade the trainee can appear in 10+2 examination through National Institute of Open Schooling (NIOS) for acquiring higher secondary certificate and can go further for general Technical education.

- Take admission in diploma course in notified branches of engineering by lateral entry
- Can join the apprenticeship training in different types of industries and obtain National Apprenticeship Certificate (NAC)
- Can join Craftsman Instructor Training Scheme (CITS) in the trade to become instructor in ITIs
- Eligible to obtain directly wireman 'B' license, which is issued by the Electrical Licensing Board Authorities

Job Opportunities: There are good numbers of job opportunities for an electrician

- Electrician in local electricity boards, railways, Telephone department, airport and other government and semi-government establishments
- Electrician in factories (Public/Private) Install, test and maintain electrical equipment in auditorium and cinema halls
- Assembler of electrical control gears and switches on panel boards at switch gear factories.
- Winder of electrical motors in winding shops
- Electrical appliances repairer in electrical shops.
- Electrician to Install, service and maintain electrical equipment and circuits in hotels, resorts hospitals and flats
- Assembler in the domestic appliances manufacturing factories
- Service technician for domestic appliances in reputed companies.

Self-employment opportunities

- Service centre for repairing electrical switch gear and motors in rural and urban areas.
- Maintenance contractor of wiring installation in hotels/ resorts/hospitals/banks etc.
- Manufacturer of sub-assembly for electrical panels
- Contractor for domestic wiring and industrial wiring
- Armature winder of electrical motors
- Repairer of simple electronic of gadgets.
- Service, maintain and repair of domestic appliances
- Dealership/agency for electrical hardware
- With an added training in the specified field can become Audio/Radio/ TV Mechanic

Safety rules - Safety signs - Hazards

Objectives: At the end of this lesson you shall be able to
- **explain the necessity of adopting the safety rules**
- **list the safety rules to be followed by the electrician.**
- **explain how to treat a person for electric shock/injury**

Necessity of safety rules: Safety consciousness is one of the essential attitudes required for any job. A skilled electrician always should strive to form safe working habits. Safe working habits always save men, money and material. Unsafeworking habits always end up in loss of production and profits, personal injury and even death. The safety hints given below should be followed by Electrician to avoid accidents and electrical shocks as his job involves a lot of occupational hazards.

The listed safety rules should be learnt, remembered and practised by every electrician. Here a electrician should remember the famous proverb, **"Electricity is a good servant but a bad master".**

Safety rules

- Only qualified persons should do electrical work.
- Keep the workshop floor clean, and tools in good condition, and keep proper places.
- Do not work on live circuits; if unavoidable, use rubber gloves rubber mats, etc.
- Use wooden or PVC insulated handle screwdrivers when working on electrical circuits.
- Do not touch bare conductors
- When soldering, place the hot soldering irons in their stand. Never lay switched 'ON' or heated soldering iron on a bench or table as it may cause a fire to break out.
- Use only correct capacity fuses in the circuit. If the capacity is less it will blow out when the load is connected. If the capacity is large, it gives no protection and allows excess current to flow and endangers men and machines, resulting in loss of money.
- Replace or remove fuses only after switching off the circuit switches.
- Use extension cords with lamp guards to protect lamps against breakage and to avoid combustible material coming in contact with hot bulbs.
- Use accessories like sockets, plugs, switches and appliances only when they are in good condition and be sure they have the mark of BIS (ISI). Necessity of using BIS(ISI) marked accessories is explained under standardisation.
- Never extend electrical circuits by using temporary wiring.
- Stand on a wooden stool, or an insulated ladder while repairing live electrical circuits/ appliances or replacing fused bulbs. In all the cases, it is always good to open the main switch and make the circuit dead.
- Stand on rubber mats while working/operating switch panels, control gears etc.
- Position the ladder, on firm ground.
- While using a ladder, ask the helper to hold the ladder against any possible slipping.
- Always use safety belts while working on poles or high rise points.
- Never place your hands on any moving part of rotating machine and never work around moving shafts or pulleys of motor or generator with loose shirt sleeves or dangling neck ties.
- Only after identifying the procedure of operation, operate any machine or apparatus.
- Run cables or cords through wooden partitions or floor after inserting insulating porcelain tubes.
- Connections in the electrical apparatus should be tight. Loosely connected cables will heat up and end in fire hazards.
- Use always earth connection for all electrical appliances along with 3-pin sockets and plugs.
- While working on dead circuits remove the fuse grips; keep them under safe custody and also display 'Men on line' board on the switchboard.
- Do not meddle with interlocks of machines/switch gears.
- Do not connect earthing to the water pipe lines.
- Do not use water on electrical equipment.
- Discharge static voltage in HV lines/equipment and capacitors before working on them.

Safety practice - first aid

Electric shock

We are aware that the prime reasons for severity of shock are the magnitude of current and duration of contact. In addition, the other factors contribute to the severity of shock are:

- age of person
- body resistance
- not wearing insulating footwear or wearing wet footwear

- Weather condition
- Wet or dry floor
- Mains voltage etc.

If assistance is close at hand, send for medical aid, then carry on with emergency treatment.

If you are alone, proceed with the treatment immediately.

Make sure the victim is not in contact with the supply.

Effects of electric shock

The effect of current at very low levels may only be an unpleasant tingling sensation, but this itself may be sufficient to cause some persons to lose their balance and fall.

At higher levels of current the person receiving a shock may be thrown off his feet and will experience severe pain and possibly minor burns at the point of contact.

At an excessive shock can also cause burning of the skin at the point of contact.

Treatment of electric shock

Prompt treatment is essential.

Check for the victim's natural breathing and consciousness. Take steps to apply respiratory resuscitation if the victim is unconscious and not breathing.

Check the victim for injury and burns. Decide on the suitable method of artificial resuscitation.

In the case of injury/burns to chest and or belly, follow the mouth-to-mouth method.

In the case of burns/injury in the back, follow Nelson's method

In case the mouth is closed tightly, use Schafer's or Holgen-Nelson method.

These methods should be practiced. (Refer Exercise 1.1.06)

Treatment for electrical burns

A person receiving an electric shock may also sustain burns when the current passes through the body.

Do not waste time by rendering first aid to the victim until breathing has been restored and the patient can breathe normally unaided.

Burns are very painful. If a large area of the body is burnt, do not give treatment, except to exclude the air, eg. by covering with clean paper or a clean cloth, soaked in clean water. this relieves the pain.

Severe bleeding

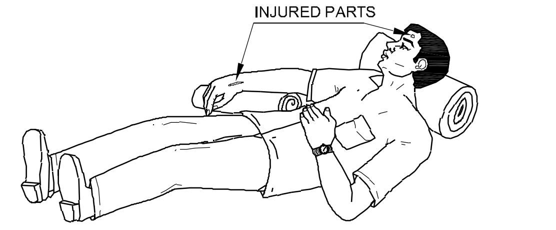
Any wound which is bleeding profusely, especially in the wrist, hand or fingers must be considered serious and must receive professional attention. As an immediate first aid measure, pressure on the wound itself is the best means of stopping the bleeding and avoiding infection.

Immediate action

Always in cases of severe bleeding

- make the patient to lie down and rest
- if possible, raise the injured part above the level of the body (Fig 1)

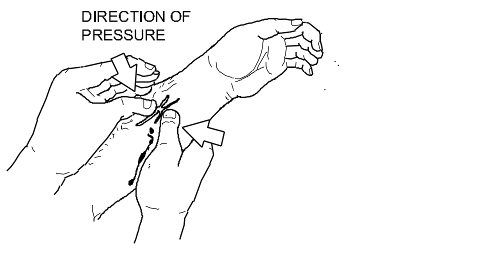
Fig 1



- apply pressure to the wound
- call for medical assistance

To control severe bleeding

Fig 2



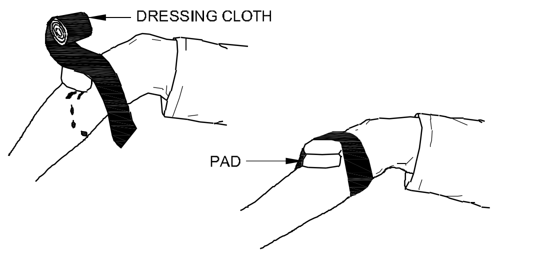
Squeeze together the sides of the wound. Apply pressure as long as it is necessary to stop the bleeding. When the bleeding has stopped, put a dressing over the wound and cover it with a pad of soft material. (Fig 2)

For an abdominal wound which may be caused by falling on a sharp tool, keep the patient bending over the wound to stop internal bleeding.

Large wound

Apply a clean pad and bandage firmly in place. If bleeding is very severe apply more than one dressing. (Fig 3)

Fig 3



Safety signs (Road signals)

Objectives: At the end of this lesson you shall be able to
- **list three kinds of road sign**
- **describe the "marking" on the road**
- **describe the various police traffic hand signal and light signal**
- **list the causes for collision.**

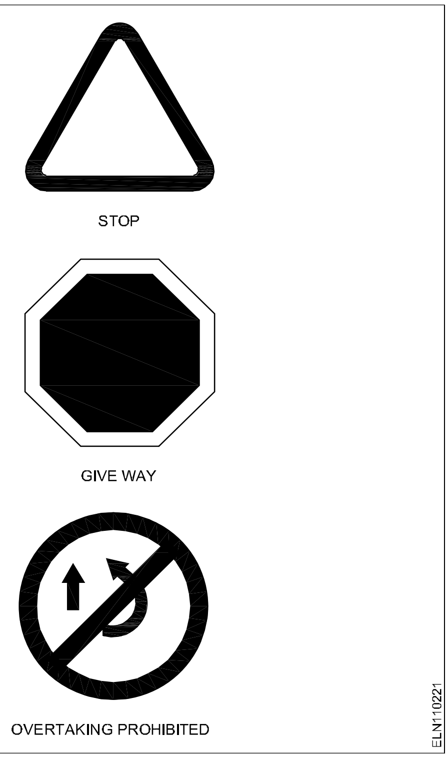
In olden days road locomotive carrying a red flag by day and red lantern by night. Safety is the prime motive of every traffic.

Kinds of road signs

- Mandatory
- Cautionary and
- Informatory

Mandatory signs (Fig 1)

Fig 1



Violation of mandatory sign can lead to penalties. Eg. Stop, give way, limits, prohibited, no parking and compulsory sign.

Cautionary signs (Fig 2)

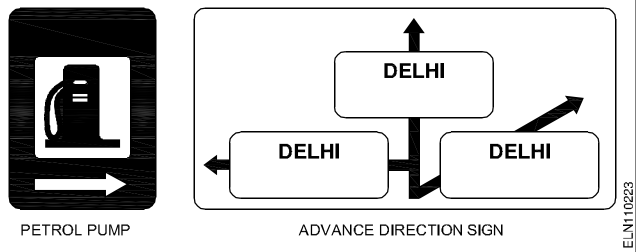
Fig 2

Cautionary/ warning signs are especially safe. Do's and don'ts for pedestrians, cyclists, bus passengers and motorists.

Information signs (Fig 3)

Information signs as especially benefit to the passengers and two wheelers.

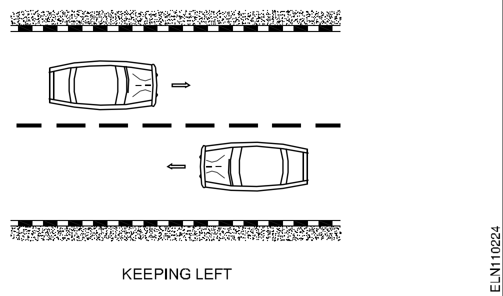
Fig 3



Marking lines on road (Fig 4)

- Marking lines are directing or warning to the moving vehicles, cyclist and pedestrians to follow the law.

Fig 4



- Single and short broken lines in the middle of the road allow the vehicle to cross the dotted lines safely overtake whenever required.
- When moving vehicle approaching pedestrian crossing, be ready to slow down or stop to let people cross.
- Do not overtake in the vicinity of pedestrian crossing.

Police signals (Fig 5)

To stop a vehicle approaching from behind. (Fig 5/1)

To stop a vehicle coming from front. (Fig 5/2)

To stop vehicles approaching simultaneously from front and behind. (Fig 5/3)

To stop traffic approaching from left and wanting to turn right. (Fig 5/4)

To stop traffic approaching from the right to allow traffic from left to turn right. (Fig 5/5)

To allow traffic coming from the right and turning right by stopping traffic approaching from the left. (Fig 5/6)

Warning signal closing all traffic. (Fig 5/7)

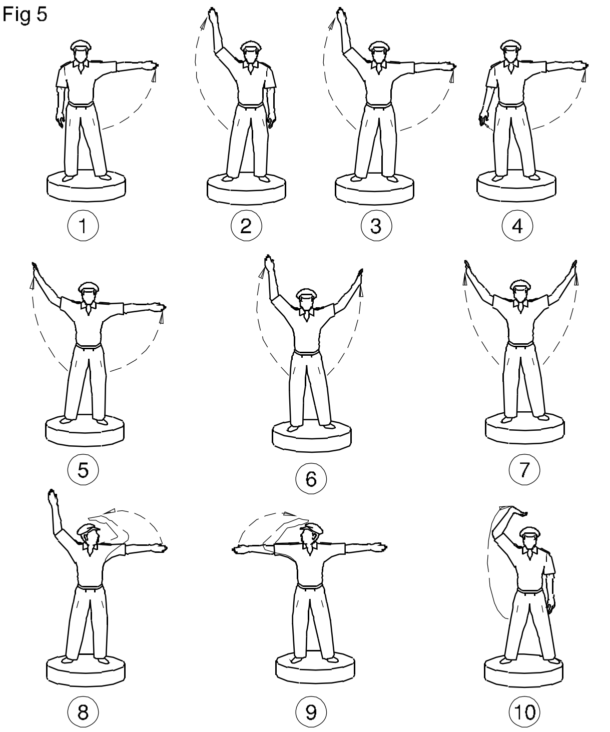


Fig 5

POLICE SIGNALS

Beckoning on vehicles approaching from left. (Fig 5/8)

Beckoning on vehicles approaching from right. (Fig 5/9)

Beckoning on vehicles from front. (Fig 5/10)

Traffic light signals (Fig 6)

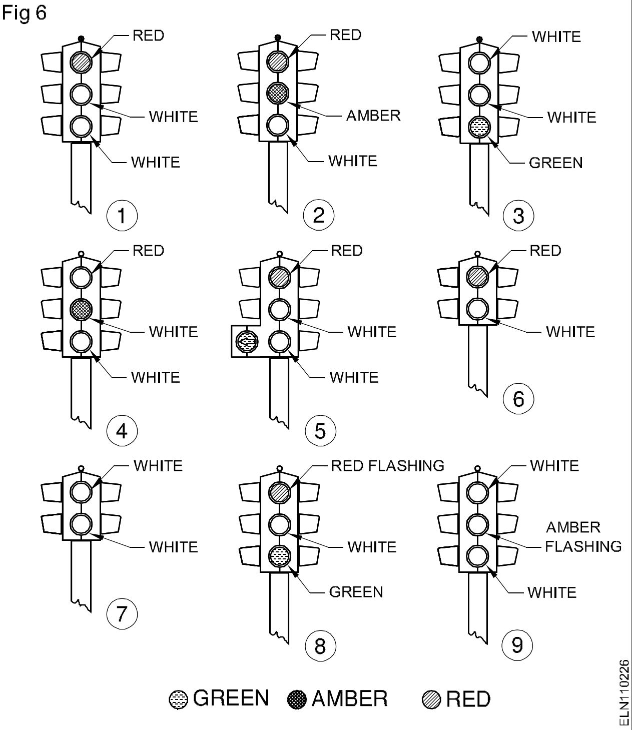


Fig 6

Red means stop. Wait behind the stop line on the carriage way. (Fig 6/1)

Red and amber also means stop. Do not pass through or start until green shows. (Fig 6/2)

Green means you may go on if the way is clear. Take special care if you mean to turn left or right and give way to pedestrians who are crossing. (Fig 6/3)

Amber means stop at the stop line. you may only go on if the amber appears after you have crossed the stop line or so close to it that to pull up may not be possible. (Fig 6/4)

Green arrow means that you may go in the direction shown by the arrow. You may do this whatever other lights may be showing. (Fig 6/5)

Pedestrians - do not cross. (Fig 6/6)

Pedestrians - cross now. (Fig 6/7)

Flashing red means stop at the stop line and if the way is clear proceed with caution. (Fig 6/8)

Flashing amber means proceed with caution. (Fig 6/9)

Collision causes (Fig 7)

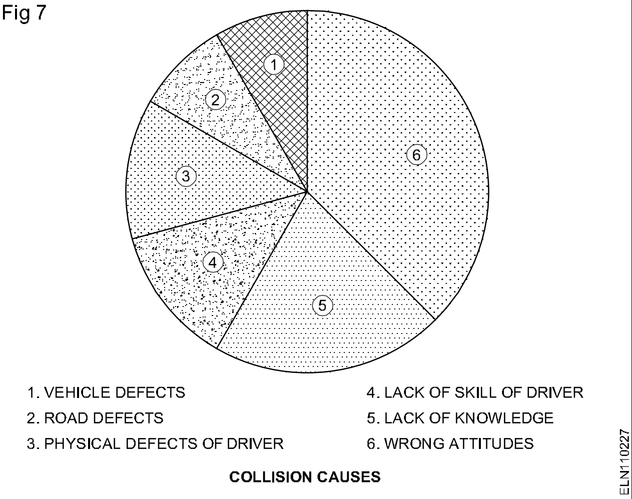


Fig 7

COLLISION CAUSES

Three factors are responsible for collision

- Roads
- Vehicles and
- Drivers

The Fig 8 shows approximately proportionate causes of collision. In wrong attitudes such that avoid foolish acts at the wheel (Fig 8). Driving time is not play time.

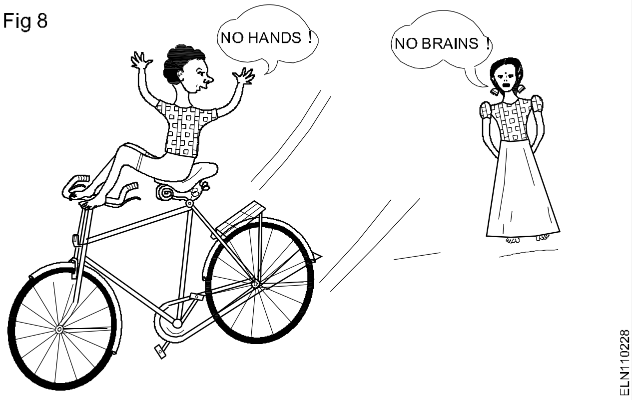


Fig 8

Safety practice - Safety signs

Objectives: At the end of this lesson you shall be able to
- **state the responsibilities of employer and employees**
- **state the safety attitude and list the four basic categories of safety signs.**

Responsibilities

Safety doesn't just happen - it has to be organised and achieved like the work-process of which it forms a part. The law states that both an employer and his employees have a responsibility in this behalf.

Employer's responsibilities

The effort a firm puts into planning and organising work, training people, engaging skilled and competent workers, maintaining plant and equipment, and checking, inspecting and keeping records - all of this contributes to the safety in the workplace.

The employer will be responsible for the equipment provided, the working conditions, what the employees are asked to do, and the training given.

Employee's responsibilities

You will be responsible for the way you use the equipment, how you do your job, the use you make of your training, and your general attitude to safety.

A great deal is done by employers and other people to make your working life safer; but always remember you are responsible for your own actions and the effect they have on others. You must not take that responsibility lightly.

Rules and procedure at work

What you must do, by law, is often included in the various rules and procedures laid down by your employer. They may be written down, but more often than not, are just the way a firm does things - you will learn these from other workers as you do your job.

They may govern the issue and use of tools, protective clothing and equipment, reporting procedures, emergency drills, access to restricted areas, and many other matters. Such rules are essential; they contribute to the efficiency and safety of the job.

Safety signs

As you go about your work on a construction site you will see a variety of signs and notices. Some of these will be familiar to you - a 'no smoking' sign for example; others you may not have seen before. It is up to you to learn what they mean - and to take notice of them. They warn of the possible danger, and must not be ignored.

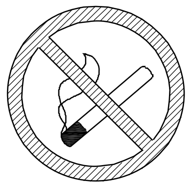
Safety signs fall into four separate categories. These can be recognised by their shape and colour. Sometimes they may be just a symbol; other signs may include letters or figures and provide extra information such as the clearance height of an obstacle or the safe working load of a crane.

The four basic categories of signs are as follows:

- prohibition signs (Fig 1 & Fig 5)
- mandatory signs (Fig 2 & Fig 6)
- warning signs (Fig 3 & Fig 7)
- information signs (Fig 4)

Prohibition signs

Fig 1



SHAPE	Circular.
COLOUR	Red border and cross bar. Black symbol on white background.
MEANING	Shows it must not be done.
Example	No smoking.

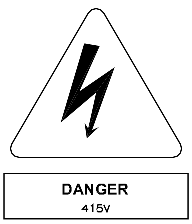
Mandatory signs

Fig 2

SHAPE	Circular.
COLOUR	White symbol on blue background
MEANING	Shows what must be done.
Example	Wear hand protection.

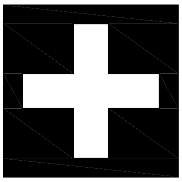
Warning signs

Fig 3



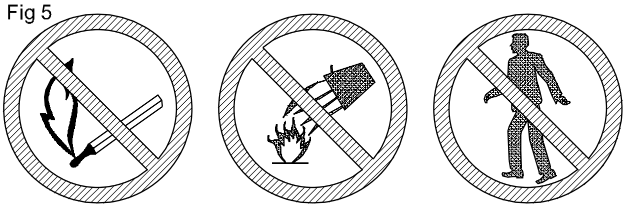
SHAPE	Triangular.
COLOUR	Yellow background with black border and symbol.
MEANING	Warns of hazard or danger.
Example	Caution, risk of electric shock.

Information signs

Fig 4		
	SHAPE	Square or oblong.
	COLOUR	White symbols on green background.
	MEANING	Indicates or gives information of safety provision.
	Example	First aid point.

Prohibition signs

Fig 5



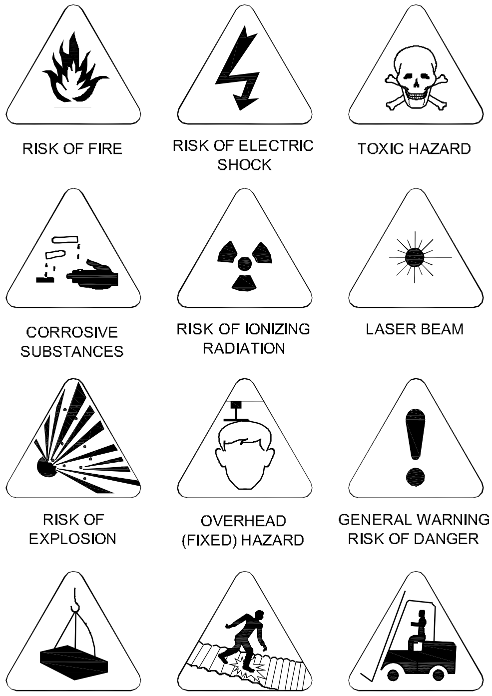
Mandatory signs

Fig 6

MANDATORY SIGNS

Warning signs

Fig 7



WARNING SIGNS

Fire - Types - Extinguishers

Objectives: At the end of this lesson you shall be able to
- **state the effects of a fire break out and causes of fire in a workshop**
- **distinguish the different types of fire extinguishers**
- **state the classification of fires and basic ways for extingushing the fire**
- **determine the correct type of fire extinguisher to be used based on the class of fire**
- **describe the general procedure to be adopted in the event of fire**
- **state the method of operation of fire extinguisher and extinguishing of fire.**

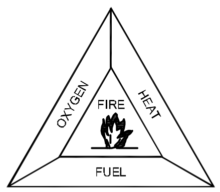
Fire

Fire is the burning of combustible material. A fire in an unwanted place and on an unwanted occasion and in an uncontrollable quantity can cause damage or destroy property and materials. It might injure people, and sometimes cause loss of life as well. Hence, every effort must be made to prevent fire. When a fire outbreak is discovered, it must be controlled and extinguished by immediate corrective action.

Is it possible to prevent fire? Yes, fire can be prevented by eliminating anyone of the three factors that causes fire.

The following are the three factors that must be present in combination for a fire to continue to burn. (Fig 1)

Fig 1



FIRE TRINAGLE

Fuel: Any substance, liquid, solid or gas will burn, if there is oxygen and high enough temperatures.

Heat: Every fuel will begin to burn at a certain temperature. It varies and depends on the fuel. Solids and liquids give off vapour when heated, and it is this vapour which ignites. Some liquids do not have to be heated as they give off vapour at normal room temperature say 15^0C, *eg.* petrol.

Oxygen: Usually exists in sufficient quantity in air to keep a fire burning.

Extinguishing of fire: Isolating or removing any of these factors from the combination will extinguish the fire. There are three basic ways of achieving this.

- **Starving** the fire of fuel removes this element.
- **Smothering** - ie. isolate the fire from the supply of oxygen by blanketing it with foam, sand etc.
- **Cooling** - use water to lower the temperature.

> **Removing any one of these factors will extinguish the fire.**

Preventing fires: The majority of fires begin with small outbreaks which burn unnoticed until they have a secure hold. Most fires could be prevented with more care and by following some simple common sense rules.

Accumulation of combustible refuse (cotton waste soaked with oil, scrap wood, paper, etc.) in odd corners are a fire risk. Refuse should be removed to collection points.

The cause of fire in electrical equipment is misuse or neglect. Loose connections, wrongly rated fuses, overloaded circuits cause overheating which may in turn lead to a fire. Damage to insulation between conductors in cables causes fire.

Clothing and anything else which might catch fire should be kept well away from heaters. Make sure that the heater is shut off at the end of the working day.

Highly flammable liquids and petroleum mixtures (thinner, adhesive solutions, solvents, kerosene, spirit, LPG gas etc.) should be stored in the flammable material storage area.

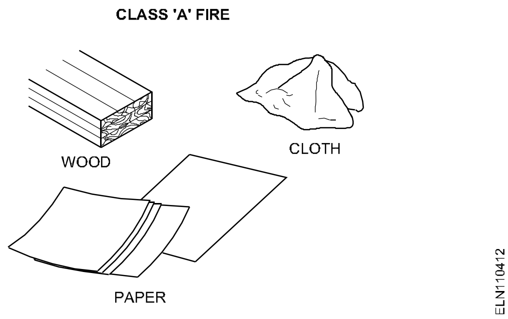
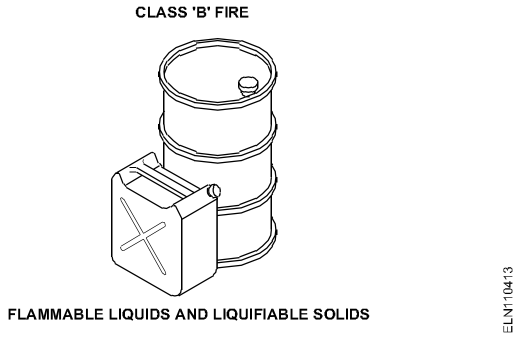
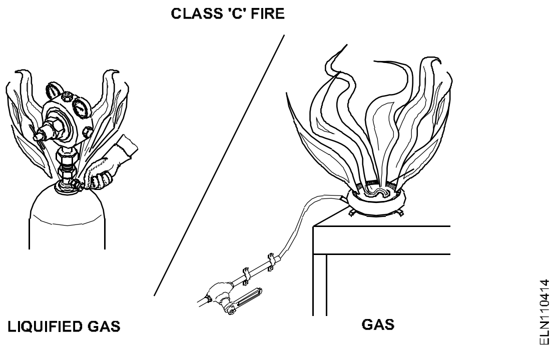
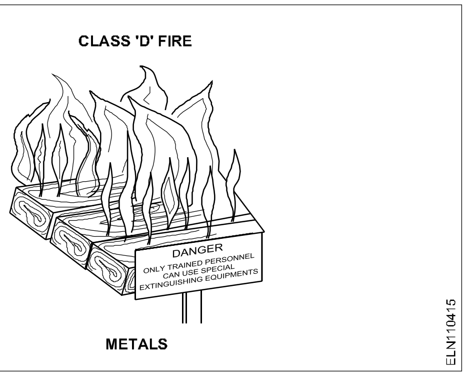
Blowlamps and torches must not be left burning when they are not in use.

Classification of fires: Fires are classified into four types in terms of the nature of fuel.

Different types of fires (Fig 2, Fig 3 Fig 4 & Fig 5) have to be dealt with in different ways and with different extinguishing agents.

An extinguishing agent is the material or substance used to put out the fire, and is usually (but not always) contained in a fire extinguisher with a release mechanism for spraying into the fire.

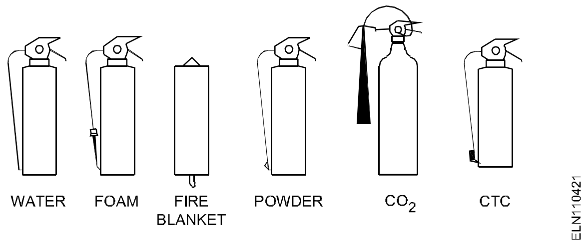
It is important to know the right type of agent for extinguishing a particular type of fire; using a wrong agent can make things worse.There is no classification for 'electrical fires' as such, since these are only fires in materials where electricity is present.

Fire Classification and Fuel	Extinguishing Method
Fig 2 	Most effective ie., cooling with water. Jets of water should be sprayed on the base of the fire and then gradually upwards.
Fig 3 	**Should be smothered** :- The aim is to cover the entire surface of the burning liquid. This has the effect of cutting off the supply of oxygen to the fire. Water should never be used on burning liquids. Foam, dry powder or CO_2 may be used on this type of fire.
Fig 4 	Extreme caution is necessary in dealing with liquefied gases. There is a risk of explosion and sudden outbreak of fire in the entire vicinity. If an appliance fed from a cylinder catches fire - shut off the supply of gas. The safest course is to raise an alarm and leave the fire to be dealt with by trained personnel. Dry powder extinguishers are used on this type of fire.
Fig 5 	Special powders have now been developed which are capable of controlling and/or extinguishing this type of fire. The standard range of fire extinguishing agents is inadequate or dangerous when dealing with metal fires. Fire on electrical equipment. Halon, Carbon dioxide, dry powder and vapourising liquid (CTC) extinguishers can be used to deal with fires in electrical equipment. Foam or liquid (eg. water) extinguishers must not be used on electrical equipment under any circumstances.

Types of Fire Extinguisher

Many types of fire extinguishers are available with different extinguishing 'agents' to deal with different classes of fires. (Fig 1)

Fig 1

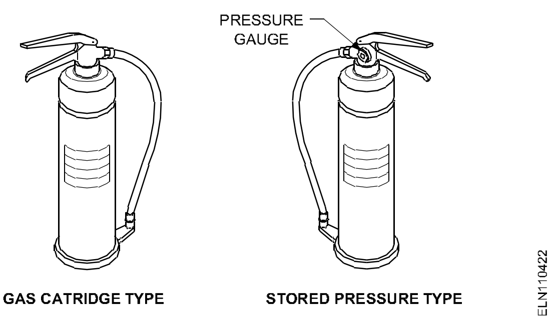


Water-filled extinguishers: There are two methods of operation. (Fig 2)

- Gas cartridge type
- Stored pressure type

With both methods of operation the discharge can be interruted as required, conserving the contents and preventing unnecessary water damage.

Fig 2



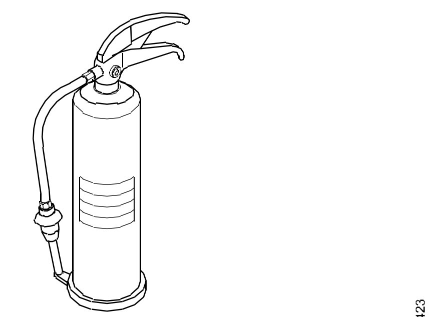
Foam extinguishers (Fig 3):These may be of stored pressure or gas cartridge types. Always check the operating instructions on the extinguisher before use.

Most suitable for

- flammable liquid fires
- running liquid fires

Must not be used on fires where electrical equipment is involved.

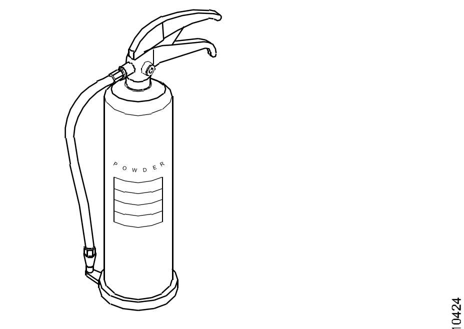
Fig 3



FOAM EXTINGUISHERES

Dry powder extinguishers (Fig 4): Extinguishers fitted with dry powder may be of the gas cartridge or stored pressure type. Appearance and method of operation is the same as that of the water-filled one. The main distinguishing feature is the fork shaped nozzle. Powders have been developed to deal with class D fires.

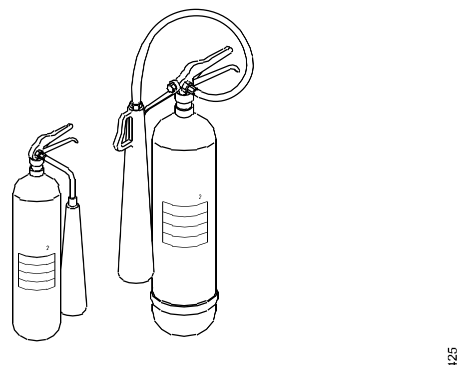
Fig 4



DRY POWDEER EXTINGUSHERS

Carbon dioxide (CO_2): This type is easily distinguished by the distinctively shaped discharge horn. (Fig 5).

Fig 5



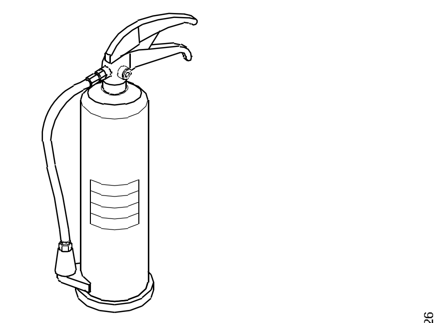
CARBAN DIOXIDE(CO_2)

Suitable for Class B fires. Best suited where contamination by deposits must be avoided. Not generally effective in open air.

Always check the operating instructions on the container before use. Available with different gadgets of operation such as - plunger, lever, trigger etc.

Halon extinguishers (Fig 6)**:** These extinguishers may be filled with carbon-tetrachloride and Bromochlorodifluoro methene (BCF). They may be either gas cartridge or stored pressure type.

Fig 6



HALON EXTINGUISHERS

They are more effective in extinguishing small fires involving pouring liquids. These extinguishers are particularly suitable and safe to use on electrical equipment as the chemicals are electrically non-conductive.

The fumes given off by these extinguishers are dangerous, especially in confined space.

The general procedure in the event of a fire:

- Raise an alarm.
- Turn off all machinery and power (gas and electricity).
- Close the doors and windows, but do not lock or bolt them. This will limit the oxygen fed to the fire and prevent its spreading.
- Try to deal with the fire if you can do so safely. Do not risk getting trapped.
- Anybody not involved in fighting the fire should leave calmly using the emergency exits and go to the designated assembly point.

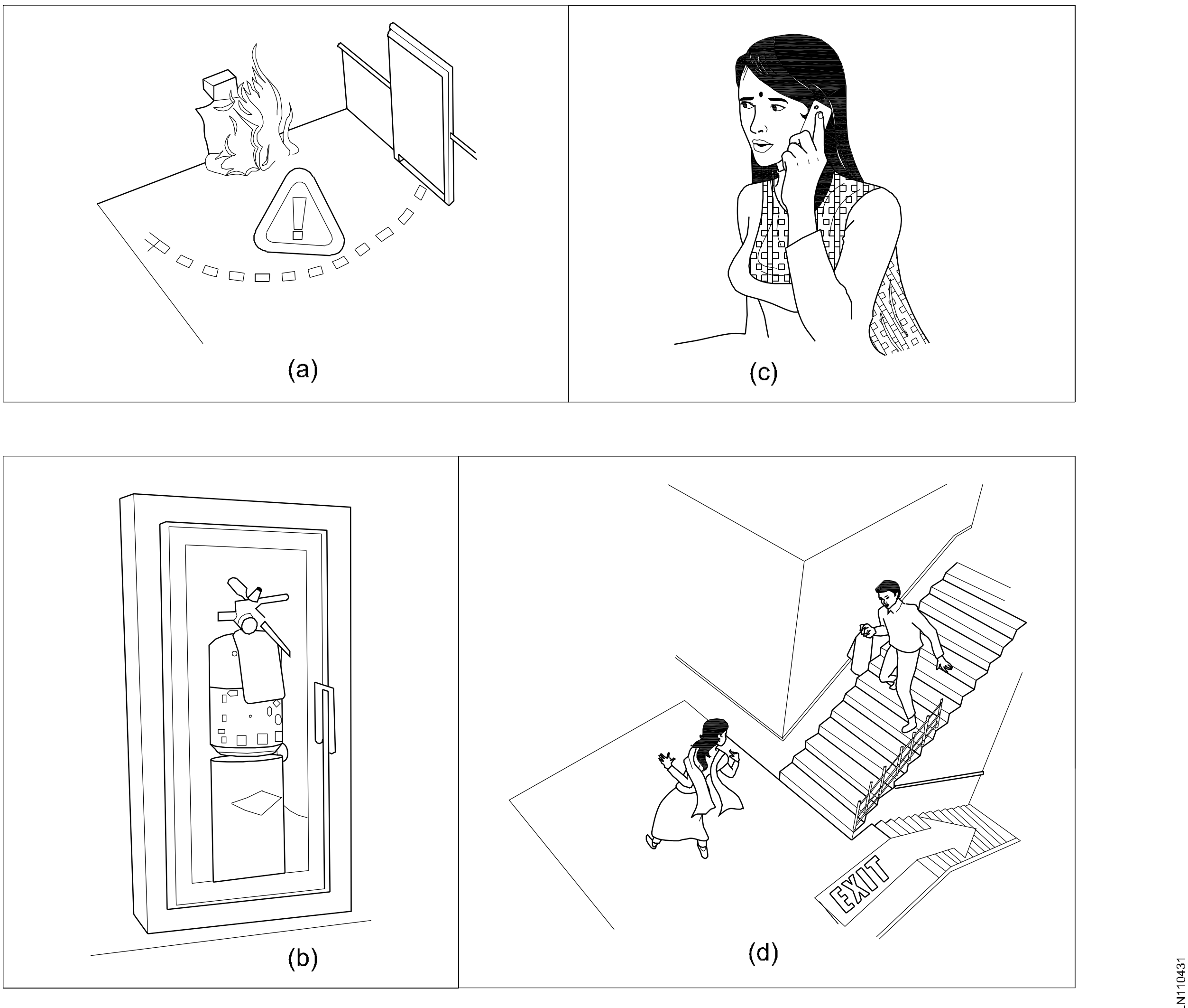
Failure to do this may mean that some person being unaccounted for and others may have to put themselves to the trouble of searching for him or her at risk to themselves.

Working on fire extinguishers:-

- Alert people sorrounding by shouting fire, fire, fire when observe the fire. (Fig 1a & b)
- Inform fire service or arrange to inform immediately. (Fig 1c)
- Open emergency exist and ask them to go away. (Fig 1d)
- Put “OFF” electrical power supply.

Don’t allow people to go nearer to the fire

Fig 1



- Analyze and identify the type of fire. Refer Table1.

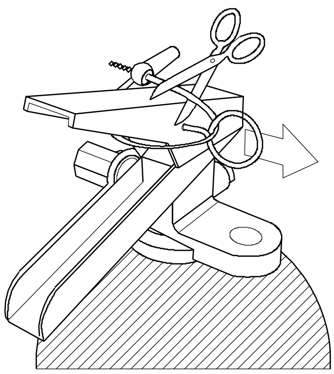
Table 1

Class 'A'	Wood, paper, cloth, solid material
Class 'B'	Oil based fire (grease, gasoline, oil) liquifiable gases
Class 'C'	Gas and liquifiable gases
Class 'D'	Metals and electrical equipment

Assume the fire is 'B; type (flammable liquifiable solids)

- Slect CO_2 (Carbon di oxide) fire extinguisher.
- Locate and pickup, CO_2 fire extinguisher. Click for its expiry date.
- Break the seal (Fig 2)

Fig 2

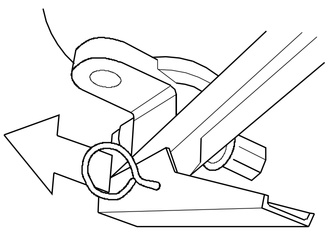


BREAK THE SEAL

ELN110432

- Pull the safety pin from the handle (Pin located at the top of the fire extinguisher) (Fig 3)

Fig 3



PULL THE SAFTY PIN

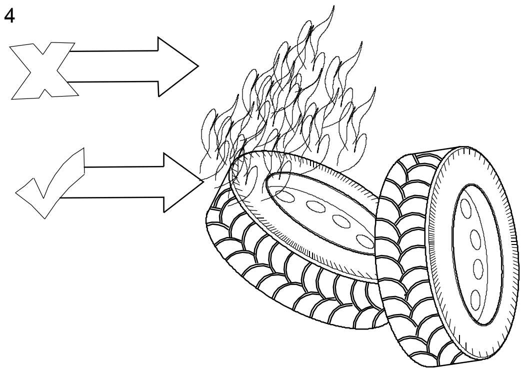
ELN110433

- Aim the extinguisher nozzle or hose at the base of the fire (this will remove the source of fuel fire) (Fig 4)

Keep your self low and safe distance

- Squeeze the handle lever slowly to discharge the agent (Fig 5)
- Sweep side to side approximately 15 cm over the fuel fire until the fire is put off (Fig 5)

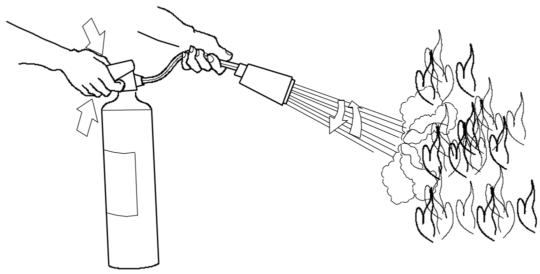
Fig 4



AIM THE EXTINGUISHER

ELN110434

Fig 5



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Fire extinguishers are manufactured for use from the distance.

Caution

- **While putting off fire, the fire may flare up**
- **Do not be panick belong as it put off promptly.**
- **If the fire doesn't respond well after you have used up the fire extinguisher move away yourself away from the fire point.**
- **Do not attempt to put out a fire where it is emitting toxic smoke leave it for the professionals.**
- **Remember that your life is more important than property. So don't place yourself or others at risk.**

In order to remember the simple operation of the extinguisher. Remember P.A.S.S. This will help you to use the fire extinguisher.

P for Pull

A for Aim

S for Squeeze

S for Sweep

Rescue operation - First aid treatment - Artificial respiration

Objectives: At the end of this lesson you shall be able to
- **explain how to rescue a person who is in contact with a live wire.**
- **state the first aid and its key aims.**
- **explain ABC of the first aid.**
- **brief how to give first aid treatment for a victim.**
- **explain how to treat a person affected due to electric shock/injury.**

The severity of an electric shock will depend on the level of current which passes through the body and the length of time of contact. Do not delay, act at once. Make sure that the electric current has been disconnected. If the victim is still in contact with the supply - break the contact either by switching off or by removing the plug or pulling the cable free.

If not, stand on some insulating material such as dry wood, rubber or plastic or newspaper and then pull his shirt sleeves. However, you have to insulate yourself and break the contact by pushing or pulling the person free. (Figs1 & 2)

Fig 1

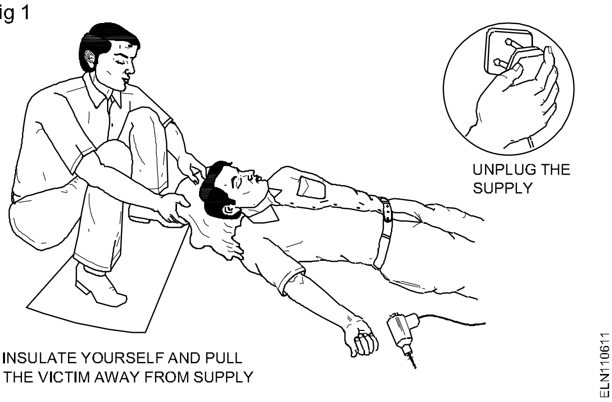
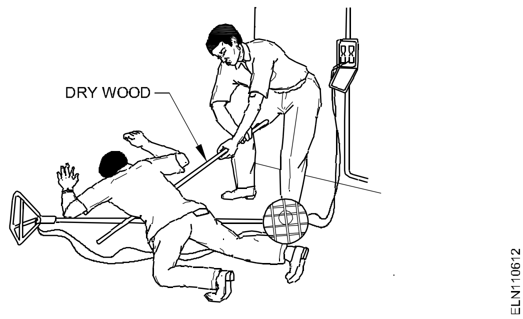


Fig 2



In any case avoid direct contact with the victim. Wrap your hands in dry material if rubber gloves are not available.

If you remain un-insulated, do not touch the victim with your bare hands until the circuit is made dead or he is moved away from the equipment.

If the victim is at a height, efforts must be taken to prevent him from falling or to make him fall safe.

Electric burns on the victim may not cover a big area but may be deep seated. All you can do is to cover the area with a clean, sterile dressing and treat for shock. Get expert help as quickly as possible.

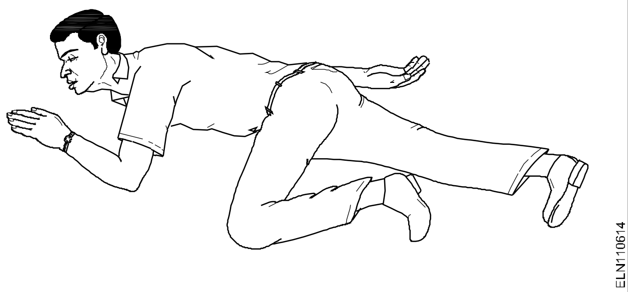
If the casualty is unconscious but is breathing, loosen the clothing about the neck, chest and waist (Fig 3) and place the casualty in the recovery position.

Fig 3

Keep a constant check on the breathing and pulse rate.

Keep the casualty warm and comfortable in the recover position. Send for help.(Fig 4)

Fig 4



> **Do not give an unconscious person anything to eat or drink.**
>
> **Do not leave an unconscious person unattended.**

If the casualty is not breathing - **Act at once to resuscitate the victim** - do not waste time.

There are four methods of artificial resuscitation is illustrated in Exercise 1.1.07 follow them.

Basic first-aid treatment

First aid is defined as the immediate care and support given to an acutely injured or ill person, primarily to save life, prevent further deterioration or injury, plan to shift the victim to safer place, provide best possible comfort and finally help them to reach the medical centre/ hospital through all available means. It is an immediate life-saving procedure using all resources available within reach.

Imparting knowledge and skill through institutional teaching at younger age group in schools, colleges, entry point at industry level is now given much importance. Inculcating such habits at early age, helps to build good healthcare habits among people.

First aid procedure often consists of simple and basic life saving techniques that an individual performs with proper training and knowledge.

The key aims of first aid can be summarized in three key points:

- **Preserve life:** If the patient was breathing, a first aider would normally then place them in the recovery position, with the patient leant over on their side, which also has the effect of clearing the tongue from the pharynx. It also avoids a common cause of death in unconscious patients, which is choking on regurgitated stomach contents.

  The airway can also become blocked through a foreign object becoming lodged in the pharynx or larynx, commonly called choking. The first aider will be taught to deal with this through a combination of 'back slaps' and 'abdominal thrusts'. Once the airway has been opened, the first aider would assess to see if the patient is breathing.

- **Prevent further harm:** Also sometimes called prevent the condition from worsening, or danger of further injury, this covers both external factors, such as moving a patient away from any cause of harm, and applying first aid techniques to prevent worsening of the condition, such as applying pressure to stop a bleed becoming dangerous.

- **Promote recovery:** First aid also involves trying to start the recovery process from the illness or injury, and in some cases might involve completing a treatment, such as in the case of applying a plaster to a small wound.

Training

Basic principles, such as knowing to use an adhesive bandage or applying direct pressure on a bleed, are often acquired passively through life experiences. However, to provide effective, life-saving first aid interventions requires instruction and practical training.

This is especially true where it relates to potentially fatal illnesses and injuries, such as those that require **Cardio Pulmonary Resuscitation (CPR)**; these procedures may be invasive, and carry a risk of further injury to the patient and the provider. As with any training, it is more useful if it occurs before an actual emergency, and in many countries, emergency ambulance dispatchers may give basic first aid instructions over the phone while the ambulance is on the way.

Training is generally provided by attending a course, typically leading to certification. Due to regular changes in procedures and protocols, based on updated clinical knowledge, and to maintain skill, attendance at regular refresher courses or re-certification is often necessary. First aid training is often available through community organization such as the Red cross and St. John ambulance.

ABC of first aid

ABC stands for **A**irway, **B**reathing and **C**irculation.

- **Airway:** Attention must first be brought to the airway to ensure it is clear. Obstruction (choking) is a life-threatening emergency.

- **Breathing:** Breathing if stops, the victim may die soon. Hence means of providing support for breathing is an important next steps. There are several methods practiced in first aid.

- **Circulation:** Blood circulation is vital to keep person alive. The first aiders now trained to go straight to chest compressions through CPR methods.

When providing first aid one needs to follow some rule. There are certain basic norms in teaching and training students in the approach and administration of first aid to sick and injured.

Not to get panic

Panic is one emotion that can make the situation more worse. People often make mistake because they get panic. Panic clouds thinking may cause mistakes. First aider need calm and collective approach. If the first aider himself is in a state of fear and panic gross mistakes may result. It's far easier to help the suffering,

When they know what they are doing, even if unprepared to encounter a situation. Emotional approach and response always lead to wrong doing and may lead one to do wrong procedures. Hence be calm and focus on the given institution. Quick and confident approach can lessen the effect of injury.

Call medical emergencies

If the situation demands, quickly call for medical assistance. Prompt approach may save the life.

Surroundings play vital role

Different surroundings require different approach. Hence first aider should study the surrounding carefully. In other words, one need to make sure that they are safe and are not in any danger as it would be of no help that the first aider himself get injured.

Do no harm

Most often over enthusiastically practiced first aid viz. administering water when the victim is unconscious, wiping clotted blood (which acts as plug to reduce bleeding), correcting fractures, mishandling injured parts etc., would leads to more complication.

Patients often die due to wrong FIRST AID methods, who may otherwise easily survive. Do not move the injured person unless the situation demands. It is best to make him lie wherever he is because if the patient has back, head or neck injury, moving him would causes more harm.

Reassurance

Reassure the victim by speaking encouragingly with him.

Stop the bleeding

If the victim is bleeding, try to stop the bleeding by applying pressure over the injured part.

Golden hours

India have best of technology made available in hospitals to treat devastating medical problem viz. head injury, multiple trauma, heart attack, strokes etc, but patients often do poorly because they don't gain access to that technology in time.

The risk of dying from these conditions, is greatest in the first 30 minutes, often instantly. This period is referred to as **Golden period**. By the time the patient reach the hospital, they would have passed that critical period. First aid care come handy to save lives.

It helps to get to the nearest emergency room as quickly as possible through safe handling and transportation. The shorter that time, the more likely the best treatment applied.

Maintain the hygiene

Most important, the first aider need to wash hands and dry before giving any first aid treatment to the patient or wear gloves in order to prevent infection.

Cleaning and dressing

Always clean the wound thoroughly before applying the bandage gently wash the wound with clean water.

Not to use local medications on cuts or open wounds

They are more irritating to tissue than it is helpful. Simple dry cleaning or with water and some kind of bandage are best.

CPR (Cardio-Pulmonary Resuscitation) can be life-sustaining

CPR can be life sustaining. If one is trained in PR and the person is suffering from choking or finds difficulty in breathing, immediately begin CPR. However, if one is not trained in CPR, do not attempt as you can cause further injury. But some people do it wrong.

This is a difficult procedure to do in a crowded area. Also there are many studies to suggest that no survival advantage when bystanders deliver breaths to victims compared to when they only do chest compressions. Second, it is very difficult to carry right maneuver in wrong places. But CPR, if carefully done by highly skilled first aiders is a bridge that keeps vital organs oxygenated until medical team arrives.

Declaring death

It is not correct to declare the victim's death at the accident site. It has to be done by qualified medical doctors.

How to report an emergency?

Reporting an emergency is one of those things that seems simple enough, until actually when put to use in emergency situations. A sense of shock prevail at the accident sites. Large crowd gather around only with inquisitive nature, but not to extend helping hands to the victims. This is common in road side injuries.

The first aiders need to adapt multi-task strategy to control the crowd around, communicate to the rescue team, call ambulance etc., all to be done simultaneously. The mobile phones helps to a greater extent for such emergencies.

Assess the urgency of the situation. Before you report an emergency, make sure the situation is genuinely urgent. Call for emergency services if you believe that a situation is life-threatening or otherwise extremely critical.

- A crime, especially one that is currently in progress. If you're reporting a crime, give a physical description of the person committing the crime.
- A fire - If you're reporting a fire, describe how the fire started and where exactly it is located. If someone has already been injured or is missing, report that as well.
- A life-threatening medical emergency, explain how the incident occurred and what symptoms the person currently displays.
- A car crash - Location, serious nature of injures, vehicle's details and registration, number of people involved etc.

Call emergency service

The emergency number varies - 100 for Police & Fire, 108 for Ambulance.

Report your location

The first thing the emergency dispatcher will ask is where you are located, so the emergency services can get there as quickly as possible. Give the exact street address, if you're not sure of the exact address, give approximate information.

Give the dispatcher your phone number

This information is also imperative for the dispatcher to have, so that he or she is able to call back if necessary.

Describe the nature of the emergency

Speak in a calm, clear voice and tell the dispatcher why you are calling. Give the most important details first, then answer the dispatcher's follow-up question as best as you can.

Do not hang up the phone until you are instructed to do so. Then follow the instructions you were given.

How to do basic first aid?

Basic first aid refers to the initial process of assessing and addressing the needs of someone who has been injured or is in physiological distress due to choking, a heart attack, allergic reactions, drugs or other medical emergencies. Basic first aid allows one to quickly determine a person's physical condition and the correct course of treatment.

Important guideline for first aiders

Evaluate the situation

Are there things that might put the first aider at risk. When faced with accidents like fire, toxic smoke, gasses, an unstable building, live electrical wires or other dangerous scenario, the first aider should be very careful not to rush into a situation, which may prove to be fatal.

Remember A-B-Cs

The ABCs of first aid refer to the three critical things the first aiders need to look for.

- **A**irway - Does the person have an unobstructed airway?
- **B**reathing - Is the person breathing?
- **C**irculation - Does the person show a pulse at major pulse points (wrist, carotid artery, groin)

Avoid moving the victim

Avoid moving the victim unless they are immediate danger. Moving a victim will often make injuries worse, especially in the case of spinal cord injuries.

Call emergency services

Call for help or tell someone else to call for help as soon as possible. If alone at the accident scene, try to establish breathing before calling for help, and do not leave the victim alone unattended.

Determine responsiveness

If a person is unconscious, try to rouse them by gently shaking and speaking to them.

If the person remains unresponsive, carefully roll them on the side (recovery position) and open his airway.

- Keep head and neck aligned.
- Carefully roll them onto their back while holding his head.

Fig 1

- Open the airway by lifting the chin (Fig 1).

Look, listen and feel for signs of breathing

Look for the victim's chest to raise and fall, listen for sounds of breathing.

If the victim is not breathing, see the section below

- If the victim is breathing, but unconscious, roll them onto their side, keeping the head and neck aligned with the body. This will help drain the mouth and prevent the tongue or vomit from blocking the airway.

Check the victim's circulation

Look at the victim's colour and check their pulse (the carotid artery is a good option; it is located on either side of the neck, below the jaw bone). If the victim does not have a pulse, start CPR.

Treat bleeding, shock and other problems as needed

After establishing that the victim is breathing and has a pulse, next priority should be to control any bleeding. Particularly in the case of trauma, preventing shock is the priority.

- **Stop bleeding:** Control of bleeding is one of the most important things to save a trauma victim. Use direct pressure on a wound before trying any other method of managing bleeding.
- **Treat shock:** Shock may causes loss of blood flow from the body, frequently follows physical and occasionally psychological trauma. A person in shock will frequently have ice cold skin, be agitated or have an altered mental status, and have pale colour to the skin around the face and lips. Untreated, shock can be fatal. Anyone who has suffered a severe injury or life-threatening situation is at risk for shock.
- **Choking victim:** Choking can cause death or permanent brain damage within minutes.
- **Treat a burn:** Treat first and second degree burns by immersing or flushing with cool water. Don't use creams, butter or other ointments, and do not pop blisters. Third degree burns should be covered with a damp cloth. Remove clothing and jewellery from the burn, but do not try to remove charred clothing that is stuck to burns.
- **Treat a concussion:** If the victim has suffered a blow to the head, look for signs of concussion. Common symptoms are: loss of consciousness following the injury, disorientation or memory impairment, vertigo, nausea, and lethargy.
- **Treat a spinal injury victim:** If a spinal injury is suspected, it is especially critical, not move the victim's head, neck or back unless they are in immediate danger.

Stay with the victim until help arrives

Try to be a calming presence for the victim until assistance can arrive.

Unconsciousness (COMA)

Unconscious also referred as Coma, is a serious life threatening condition, when a person lie totally senseless and do not respond to calls, external stimulus. But the basic heart, breathing, blood circulation may be still intact, or they may also be failing. If unattended it may lead to death.

The condition arises due to interruption of normal brain activity. The causes are too many.

Causes for COMA Stage

- Shock (Cardiogenic, Neurogenic)
- Head injury (Concussion, Compression)
- Asphyxia (obstruction to air passage)
- Extreme of body temperature (Heat, Cold)
- Cardiac arrest (Heart attack)
- Stroke (Cerbro-vascular accident)
- Blood loss (Haemorrhage)
- Dehydration (Diarrohea & vomiting)
- Diabetes (Low or high sugar)
- Blood pressure (Very low or very high)
- Over dose of alcohol, drugs
- Poisoning (Gas, Pesticides, Bites)
- Epileptic fits (Fits)
- Hysteria (Emotional, Psychological)

The following symptoms may occur after a person has been unconscious:

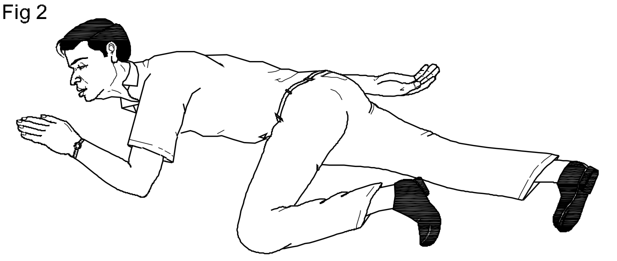
- Confusion
- Drowsiness
- Headache
- Inability to speak or move parts of his or her body (see stroke symptoms)
- Light headedness
- Loss of bowel or bladder control (incontinence)
- Rapid heartbeat (palpitation)
- Stupor

First aid

- Call EMERGENCY number.
- Check the person's airway, breathing, and pulse frequently. If necessary, begin rescue breathing and CPR.
- If the person is breathing and lying on the back and after ruling out spinal injury, carefully roll the person onto the side, preferably left side.

  Bend the top leg so both hip and knee are at right angles. Gently tilt the head back to keep the airway open (Fig 2). If breathing or pulse stops at any time, roll the person on to his back and begin CPR.
- If there is a spinal injury, the victims position may have to be carefully assessed. If the person vomits, roll the entire body at one time to the side. Support the neck and back to keep the head and body in the same position while you roll.

Fig 2



- Keep the person warm until medical help arrives.
- If you see a person fainting, try to prevent a fall. Lay the person flat on the floor and raise the level of feet above and support.
- If fainting is likely due to low blood sugar, give the person something sweet to eat or drink when they become concious.

DO NOT

- Do not give an unconscious person any food or drink.
- Do not leave the person alone.
- Do not place a pillow under the head of an unconscious person.
- Do not slap an unconscious person's face or splash water on the face and try to revive him.

Loss of consciousness may threaten life if the person is on his back and the tounge has dropped to the back of the throat, blocking the airway. Make certain that the person is breathing before looking for the cause of unconsciousness. If the injuries permit, place the casualty in the recovery position (Fig 2) with the neck extended. Never give any thing by mouth to an unconscious casualty.

How to diagnose an unconscious injured person

- **Consider alcohol:** look for signs of drinking, like empty bottles or the smell of alcohol.
- **Consider epilepsy:** are there signs of a violent seizure, such as saliva around the mouth or a generally dishevelled scene?
- **Think insulin:** might the person be suffering from insulin shock.
- **Think about drugs:** was there an overdose? Or might the person have under dosed - that is not taken enough of a prescribed medication?
- **Consider trauma:** is the person physically injured?
- **Look for signs of infection:** redness and/ or red streaks around a wound.
- **Look around for signs of Poison:** an empty bottle of

pills or a snakebite wound.

- **Consider the possibility of psychological trauma:** might the person have a psychological disorder of some sort?
- Consider stroke, particularly for elderly people.
- Treat according to what you diagnose.

Electric Shock (Fig 3)

A severe loss of body fluid will lead to a drop in blood pressure. Eventually the blood's circulation will deteriorate and the remaining blood flow will be directed to the vital organs such as the brain. Blood will therefore be directed away from the outer area of the body, so the victim will appear pale and the skin will feel ice cold.

As blood flow slows, so does the amount of oxygen reaching the brain. The victim may appear to be confused, weak, and dizzy and may eventually deteriorate into unconsciousness. Try to compensate for this lack of oxygen, the heart and breathing rates both speed up, gradually becoming weaker, and may eventually cease.

Fig 3

Potential causes of shock include: sever internal or external bleeding; burns; severe vomiting and diarrohea, especially in children and the elderly; problems with the heart.

Symptoms of shock

Victims appear pale, ice cold, pulse appear initially faster and gets slower, breathing becomes shallow. Weakness, dizziness, confusion continue. If unattended the patient may become unconscious and die.

First aid

Keep the patient warm and at mental rest. Assure of good air circulation and comfort. Call for help to shift the patient to safer place/ hospital.

- **Warmth:** Keep the victim warm but do not allow them to get overheated. If you are outside, try to get something underneath her if you can do easily. Wrap blankets and coats around her, paying particular attention to the head, through which much body heat is lost.
- **Air:** Maintain careful eye on the victim's airway and be prepared to turn them into the recovery position if necessary, or even to resuscitate if breathing stops. Try to keep back bystanders and loosen tight clothing to allow maximum air to victim.
- **Rest:** Keep the victim still and preferably sitting or lying down. If the victim is very giddy, lay them down with there legs raised to ensure that maximum blood and therefore maximum oxygen is sent to the brain.

Treatment of electric shock

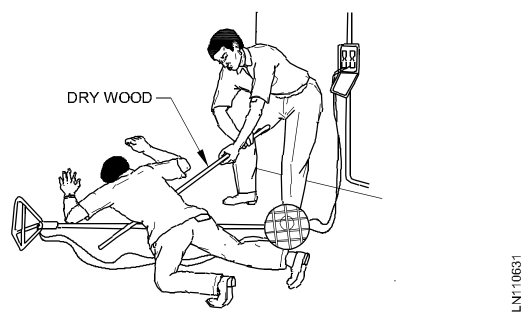
Prompt treatment is essential.

If assistance is close at hand, send for medical aid, then carry on with emergency treatment.

If you are alone, proceed with treatment at once.

Switch off the supply, if this can be done without undue delay. Otherwise, remove the victim from contact with the live conductor, using dry non-conducting materials such as a wooden bar, rope, a scarf, the victim's coat-tails, any dry article of clothing, a belt, rolled-up newspaper, non-metallic hose, PVC tubing, bakelised paper, tube etc. (Fig 4)

Fig 4



Avoid direct contact with the victim. Wrap your hands in dry material if rubber gloves are not available.

Electrical burns: A person receiving an electric shock may also sustain burns when the current passes through his body. Do not waste time by applying first aid to the burns until breathing has been restored and the patient can breathe normally - unaided.

Burns and scalds: Burns are very painful. If a large area of the body is burnt, give no treatment, except to exclude the air, eg.by covering with water, clean paper, or a clean shirt. This relieves the pain.

Artificial respiration methods to the electric shock victim

Artificical respiration methods already dealt in practical exercise 1.1.07 in detail. Refer practical book.

Disposal of waste material

Objectives: At the end of this lesson you shall be able to
- **state about the waste material**
- **state the types of waste material and source of waste**
- **list out the waste material in workshop**
- **explain the methods of disposal of waste material.**

Waste

Waste are unwanted or unusable materials. Waste is any substance which is discarded after primary use, or it is worthless, defective and of no use.

Waste is the by product of all the matter which is consumed by living organisms and is used in the industries as well as in agriculture and other fields. Usually this waste is thrown on areas outside the cities but this open disposal decreases the usable land into non-usable land and also polluting the environment.

Waste can be broadly classified as follows

a) Rural waste

b) Urban waste

   i) Solid waste

   II) Liquid waste

a) Rural waste

Rural waste is the waste from agricultural and dairy forms. These can be reused by burning agricultural waste and composing. The waste produced by the man and animal is now used in the production of fuel by bio-gas plants.

b) Urban waste

It is the waste from house hold articles or from industries within municipal limit

It can be again classified into two types.

i) Solid waste

Solid waste is the material is hard (from industries) such as newspaper, cans, bottles, broken glass, plastics container, polythene bags etc.

ii) Liquid waste

It is the water based waste which is produced by the main activation sources of waste.

Sources of waste

i) Industrial waste

It contains solid as well as liquid waste and is formed by the processing of various materials and it contains harmful chemical and solid metal waste.

ii) Domestic waste

It includes all rubbish, garbage, dust, sewage waste etc. It contains combustible and non-combustible materials. When these waste disposal off openly cause various harmful effects.

iii) Agricultural waste

It includes the waste produced from the crops and cattle etc. Open disposal of thin waste create problems for health of man and other animals.

iv) Flu ash produced by interval power plants.

v) Hospital waste is most harmful waste off contains micro organisms which cause both communicable and non-communicable deseases.

List out the waste material in workshop (Fig 1)

- Oily waste such as lubricating oil, coolant etc.
- Cotton waste.
- Metal chips of different materials.
- Electrical waste such as used and damaged accessories, wires, cables, pipes etc.

Methods of disposal of waste (Fig 2)

Disposal process : This is the final step of the waste management. From this disposal point or site the materials are selected steps as

- Recycling
- Composing

Fig 1

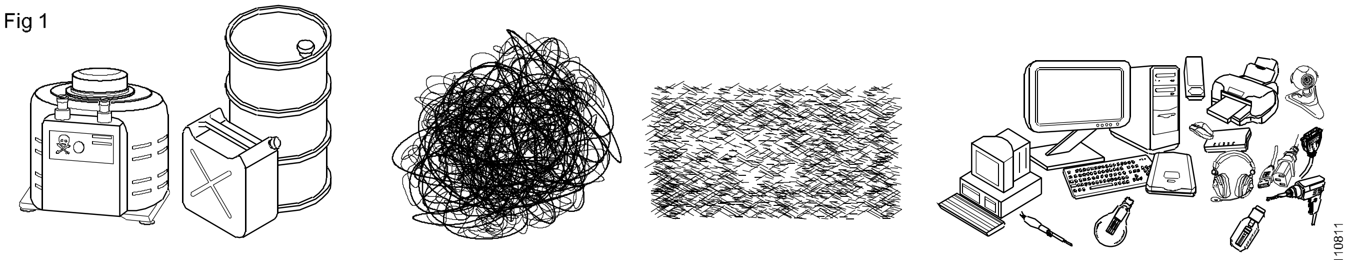
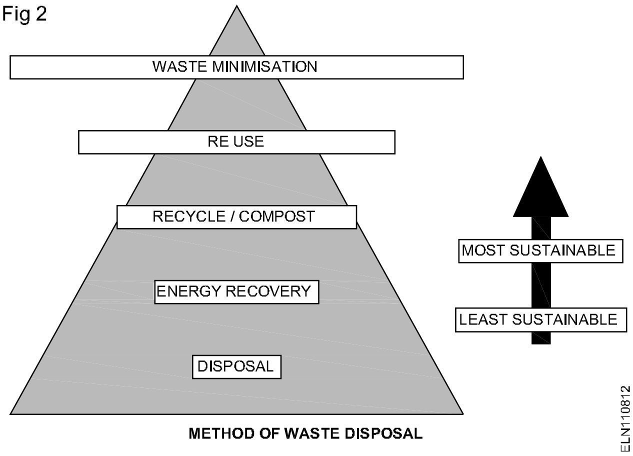


Fig 2



- Landfill
- Incineration
- Waste compaction
- Reuse
- Animal Feed
- Fire Wood

Recycling

Recycling is one of the most well known method of managing waste. It is not expensive and can be easily done by you. If you carry out recycling, you will save a lot of energy, resources and thereby reduce pollution.

Composting

This is a natural process that is completely free of any hazardous by-products. This process involves breaking down the material into organic compounds that can be used as manure.

Landfill

In this process, the waste cannot be reused or recycled separated out and spread as a thin layer in some low-lying areas across the city. A layer of soil added after each layer of garbage. Once this process is complete, this area declared unfit for building construction and is only used as a playground or a park.

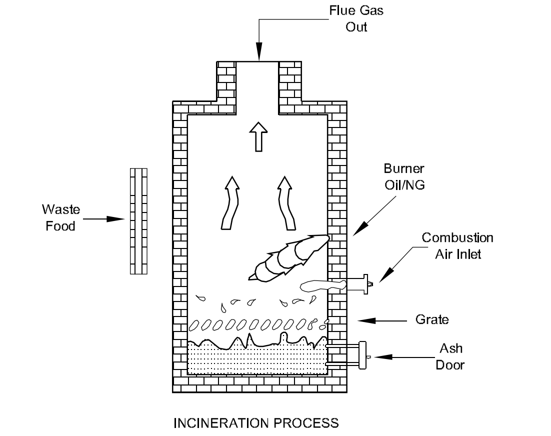
Incineration (Fig 3)

It is the process of controlled combustion of garbage to reduce it to incombustible matter, ash, waste gas and heat. It is treated and released into the environment (Fig 3). This reduced 90% volume of waste, some time the heat generated used to produce electric power.

Waste compaction

The waste materials such as cans and plastic bottles compact into blocks and send for recycling. This process need space, thus making transportation and positioning difficult.

Fig 3



Reuse

The amount of waste disposal can be reduced by carefully considering the exact throwing away. Before discarding the item think for the possibility to wash and reuse them. Plastic tubs contents butter or icecream can become effective storage containers for a range of small item like nails or screws.

Animal Feed:

Vegetable peel and food scraps can be retained to feed small animals such as lamsters rabbit etc. Large meat bones will be greately reused by feeding dog.

Fire Wood:

A small amount of waste disposal can be reused when it comes to refurnishing have or replacing furniture. before dicarding the furniture, cut it into more meaningful process and use as fire wood.

Personal Protective Equipment (PPE)

Objectives: At the end of this lesson you shall be able to
- **state about Personal Protective Equipment (PPE) and its purpose**
- **explain the occupational health safety, hygien**
- **explain occupational hazards**
- **list the most common type of personal protective equipment for hazards**

Personal Protective Equipment (PPE)

The Devices, equipment, or clothing used or worn by the employees, as a last resort, to protect against hazards in the workplace. The primary approach in any safety effort is that the hazard to the workmen should be eliminated or controlled by engineering methods rather than protecting the workmen through the use of personal protective equipment (PPE).

Engineering methods could include design change, substitution, ventilation, mechanical handling, automation, etc. In situations where it is not possible to introduce any effective engineering methods for controlling hazards, the workman shall use appropriate types of PPE.

The Factories Act, 1948 and several other labour legislations 1996 have provisions for effective use of appropriate types of PPE. Use of PPE is an important.

Ways to ensure workplace safety and use personal protective equipment (PPE) effectively.

- Workers to get up-to-date safety information from the regulatory agencies that oversees workplace safety in their specific area.
- To use all available text resources that may be in work area and for applicable safety information on how to use PPE best.
- When it comes to the most common types of personal protective equipment, like goggles, gloves or bodysuits, these items are much less effective if they are not worn at all times, or whenever a specific danger exists in a work process. Using PPE consistently will help to avoid some common kinds of industrial accidents.
- Personal protective equipment is not always enough to protect workers against workplace dangers. Knowing more about the overall context of your work activity can help to fully protect from anything that might threaten health and safety on the job.
- Inspection of gear thoroughly to make sure that it has the standard of quality and adequately protect the user should be continuously carried out.

Categories of PPEs

Depending upon the nature of hazard, the PPE is broadly divided into the following two categories:

1 **Non-respiratory:** Those used for protection against injury from outside the body, i.e. for protecting the head, eye, face, hand, arm, foot, leg and other body parts

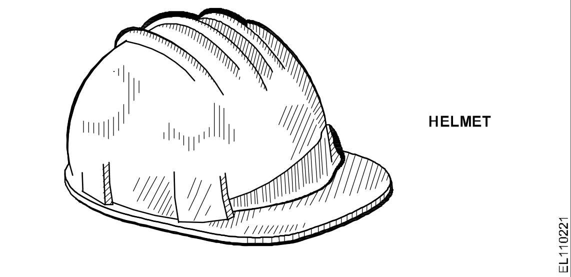
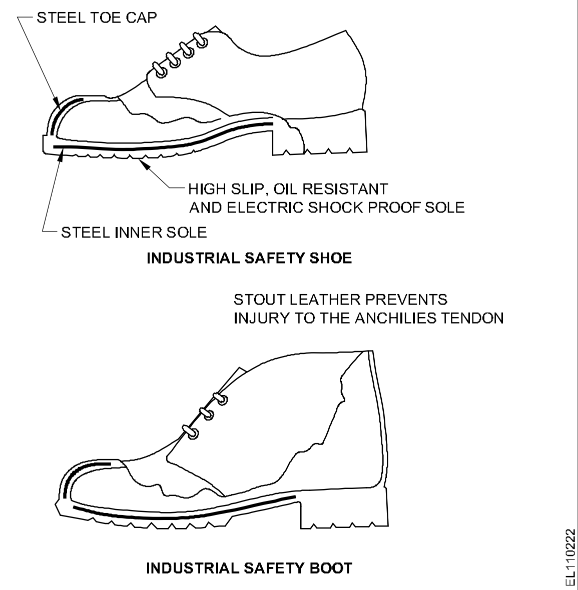
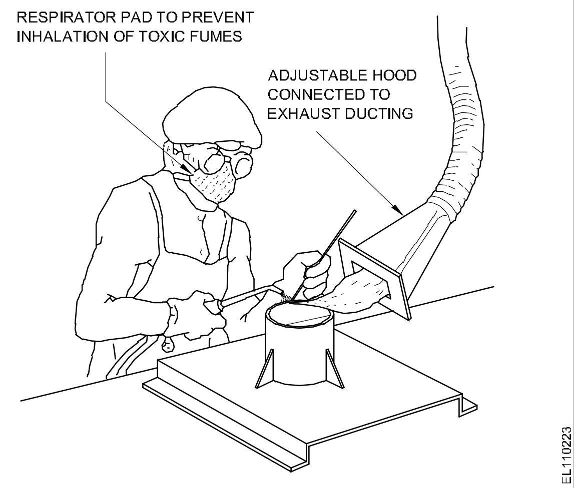
2 **Respiratory:** Those used for protection from harm due to inhalation of contaminated air.

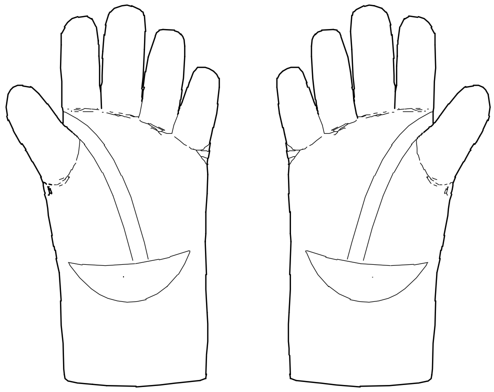
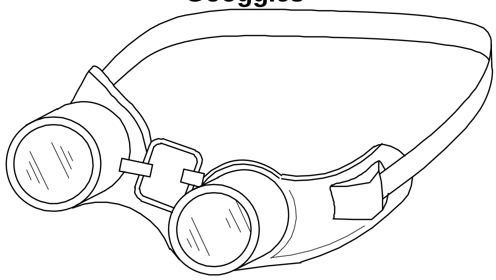
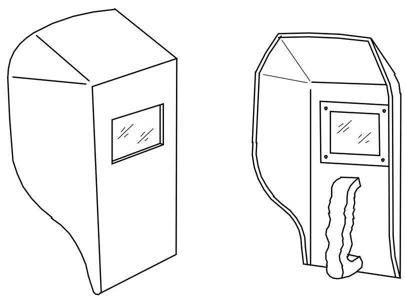
The guidelines on 'Personal Protective Equipment' is issued to facilitate the plant management in maintaining an effective programme with respect to protection of persons against hazards, which cannot be eliminated or controlled by engineering methods listed in table1.

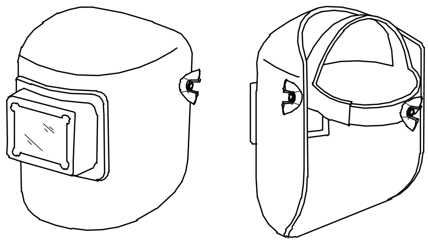
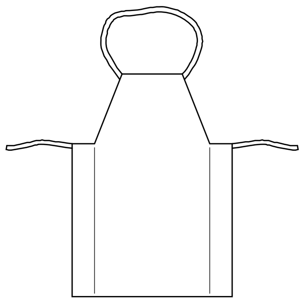
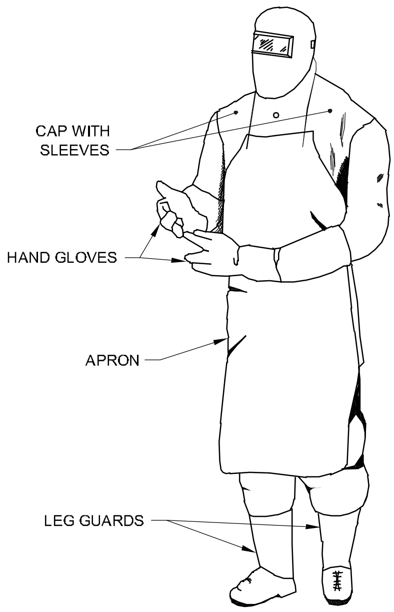
Table1

No.	Title
PPE1	Helmet
PPE2	Safety footwear
PPE3	Respiratory protective equipment
PPE4	Arms and hands protection
PPE5	Eyes and face protection
PPE6	Protective clothing and coverall
PPE7	Ears protection
PPE8	Safety belt and harnesses

Personal protective equipments and their uses and hazards are as follows

Types of protection	Hazards	PPE to be used
Head Protection (Fig 1)	1. Falling objects 2. Striking against objects 3. Spatter	Fig 1 
Foot protection (Fig 2)	1. Hot spatter 2. Falling objects 3. Working wet area	Fig 2  **and** **leather leg guards**
Nose (Fig 3)	1. Dust particles 2. Fumes/ gases/ vapours	Fig 3 **Nose Mask** 

Types of protection	Hazards	PPE to be used
Hand protecion (Fig 4)	1. Heat burn due to direct contact 2. Blows sparks moderate heat 3. Electric shock	Fig 4 **Hand Gloves**  GLOVES EL110224
Eye protection (Fig 5, Fig 6)	1. Flying dust particles 2. UV rays, IR rays heat and High amount of visible radiation	Fig 5 **Googgles**  EL110225 **and** **Face Shield** **Head Shield** **Hand Shield**
Face Protection (Fig 6, Fig 7)	1. Spark generated during Welding, grinding 2. Welding spatter striking 3. Face protection from UV rays	Fig 6  HAND SCREEN EL110226 **and** **Face Shield** **Head Shield with or without Ear Muff** **Helmets with screen for welders**

Types of protection	Hazards	PPE to be used
Ear protection (Fig 7)	1. High noise level	Fig 7  **Head shield with Ear muff** **and** **Ear plug** **Ear Muff**
Body protection (Fig 8, Fig 9)	1. Hot particles	Fig 8  Fig 9  **Body Guard**

Quality of PPE's

PPE must meet the following criteria with regard to its quality-provide absolute and full protection against possible hazard and PPE's be so designed and manufactured out of materials that it can withstand the hazards against which it is intended to be used.

Selection of PPE's requires certain conditions

- Nature and severity of the hazard
- Type of contaminant, its concentration and location of contaminated area with respect to the source of respirable air
- Expected activity of workman and duration of work, comfort of workman when using PPE
- Operating characteristics and limitations of PPE
- Easy of maintenance and cleaning
- Conformity to Indian/ International standards and availability of test certificate.

Proper use of PPEs

Having selected the proper type of PPE, it is essential that the workman wears it. Often the workman avoids using PPE. The following factors influence the solution to this problem.

- The extent to which the workman understands the necessity of using PPE
- The ease and comfort with which PPE can be worn with least interference in normal work procedures
- The available economic, social and disciplinary sanctions which can be used to influence the attitude of the workman
- The best solution to this problem is to make 'wearing of PPE' mandatory for every employee.
- In other places, education and supervision need to be intensified. When a group of workmen are issued PPE for the first time.

Occupational health hazard and safety

Safety

Safety means freedom or protection from harm, danger, hazard, risk, accident, injury or damage.

Occupational health and safety

- Occupational health and safety is concerned with protecting the safety, health and welfare of people engaged in work or employment.
- The goal is to provide a safe work environment and to prevent hazards.
- It may also protect co-workers, family members, employers, customers, suppliers, nearby communities, and other members of the public who are affected by the workplace environment.
- It involves interactions among many related areas, including occupational medicine, occupational (or industrial) hygiene, public health, and safety engineering, chemistry, and health physics.

Need of occupational health and safety

- Health and safety of the employees is an important aspect of a company's smooth and successful functioning.
- It is a decisive factor in organizational effectiveness. It ensures an accident-free industrial environment.
- Proper attention to the safety and welfare of the employees can yield valuable returns.
- Improving employee morale
- Reducing absenteeism
- Enhancing productivity
- Minimizing potential of work-related injuries and illnesses
- Increasing the quality of manufactured products and/ or rendered services.

Occupational (Industrial) hygiene

- Occupational hygiene is anticipation, recognition, evaluation and control of work place hazards (or) environmental factors (or) stresses
- This is arising in (or) from the workplace.
- Which may cause sickness, impaired health and well being (or) significant discomfort and inefficiency among workers.

Anticipation (Identification): Methods of identification of possible hazards and their effects on health

Recognition (Acceptance): Acceptance of ill-effects of the identified hazards

Evaluation (Measurement & Assessment): Measuring or calculating the hazard by Instruments, Air sampling and Analysis, comparison with standards and taking judgement whether measured or calculated hazard is more or less than the permissible standard.

Control of workplace hazards: Measures like Engineering and Administrative controls, medical examination, use of Personal Protective Equipment (PPE), education, training and supervision

Occupational hazards

"Source or situation with a potential for harm in terms of injury or ill health, damage to property, damage to the workplace environment, or a combination of these".

Types of occupational health hazards

- Physical Hazards
- Chemical Hazards
- Biological Hazards
- Physiological Hazards

- Mechanical Hazards
- Electrical Hazards
- Ergonomic Hazards.

1 Physical hazards

- Noise
- Heat and cold stress
- Vibration
- Radiation (ionising & Non-ionising)
- Illumination etc.,

2 Chemical hazards

- Inflammable
- Explosive
- Toxic
- Corrosive
- Radioactive

3 Biological hazards

- Bacteria
- Virus
- Fungi
- Plant pest
- Infection.

4 Physiological

- Old age
- Sex
- Ill health
- Sickness
- Fatigue.

5 Psychological

- Wrong attitude
- Smoking
- Alcoholism
- Unskilled
- Poor discipline
  - absentism
  - disobedience
  - aggressive behaviours
- Accident proneness etc,
- Emotional disturbances
  - voilence
  - bullying
  - sexual harassment

6 Mechanical

- Unguarded machinery
- No fencing
- No safety device
- No control device etc.,

7 Electrical

- No earthing
- Short circuit
- Current leakage
- Open wire
- No fuse or cut off device etc,

8 Ergonomic

- Poor manual handling technique
- Wrong layout of machinery
- Wrong design
- Poor housekeeping
- Wrong tools etc,

Safety Slogan
A Safety rule breaker, is an accident maker

Guidelines for cleanliness of workshop and maintenance

Objectives: At the end of this lesson you shall be able to
- **state the necessity of cleaning of workshop**
- **list the benefits of shop floor cleaning and maintenance**
- **state the common cleaning procedure in workshop**
- **list the different methods of cleaning process**
- **state the concept of 5s techniques and their description**
- **list the benefits of 5s techniques.**

Cleaning process

Cleaning is the process of removal of unwanted matter, contaminants or pollutants from the environment or the prevention of soiling thus it should be - GREEN clean.

'Green-cleaning" means the need to clean up the cleaning process and protect themselves.

Cleaning is about removing pollution, not additing to it.

Necessity of cleaning of workshop

A clean workplace ensures safety and health of employees and injuries can be prevented by taking action to ensure a clean, safe work environment.

Reasons for cleaning the workplace

- Cleaning of dry floors essentially to prevent slips and falls in the workplace.
- Disinfectants prevents the spread germs and illness, because it will stop germs in their tracks.
- Proper air filteration reduces the exposures of hazardous substances like dust and vapors.
- Cleaning of light fixtures improve lighting efficiency.
- Using green cleaning products which is safer for both employees and the environment.
- Proper disposal of waste and recyclable materials keeps work areas clean.

Benefits of a shop floor maintenance

- Productive can be improved.
- Improves operator's efficiencies.
- Improves the support operations such as replacement moves and finished goods.
- Reduction of scrap.
- Manufacturing process can be controlled effectively.
- Reduction of downtime due to better machine and tool manitoring.
- Better control of inventory process.

Common cleaning procedure

- Before starting to clean, read the product and equipment labels and usage instructions.
- Wear recommended Personal Potective Equipment (PPE) like rubber or surgical type gloves, goggles, dust mask or respirator, earplugs etc.
- Cleaning must be performed to prevent or remove soils, contaminants or pollutants.
- Select and use less toxic products and this system is known as **"Standard Operating Procedures" (SOPs)**.
- SOPs is the part of the over all operation and maintenance plan for bending.

Other different methods of cleaning are

- Sprinkling
- Spraying
- Power wash process
- Boiling under pressure
- Carbon dioxide cleaning
- Pre cleaning
- Main cleaning
- Rinsing
- Drying etc,

For improving the standardising the way to clean **Standard Operating Procedures (SOPs)** as a set of written guidelines must be provided to the cleaners which includes

1 Cleaning procedures
2 Chemical handling and tracking requirements
3 Communication protocols
4 Training and inspection programs
5 Reporting and record keeping procedures.

The above guidelines should be made available to all cleaning personel and occupants.

Recommended activities for green cleaning

- Provide easily understood directions to cleaning staff in written with local languages.
- Use the appropriate technology (coarse spray, automatic chemical dispensers etc).
- Provide directory for the proper rinsing and disposal of expended or empty solution containers.
- Reduce, minimize or eliminate the need for using cleaning chemicals if possible.

5 Steps (5s) - Concept

5s is a people-oriented and practice-oriented approach. 5s expects every one to participate in it. It becomes a basic for continuous improvement in the organisation.

The terms (5s) 5 steps are

Step 1: SEIRI (Sorting out)

Step 2: SEITON (Systematic arrangement)

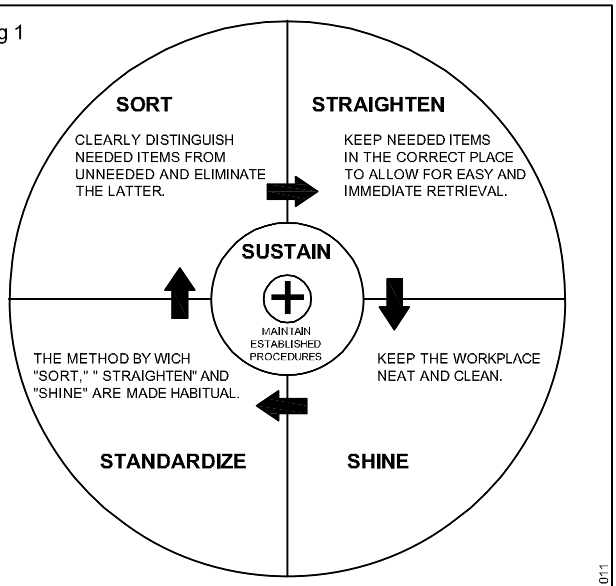
Step 3: SEISO (Shine cleanliness)

Step 4: SEIKTSU (Stanardization)

Step 5: SHITSURE (Self discipline)

Fig 1 shows the 5s concept wheel.

Fig 1



5s WHEEL

The list describes how to organize a work space for efficiency and effectiveness by identifying and storing the items used, maintaining the area and items and sustaining the new order.

Benefits of 5s

- Work place becomes clearer and better organised.
- Working in working place becomes easier.
- Reduction in cost.
- People tend to be more disciplined.
- Delay is avoided.
- Less absenteeism.
- Better use of floor space.
- Less accidents.
- High productivity with quality etc.

Trade hand tools - specification - standards - NEC code 2011 - lifting of heavy loads

Objectives: At the end of this lesson you shall be able to
- **list the tools necessary for an electrician**
- **specify the tools and state the use of each tool**
- **explain the care and maintenance of electrician hand tools.**

It is important that the electrician uses proper tools for his work. The accuracy of workmanship and speed of work depend upon the use of correct tools. If the tools are properly used, and maintained, the electrician will find the working efficiency increases and the skills becomes a work habit.

Listed below are the most commonly used tools by electrician.

Their specifications and BIS number are given for your reference. Proper method of care and maintenance will result in prolonged tool life and improved working efficiency.

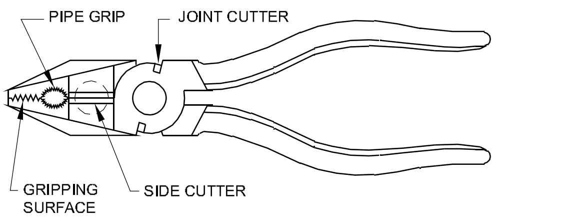
Pliers

They are specified with their overall dimensions of length in mm. The pliers used for electrical work will be of insulated grip.

1 **Combination pliers with pipe grip, side cutter and insulated handle**. BIS 3650 (Fig 1)

Size 150 mm, 200 mm etc.

Fig 1



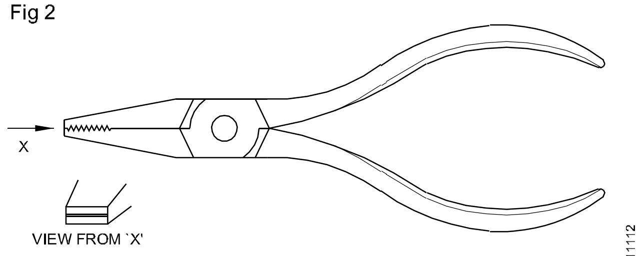
COMBINATION SIDE CUTTING PLIERS (ENGINEER'S PLIERS, COMBINATION PLIERS)

It is made of forged steel. It is used for cutting, twisting, pulling, holding and gripping small jobs in wiring assembly and repairing work. A non-insulated type is also available. Insulated pliers are used for work on live lines.

2 **Flat nose pliers** BIS 3552 (Fig 2)

Size 100 mm, 150 mm, 200 mm etc.

Fig 2



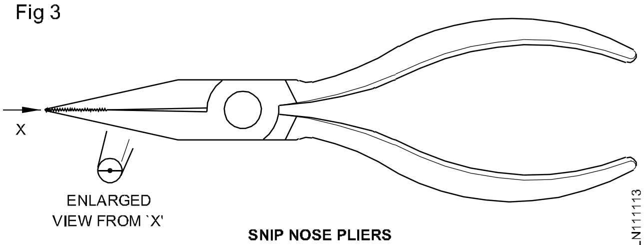
FLAT NOSE PLIERS

Flat nose pliers are used for holding flat objects like thin plates etc.

3 **Long nose pliers** or (snip nose pliers) with side cutter.BIS 5658 (Fig 3)

Size 100 mm, 150 mm etc.

Fig 3

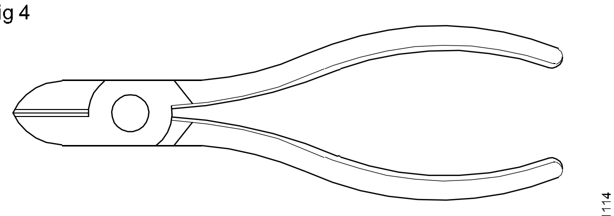


SNIP NOSE PLIERS

Long nose pliers are used for holding small objects in places where fingers cannot reach.

4 **Side cutting pliers** (Diagonal cutting pliers) BIS 4378 (Fig 4) Size 100 mm, 150 mm etc.

Fig 4



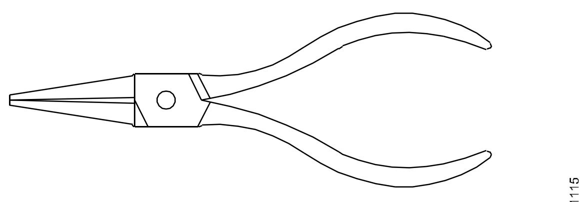
DIAGONAL CUTTING PLIERS/NIPPER

It is used for cutting copper and aluminium wires of smaller diameter (less than 4mm dia).

5 **Round nose pliers** BIS 3568 (Fig 5)

Size 100 mm, 150 mm etc.

Fig 5



ROUND NOSE PLIERS

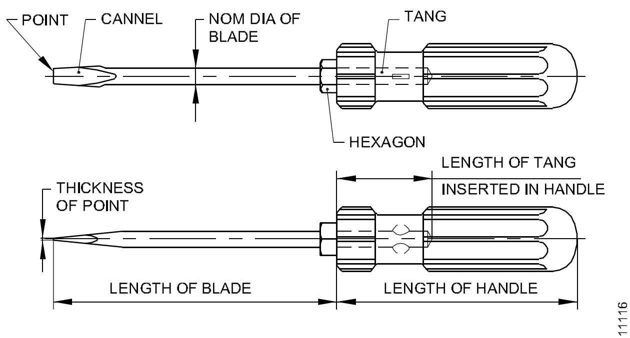
Wire hooks and loops could be made using the round nose pliers.

Care and maintenance of pliers

- Do not use pliers as hammers.
- Do not use pliers to cut large sized copper or aluminium wires and hard steel wires of any size.
- While using the pliers avoid damages to the insulation of hand grips.
- Lubricate hinged portions.

6 **Screwdriver BIS 844** (Fig 6)

Fig 6



NOMENCLATURE FOR SCREWDRIVERS

The screwdrivers used for electrical works generally have plastic handles and the stem is covered with insulating sleeves. The size of the screw driver is specified by its blade length in mm and nominal screwdriver's point size (thickness of tip of blade) and by the diameter of the stem.

eg. 75 mm x 0.4 mm x 2.5 mm

150 mm x 0.6 mm x 4 mm

200 mm x 0.8 mm x 5.5 mm etc.

The handle of screwdrivers is either made of wood or cellulose acetate.

Screwdrivers are used for tightening or loosening screws. The screwdriver tip should correctly fit the grooves of the screw to have maximum efficiency and to avoid damage to the screw heads.

As the length of the screw driver is proportional to the turning force, for small work choose a suitable small sized screwdriver and vice versa.

Star-head Screwdriver

It is used for driving star headed screws.

Care and maintenance

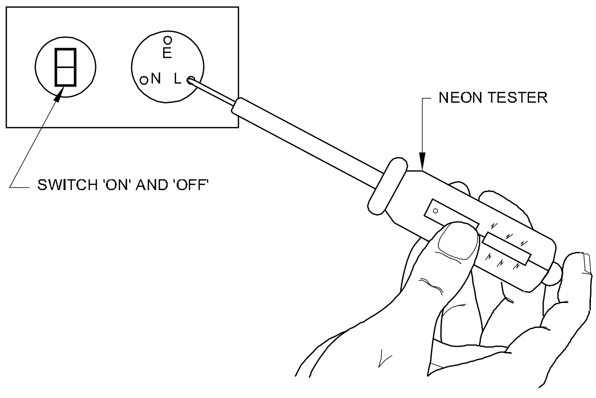
- Never use a screwdriver as a lever to apply force as this action will make the stem to bend and the use of the screw driver will be lost.
- Keep the tip in correct shape and in rare cases it could be grinded to shape.

7 **Neon tester** BIS 5579 - 1985 (Fig 7)

It is specified with its working voltage range 100 to 250 volts but rated to 500 V.

It consists of a glass tube filled with neon gas, and electrodes at the ends. To limit the current within 300 micro-amps at the maximum voltage, a high value resistance is connected in series with one of the electrodes. It may have a tip like a probe or screwdriver at one end. The presence of supply is indicated by the glow of the lamp when the tip is touched on the live supply and the brass contact in the other end of neon tester is touched by hand.

Fig 7



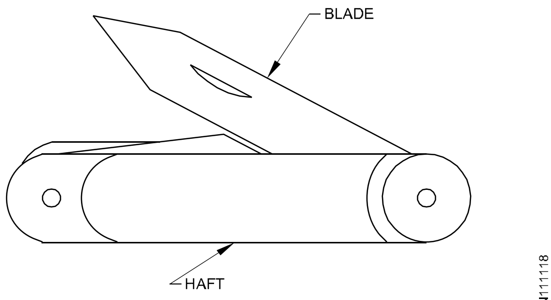
NEON TESTER

Care and maintenance

- Never use the neon tester for voltage higher than the specified range.
- While testing see the circuit is completed through the body. In case if you are using rubber soled shoes, the earthing of the body could be provided by touching the wall by one hand.
- Use the screwdriver tipped neon tester for light duty work only.

8 **Electrician's knife** (Double blade) (Fig 8)

Fig 8



ELECTRICIAN'S KNIFE

The size of the knife is specified by its largest blade length eg. 50 mm, 75 mm.

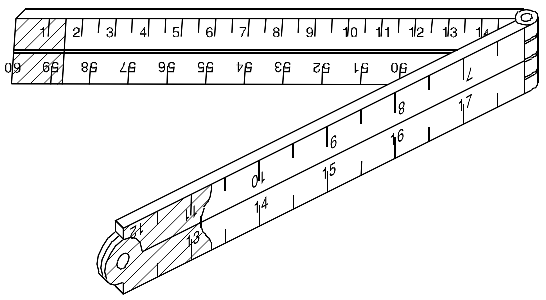
It is used for skinning the insulation of cables and cleaning the wire surface. One of the blades which is sharp is used for skinning the cable and the rough edged blade is used for cleaning the surface of the wires.

Care and maintenance

- Do not use the knife for cutting wires.
- Keep it free from rust.
- Keep one of the blades in a sharp condition.
- Fold the knife blade when not in use.

9 **Four-fold box wood rule 600mm** (Fig 9)

Fig 9

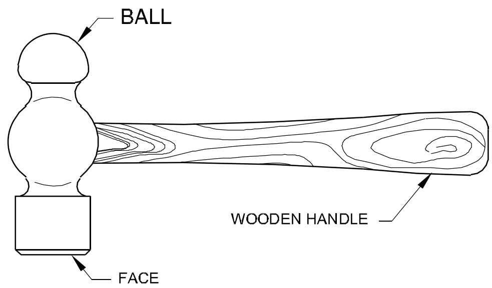


FOUR-FOLD BOX WOOD RULE

Used for measuring short lengths. To be kept in folded condition when not in use.

10 **Hammer ball pein** (Fig 10)

Fig 10



BALL PEIN HAMMER

The size of the hammer is expressed in weight of the metal head. Eg.125 gms, 250 gms etc.

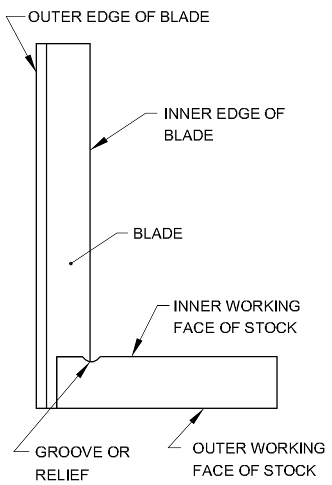
The hammer is made out of special steel and the striking face is tempered. Used for nailing, straightening, and bending work. The handle is made of hard wood.

Care and maintenance

- Do not use a hammer with a loose handle.
- The face of the hammer must be free from oil, grease and mushrooms.

11 **Try-square** (Engineer's square) (Fig 11) BIS 2103

Fig 11



TRY-SQUARE

This is specified by its blade length.

Eg. 50 mm x 35 mm

100 mm x 70 mm

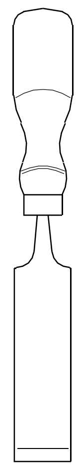
150 mm x 100 mm etc.

There are two types; one is the bevelled edge with stock and the other is the flat edge without stock. It is used to check whether the object is plane, perpendicular and at right angle. Two straight blades set at right angles to each other constitute the try-square. The steel blade is riveted to the stock. The stock is made of cast iron. The stock should be set against the edge of the job.

Do not use it as a hammer.

12 **Firmer chisel** (Fig 12)

Fig 12



FIRMER CHISEL

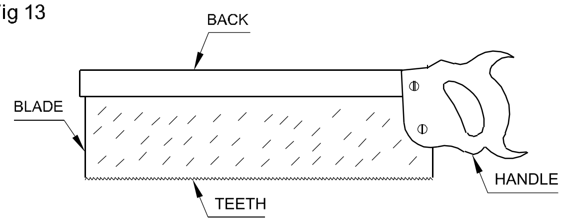
It has a wooden handle and a cast steel blade of 150 mm length. Its size is measured according to the width of the blade eg. 6 mm, 12 mm, 18 mm, 25 mm. It is used for chipping, scraping and grooving in wood.

Care and maintenance

- Do not use it for driving screws.
- Use mallet for chiseling.
- Grind on a water stone and sharpen on an oilstone.
- Do not use it in places where nails are driven.

13 **Tenon-saw** (Fig 13) BIS 5123, BIS 5130, BIS 5031

Fig 13



TENON-SAW

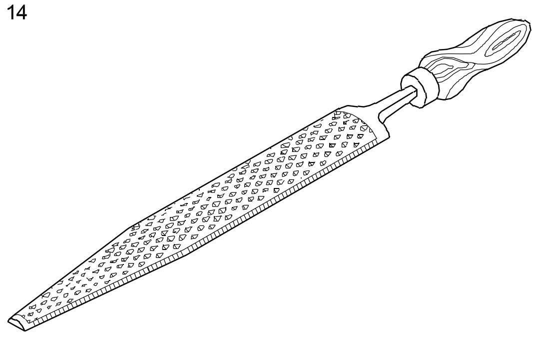
Generally the length of a tenon-saw will be 250 or 300 mm. and has 8 to 12 teeth per 25.4 mm and the blade width is 10 cm. It is used for cutting thin, wooden accessories like wooden batten, casing capping, boards and round blocks.

Care and maintenance

- Keep free from rust.
- Apply grease when not in use.

14 **Wood rasp file** (Fig 14) BIS 1931

Fig 14



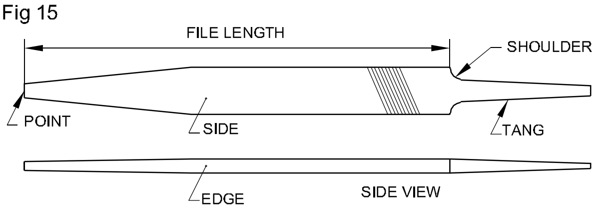
WOOD RASP FILE

ELN11111E

It is used for filing wooden articles where finish is not important. Wood rasp files are of half round shape. They have sharp coarse single cut teeth.

15 **Files** (Fig 15) BIS 1931

Fig 15



FILE

ELN11111F

These are specified by their nominal length.

Eg.150 mm, 200 mm, 250 mm 300 mm etc.

These files have different numbers of teeth designed to cut only in the forward stroke. They are available in different lengths and sections (Eg.flat, half round, round, square, triangular), grades like rough, bastard second cut and smooth and cuts like single and double cut.

These files are used to remove fine chips of material from metals. The body of the file is made of cast steel and hardened except the tang.

Care and maintenance

- Never use the file as a hammer.
- Do not use the file without the handle.
- Do not throw a file since the teeth get damaged.

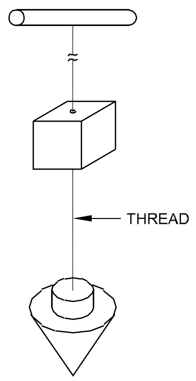
16 **Plumb bob** (Fig 16)

It has a pointed tip with a centre hole at the top for attaching a string as shown in Fig 16. It is used for marking vertical lines on the wall.

Care and maintenance

Do not drop to the ground.

Fig 16



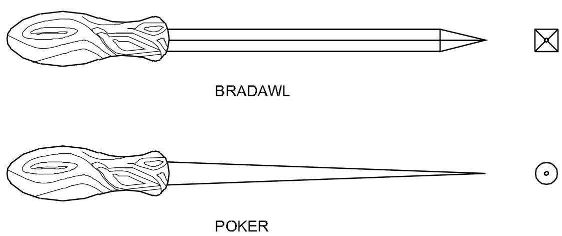
PLUMB BOB

ELN11111G

17 **Bradawl square pointed (or poker) (**Fig 17)

BIS 10375 - 1982

Fig 17



ELN11111H

It is specified by its length and diameter eg. 150 mm x 6 mm.

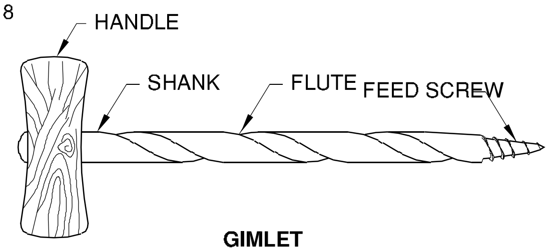
It is a long sharp tool used for making pilot holes on wooden articles to fix screws.

Care and maintenance

- Do not use it on metals for making holes.
- Keep it in good sharpened condition.

18 **Gimlet** (Fig 18)

Fig 18



GIMLET

ELN11111I

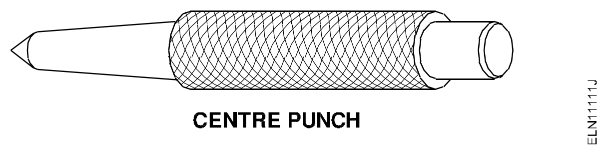
It is used for boring small holes on wooden articles. It has a wooden handle and a boring screwed edge. The size of it depends upon its diameter. Eg. 3 mm, 4 mm, 5 mm, 6 mm.

Care and maintenance

- Do not use it without the handle.
- Do not use it on nails.
- Keep it straight while making holes, otherwise the screwed portion can get damaged.

19 **Centre punch** (Fig 19) BIS 7177

Fig 19



CENTRE PUNCH

The size is given by its length and diameter of the body.

Eg. 100 mm x 8 mm. The angle of the tip of the centre punch is 90°.

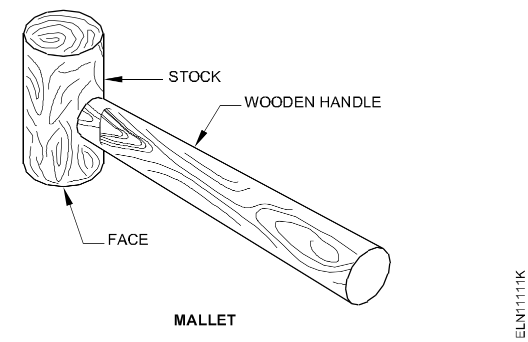
It is used for marking and punching pilot holes on metals. It is made of tool steel and the ends are hardened and tempered.

Care and maintenance

- Keep the tip sharp and at a proper angle.
- Avoid mushroom heads.

20 **Mallet** (Fig 20)

Fig 20



MALLET

The mallet is specified by the diameter of the head or by the weight.

eg. 50 mm x 150 mm

75 mm x 150 mm or 500gms, 1 Kg.

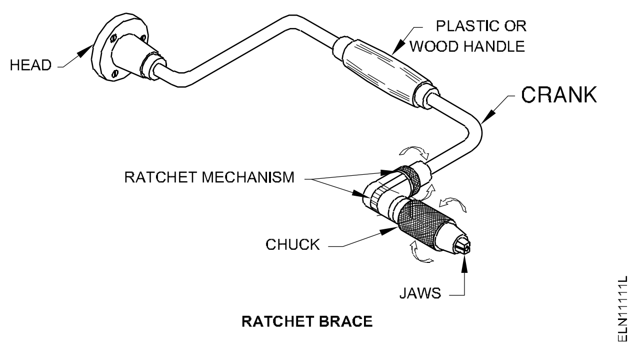
It is made out of hard wood or nylon. It is used for driving the firmer chisel, and for straightening and bending of thin metallic sheets. Also it is used in motor assembly work.

Care and maintenance

- Do not use it for fixing nails.
- Never use it on hard metal like steel and iron.

21 **Ratchet brace** (Fig 21) BIS 7042

Fig 21

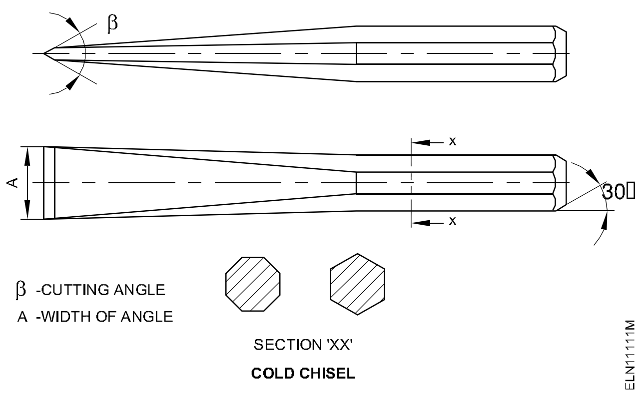


RATCHET BRACE

The size of a ratchet brace is given by the size of drill bit it can accommodate ie. 0 - 6 mm, 0 - 12 mm. It is used to drill holes on wooden blocks.

22 **Flat cold chisel** (Fig 22) BIS 402

Fig 22



COLD CHISEL

Its size is given by the nominal width and length.

ie. 14 mm x 100 mm

15 mm x 150 mm

20 mm x 150 mm

The body shape of a cold chisel may be round or hexagon.

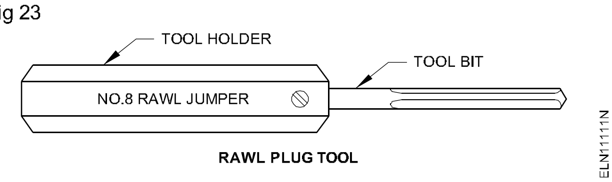
The cold chisel is made out of high carbon steel. Its cutting edge angle varies from 35° to 45°. The cutting edge of the chisel is hardened and tempered. This chisel is used for making holes on wall etc.

Care and maintenance

- The edge of a chisel must be maintained as per the required angle.
- While grinding a chisel apply a coolant frequently so that its temper may not be lost.

23 **Rawl plug tool and bit** (Fig 23)

Fig 23



RAWL PLUG TOOL

Its size depends upon the number. As the number increases, the thickness of the bit as well as the plug also increases. Eg. Nos.8, 10, 12, 14 etc.

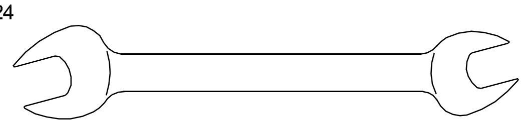
A rawl plug tool has two parts, namely the tool bit and tool holder. The tool bit is made of tool steel and the holder is made of mild steel. It is used for making holes in bricks, concrete wall and ceiling. Rawl plugs are inserted in them to fix accessories.

Care and maintenance

- Slightly rotate the holder after each hammering stroke.
- Hold the tool straight.
- Do not throw it on the ground.
- Keep its head free from mushrooms.

24 **Spanner: double ended** (Fig 24) BIS 2028

Fig 24



DOUBLE ENDED OPEN JAW SPANNER

The size of a spanner is indicated so as to fit on the nuts. They are available in many sizes and shapes.

The sizes, indicated in double-ended spanners are

10-11 mm

12-13 mm

14-15 mm

16-17 mm

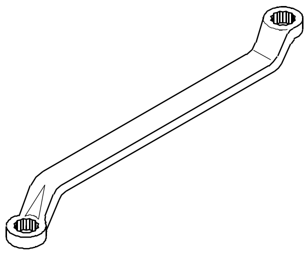
18-19 mm

20-22 mm.

For loosening and tightening of nuts and bolts, spanner sets are used. It is made out of cast steel. They are available in many sizes and may have single or double ends.

25 **Ring spanner set** (Fig 25) BIS 2029

Fig 25

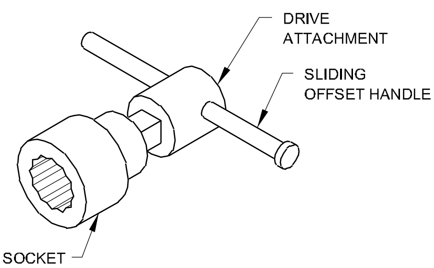


RING SPANNER

The ring spanner is used in places where the space is restricted and where high leverage is required.

26 **Socket (box) spanner** (Fig 26) BIS 7993, 7991, 6129

Fig 26



SOCKET SPANNER

These spanners are useful at places where the nut or bolt is located in narrow space or at depth.

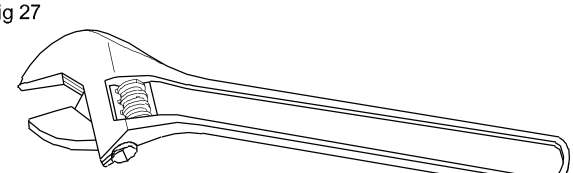
27 **Single ended open jaw adjustable spanner** (Fig 27) BIS 6149

It saves time and working. The movable jaw is made adjustable by operating a screw. It is known as a monkey wrench also. Available in 150,200,250mm etc.

Care and maintenance

- Use correct size spanner suitable to the size of nut and bolt.
- Do not use a spanner as a hammer.
- While using a spanner do not strike it with a hammer.
- Prevent the grease and oil traces on its jaws.

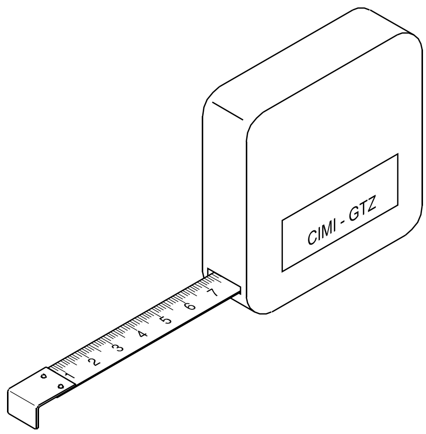
Fig 27



ADJUSTABLE SPANNER

28 **Measuring steel tape** (Fig 28)

Fig 28



MEASURING STEEL TAPE

The size will be the maximum length it can measure. Eg.Blade 12 mm wide 2 metres long.

The measuring tape is made of thin steel blade, bearing dimensions on it.

It is used for measuring the dimension of the wiring installation and general measurements.

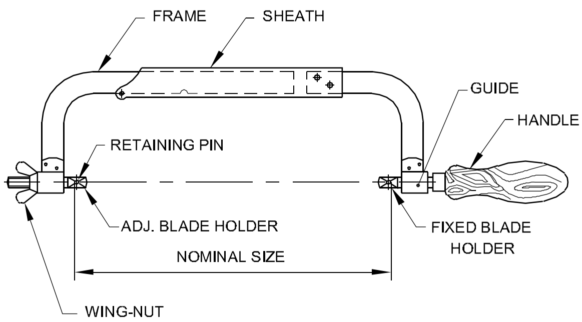
Care and maintenance

Handle with great care as carelessness may spoil the graduation.

29 **Hacksaw** (Fig 29) BIS 5169-1986 for frames

BIS 2594 - 1977 for blades

Fig 29



NOMENCLATURE FOR HACKSAW FRAME

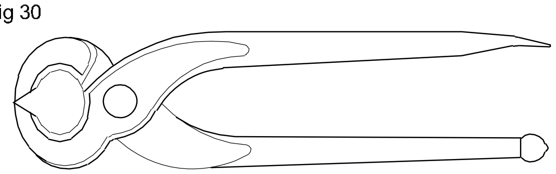
It is made out of sturdy nickel plated steel frame. The frame can be adjusted for 250 mm to 300 mm blades. It should be fixed on the frame with its teeth pointing away from the handle in order to do the cutting in forward stroke. It is mainly used for cutting metals.

Care and maintenance

- The blade should be properly tightened.
- Use a coolant while cutting.
- It should be straight during cutting.
- Lift the saw slightly on the return stroke.
- Do not attempt to saw too fast.

30 **Pincers** (Fig 30) BIS 4195

Fig 30



PINCERS

The size is given by its length. Eg. 100 mm, 150 mm, 200 mm.

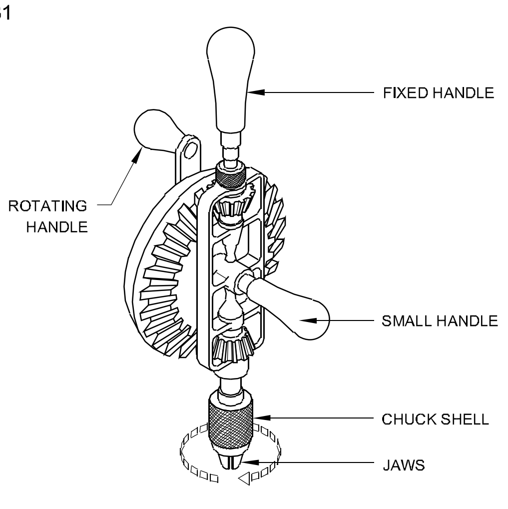
It is used for extracting nails from the wood.

Care and maintenance

- Do not use it as a hammer.

31 **Hand drill** (Fig 31)

Fig 31



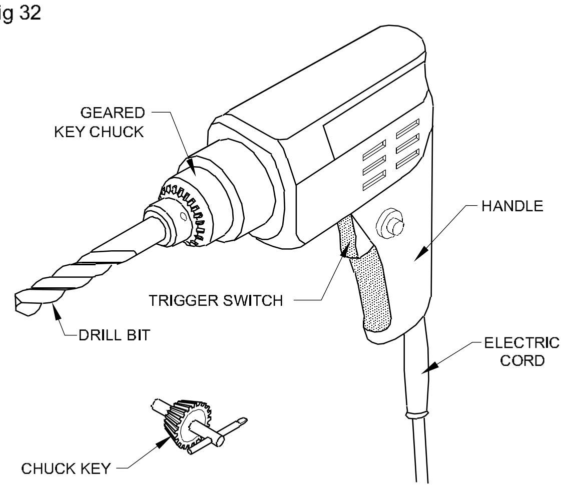
HAND DRILL

The size is given by the twist drill bits which can be fitted in. Eg. 6 mm, 0-12 mm capacity.

A hand drill machine is used for making holes in thin metal sheets or wooden articles.

32 **Portable Electric drilling machine** (Fig 32)

Fig 32



ELECTRIC DRILLING MACHINE

When power is available, a power drilling machine is a more convenient and accurate tool for drilling holes on wooden and metal articles.

Care and maintenance

- Lubricate all the moving parts of the machine.
- Fix the drill bit firmly in the jaws.
- Before drilling, mark the job with a centre punch.
- For taking out the drill bit move the chuck in the reverse direction.
- Do not apply excess pressure on small bits.
- In the case of an electric drilling machine it must be properly earthed and the insulation should be sound.

Standard and standardisation

Objectives: At the end of this lesson you shall be able to
- **state what is meant by standardisation and standard**
- **state the names of various standard organisation**
- **read and interpret the basic concept of electrical code 2011**
- **state the types of injury caused by the improper lifting method**
- **describe the procedure to be followed for moving heavy equipments**

Standardisation can be defined as the process of formulating and applying rules for an orderly approach to specific activity for the benefit of the user and the manufacturer, and in particular for the promotion of optimum overall economy taking due account of functional conditions and safety requirement.

It is based on the consolidated results of science, technique and experience. It determines not only the basis for the present but also for future development, and to keep pace with progress.

The materials/tools/equipment produced in any country should be of certain standard. To meet this requirement, the international organisation for standarization(ISO) is started and specifies the units of measurement, technology and symbols, products and processes, safety of persons and goods through a number of booklets coded with ISO number.

Standard can be defined as a formulation established verbally, in writing or by any other graphical method or by means of a model, sample or other physical means of representation to serve during a certain period of time for defining designating or specifying certain features of a unit or basis of measurement, physical object, an action, process, method, practice, capacity, function, duty, right of responsibility, a behaviour, an attitude a concept or a conception.

To sell Indian goods in the local and international market certain standardization methods are essential. The standard is specified by the **B**ureau of **I**ndian **S**tandard **BIS**(ISI) for various goods through their booklets. The BIS only certifies a good often the product meets the specification and passes necessary tests. The manufacturer allows to use the BIS(ISI) mark on the product only after BIS certification.

These are a number of organisation for standardisation throughout the world in different countries.

The standard organisation and the respective countries are given below:

BIS	-	Bureau of Indian Standard (ISI) - India
ISO	-	International standard Organisation
JIS	-	Japanese Industrial Standard - Japan
BSI	-	British Standards Institution BS(S) - Britain
DIN	-	Deutche Industrie Normen - Germany
GOST	-	Russian
ASA	-	American standards association - America

Advantages of BIS(ISI) certification marks scheme:

A number of advantages accrue to different sectors of economy from the BIS(ISI) certification marks scheme.

To manufacturers

- Streamlining of production processes and introduction of quality control system.
- Independent audit of quality control system by BIS
- Reaping of production economics accruing from standardization
- Better image of products in the market, both internal and overseas
- Winning for whole-salers, retailers and stockists consumer confidence and goodwill
- Preference for ISI-marked products by organised purchasers, agencies of Central and State Governments, local bodies, public and private sector undertakings etc. Some organised purchasers offer even higher price for ISI-marked goods.
- Financial incentives offered by the Industrial Development Bank of India (IDBI) and nationalised banks.

To consumers

- Conformity with Indian Standards by an independent technical, National Organisation
- Help in choosing a standard product
- Free replacement of ISI-marked products in case of their being found to be of substandard quality
- Protection from exploitation and deception
- Assurance of safety against hazards to life and property

To organised purchasers

- Convenient basis for concluding contracts
- Elimination of the need for inspection and testing of goods purchased, saving time, labour and money
- Free replacement of products with ISI-mark, found to be sub-standard

To exporters

- Exemption from pre-shipment inspection, wherever admissible
- Convenient basis for concluding export contracts

To export inspection authorities

- Elimination of the need for exhaustive inspection of consignments exported from the country, saving expenditure, time and labour.

Introduction to National Electrical Code - 2011

National Electrical Code - 2011

National electrical code describes several indian standards deciding with the various aspects relating to electrical installation practice. It is there fore recommended that individual parts/ sections of the code should be read in conjunction with the relevant indian standards.

There are 8 parts and each part contains number of sections. Each section refers the description of the electrical item/ devices, equipment etc.

Here, 20 sections of the part - 1 are described which aspect it covers

In part 1, 20 sections are there. Each sections reference is given below.

Section 1 part 1/ section 1 of the code describes the scope of the NEC.

Section 2 covers definition of items with references.

Section 3 covers graphical symbols for diagrams, letter symbols and signs which may be referred for further details.

Section 4 covers of guidelines for preparation of diagrams, chart and tables in electro technology and for marking of conductors.

Section 5 covers units and systems of measurement in electro technology.

Section 6 covers standard values of AC and DC distribution voltage preferres values of current ratings and standard systems frequency.

Section 7 enumerates the fundamental principles of design and execution of electrical installation.

Section 8 covers guidelines for assesing the characteristics of buildings and the electrical installation there in.

Section 9 Covers the essential design and constructional requirement for electrical wiring installation.

Section 10 covers guidelines and general requirements associated with circuit calculators.

Section 11 covers requirements of installation work relating to building services that use electrical power.

Section 12 covers general criteria for selection of equipment.

Section 13 covers general principles of installation and guide lines on initial testing before commissioning.

Section 14 covers general requirements associated with earthing in electrical installations. Specific requirements for earthing in individual installations are covered in respective parts of the code.

Section 15 covers guidelines on the basic electrical aspects of lightning protective systems for buildings and the electrical installation forming part of the system.

Section 16 covers the protection requirements in low voltage electrical installation of buildings.

Section 17 covers causes for low power factor and guidelines for use of capacitors to improve the same in consumer installations.

Section 18 covers the aspects to be considered for selection of equipment from energy conservation point of view and guidence on energy audit.

Section 19 covers guidelines on safety procedures and practices in electrical work.

Section 20 gives frequently referred tables in electrical engineering work.

The above description is part 1 only you can refer remaining parts and section for other electrical installation, items devices and equipments.

Lifting and handling of loads

Many of the accidents reported involve injuries caused by lifting and carrying loads. A electrician may need to install motors, lay heavy cables, do wiring, which may involve a lot of lifting and carrying of loads. Wrong lifting techniques can result in injury.

A load need not necessarily be very heavy to cause injury. The wrong way of lifting may cause injury to the muscles and joints even though the load is not heavy.

Further injuries during lifting and carrying may be caused by tripping over an object and falling or striking an object with a load.

Types of injury and how to prevent them?

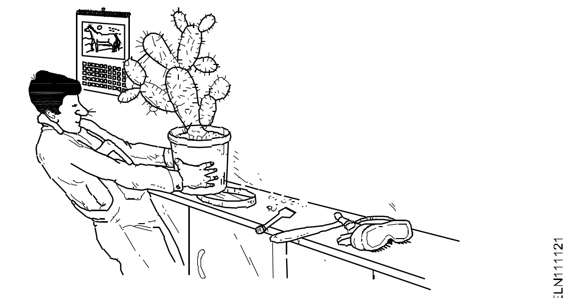
Cuts and abrasions

Cuts and abrasions are caused by rough surfaces and jagged edges:

- By splinters and sharp or pointed projections. (Fig 1)

Leather hand gloves will usually be sufficient for protection, but the load should be checked to make sure of this, since large or heavy loads may involve body contact as well.

Fig 1

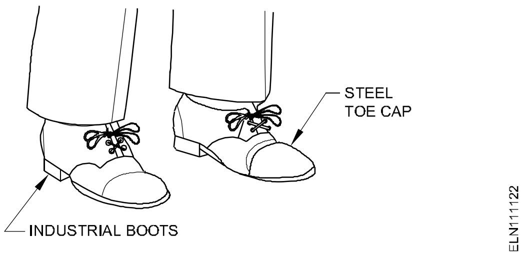


Crushing of feet or hands

Feet or hands should be so positioned that they will not be trapped by the load. Timber wedges can be used when raising and lowering heavy loads to ensure fingers and hands are not caught and crushed.

Safety shoes with steel toe caps will protect the feet. (Fig 2)

Fig 2



Strain to muscles and joints

Strains to muscles and joints may be the result of:

- Lifting a load which is too heavy, or of lifting incorrectly.

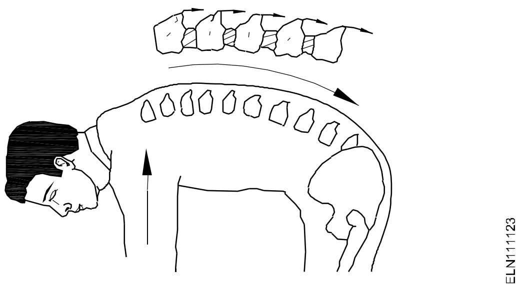
Sudden and awkward movements such as twisting or jerking during a lift can put severe strain on muscles.

'Stoop lifting' - lifting from a standing position with the back rounded increases the chance of back injury.

The human spine is not an efficient weight lifting machine and can be easily damaged if incorrect techniques are used.

The stress on a rounded back can be about six times greater than if the spine is kept straight. Fig 3 shows an example of stoop lifting.

Fig 3



Preparaing to lift

Load which seems light enough to carry at first will become progressively heavier, the farther you have to carry it.

The person who carries the load should always be able to see over or around it.

The weight that a person can lift will vary according to:

- Age
- Physique, and
- Condition

It will also depend on whether one is used to lifting and handling heavy loads.

What makes an object difficult to lift and carry?

1 Weight is not the only factor which makes it difficult to lift and carry.

2 The size and shape can make an object awkward to handle.

3 Loads high require the arms to be extended in front of the body, place more strain on the back and stomach.

4 The absence of hand holds or natural handling points can make it difficult to raise and carry the object.

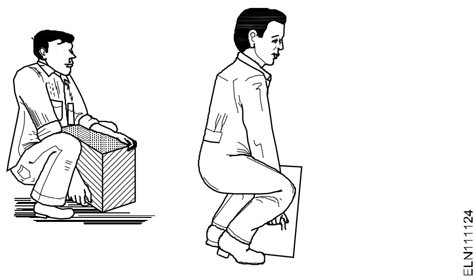
Correct manual lifting techniques

1 Approach the load squarely, facing the direction of travel

2 The lift should start with the lifter in a balanced squatting position, with the legs slightly apart and the load to be lifted held close to the body.

3 Ensure that a safe firm hand grip is obtained. Before the weight is taken, the back should be straightened and held as near the vertical position as possible. (Fig 4)

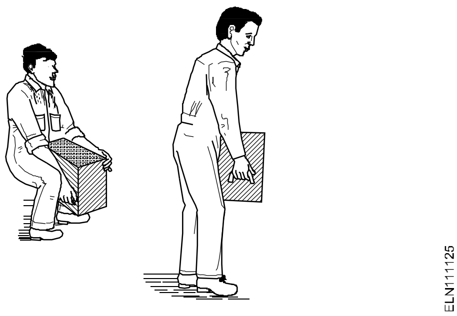
Fig 4



4 To raise the load, first straighten the legs. This ensures that the lifting strain is being correctly transmitted and is being taken by the powerful thigh muscles and bones.

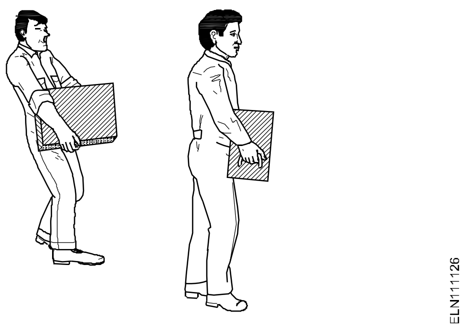
5 Look directly ahead, not down at the load while straightening up, and keep the back straight; this will ensure a smooth, natural movement without jerking or straining (Fig 5)

Fig 5



6 To complete the lift, raise the upper part of the body to the vertical position. When a load is near to an individual's maximum lifting capacity it will be necessary to lean

Fig 6



back on the hips slightly (to counter balance the load) before straightening up. (Fig 6)

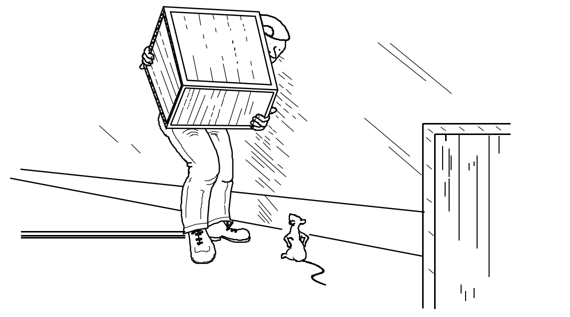
Keeping the load well near to the body, carry it to the place where it is to be set down. When turning, avoid twisting from the waist - turn the whole body in one movement.

Lowering the load

Make sure the area is clear of any obstructions. (Fig 7)

Bend the knees to a semi-squatting position; keep the back and head erect by looking straight a head, not down at the load. It may be helpful to rest the elbows on the thighs during the final stage of lowering.

Fig 7



Moving heavy equipment

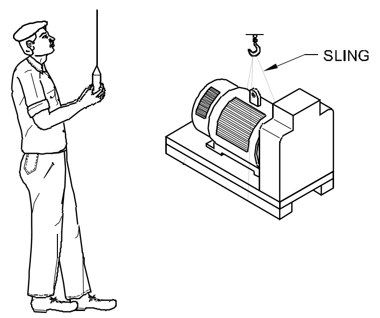
Heavy equipments are moved in industry using any of the following methods.

- Crane and slings
- Winches
- Machine moving platforms
- Layers and rollers

Using crane and slings

This method is used whenever loads are to be lifted and moved. (Fig 1)

Fig 1



Examine the steel rope sling for any cut, abrasion, wear, fraying or corrosion.

Damaged slings must not be used.

Distribute the weight as evenly as possible between the slings when using more than one sling. (Fig 1)

Keep the slings as near to vertical as possible.

Winches

Winches are used to pull heavy loads along the ground. They may be power-driven (Fig 2) or hand operated. (Fig 3).

Fig 2

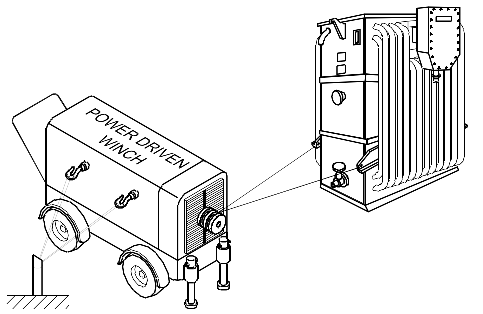
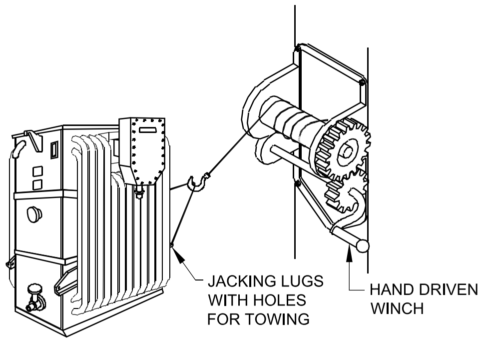


Fig 3



Ensure that the safe working load (SWL) of the winch is adequate for the task.

Secure the winch to a structure which is strong enough to withstand the pull.

On open ground, drive long stakes into the ground and secure the winch to them.

Choose a suitable sling and pass it around the base of the load. Secure it to the hook of the winch.

Some heavy items have special lugs welded to them for jacking and towing purposes.

Safety consideration

Before using any winch, check that the brake and ratchet mechanism are in working order. Practise how to use the brakes.

Keep hands and fingers well away from the gear wheels.

Keep the bearings and gears oiled or greased.

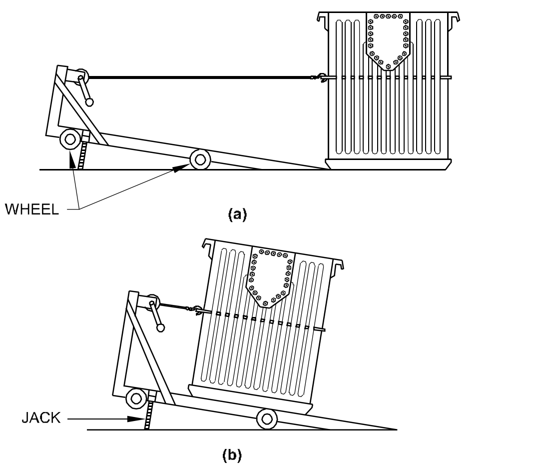
Machine moving platforms

This is a special device made to move heavy equipment in industry. Fig 4 shows the method of loading a heavy transformer.

Pass a suitable sling round the load at a convenient height.

Attach the sling to the hook of the winch and draw the load on the platform until its centre of gravity lies between the front and rear wheels.

Fig 4



Lower the jacks so that the platform rests on ist wheels.

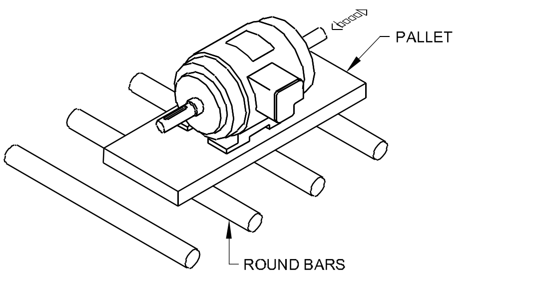
For unloading follow the procedure in the reverse order.

Using layers and rollers

Sometimes a load cannot be moved along the ground because of the irregular shape of its base or because it is not rigid enough.

Place such a load on a flat-bottomed pallet or 'layer' resting on the round bars. (Fig 5)

Fig 5



Ensure the bars (rollers) are long enough to project at each side of the load, for ease of handling.

They should be large enough to roll easily over any uneven surface along the route but should be small enough to be handled easily.

Two or three bars of equal diameter are sufficient for most loads but if four or more are used, the load may be moved faster as there is no delay when moving the rear bar to the front. (Fig 5)

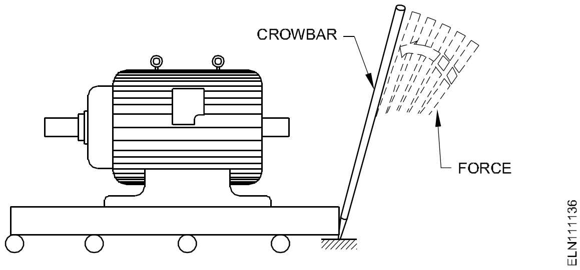
Move the load by using a crowbar as shown in Fig 6. Keep the crowbar at the end of the pallet with an angle and a firm grip on the ground. Apply the force at the top of the bar as shown.

When a load is on rollers, only shallow slopes can be negotiated.

Hold the load in check all the time if it is on the slope.

Use a winch with an effective brake for this operation.

Fig 6

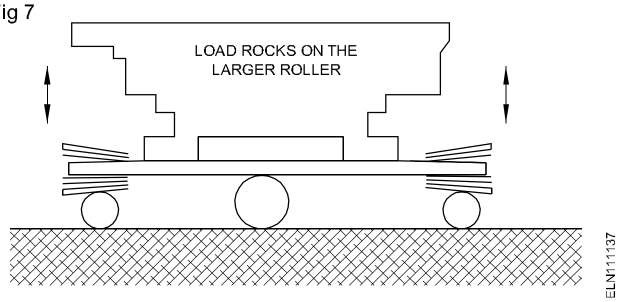


To negotiate a corner on rollers

For a moderate load, insert one roller a little larger in diameter than the others as the corner is approached.

When this roller is under the centre of gravity of the load, the load can be rocked to and fro on the roller and swivelled around sideways. (Fig 7)

Fig 7

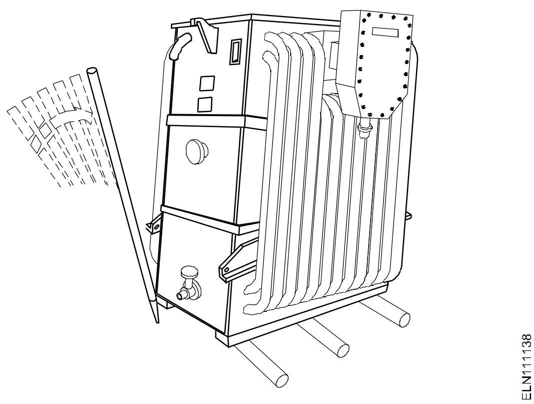


For heavier loads

Stop the load on the roller at the beginning of the corner.

Twist the load round on the rollers by pushing the sides with crowbars until the load is just over the ends of the rollers. (Fig 8)

Fig 8



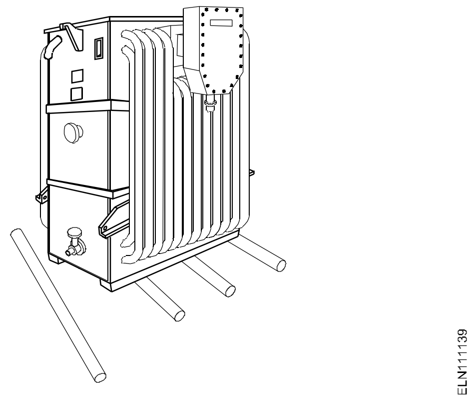
Place some rollers at an angle to the front of the load. (Fig 9)

Push the load forward on to these rollers.

Twist the load further round and place the freed rollers in front of and at an angle to the load.

Continue until the load is pointing in the desired direction.

Fig 9



Safety consideration

Moving heavy loads with crowbars or jacks

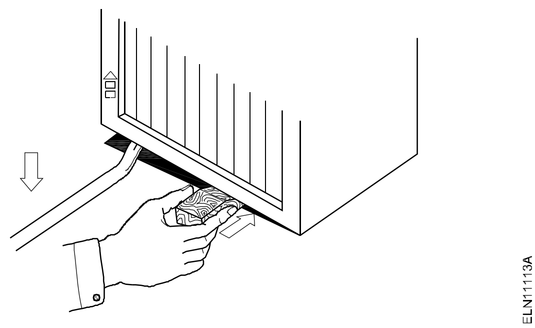
Make sure your hands are clear of the load before lowering it on to the packing or rollers.

Do not use your hands underneath the packing when positioning it. Use a push block.

Place the packing on the floor and push it under the load. (Fig 10)

Hold it by its side faces keeping the fingers well away from the lower edge of the load and from the floor. (Fig 10)

Fig 10



Raising a load

Check that the slings are correctly secured to the load and to the hook. Ensure they are not twisted or caught on a projecting part of the load.

Before starting to lift a load, if you cannot see an assistant on the far side of the load, verify that he is ready to lift the load and ensure that his hands are clear of the slings.

Warn nearby workers that the lifting is about to begin.

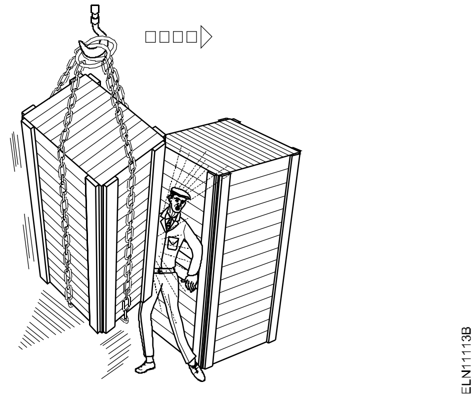
Lift slowly.

Take care to avoid being crushed against other objects as the load rises. (Fig 11) it may swing or rotate as it leaves the ground.

Minimise such movement by locating the hooks as accurately as possible above the centre of gravity of the load.

Keep the floor clear of unnecessary objects.

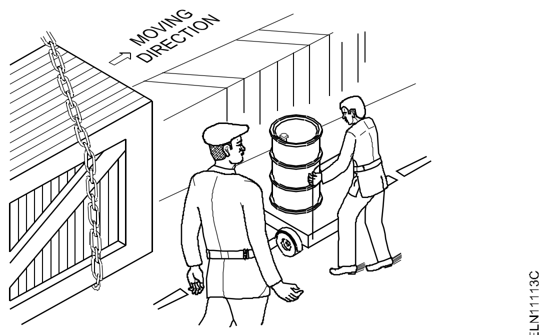
Fig 11



Moving a load

Check that there are no obstacles in the way of the crane and load. (Fig 12)

Fig 12



Stand clear off the load and move it steadily.

Be prepared to stop the load quickly if somebody moves into its path.

Allow for the natural swing of the load when changing speed or direction.

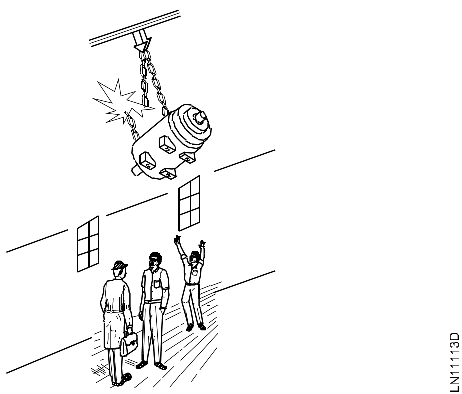
Ensure that the load will not pass over the head of other people. (Fig 13)

The tackle or sling may fall or slip.

Warn other workers to stand clearly away from the route of the load.

Remember that accidents do not happen, they are caused.

Fig 14



Fitting tools - marking tools - specification - grades - uses

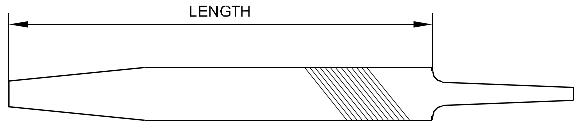
Objectives : At the end of this lesson you shall be able to
- **state the different types of files and their grades, shapes, specification and application.**
- **state the different cuts of files and their uses**
- **state the parts of file**

File : File is a filing tool, which is used to file the rough surface & smooth surface on metals

File specification: Files are specified according to their

- length
- grade
- cut
- shape

Fig 1



Length is the distance from the tip to the heel (Fig 1). It may be 300mm, 250mm, 200mm,150mm or 100mm.

Rough, bastard, second cut, smooth and dead smooth are the different **grades** of files commonly available.

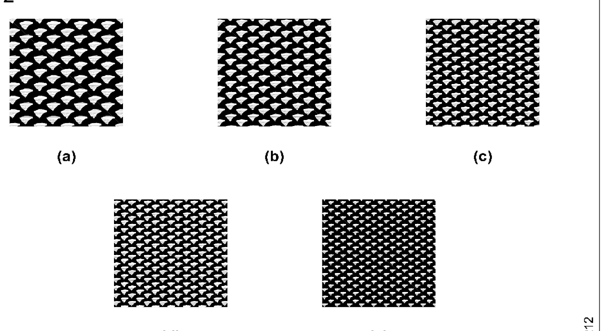
A rough file is used for removing more quantity of metal quickly. (Fig 2a)

A bastard file is used for ordinary filing purposes. (Fig 2b)

A second cut file is used for good finishing purposes. (Fig 2c)

A smooth file is used for removing less metal and for giving good surface finish. (Fig 2d)

Fig 2



GRADES OF FILES

A dead smooth file is used for high degree finishing. (Fig 2e)

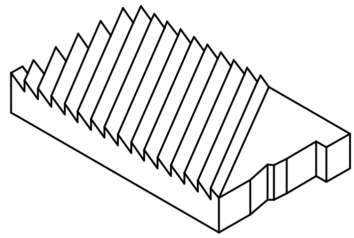
Cut of file: The rows of teeth determine the cut of a file.

Types of cut

Single cut, double cut, rasp cut and curved cut are the different types of cuts of files.

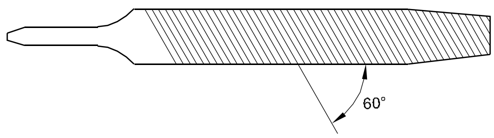
Single cut: A single cut file has a single row of teeth in one direction on the face of the file at an angle of 60° and this file is used for filing soft material such as lead, tin, aluminium etc. (Figs 3 & 4)

Fig 3



CUT OF FILE

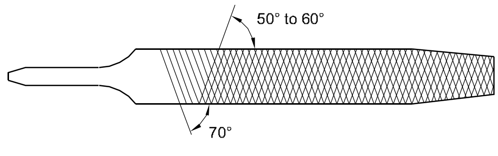
Fig 4



SINGLE CUT FILE

Double cut: A double cut file has rows of teeth in two directions across each other, one at an angle of 50° to 60°, another row at 70° which is used to file hard materials such as steel, brass, bronze, etc. (Fig 5)

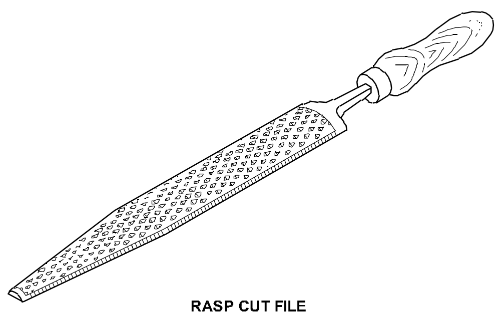
Fig 5



DOUBLE CUT FILE

Rasp cut: This has individual, sharp, pointed teeth in a line, and is useful for filing wood, leather and other soft materials. These files are available only in half-round shape. (Fig 6)

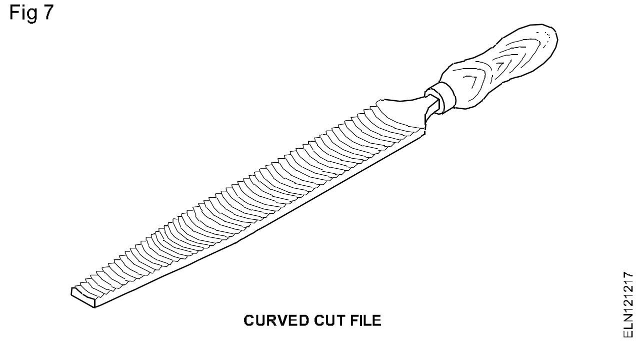
Fig 6



RASP CUT FILE

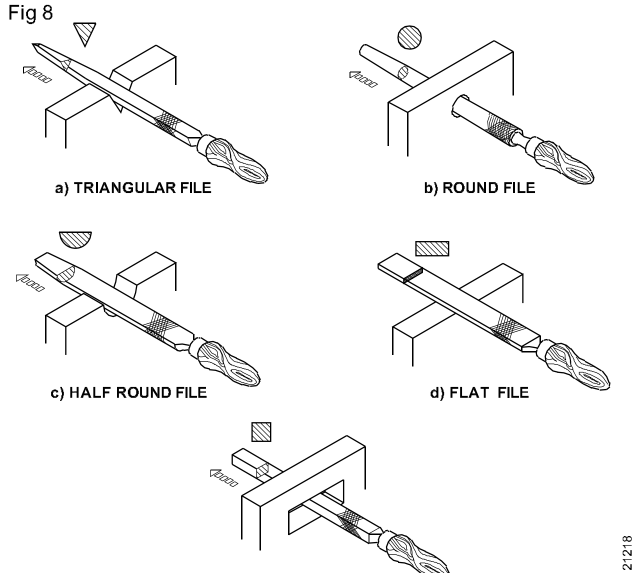
Curved cut: These files have deeper cutting action, and are useful for filing soft materials like - aluminium, tin, copper and plastic. These are available only in flat shape. (Fig 7)

Fig 7



CURVED CUT FILE

Fig 8



a) TRIANGULAR FILE b) ROUND FILE c) HALF ROUND FILE d) FLAT FILE e) SQUARE FILE

The selection of the type of cut is based on the material to be filed. Single cut files are used for filing soft materials. But certain special files, for example - those used for sharpening saws, are also of single cut.

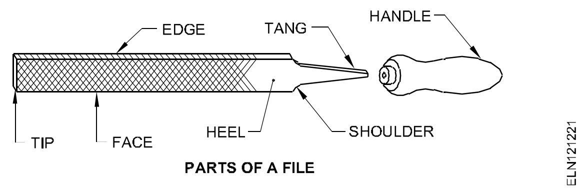
Shape: The various shapes of files with their application are shown below. The cross-section drawn in the file refers to the shape of the file. (Fig 8)

Parts of file

File : A file is a cutting tool with multiple cutting edges used for filing different materials.

Parts of a file (Refer Fig 1 below)

Fig 1



PARTS OF A FILE

Tip or point: This is the end of the file opposite to tang.

Face or side: The broad part of the file with teeth cut on it.

Edge: The thin part of the file with a simple row of parallel teeth.

Heel: It is the broad part of the file without teeth.

Shoulder : It is the curved part of a file separating the tang from the body.

Tang: Narrow and thin part of a file which fits into the handle.

Handle: The part fitted to the tang to hold and use the file.

Bench vice

Objectives: At the end of this lesson you shall be able to
- **name the parts and state the uses of a bench vice**
- **specify the size of a bench vice**
- **state the uses of vice clamps.**

Bench vice: Vices are used for holding workpieces. They are available in different types.

The vice used for bench work is the bench vice (Engineer's vice).

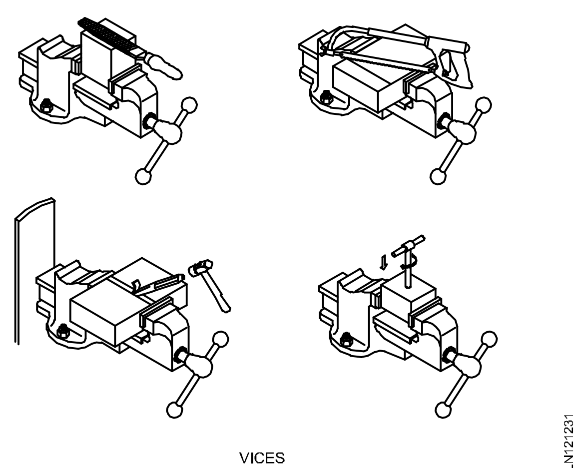
A bench vice is made of cast iron or cast steel, and it is used to hold work for filing, sawing, threading and other hand operations. (Fig 1)

The size of the vice is stated by the width of the jaws.

Parts of a bench vice (Fig 2)

- Fixed jaw (1)
- Movable jaw (2)
- Hard jaw (3)

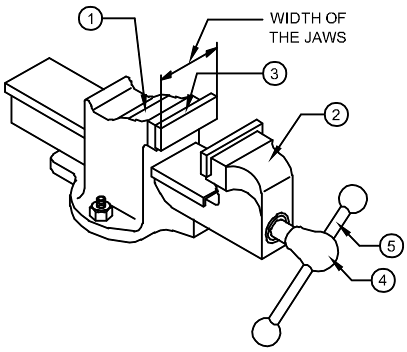
Fig 1



VICES

- Spindle (4)
- Handle (5)
- Box nut (6)
- Spring (7)

Fig 2

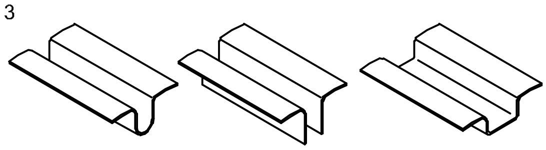


BENCH VICE

The box nut and the spring are the internal parts.

Vice clamps or soft jaws: To hold a finished work use soft jaws (vice clamps), (Fig 3) made of aluminium over the regular hard jaws. This will protect the work surface from damage. Do not over-tighten the vice so as to prevent damage to the spindle.

Fig 3



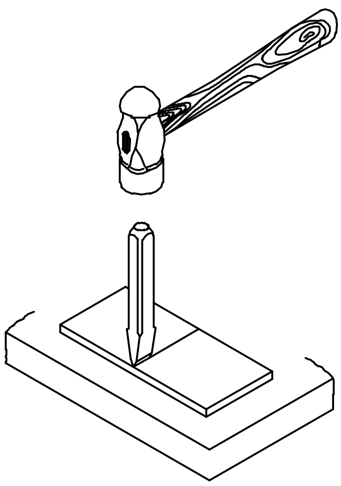
VICE CLAMPS

Hammer

Objectives: At the end of this lesson you shall be able to
- **state the uses of an engineer's hammer**
- **name the parts of an engineer's hammer and state their functions**
- **name the types of engineer's hammers with specifications**

Hammer: Engineer's hammer is a hand tool used for various striking purposes like punching, bending, straightening, chipping, forging and riveting. (Fig 1)

Fig 1



STRIKING WITH HAMMER

Major parts of a hammer (Fig 2)

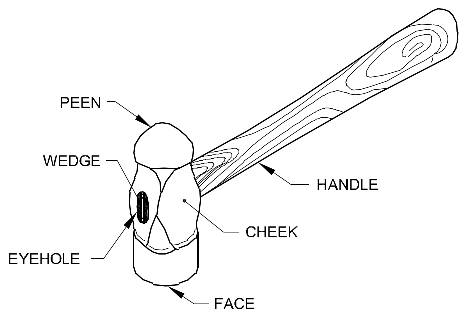
- Head
- Handle

The head is made of drop-forged carbon steel, and the wooden handle must be capable of absorbing shock.

The parts of the hammer head are:

- face
- peen

Fig 2



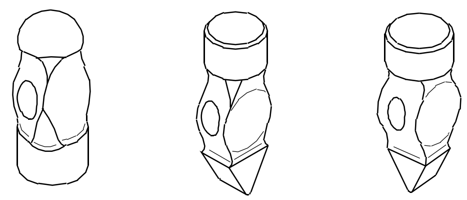
HAMMER

- cheek
- eyehole

Face: Face is the striking portion. A slight convexity is given to it, to avoid digging of the edge.

Peen: Peen is the other end of the head. It is used for shaping and forming work like riveting and bending. The peen is of different shapes. (Fig 3) They are:

Fig 3



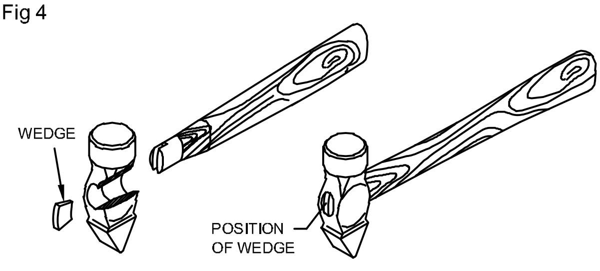
BALL PEEN CROSS-PEEN STRAIGHT PEEN

- ball peen
- cross-peen
- straight peen

Cheek: Cheek is the middle portion of the hammer head. The weight of the hammer is stamped here.

Eyehole: Eyehole is meant for fixing the handle. It is shaped to fix the handle rigidly. The wedge fixes the handle in the eyehole. (Fig 4)

Fig 4



HAMMER WEDGE

Specifications: The face and peen are hardened.

The cheek is left soft.

Engineer's hammers are specified by the weight of the head and shape of the peen. The weight varies from 125 gms to 1.5 kg.

The weight of the engineer's hammer used for marking purposes is 250 gms.

The ball peen hammer is used for general work in machine fitting shops.

Before using a hammer:

- make sure the handle is properly fitted
- select the correct weight of hammer suitable for the type of work
- check the head and handle for any crack
- ensure the face of the hammer is free from oil or grease.

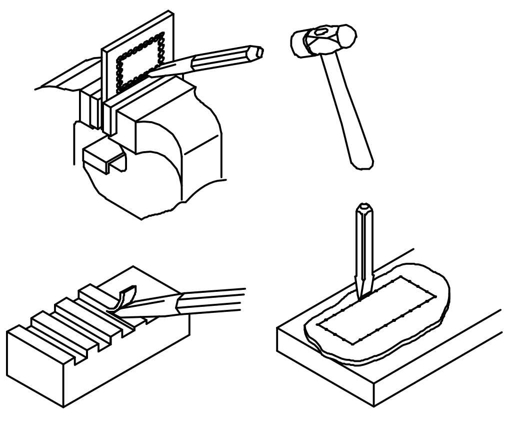
Chisel

Objectives: At the end of this lesson you shall be able to
- **list the uses of a cold chisel**
- **name the parts of a cold chisel and it's types**
- **state the different types of hacksaw frames, blades and their uses.**

The cold chisel is a hand cutting tool used by fitters for chipping and cutting operations.

Chipping is an operation of removing excess metal with the help of a chisel and hammer. (Fig 1) The chipped surfaces being rough, they should be finished by filing.

Fig 1



CHIPPING PROCESS

Parts of a chisel (Refer Fig 2)

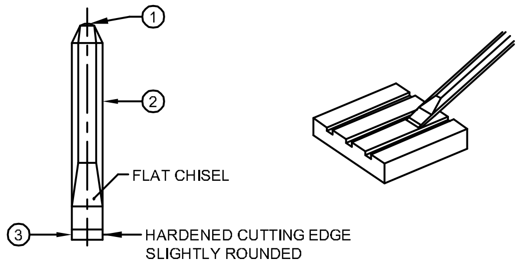
– Head (not hardened) (1)

– Body (2)

– Point or cutting edge (3)

Chisels are made from high carbon steel or chrome-vanadium steel. The cross-section of chisels is usually hexagonal or octagonal.

Fig 2



FLAT CHISEL

Common types of chisels

- Flat chisel
- Cross-cut chisel
- Half-round nose chisel
- Diamond point chisel

Flat chisels are used to:

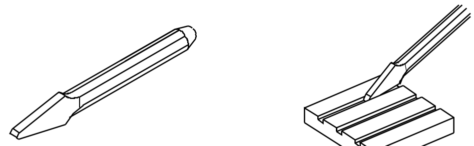
- remove metal from large flat surfaces
- chip excess metal off from welded joints and castings
- part off metal after chain drilling. (Fig 1)

Cross-cut or cape chisels are used for cutting keyways, grooves and slots. (Fig 3)

Half round, nose chisels are used for cutting curved grooves (oil grooves). (Fig 4)

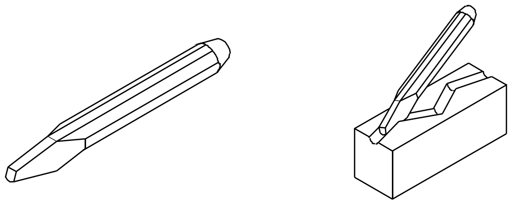
Diamond point chisels are used for squaring materials at the corners. (Fig 5)

Fig 3



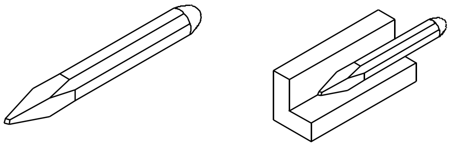
CROSS-CUT CHISEL

Fig 4



HALF ROUND CHISEL

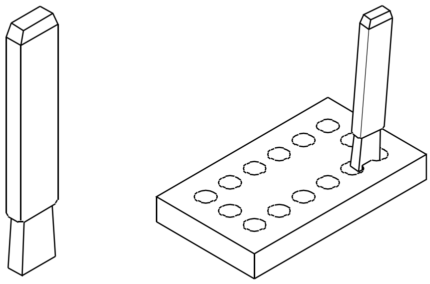
Fig 5



DIAMOND POINT CHISEL

Web chisels/punching chisels are used for separating metals after chain drilling. (Fig 6)

Fig 6



WEB CHISEL

Chisels are specified according to the:

- length
- width of the cutting edge
- type
- cross-section of the body.

The length of chisels ranges from 150 mm to 400 mm.

The width of the cutting edge varies according to the type of chisels.

Hacksaw frame and blade

The hand hacksaw is used along with a blade to cut metals of different sections. It is also used to cut slots and contours.

Types of hacksaw frames

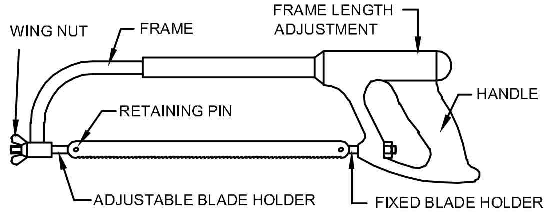
Bold frame: Only a particular standard length of blade can be fitted.

Adjustable frame (flat)**:** Different standard lengths of blades can be fitted.

Adjustable frame tubular type (Fig 1)**:** This is the most commonly used type. It gives a better grip and control while sawing.

Hacksaw blades : The hacksaw blade is a thin, narrow, steel band with teeth and two pin holes at the ends. It is used along with a hacksaw frame. These blades are made of either low alloy steel (la) or high speed steel (hs) and are available in standard lengths of 250mm and 300mm.

Fig 1



HACKSHAW FRAME

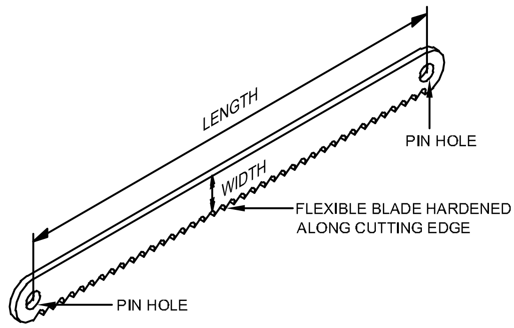
For proper working, it is necessary to have frames of rigid construction.

Types of hacksaw blades

All-hard blades: The width between the pin holes is hardened all allong the length of the blade.

Flexible blades: For these types of blades only the teeth are hardened. Because of their flexibility, these blades are useful for cutting along curved lines (Fig 2).

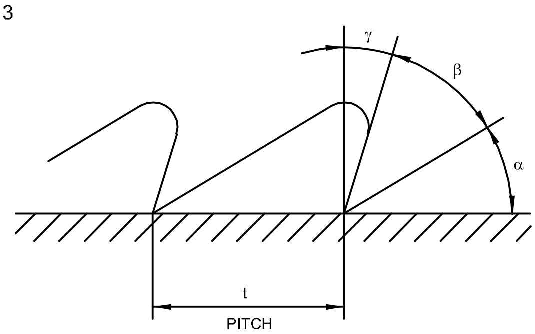
Fig 2



HACKSHAW BLADE

Pitch of the blade: This is the distance between two adjacent teeth. (Refer Fig 3) Hacksaw blades are designated according to length, pitch and the type of blade

Fig 3



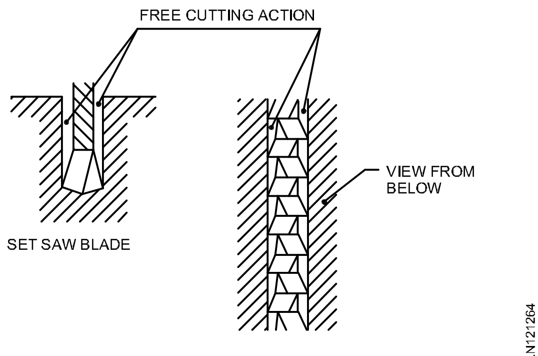
PITCH OF BLADE

Pitches of blades

Classification	Pitch
Coarse	1.8mm
Medium	1.4 mm & 1.0 mm
Fine	0.8mm

Setting of the saw: To prevent the saw from binding when penetrating into the material and to allow free movement of the blade, the cut is to be broader than the thickness of the saw blade. This is achieved by a proper setting of the saw teeth (Fig 4). There are two types of saw settings.

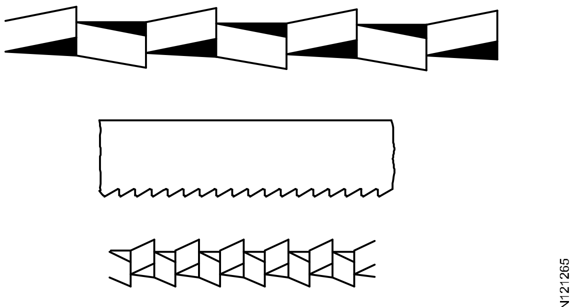
Fig 4



TYPE OF SAW SETTING

Staggered set: Alternate teeth or groups of teeth are staggered. This arrangement helps for free cutting, and provides for good chip clearance. (Fig 5)

Fig 5



STAGGERED SET TEETH

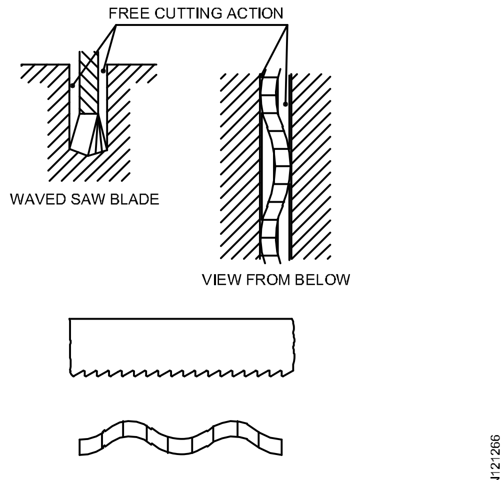
Classification of sets

Pitch	0.8mm	wave set.
Pitch	1.0mm	wave or staggered.
Pitch over	1.0mm	staggered.

Wave set: In this, the, teeth of the blade are arranged in a wave-form. (Fig 6).

For satisfactory results a blade of the correct pitch should be selected and fitted correctly.

Fig 6

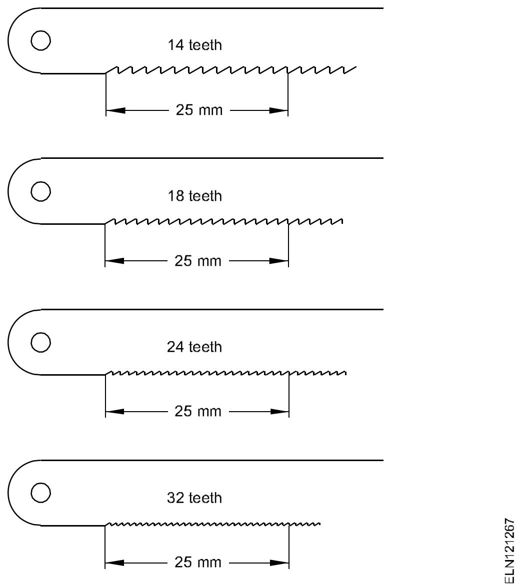


WAVE SET TEETH

Saw blades for hacksaws are available with small and large cutting of teeth, depending on the type and size of material they are to cut. The size of the teeth is directly related to their pitch, which is specified by the number of teeth per 25mm of the cutting edge. Hacksaw blades are avaialable in pitches of: (Fig 7)

- 14 teeth per 25 mm
- 18 teeth per 25 mm
- 24 teeth per 25 mm
- 32 teeth per 25 mm.

Fig 7



Marking tools - steel rule - punches - calipers - try square - gauges

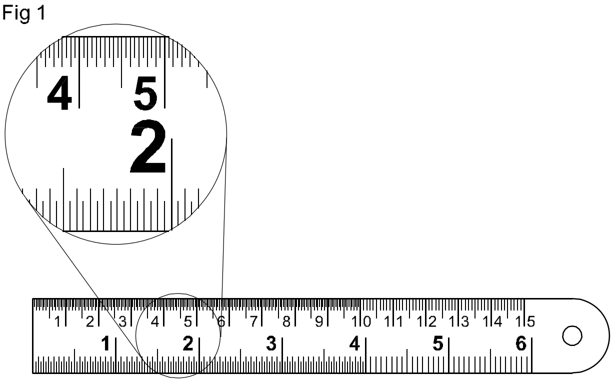
Objectives: At the end of this lesson you shall be able to
- **state the constructional features of an engineer's steel rule**
- **explain the uses of the steel rule**
- **state the maintenance aspects to be considered in respect of the steel rule.**

Engineer's steel rule: When dimensions are given in a drawing without any indication about the tolerance, it has to be assumed that measurements are to be made with a steel rule.

Material and sizes of steel rules: Steel rules are made of spring steel or stainless steel. The edges are accurately ground to form a straight line.

Steel rules are available in different lengths; the common sizes are 150mm, 300mm and 600mm. (Refer Fig 1)

Fig 1



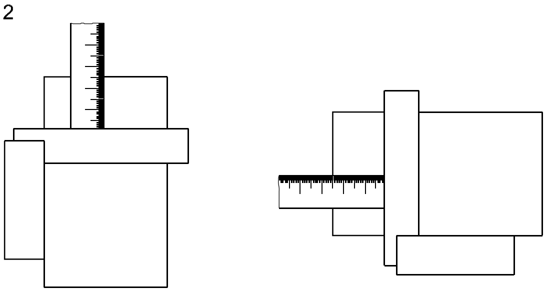
ENGINEER'S STEEL RULE

The surfaces of the steel rules are satin-chrome finished to reduce glare and also to prevent rusting. The engineer's rule is graduated in 10mm, 5mm, 1mm and 0.5mm. Thus the reading accuracy of a steel rule is 0.5mm.

Graduation: The minimum graduation is 0.5mm.

Uses: Use a try square on one datum edge and measure the distance from the other datum edge using a steel rule. (Figs 2a & b)

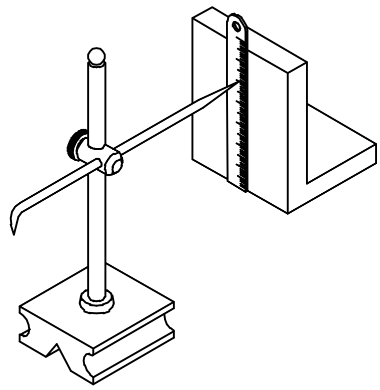
Fig 2



USE OF A STEEL RULE

A steel rule is used to take the desired height for the marking surface gauge. (Fig 3)

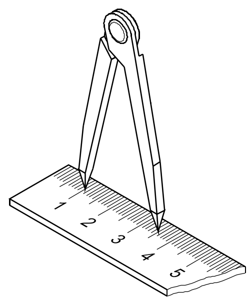
Fig 3



MARKING SURFACE GAUGE

Transfer of measurement from the steel rule to the divider is shown in Fig 4.

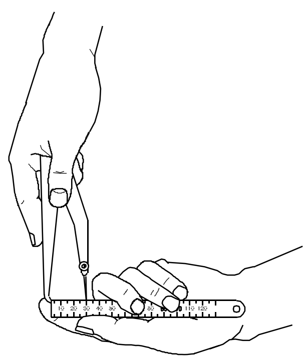
Fig 4



TRANSFER OF MEASUREMENT - DIVIDER

Steel rule is used to transfer measurements from the rule to the odd leg calipers. (Fig 5)

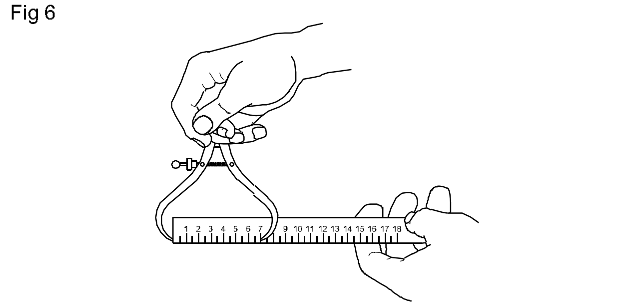
Fig 5



TRANSFER OF MEASUREMENT - ODD LEG CALIPER

Steel rule is used to transfer measurements from the steel rule to outside calipers. (Fig 6)

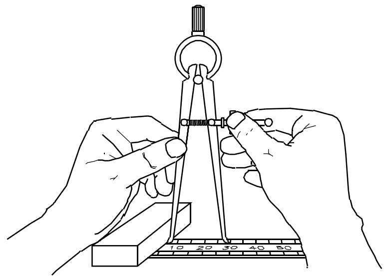
Fig 6



TRANSFER OF MEASUREMENT - OUTSIDE CALIPER

A steel rule is also used to transfer measurements to inside calipers. (Fig 7)

Fig 7



TRANSFER OF MEASUREMENT - INSIDE CALIPER

Marking media

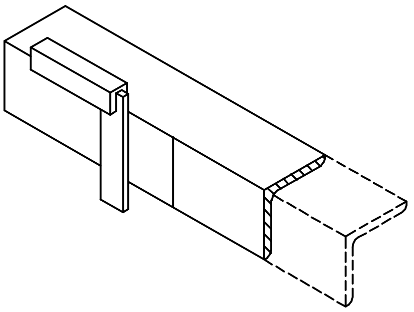
Objectives: At the end of this lesson you shall be able to
- **name the common types of marking media**
- **select the correct marking media for different applications.**

Different types of marking media

Whitewash: This is applied to rough forgings and castings with oxidised surfaces. (Fig 1) Whitewash is prepared in many ways.

- Chalk powder mixed with water
- Chalk mixed with methylated spirit
- White lead powder mixed with turpentine

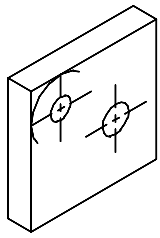
Fig 1



SURFACE MARKING

Prussian blue: Used on filed or machine-finished surfaces. This will give very clear lines but takes more time for drying than the other marking media. (Fig 2)

Fig 2



MARKED SURFACE

Copper sulphate: Used on filed or machine-finished surfaces. Copper sulphate sticks to the finished surfaces well. The solution is prepared by mixing copper sulphate in water with a few drops of nitric acid added.

Copper sulplate needs to be handled carefully as it is poisonous. Copper sulphate coating should be dried well before commencing marking as otherwise the solution may stick on the instruments used for marking.

Cellulose lacquer: This is a commercially available marking medium. It is made in different colours and dries very quickly.

The selection of marking media depends on the:

- the surface finish
- the accuracy of the workpiece.

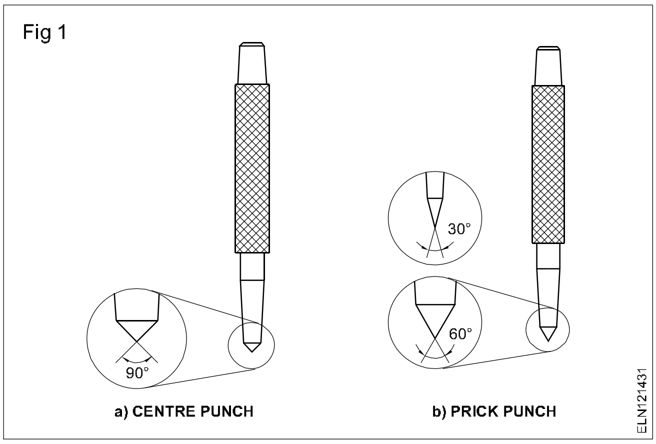
Types of marking punches

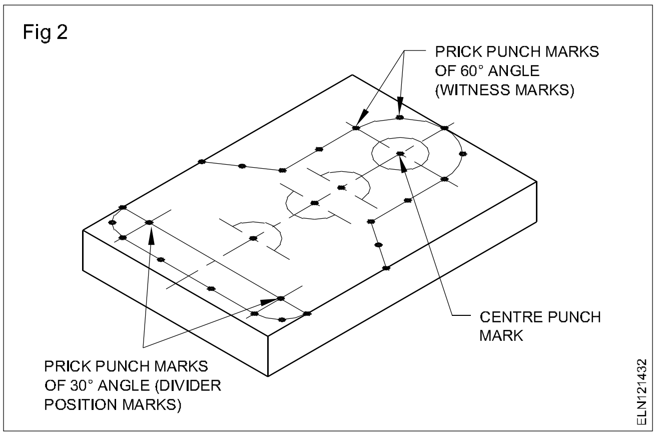
Objectives: At the end of this lesson you shall be able to
- **name the different punches used in marking**
- **state the features of each punch and its uses.**

Types of marking punches: In order to make certain dimensional features of the layout permanent, punches are used. There are two types of punches.

Centre punch: The angle of the point is 90°. The punch mark made by this is wide and not very deep. This punch is used for locating holes. The wide punch mark gives a good seating for starting the drill. (Figs 1a)

Prick punch: The angle of the prick punch is 30° or 60° (Fig 1b). The 30° point punch is used for making light punch marks needed to position dividers. The divider leg will get proper seating in this punch mark. The 60° punch is used for Witness Marks. Witness marks should not be too close. (Fig 2)





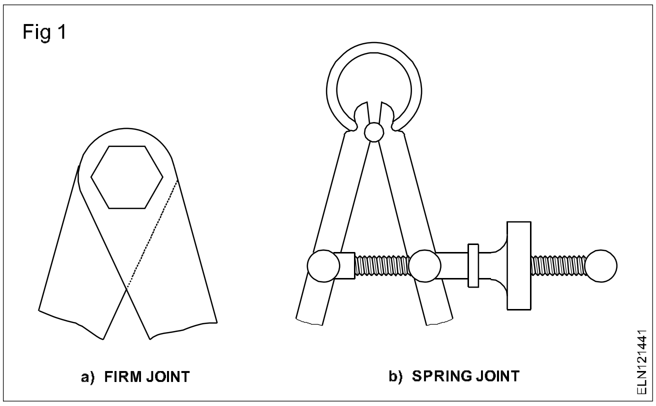
Types of calipers

Objectives: At the end of this lesson you shall be able to
- **name the commonly used calipers**
- **compare the features of firm joint and spring joint calipers**
- **state the advantages of spring joint calipers.**

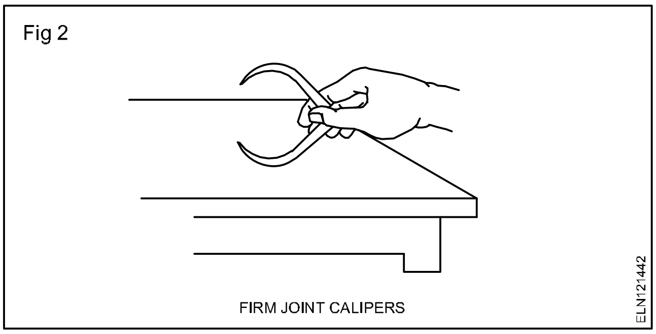
Calipers (firm and spring joints) : Calipers are simple measuring instruments used to transfer measurements from the steel rule to objects and vice versa.

The commonly used calipers are:

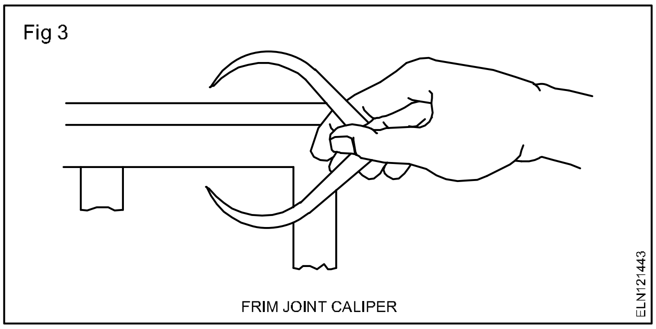
- firm joint calipers (Fig 1a)
- spring joint calipers. (Fig 1b)



Firm joint calipers : In the case of firm joint calipers both legs are pivoted on one end. To take measurement of the workpiece, it is opened roughly to the size. Fine setting is done by lightly tapping it on a wooden surface. (Figs 2 & 3)



Spring joint calipers: For these type of calipers, the legs are assembled by means of a pivot loaded with a spring. For opening and closing of the caliper legs a screw and nut are provided.

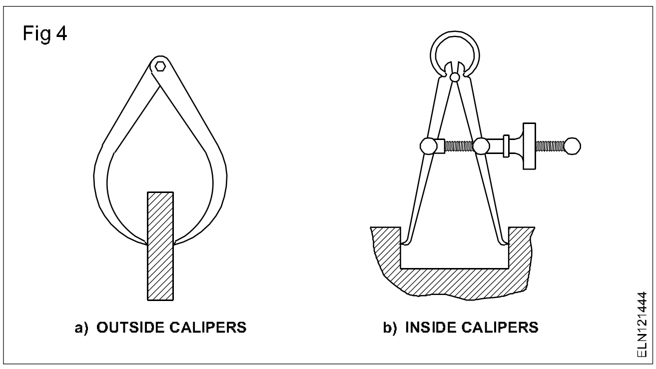


Spring calipers have the advantage of quick setting. The setting made will not change unless the nut is turned. Caliper sizes are specified by the length which is the distance between the pivot centre and the tip of the leg.

Accuracy of the measurement taken depends very much on the sense of `FEEL' or `TOUCH' while measuring the job. You should get the feel when the legs are just touching the surface.

Outside and inside measurements: Calipers used for outside measurements are known as outside calipers while calipers used for internal measurements are the inside calipers. (Figs 4a & 4b)

Calipers are used with steel rules whose accuracy is limited to 0.5 mm; parallelism can be checked with a higher degree of accuracy.



Jenny calipers

Objectives: At the end of this lesson you shall be able to
- **state the constructional features of jenny calipers**
- **name the types of jenny calipers**
- **state the uses of jenny calipers.**

Jenny calipers: Jenny calipers are used for marking and layout work.

These calipers are also known as

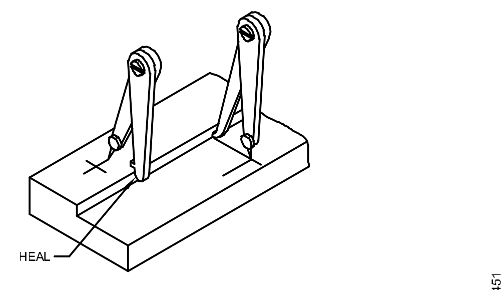
- hermaphrodite calipers
- odd leg calipers
- leg and joint calipers

Jenny calipers have one leg with an adjustable divider point while the other is a bent leg. The legs are joined together to make a firm joint.

Uses

- To mark lines parallel to edges inside and outside. (Fig 1)

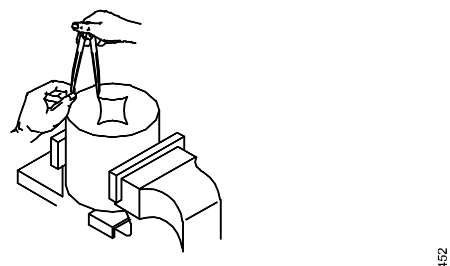
Fig 1



JENNY CALIPERS

- To locate the centre of round bars. (Fig 2)

Fig 2

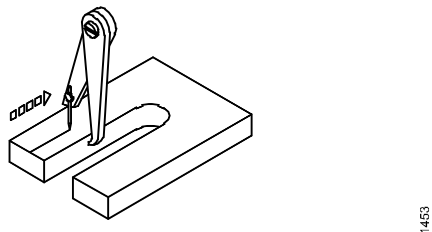


CENTRE LOCATION OF ROUND BAR

Calipers are available with the usual bent leg or with a heel. Calipers with ordinary bent legs are used for drawing lines parallel along an inside edge, while the heel type is used for drawing parallel lines along the outer edges.

Jenny calipers can also be used for scribing lines along curved edges. While setting dimensions and scribing lines, both legs should be of equal length. (Fig 3)

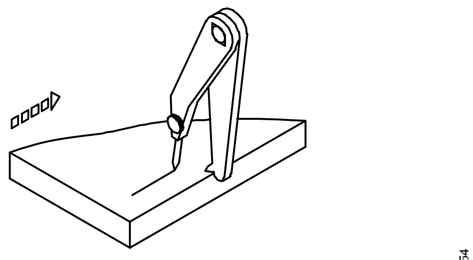
Fig 3



JENNY CALIPER

The jenny caliper should be slightly inclined while scribing lines, Fig 4.

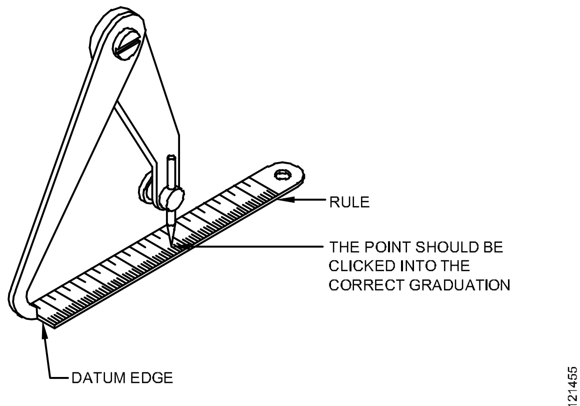
Fig 4



SCRIBING WITH JENNY CALIPER

While setting dimensions for accurate setting, the jenny caliper's point should `click' into the graduation, Fig 5.

Fig 5



ACCURATE MEASUREMENT SETTING

Length measurement

Objectives: At the end of this lesson you shall be able to
- **name the base unit of length measurement as per SI (System of International)**
- **state the multiples of metre and their values.**

Length measurement SI units: When we measure an object we are actually comparing it with a known standard of measurement.

The base unit of length as per SI is the metre.

Length: SI unit and multiples

Base unit: The base unit of length as per the System Internationale is the metre.

Metre (m)	=	1000 mm
Centimetre (cm)	=	10 mm

Millimetre (mm)	= 0.001 m	= 10^{-3} m
1 Micrometre μm	= 10^{-6} m	= 0.000001 m
1 Micrometer	= 10^{-3} mm	= 0.001 mm

Measurement in engineering practice: Usually, in engineering practice, the preferred unit of length measurement is the millimetre. Both large and small dimensions are stated in millimetres.

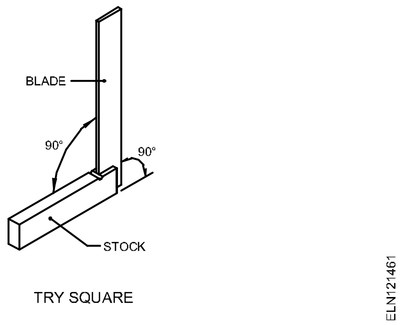
The British system of length measurement: The other system of length measurement is the British system. In this system the base unit is the imperial standard yard. Most countries including Great Britain have, however, switched over to the SI units in recent years.

Try square

Objectives: At the end of this lesson you shall be able to
- **name the parts of a try square**
- **state the uses of a try square.**

Try square: The try square is a precision instrument which is used to check squareness (angles of 90°). The accuracy is about 0.002 mm per 10 mm length, which is accurate enough for most workshop purposes. The try square has a blade with parallel surfaces. The blade is fixed in the stock at 90°. (Fig 1)

Fig 1

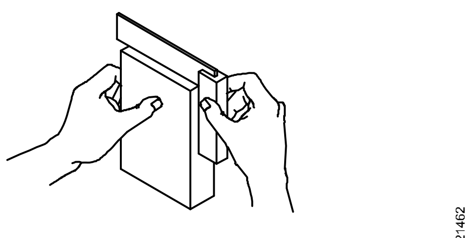


TRY SQUARE

The try square is used to

- check the squareness of machined or filed surfaces. (Fig 2)

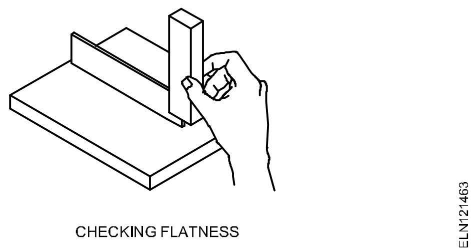
Fig 2



CHECKING SQUARENESS

- check the flatness of surfaces (Fig 3)

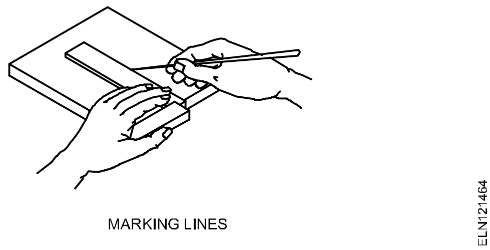
Fig 3



CHECKING FLATNESS

- mark lines at 90° to the edges of workpieces (Fig 4)

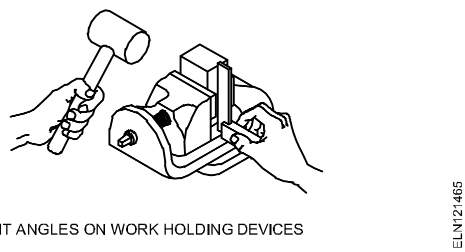
Fig 4



MARKING LINES

- set workpieces at right angles on work-holding devices. (Fig 5)

Fig 5



RIGHT ANGLES ON WORK HOLDING DEVICES

Try squares are made of hardened steel.

Try sqaures are specified according to the length of the blade i.e. 100 mm, 150 mm, 200 mm.

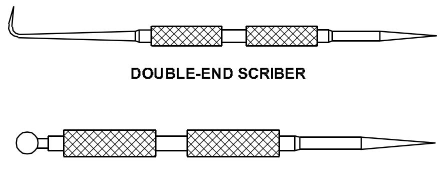
Scriber, divider

Objectives: At the end of this lesson you shall be able to
- **state the features of scribers and dividers**
- **state the uses of scribers and dividers.**

Scriber: A scriber is a sharp, pointed, steel tool made from carbon tool steel. There are two types of scribers.

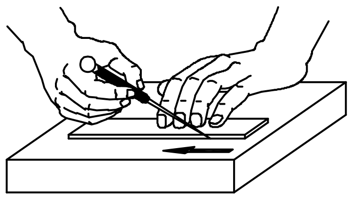
- Double end and plain scribers (Fig 1)

Fig 1



Uses: Used for scribing lines on the metal being laid out. (Fig 2)

Fig 2



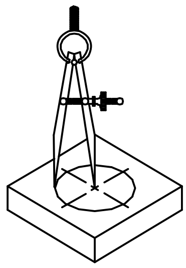
SCRIBING LINES

Divider: A divider consists of a pair of steel legs adjusted by a screw and nut, and held together by a circular spring at one end. A handle is inserted on the spring.

Uses: A divider is used for

- measuring distances between points
- transferring measurements directly from a rule
- scribing circles and arcs on metals. (Fig 3)

Fig 3



SCRIBING CIRCLES

Radius gauges

Objectives: At the end of this lesson you shall be able to
- **state the uses of radius gauges**
- **state the features of radius gauges.**

Radius gauges: Radius gauges are used to check the internal and external radius of workpieces.

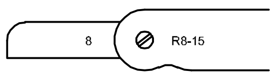
These gauges are made of high quality steel sheets and are finished to accurate radius.

The radius of parts are checked by comparing the radius of the gauges.

Radius gauges are available in sets of several blades held in a holder. Each blade can be separately pulled out of the holder when in use.

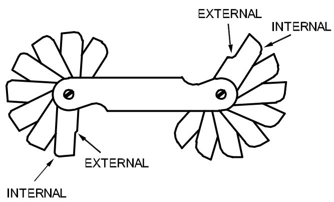
The size of the radius is marked on individual blades of the gauges. (Fig 1)

Fig 1



BLADE OF RADIUS GAUGE

Fig 2

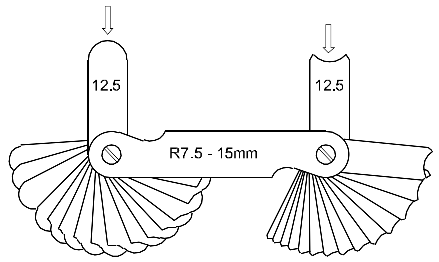


RADIUS GAUGE

The radius gauges are available in different combinations.

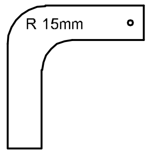
– Sets with internal and external radius.(Figs 2 & 3)

Fig 3



– Individual gauges for each radius. (Fig 4)

Fig 4



INDIVIDUAL RADIUS GAUGE

Before using radius gauges:

- ensure the gauges are perfectly clean
- remove burrs, if any, from the workpiece
- check and make sure there is no damage to the profile of the gauge.

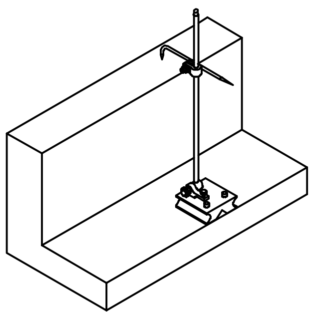
Universal surface gauge

Objectives: At the end of this lesson you shall be able to
- **state the constructional features of surface gauges**
- **name the different types of surface gauges**
- **state the uses of surface gauges**
- **state the advantages of universal surface gauges.**

Universal surface gauge : A surface gauge is one of the most common marking tools used for:

- scribing lines parallel to a datum surface (Fig 1)

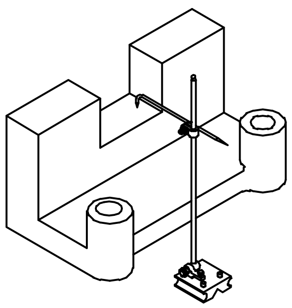
Fig 1



JOB SETTING ON MACHINE

- setting jobs on machines parallel to a datum surface (Fig 2)

Fig 2



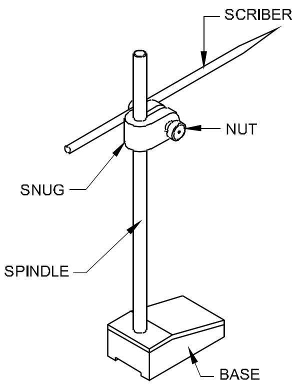
JOB SETTING ON MACHINE

- checking the height and parallelism of jobs
- setting jobs concentric to the machine spindle.

Types of surface gauges: A surface gauge/scribing block is of two types.

- Fixed Surface gauge (Fig 3)

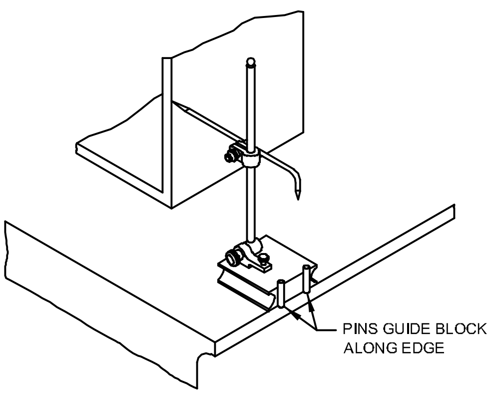
Fig 3



FIXED SURFACE GAUGE

- Universal Surface gauge(Fig 4)

Fig 4



PIN GUIDE BLOCK UNIVERSAL SURFACE GUAGE

Surface gauge (fixed type)**:** This consists of a heavy flat base and a spindle, fixed upright to which a scriber is attached with a snug and a clamp nut.

Universal surface gauge: This has the following additional features.

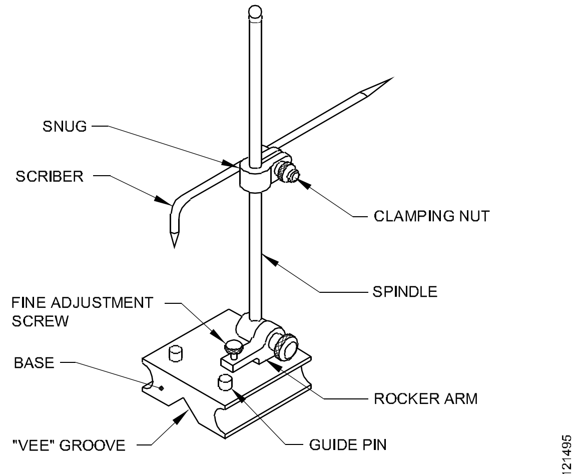
- The spindle can be set to any position.
- Fine adjustments can be made quickly.
- Can also be used on cylindrical surfaces.
- Parallel lines can be scribed from any datum edge with the help of guide pins.(Fig 4)

Parts and functions of a universal surface gauge (Fig 5)

Base: The base is made of steel or cast iron with a `Vee' groove at the bottom. The `Vee' helps to seat on the circular work. The guide pins fitted in the base are helpful for scribing lines from any datum edge.

Rocker arm: A rocker arm is attached to the base along with a spring and a fine adjustment screw. This is used for fine adjustments.

Fig 5



UNIVERSAL SURFACE GAUGE

Spindle: The spindle is attached to the rocker arm.

Scriber: The scriber can be clamped in any position on the spindle with the help of a snug and clamp nut.

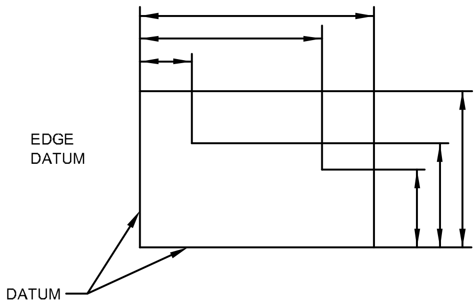
Datum

Objectives: At the end of this lesson you shall be able to
- **state the need for datum while marking**
- **name the different datum points, surfaces or lines**
- **state the basis of determining the datum while marking.**

Datum: The height of a person is measured from the floor on which he stands. The floor becomes the common basis for measurement, i.e. it becomes the DATUM.

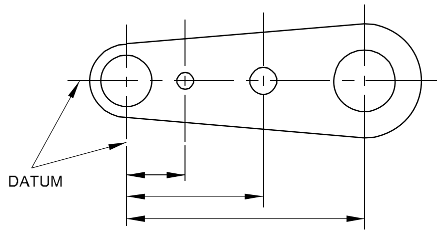
A datum is a reference surface, line or point and its purpose is to provide a common position from which measurements may be taken. The datum may be an edge or centre line depending on the shape of the work. For positioning a point, two datum references are required. (Figs 1 and 2)

Fig 1



DATUM EDGE LINE

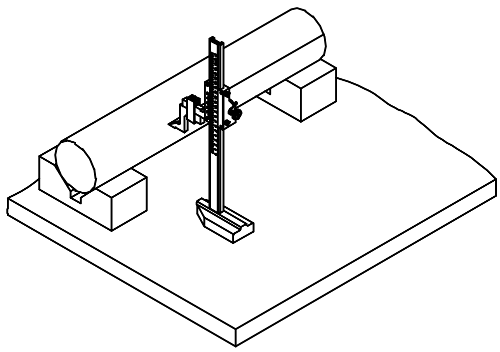
Fig 2



DATUM CENTRE LINE

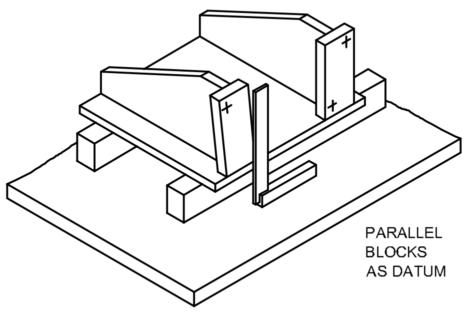
Marking table, surface plate, angle, plate, vee blocks and parallel blocks - all these serve as datum references. (Figs 3 and 4)

Fig 3



DATUM MARKING ANGLE

Fig 4



DATUM MARKING PLATE

The datum should be indicated in the drawing.

The same datum must be used for transferring dimensions to the workpiece.

Carpenter tools - wood saws - planes - wooden joints

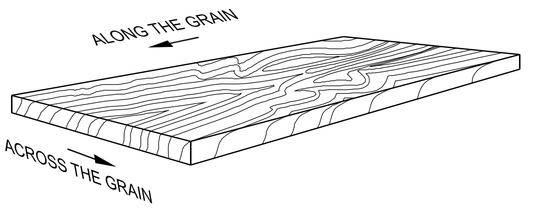
Objective : At the end of this lesson you shall be able to
- **state about the timber**
- **state the grain direction of wood and the common defects in timber**

Timber is a raw material used for manufacturing wooden articles. Timber is a product of a tree.

Wood is made up of numerous tube like cells packed closely together. During the growth of the tree, these cells are positioned in a certain direction. The direction of these cells is referred to as the `grain'. The direction of the grain can be identified by the visible lines on the surface of the timber.

Any operation performed in the grain direction is called an operation `along the grain'. (Fig 1)

Fig 1



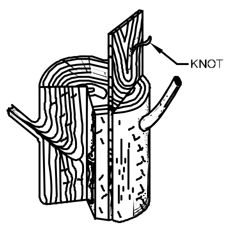
GRAIN DIRECTION IN WOOD

Any operation performed at right angle to the grain direction is called `across the grain'.

Any irregularity occuring in the timber is a defect in the timber. These defects in the timber reduce its strength, durability and utility value.

Common defects in timber : A knot is caused due to the growth of branches on the tree. It appears on the surface of planks and on boards when the logs are sawn. (Fig 2)

Fig 2

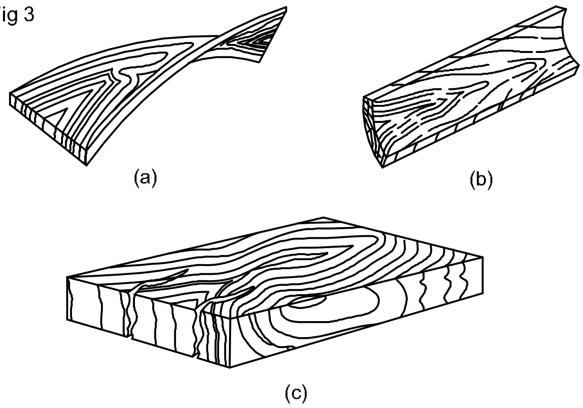


TIMBER WITH KNOT

The following defects are caused due to uneven shrinkage, improper seasoning and defective storage.

- Twisting (Fig 3a)
- Cupping (Fig 3b)
- Cracking (Fig 3c)

Fig 3



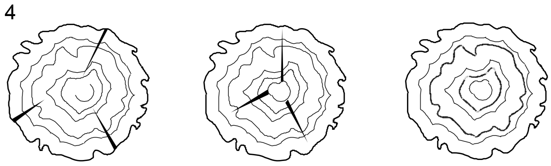
DEFECTS IN TIMBER

Shakes

- Radial shake (Fig 4a)
- Star shake (Fig 4b)
- Cup shake (Fig 4c)

Avoid defective pieces while selecting timber to get better results.

Fig 4



Marking and measuring tools

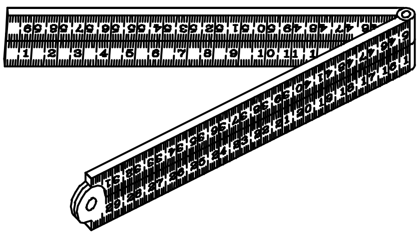
Objectives : At the end of this lesson you shall be able to
- **name the marking and measuring tools and their functions**
- **state the functions of straight edge, marking gauge and wooden folding rule**

Marking and measuring tools are used in woodwork for marking, measuring and checking the work at various stages.

Common marking tools
- Wooden folding rule
- Steel rule

Wooden folding rule: A wooden folding rule is graduated both in centimetres and inches. The most commonly used is the two feet, 4-fold wood rule which is shown in Fig 1.

Fig 1



WOODEN FOLDING RULE

ELN121521

It is used for taking linear measurements, to an accuracy of 1 mm or 1/16th of an inch.

Steel rule : It is graduated in centimetres/inches with their subdivisions. The reading accuracy is 0.5 mm.

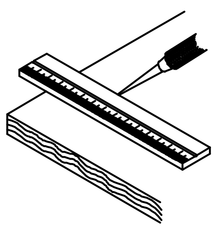
Common marking tools

They are:

- straight edge
- marking gauge
- try square.

Straight edge: It is made of steel with perfect straight and parallel edges. It is normally used for drawing straight lines on a job. It can also be used for testing flatness of a surface and straightness of an edge. (Fig 2)

Fig 2



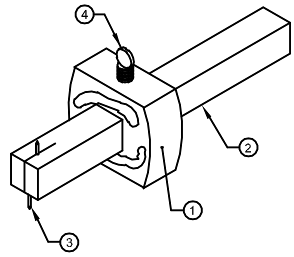
STRAIGHT EDGE

ELN121522

Marking gauge: It is a marking tool,consisting of (1)stock,(2)stem ,(3)spur and (4) thumb (locking) screw as shown in Fig 3.

The stock can be adjusted over the stem to set the required distance between the spur and the face of the stock. The thumb screw is tightened to retain the measurement. The spur, a pointed steel, inscribes lines on the surface of the wood.

Fig 3

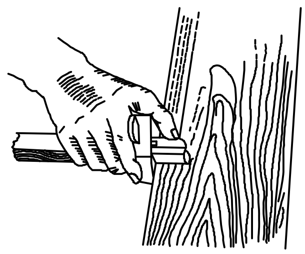


MARKING GAUGE

ELN121523

It is used for marking lines parallel to the face or edges. (Fig 4)

Fig 4



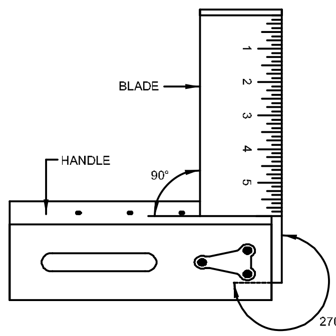
MARKING LINES WITH MARKING GAUGE

ELN121524

Try square : It is used for checking marking lines at right angles. It is also used for checking right angles and flatness of surfaces.

The parts of a try square are shown in Fig 5. It is available in different sizes, from 150 mm to 800 mm.

Fig 5



TRY SQUARE

ELN121525

Remember: Keep these tools separately from the other tools to prevent damage.

Avoid dropping or knocking them off the workbench.

The mallet

Objectives: At the end of this lesson you shall be able to
- **state the constructional feature of mallet**
- **state the use of mallets**
- **state specification of mallets.**

The mallets are made of hard wood and it is used in place of hammer. But the difference is head only.

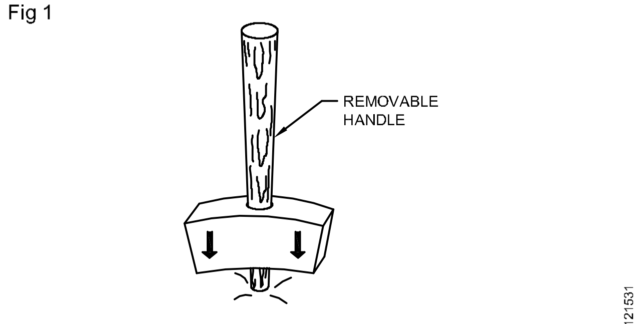
Mallet are used for driving wood chisels and for adjusting wooden planes. It is used for assembling and dismantling wooden works and for adjusting stop dogs in the work bench.

The handle is made of beech or ash with straight grained fibres. The head is made of hard wood with twisted fibres. This prevents splitting of the wood.

A special type of mallet is made of 'Ligno stone' which is made of special wood that is treated with heat and high pressure.

Some mallets have removable handles (Fig 1) which can be taken out of the head easily so that parts can be stored easily. Fig 2.

Fig 1

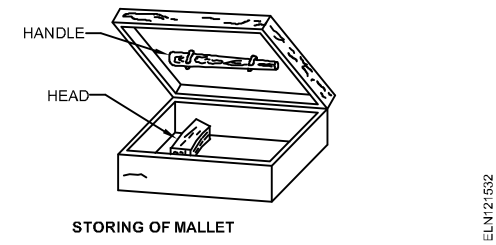


REMOVABLE HANDLE MALLET

The striking faces of mallet heads are so bevelled so that they can hit the chisel. For most purposes a head of 110 mm long, 80mm wide and 60 mm thick is suitable. The handle is driven in from the top and is tapered in its width. Its head is either round or square. (Fig 3)

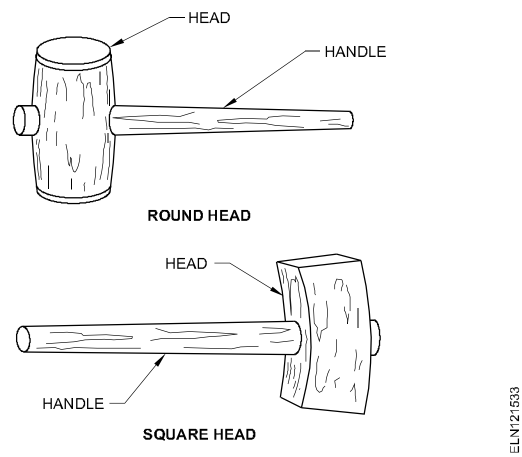
The mallet is held upside down and dropped once or twice on the work bench, the head of the mallet will be tightened on the handle.

Fig 2



STORING OF MALLET

Fig 3



SQUARE HEAD

Carpenter's hammer

Objectives : At the end of this lesson you shall be able to
- **state the uses of an carpenter's hammer**
- **name the parts of a carpenter's hammer and state their function**
- **name the type of carpenter's hammers with specification**

A carpenter's hammer is a hand tool used for striking purpose while

1 punching

2 striking

3 pulling

- The major parts of a hammer are a head and a handle
- The head is made of drop-forged carbon steel
- The wooden handle must be capable of absorbing shock.

Parts of hammer head (Fig 1)

Handle

Pein

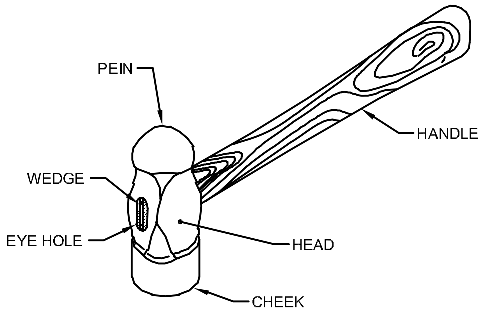
Cheek

Eye hole

Cheek

The cheek is the striking portion slight convexly is given to it to avoid digging of the edge.

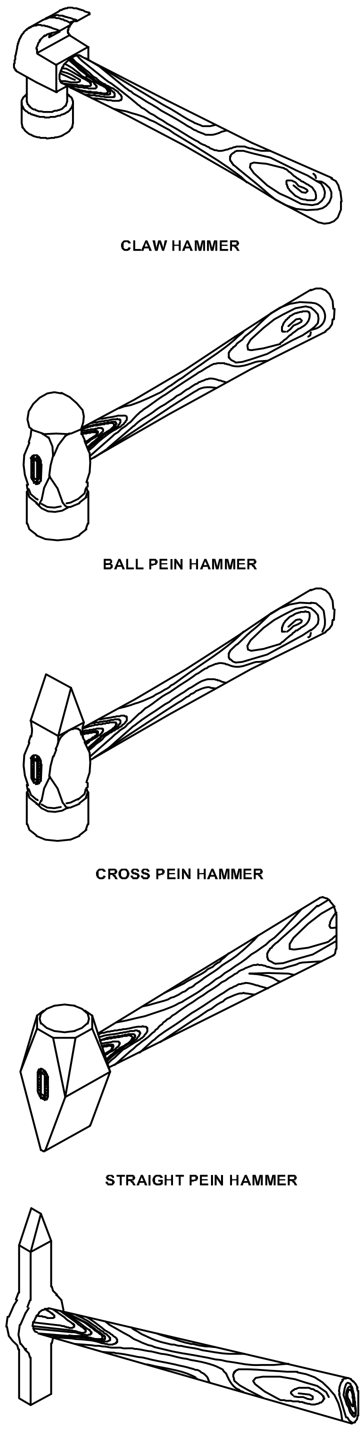
Fig 1



HAMMER HEAD PARTS

ELN121541

Fig 2



TYPES OF HAMMERS

ELN121542

Pein (Fig 2)

The pein is the other end of the head.

It is used for shapping and forming. Work like Rivetting and bending the pein is of different shapes like (Fig 2)

1 Ball pein (hammer)

2 Cross pein (hammer)

3 Straight pein (hammer)

4 Claw (hammer)

5 Tacks (hammer)

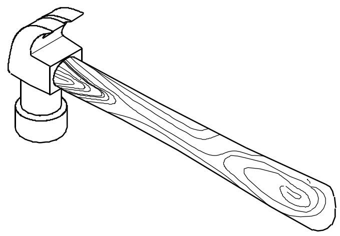
Eye hole

An eye hole is meant for the handle. It is shaped to fit the handle rigidly. The wedges fix the handle in the eye hole.

Specification

Carpenter's hammer's are specified by their weight and the shape of the pein. Their weight varies from 125gms to 1500gms.

Fig 3



CLAW HAMMER

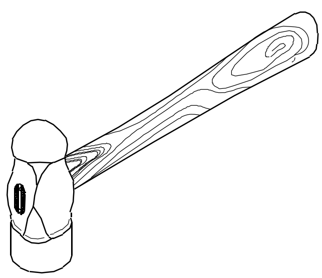
ELN121543

Claw hammer (Fig 3)

It is made of cast steel and carries the striking face at one end and the claw at the other. The face is used to drive the nail into the wood and other striking purposes and the claw is used for extracting the nails out of the wood. Its size is designated by its weight and it varies from 0.25kg to 0.75 kg.

Ball pein hammer (Fig 4)

Fig 4



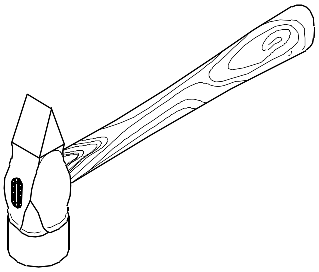
BALL PEIN HAMMER

ELN121544

It is made of cast steel and weight of about 110 gm to 910 grams. It is also called as engineers' hammer. One side of it is in the shape of ball and hence the name it is also used for riveting.

Cross pein hammer (Fig 5)

Fig 5



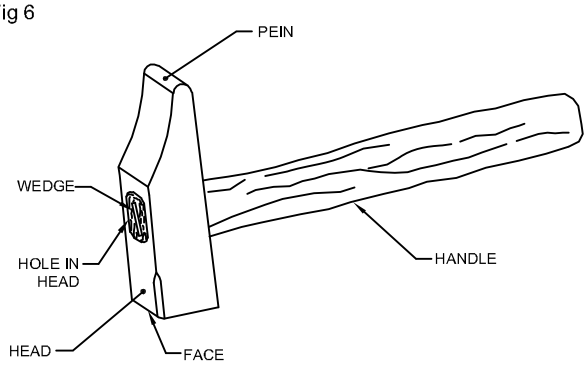
CROSS PEIN HAMMER

The head part of this hammer is across the handle and hence the name. It is used for all light works.

Due to this magnetism nails and screws are taken easily and is used to hammer or strike very thin nails. Some times it is called as pin hammer. It is weight is 100gms.

Carpenters' hammer (Fig 6)

Fig 6



CARPENTER'S HAMMER

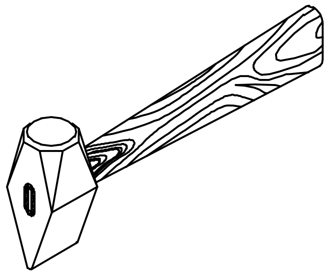
The hammer head has a rectangular or oval hole which is tapered on the inside. The shape of this hole offers a good hold for the handle when wedged.

The handle must firmly be secured in the head to prevent accidents. The wedge is driven diagonally into the end of the handle. The wood splits and is pressed against the inner wall of the hole.

In carpenter shop it is called as warrington hammer. To extend the iron frames, for bending and for other works it is used. Its weight varies from 220gms to 910gms.

Straight pein hammer (Fig 7)

Fig 7

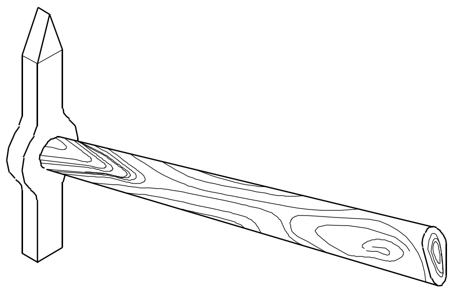


STRAIGHT PEIN HAMMER

The hammer head is straight to the hammer handle. The bottom part of the head is large and tapering towards end side. It is used in rivetting and to extend metal frames. Its weight is 110gm and varies up to 900gms.

Tacks hammer (Fig 8)

Fig 8



TACKS HAMMER

It is lesser in weight than all other hammers. The hammer head is straightly fitted to the handle of hammer. It has slight magnetic properties.

> **Precaution**
>
> **Make sure the handle is properly fitted. Select a hammer with correct weight suitable for the job.**
>
> **Check the head and handle for any cracks. Ensure the face of the hammer is free from oil and grease.**

Wood working saws

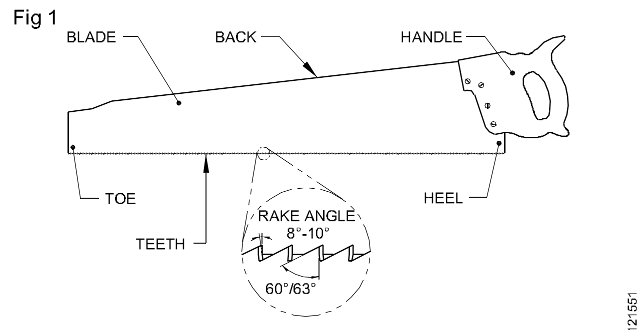
Objectives: At the end of this lesson you shall be able to
- **state the functions and use of a handsaw**
- **distinguish between a tenon-saw and a handsaw**
- **illustrate the setting of the teeth of a saw.**
- **name the various holding tools and their application**

The saws are used to cut the timber to the required shapes and sizes.

The saws most commonly used by an electrician are:

- handsaw
- tenon-saw.

Handsaw: Figure 1 shows the parts of a handsaw. They are the handle and the blade.



RIP SAW/HANDSAW/PANEL SAW

Handle: It is generally made of wood.

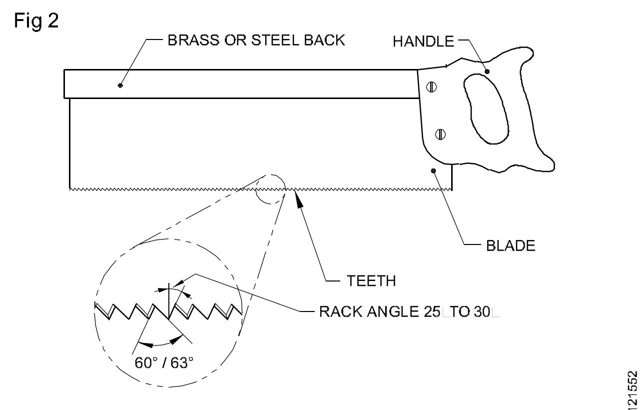
Blade: It is made of tempered steel having teeth on the lower edge. The best quality saws are made from spring steel which decreases in thickness slightly from the teeth to the back.

The blade is about 66cm (26 inches) long, and normally has 2 1/4 teeth per cm (6tpi). The number of teeth of a handsaw varies up to 4 teeth per cm (10tpi).

A saw blade with less number of teeth per inch has bigger teeth. Therefore, it is used for rough work as it cuts quickly.

Tenon-saw: The tenon-saw is intended for finer work and is manufactured with a thinner blade. It is used for general bench work such as joint construction, where more accuracy is needed.

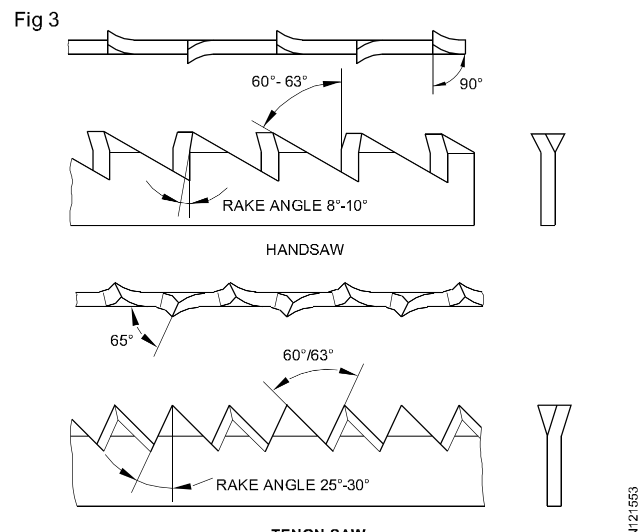
This saw is also known as the back saw. (Fig 2)



TENON-SAW/CROSS-CUT SAW

The blade is stiffened with a brass or steel back. The blade is about 30cm (12 inch) long. The number of teeth of a tenon-saw is 12 to 14 per inch.

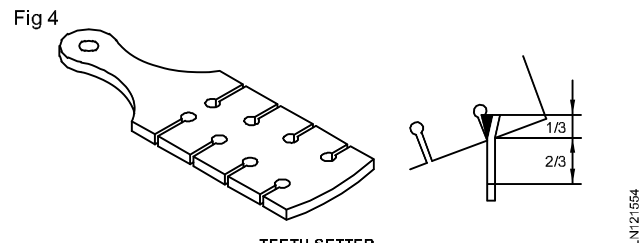
Tooth geometry: The angle between the trailing edge of one tooth and the leading edge of another is constant at about 60° - 63° on all styles of saws. The angle on the leading edge of the tooth varies according to the style of saw, and the purpose for which it is designed. (Fig 3)



TENON-SAW

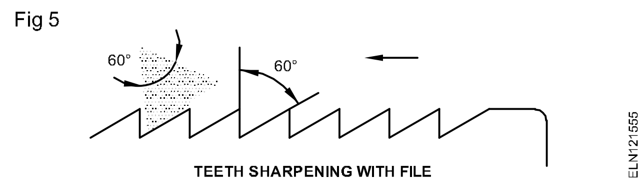
The hand saw has a rake angle of 8° to 10°. The tenon-saw has a rake angle of 25° to 30°.

Setting of teeth: The teeth are set using setters as shown in Fig 4. It helps to keep the blade free in the cut slit.



TEETH SETTER

Sharpening the blunt teeth is done with a triangular file as shown in Fig 5.



TEETH SHARPENING WITH FILE

Uses: This saw is used for cutting tenons, sawing sides of trenches and for general bench work and for cutting in round blocks and T.W. battens and T.W. boards for wiring purposes.

Always use the right saw for the right job.

Do not apply excessive force to the saw while cutting as very little effort is required to operate a sharpened saw.

Holding devices

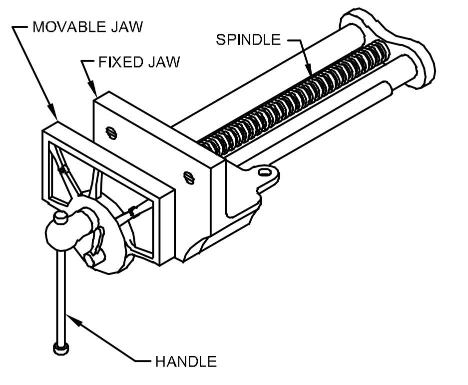
In woodwork various holding devices are used to hold thewhile performing different operations such as planing, chiselling, sawing and filing.

The common holding tools are:

- woodworker's vice/carpenter's vice.
- `G' clamp.
- bench hook.

Woodworker's vice (Fig 1)**:** It is made of metal and is fitted to the workbench. It is available in various sizes.

Fig 1

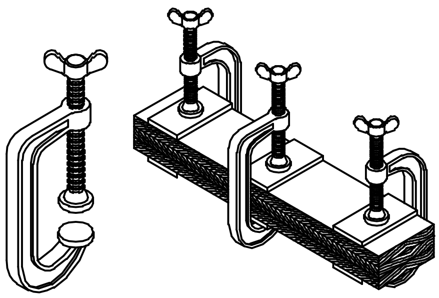


WOOD WORKER'S VICE

It consists of two jaws - movable and fixed. The anticlockwise rotation of the handle, attached to the spindle, causes the movable jaw to open. The job is held between the two jaws by rotating the handle in the clockwise direction.

G Clamp (Fig 2)**:** It is a metal clamp in the shape of the letter`G' used for holding the job to the bench, while sawing or chiselling. It is also used to hold small parts of a job for gluing.

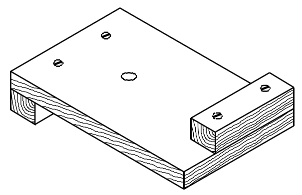
Fig 2



G CLAMP

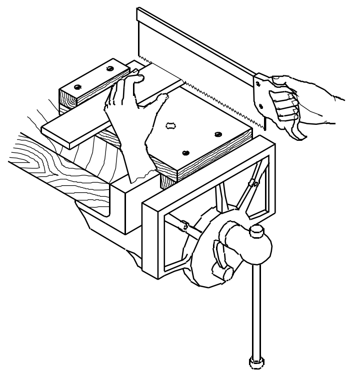
Bench hook: It is also known as cutting board and made of hardwood. (Fig 3) It is used to hold the job while sawing or chiselling and at the same time protecting the workbench and surface from damages. (Fig 4)

Fig 3



BENCH HOOK OR EARTHING BOARD

Fig 4



THE USE OF BENCH HOOK WHEN SAWING SMALL PIECES

Using a tenon-saw and a bench hook

- Position the bottom rail of the bench hook against the edge of the bench or hold it in the vice.
- Place the timber against the top rail of the hook, the cutting mark just clear of the edge.
- Grip the timber and the top rail together. Use the thumb to act as a guide for the saw at the start of the cut.

Keep your thumb clear off the saw teeth.

Bench planes

Objectives: At the end of this lesson you shall be able to
- **state the different types of planes and their functions**
- **state the purpose of setting the jack plane blade.**
- **state the parts and function of a rebate plane**

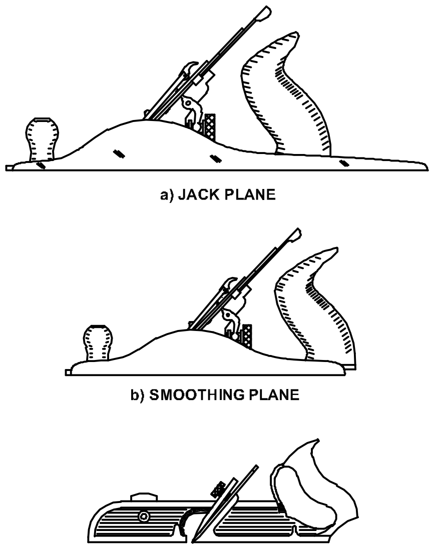
Planes are used for producing flat and smooth surfaces by taking off thin shavings of wood. Different types of planes are used for this purpose.

Types of planes

The most commonly available types of planes are:

- jack plane (Fig 1a)
- smoothing plane (Fig 1b)
- rebate plane. (Fig 1c)

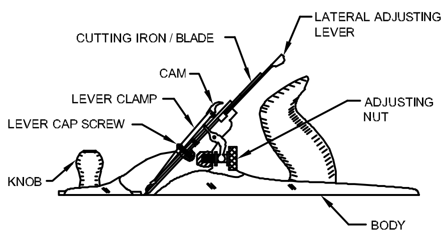
Fig 1



TYPES OF PLANES

Jack plane: It is used for initial planing of timber to bring the size nearer to the required measurements. Its main parts are indicated in Fig 2.

Fig 2



JACK PLANE

These parts are made of different materials as listed below.

Body	–	iron
Handle	–	wood
Knob	–	wood
Cutting iron/blade	–	tungsten steel
All other parts	–	metal

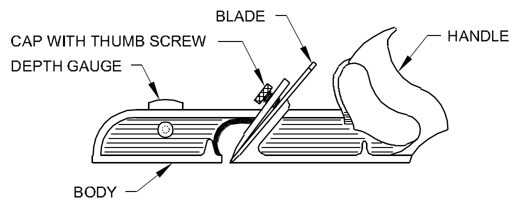
The size of the plane commonly used by an electrician is 350 mm long with a 50 mm blade.

Smoothing plane: It is used for finishing the job to the required size, and for planing small wooden pieces/parts of the job. It is shorter in length as compared to the jack plane. (Fig 1b)

The parts of a smoothing plane are similar to those of the jack plane. (Fig 2)

Rebate plane: It is used for planing or finishing rebates i.e. rectangular recesses cut along or across the edge. Its main parts are shown in Fig 3.

Fig 3



REBATE PLANE

The width of the plane and blade is less as compared to that of the jack plane.

> **Ensure that the blades are well sharpened before use. Always use the approporiate type of plane for a given job.**

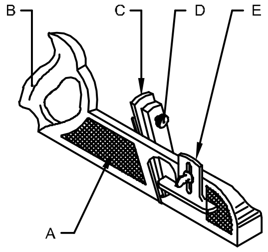
Rebate plane - parts and their functions

A rebate plane is used for planing and finishing the rebates.

Parts of a rebate plane

A metal rebate plane: A metal rebate plane consists of the following parts. (Fig 1)

Fig 1



REBATE PLANE

A **Body:** Made of metal with its face perfectly flat.

B **Handle:** It is the integral part of the body.

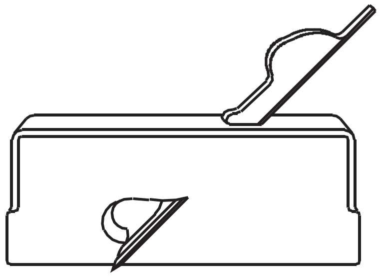
C **Blade:** It is made of well tempered steel.

D **Cap with thumb screw:** It is made of metal and it holds the cutter in position.

E **Depth gauge:** It is made of metal attached to one side of the plane, and it can be adjusted according to the depth of the rebate.

Wooden rebate plane: It consists of the following parts. (Fig 2)

Fig 2



WOODEN REBATE PLANE

Body: made of wood and holds the other parts.

Blade: made of well tempered steel.

Wedge: made of wood to hold the blade in the body to a set position.

> **Be sure that the blade is sharp and it is set squarely to its base before use.**

Drill bits - Types and sizes

Objectives: At the end of this lesson you shall be able to
- **state the different types of drill bits, and their uses**
- **state the parts of a drill bit.**
- **state the different types of nails, wood screws and their uses**

For marking round holes in different types of materials, such as metal, wood, plastic etc. drills are used.

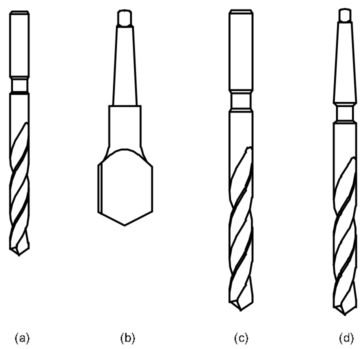
Types of drill bits

The most common drill bits are (a) twist drill and (b) flat drill.

Twist drills may be:

- parallel shank
- taper shank drills. (Fig 1)

Fig 1



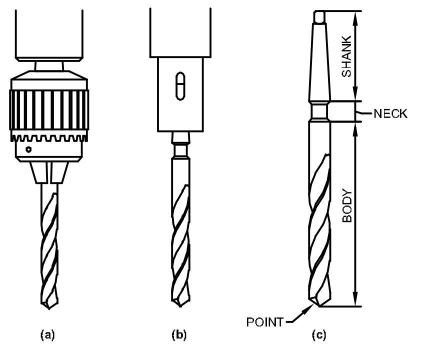
TAPER SHANK DRILLS

Parallel or straight shank drills are held in the drill chuck. (Fig 2a)

Taper shank drills are held in taper sockets in the drilling machine. (Fig 2b)

Parts of a twist drill: A twist drill consists of a body, point, neck and shank. The point comprises the cutting elements, while the body guides the drill in operation. (Fig 2c)

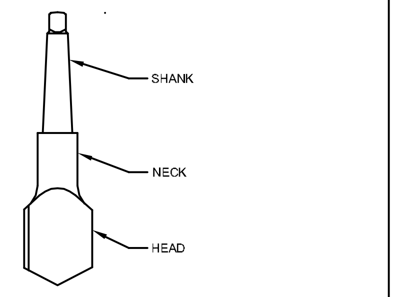
Fig 2



DRILL CHUNK TAPER SHANK DRILL IN OPERATION

Parts of a flat drill: The flat drill consists of a head, neck and shank. It has a tapered shank. (Fig 3)

Fig 3



FLAT DRILL

Flat drill is used for drilling shallow holes in heavy works.

Sizes of the drill bits: Drills are available in various sizes. The size of the drill is indicated on the plain portion of its shank.

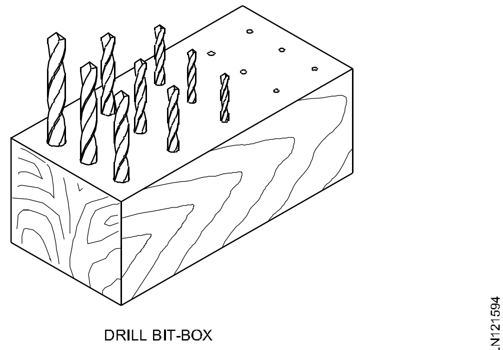
Parallel shank drills are available in small sizes up to 12mm diameter.

Taper shank drills are available in sizes from 3mm to 50mm dia.

To protect the twist drill bits from damage, place them separately in small boxes/containers. (Fig 4)

These chill bits are attached to either hand drilling machine or electric drilling machine to drill holes.

Fig 4



DRILL BIT-BOX

Types of nails and wood screws

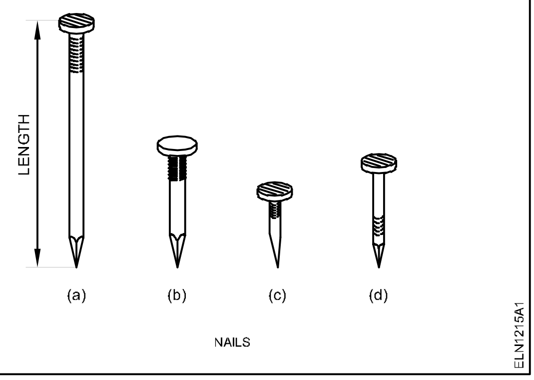
Both nails and screws are used as fasteners in woodwork. Nails are used for cheaper types of work, and screws are used for a better class of work where additional strength and durability is a must.

Specification of nails: Nails are specified stating their

- length,
- type, and
- gauge number.

Length in the case of nail includes the head of the nail. (Fig 1)

Fig 1



NAILS

`Type' includes shape of the head, cross-section, purpose, and the metal the nail is made of.

Gauge is indicated by a number in accordance with the standard wire gauge, where higher gauge number indicates a smaller diameter of nail and vice versa.

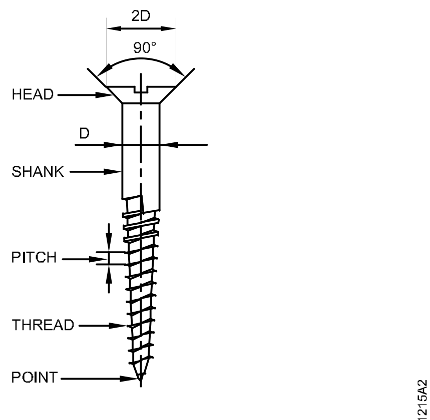
Types of nails: There are different types of nails made for different purposes. Those that are generally used in electrical work are:

- wire nail (Fig 1a)
- wire clout nail (Fig 1b)
- cut tack or stud (Fig 1c)
- wire tack. (Fig 1d)

Specification of screws: Screws also are specified in a similar way as nails are i.e. stating their length, designation number, type and the metal they are made of.

Parts of a wood screw: The parts of a wood screw are shown in Fig 2.

Fig 2



WOOD SCREW

Head : Uppermost part

Shank : Plain or unthreaded portion of 1/3 of the length of the screw.

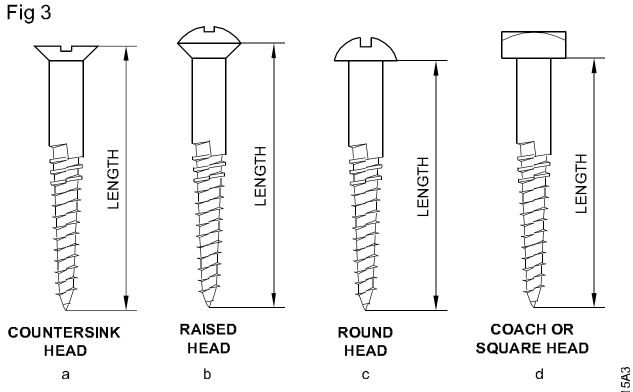
Pitch : It is the distance between adjacent threads

Point : The sharp edge of the screw end.

Thread : A special ridge around the core.

Length is measured from the point of the screw to the portion it can enter the timber. (Fig 3)

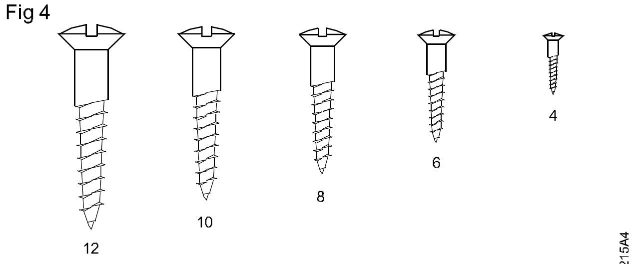
Fig 3



TYPES OF WOOD SCREWS

The designation number of a screw indicates the diameter of the unthreaded shank. The screw number and the corresponding diameter of the shank are given in IS 6739, 6736 and 6760. The screw number is the screw designation. It is different from the SWG of wire nails. (Fig 4)

Fig 4



SIZES AND DESIGNATION NUMBERS OF WOOD SCREWS

Types of screws

According to the shape of the head, screws are classified into:

- **slotted countersunk (flat) head wood screw (Fig 3a)**
  - used for general purpose (IS:6760-1972)
- **slotted countersunk raised head wood screw (Fig 3b)**
  - used for fixing thick sheets to woods (IS:6736-1972)
- **slotted round head screw (Fig 3c)**
  - It is used for fixing thin sheets to woodwork. (IS:6739-1972)
- **coach or square head screw (Fig 3d)**
  - is used for heavy duty work. It is tightened using spanner.

Availability: Wood screws are generally made of mild steel, aluminium and brass, and are from 8 mm to 200 mm length, with the screw numbers ranging from 0 to 24.

The chart of preferred lengths and screw number combinations for wood screws is available in the relevant IS.

The screws commonly used by electricians are from screw No. 4 to 12 and 12 mm to 50 mm in length.

Wood screws are available in packets of 100 and 200 numbers. The size and number of the screw are indicated on the packet.

Mild steel screws are most commonly used for general work. Brass and aluminium screws are used to match the metal fitting and also to prevent rust under damp conditions.

Ratchet brace

Objective: At the end of this lesson you shall be able to
- **name the parts of a ratchet brace and state their functions.**
- **state the countersunk bits sizes**

One of the tools for holding various types of bits for making holes of various diameters in wood by manual operation is the ratchet brace.

It is used for jobs that require slow speed and high torque operation.

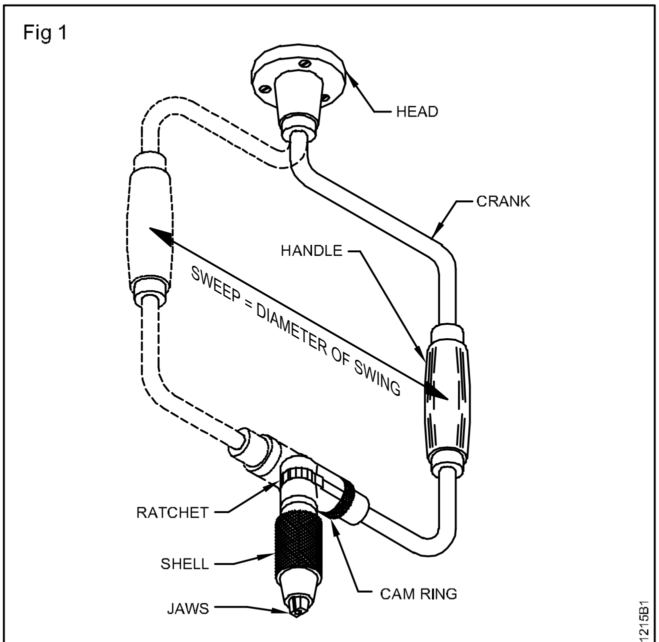
Parts and their functions (Fig 1)

Head: The head is made of wood and is fitted to the upper end of the crank with ball bearings. It is used to hold the brace in an upright position by one hand, and also apply the required force during operation.

Crank: It is a metal rod bent to the form shown in Fig 1. Ratchet braces with different sweep sizes of crank are available. The size mostly used is one of 250mm sweep. A wooden handle is provided to rotate the crank by the hand that is free.

Chuck: It is fitted at the lower end of the crank. It has two jaws for holding square shank bits, and a shell for tightening and slackening jaws.

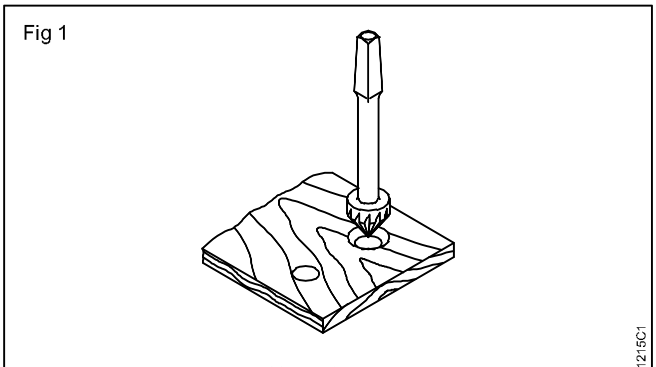
Ratchet: It permits the chuck to rotate in only one selected direction. The selection of direction is done by turning the cam ring. This allows to rotate the bit continuously, and in confined spaces as well where the full sweep of the crank is restricted. (Fig 1)



RATCHET BRACE

Countersunk bits - types - sizes

Countersunking is done on a drilled screw hole to accommodate the countersunk head of the wood screw. The process of removing out material round a hole at its surface up to a depth to match the CS screw head is known as countersinking. (Fig 1)



COUNTERSUNK BITS

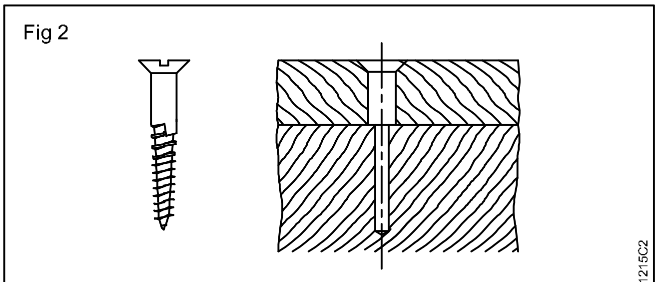
Variation of the size of head CS screws with the screw number makes it necessary to select the suitable CS bit.

Sizes of countersunk bits: The countersunk bit size is specified by the rim diameter.

The general size of the bit varies from 10 mm to 25 mm.

The 82° cutting angle CS bits are used because wood screws always bear 90° slope.

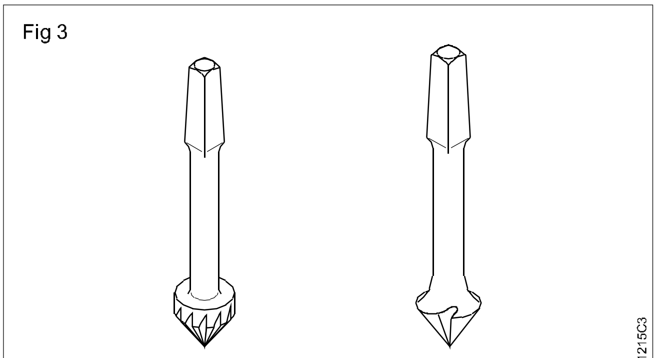
Method of selection: Select the countersunk bit of the next higher dia. size to that of the wood screws head diameter. With the head of screw ensure the required depth while countersunking. (Fig 2)



HEAD OF WOOD SCREW FOR COUNTER SUNKING

Types: The two types of bits are:

- Rose countersunk bit (Fig 3a) which is a multi-cutting edge tool
- Nail countersunk bit (Fig 3b) which has a single-cutting edge.



a) ROSE COUNTERSINK BIT b) NAIL COUNTERSINK BIT

Screwdrivers used in woodwork

Objective: At the end of this lesson you shall be able to
- **name the various types of screwdrivers, and state their sizes and uses.**

Screwdrivers are available in different sizes and patterns according to their application.

Types of screwdrivers: London pattern is a heavy screwdriver having a size of 75 to 350mm with a flat shank. It is used for general woodwork. (Fig 1a)

Cabinet pattern is a medium screwdriver having a size of 75 to 350mm. It is used for cabinet works. (Fig 1b)

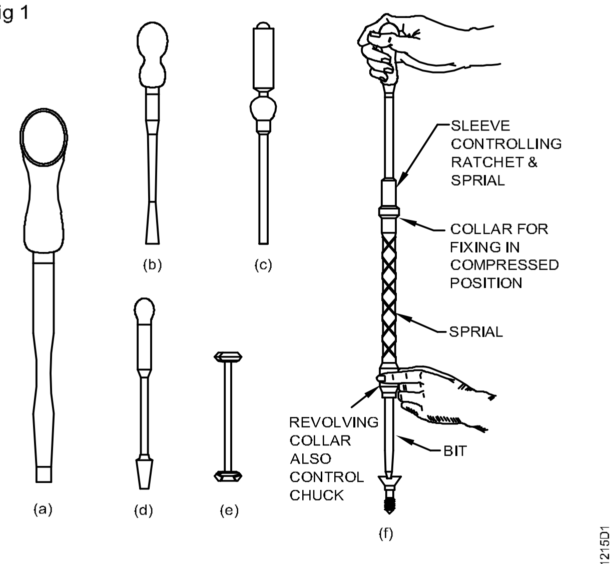
Electrician pattern is a common type of screwdriver used by electricians. It is available from 100mm to 300mm size. The handle is made of either wood or plastic. The shank is either insulated or non-insulated. (Fig 1c)

In the **ratchet type of a screwdriver**, a ratchet is fitted within the handle. The blade of the screwdriver can be set to different positions i.e for clockwise or anti-clockwise revolution of the screwdriver blade. It can also be set to a neutral position (locked). It is used for general purposes and is available in sizes ranging from 50mm to 200mm. (Fig 1d)

A cranked screwdriver is a special type used where normal screwdrivers cannot be applied. (Fig 1e)

A spiral ratchet works on rotary action. It is used with interchangeable blades of different sizes and patterns available in 300, 500, 600mm length. Only downward pressure need be applied while using this type of screwdrivers. This type of screwdriver can also be set in both clock and anticlockwise revolution for screwing and unscrewing purposes. (Fig 1f)

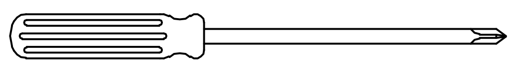
Fig 1



SCREW DRIVERS

A Phillips screwdriver is used to drive Phillips head screws. It is a special purpose screwdriver available in 75 to 200mm sizes. The Phillips screwdriver (Fig 2) will not slip and burr the head of the screw if a proper size is selected.

Fig 2



A PHILLIPS SCREW DRIVER

Sharpening and setting of saw teeth

Objective: At the end of this lesson you shall be able to
- **describe the steps involved in `sharpening and setting' of the saw teeth**
- **explain the methods of re-sharpening jack plane blade**

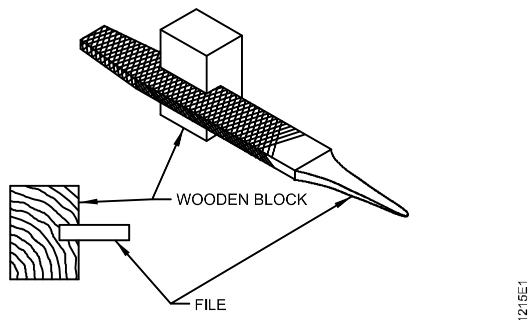
To perform the sawing operations with ease and accuracy, the saw must be in good condition with its teeth sharpened and well set.
Sharpening of a saw involves 4 steps which are as follows.

Topping or jointing: This is done to bring down the points of all the teeth to the same level. A flat file is held in a wooden block and rubbed over the teeth until the lowest tooth touches the file face. (Fig 1)

Reshaping: It is necessary to restore the tips of the teeth. Therefore the gullet of each tooth is filed down using a suitable size triangular file. Care is taken to maintain a uniform depth of gullets, pitch and angles of teeth. (Fig 2)

Setting: Setting is a process of bending every alternate tooth to the opposite direction. This is carried out by using a saw-set pliers. (Fig 3)

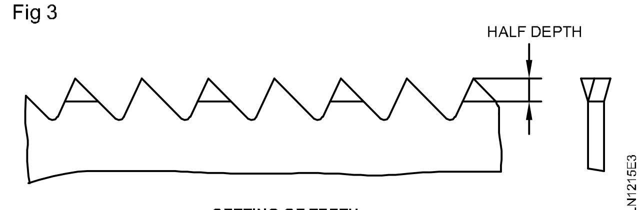
Fig 1



TOPPING OF FILE

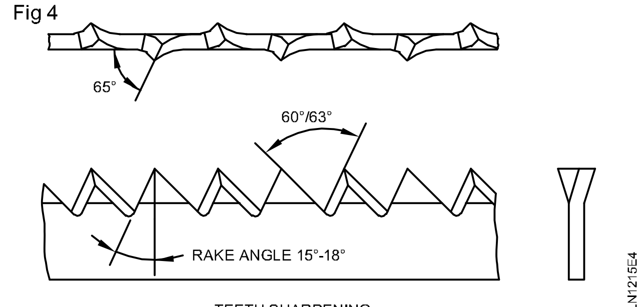
Fig 2

TEETH RESHAPING WITH FILE



SETTING OF TEETH

Sharpening: This is the final step in which the gullet of each tooth of the saw is filed to produce a keen cutting edge, using a suitable size of a triangular file. (Fig 4)



TEETH SHARPENING

Topping is necessary only when the saw teeth have become uneven in their height, and re-sharpening follows it.

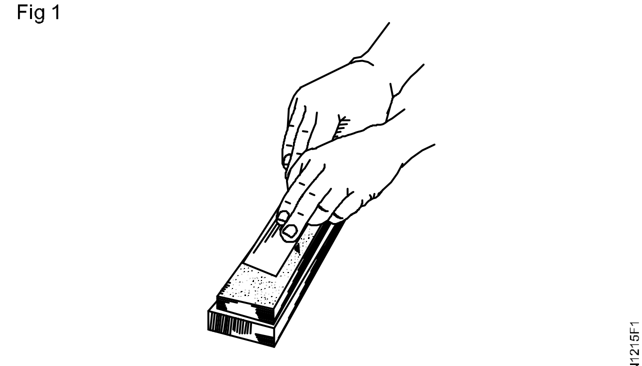
Re-sharpening of a plane blade

Sharpening of a plane blade is necessary to produce a keen cutting edge for good surface finish, and perfect planing with minimum effort.

Sharpening and honing: The process of sharpening is carried out on an oilstone by rubbing the blade with its bevel down, maintaining a constant and correct angle, 25° to 30°. (Fig 1) This rubbing is continued until a burr or wire edge is produced.

The burr is removed by rubbing the back of the flat face of the plane blade on the oilstone, keeping its bevel up. (Fig 2)

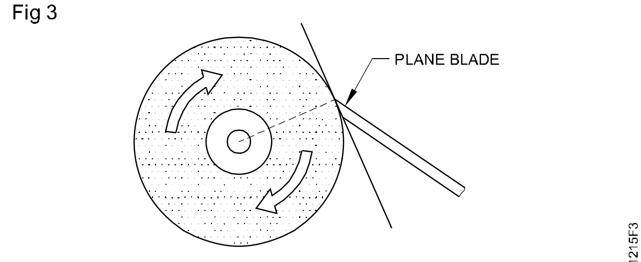
During sharpening, oil is used to minimise the heat caused due to friction and to float off the metal particles from the pores of the oilstone so as to prevent clogging of the oilstone.



SHARPENING OF PLANE BLADE

BURR REMOVAL

Because of the continuous use and numerous sharpenings, the bevel of the blade is likely to become shortened or rounded. The correct bevel is restored by grinding it over an emery wheel or grindstone. (Fig 3)



GRINDSTONE OR EMERY WHEEL

Chisel - parts - types - uses

Objectives: At the end of this lesson you shall be able to
- **state the parts of firmer chisel and their types**
- **name the specific use of each chisel.**

Chisels are used for shaping and finishing the parts of wood joints. They are also used for shaping different profiles in woodwork. The size of the chisel is determined by the width of the blade.

Parts of a chisel

A chisel has the following parts. (Fig 1)

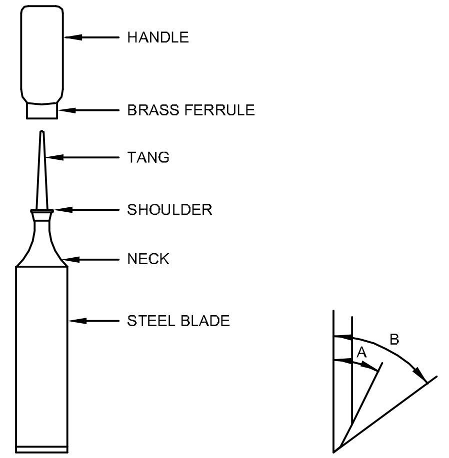
Handle	:	made of wood.
Ferrule	:	fitted to the handle.
Tang	:	tapered end of the blade.
Shoulder	:	the lower end of tang.
Neck	:	shaped portion beneath the shoulder.
Blade	:	the portion beneath the neck up to the cutting edge.

Types of chisels

Firmer chisel (Fig 2a) **:** It posseses a rectangular-sectioned steel blade, the size (width of blade) being 3 mm to 50 mm. It is used for general chiselling work.

Bevel-edge firmer chisel (Fig 2b) **:** Its edges are bevelled

Fig 1



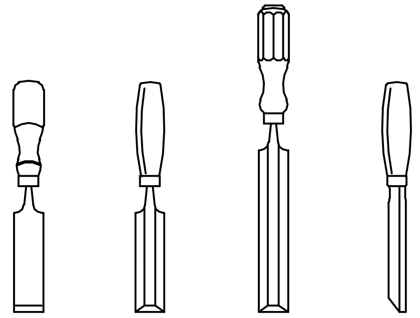
CHISEL PARTS

along the length. It is used for light chiselling and to clean sharp corners where the edges of a normal firmer chisel may not reach.

Paring chisel (Fig 2c) **:** It has an extra long, thin blade with the edges bevelled. It is used for paring and finishing joints.

Mortise chisel (Fig 2d) **:** It posseses a stronger, square-sectional blade.It is used for mortising i.e. making rectangular holes in wood.

Fig 2



TYPES OF CHISELS

Half- lap joints - types - uses

Objectives: At the end of this lesson you shall be able to
- **state the necessity of lap joints**
- **state the types of lap joints.**

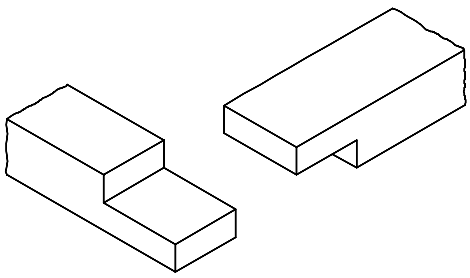
Necessity of lap Joint:

Half-lap joints are employed in frame construction where two parts of a job meet either near the ends or at a distance. To keep them flush, laps are made equal to half the thickness in each part. These joints are strengthened by fixing screws.

Types of half-lap joints

End-lap joint (Fig 1)**:** This joint is used where two parts of a job cross each other at the ends, say at the corners.

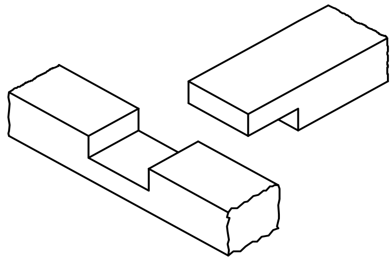
Fig 1



HALF LAP JOINT

Middle-lap joint (Fig 2)**:** This joint is used where one part of a job meets another part at some distance from the ends.

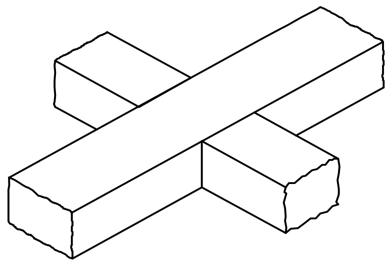
Fig 2



MIDDLE-LAP JOINT

Cross-lap joint (Fig 3)**:** This joint is used where two parts of a frame cross each other at a distance from the ends.

Fig 3



CROSS-LAP JOINT

Curve-cutting saws - types - uses

Objectives: At the end of this lesson you shall be able to
- **state the necessity of curve-cutting saws**
- **state the types of curve-cutting saws and their application.**

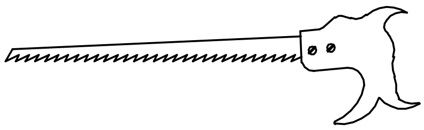
Curve-cutting saws have narrow blades which enable them to turn along the curve with ease while sawing along the curves. Stiff and wider blades are provided with handles, while very fine blades are held in frames to keep them under tension. Very narrow, fine blades are dispensed with and replaced as soon as they become blunt. The other blades are re-sharpened.

There are various types of curve-cutting saws. The saws, with slightly wider blades are used for cutting larger curves, and the saws with finer blades are used for cutting sharp curves.

Types of curve-cutting saws

- **Compass saw** (Fig 1)**:** Used for larger curve cutting.

Fig 1

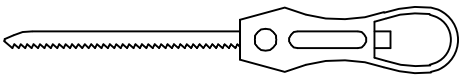


COMPASS SAW

ELN1215H1

- **Keyhole saw or pad saw** (Fig 2): It is used for internal cutting.

Fig 2



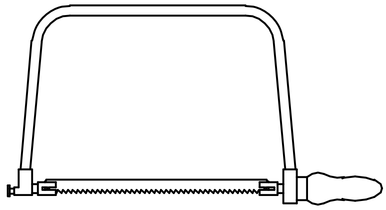
KEYHOLE SAW

ELN1215H2

- **Coping saw:** It is used for cutting sharp corners. (Fig 3)

– **Fretsaw:** It has a very fine blade. (Fig 4) It is used for cutting sharp and fine curves.

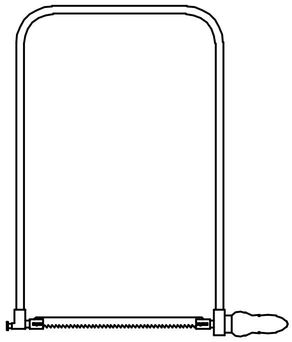
Fig 3



COPING SAW

ELN1215H3

Fig 4



FRET SAW

ELN1215H4

Blades with larger teeth will cut faster, but the surface will be rough and the blades with smaller teeth will cut slower, but the surface will have a fine finish.

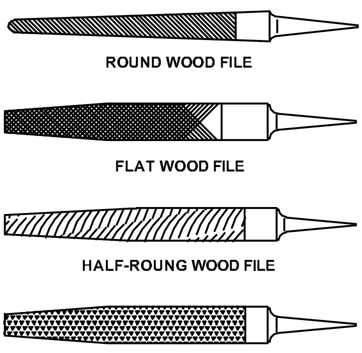
Wood working files - parts - uses

Objectives : At the end of this lesson you shall be able to
- **state the use of wood working files**
- **state the types of wood working files and their application.**

Wood working files are used to shape various profiles for smooth finish in wood or laminates.

Types and uses of wood working files : Various types of the available wood working files are named according to the shape of their cross-section. (Fig 1)

Fig 1



TYPES OF WOOD WORKING FILES

ELN1215I1

Round files: Used for finishing concave corners, and for finishing and enlarging.

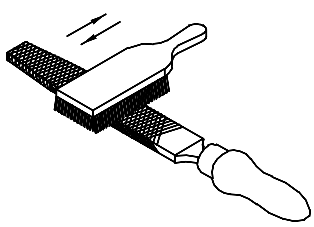
Flat files: Used for finishing end grains and corner edges.

Half-round files: Used for finishing both corner and convex edges.

Wood rasp files: Used for preliminary rough work for rapid removal of waste part of the wood.

All files should be cleaned frequently. (Fig 2)

Fig 2



CLEANING OF FILE

ELN1215I2

Sheet metal - marking and cutting tools - rivet joints

Objectives : At the end of this lesson you shall be able to
- **state the six types of metal sheets used in sheet metal work**
- **state how the plate and the sheet are differentiated from each other.**
- **state the different types of snips and their uses**
- **state the uses of solid cold punches**
- **state the uses of self tapping screw**

A large quantity of sheet metal used in the sheet metal industry is steel, rolled into sheets of various thicknesses and coated with zinc, tin or other metals. Other than steel, the worker uses sheets made out of zinc, copper, aluminium, stainless steel etc.

The term `sheet metal' generally applies to metals and alloys in sheets rolled into various thicknesses less than 5mm. Sheets over 5 mm thick are called plates.

Earlier, the sheets were specified by standard wire gauge numbers. Each gauge is designated with a definite thickness. (Table 1) The larger the gauge number, the lesser the thickness. Now the sheet thickness is specified in mm, say 0.40, 0.50, 0.63, 0.80, 0.90, 1.00, 1.12, 1.25 etc.

Table - 1

Sheet thickness		
Gauge No.	**Inch**	**mm**
18	0.048	1.22
19	0.040	1.02
20	0.036	0.91
21	0.032	0.81
22	0.028	0.71
23	0.024	0.61
24	0.022	0.56
25	0.020	0.51
27	0.0164	0.42
28	0.0148	0.38

Types of sheets

Sheet steel: It is an uncoated sheet with bluish-black appearance. The use of this metal is limited to articles that are to be painted or enamelled.

Galvanised iron sheet: The zinc-coated iron sheet is known as galvanised iron sheet, popularly known as GI sheet. The zinc coating resists rust. Articles like pans, buckets, furnaces, cabinets are made with GI sheet.

Copper sheets: Copper sheets are available either as cold-rolled or hot-rolled sheets. Cold-rolled sheets are worked easily in sheet metal shops. Gutters, roof flashing and hoods are common examples where copper sheet is used.

Aluminium sheets: Aluminium sheets are highly resistive to corrosion, whitish in colour and light in weight. They are widely used in the manufacture of a number of articles such as household utensils, lighting fixtures, windows etc.

Tin plates: Tin plate is sheet iron coated with tin to protect the iron sheet against rust. The size and thickness of the tin plate are denoted by special marks, not by gauge numbers.

Tin plates are used for food containers, dairy equipment, furnace fittings etc.

Brass sheet: Brass is an alloy of copper and zinc in various proportions. It will not corrode and is extensively used in craft.

Snips

A snip is a cutting tool and is used for cutting thin sheets of metal.

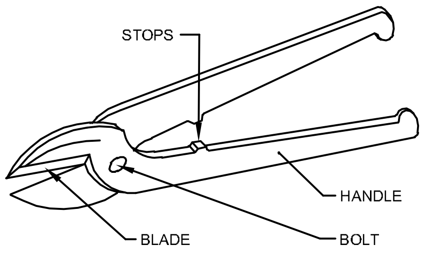
There are two types of snips.

- Straight snips
- Bent snips

Parts of a straight snip (Fig 1)

- Handle (1)
- Blade (2)
- Stops (3)

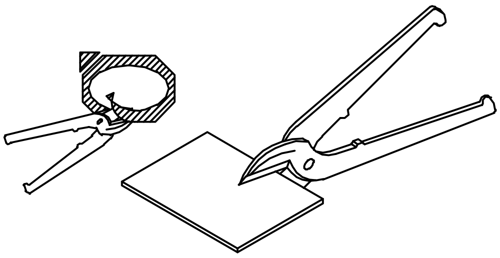
Fig 1



SNIP

Straight snips: A straight snip has straight blades for straight line cutting. It can also be used for external curved cuts.(Fig 2)

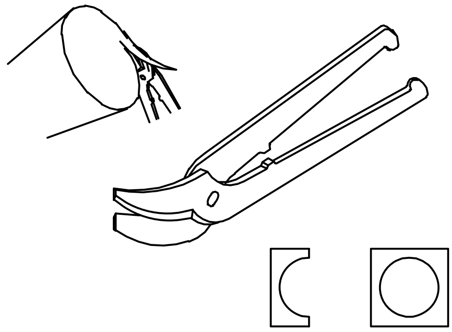
Fig 2



STRAIGHT SNIP

Bent snip: Bent snips have curved blades used for cutting internal curves. For trimming a cylinder keep the lower blade on the outside of cut. (Fig 3)

Fig 3



BENT SNIP

Solid cold punches

For making holes in sheet metal, cold punches can be utilized.

There are two types of cold punches used on sheet metal.

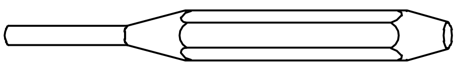
- Solid cold punch
- Hollow cold punch

In this lesson you will know about solid cold punches.

Solid cold punch: It is used to punch small holes in sheet metal (thin gauge).

Generally small holes can be made by this punch. (Fig 1)

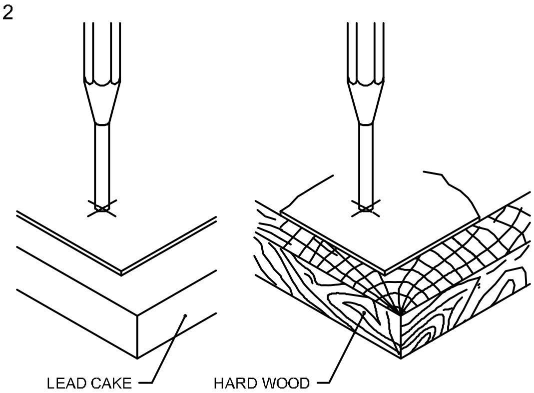
Fig 1



COLD PUNCH

Precautions to be observed while using a solid cold punch: The sheet should be kept on lead cake or on a hardwood block while punching (Fig 2).

Fig 2



METHOD OF PUNCHING SMALL HOLES

While striking, watch the cutting point, not the head of the punch.Hold the punch in a vertical positon on the correct locations.

Self-tapping screws

Self-tapping screws are used in assembly where thin section metal sheets are used. Joints made using these screws are vibration-resistant, and can be assembled and dismantled many times. The three types of self-tapping screws are:

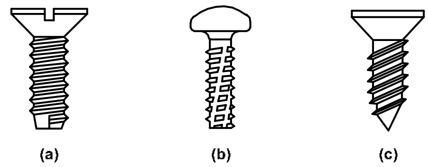
- thread forming (Fig 1a)
- thread cutting (Fig 1b)
- self-piercing. (Fig 1c)

Since these screws cut threads in mild steel and soft steel metal, they are called self-tapping screws.

The thread forming type (Fig 1a)**:** This type of metal screws produces the mating thread by displacing the material. These are useful for softer and thinner materials.

The thread cutting type (Fig 1b)**:** This type cuts the mating thread in the same way as the thread cutting tap. These screws will have projected ridges in the shape of thread for the cutting action. These are quite useful for self-tapping on hard or brittle materials with thin wall sections.

Fig 1



TYPES OFSELF TAPPING SCREWS

Self-piercing and tapping (Fig 1c)**:** These screws have a special piercing point and a twin-start thread. These screws are used along with a special gun. The sheet is pierced and the screw driven home.

Folding tools

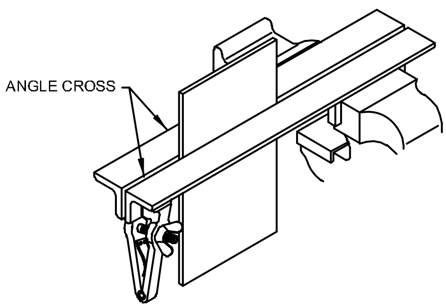
Objectives: At the end of this lesson you shall able to
- **list out the different folding tools**
- **state the uses of folding tools.**
- **state the types of notches and their uses**
- **state the types of hem and their application**

The common tools used in the folding of sheet metal are:

- angle steel and folding bar
- C clamp
- stakes
- mallet.

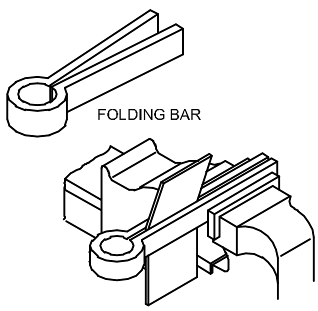
Angle steel: Two pieces of angles are used for folding at 90°. For longer sheets lengthy angles will be used along clamp (or) hand vice. (Fig 1)

Fig 1



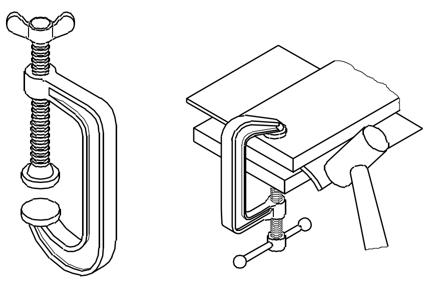
Folding bar: The sheet metal to be bent is clamped in the folding bars. The folding bars are clamped in the vice as shown in the figure. (Fig 2)

Fig 2



**`C' clamp:** The shape of the clamp is in the form of the letter `C'. `C' clamp is a holding device. This clamp is used when the piece has to be securely fixed to another piece. It is available in different sizes according to the opening of jaws. (Fig 3)

Fig 3



`C' CLAMP / `G' CRAMP

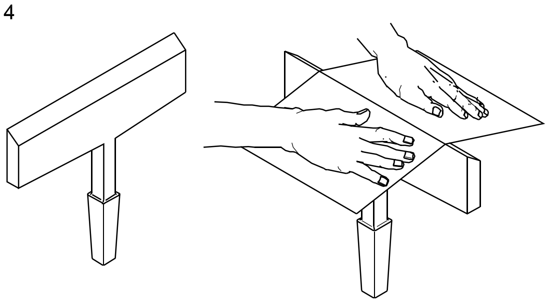
Stakes: Stakes are used for bending, seaming and forming of sheet metal that cannot be done on any regular machine. For the above purposes, different stakes are used. Stakes are made of forged steel or cast steel.

Types of stakes

- Hatchet stake
- Square stake
- Blow-horn square stake
- Bevel-edge square stake.

Hatchet stake: A hatchet stake has a sharp straight edge bevelled on one side. It is used for making sharp bends, for bending edges and for folding sheet metal. (Fig 4)

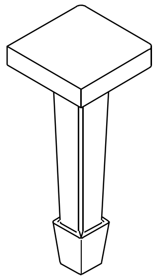
Fig 4



HATCHET STAKE

Square stake: A square stake has a flat and square-shaped head with a long shank. It is used for general purposes. (Fig 5)

Fig 5

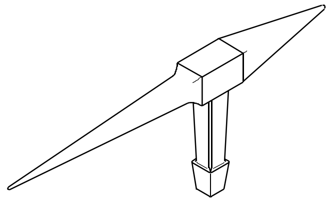


SQUARE STAKE

Blow-horn stake: It has a short tapered horn at one end, and a long tapered one at the other end. It is used in forming, riveting or seaming tapered, cone-shaped articles, such as funnels etc. (Fig 6)

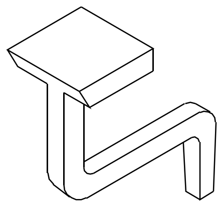
Bevel-edged square stake: A bevel-edged square stake is used to form corners and edges.(Fig 7)

Fig 6



BLOW HORN STAKE

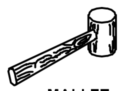
Fig 7



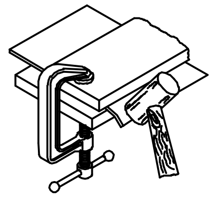
BEVEL-EDGED SQUARE STAKE

Mallet: A mallet is used for working on sheet metal. It will not damage the sheet surface while working. Mallets are made of wood, rubber, copper etc.(Fig 8)

Fig 8



MALLET

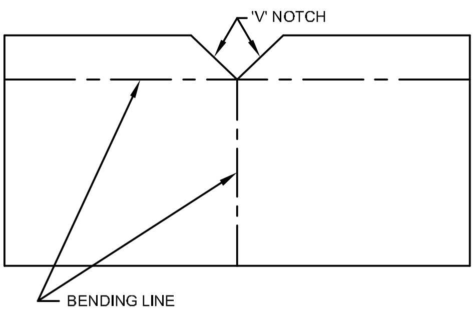


USE OF MALLET

Notches

Notches: Notches are the spaces provided for joining the edges when sheet metals are cut from the layout. (Fig 1)

Fig 1

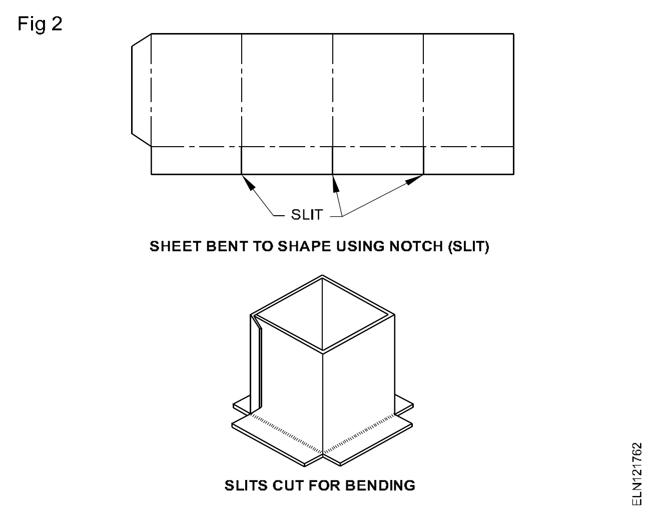


NOTCH

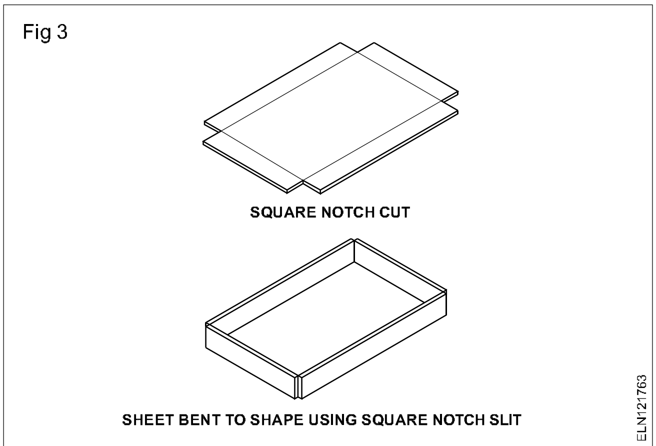
Purpose of notches

- To prevent excess material from overlapping and causing a bulge at the seam and edges.
- To allow the work to be formed to the required size and shape.

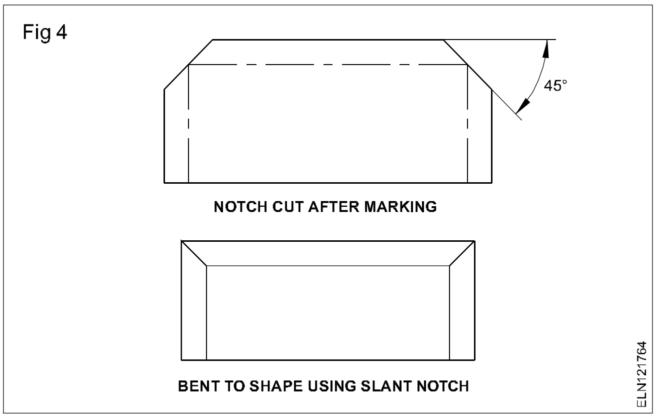
Types of notches: A straight notch or slit is a straight cut made in the edge of the sheet where it is to be bent. (Fig 2)



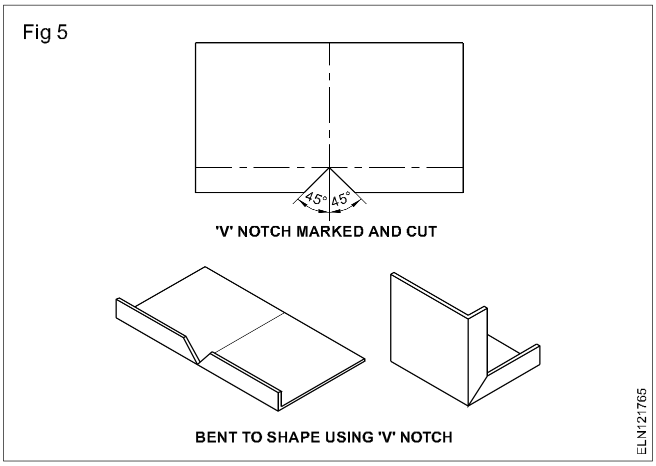
A square notch is used when forming a square or rectangular box. (Fig 3)



A slant notch is cut at an angle of 45° to the corner of the sheet. It is used when a single hem meets at right angles.(Fig 4)

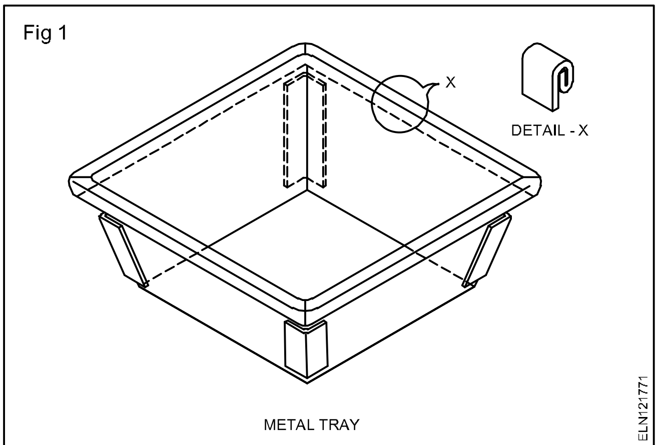


In a `V' notch both the sides are cut at a 45°angle to the edge of the sheet. The sides of the notch meet at 90°. This notch is used when making a job with a 90° bend and an inside flange.(Fig 5)



Edge stiffening

The edges of light gauge sheet metal articles are very sharp and are unsafe to handle. Safe edges are used to strengthen the sheet metal and to enhance the appearance of the finished article like metal tray. (Fig 1)



What is hem?: A hem is an edge or border made by folding.

It stiffens the sheet of the metal and does away with sharp edges.

It prevents the sheet from damage and wear of the edge.

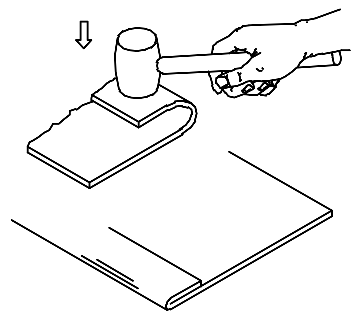
Types of hems: There are three types of hems.

- Single hem
- Double hem
- Wired edge.

Single hem (Fig 2)**:** The single hem is made by folding the edges of the sheet metal with a single folding.

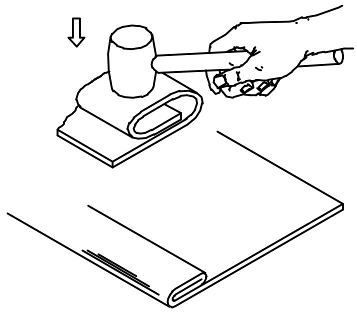
It makes the edge smooth and stiff and is done in the case of small articles.

Fig 2



SINGLE HEM

Fig 3



DOUBLE HEM

Double hem (Fig 3)**:** A double hem is made by folding the edges over twice to make it smooth, and this is done normally to strengthen the edges of lengthy articles.

Pattern development

Objectives: At the end of this lesson you shall able to
- **state about pattern development**
- **state the different types of pattern development.**

Before starting on any project in sheet metal, a pattern should be developed for the accuracy of the finished articles.

The pattern is nothing but a flat outline of the job. Most of the patterns are obtained from development of surfaces of some common geometrical solids such as cylinder, cone, prism, pyramid etc.

The pattern or outline of an object may be drawn on paper. Then it can be transfered to the sheet metal or it can be directly developed on the sheet and cut from the metal.

Generally there are three methods of development of patterns.

- Parallel line development
- Radial line development
- Triangulation

Methods of pattern development

There are three methods in general use.

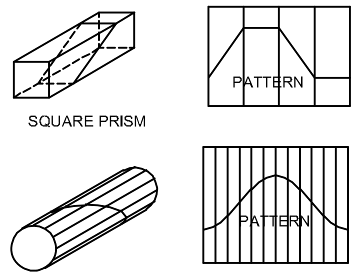
The class of geometrical form of the object to be made must be taken into account when deciding on which method is to be used.

Parallel line method (Fig 1)**:** This method is used to develop patterns for shapes like boxes, prisms and cylinders.

Radial line method (Fig 2)**:** Objects like pyramids and cones can be developed using this method. These include all shapes which form parts of pyramids or cones.

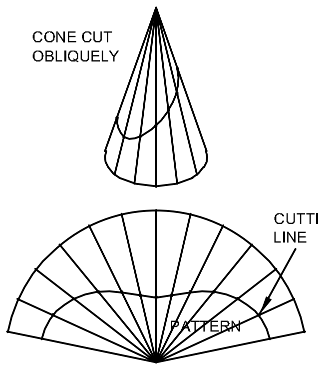
All lines radiate from the apex.

Fig 1



PARALLEL LINE METHOD

Fig 2

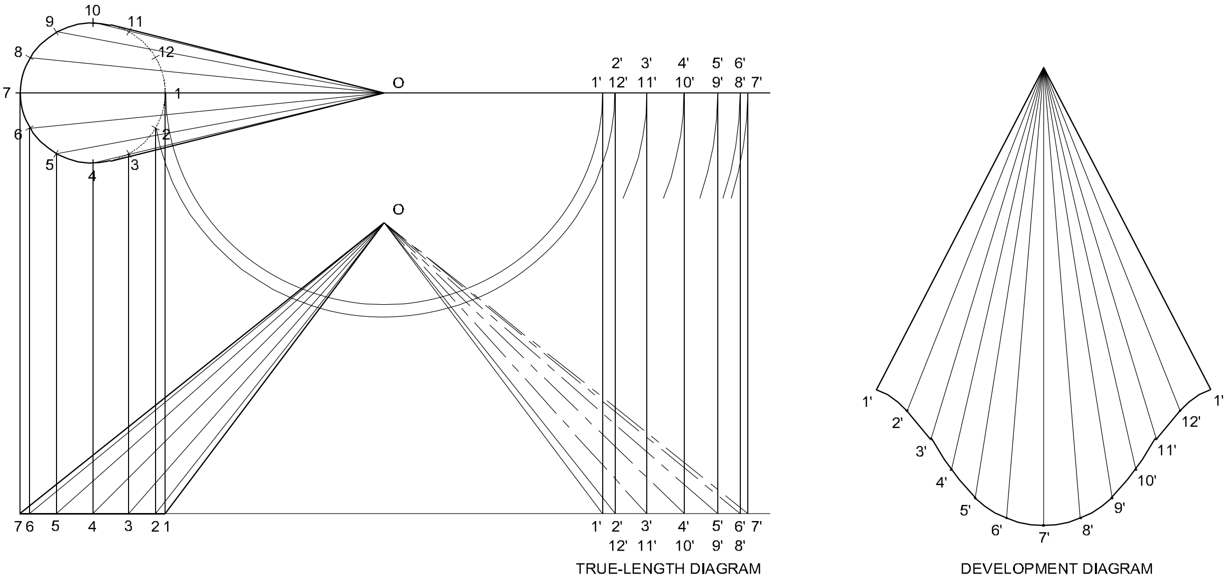


RADIAL LINE METHOD

Triangulation (Fig 3)**:** This method is used to develop patterns for shapes having no apex and in which not all sides are parallel, i.e. Class 3.

While both the radial and parallel line methods cannot be applied to shapes shown in Fig 3, the method of triangulation can be used in the development of patterns for shapes depicted in Fig 1 and Fig 2.

Fig 3



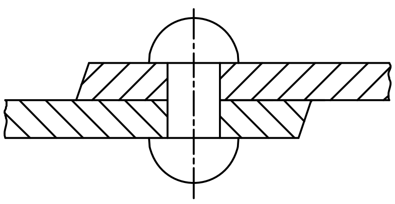
DEVELOPMENT OF AN OBLIQUE CONE BY TRIANGULATION

Rivets

Objectives : At the end of this lesson you shall be able to
- **define riveting and state their uses**
- **list out the different types of rivets and which materials the rivets are made.**

Riveting: Riveting is one of the satisfactory methods of making permanent joints of two pieces - metal snips. (Fig 1)

Fig 1



RIVET

It is customary to use rivets of the same metal as that of the parts that are being joined.

Uses: Rivets are used for joining metal sheets and plates in fabrication work, such as bridges, ships, cranes, structural steel work, boilers, aircraft and in various other works.

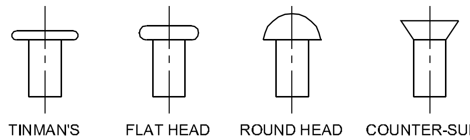
Material: In riveting, the rivets are secured by deforming the shank to form the head. These are made of ductile materials like low carbon steel, brass, copper and aluminium.

Types of rivets (Fig 2)

The four most common types of rivets are:

- tinmen's rivet
- flat head rivet
- round head rivet
- countersunk head rivet.

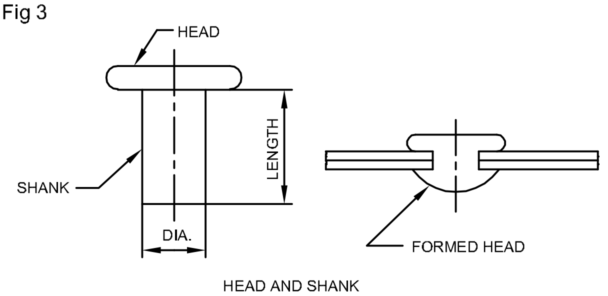
Fig 2



TYPES OF RIVETS

Each rivet consists of a head and a cylindrical body called as shank. (Fig 3)

Fig 3



HEAD AND SHANK

Sizes of rivets: Sizes of rivets are determined by the diameter and length of the shank.

Selection of rivet size: The diameter of the rivet is calculated by using the formula

$$D = \left(2\frac{1}{2} \text{ to } 3\right) \text{x } T$$ where T is total thickness.

The shank length is given by

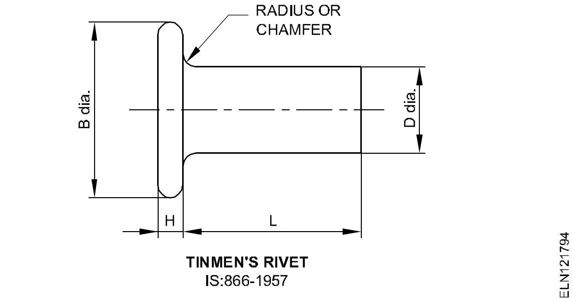
$$L = 2T + \left(1\frac{1}{2}D\right)$$

where `T' is the sheet thickness and `D' is the diameter of the rivet.

Normally tinmen's rivets are designated by numbers.

The dimension of the tinmen's rivets is given below. (Fig 4)

Fig 4



Method of riveting: Riveting may be done by hand or by machine.

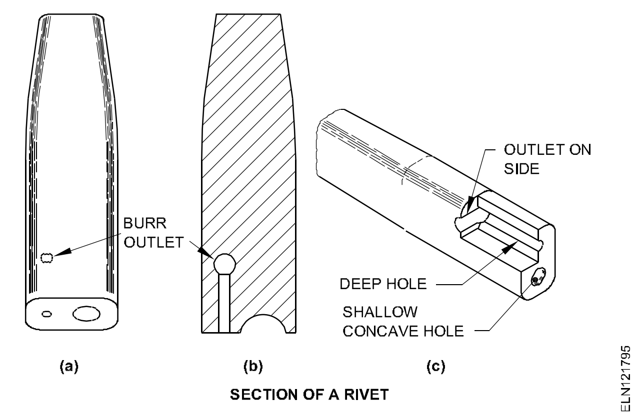
While riveting by hand, it can be done with a hammer and a rivet set.

Rivet set: A cross-section of a rivet set is shown in the figure 5a, b and c. The shallow, cup-shaped hole is used to draw the sheet and the rivet together. The outlet on the side allows the slug to drop out.

The cup shape is used for forming the rivet head.

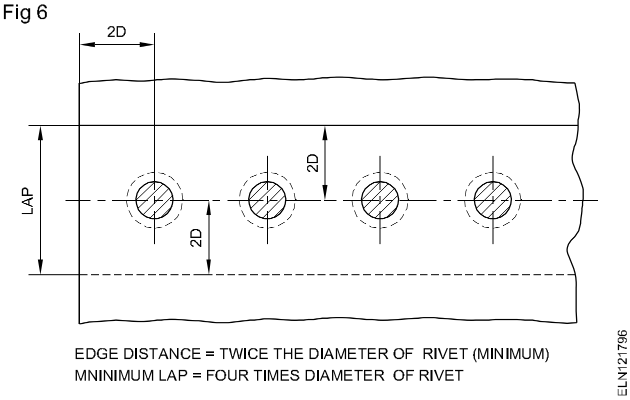
The rivet set selected should have a hole slightly larger than the diameter of the rivet.

Fig 5



Spacing of rivets: The space or distance from the edge of the metal to the centre of any rivet should be atleast twice the diameter of the rivet to avoid tearing. The `Lap' distance (4D) is shown in Fig 6.

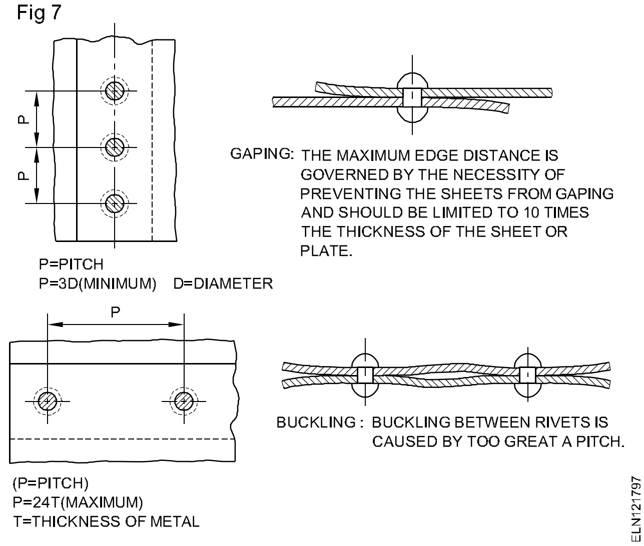
Fig 6



The minimum distance between the rivets (pitch) should be sufficient to allow the rivets to be driven without interference. The distance should be atleast three times the thickness of the sheet or above.

The maximum distance should never exceed 24 times the thickness of the sheet. Otherwise buckling will take place as shown in Fig 7.

Fig 7



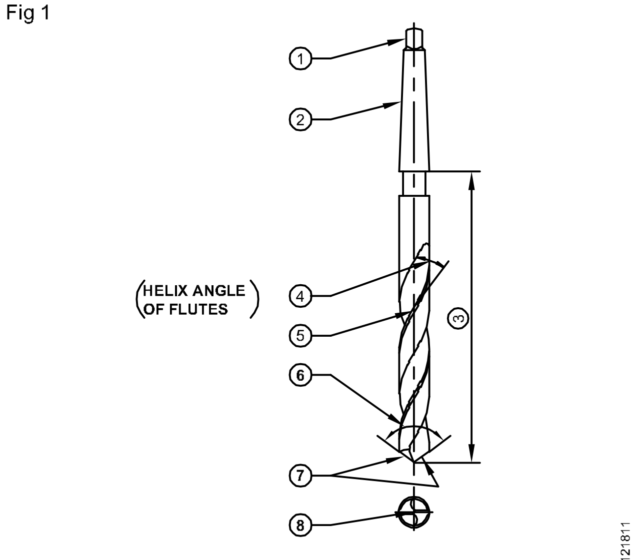
Drills and drilling machines - Internal and external threads

Objectives : At the end of this lesson you shall be able to
- **state the functions of drills**
- **name the parts of a drill**
- **name the drill bit holders**
- **state the uses of countersunking bits**

Drill: Drilling is a process of making holes on workpieces by using a drill.

Parts of a drill (Fig 1)

Fig 1



DRILL

- Tang (1)
- Shank (2)
- Body (3)
- Flute (4)
- Land (5)
- Point angle (6)
- Cutting lip (7)
- Chisel edge (8)

Tang: Tang is the part that fits into the slot of the drilling machine spindle.

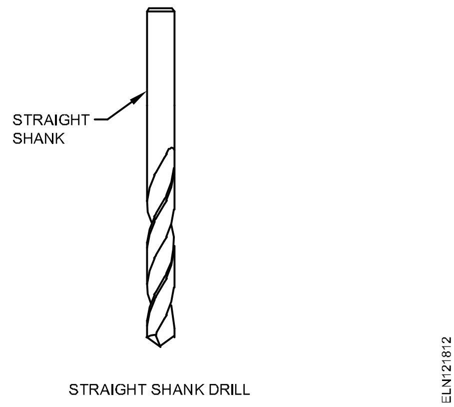
Shank: This is the driving end of the drill which is fitted on the machine. Shanks are of two types.

- Taper shank: for larger diameter drills.
- Straight shank: for smaller diameter drills.

The shank may be parallel or tapered.(Figs 2 and 3) Drills with parallel or straight shanks are made in small sizes, up to 12mm (1/2 in) diameter and the shank has the same diameter as the flutes.

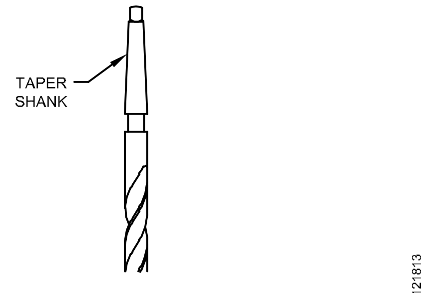
Taper shank drills are made in sizes from 3mm (1/8 in) diameter up to 50mm (2 in) diameter.

Fig 2



STRAIGHT SHANK DRILL

Fig 3



TAPER SHANK DRILL

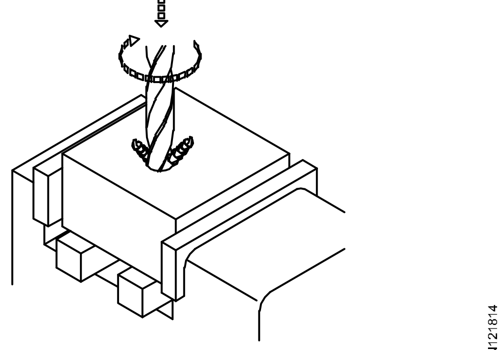
Body: The body is the portion between the point and shank.

Flutes: Flutes are the spiral grooves which run to the length of the drill.

The flutes help:

- to form the cutting edges
- to curl the chips and allow them to come out (Fig 4)
- the coolant to flow to the cutting edge.

Fig 4



DRILLING BY DRILL BIT

Land/margin: Land/margin is the narrow strip which extends to the entire length of the flutes. The diameter of the drill is measured across the land/margin.

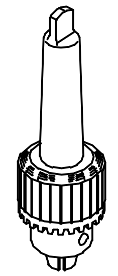
Body clearance: Body clearance is the part of the body which is reduced in diameter to cut down the friction between the drill and the hole being drilled.

Web: Web is the metal column which separates the flutes. It gradually increases in thickness towards the shank.

Drill bit holder

Drill chuck: Drill chuck is attached to the main spindle for straight shank basis. (Fig 5)

Fig 5



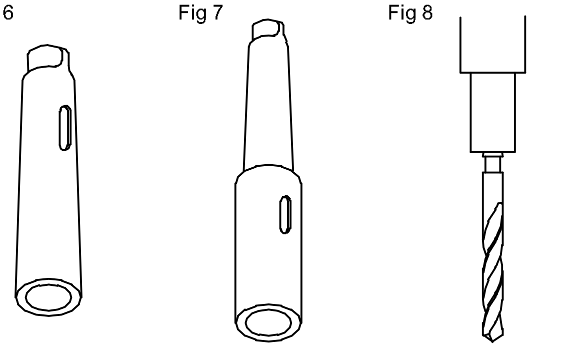
DRILL CHUCK

Sleeve: This is used to match bit tapers and the spindle taper holes. (Fig 6)

Socket: This is used when the main spindle length is too short, and the bit is changed frequently. (Fig 7)

Taper shank drills are held in taper sockets in the machine.(Fig 8)

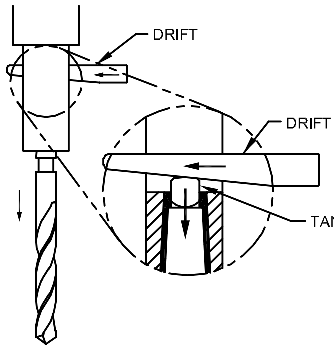
Fig 6 Fig 7 Fig 8



PARTS OF DRILL HOLDERS

The tang on a taper shank drill enables easy removal of the drill from the socket at the end of the drilling work. This is done using a drift. (Fig 9) The tang also serves to prevent the drill from rotating in the socket.

Fig 9



TANG ON A TAPER SHANK

Use of a coolant: A coolant is used to cool the cutting tool and the job.

Drilling machines

Objectives: At the end of this lesson you shall be able to
- **state the types of hand drilling machines and their uses**
- **state the parts of bench and pillar drilling machine**
- **explain the features of machine vice**

Making holes in sheet metal by using solid punches is a slow and inefficient process.

It is necessary to drill holes when working with heavy material.

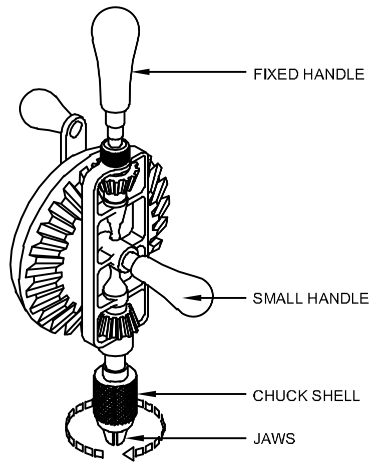
The holes can be drilled by hand or by machine. When drilling by hand, a hand drilling machine (Fig 1) or the electric hand drilling machine (Fig 2) is used.

Twist drills are used as a cutting tool for drilling holes. The hand drill is used for drilling holes up to 6.5 mm diameter.

The portable electric hand drilling machine is a very popular and useful power tool. It comes in different sizes and capacities.

The handle shown in Fig 2 is called a pistol grip handle.

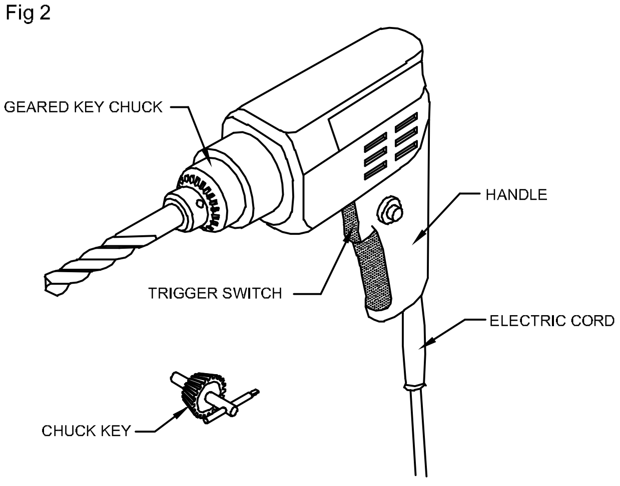
Fig 1



HAND DRILLING MACHINE

The parts of an electric hand machine are shown in Fig 2.

Fig 2



ELECTRIC - HAND DRILLING MACHINE

Precautions to be observed : Make sure the holes are properly located and punched with a centre punch.

Check the drill size. If the markings on the drill are not clear, use a drill gauge.

Be sure the drill is properly centred in the chuck by turning (rotating).

Be sure the work is mounted properly in a holding device such as a vice or `G' clamp.

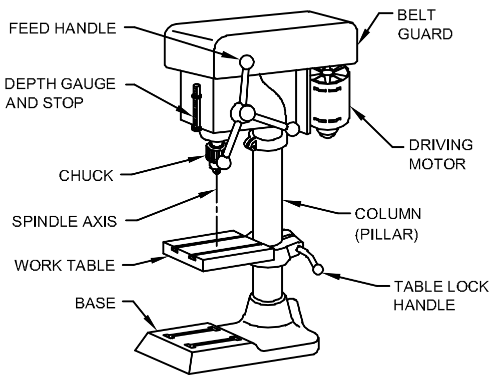
Check the centering of the drill after the point has just started in the metal. Relocate the hole with a centre punch, if necessary. Feed the drill with a light, even pressure.

Types of Electric Drilling Machines: Some of the electric drilling machines are listed here.

- The sensitive bench dilling mchine
- The pillar drilling machine
- The radial arm drilling machine. (Radial drilling machine)

(As you are not likely to use the column and radial type of drilling machines now, only the sensitive and pillar type machines are explained here.)

Fig 3



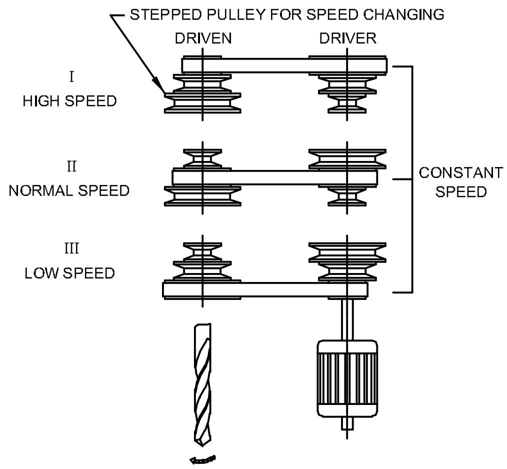
BENCH DRILLING MACHINE

Sensitive bench driling machine: The simplest type of sensitive bench drilling machine is shown in the (figure 3) with its various parts marked. This machine is used for light duty work. (Fig 3)

This machine is capable of drilling holes up to 12.5mm diameter. The drills are fitted in the chuck or directly in the tapered hole of the machine spindle.

Different spindle speeds are achieved by changing the belt position in the stepped pulley (Fig 4).

Fig 4

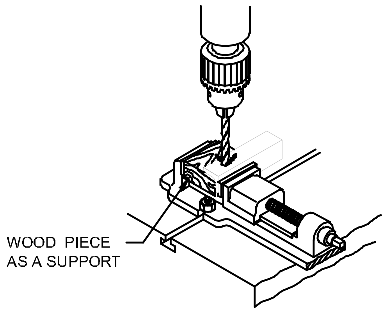


BELT ARRANGEMENT IN BENCH DRILLING MACHINE

For normal drilling, the work surface is kept horizontal. If the holes are to be drilled at an angle, the table can be tilted.

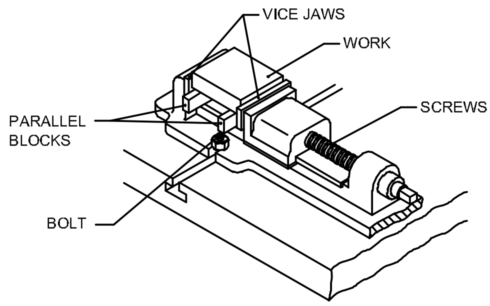
The pillar drilling machine: This is an enlarged version of the sensitive bench drilling machine. These drilling machines are mounted on the floor and are driven by more powerful electric motors. They are used for heavy duty work. Pillar drilling machines are available in different

Fig 5



WORKPIECE SUPPORT WITH WOODENPIECE

Fig 6



PARTS OF MACHINE VICE

sizes. Large machines are provided with a rack and pinion mechanism for moving the table for setting the work.

The machine vice: Most of the drilling works can be held in a vice. Ensure that the drill does not drill through the vice after it has passed through the work. For this purpose, the work can be lifted up and secured on parallel blocks, providing a gap between the work and the bottom of the vice. (Fig 6) Workpieces which are not accurate may be supported by wooden pieces. (Fig 5)

Parallels: The workpiece can be set on parallels to raise it off the reference surface, and still maintain parallelism. Parallels are made in pairs to precisely the same dimensions, from hardened steel, finish-ground, with the opposite faces parallel and adjacent faces square. A variety of sizes is available.

Cutting speed and RPM (Revolutions Per Minute)

Objectives : At the end of this lesson you shall be able to
- **define cutting speed and rpm**
- **state the factors for determining cutting speed**
- **determine rpm/spindle speed**

Cutting speed and r.p.m.: For a drill to give satisfactory performance, it must operate at the correct cutting speed and feed.

Cutting speed is the speed at which the cutting edge passes over the material while cutting, and is expressed in metres per minute.

Cutting speed is also sometimes stated as surface speed or peripheral speed.

Selection of the correct cutting speed for drilling depends on the materials to be drilled and the tool material. The recommended cutting speeds for different materials are given in the table. Based on the cutting speed recommended, the r.p.m. at which a drill has to be driven is determined.

Materials being drilled	Cutting speed m/min.
Aluminium	70 - 100
Brass	35 - 50
Bronze	20 - 35
Cast iron (grey)	25 - 40
Copper	35 - 45
Steel (mild)	30 - 40
Steel (medium carbon)	20 - 30
Steel (alloy-high tensile)	5 - 8
Thermo-setting plastic (Low speed due to abrasive properties.)	20 - 30

RPM

The r.p.m. will differ according to the diameter of the drills. The cutting speed being the same, larger diameter drills will have lesser r.p.m., and smaller diameter drills will have a higher r.p.m.

Calculating r.p.m.

$$CS = \frac{N\pi d}{1000}$$

$$N = \frac{1000 \times CS}{\pi d}$$

N = r.p.m.

CS = Cutting speed m / min

d = dia of drill in mm; $\pi = 3.14$

Example

Calculate the spindle speed (r.p.m.) for a high speed steel drill of 24mm dia. to cut mild steel.

$$N = \frac{1000 \times 30}{3.14 \times 24} = 398 \text{ r.p.m.}$$

The spindle speed is 400 r.p.m.

Feed of drill = Penetration of drill in a job per revolution of drill.

Angle of chisels

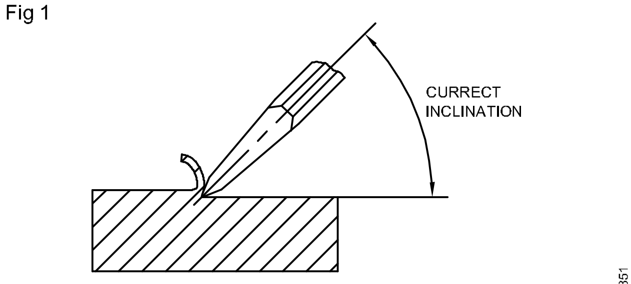
Objectives : At the end of this lesson you shall be able to
- **state the point angles of chisels for different materials**
- **state the different cutting angles of a chisel**
- **state the effect of rake and clearance angles.**

Point angles and materials

The coreect point/ cutting angles (b) of the chisel depends on the materials to be chipped. sharp angles are given for soft materials and wide angles for hard materials.

The correct point angle and angle of inclination generate the correct rake and clearance angles. (Fig 1)

Fig 1



CUTTING ANGLE OF INCLINATION

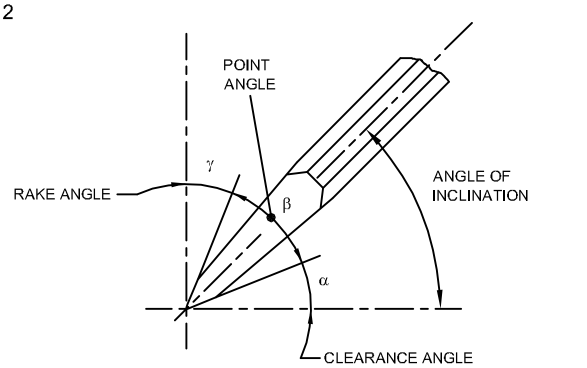
Rake angle

Rake angle (g) is the angle between the top face of the cutting point and normal to the work surface at the cutting edge. (Fig 2)

Clearance angle

Clearance angle (a) is the angle between the bottom face of the point and tangent to the work surface originating at the cutting edge. (Fig 2).

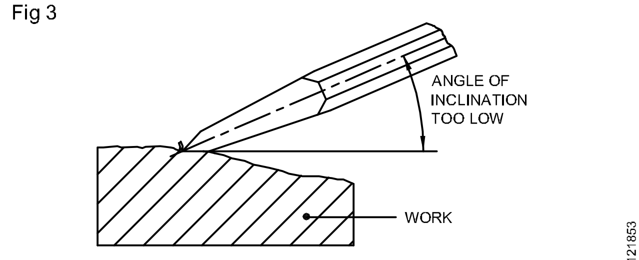
Fig 2



RAKE AND CLEARANCE ANGLE

If the clearance angle is too low or zero, the rake angle increases. the cutting edge cannot penetrate into the work. the chisel will slip. (Fig 3)

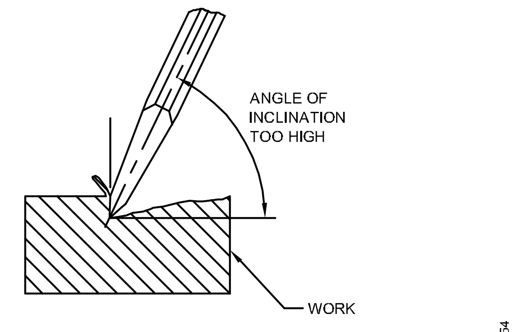
Fig 3



CLEARANCE ANGLE TOO LOW

If the clearance angle is too great, the rake angle reduces. The cutting edge digs in and the cut progressively increases. (Fig 4)

Fig 4



CLEARANCE ANGLE TOO HIGH

Table

Material to be cut	Point angle	Angle of inclination
High carbon Steel	65°	39.5°
Cast iron	60°	37°
Midld steel	55°	34.5°
Brass	50°	32°
Copper	45°	29.5°
Aluminium	30°	22°

Vee threads - Tap and die set

Objectives : At the end of this lesson you shall be able to
- **state the types of threads**
- **describe the designation of ISO threads.**
- **state pipe thread, parallel female thread and tappered thread**

Types of vee threads

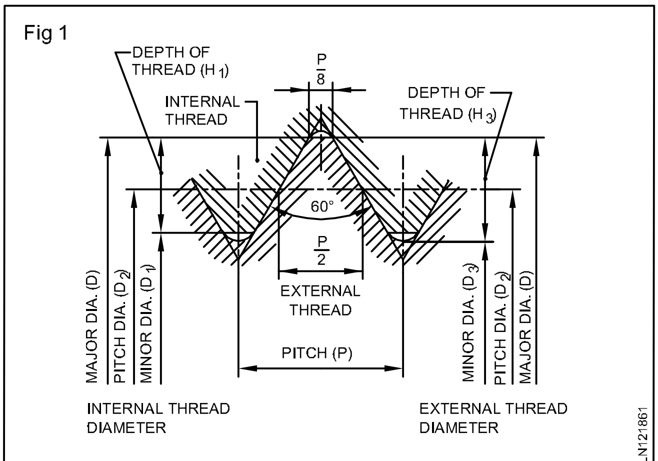
Vee threads are available in different forms and standards. The different types of vee threads used for general engineering threaded fasteners are:

- ISO metric thread
- British Standard Whitworth thread
- British Standard fine thread.

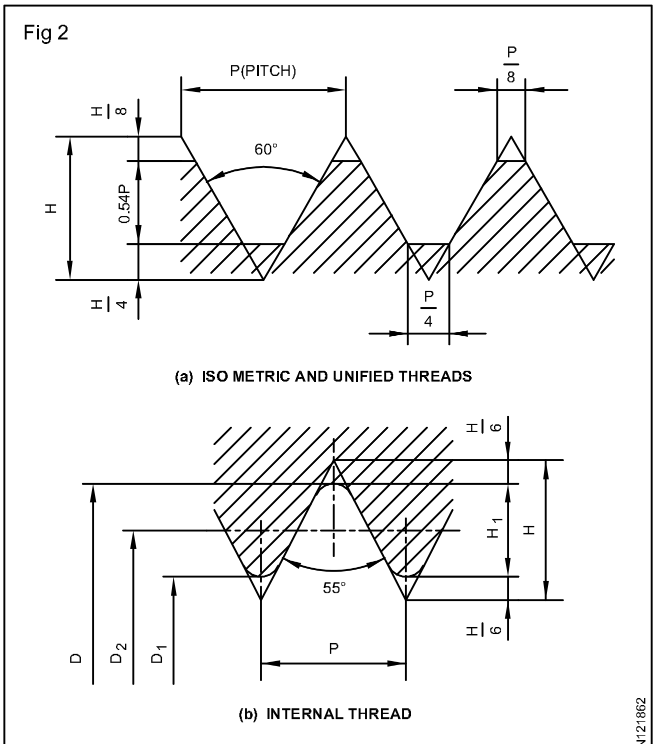
ISO metric thread (Fig 1)**:** This is the form of thread indicated by B.I.S. for threaded fastening. The standard identifies two series of threads.

- ISO Metric coarse
- ISO Metric fine

The thread angle is 60°. The root of the external thread is rounded. The crest of the external thread is flat, but sometimes is rounded depending on the type of manufac-



ISO METRIC THREAD



BSW THREADS

turing process. The root of the internal thread is cleared beyond the width equal to one eighth of the pitch, and is rounded. The crests of the internal threads are left flat.

Designation of ISO metric thread: ISO metric course threads are designated as, for example - M12.

The symbol M indicates that it is ISO metric thread and 12 is the diameter of the thread. For coarse series the pitch of the threads is standardized for each diameter.

ISO metric fine threads are designated as, for example - M12 x 1.25.

The addition of 1.25 in this case indicates the pitch of the thread.

ISO inch (unified) thread: The ISO inch system (unified) is a recognized standard for interchangeability with the American National Thread.

These threads are used for general purpose engineering threaded fastening and are of two types, namely

- unified coarse (UNC)
- unified fine (UNF).

For unified threads the angle is 60°. The thread profile is similar to that of the ISO matric thread.

Designation of ISO inch (unified) threads

Examples

(a) $\frac{1}{4}$ 20 UNC

(b) $\frac{1}{4}$ 28 UNF

Example

This indicates that the diameter of the thread is 1/4", that it has 20 threads per inch (TPI). The ISO thread series is UNC (unified coarse). Example (b) has 28 TPI and is of UNF series.

British Standard Whitworth (BSW) thread (Fig 2)**:** This thread is being replaced by ISO metric thread. However the application of this thread is still being continued in a limited manner, particularly in the production of spare parts and repair works.

These threads have 55° angle and are rounded at the crest and root. There are a definite number of threads per inch for a particular diameter.

The threads are designated by the diameter in inches followed by the abbreviation of the thread series.

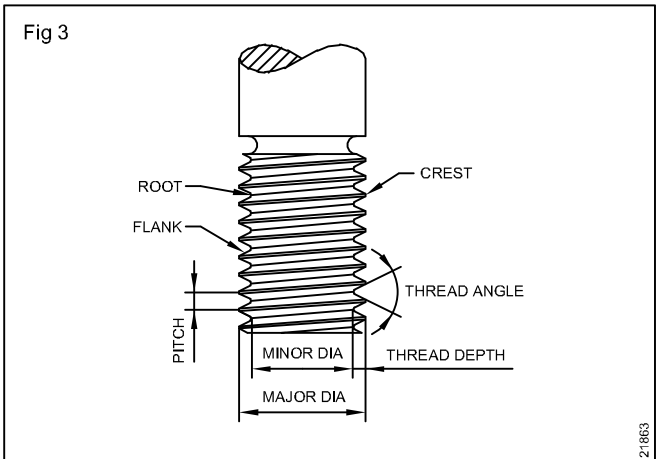
Example - 1/2" BSW

British Standard fine (BSF) thread: This thread has the same form as BSW, but with finer pitches.

The threads are designated by the diameter in inches followed by the thread series.

Example - 3/8" BSF

Screw thread - terms: It is important that the terms used in describing threads are clearly understood. The following diagram shows how the terms used relate to a screw of V form (Fig 3).



SCREW THREAD

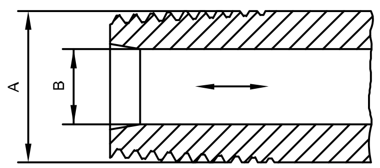
Pipe threads

Pipe threads on iron pipe are tapered, so that they form a water-tight joint when tightened securely. (Fig 1)

BSP-Whitworth threads for pipes

BSP-Pipe sizes of DIN 2999 (inside)(B)	Threads/ inch	Outside diameter/ mm of the pipe (A)
1/2"	14	20.955mm
3/4"	14	26.441
1"	11	33.249
1 1/4"	11	41.910
1 1/2"	11	47.803
2"	11	59.614
2 1/2"	11	75.184
3"	11	87.884
4"	11	113.030

Fig 1



IRON PIPE THREAD

*(BSP - and DIN - pipes meet ISO/P7 standards.)

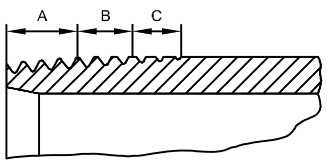
BSP - British Standard Pipe

DIN - German Industrial Norm

ISO - International Organization for Standardization

The illustration shows a galvanized steel pipe with several full form threads on the end (A) the next two threads have full form bottoms but flat tops (B) and the last four threads have flat tops and bottoms (C).(Fig 2)

Fig 2



TAPPERED IRON PIPE THREAD

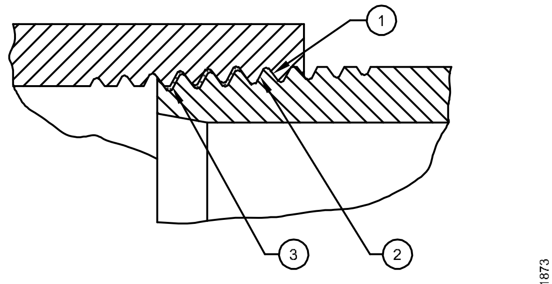
The actual work of assembling galvanized steel pipe consists of screwing together lengths of pipes with pipe fittings. Sealing material must then be applied to fill the space between the male and female threads in order to make the joint absolutely water-tight. The Fig 3 shows a galvanized steel pipe joint.

– Parallel female thread (1)

– Tapered male thread (2)

– Hemp (3)

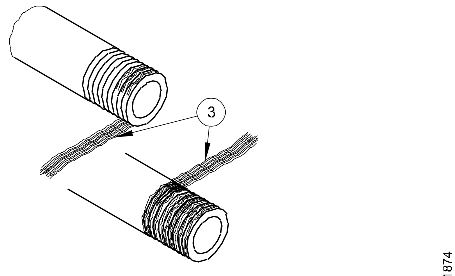
Fig 3



GALVANIZED STEEL PIPE JOINT

Hemp packing is used to ensure that any small space between two metal threads (male and female threads) is filled up.(Fig 4)

Fig 4



HEMP PACKING

Hand taps and wrenches

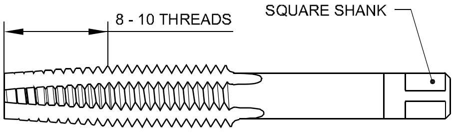
Objectives: At the end of this lesson you shall able to
- **list the uses of hand taps**
- **state the different types of tap wrenches, and state their uses.**
- **distinguish right and left hand thread**
- **solve the problems related tap drill sizes**

Taps: A tap cuts an internal (female) thread either left or right hand. Taps are usually made in sets of three.

- First tap or taper tap
- Second tap or intermediate tap
- Plug or bottoming tap.

The taper tap is tapered off for 8 to 10 threads and is used first, cutting to the full thread gradually. (Fig 1)

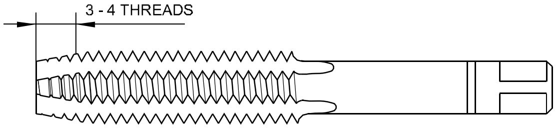
Fig 1



TAPER TAP (OR) 1ST TAP

The intermediate tap usually has three or four threads chamfered. This second tap can finish a through hole. (Fig 2)

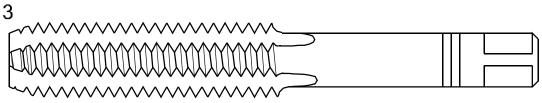
Fig 2



INTERMEDIATE TAP (OR) 2ND TAP

The plug tap has a full-sized untapered thread to the end, and is the main finishing tap. In the case of a blind hole, a plug tap must be used. (Fig 3)

Fig 3



PLUG TAP (OR) BOTTOMING TAP

Beware of the cutting edges of taps when handling them.

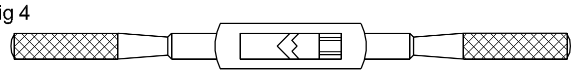
Tap wrenches: Tap wrenches are used to align and drive the hand taps correctly into the hole to be threaded.

Tap wrenches are of different types.

- Double - ended adjustable wrench
- T-handle tap wrench
- Solid type tap wrench

Double-ended adjustable tap wrench (Bar type tap wrench) (Fig 4)

Fig 4



DOUBLE ENDED ADJUSTABLE TAP WRENCH

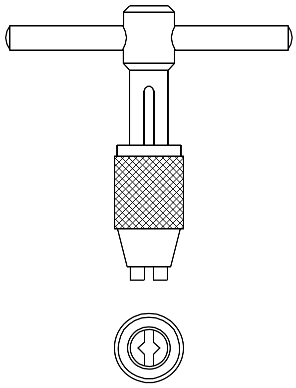
This is the most commonly used type of tap wrench. These tap wrenches are available in various sizes. They are more suitable for large diameter taps, and can be used in open places where there is no obstruction to turn the tap. It is important to select the correct size of the wrench.

T-handle tap wrench (Fig 5)**:** These are small adjustable chucks with two jaws and a handle to turn the wrench.

This tap is useful for working in resctricted places and is turned with one hand only.

This wrench is not available for holding large diameter taps.

Fig 5



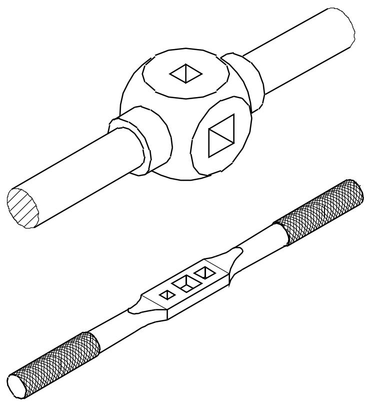
T - HANDLE TAP WRENCH

Soild type tap wrench (Figs 6a and 6b)**:** These wrenches are not adjustable.

They can take only a certain size of a tap. This eliminates the use of a wrong length of tap wrenches, and thus prevents damage to the taps.

Fig 6a

Fig 6b



SOLID TAP WRENCH

Tap drill size

Before a tap is used for cutting internal threads, a hole is to be drilled. This hole diameter should be such that is should have sufficient material in the hole for the tap to cut the thread.

Tap drill sizes for different threads

Tapping drill size for M10 x 1.5 thread

Minor diameter	=	Major diameter – (2 x depth)
Depth of thread	=	0.6134 x pitch of a screw
2 depth of thread	=	0.6134 x 2 x pitch
	=	1.226 x 1.5 mm = 1.839 mm
Minor dia.(D1)	=	10 mm – 1.839 mm
	=	8.161 mm or 8.2 mm.

This tap drill will produce 100% thread because this is equal to the minor diameter of the drill. For most fastening purposes a 100% formed thread is not required.

A standard nut with 60% thread is strong enough to be tightened until the bolt is held firm without stripping the thread. Further it also requires greater force of turning the tap if a higher percentage formation of thread is required.

Considering this aspect a more practical approach for determining the tap drill sizes is

tap drill size = (major diameter) – pitch

= 10 mm – 1.5 mm = 8.5 mm.

Compare this with the table of tap drill sizes for ISO metric threads.

ISO inch (Unified) threads formula

Tap drill size

$$= \textbf{(Major diameter)} - \frac{1}{\text{No. of teeth per inch (pitch)}}$$

For calculating the tap drill size for $\frac{5"}{8}$ UNC thread

$$\text{Tap drill size} = \frac{5"}{8} - \frac{1"}{11}$$

$$= 0.625" - 0.091"$$

$$= 0.534"$$

The next drill size is $\frac{17"}{32}$ (0.531 inches).

Compare this with the table of drill sizes for unified inch threads.

What will be the tapping size for following threads?

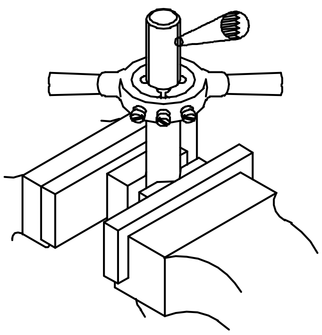
a M 20 b UNC $\frac{3}{8}$

Die and die stock

Objectives: At the end of this lesson you shall be able to
- **state the use of each type of die**
- **state the type of diestock for each type of die.**
- **list the different types of dies**
- **state the uses of 'Vee' blocks**

Uses of dies: Threading dies are used to cut external threads on cylindrical workpieces. (Fig 1)

Fig 1



EXTERNAL THREADING

Types of dies: The following are the different types of dies.

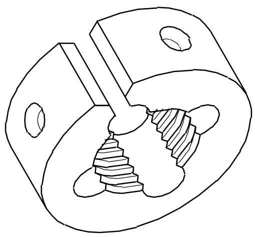
Circular split die (Button die)

Half die

Adjustable screw plate die

Circular split die\ button die (Fig 2)**:** This has a slot cut to permit slight variation in size.

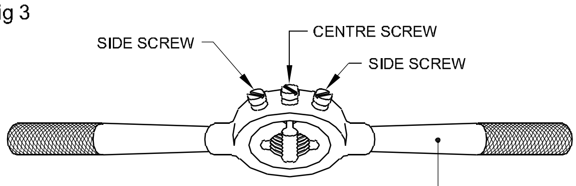
Fig 2



CIRCULAR SPLIT DIE / BUTTON DIE

When held in the diestock, variation in the size can be made by using the adjusting screws. This permits increasing or decreasing of the depth of cut. When the side screws are tightened the die will close slightly. (Fig 3) For adjusting the depth of the cut, the centre screw is advanced and locked in the groove. This type of die stock is called button pattern stock.

Fig 3



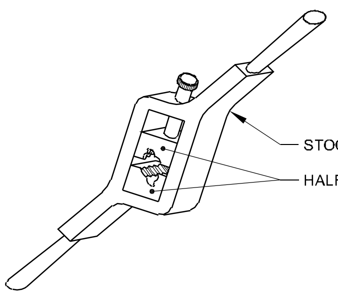
DIE STOCK & DIE FOR BUTTON DIE

Half die (Fig 4)**:** Half dies are stronger in construction.

Adjustments can be made easily to increase or decrease the depth of cut.

These dies are available in matching pairs and should be used together.

Fig 4



HALF DIE WITH STOCK

By adjusting the screw of the diestock, the die pieces can be brought closer together or can be moved apart.

They need a special die holder.

Adjustable screw plate die (Fig 5)**:** This is another type of a two piece die similar to the half die.

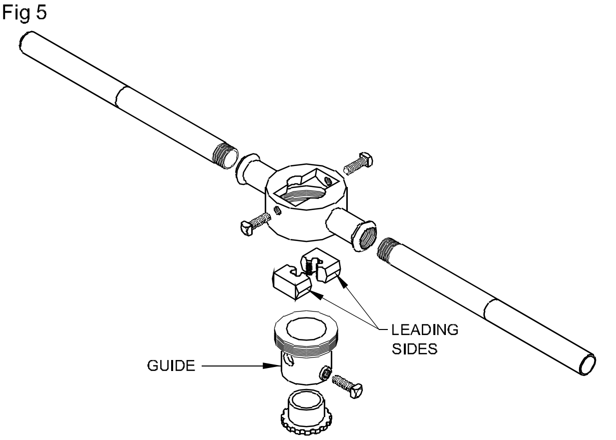
This provides greater adjustment than the split die.

The two die halves are held securely in a collar by means of a threaded plate (guide plate) which also acts as a guide while threading (Fig 5)

When the guide plate is tightened after placing the die pieces in the collar, the die pieces are correctly located and rigidly held.

The die pieces can be adjusted, using the adjusting screws on the collar.

Fig 5



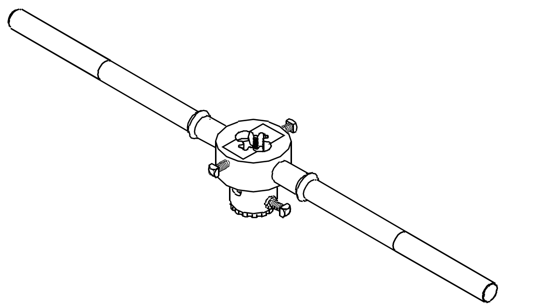
QUICK CUT STOCK

This type of die stock is called quick cut diestock.(Fig 6)

The bottom of the die halves is tapered to provide the lead for starting the thread. On one side of each die head, the serial number is stamped.

Both pieces should have the same serial numbers.

Fig 6



ASSEMBLED VIEW OF QUICK CUT DIESTOCK

Different types of threads (Fig 7)

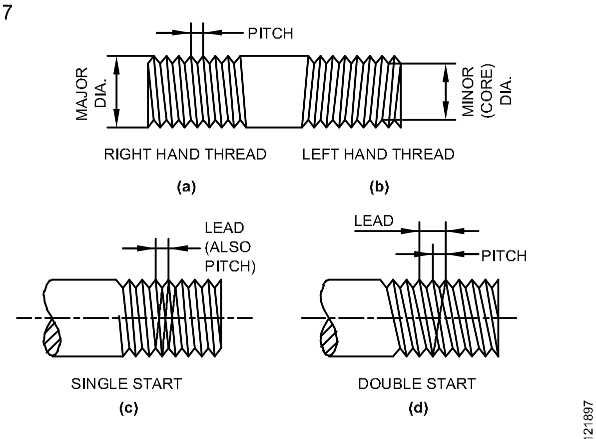
Right hand thread: The shape of thread from right to left (a).

Left hand thread: The shape of thread from left to right (b).

Single start thread: The pitch and lead are equal or identical (c).

Double start thread: The lead is twice the pitch (d).

Fig 7

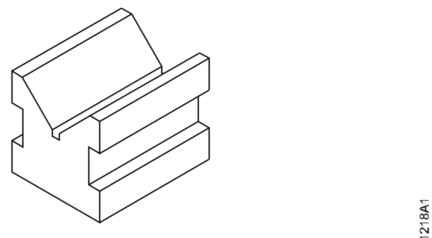


TYPES OF THREADS

`V' Block

Generally Vee blocks are made of cast iron and have a large vee on the top surface and a flat bottom or a smaller vee on the bottom surface.(Fig 1)

Fig 1

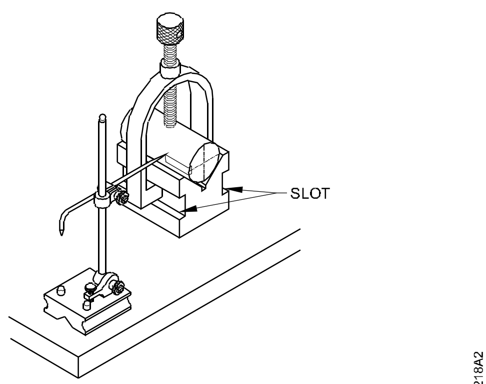


VEE BLOCK

Vee block with clamp for marking round bar (Fig 2)**:** This Vee block has a slot machined on each side so that a clamp, which is supplied with the block, can be used to clamp small workpieces for light drilling operations etc.

A pair of Vee blocks can be used when the length of bar is big for the drilling operation.

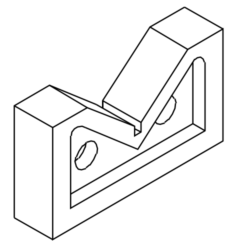
Fig 2



VEE BLOCK HOLDING A ROUND BAR FOR MARKING

Larger sizes are made of cast iron and have one vee only, machined on the top surface.(Fig 3) These are intended for supporting larger workpieces, and are not provided with slots for a clamp. Vee blocks of this type are available in different sizes.

Fig 3



LARGER SIZED VEE BLOCK

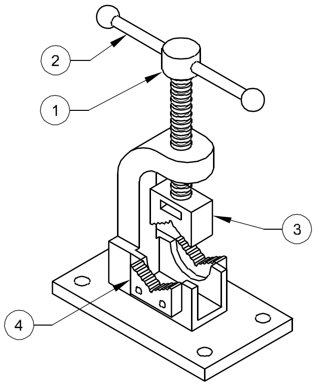
Pipe vices

Objectives: At the end of this lesson you shall be able to
- **name the parts of pipe vice**
- **state the types and uses of pipe vice**

Pipe vices are used to hold pipes, conduits for cutting in length, thread forming and assembly.

Open pipe vice (Fig 1)**:** This type of pipe vice is opened and closed by turning a spindle with a handle. The movable jaw is attached to the end of the spindle.

Fig 1



OPEN PIPE VICE

Parts

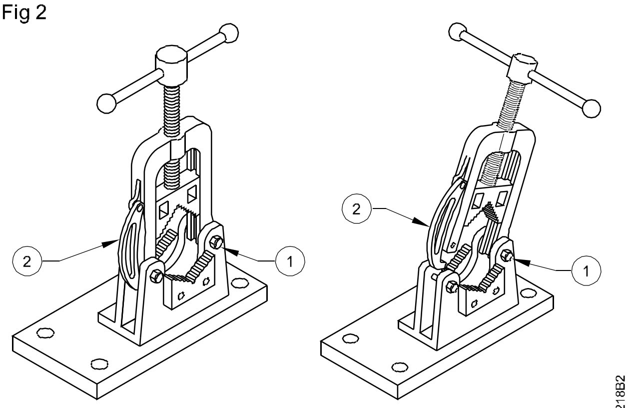
1. Spindle
2. Handle
3. Movable jaw
4. Fixed jaw

Several sizes of one side or open pipe vices are available. They are mainly specified by the maximum outside diameter of the pipe they can hold and by the maximum opening of the jaws. Three sizes are listed below as an example.

Maximum opening of jaws	Maximum outside diameter of pipe
60 mm	50 mm
90 mm	75 mm
120 mm	100 mm

Self-locking hinged pipe vice (Fig 2a)**:** To place the pipe between the jaws of a self locking hinged pipe vice, the hinged frame is opened as shown in Fig 2b. A self-locking hook locks the frame, and the pipe is then gripped between the jaws by turning the spindle of the vice.

Fig 2



a) SELF-LOCKING HINGED PIPE VICE   b) SELF-LOCKING HINGED VICE

- Hinge to open the frame of the vice. (Refer (a) of Fig 2)
- Self-locking hook. (Refer (b) of Fig 2)

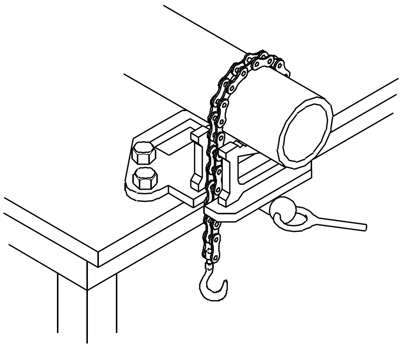
Self-locking, hinged pipe vices are available in a number of sizes to hold pipes and conduits up to an outside diameter of 150mm.

Chain pipe vice (Fig 3)**:** A chain pipe vice has only a set of fixed jaws which are mounted on to a table top or a metal stand. A strong chain made from high quality steel holds the pipe to the jaws. The chain is then tightened by turning the tightening lever of the vice.

Chain pipe vices can hold pipes to an outside diameter of 200mm.

Self-locking hinged pipe vice mounted on tripod stand (Fig 4)**:** This is a self-locking, hinged pipe vice, mounted on to a foldable metal tripod stand. This kind of arrangement is very practical as a mobile work-place for use at building sites, etc.

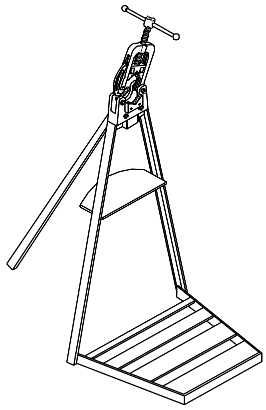
Fig 3



CHAIN PIPE VICE

ELN1218B3

Fig 4



PIPE VICE WITH THE TRIPOD STAND

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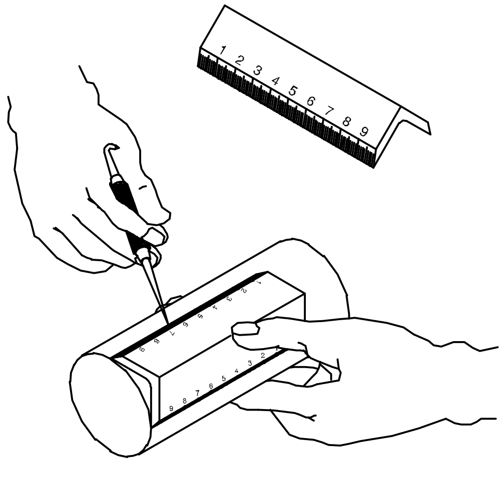
Marking accessories

Objectives : At the end of this lesson you shall be able to
- **state the uses of a box square**
- **state the uses of a surface plate**
- **state the uses of an angle plate.**

Box square (Fig 1): A box square, or key-seat rule, is used for marking lines on round bars or tubes.

Fig 1



BOX SQUARE

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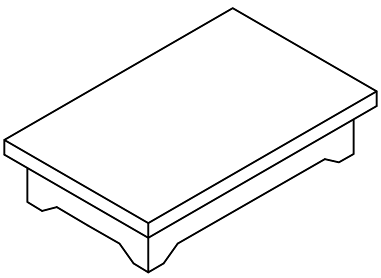
Surface plate (Fig 2)**:** This plate with a flat surface of great accuracy is used for testing the flatness of other surfaces together with other instruments for measuring, testing and marking out purposes.

Fig 2



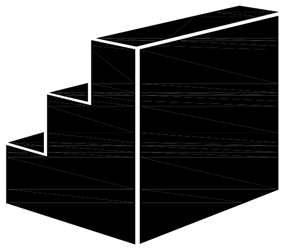
SURFACE PLATE

ELN1218C2

The surface plate is usually made of cast iron or granite.

Angle plate: It is made of cast iron. Granite angle plates are also available.(Fig 3)

Fig 3

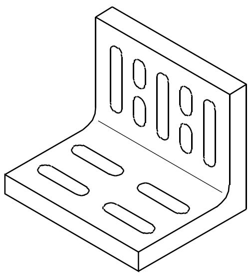


GRANITE ANGLE PLATE

ELN1218C3

It is used as a fixture for holding the work to be laid out and machined. Faces are right angles, may have slots and may be fitted with clamps for holding workpieces. (Figs 4 and 5)

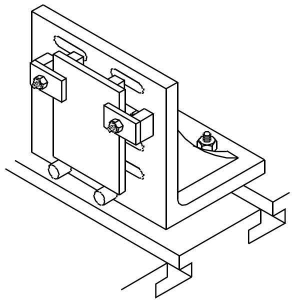
Fig 4



CAST IRON ANGLE PLATE

ELN1218C4

Fig 5



WORKPIECE CLAMPED WITH ANGLE PLATE

ELN1218C5

Limit gauges

Objectives: At the end of this lesson you shall able to
- **state the principle of the Go and No-Go gauges and their features**
- **list out the common types of limit gauges**
- **state the uses of each type of limit gauges.**

When a number of components have to be checked it is not necessary to meassure their sizes exactly but only check that the component's sizes lie within the limits of tolerance. The most economical method of checking a component is with a limit gauge.

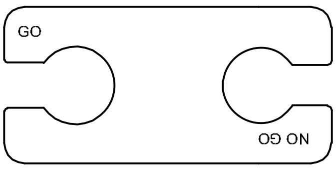
These gauges are used in inspection because they provide a quick means of checking a specific dimension.

'Go' and 'No-Go' end principle

The dimensions of the 'Go' and 'No-Go' ends of gauges are determined from the limits stated on the dimension to be gauged.

The 'Go' and 'No-Go' principle of gaguing is that the 'Go' end of the gauges must go into the feature being checked and the 'No-Go' end must not go into the same feature. The dimension of the 'Go' end is equal to the maximum permissible dimension and that of the 'No-Go' end is equal to the minimum permissible dimension of the component for external measurements. (Fig 1)

Fig 1



EXTERNAL MEASUREMENT

ELN1218D1

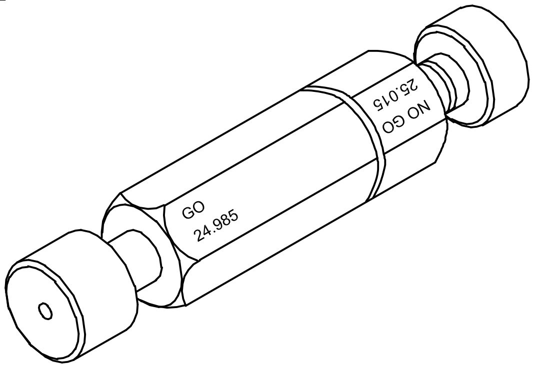
For internal measurements the 'Go' end of the gauge is equal to the minimum limit and that of the 'No-Go' end is equal to the maximum limit of the component. (Fig 2)

Essential features

These gauges must be easy to handle and accurately finished. They are generally finished to one tenth the tolerance they are designed to control. For example, if the tolerance is to be maintained at 0.02mm, then the gauge must be finished to within 0.002mm, of the required size.

They must be resistant to wear, corrosion, and expansion due to temperature.

Fig 2



INTERNAL MEASUREMENT

ELN1218D2

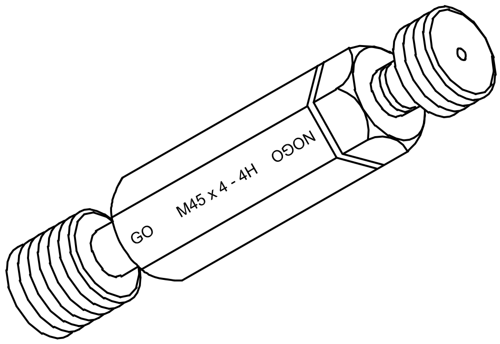
Their production cost must be lower.

The 'Go' end is made longer than the 'No-Go' end for easy identification. Sometimes a groove is cut on the handle near the 'No-Go' end to distinguish it from the 'Go' end. This applies to plug gauges. The dimensions of these gauges are usually stamped.

Thread plug gauges (Fig 3 and 4)

Internal threads are checked with thread plug gauges of 'Go' and 'No-Go' variety which employ the same principle as cylindrical plug gauges.

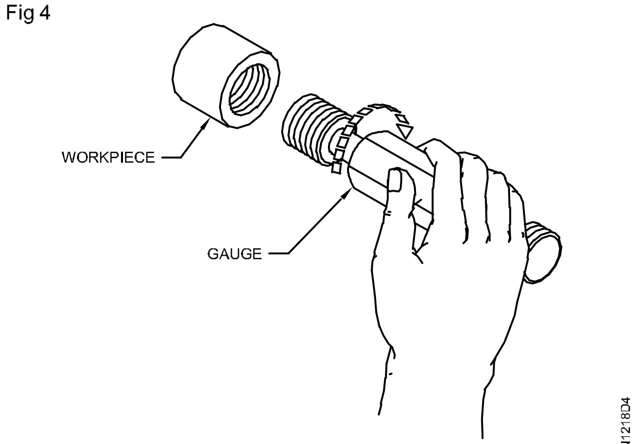
Fig 3



THREAD PLUG GAUGES

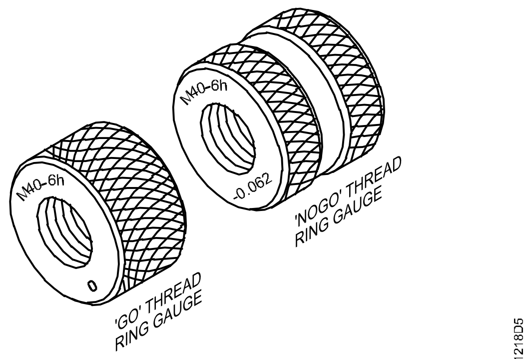
ELN1218D3

Fig 4



INTERNAL THREAD PLUG GAUGES

Fig 5



THREAD RING GAUGES

Thread ring gauges (Fig 5)

These gauges are used to check the accuracy of an external thread. They have a threaded hole in the centre with three radial slots and a set screw to permit small adjustments.

Fundamental of electricity - conductors - insulators - wire size measurement - crimping

Objectives: At the end of this lesson you shall be able to
- **define electricity and atom**
- **explain about the atomic structure**
- **define the fundamental terms and definition of electricity**
- **state the type of supply, polarity and the effects of electric current**
- **state the conductors, insulators, wires - size measurement methods**

Introduction

Electricity is one of the today's most useful sources of energy. Electricity is of utmost necessity in the modern world of sophisticated equipment and machinery.

Electricity in motion is called electric current. Whereas the electricity that does not move is called static electricity.

Examples of static electricity

- Shock received from door knobs of a carpeted room.
- Attraction of tiny paper bits to the comb.

Structure of matter

Electricity is related to some of the most basic building blocks of matter that are atoms (electrons and protons). All matter is made of these electrical building blocks, and, therefore, all matter is said to be 'electrical'.

Atom

Matter is defined as anything that has mass and occupies space. A matter is made of tiny, invisible particles called molecules. A molecule is the smallest particle of a substance that has the properties of the substance. Each molecule can be divided into simpler parts by chemical means. The simplest parts of a molecule are called atoms.

Basically, an atom contains three types of sub-atomic particles that are of relevance to electricity. They are the electrons, protons and neutrons. The protons and neutrons are located in the centre, or nucleus, of the atom, and the electrons travel around the nucleus in orbits.

Atomic structure

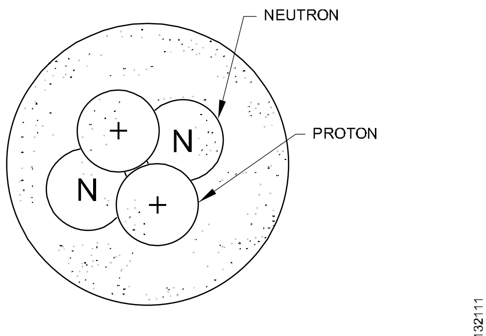
The Nucleus

The nucleus is the central part of the atom. It contains the protons and neutrons in equlal numbrs shown in Fig 1.

Protons

The proton has a positive electrical charge. (Fig 1) It is almost 1840 times heavier than the electron and it is the permanent part of the nucleus; protons do not take an active part in the flow or transfer of electrical energy.

Fig 1

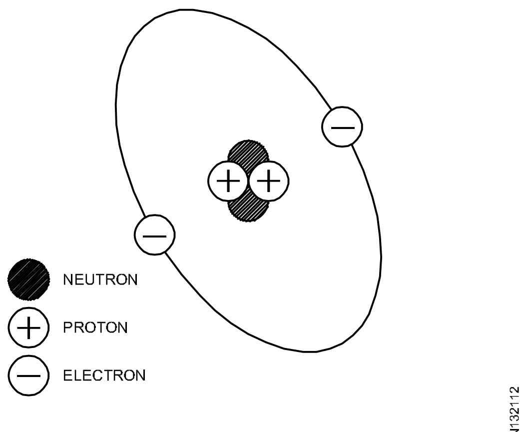


NUCLEUS OF AN ATOM

Electron

It is a small particle revolving round the nucleus of an atom (as shown in Fig 2). It has a negative electric charge. The electron is three times larger in diameter than the proton. In an atom the number of protons is equal to the number of electrons.

Fig 2



REVOLVING OF ELECTRON

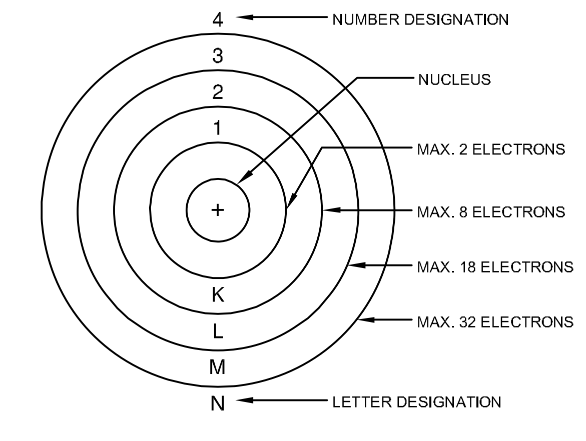
Neutron

A neutron is actually a particle by itself, and is electrically neutral. Since neutrons are electrically neutral, they are not too important to the electrical nature of atoms.

Energy shells

In an atom, electrons are arranged in shells around the nucleus. A shell is an orbiting layer or energy level of one or more electrons. The major shell layers are identified by numbers or by letters starting with 'K' nearest the nucleus and continuing alphabetically outwards. There is a maximum number of electrons that can be contained in each shell. Fig 3 illustrates the relationship between the energy shell level and the maximum number of electrons it can contain.

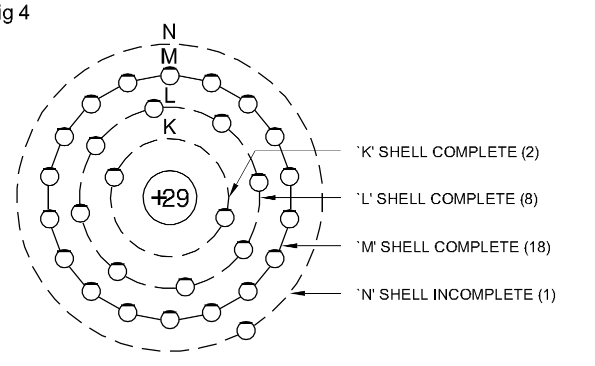
Fig 3



SHELL LEVEL AND ELECTRONS

If the total number of electrons for a given atom is known, the placement of electrons in each shell can be easily determined. Each shell layer, beginning with the first, is filled with the maximum number of electrons in sequence. For example, a copper atom which has 29 electrons would have four shells with a number of electrons in each shell as shown in Fig 4.

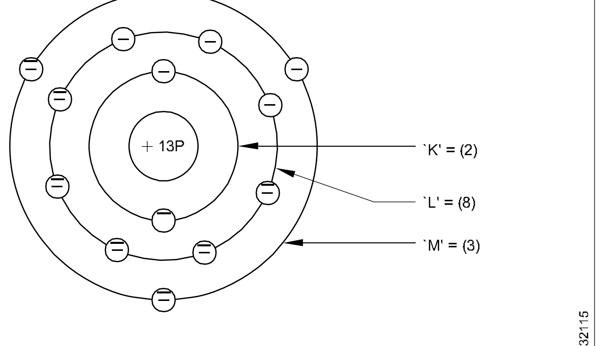
Fig 4



COPPER ATOM

Similarly an aluminium atom which has 13 electrons has 3 shells as shown in Fig 5.

Fig 5



ALUMINIUM ATOM

Electron distribution

The chemical and electrical behaviour of atoms depends on how completely the various shells and sub-shells are filled.

Atoms that are chemically active have one electron more or one less than a completely filled shell. Atoms that have the outer shell exactly filled are chemically inactive. They are called inert elements. All inert elements are gases and do not combine chemically with other elements.

Metals possess the following characteristics.

- They are good electric conductors.
- Electrons in the outer shell and sub-shells can move more easily from one atom to another.
- They carry charge through the material.

The outer shell of the atom is called the valence shell and its electrons are called valence electrons. Because of their greater distance from the nucleus, and because of the partial blocking of the electric field by electrons in the inner shells, the attracting force exerted by nucleus on the valence electrons is less. Therefore, valence electrons can be set free most easily. Whenever a valence electron is removed from its orbit it becomes a free electron. Electricity is commonly defined as the flow of these free electrons through a conductor. Though electrons flow from negative terminal to positive terminal, the conventional current flow is assumed as from positive to negative.

Conductors, insulators and semiconductors

Conductors

A conductor is a material that has many valance electrons permitting electrons to move through it easily. Generally, conductors have many valence shells of one, two or three electrons. Most metals are conductors.

Some common good conductors are Copper, Aluminium, Zinc, Lead, Tin, Eureka, Nichrome, are conductors, where as silver and gold are very good conductors

Insulators

An insulator is a material that has few, if any, free electrons and resists the flow of electrons. Generally, insulators have full valence shells of five, six or seven electrons. Some common insulators are air, glass, rubber, plastic, paper, porcelain, PVC, fibre, mica etc.

Semiconductors

A semiconductor is a material that has some of the characteristics of both the conductor and insulator. Semiconductors have valence shells containing four electrons.

Common examples of pure semiconductor materials are silicon and germanium. Specially treated semiconductors are used to produce modern electronic components such as diodes, transistors and integrated circuit chips.

Simple electrical circuit and its elements

Objectives: At the end of this lesson you shall be able to
- **describe a simple electric circuit**
- **explain the current, its units and method of measurement (ammeter)**
- **explain the emf, potential difference, their units and method of measurement (voltmeter)**
- **explain resistance and its unit, and quantity of electricity.**

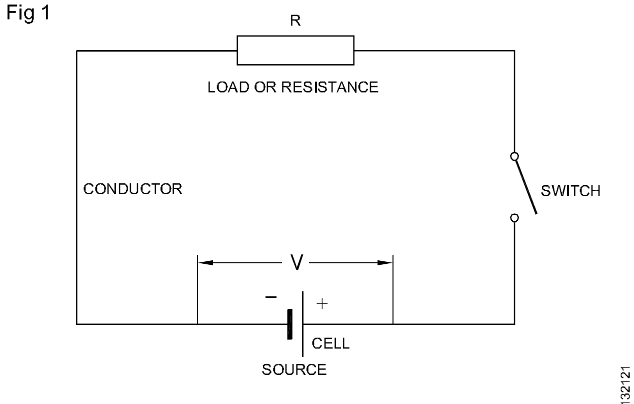
Simple electric circuit

A simple electrical circuit is one in which the current flows from the source to a load and reaches back the source to complete the path.

As shown in Fig 1, the electrical circuit should consist of the following.

- An energy source (cell) to provide the voltage needed to force the current through the circuit.
- Conductors through which the current can flow.
- A load (resistor 'R') to control the amount of current and to convert the electrical energy to other forms.
- A control device (switch 'S') to start or stop the flow of current.

Fig 1



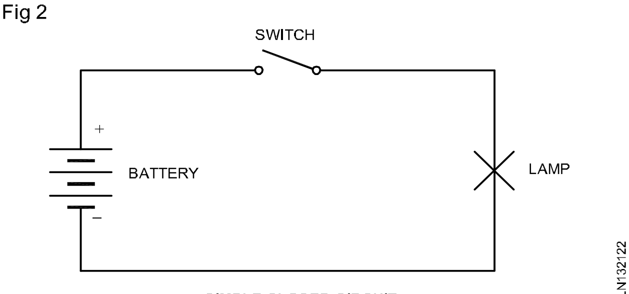
ELECTRICAL CIRCUIT

In addition to the above, the circuit may have insulators (PVC or rubber) to confine the current to the desired path, and a protection device (fuse 'F') to interrupt the circuit in case of malfunction of the circuit (excess current).

Electric current

Fig 2 shows a simple circuit which consists of a battery as the energy source and a lamp as the resistance. In this circuit, when the switch is closed, the lamp glows because of the electric current flows from the +ve terminal of the source (battery) via the lamp and reaches back the –ve terminal of the source.

Fig 2



SIMPLE CLOSED CIRCUIT

Flow of electric current is nothing but the flow of free electrons. Actually the electrons flow is from the negative terminal of the battery to the lamp and reaches back to the positive terminal of the battery.

However direction of current flow is taken conventionally from the +ve terminal of the battery to the lamp and back to the –ve terminal of the battery. Hence, we can conclude that conventional flow of current is opposite to the direction of the flow of electrons. Throughout the Trade Theory book, the current flow is taken from the +ve terminal of source to the load and then back to the –ve terminal of the source.

Ampere

The unit of current (abbreviated as I) is an ampere (symbol A). If 6.24×10^{18} electrons pass through a conductor per second having one ohm resistance with a potential difference of one volt causes one ampere current has passed through the conductor.

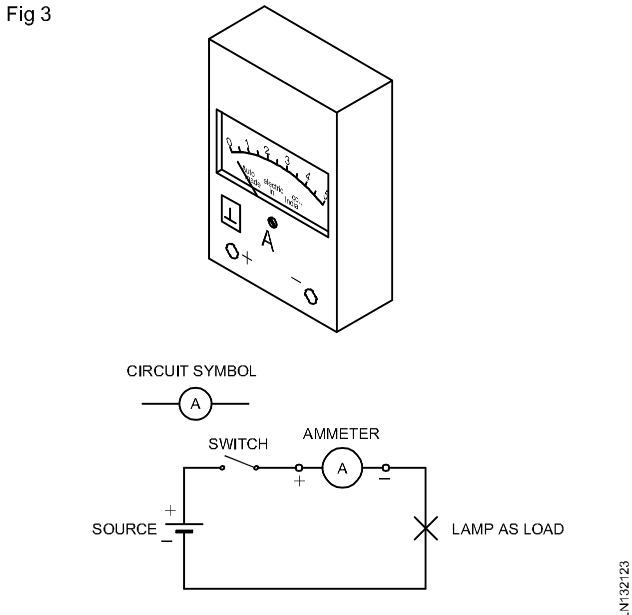
Ammeter

We know the electrons cannot be seen and no human being can count the electrons. As such an instrument called ammeter is used to measure the current in a circuit.

As an ammeter measures the flow of current in amperes it should be connected in series with the resistance (Load).

as shown in Fig 3. For the decimal and decimal sub-

Fig 3



AMMTER WITH LOAD

multiples of the ampere we use the following expressions.

1 kilo-ampere = 1 kA = 1000 A = 1×10^{3}A

1 milli-ampere = 1 mA = 1/1000 A = 1×10^{-3}A

1 micro-ampere = 1 μA = 1/1000000 A = 1×10^{-6}A

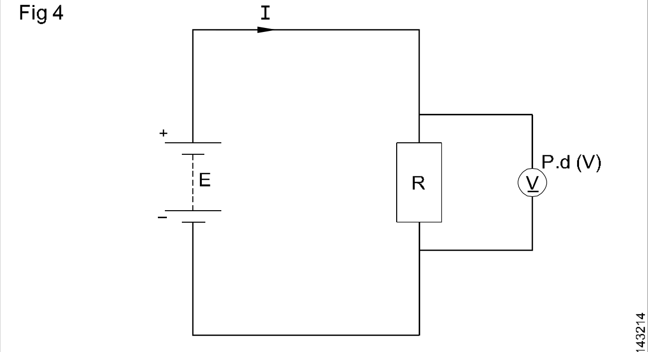
Electro Motive Force (EMF)

In order to move the electrons in a circuit- that is to make the current to flow, a source of electrical energy is required. In a torch light, the battery is the source of electrical energy.

The terminals of the battery are indicated in the circuit symbol by two lines, the longer line for the positive and the shorter for the negative terminal.

Within the battery the negative terminal contains an excess of electrons whereas the positive terminal has a deficit of electrons. The battery is said to have an electromotive force (emf) which is available to drive the free electrons in the closed path of the electrical circuit. The difference in the distribution of electrons between the two terminals of the battery produces this emf.

Fig 4



ELECTROMOTIVE FORCE

In Simple,

Electromotive force (EMF) is the electrical force, which is initially available in elecrical source, cause to move the free electrons in a conductor

Its unit is 'Volt'

It is denoted by letter 'E'

It cannot be measured by any meter. It can be only calculated by using the formula

E = Potential Difference (P.D) + V. drop

= p.d + V.drop

E = V + IR

Electromotive force is essential to drive the electrons in circuit

This force is obtained from the source of supply i.e. Torch lights, dynamo

System International (SI) unit of electromotive force is Volts (symbol 'E')

Potential Difference (PD)

The difference of volatge and pressure across two points in a circuit is called a potential difference (p.d) and is measured in volts.

In a circuit, when a current flows, there will be a potential difference across the terminals of the resistor/load. In the circuit shown in Fig 4, when the switch is in open conidition, the voltage across the terminals of the cell is called electromotive force (E) whereas when the switch is in the closed position, the voltage across the cell is called potential difference (p.d) which wil be lesser in value than the electromotive force earlier measured. This is due to the fact that the internal resistance of the cell drops a fer volts when the cell supplies current to the load.

The force which causes current to flow in the circuit is called emf. Its symbol is E and its unit is Volts (V). It can be calculated as

EMF = voltage at the terminal of source of supply + voltage drop in the source of supply

or emf = V_T + IR

Terminal voltage (p.d)

It is the voltage available at the terminal of the source of supply. Its symbol is V_T. Its unit is also the volt and is also measured by a voltmeter. It is given by the emf minus the voltage drop in the source of supply, i.e.

V_T = EMF - IR

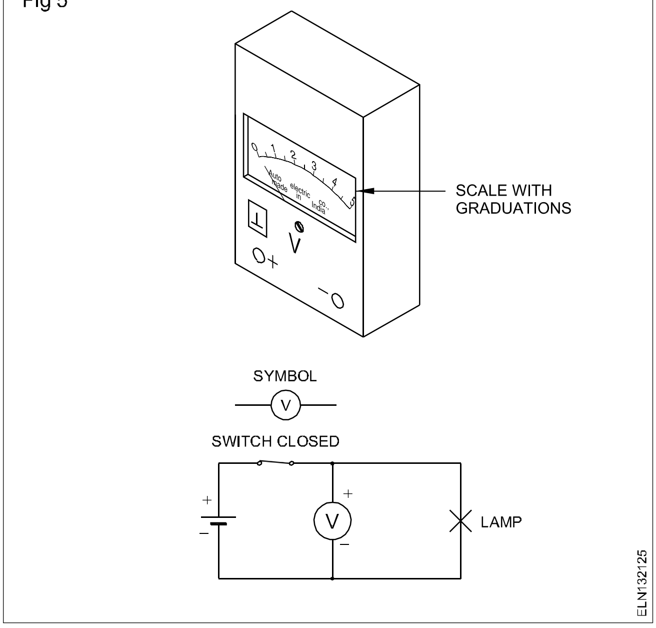
where I is the current and R is the resistance.

Hence EMF is always greater than p.d [E.M.F>p.d]

Voltmeter

Electrical voltage is measured with a voltmeter. In order to measure the voltage of a source, the terminals of the voltmeter must be connected to the terminals of the source. Positive to the positive terminal and negative to the negative terminal, as shown in Fig 5. The voltmeter connection is across or it is a parallel connection.

Fig 5



For the decimal or decimal sub-multiples of the volt, we use the following expressions.

1 kilo-volt = 1 KV = 1000 V

= 1 x 10^3V

1 milli-volt = 1 mV = 1/1000 V

= 1 x 10^{-3}V

1 micro-volt = 1 μV = 1/1000000 V = 1 x 10^{-6}V

Resistance (R)

In addition to the current and voltage there is a third quantity which plays a role in a circuit, called the electrical resistance. Resistance is the property of a material by which it opposes the flow of electric current.

The resistance is the property of opposition to the flow of the current offered by the circuit elements like resistance of the conductor or load is limit the flow of current

> **In absence of resistance in a circuit, the current will reach an abnormal high value endangering the circuit itself**

Ohm

The unit of electrical resistance (abbreviated as R) is ohm (symbol Ω).

For the decimal multiples or decimal sub-multiples of the ohm we use the following expressions:

1 megohm = 1 MΩ = 1000000Ω = 1 x 10^{6}Ω

1 kilo-ohm = 1 kΩ = 1000Ω = 1 x 10^{3}Ω

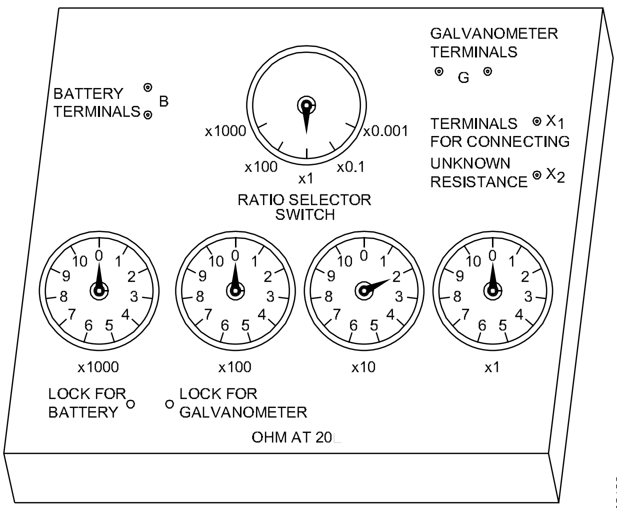
1 milli-ohm = 1 mΩ = 1/1000Ω = 1 x 10^{-3}Ω

1 micro-ohm = 1 μΩ = 1/1000000Ω = 1 x 10^{-6}Ω

Meter to measure resistance

Ohmic value of a medium resistance is measured by an ohmmeter or a Wheatstone bridge. (Fig 6) There is a provision to measure the ohmic value of a resistance in a multimeter. There are various methods to determine the ohmic value of resistance. Some of these methods will be explained later in this book.

Fig 6



WHEATSTONE BRIDGE

International Ohm

It is defined as that resistance offered to an unvarying current (DC) by a column of mercury at the temperature of melting ice (i.e. 0°C), 14.4521 g in mass, of constant cross-sectional area (1 sq. mm) and 106.3 cm in length.

International ampere

One international ampere may be defined as that unvarying current (DC) which when passed through a solution of silver nitrate in water, deposits silver at the rate of 1.118 mg per second at the cathode.

Internation volt

It is defined as that potential difference which when applied to a conductor whose resistance is one international ohm produces a current of one international ampere. Its value is equal to 1.00049V.

Conductance

The property of a conductor which conducts the flow of current through it is called conductance. In other words, conductance is the reciprocal of resistance. Its symbol is G (G = 1/R) and its unit is mho represented by ℧. Good conductors have large conductances and insulators have small conductances. Thus if a wire has a resistance of R Ω, its conductance will be 1/R

Quantity of electricity

As the current is measured in terms of the rate of flow of electricity, another unit is necessary to denote the quantity of electricity (Q) passing through any part of the circuit in a certain time. This unit is called the coulomb (C). It is denoted by the letter Q. Thus

Quantity of electricity = current in amperes (I) x time in seconds (t)

or $Q = I \times t$

Coulomb

It is the quantity of electricity transferred by a current of one ampere in one second. Another name for the above unit is the ampere-second. A larger unit of the quantity of electricity is the ampere-hour (A.h) and is obtained when the time unit is in hours

1 A.h = 3600 Asec or 3600 C

Types of electrical supply

Objectives: At the end of this lesson you shall be able to
- **explain the difference types of electrical supply**
- **differentiate between alternating current and direct current**
- **explain the method of identification of polarity in DC source**
- **state the effect of electric current**

There are various types of instruments working on different principles. Each instrument is designed to measure a particular electrical quantity or more than one quantity with suitable modification and necessary instruction. Further they may be designed to measure AC or DC supply quantities or can be used in either supply.

To enable proper use of the instruments, the technician should be able to identify the type of supply with the help of the details given below.

Type of electrical supply (Voltage)

There are two types of electrical supply in use for various technical requirements. The alternating current supply (AC) and the direct current supply (DC).

___ DC is represented by this symbol.

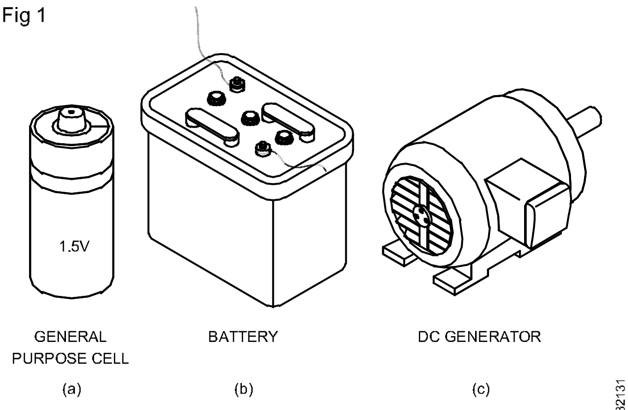
~ AC is represented by this symbol.

DC Supply

The most common sources of DC supply are the cells/ batteries (Figs 1a and 1b) and DC generators (dynamos). (Fig 1C)

Direct voltage is of constant magnitude (amplitude). It remains at the same amplitude from the moment of switching on to the moment of switching off. The polarity of the voltage source does not change. (Fig 2)

Fig 1



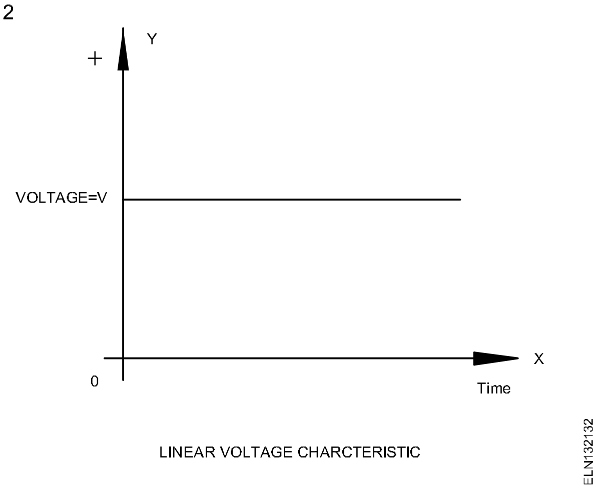
VARIOUS DC SOURCES

The polarity of direct voltage (commonly known as DC voltage) is positive (+ve) and negative (–ve). The direction of conventional flow of current is taken as from the positive to the negative terminal outside the source. (Fig 3)

Direct Current (D.C) (Fig 4)

Voltage is the cause of electrical current. If a direct current flows through a circuit, the movement of electrons in the circuit is unidirectional.

Fig 2



LINEAR VOLTAGE CHARCTERISTIC

Fig 3

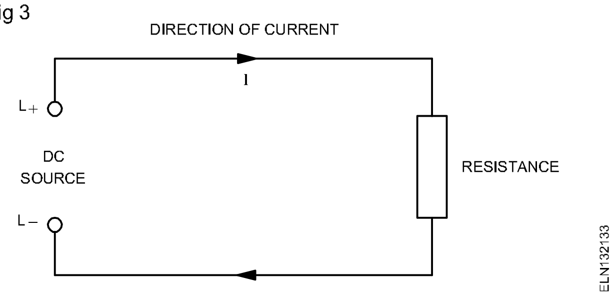
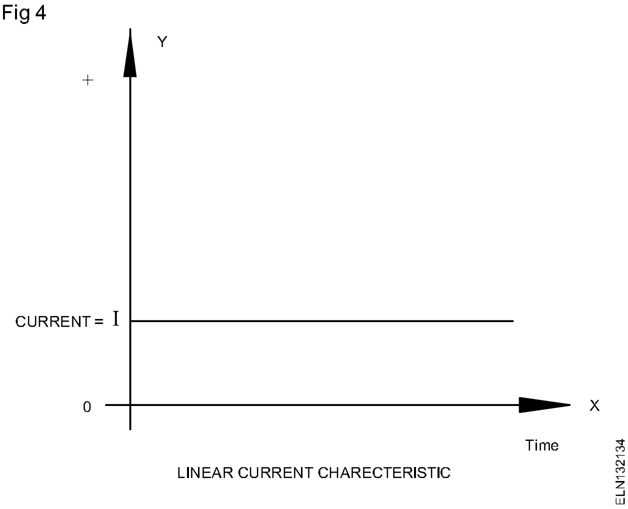


Fig 4



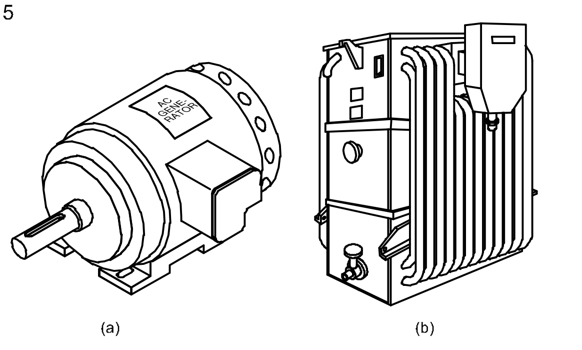
LINEAR CURRENT CHARECTERISTIC

Thus direct current remains at the same value from the moment of switching on to the moment of switching off. (Direct current in common usage is known as DC current.)

AC Supply

The source of AC supply is AC generators (alternators). (Fig 5a) The supply from a transformer (Fig 5b) is also AC.

Fig 5

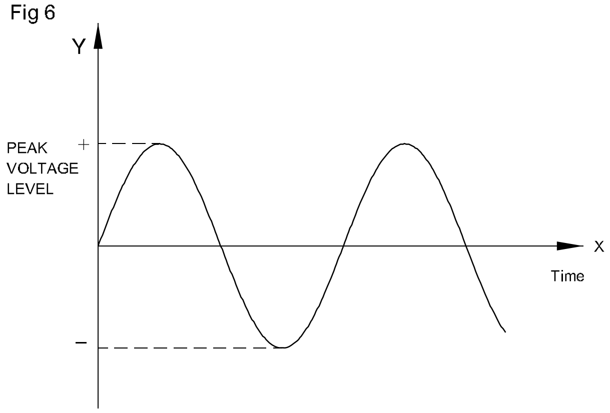


VARIOUS AC SOURCES

Alternating voltage

AC supply sources change their polarity constantly, and consequently the direction of voltage also magnitude. The voltage supplied to our homes by power plants is alternating. Fig 6 shows a sinusoidal alternating voltage over time (wave-form).

Fig 6



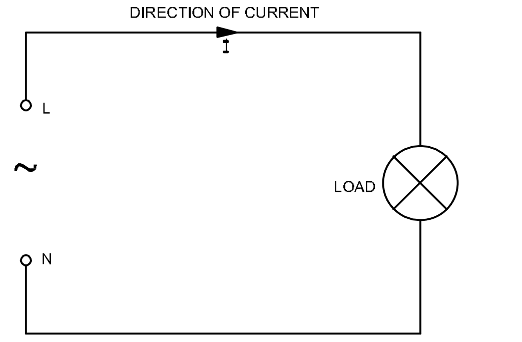
AC VOLTAGE

AC supply is expressed by the effective value of the voltage, and the number of times it changes in one second is known as frequency. Frequency is represented by 'F' and its unit is in Hertz(Hz).

For example, the AC supply used for lighting is 240V 50 Hz. (Alternating voltage in common use is known as AC voltage.) AC supply terminals are marked as phase/line(L) and neutral(N).

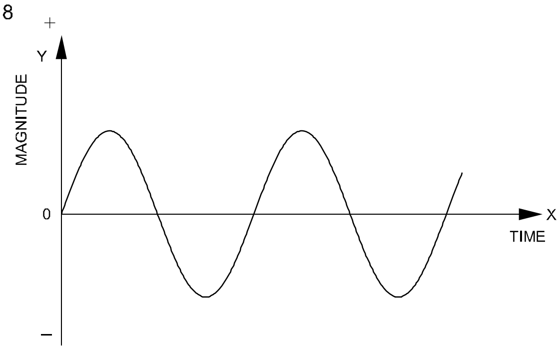
Current is caused in an electric circuit due to the application of voltage. If an alternating voltage is applied to an electrical circuit, an alternating current (commonly known as AC current) will flow. (Figs 7 and 8)

Fig 7



ALTERNATING CURRENT FLOW (AC)

Fig 8



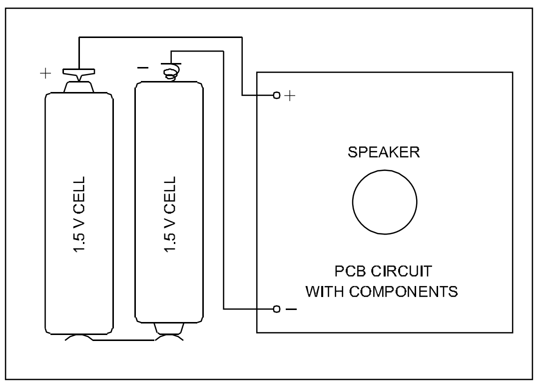
ALTERNATING CURRENT

Polarity test in DC

Polarity

The polarity of a DC supply source should be identified as positive or negative. We can also use the term to indicate how an electric device is to be connected to the supply. For example, when putting new cells in a transistor radio we must put the cells correctly such that the positive terminal of one cell connects to the positive terminal of the radio and the negative terminal of the other cell connects to the negative terminal of the radio as shown in Fig 1.

Fig 1



TRANSISTOR RADIO

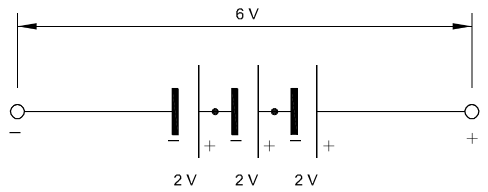
Importance of the polarity

Direct current supply has fixed polarity, positive and negative marked as + and –. Electric devices which have positive and negative identifications on their terminals are said to be polarised. When connecting such devices to a source of voltage (such as a battery or DC supply)

We must observe the correct polarity markings. That is the positive terminal of the device must be connected to the positive terminal of the source, and the negative to the negative. If the polarity is not observed correctly (that is, if +ve is connected to –ve) the device will not function and may be damaged.

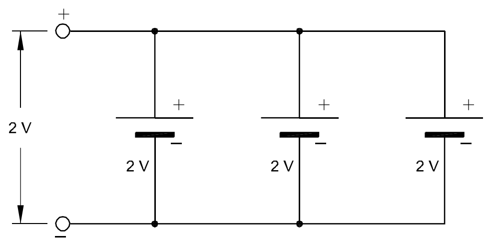
To get more voltage, current and power, the voltage sources like cells, batteries and generator are often connected in series, or in parallel or in series/parallel combination circuit. To connect them in such a manner we must know the correct polarity of the source. Fig 2 shows the method of connecting 3 cells in series to get more voltage. Fig 3 shows connection of 3 cells in parallel for getting more current.

Fig 2



CELL IN SERIES FOR GETTING MORE VOLTAGE

Fig 3



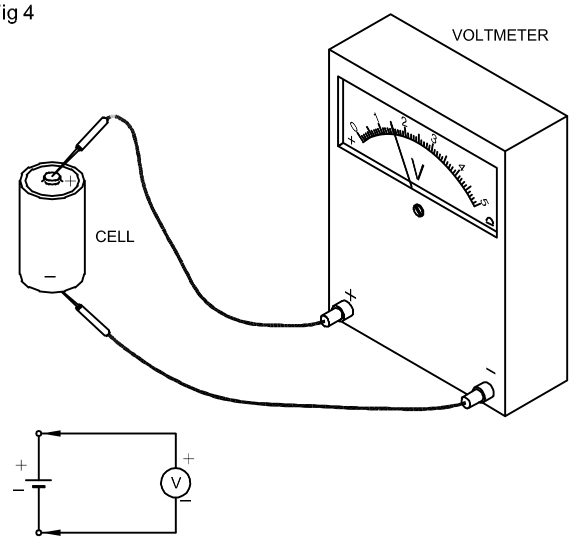
CELLS IN PARALLEL FOR GETTING MORE CURRENT.

Testing polarity by MC meter

The polarity of a cell is determined by the use of a moving coil volt-meter. The terminals of the MC meter are marked as +ve and –ve. MC meters are called as polarised as they have to be connected as per the polarity marking. By using a low range (0-10V) MC voltmeter we can find out the voltage of a cell.

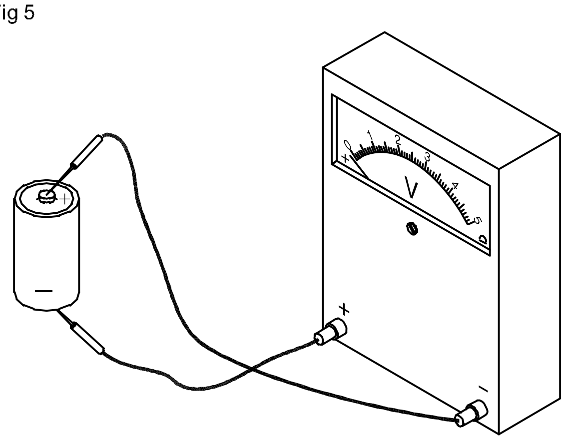
The connections are made as per Fig 4 the voltmeter reads 1.5 volts. The polarity of the cell is correct as per the marked polarity on the meter terminals. If the pointer of the voltmeter deflects as in Fig 5, below zero, the polarity is not correct. From this we conclude that the meter reads in forward direction only if the instrument is connected with correct polarity as per the markings on the instrument terminals.

Fig 4



CORRECT POLARITY INDICATION

Fig 5



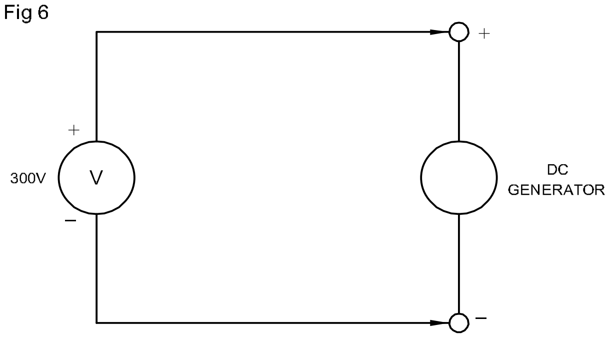
WRONG POLARITY INDICATION

Polarity of the battery

To determine the polarity of the terminals of an unmarked battery, that is +ve and –ve we can use a low range MC voltmeter. If the voltmeter reads positive reading, say 10 or 12 volts then the polarity of the terminals are correct as per the markings on the meter terminals. If the meter reading is negative, that is below zero, the battery polarity is not correct with respect to the meter.

Polarity of DC supply

Fig 6



POLARITY TEST BY D.C GENERATOR

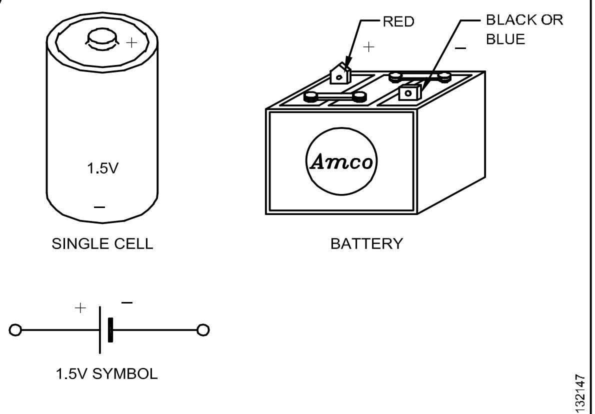
In the same way to find out the polarity of DC generator or a DC source it is advisable to use a moving coil type voltmeter with a suitable range, of say 0-300 volts (Fig 6). To protect the meters, always use higher range meters above the rated voltage of the generator or DC source supply.

Marking made in practice

Generally in DC source the +ve terminal of the supply lead is Red in colour and –ve terminal of the supply lead is Blue or Black in colour. Battery terminals are marked as +ve and –ve on the body or on the terminal post.

- For cells on top of the cell is marked as +ve and the bottom is marked as –ve
- The battery terminal is marked as + and is Red in colour, and the other terminal is marked as – and Black or Blue in colour. (Fig 7)

Fig 7



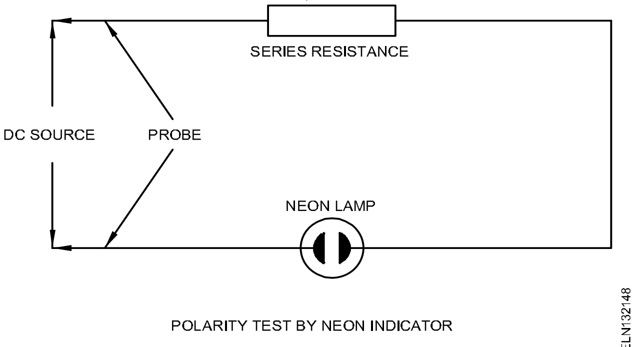
CELL & BATTERY WITH COLOUR POLARITY

Neon polarity indicator

To check the polarity, a neon lamp in series with a 220k ohms resistor could be used (as shown in Fig 8). Touch the probes of the neon lamp circuit across the circuit to be tested. The lamp will light when voltage is present. If both electrodes in the lamp glow, you have an AC power source. If only one electrode glows, the voltage is DC and the lighted electrode will be on the side of the negative polarity of the source.

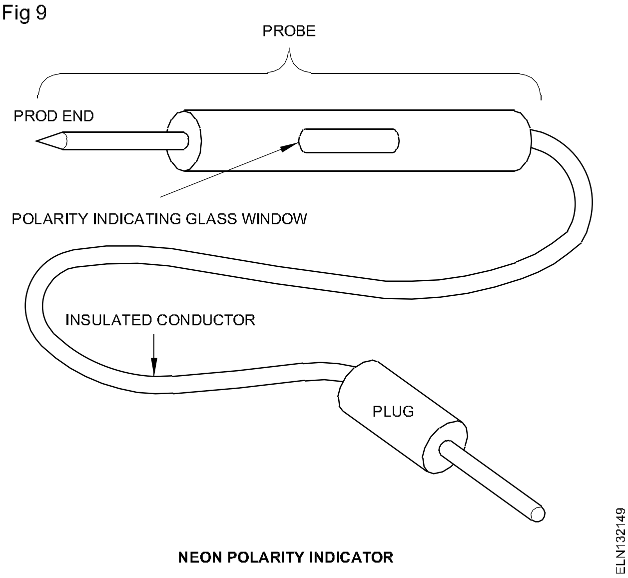
Therefore, you also have a polarity check on DC circuits. (Fig 8) A commercial neon polarity indicator is shown in Fig 9. It has an indicating glass window in which the polarity touched by the pointed end of the indicator will be displayed as +ve or –ve through neon signs.

Fig 8



POLARITY TEST BY NEON INDICATOR

Fig 9



NEON POLARITY INDICATOR

Effects of electric current

When an electric current flows through a circuit, is judged by its effects, which are given below.

1 Chemical effect

When an electric current is passed through a conducting liquid (i.e. acidulated water) called an electrolyte, it is decomposed into its constituents due to chemical action. The practical application of this effect is utilized in electroplating, block making, battery charging, metal refinery, etc.

2 Heating effect

When an electric potential is applied to a conductor, the flow of electrons is opposed by the resistance of the conductor and thus some heat is produced. The heat produced may be greater or lesser according to the circumstances, but some heat is always produced. The application of this effect is in the use of electric presses, heaters, electric lamps, etc.

3 Magnetic effect

When a magnetic compass is placed under a current carrying wire, it is deflected. It shows that there is some relation between the current and magnetism. The wire carrying current does not become magnet but produces a magnetic field in the space. If this wire is wound on an iron core (i.e. bar), it becomes an electro-magnet. This effect of electric current is applied in electric bills, motors, fans, electric instruments, etc.

4 Gas ionization effect

When electrons pass through a certain gase sealed in a glass tube, it becomes ionised and starts emitting light rays, such as in fluorescent tubes, mercury vapour lamps, sodium vapour lamps, neon lamps, etc.

5 Special rays effect

Special rays like X-rays and laser rays can also be developed by means of an electric current.

6 Shock effect

The flow of current through the human body may cause a severe shock or even death in many cases. If this current is controlled to a specific value, this effect of current can be used to give light shocks to the brain for the treatment of mental patients.

Conductors - insulators - wires - types

Objectives: At the end of this lesson you shall be able to
- **differentiate between conducting and insulating materials**
- **state the electrical properties of conducting materials**
- **state the terms used in electrical cables**
- **state the characteristics of copper and aluminium conductors**
- **state the types and propertites of insulating materials.**
- **describe the method of measurement of wire size using SWG**
- **explain the method of measure wire size by outside micrometer**

Conductors and insulators

Material with high electron mobility (many free electrons) are called conductor.

Materials that contain many free electrons and are capable of carrying an electric current are known as conductors.

Examples - silver, copper, aluminium and most other metals.

Materials with low electron mobility (few (or) no free electron) are called insulators

Materials that have only a few electrons and are incapable of allowing the current to pass through them are known as insulators.

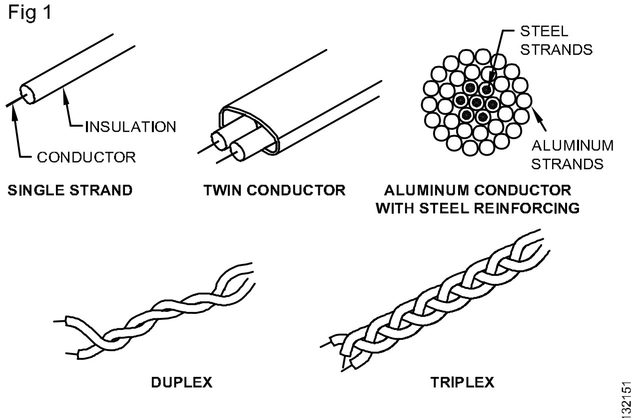
Examples - wood, rubber, PVC, porcelain, mica, dry paper and fibreglass.

Conductors

The use of conductors and their insulation is regulated by I E regulations and BIS (ISI) code of practice.

The I E regulations and I S cover all electrical conductors listing the minimum safety precautions needed to safeguard people, buildings and materials from the hazards of using electricity.

Fig 1



VARIOUS FORMS OF CONDUCTOR

Wires and cables are the most common forms of conductors. They are made in a wide variety of forms to suit many different applications. (Fig 1)

Conductors form an unbroken line carrying electricity from the generating plant to the point where it is used. Conductors are usually made of copper or aluminium.

Current passing through a conductor generates heat. The amount of heat generated depends on the square of the current that passes through the conductor and the resistance of the conductor.

As the heat developed in the conductor depends upon the resistance of the conductor the cross-sectional area of the conductor must have a large enough area to give it a low resistance. But the cross- sectional area must also be small enough to keep the cost and weight as low as possible.

The best cross-sectional area depends upon how much current the conductor can carry without much voltage drop in the line and heat generation in the conductor.

There is a limit to the temperature each kind of insulation can safely withstand and also the type of insulation which can withstand the physical chemical and temperature zones of the surroundings.

BIS (ISI) code specifies the maximum current considered safe for conductors of different sizes, having different insulation and installed in different surroundings.

Size of conductors

The size is specified by the diameter in mm or the cross-sectional area. Typical sizes are 1.5 sq.mm, 2.5 sq.mm, 6 sq.mm etc.

Still in India the old method of specifying the diameter by the standard wire gauge number is in use.

Classfication of conductors

Wires and cables can be classified by the type of covering they have.

Bare conductors

They have no covering. The most common use of bare conductors is in overhead electrical transmission and distribution lines. For earthing also bare conductors are used.

Insulated conductors

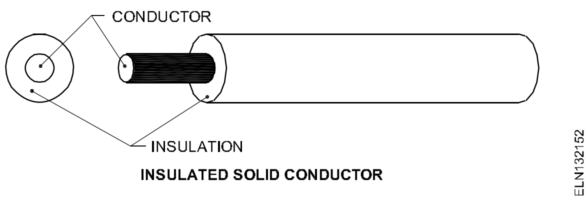
They have a coating of insulation. The insulation separates the conductor electrically from other conductors and from the surroundings. It allows conductors to be grouped without danger. Additional covering over the insulation adds mechanical strength and protection against weather, moisture and abrasion.

Solid and stranded conductors

A solid conductor is one in which there will be only one conductor in the core as shown in Fig 2. A stranded conductor is one in which there will be a number of smaller sized conductors twisted to form the core as shown in Fig 3.

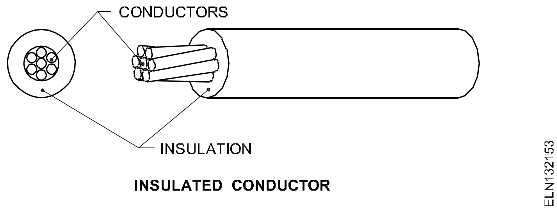
The number of conductors ranges from 3 to 162 and the conductor size varies from 0.193 mm to 3.75 mm diameter depending upon the current carrying capacity and also upon whether these conductors are used in cables or overhead lines.

Fig 2



INSULATED SOLID CONDUCTOR

Fig 3



INSULATED CONDUCTOR

Normally stranded conductors are designated as 10 sq. mm cable of size 7/1.40 where 10 sq.mm gives the area of the cross-section, in the size, numerator (7) gives the number of conductors and the denominator 1.40 gives the diameter of the conductor in mm. Alternatively 7/1.40 cable is the same as 7/17 whereas in the latter case the denominator is expressed in Standard Wire Gauge (SWG) number.

Stranded conductors are more flexible and have better mechanical strength. According to recent stipulation, the cable size should be expressed in sq. millimetres or they can be expressed in terms of the number of conductors in the cable and the diameter of the conductor in mm.

Cable

A cable is a length of single, insulated conductor (single or stranded), or two or more such conductors - each provided with its own insulation, and are laid up together. The insulated conductor or conductors may or may not be provided with an overall mechanical protective covering.

Cable (armoured)

An armoured cable is provided with a wrapping of metal (usually in the form of tape or wire), serving as a mechanical protection.

Cable (flexible)

A flexible cable contains one or more cores, each formed of a group of wires, the diameters of the cores and of the wires being sufficiently small to afford flexibility.

Core

All cables have one central core or a number of cores of stranded conductors farming high conductivity; generally there are one, two, three, three and half and four cores. Each core is insulated separately and there is overall insulation around the cores.

Wire

A solid substance (conductor) or an insulated conductor (solid or stranded) subjected to tensile stress with or without screen is called a wire.

Copper and aluminium

In electrical work, mostly copper and aluminium are used for conductors. Though silver is a better conductor than copper, it is not used for general work due to higher cost.

Copper used in electrical work is made with a very high degree of purity, say 99.9 percent.

Characteristics of copper

1 It has the best conductivity next to silver.

2 It has the largest current density per unit area compared to other metals. Hence the volume required to carry a given current is less for a given length.

3 It can be drawn into thin wires and sheets.

4 It has a high resistance to atmospheric corrosion: hence, it can serve for a long time.

5 It can be joined without any special provision to prevent electrolytic action.

6 It is durable and has a high scrap value.

Next to copper, aluminium is the metal used for electrical conductors.

Characteristics of aluminium

1 It has good conductivity, next to copper. When compared to copper, it has 60.6 percent conductivity. Hence, for the same current capacity, the cross-section for the aluminium wire should be larger than that for the copper wire.

2 It is lighter in weight.

3 It can be drawn into thin wires and sheets. But loses its tensile strength on reduction of the cross-sectional area.

4 A lot of precautions needs to be followed while joining aluminium conductors.

5 The melting point of aluminium is low, hence it may get damaged at points of loose connection due to heat developed.

6 It is cheaper than copper.

Table 1 shows the properties of copper compared with those of aluminium.

Table 1

Chararacteristics of conductor materials

Sl. No.	Properties	Copper (Cu)	Aluminium (Al)
1	Colour	Reddish	White brown
2	Electrical conductivity in MHO/metre	56	35
3	Resistivity at 20°C in ohm/metre (Cross-sectional area in 1 mm^2)	0.01786	0.0287
4	Melting point	1083°C	660°C
5	Density in kg/cm^3	8.93	2.7
6	Temperature coefficient of resistance at 20°C per °C	0.00393	0.00403
7	Coefficient of linear expansion at 20°C per °C	17×10^{-6}	23×10^{-6}
8	Tensile strength in Nw/mm^2	220	70

Properties of insulating materials

Two fundamental properties of insulation materials are insulation resistance and dielectric strength. They are entirely different from each other and measured in different ways.

Insulation resistance

It is the electrical resistance of the insulation against the flow of current. Megohmmeter (Megger) is the instrument used to measure insulation resistance. It measures high resistance values in megohms without causing damage to the insulation. The measurement serves as a guide to evaluate the condition of the insulation.

Dielectric strength

It is the measure of how much potential difference the insulation layer can withstand without breaking down. The potential difference that causes a breakdown is called the breakdown voltage of the insulation.

Every electrical device is protected by some kind of insulation. The desirable characteristics of insulation materials are:

- high dielectric strength
- resistance to temperature
- flexibility
- mechanical strength.

No single material has all the characteristics required for every application. Therefore, many kinds of insulating materials have been developed.

Insulating tapes

Various tapes are used for insulating electrical equipments, conductors and components. Some of these are adhesive. The tapes commonly used include friction, rubber, plastic and varnished cambric tapes.

Rubber tape

Rubber tapes are used for insulating joints. The tape is applied under slight tension. Pressure causes the layers to bend together. Application of this restores insulation but will not be mechanically strong.

Friction tape

This is used over rubber tape insulation. This is made up of cotton cloth impregnated with an adhesive. It does not stretch like the rubber tape. The friction tape does not have insulating qualities of the rubber tape, hence should not be used by itself for insulation.

Plastic tape (PVC tape)

This is used more than the other tapes. PVC tapes have the following advantages.

- High dielectric strength
- Very thin
- Stretches to conform to contours of joints

Varnished cambric tapes

These tapes are made of cloth impregnated with varnish. It usually has no adhesive coating. Available in sheets and rolls and are ideal for insulating motor connecting leads.

Measurement of wire sizes - standard wire gauge - outside micrometer

Necessity of measuring the wire sizes

To execute a wiring job proper planning is necessary. After considering the requirements of the house owner, the electrician prepares a layout plan of the wiring and an estimate of the cost of the wiring materials and labour. A proper estimate involves determination of current in different loads, correct selection of the type of cable, size of the cable and the required quantity. Any error will result in defective wiring, fire accidents and bring unhappiness to both the house owner and the electrician.

While selecting the cable sizes, the electrician has to take into consideration the proposed connected load, future changes in load, the length of the cable run and the permissible voltage drop in the cable.

A sound knowledge about the area of the cross-section of the core, the diameter of the single strand of the conductor and the number of conductors in each core of the stranded conductor is essential for a wireman to be successful in his carreer.

Table 1 - Conversion table SWG to mm/inch

SWG No.	mm	inch
7/0	12.7	0.500
6/0	11.38	0.464
5/0	10.92	0.432
4/0	10.16	0.400
3/0	9.44	0.372
2/0	8.83	0.348
0	8.23	0.324
1	7.62	0.300
2	7.01	0.276
3	6.40	0.252
4	5.89	0.234
5	5.38	0.212
6	4.88	0.192
7	4.47	0.176
8	4.06	0.160
9	3.66	0.144
10	3.25	0.128
11	2.95	0.116
12	2.64	0.104
13	2.34	0.092
14	2.03	0.080
15	1.83	0.072
16	1.63	0.064
17	1.42	0.056
18	1.22	0.048
19	1.02	0.040
20	0.91	0.036
21	0.81	0.032
22	0.71	0.028

SWG No.	mm	inch
23	0.61	0.024
24	0.56	0.022
25	0.51	0.020
26	0.46	0.018
27	0.42	0.0164
28	0.38	0.0148
29	0.34	0.0136
30	0.31	0.0124
31	0.29	0.0116
32	0.27	0.0108
33	0.25	0.0100
34	0.23	0.0092
35	0.21	0.0084
36	0.19	0.0076
37	0.17	0.0068
38	0.15	0.0060
39	0.13	0.0052
40	0.12	0.0048
41	0.11	0.0044
42	0.10	0.0040
43	0.09	0.0036
44	0.08	0.0032
45	0.07	0.0028
46	0.06	0.0024
47	0.05	0.0020
48	0.04	0.0016
49	0.03	0.0012
50	0.02	0.0010

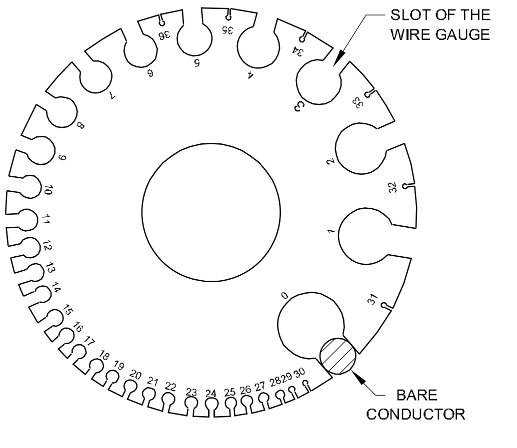
To measure the size of conductors, a electrician can use normally a standard wire gauge or an outside micrometer for more accurate results.

The size of wires are designed more carefully by the manufacturers. Though the Bureau of Indian Standards (BSI) specifies the cables by the area of the cross-section in square millimetres, the manufacturers still produce the cable with the diameter of each wire and number of wires in the stranded cables. Sometimes the indicated size of cable by the manufacturer may not be correct and the electrician has to ascertain the size by measurement.

Standard Wire Gauge (SWG)

The size of the conductor is given by the standard wire gauge number. According to the standards each number has an assigned diameter in inch or mm. This is given in Table 1. The standard wire gauge, shown in Figure 1 could measure the wire size in SWG numbers from 0 to 36. It should be noted that the higher the number of wire gauge the smaller is the diameter of the wire.

Fig 1



STANDARD WIRE GAUGE

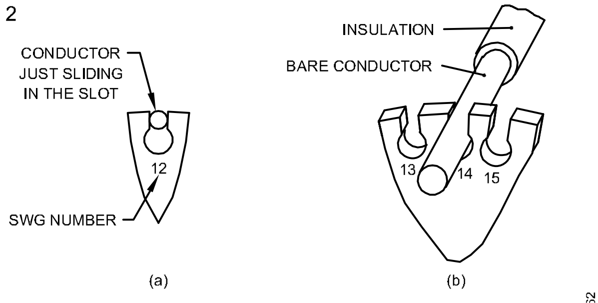
For example, SWG No. 0 (zero) is equal to 0.324 inch or 8.23 mm in diameter whereas SWG No.36 is equal to 0.0076 inch or 0.19 mm in diameter.

While measuring the wire, the wire should be cleaned and then inserted into the slot of the wire gauge to determine the SWG number (Fig 2). The slot in which the wire just slides in is the correct slot and the SWG number could be read in the gauge directly. In most of the wire gauges to save the trouble of referring to the table, the wire diameter is inscribed on the reverse of the gauge.

American Wire Gauge (AWG)

The American wire gauge is different from the British standard wire gauge. In an American wire gauge (AWG) the diameter is represented in mils rather than inch or mm. One mil is one thousandth part of an inch. Please note there is no direct conversion from AWG to SWG.

Fig 2



MEASURING METHODS

Measurement of wire size by Outside micrometers

A micrometer is a precision instrument used to measure a job, generally within an accuracy of 0.01 mm.

Micrometers used to take the outside measurements are known as outside micrometers. (Fig 1)

The parts of a micrometer

Frame

The frame is made of drop-forged steel or malleable cast iron. All other parts of the micrometer are attached to this.

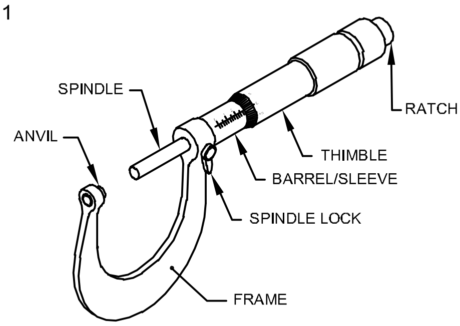
Barrel/sleeve

The barrel or sleeve is fixed to the frame. The datum line and graduations are marked on this.

Thimble

The thimble is attached to the spindle and on the bevelled surface of the thimble, the graduation is marked.

Fig 1



OUTSIDE MICROMETER - PARTS

Spindle

One end of the spindle is the measuring face. The other end is threaded and passes through a nut. The threaded mechanism allows for the forward and backward movement of the spindle.

Anvil

The anvil is one of the measuring faces which is fitted on the micrometer frame. It is made of alloy steel and finished to a perfectly flat surface.

Spindle lock-nut

The spindle lock-nut is used to lock the spindle at a desired position.

Ratchet stop

The ratchet stop ensures a uniform pressure between the measuring surfaces.

Principle of the micrometer

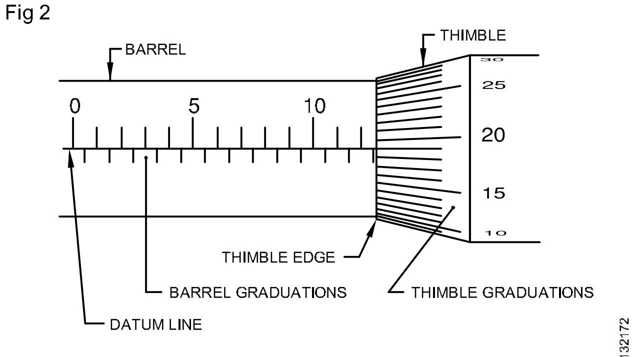
The micrometer works on the principle of screw and nut. The longitudinal movement of the spindle during one rotation is equal to the pitch of the screw. The movement of the spindle to the distance of the pitch or its fractions can be accurately measured on the barrel and thimble.

Graduations

In metric micrometers the pitch of the spindle thread is 0.5 mm.

Thereby, in one rotation of the thimble, the spindle advances by 0.5 mm.

Fig 2



GRADUATIONS MARKINGS ON OUTSIDE DIAMETER

In a 0-25 mm outside micrometer, on the barrel a 25 mm long datum line is marked. (Fig 2) This line is further graduated in millimetres and half millimetres (ie. 1 mm & 0.5 mm). The graduations are numbered as 0, 5, 10, 15, 20 & 25 mm on the barrel.

The circumference of the bevel edge of the thimble is graduated into 50 divisions and marked 0-5-10-15... 45-50 in a clockwise direction.

The distance moved by the spindle during one rotation of the thimble is 0.5 mm.

Movement of one division of the thimble

= 0.5 x 1/50 = 0.01 mm.

This value is called the least count of the micrometer.

The accuracy or least count of a metric outside micrometer is 0.01 mm.

Outside micrometers are available in ranges of 0 to 25 mm, 25 to 50 mm, and so on. For electrician, to read the size of the wire 0 to 25 mm is only suitable.

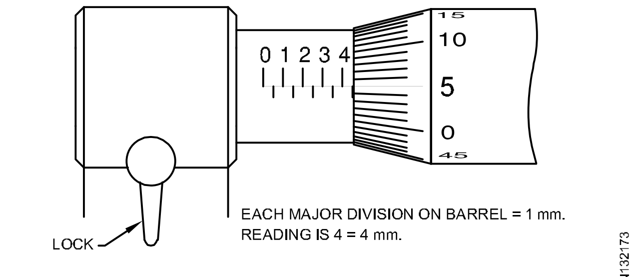
Reading micrometer measurements

How to read a measurement with an outside micrometer?

a) Read on the barrel scale, the number of whole millimetres that are completely visible from the bevel edge of the thimble. It reads 4 mm. (Fig 3)

b) Add to this any half millimetre that is completely visible from the bevel edge of the thimble and away from the whole millimetre reading.

Fig 3

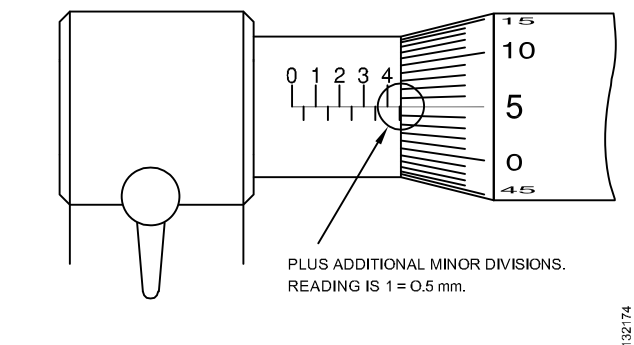


READING MICROMETER MEASUREMENT

The figure reads one division (Fig 4) mm after the 4 mm mark. Hence 0.5 mm to be added to the previous reading.

c) Add the thimble reading to the two earlier readings.

Fig 4



THIMBLE READING ON MICROMETER

The figure shows the 5th division of the thimble is coinciding with the datum line of the barrel. Therefore, the reading of the thimble is 5 x 0.01 mm = 0.05 mm. (Fig 5)

The total reading of the micrometer.

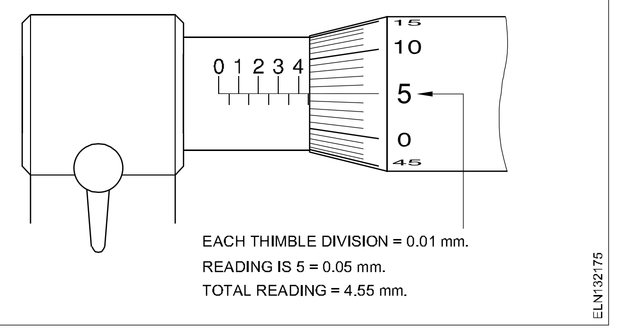
a 4.00 mm

b 0.50 mm

c 0.05 mm.

Total reading = 4.55 mm (Fig 5)

Fig 5



Precautions to be followed while using a micrometer

Before using the micrometer for measurement, it is necessary to ascertain that there is no error in the micrometer. To find the error, close the jaws of the measuring surfaces using the ratchet. Read the micrometer. If the thimble zero is coincident with the datum line of the barrel, error is zero. If it reads higher value, the error is +ve; if it reads lesser value the difference between zero and the read value is -ve error.

If there is minus error it should be added to the total reading and if there is plus error the value should be subtracted from the total reading.

The faces of the anvil and spindle must be free from dust, dirt and grease.

While reading the micrometer, the spindle must be locked with the reading.

Do not drop or handle the micrometer roughly.

Skinning of cables

Objective: At the end of this lesson you shall be able to
- **state the method of skinning of cable.**

The installation technique for aluminium cables is the same as that for copper cables. Certain additional precautions are necessary as aluminium has low mechanical strength, less current carrying capacity for the same area of cross-section, low melting point, and is quicker in forming oxides on the surface than copper.

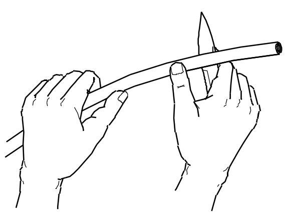
Accordingly, while, using aluminium cables proper care is to be taken regarding the following.

- Handling
- Skinning of the cables
- Connecting the cable ends

Handling: Remember that aluminium conductors when compared to copper conductors have less tensile strength and less resistance to fatigue. As such, bending or twisting of aluminium conductors while laying the cables should be avoided as far as possible.

Skinning of cables: While skinning the insulation from the cables, knicks and scratches should be avoided. As shown in Fig 1, the insulation should not be ringed as there is a danger of nicking the aluminium conductor while ringing the insulation with a knife.

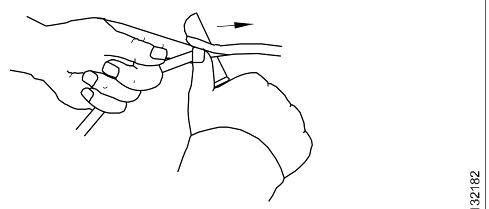
Fig 1



WRONG METHOD

Using the knife as shown in Fig 2 at an angle of 20° to the axis of the core will avoid knicking of the conductor.

Fig 2



RIGHT METHOD

Connecting the cable ends

The following problems are encountered while connecting aluminium cables to the accessories.

The termination holes in the accessories may be undersized.

This normally happens in old accessories as they are designed for copper cable ends. Hence, while selecting accessories, a thorough check is necessary of all accessories to ensure whether the holes in the terminating connectors as shown in Fig 4 are suitable to accommodate the specified aluminium conductors. In any case, the strands should not be cut or the conductor filed as shown in Fig 3 to enable insertion in the undersized hole as this operation results in the heating of the cable end on load condition.

Joints in electrical conductors are necessary to extend the cables, overhead lines, and also to tap the electricity to other branch loads wherever required.

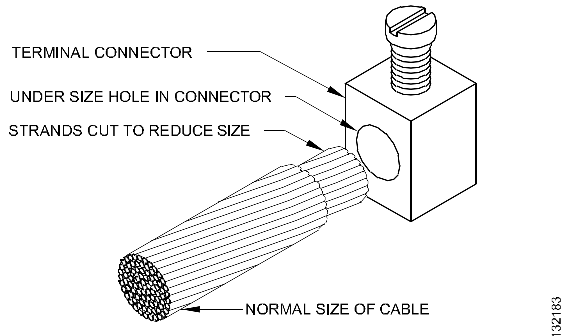


Fig 3

WRONG METHOD

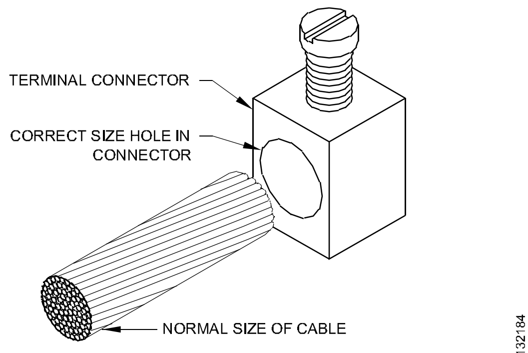


Fig 4

RIGHT METHOD

Cable end termination - crimping tool

Objectives: At the end of this lesson you shall be able to:
- **state the necessity of proper termination**
- **list the different types of terminations**
- **describe the parts and their functions of crimping tool**
- **state the advantages of crimping termination**

Necessity of termination

Cables are terminated at electrical appliances, accessories and equipment etc. for providing electrical connections. All terminations must be made to provide good electrical continuity, and made in such a manner as to prevent contact with other metallic parts and other cables.

Loose terminations will lead to overheating of cables, plugs and other connecting points due to higher resistance at those terminations. Fires may also be started due to the excess heat. Wrong termination like excess or extended conductor touching metallic part of the equipment may lead to giving shock to the person who comes in contact with the equipment.

Touching of strands projecting from one terminal with other terminal leads to short circuit. To conclude, we can state that wrong termination will lead to overheating of terminating points and cables, short circuits and earth leakage.

Types of termination

Crimp connection: In this type of connection the conductor is inserted into a crimp terminal and is then crimped with a crimping tool (Fig 1).

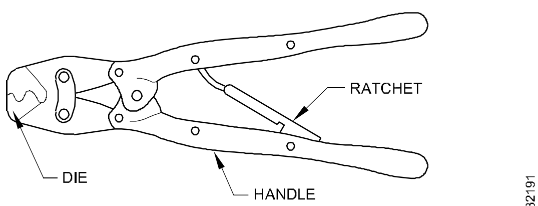


Fig 1

CRIMPING TOOL

It is important to choose a crimp terminal that matches the conductor diameter and the dimensions of the connecting screw terminal. (Figs 2 and 3)

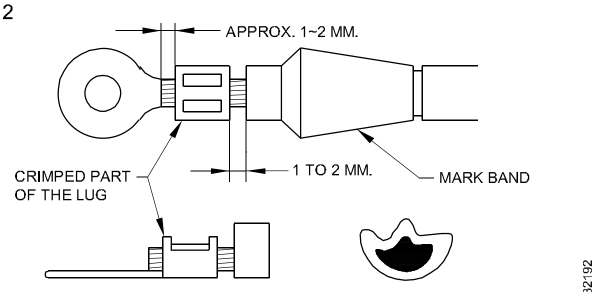


Fig 2

CRIMP TERMINAL CONNECTION

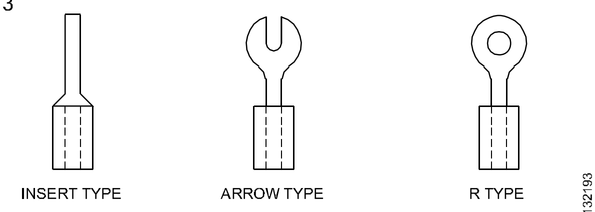


Fig 3

VARIOUS KINDS OF CRIMP TERMINALS

Insert screw setting: The conductor is inserted between the terminal block and the special form of washer (Fig 4), and then the screw is tightened.

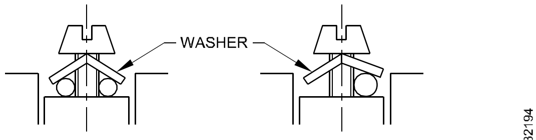
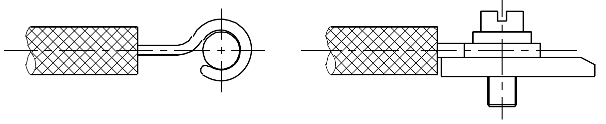


Fig 4

INSERT AND SCREW SETTING

Screw on terminals with loop/ring conductor: A loop is formed clockwise in the bare portion of the conductor to match the size of the screw diameter. Then the loop is inserted to the screw and tightened. (Fig 5) In the case of a stranded conductor, soldering of the loop is essential to prevent strands getting fray.

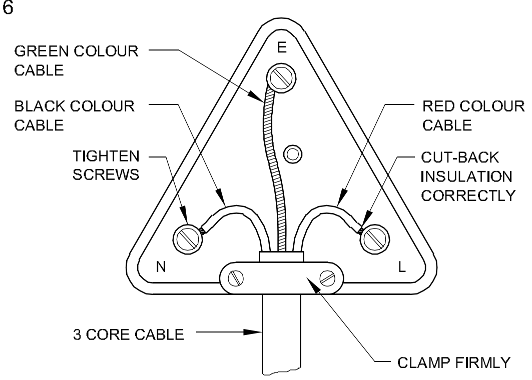
Fig 5



RING MAKE-UP SCREW SETTING

While connecting the plug and socket for extension of the cable, Line (L), the Neutral (N) and Earth (E) terminals must be properly identified by markings on them .(Fig 6)

Fig 6



INSIDE VIEW OF A 3-PIN PLUG

The colour code while connecting 3 core cable must be properly followed. Red wire to L, black/blue to N, green wire or yellow with green line to E terminal. The earth terminal in a 3 pin plug is bigger than the other two.

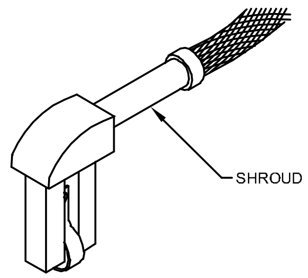
Connections and terminals

There is an electrical fire risk if:

- the current-carrying capacity of the cable is inadequate
- the capacity of the plug is inadequate
- the insulation is cut back too far
- the conductor is damaged while cutting back the insulation
- the connections are not right
- the cable is not adequately supported at the point of entry to the plug or to the appliance.

When a reinforcing rubber shroud is provided, ensure that it is used. (Fig 7)

Fig 7



RUBBER SHROUD FITTING ON CABLE

Crimping and crimping tool

The ends of cables can be prepared for termination with lugs by the soldering process or by mechanical means - compression or crimp fitting.

In crimp compression fitting, a ring-tongued terminal (lug) is to be compressed to the bared end of an insulated multi-strand cable. The process is called crimping and the tool used is called crimping pliers or crimping tool.

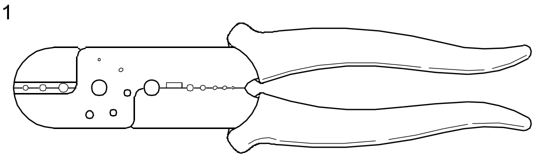
Compression type connectors apply and maintain pressure by compressing the connector around the conductor.

The principal purpose of the pressure is to establish and maintain suitable low contact resistance between the contact surfaces of the conductor. Improper crimping will create increased contact resistance and will cause overheating while carrying electrical load.

Crimping tools

The crimping pliers illustrated in Fig 1 is of a type which crimps from 0.5 to 6 mm cables.

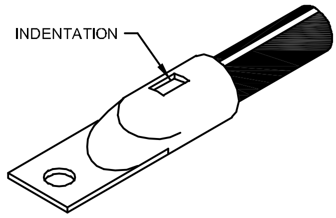
Fig 1



HAND CRIMPING PLIERS

The tool is operated by squeezing the handles. The jaws move together, grip and then crimp the fitting. Using the crimping tool that matches the specific crimp lug will give the correct crimping force for a properly executed crimp. Properly executed crimp will indent the top of the lug and the indentation will hold the conductor securely as shown in Fig 2.

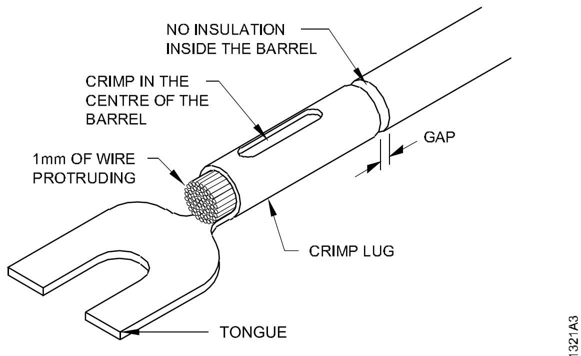
Fig 2



CORRECT EXECUTED CRIMPING

If the terminal has too deep a crimp, the strength of the joint is reduced. With too shallow a crimp, the electrical contact has a high resistance. Selection of the correct crimping tool is essential. A properly crimped terminal is shown in Fig 3.

Fig 3

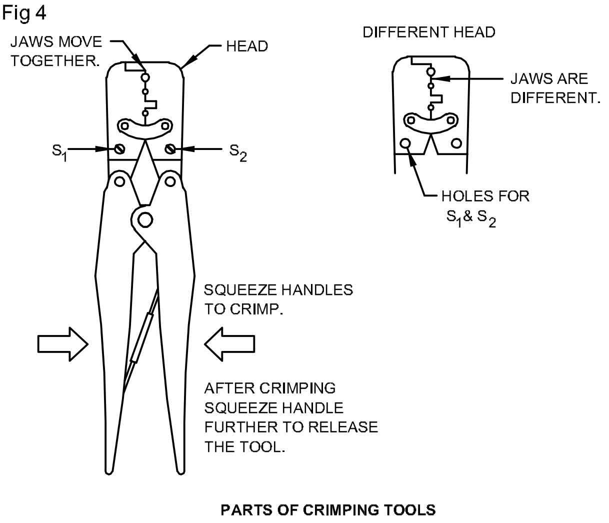


A PROPERLY CRIMPED TERMINAL

Terminal lug crimping pliers are available in lengths ranging from 180 to 300 mm. Crimping tools are available in sets. For higher capacity cables crimping tools are operated by hydraulic force.

Fig 4 shows another type of crimping tool which crimps from 26 to 10 SWG.

Fig 4



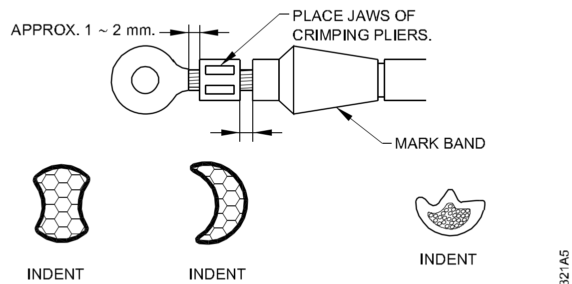
PARTS OF CRIMPING TOOLS

The head and jaws, may be removed, by unscrewing the screws S_1 and S_2. A head with different shaped jaws may then be secured to the tool. The shape of the jaws determines the shape of the crimp (indent). Some crimp sections are shown in Fig 5.

Safety

When using this type of crimping tool care must be taken not to trap the finger, as the operating cycle of the tool is non-reversible i.e. once the handles are squeezed together the jaws can only be released by applying further pressure to the handles as shown in Fig 4.

Fig 5



CRIMPED SECTION

Terminal types

It is important to consider both the mechanical and electrical requirements when selecting a lug connector.

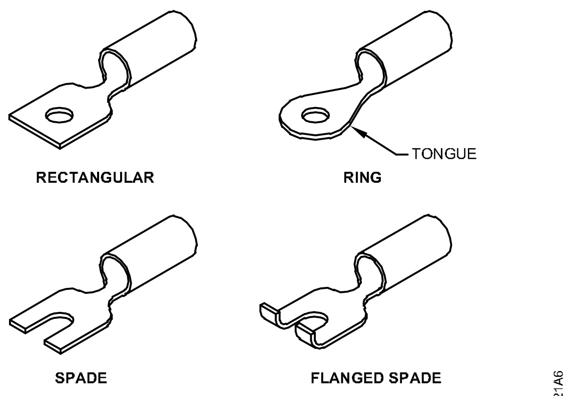
The factors are:

- the type of tongue, i.e. rectangular, ring, spade, etc.
- the mechanical size, i.e. tongue size and thickness, hole size etc. for the cable selected
- the electrical considerations such as the current carrying capacity, that may also determine some of the mechanical dimensions.

The electrical and mechanical requirements for the lug and the base material of the lug are decided by the cable material, and the place of connection will determine the minimum tongue size and the barrel size. The most commonly used base materials are copper and brass. Nickel, aluminium and steel are also used, but less frequently.

Fig 6 shows some lug connectors normally used in practice terminals. They are ring, rectangular, spade, flanged spade etc. Ring and rectangular terminals are not intended for frequent removal to disconnect the terminal whereas in spade and flanged spade lugs (terminals) the screw need not be removed to disconnect.

Fig 6



LUG CONNECTORS

Precautions for crimping tool application

Do not handle the job/tool roughly e.g. drop, hammer, etc. which may harm the tool.

Do not alter the crimping tool, e.g. alter the shape of the die etc.

Do not let metal chips adhere to the working position of the tool, particularly on the lower surface of replaceable die on the crimping part.

If a pin, spring, etc. is found damaged in the crimping tool, repair it immediately.

Apply oxide inhibiting grease to the aluminium conductor end just before crimping.

Advantages of crimping terminations

1 A properly made crimp is better in electrical conductivity and mechanical strength.

2 Less costly.

3 When the same size cables are to be terminated through lug connectors, the crimping process is faster than soldering.

4 The crimping operation surely needs good skill but soldering operation needs advanced skills.

5 Heat generated in the conductor sometimes melts the solder and the connection is open circuited. But crimped connection will not open that easily.

Current carrying capacity of copper & aluminium cables - voltage grading

Objectives: At the end of this lesson you shall be able to

- **list out the factors for selection of cables**
- **state the types of protection based on current carrying capacity**
- **state the size and number of strands available in copper and aluminium cables and their current carrying capacity**
- **state the rating factor and determine the current capacity of cables with respect to temperature**
- **differentiate between solid and stranded conductors.**

Selection of cables

The current carrying capacity of a particular area of cross-section cable depends upon the following factors.

- Type of conductors (metal)
- Type of insulation
- Cable run in conduit or in open surface
- Single or three phase circuit
- Type of protection - coarse or close excess current protection
- Ambient temperature
- Number of cables in bunches
- Length of circuit (permissible voltage drop) - this will be discussed at a later stage.

Depending upon the above factors the current rating of cables may vary to a great extent.

Information in this lesson will enable the wireman to select the correct cable under normal working conditions.

Current rating of cables based on type of protection

Cables insulated with PVC, may sustain serious damage when subjected, even for relatively short periods, to higher temperature than the temperature permissible for continuous operation.

Therefore, current ratings of cables insulated with PVC are determined not only by the maximum conductor temperature admissible for continuous rating but also by the temperature likely to be attained under conditions of excess current.

Hence, the current rating of cables are given under two headings:

- cables provided with coarse excess current protection
- cables provided with close excess current protection.

Coarse excess current protection

In this type of protection, circuit protection will not operate within four hours at 1.5 times the designed load current of the circuit which it protects.

The devices affording coarse excess current protection include:

- fuses which are having a fusing factor exceeding 1.5 times the marked rating.
- carriers and bases used in rewirable type electrical fuses.

Close excess current protection

In this type of protection the circuit protection will operate within four hours at 1.5 times the designed load current of the circuit which it protects.

Devices include:

- fuses fitted with fuse links having fusing factor not exceeding 1.5 times the marked rating (H R C & cartridge etc.)
- miniature and moulded case circuit breakers.
- circuit breakers set to operate at an overload not exceeding 1.5 times the designed load current of the circuit.

Electrical inspectors, who are assigned by the Government to test installation and give permission for effecting supply, now recommend close excess current protection devices like MCB and HRC fuses to be included in the circuit for safety to the user and to reduce fire accidents.

Rating factor with respect to protection

For circuits with coarse excess current protection (rewirable fuse unit) current rating of cables is given in Table 1. Though the cables can carry a higher value of current than the current notified in the Table 1, for circuits having coarse excess current protection, the permissible current in cables is obtained by multiplying the normal current capacity by a rating factor of 0.81, whereas for circuits protected by close current protection the normal current capacity is multiplied by a rating factor of 1.23.

The following example will clarify the above information.

Normal current carrying capacity of 1.5 sq mm copper cable = 16 amps (normal rating)

Current capacity of the same cable when protected by coarse excess current protection (Rating factor 0.81)

= Normal capacity x Rating factor

= 16 x 0.81 = 13 amps.

Close excess current protection (Rating factor 1.23)

= Normal capacity x Rating factor

= 16 x 1.23 = 19.7 = 20 amps.

Current capacity for close excess current protection could be obtained by the following formula also.

$$= \frac{\text{Coarse excess current protection rating}}{\text{Rating factor of coarse protection}} \times \text{Rating factor of close excess current protection}$$

Table 1

Current rating for single core PVC insulated sheathed copper and aluminium conductor cables of size 1 to 50 sq. mm at ambient temperature of 40°c (Refer to IS 694 Part I -1964). (Cables provided with coarse excess current protection.)

Nominal cross-sectional area	**Number and diameter of wires**	**Bunched and enclosed in conduit or trunking**			
		2 cables single phase AC or DC		**3 or 4 cables 3-phase AC**	
mm^2	Number of strands/ dia, in mm	Copper Amps.	Aluminium Amps.	Copper Amps.	Aluminium Amps.
1	1/1.12	11	–	9	--
1.5	1/1.40	13	8	11	7
2.5	1/1.80	18	11	16	10
4	1/2.24	24	15	20	13
6	1/2.80	31	19	25	16
10	1/1.40	42	26	35	22
16	7/1.70	57	36	48	30
25	7/2.24	71	45	60	38
35	7/2.50	91	55	77	47
50	19/1.80	120	69	100	59

Rating factor for ambient temperature

Further the current rating of cables is greatly affected by the ambient temperature. As such if the ambient temperature is other than 40°C the current rating shown in the above table should be multiplied by the rating factor given in Table 2.

Table 2

SL. No.	Ambient Temp. °C Rating factor for cables	25	30	35	40	45	50	55	60	65
1	Having coarse excess current protection	1.09	1.06	1.03	1.00	0.97	0.94	0.82	0.67	0.46
2	Having close excess current protection	1.22	1.15	1.08	1.00	0.91	0.82	0.70	0.57	0.40
3	Flexible cords	--	1.09	1.04	1.00	0.95	0.77	0.54	--	--

Example 1

Find the current rating of 2.5 sq mm, aluminium cable at 50°C. The circuit is single phase AC, protected by rewirable fuses and the cable is run in conduit.

Solution

The protection is coarse excess current protection. Hence referring to Table 1 the current rating of 2.5 sq mm aluminium cable at 40°C is = 11 amps.

Rating factor at 50°C referring to Table 2 = 0.94.

The current rating of 2.5 sq.mm aluminium cable protected by coarse excess current protection run in conduit and at ambient temperature of 50°C = 11 x 0.94 = 10 amps.

Example 2

Find the current rating of 4 sq mm copper cable at 60°C, when used in a 3-phase circuit and the circuit is protected by H R C fuses.

Solution

The protection is close excess current protection.

Referring to Table 1, the current rating of 4 sq. mm copper cable for coarse excess current protection (rewirable fuse) at 40°C, when used in 3 phase circuit is = 20 amps

Current rating for closed excess current protection at 40°C when used in 3-phase circuit =(20 x 1.23)/0.81 = 30.37 amps.

The rating factor at 60°C is (Referring to Table 2) = 0.57.

Hence, the current rating of 4 sq. mm copper cable in a circuit protected by close excess current protection at an ambient temperature of 60°C is = 30.37 x 0.57

= 17.31 amps

= say 17 amps.

Current rating of flexible cables is given in Table 3.

Advantages of stranded conductors over solid conductors

As stranded conductors are more flexible, chances of break of conductors and crack of insulation at the bend is less. They can be easily handled and laid.

Connections and joints of stranded conductors are stronger and have longer life.

Table 3

Current ratings for copper conductor flexible cords, insulated with PVC according to BIS No.694

Nominal cross-sectional area of conductor mm^2	Number and diameter of wires Number/mm	Current rating DC, single phase or 3-phase AC (Amperes)
0.50	16/0.20	4
0.75	24/0.20	7
1.00	32/0.20	11
1.50	48/0.20	14
2.50	80/0.20	19
4.00	128/0.20	26

Comparison between solid and stranded conductors

Solid conductor	Stranded conductor
Rigid.	Flexible.
Less mechanical strength.	More mechanical strength
Available in square,round and flat shapes.	Available in round shape having small diameters.
Used for bus-bars and in the winding of large capacity transformers.	Used for cables and wires.

In stranded conductors the insulation has a better grip on the wire.

Solid conductors between supports of overhead lines may break due to vibration. This breakage is less in stranded conductors.

The space between the strands permits flow of oil in U G cables enabling better insulation properties and cooling.

For a given area of cross- section stranded cables carry more current than solid conductors.

Table 4 shows the various types of cables.

Classification of voltage grading

Voltage is classified as

1 Low voltage (L.V): Normally not exceeding 250V (i.e.) from 0 to 250 volts.

2 Medium voltage (M.V): Exceeding 250V but not exceeding 650V from 250 to 650 volts

3 High voltage (H.V): Exceeding 650V but not exceeding 33000V.(650-33000 volts)

4 Extra high voltage: All voltages above 33000V comes under this category.

TABLE 4

Various types of electrical cables

Type of code	Voltage grade	Range of cross section in (mm^2)	Application	B.I.S. applicable
A.Wiring cable				
1 PVC insulated a)non-sheathed single core	250/440,650/ 1100	1.5 to 50	Domestic/industrial wiring in conduits. Domestic/industrial wiring in batten.	694 part II
b) PVC sheathed				
i) single core	-do-	-do-	-do-	
ii) flat twin-core	-do-	1.5 to 16	Domestic wiring for power plug.	
iii) flat twin-core ECC and 3-core	250/440	1.5 to 50	Domestic/industrial wiring on batten.	
iv) circular 2,3 or 4 core	650/1100V	1.5 to 300	Sub-main/industrial.	
c)non-sheathed single core and twisted twin flexible copper	250/400 650/1100	4 to 5	Temporary wiring interconnections, household applicances.	694 part I 694 part I&II
d)PVC sheathed circular twin, 3 and 4 core flexible copper	-do-	-do-		
e)Single extrusion	-do-	1.5 to 50	Domestic wiring on batten	694 part I,II
2 Polythene insulated and PVC sheathed with aluminium conductor				
a) single core flat & circular twin core	250/440	1.5 to 50	Domestic wiring on batten	1596
b) flat twin with ECC & circular	-do-	1.5 to 10	-do-	1596
3 Lead alloy sheathed i) single core ii) 2,3 and 4-core circular iii) twin & 3 core flat (ECC) 250/440	250/440 650/1100	Aluminium Copper 1.5 to 50 1.5 to 50 70 to 625 64.5 to 645 1.5 to 16 1.5 to 16 corrosive atmosphere.	Industrial wiring in damp	434 part I,II

Type of code	Voltage grade	Range of cross section in (mm^2)	Application	B.I.S. applicable
4 TRS sheathed i) single core ii) 2,3 and 4-core circular iii) Twin & 3 core flat (ECC) e) TRS sheathed flexible f) Fire resisting asbestos sheathed g) Poly Phropene sheathed flexible	 -do- -do- 250/440 650/1100 -do- -do-	 1.5 to 50 0.5 to 50 1.5 to 625 64.5 to 645 1.5 to 16 1.5 to 16	 Wiring residential on batten,industrial wiring Residential batten Welding cables in fire hazards. Training cable for lifts and other mobile equipments	 434 part I,II -do- -do- -do-
5 Weather-proof cables a)VIR insulated cotton, braided and treated with weather resistance compound b)PVC insulated PVC sheathed c)Polythene insulated, taped braided and compounded	250/440 650/1100 -do- -do-	1.50 to 50 -do- -do-	 Service connection and other outdoor application.	 434 part I,II 3035 part I 3035 part II
6 Power cables heavy duty 1.1kV grade PVC insulated PVC sheathed cable a)Unarmoured/armoured i) Single core ii) Twin core iii) Three-core iv) Three and a half core v) Four core	 650/1100 650/1100 -do- -do- -do-	 1.5 to 1000 1.5 to 500 1.5 to 400 16 to 400 1.5 to 50	 Armoured cable in singlecore not available. Unarmoured power cables are used only in protected places. Use of copper is banned for such applications	 1554 Part I/76
7 Paper insulated, lead, covered, single core, unarmoured. a) Twin-core, armoured b) Three and three and half, armoured.	1.1kV -do- -do- -do-	6 to 625 6 to 625 -do- -do- -do- -do- -do- -do-	Dry places, heavy duty, hazardous applications underground. Dry places for cotton braided, otherwise metal sheathed.	692-73 693-1965
8 Varnished cambric insulated	-do-			

N.B. 1 Where material of core is not mentioned, it is aluminium.
2 ECC - Earth continuity conductor.

Wire joints - Types - Soldering methods

Objective: At the end of this lesson you shall be able to
- **state the different types of wire joints and their uses**
- **state the necessity of soldering and types of soldering**
- **state the purpose and types of fluxes**
- **explain the different method of soldering and techniques of soldering**
- **explain the type of solder and flux used for soldering aluminium conductor**

Joints in electrical conductors are necessary to extend the cables, overhead lines, and also to tap the electricity to other branch loads wherever required.

Definition of joint: A joint in an electrical conductor means connecting/tying or interlaying together of two or more conductors such that the union/junction becomes secured both electrically and mechanically.

Types of joints: In electrical work, different types of joints are used, based on the requirement. The service to be performed by a joint determines the type to be used.

Some joints may require to have good electrical conductivity. They need not necessarily be mechanically strong.

Example : The joints made in junction boxes and conduit accessories.

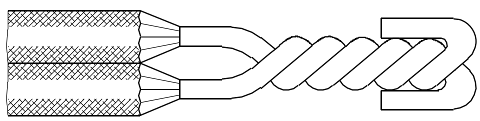
On the other hand, the joints made in overhead conductors, need to be not only electrically conductive but also mechanically strong to withstand the tensile stress due to the weight of the suspended conductor and wind pressure.

Some of the commonly used joints are listed below.

- Pig-tail or rat-tail
- twisted joints
- Married joint
- Tee joint
- Britannia straight joint
- Britannia tee joint
- Western union joint
- Scarfed joint
- Tap joint in single stranded conductor

Pig-tail/Rat-tail/Twisted joint: (Fig 1) This joint is suitable for pieces where there is no mechanical stress on the conductors, as found in the junction box or conduit accessories box. However, the joint should maintain good electrical conductivity.

Fig 1



RAT TAIL JOINT

ELN132511

Married joint: (Fig 2) A married joint is used in places where appreciable electrical conductivity is required, along with compactness.

Fig 2

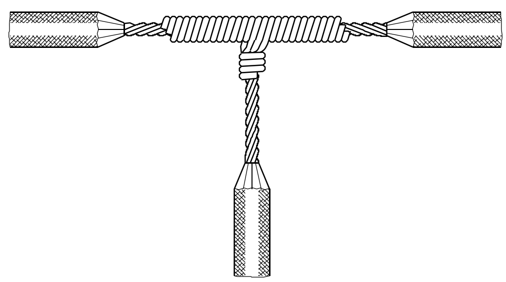
MARRIED JOINT

ELN132512

As the mechanical strength is less, this joint could be used at places where the tensile stress is not too great.

Tee joint (Fig 3)**:** This joint could be used in overhead distribution lines where the electrical energy is to be tapped for service connections.

Fig 3

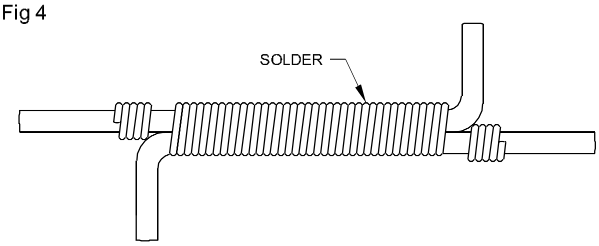


TEE JOINT

ELN132513

Britannia joint: (Fig 4) This joint is used in overhead lines where considerable tensile strength is required.

Fig 4



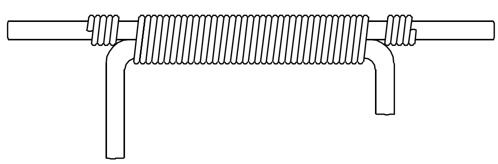
BRITANNIA JOINT

ELN132514

It is also used both for inside and outside wiring where single conductors of diameter 4 mm or more are used.

Britannia tee joint: This joint (shown in Fig 5) is used for overhead lines for tapping the electrical energy perpendicular to the service lines.

Fig 5

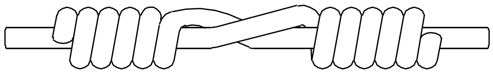


BRITANNIA TEE JOINT

ELN132515

Western union joint (Fig 6)**:** This joint is used in overhead lines for extending the length of wire where the joint is subjected to considerable tensile stress.

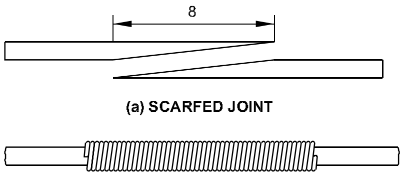
Fig 6



WESTERN UNION JOINT

Scarfed joint (Fig 7)**:** This joint is used in large single conductors where good appearance and compactness are the main considerations, and where the joint is not subjected to appreciable tensile stress as in earth conductors used in indoor wiring.

Fig 7



(b) SCARFED JOINT

Tap joints in single stranded conductors of diameter 2 mm or less

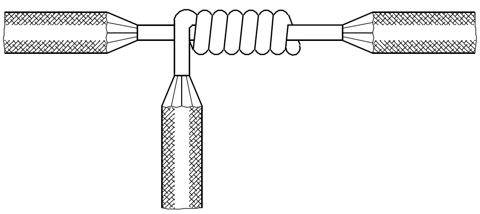
By definition, a tap is the connection of the end of one wire to some point along the run of another wire.

The following types of taps are commonly used.

- Plain
- Aerial
- Knotted
- Cross - Double - Duplex

Plain tap joint: (Fig 8) This joint is the most frequently used, and is quickly made. Soldering makes the joint more reliable.

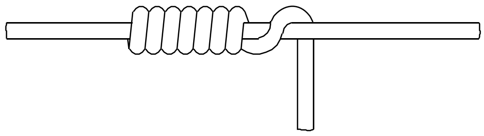
Fig 8



PLAIN TAP JOINT

Aerial tap joint : (Fig 9) This joint is intended for wires subjected to considerable movement, and it is left without soldering for this purpose. This joint is suitable for low current circuits only. It is similar to the plain tap joint except that it has a long or easy twist to permit the movement of the tap wire over the main wire.

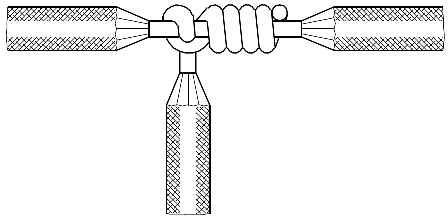
Fig 9



AERIAL TAP JOINT

Knotted tap joint : (Fig 10) A knotted tap joint is designed to take considerable tensile stress.

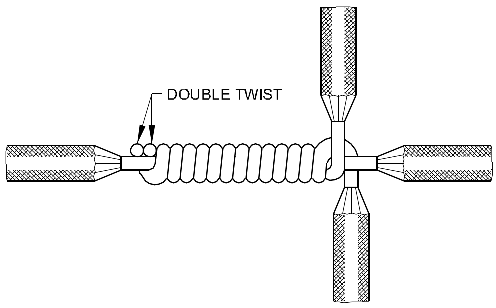
Fig 10



KNOTTED TAP JOINT

Duplex cross-tap joint: (Fig 11) This joint is used where two wires are to be tapped at the same time. This joint could be made quickly.

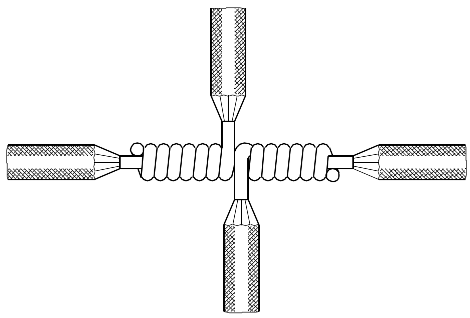
Fig 11



DUPLEX-CROSS TAP JOINT

Double-cross tap joint: (Fig 12) This joint (shown in Fig 12) is simply a combination of two plain taps.

Fig 12



DOUBLE-CROSS TAP JOINT

Soldering - types of solders, flux and methods of soldering

Soldering: Soldering is the process of joining two metal plates or conductors without melting them, with an alloy called solder whose melting point is lower than that of the metals to be soldered. The molten solder is added to the two surfaces to be joined so that they are linked by a thin film of the solder which has penetrated into the surfaces.

Necessity of soldering: Wire and cable joints should have the same electrical conductivity and mechanical strength as that of the parent conductor. This cannot be achieved by a mere mechanical joint. As such cable joints are soldered to have good mechanical strength, electrical conductivity and also to avoid corrosion.

Solders

The following are the general proportions of tin and lead used in the solders.

Designation	Compo-sition	Working temp.	Uses
Plumbing/ Tinman's solder	Tin-50% Lead-50%	212°C.or 413.6°F.	Heavy duty soldering
Electrician's solder	Tin-60% Lead-40%	185°C. or 365°F.	Tinning and soldering electrical joints etc.
Fine solder	Tin-63% Lead-37%	183°C.or 361°F.	Tinning/ Electrical/ Electronic Compound

Solder used for copper: The metal alloy used as a bonding agent in soldering is called a solder. The solders used for soft soldering consist of an alloy (mixture) of mostly tin and lead.

Factors influencing the choice of a solder

The factors that influence the choice of a solder are:

- place of use
- melting point
- solidification range
- strength
- hardness
- sealability
- price.

Flux: Flux is a substance used to dissolve oxides on the surface of conductors and to protect against de-oxidisation during the soldering process.

General properties of flux

The purpose of the flux is to

- dissolve oxides, sulphides etc. thereby making the soldering surface free of oxides and dirt
- prevent re-oxidation during the soldering operation thereby making the solder adhere to the surface to be soldered.
- facilitate the flow of the solder through surface tension so as to make the solder flow into the surface to be soldered.

The state of the flux can be solid or liquid.

The activity of the flux can be weak or strong, and is classified with regard to the corrosive properties, as slightly corrosive or highly corrosive.

The type of solder often determines the flux to be used for soldering.

The following table lists the fluxes used for soldering.

Table

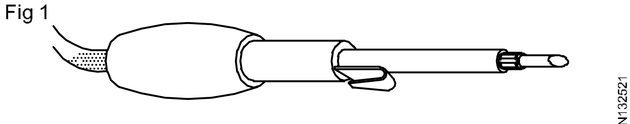
Sl. No.	Suitable flux	Metals/job - used for	Type of solder
1	Zinc chloride (acidic)	Cast iron, wrought iron, mild steel,cast steel, brass, bronze, copper etc. for soldering at low temperature	Tinman's solder Fine solder
2	Hydrochloric acid 10% diluted with water 90%	Zinc Galvanised iron	Coarse solder
3	Sal ammonia rosin (Not fully acid-free)	Copper, brass, tin plate, gun-metal: for clean and finer soldering work.	Coarse solder
4	Rosin	Joining electrical conductors	Electrician's solder
5	Tallow - (turpentine, acid free)	For joining electrical conductors, for soldering.	Electrician's fine solder

Fluxes shown under 1, 2 and 3 are not recommended for electrical purposes as they are highly corrosive, hygroscopic (absorb moisture), and the residues are electricity conductive.

Soldering methods

Soldering with a soldering iron: The most common method of soldering is with a soldering iron as shown in Fig 1. This is widely used for most kinds of soft soldering work.

Fig 1



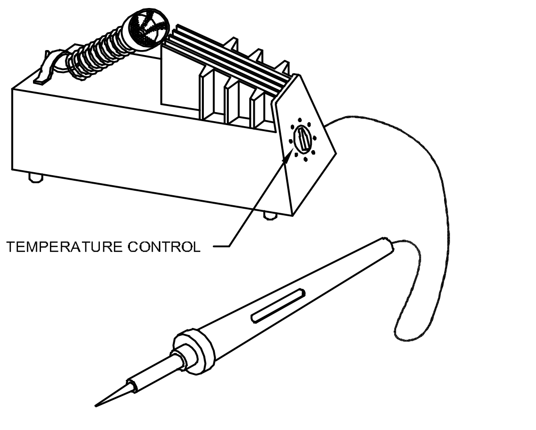
SOLDERING IRON

This tool is simple and inexpensive. Soldering irons are available in a wide range of sizes and models. Heating is generally by electrical means, though non-electrical irons are also used.

Temperature controlled soldering

For soldering miniature components on printed circuit boards, a temperature-controlled soldering iron is used as shown in Fig 2. The electrical supply given to the soldering iron is of low voltage, and is completely isolated from the main supply. Low voltage does not endanger the life of the user and will also not spoil the sensitive electronic components. Controlled temperature makes the job easy for the user.

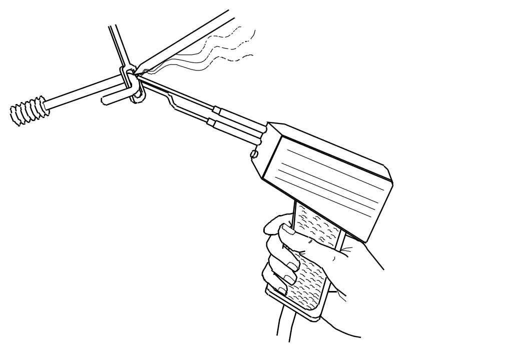
Fig 2



TEMPERATURE CONTROLLED SOLDERING IRON

Soldering with a soldering gun: This method, shown in Fig 3, is used for individual soldering, e.g. for servicing and repair work.

Fig 3



SOLDERING WITH A SOLDERING GUN

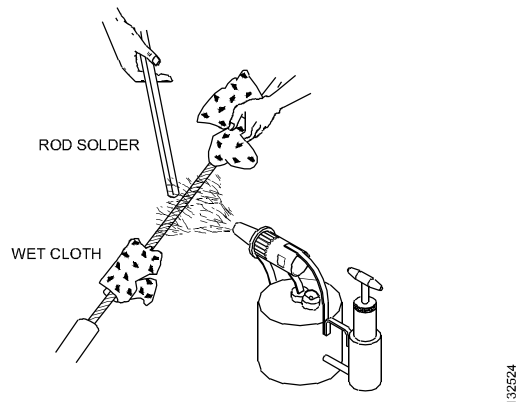
The principle of this method is that an electric current flows through a wire coil heating it. The temperature is difficult to check, and overheating can easily occur. This is the disadvantage.

Soldering with a flame: Soldering with a flame is used when the heat capacity of a soldering iron is insufficient.

This method, shown in Fig 4, permits rapid heating and is used primarily for larger jobs, such as piping and cable work, vehicle body repairs and some applications in the building trade.

This method requires skilful management of the flame.

Fig 4



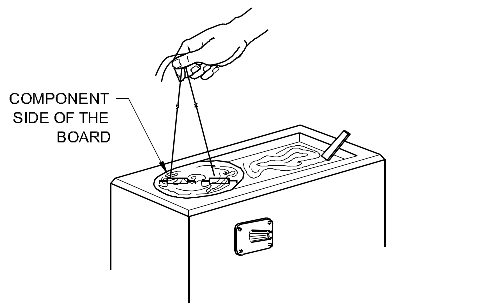
SOLDERING WITH BLOWLAMP

Dip soldering: This method, shown in Fig 5, is used for quantity production and for tinning work similar to component soldering on Printed Circuit Boards (P.C.B.). Components to be soldered or tinned are dipped into a bath of molten solder, which is heated electrically.

The solder is kept in motion by an agitator in order to obtain an even temperature and to keep the surface free from oxides. If no agitator is provided, the surface must be protected or skimmed at regular intervals to remove the oxides.

The temperature can be controlled very accurately.

Fig 5



DIP SOLDERING

Machine soldering: This method, shown in Fig 6, is used for quantity production, and is based on the principle that molten solder or a mixture of oil and molten solder is set in rapid motion, thus breaking up the oxide film. The solder comes into direct contact with the component ends to be soldered.

Soldering machines of different designs are used for wave soldering, cascade soldering and jet soldering.

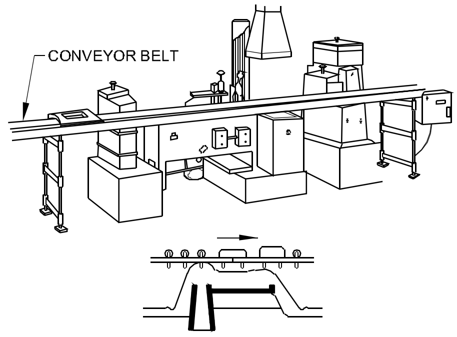
Equipment for machine soldering is expensive and the cost of production is high.

Accurate temperature control can be arranged.

Apart from these, any one of the following methods can also be used for soldering.

- Resistance soldering
- Induction soldering
- Oven soldering
- Soldering in vegetable oil
- Soldering by hot gas

Fig 6



MACHINE SOLDERING

Soldering - Techniques - pot and laddle

Soldering with electric soldering iron: In this method, the joining surface is first cleaned and then the flux is applied over the surface. The joint is then heated, and the solder is kept over the surface to be soldered, and heat is applied by keeping the soldering iron tip over it. The solder melts and spreads on the surface evenly.

The electric soldering iron: The heating element in the iron is heated by an electric current passing through it.

The bit is heated by the heating element.

The face of the bit is the part of the iron, used to make contact with the surfaces to be soldered.

Soldering irons of the following voltages and input power (wattage) are available (I.S.950-1980).

Ratings

Voltage	6	12	24	50	110	230 or 240
Wattage	25	25	25	25	25,75, 250	5,10,25,75, 125,250,500

Select an iron with adequate power to suit the size of the work.

The bit: Most bits are made of copper because it is a good conductor of heat. The face of the bit may be either:

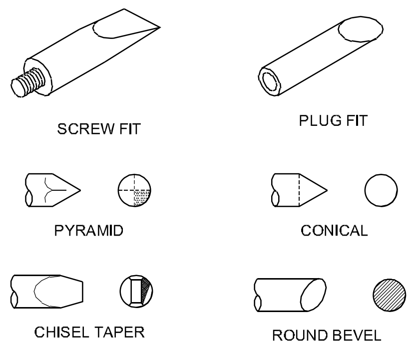
- un-plated or
- iron-plated.

Iron-plated faces do not wear out as rapidly as un-plated faces.

Most irons are so constructed that the bit can be changed.

Different shapes of bits are available as shown in Fig 1.

Fig 1

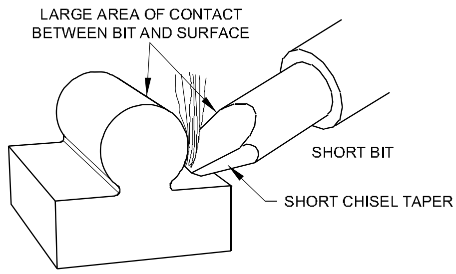


SHAPES OF SOLDERING BITS

Selecting the bit (Fig 2)**:** Select the bit to give a compromise between:

- the best approach to the work
- the shortest bit and bit taper
- the ideal contact with the surfaces.

Fig 2



SELECT CORRECT SOLDERING BIT FOR THE JOB

Care of the bit (Fig 3)**:** Un-plated bits become pitted quickly and get covered in oxide. If the iron is in constant use, this will occur within a few hours.

Fig 3

SOLDERING BITS

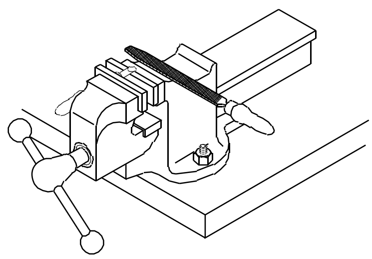
To make a good soldered joint, the bit must be maintained clean, smooth and correctly shaped.

Dressing the bit (Fig 4)**:** To dress an un-plated bit follow the procedure stated below.

- Switch off, unplug the iron and allow it to cool.
- Remove the bit from the iron, if possible.
- Mount the bit in a vice.
- File to shape.

Do not file the bit in an electronic assembly area. Copper dust from the bit may settle in the equipment and cause a short circuit. Iron-plated bits must not be filed. Renew when worn out.

Fig 4

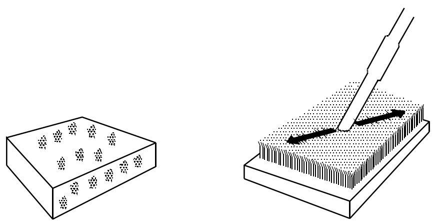


FILING THE SOLDERING BIT

Cleaning the bit: (Fig 5) The bit should be cleaned frequently. To clean the bit, rub the face of the un-plated bits on a wire brush or special sponge pad when the iron is hot.

Iron-plated bits must not be cleaned on a wire brush. Rub on a sponge pad.

Fig 5



CLEANING THE SOLDERING BIT

Wetting (soldering): To make a good joint, the solder must flow evenly over and between the surfaces to be soldered. Wetting is a term used to describe the extent to which this occurs.

Good wetting results can be obtained if:

- the surfaces are clean
- sufficient flux of the correct type is used
- the surfaces are hot enough
- the surfaces have been tinned.

Techniques of soldering

Soldering involves the following main operations.

- Tinning the soldering iron
- Cleaning the parts to be soldered
- Applying the solder

Tinning the soldering iron: To make the solder adhere to the tip of the soldering iron, the surface of the tip must be coated with the solder, and this operation is known as tinning.

First the tip is cleaned with a cloth and heated either directly or indirectly. The tip is then filed to remove the scales, and is wiped again with a cloth.

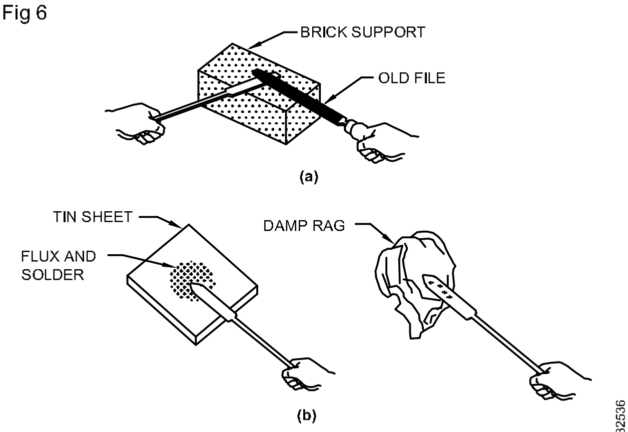
The right temperature for tinning could be judged by the change of colour of the tip when heated. If the surface of the copper tip tarnishes immediately, the temperature is high and needs to be cooled slightly by withdrawing the source of heat temporarily. A correctly heated tip tarnishes slowly.

After the soldering iron tip attains the correct temperature, place a small quantity of solder and the flux on a tin plate and rub the bit on the mixture. The solder should stick to the surface of the tip evenly. Wipe out the superfluous solder with a clean damp cloth.

The whole process of tinning is shown in Figures 6a and 6b.

The surface should present a bright silvery appearance when properly tinned.

Fig 6

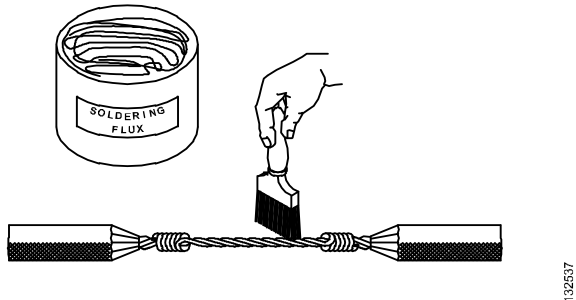


TINNING PROCESS

Cleaning the surface to be soldered: The parts to be soldered should be well cleaned for perfect soldering. The scales, dirt, oil and grease should be completely removed either by wiping or by rubbing with a sandpaper. Immediately after cleaning, the flux should be applied on the surface to avoid oxidization.

Applying the flux: The rosin which is recommended as a flux may be sprinkled over the surface to be soldered or may be applied with a brush as shown in the Fig 7.

Fig 7



APPLYING SOLDERING FLUX

Applying the solder: The quantity of the solder to be applied depends upon the size of the job. For small jobs like printed circuit boards soldering or soldering joints in wires of diameter 2 mm or lower, an electric soldering iron is used whereas for soldering joints of large sized cables, pot and ladle are used.

Soldering precautions: Remove the iron as soon as the solder has flowed over the surfaces.

Excessive heating may damage:

- the wire and its insulation
- the component being soldered
- the adjoining components.

Safety

Soldering irons can be dangerous if not maintained or used proprerly. Follow the directions given below.

Inspect the iron regularly for physical damage, especially the power cord. Replace it, if found damaged.

Keep the iron in a stand when not in use. This prevents burns and fires and protects the iron from damage.

Do not subject the iron to rough treatment.

Keep the iron away from all parts of the body and from its own power cord.

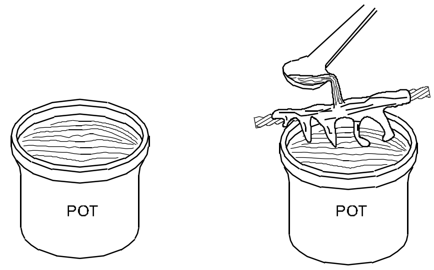
A proper earth connection must be made to all mains-connected irons. If you suspect that an iron is not earthed, do not use the iron.

Never flick excess solder off the bit. The hot solder may cause burns to someone or fall into a part of the work, and cause a short circuit.

Soldering with pot and ladle: (Fig 8) For larger sized jobs like underground cable jointing, a melting pot and ladle are used. The solder is kept in the pot and heated either by a blowlamp or by charcoal. Initially the surface to be soldered is cleaned and a coat of flux is given.

Then the surface to be soldered is heated by pouring molten solder over it in quick succession. The dripping solder is collected in a clean tray. After several pourings, the surface attains the same temperature as that of the molten solder. The flux is again applied and the solder is slowly poured on the surface as it forms an even layer. Superfluous solder collected in the tray is re-melted in the pot.

Fig 8



POT AND LADLE METHOD OF SOLDERING

Safety

Ensure that the conductor is dry and clean before applying the molten solder, and that it is not allowed to enter the insulation.

Never drop anything, including the metal to be soldered into the bath. Splashes of hot molten solder can cause serious injury. Always wear protective clothing when working with solder baths, like gloves, apron, boots etc. and ensure that no unprotected part of the body touches the pot.

When pouring solder over a joint, keep the ladle low as far as possible to prevent splashing of the molten solder over the sides of the pot.

During the solidification period, the parts of the joint must not be disturbed under any circumstances. If they are disturbed, the strength, conductivity and appearance of the joint will be endangered. The result will be what is often called cold solder and the joint will be defective.

Cooling must not be accelerated. If cooling is accelerated, the solder will assume a crystalline form. This lowers the mechanical strength.

Do not allow the molten solder to fall on to the gas pipe or the electric cables nearby.

Beware of the naked flames to avoid a fire risk.

Reconditioning of solder which is subjected to repeated melting

In practice, when the solder is subjected to repeated melting during the soldering process, the tin content in the solder is considerably reduced due to:

- the slug formation of tin on the molten solder
- oxidization of tin due to its low boiling point.

As such the solder, which is subjected to repeated heating, will have a low percentage of tin as compared with the solder taken from the stores.

To recondition the solder and to bring up the tin percentage, tin is added to the solder at the end of each use. The quantity to be added depends upon the length of time the solder is kept in the molten state.

Soldering aluminium cables

Soldering of aluminium cables: Soldering aluminium conductors is more difficult than soldering copper conductors owing to the highly tenacious, refractory and stable nature of the oxide film which forms immediately on any aluminium exposed to air.

This oxide film does not allow the solder to wet the surface to be soldered, and also prevents the solder from entering the interior surface by capillary action. Hence special solders and fluxes are used for aluminium soldering.

Solder: A special soft solder having a small percentage of zinc is used for joining aluminium conductors. (Soft solders are alloys which have a melting point below 300^0C.) IS 5479-1985 gives details of the chemical composition of soft solders and their grades used for soldering aluminium conductors. Details are given in Table 1.

The object of this small zinc content which is a common feature of aluminium solders is to fecilitate the alloying of the solder with an aluminium surface. A typical composition of solder with 51% lead, 31% tin, 9 % zinc and 9% cadmium with the brand name `ALCA P' solder is available in the market for soldering aluminium conductors. In addition a special solder by name Ker-al-lite is also available for soldering aluminium conductors.

Flux: In soldering aluminium conductors, organic fluxes of reaction type, free from chlorides and suitable for soft soldering are used.

The composition of the organic fluxes decomposes at approximately 250°C to effect the removal of the oxide film and also to assist in the spreading of the molten solder to enable tinning the de-oxidised surface immediately.

The major disadvantage of organic flux is that it tends to char at a temp. above 360°C. The charring, thus caused, renders the flux ineffective and gives rise to the danger of creating voids in the joint due to charred flux residues. For this reason, it is essential that the temp. of this solder during the operation is maintained well within 360°C. The commercial name of fluxes used for joining aluminium conductors are Kynal Flux and Eyre No.7.

Procedure of soldering aluminium cables

The procedure of soldering aluminium cables to standard copper lugs employing **Kynal's flux** and **Ker-al-lite** special solder is explained below.

Strip the cable in preparation for jointing in the usual manner.

Spread out the strands so as to effect a general loosening and slight displacement of the wires, and clean the surface preferably with a wire brush.

Apply a small quantity of flux by brushing well into the fanned-out ends of the conductor and baste (moisten) the fluxed conductor with a full ladle of molten solder.

Apply more flux and baste again with the molten solder. Continue to make repeated alternate applications of flux and solder until the wires exhibit a brightly tinned surface free from dull spots.

After the final basting, wipe off the surplus metal from the strands with a clean and dry piece of cloth.

Flux the lug inner surface and fill it with the molten solder.

Insert the tinned end of the cable inside the lug and hold both the cable and the lug firmly without shaking.

Allow the lug to cool and baste the surface quickly with the molten solder to remove the excess solder.

Wipe the lug surface with a clean cloth.

Apply a coating of graphite conducting grease on the lug before using.

Precautions to be followed while soldering aluminium

All surfaces must be scrupulously clean.

When a joint is being made between stranded conductors, the strands must be `stepped' to increase the surface area.

The surface must be fluxed before the heat is applied.

Safety

During the jointing operation copious fumes are given off when the flux is heated. These fumes contain small quantities of fluorine, and it is, therefore, advisable not to inhale them.

As smoking during the jointing operation results in the inhaling of toxic fumes, smoking during soldering should be avoided.

Table 1

Grade	**% of alloying elements**			**Melting temp.**	**Flux type**	**Applications**
	Zinc	**Lead**	**Tin**	**in °C**		
SnPb53Zn	1.75–2.25	52–54	45.71–45.21	170–215	Organic	Conductors of electrical cables
SnPb58Zn	1.75–2.25	57–59	40.66–40.6	175–220		-do-

Under ground (UG) cables - construction - materials - types - joints - testing

Objectives: At the end of this lesson you shall be able to
- **define UG cable**
- **explain the construction of UG cables**
- **list and state the insulating materials used in cables**
- **list out and state the types of UG cables used for 3 phase service**
- **state the types of cable joints and laying methods**
- **expalin the faults and testing procedures of cables.**

Under Ground (UG) cables

"A cable so prepared that it can withstand pressure and can be installed below the ground level and normally two or more conductors are placed in an UG cablewith separate insulation on each conductor"

Electric power can be transmitted (or) distributed either by over-head lines system or by underground cable system. The underground cable system have several advantage, such

Advantages

- Less chance to damage through storms or lightning.
- Low maintenance cost.
- Less chances of fault.
- Not affected by man- made problems like sabotage, strike etc.
- Voltage regulation in UG cables system is much better, because they have less inductive losses.
- Better general appearance of area compared to O.H lines.

Disadvantages

However, their major draw back / disadvantages are

- Initial cost of UG cable system is heavy.
- The cost of joints are more.
- Introduce insulation problems at high voltages compared with O.H lines.

For these reasons UG cables are employed where it is impracticable to use O.H lines like (i) thickly populated areas, where municipal authorities prohibit O.H lines for the reason of safety.

ii Around plants

iii In Substations,

iv Where maintenance conditions do not permit the use of O.H construction.

The UG cable were used many years for distribution of electric power in congested urban areas to low and medium voltages. Then with improvement and development of design, the manufactures have made it possible to use at high voltage transmission of electric power for same moderate distances.

General construction of UG cables

An underground cable essentially consists of one or more conductors covered with suitable insulation and surrounded by a protecting cover.

Necessity requirements for cables

In general, a cable must fulfill the following necessary requirements.

i The conductor used in cables should be tinned stranded copper or aluminum of high conductivity. (Strands of cable gives flexibility and carry more current).

ii The size of the conductor should be selected, so that the cable carries the desired load current without overheating and limits the voltage drop to a permissible value.

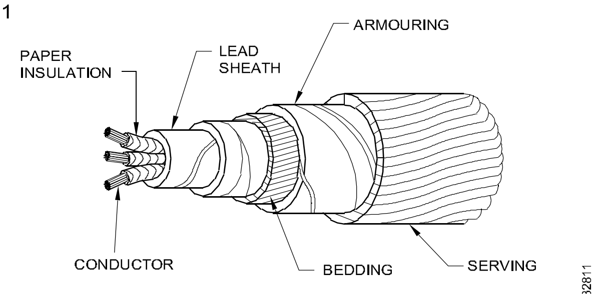
iii The cable must have proper thickness of insulation to ensure the safety and reliability for the designed voltage.

General construction of UG cables

iv The cable must be provided with suitable mechanical protection so that it may withstand the rough use in laying it.

v The materials used in cables should be with complete chemical and physical stability throughout.

Fig 1



CONSTRUCTION OF CORE CABLE

Construction of Cables

Fig 1 shows the general construction of a 3-core cable. The various parts are:

i) Cores or conductors: A cable may have one or more than one core (conductor) depending upon the type of service for which it is intended. For instance, the 3-

conductor cable shown in Fig 1 is used for 3-phase service. The conductors are made of tinned copper or aluminium and are usually stranded in order to provide flexibility to the cable and having high conductivity.

ii **Insulation:** Each core or conductor is provided with a suitable thickness of insulation, the thickness of layer depending upon the voltage to be withstood by the cable. The commonly used materials for insulation are impregnated paper, varnished cambric or rubber mineral compound. Petrolium jelly is applied to the layers of the cambric to prevent damage.

iii **Metallic sheath:** In order to protect the cable from moisture, gases or other damaging liquids (acids or alkalies) in the soil and atmosphere, a metallic sheath of lead or aluminium is provided over the insulation as shown in Fig 1. The metallic sheath is usually a lead or lead alloy.

iv **Paper Belt:** Layer of imprignated paper tape is wound round the grouped insulated cores. The gap in the cores is filled with fibrous insulating material (jute etc.)

v **Bedding:** Over the metallic sheath is applied a layer of bedding which consists of a fibrous material like jute or hessian tape. The purpose of bedding is to protect the metallic sheath against corrosion and from mechanical injury due to armouring.

vi **Armouring:** Over the bedding, armouring is provided which consists of one or two layers of galvanized steel wire or steel tape. Its purpose is to protect the cable from mechanical injury while laying it and during the course of handling. Armouring may not be done in the case of some cables.

vii **Serving:** In order to protect armouring from atmospheric conditions, a layer of fibrous material (like jute) similar to bedding is provided over the armouring. This is known as serving.

It may not be out of place to mention here that bedding, armouring and serving are only applied to the cables for the protection of conductor insulation and to protect the metallic sheath from mechanical injury.

Insulating materials for cables

The satisfactory operation of a cable depends to a great extent upon the characteristics of insulation used. Therefore, the proper choice of insulating material for cables is of considerable importance. In general, the insulating material used in cables should have the following properties:

i) High insulation resistance to avoid leakage current.

ii) High dielectric strength to avoid electrical breakdown of the cable.

iii) High mechanical strength to withstand the mechanical handling of cables.

iv) Non-hygroscopic i.e. it should not absorb moisture from air or soil The moisture tends to decrease the insulation resistance and hastens the breakdown of the cable. In case the insulating material is hygroscopic, it must be enclosed in a waterproof covering like lead sheath.

v) Non-inflammable

vi) Low cost compared to O.H. system.

vii) Unaffected by acids and alkalies to avoid any chemical action.

The type of insulating material to be used depends upon the purpose for which the cable is required and the quality of insulation to be aimed at.

The principal insulating materials used in cables are

(i) Rubber

(ii) Vulcanized India rubber

(iii) Impregnated paper

(iv) Varnished cambric and

(v) Polyvinyl chloride.

1 **Rubber:** Rubber may be obtained from milky sap of tropical trees or it may be produced from oil products. It has relative permittivity varying between 2 and 3, dielectric strength is about 30 KV/mm and resistivity of insulation is $10^{17}\ \Omega$ cm.

It suffers from some major drawbacks viz readily

(i) absorbs moisture

(ii) maximum safe temperature is low (about 38^0 C)

(iii) soft and liable to damage due to rough handling and ages when exposed to light.

Therefore, pure rubber cannot be used as an insulating material.

2 **Vulcanised Indian Rubber (V.I.R.) :** It is prepared by mixing pure rubber with mineral matter such as zinc oxide, red lead etc. and 3 to 5% of sulphur. The compound so formed is rolled into thin sheets and cut into strips. The rubber compound is then applied to the conductor and is heated to a temperature of about 150°C. The whole, process is called **vulcanization** and the product obtained is known as **V**ulcanized **I**ndian **R**ubber.

Advantages: Vulcanised India rubber has greater mechanical strength, durability and water resistant property than pure rubber.

Disadvantages: Its main drawback is that sulphur reacts quickly with copper. So, cables using VIR insulation must have tinned copper conductor. The VIR insulation is generally used for low and moderate voltage cables.

3 **Impregnated paper:** It consists of chemically pulped paper made from wood chippings and impregnated with some compound such as paraffinie or naphthenic material.
Aadvantages:

(i) Low cost

(ii) Low capacitance

(iii) High dielectric strength and

(iv) High insulation resistance.

Disadvantages:

(i) The paper is hygroscopic and even if it is impregnated with suitable compound

(ii) It absorbs moisture and thus lowers the insulation resistance of the cable.

For this reason, paper insulated cables are always provided with some protective covering and are never left unsealed. If it is required to be left unused on the site during laying, its ends are temporarily covered with wax or tar.

Since the paper-insulated cables have the tendency to absorb moisture, they are used where the cable route has a few joints. For instance, they can be profitably used for distribution at low voltages in congested areas where the joints are generally provided only at the terminal apparatus. However, for smaller installations, where the lengths are small and joints are required at a number of places, VIR Cables will be cheaper and durable than paper insulated cables.

4 Varnished cambric: It is a cotton cloth impregnated and coated with varnish. This type of insulation is also known as empire type. The cambric is lapped on to the conductor in the form of tape and its surface is coated with petroleum jelly compound to allow for the sliding of one turn over another as the cable is bent. As the varnished cambric is hygroscopic, therefore, such cables are always provided with metallic sheath. Its dielectric strength is about 4 KV/mm and permittivity is 2.5 to 3.8.

5 Polyvinyl chloride (PVC): This insulating material is a synthetic compound. It is obtained from the polymerization of acetylene and is in the form of white powder. For obtaining this material as a cable insulation, it is compounded with certain materials known as plasticiser which are liquids with high boiling point.

Advantages:

(i) It has high insulation resistance

(ii) Good dielectric strength

(iii) Mechanical toughness over a wide range of temperature.

This type of insulation is preferred over VIR in extreme environmental conditions such as in cement factory or chemical factory.

Classification of cables

Cables for underground service may be classified in two ways according to (i) the type of insulating material used in their manufacture (ii) the voltage for which they are manufactured. However, the later method of classification is generally preferred as

(i) Low-tension (L.T) cables – upto 1100 V

(ii) High-tension (H.T) cables – upto 11,000 V

(iii) Super-tension (S.T cables – from 22 KV to 33 KV

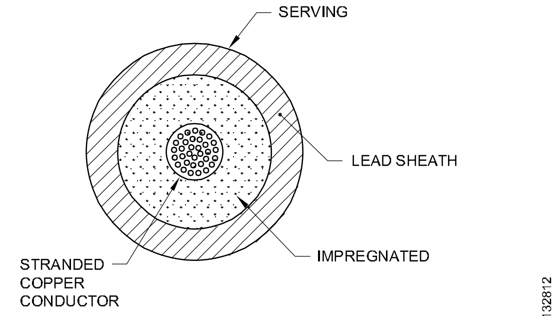
(iv) Extra high-tension (E.H.T) cables – from 33 to 66 KV

(v) Extra super voltage cables – beyond 132 KV

A cable may have one or more than one core depending upon the type of service for which it is intended. It may be (i) single-core (ii) two-core (iii) three-core (iv) four-core etc. For a 3-phase service, either 3-single core cables or three-core cable can be used depending upon the operating voltage and load demand.

Fig 2 shows the constructional details of a single-core low tension cable. The cable has ordinary construction because the stresses developed in the cable for low voltages (upto 6600 V) are generally small. It consists of one circular core of tinned stranded copper (or aluminium) insulated by layers of impregnated paper. The insulation is surrounded by a lead sheath which prevents the entry of moisture into inner parts. In order to protect the lead sheath from corrosion, an overall serving of compounded fibrous material (jute etc.) is provided. Single-core cables are not usually armoured in order to avoid excessive sheath losses. The principal advantages of single-core cables are simple construction and availability of large copper section.

Fig 2



SINGLE CORE L.T. CABLE

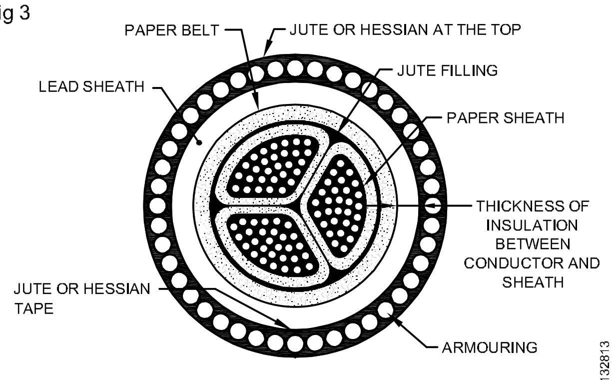
Cables for 3-Phase Service

In practice, underground cables are generally required to deliver 3-phase power. For the purpose, either three-core cables or three single core cables may be used. For voltages upto 66 KV, 3-core cable (i.e. multi-core construction) is preferred due to economic reasons. The following types of cables are generally used for 3-phase service.

1. Belted cables – upto 11 KV
2. Screened cables – from 22 KV to 66 KV
3. Pressure cables – beyond 66 KV

1. Belted cables

Fig 3



BELTED TYPE CABLE

These cables are used for voltages upto 11 KV but in extraordinary cases, their use may be extended upto 22 KV. Fig 3 shows the constructional details of a 3-core belted cables. The cores are insulated from each other by layers of impregnated paper.

Another layer of impregnated paper tape called paper belt is wound round the grouped insulated cores. The gap between the insulated cores is filled with fibrous insulating material (jute etc.) The belt is covered with lead sheath to protect the cable against ingress of moisture and mechanical injury.

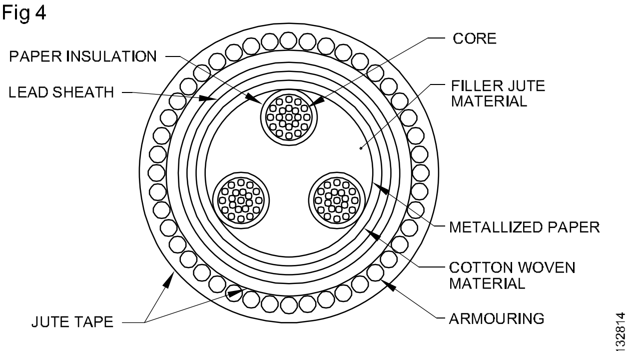
The belted type construction is suitable only for low and medium voltages as the electrostatic stresses developed in the cables for these voltages are more or less radial i.e. across the insulation. However, for high voltages (beyond 22 KV), the tangential stresses also become important.

2. Screened cable

These cables are meant for use upto 33 KV but in particular cases their use may be extended to operating voltages upto 66 KV. Two principal types of screened cables are H-type cable and S.L. type cables.

(i) **H-type cables**. This type of cable was first designed by H. Horchstadter and hence the name. Fig 4 shows the constructional details of a typical 3-core, H-type cable. Each core is insulated by layers of impregnated paper. The insulation on each core is covered with a metallic screen which usually consists of a perforated aluminium foil.

Fig 4



H TYPE CABLE

The cable has no insulating belt but lead sheath, bedding, armouring and serving follow as usual. As all the four screens (3 core screens and one conducting belt) and the lead sheath are at earth potential.

Advantages:

• The posibility of air pockets or volds in the dielectric is eleminated

• The metalic screen increase the heat dissipating power of the cable

(ii) **S.L. type cables** Fig 5 shows the constructional details of 3-core S.L **(separate lead)** type cable. It is basically H-type cable but the screen round each core insulation is covered by its own lead sheath. There is no overall lead sheath but only armouring and serving are provided.

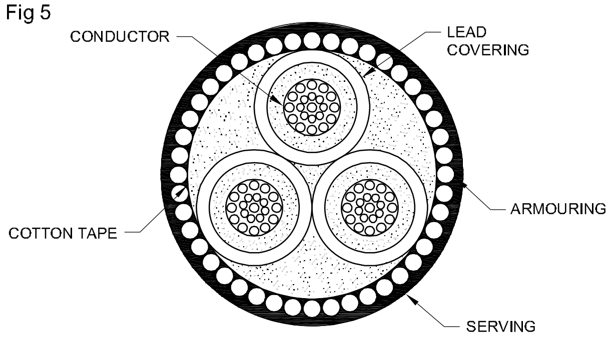
The S.L type cables have two main advantages over H-type cables.

a) The separate sheaths minimize the possibility of core-to-core breakdown.

b) Bending of cables become easy due to the elimination of overall lead sheath.

The disadvantage is that the three lead sheaths of S.L. cable are much thinner than the single sheath of H-cable

Fig 5



SL TYPE CABLE

Limitations of solid type cables

All the cables of above constructions are referred to as solid type cables because solid insulation is used and no gas or oil circulates in the cable sheath. The voltage limit for solid type cables is 66 KV due to the following reasons:

a. As a solid cable carries the load, its conductor temperature increases and the cable compound (i.e. insulating compound over paper) expands. This action stretches the lead sheath which may be damaged.

b. When the load on the cable decreases, the conductor cools and a partial vacuum is formed within the cable sheath. If the pinholes are present in the lead sheath, moist air may be drawn into the cable. The moisture reduces the dielectric strength of insulation and may eventually cause the breakdown of the cable.

c. In practice, voids are always present in the insulation of a cable. Modern techniques of manufacturing have resulted in void free cables. However, under operating conditions, the voids are formed as a result of the differential expansion and contraction of the sheath and impregnated compound.

3. Pressure cables

For voltages beyond 66 KV, solid type cables are unreliable because there is a danger of breakdown of insulation due to the presence of voids. When the operating voltages are greater than 66 KV, pressure cables are used. In such cables, voids are eliminated by increasing the pressure of compound and for this reason they are called pressure cables. Two types of pressure cables viz oil filled cables and gas pressure cables are commonly used.

(i) **Oil filled cables.** In such type of cables, channels of ducts are provided in the cable for oil circulation. The oil under pressure (it is the same oil used for impregnation) is kept constantly supplied to the channel by means of external reservoirs placed at suitable distances (say 500 m) along the route of the cable.

Oil under pressure compresses the layers of paper insulation and is forced into any voids that may have formed between the layers. Due to the elimination of voids, oil-filled cables can be used for higher voltages, the range being from 66 KV upto 230 KV.

Oil-filled cables are of three types viz.

(i) Single-core conductor channel

(ii) Single-core sheath channel and

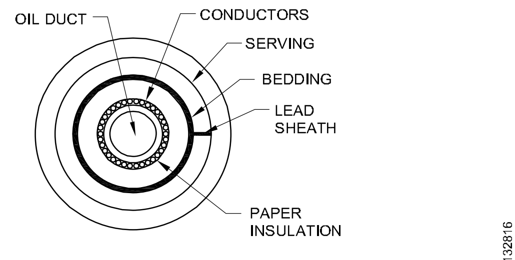
(iii) Three-core filler-space channels.

(i) Single-core Conductor channel

Fig 6 shows the constructional details of a single-core conductor channel, oil-filled cable. The oil channel is formed at the centre by stranding the conductor wire around a hallow cylindrical steel spiral tape. The oil under pressure is supplied to the channel by means of external reservoir. As the channel is made of spiral steel tape, it allows the oil to percolate between copper strands to the wrapped insulation.

The oil pressure compresses the layers of paper insulation and prevents the possibility of void formation. The disadvantage of this type of cable is that the channel is at the middle of the cable which is at full voltage w.r.t earth, so that a very complicated system of joints is necessary.

Fig 6

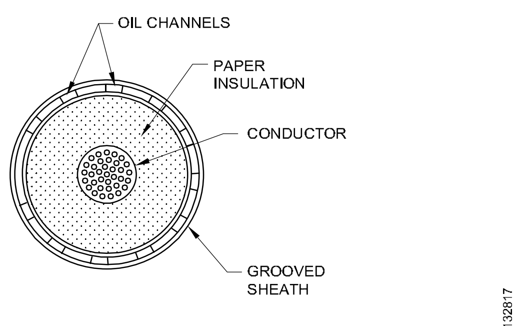


SINGLE - CORE CONDUCTOR CHANNEL OIL - FILLED CABLE

(ii) Single-core sheath channel (Fig 7)

In this type of cable, the conductor is solid similar to that of solid cable and is paper insulated. However, oil ducts are provided in the metallic sheath.

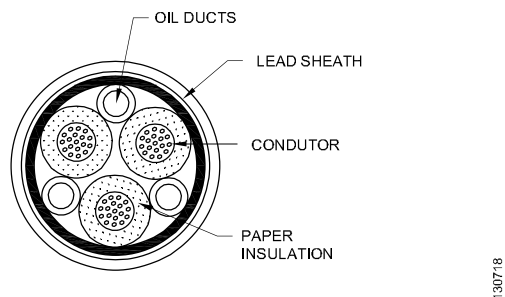
Fig 7



OIL - FILLED CABLES

In the 3-core oil-filled cable shown in Fig 8, the oil ducts are located in the filler space. These channels are composed of perforated metal-ribbon tubing and are at earth potential.

Fig 8



THREE CORE OIL FILLED CABLES

Advantages

(a) Formation of voids and ionization are avoided.

(b) Allowable temperature range and dielectric strength are increased.

(c) If there is leakage, the defect in the lead sheath is at once indicated and the possibility of earth faults is decreased.

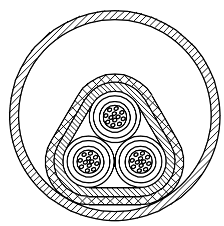
Disadvantages

(a) High initial cost and complicated system of laying

(ii) **Gas pressure cables**. The voltage required to set up ionization inside a void increases as the pressure is increased. Therefore, if ordinary cable is subjected to a sufficiently high pressure, the ionization can be altogether eliminated. At the same time, the increased pressure produces radial compression which tends to close any voids. This is the underlying principle of gas pressure cables.

Fig 9 shows the section of external pressure cable designed by Hockstadter, Vogal and Bowden. The construction of the cable is similar to that an ordinary solid type except that it is of triangular shape and thickness of lead sheath is 75% that of solid cable. The triangular section reduces the weight and gives low thermal resistance but the main reason for triangular shape is that the lead sheath acts as a pressure membrane. The sheath is protected by a thin metal tape. The cable is laid is a gas-tight steel pipe.

Fig 9



EXTERNAL PRESSURE CABLE

The pipe is filled with dry nitrogen gas at a pressure of 12 to 15 atmospheres. The gas pressure produces radial compression and closes the voids that may have formed between the layers of paper insulation.

Advantages:

a) Cables can carry more load current

b) Operate at higher voltages than a normal cable.

c) Maintenance cost is small and the nitrogen gas helps in quenching any flame.

Disadvantages:

The overall cost is very high.

Further the cables are also classified according to their insulation system as under:

PVC insulated cables	(Poly vinyl chloride)
MI cables	(Mineral insulation)
PILC cables	(Paper insulated lead covered)
XLPE cables	(Cross linked poly ethylene)
PILCDTA cables	(Paper insulated lead covered double tape armoured)

The specification of underground cables

The cables shall carry the following information either labelled or stenciled on the reel or drum or container.

1 Reference to the Indian Standard; for example Ref. IS 694-1977.

2 Manufacturer's name, brand name or trademark.

3 Type of cable and voltage grade.

4 Number of cores.

5 Nominal cross-sectional area of conductor.

6 Cable code.

7 Colour of cores (in case of single core cables)

8 Length of cable on the reel, drum or coil

9 Number of lengths on the reel, drum or coil (if more than one).

10 Direction of rotation of drum (by means of arrow).

11 Approximate gross weight.

12 Country of manufacturing.

13 Year of manufacture.

Fig 10 shows the paper insulated 3 phase 3 ½ core cable.

UG cables laying method

The reliability of the underground cable (UG) installation depends upon the proper laying and attachment of fittings (i.e) cable and boxes, joints, branch connectors etc.

Methods of laying of UG cables

The following are the methods of laying underground cables

1 Laying direct in ground

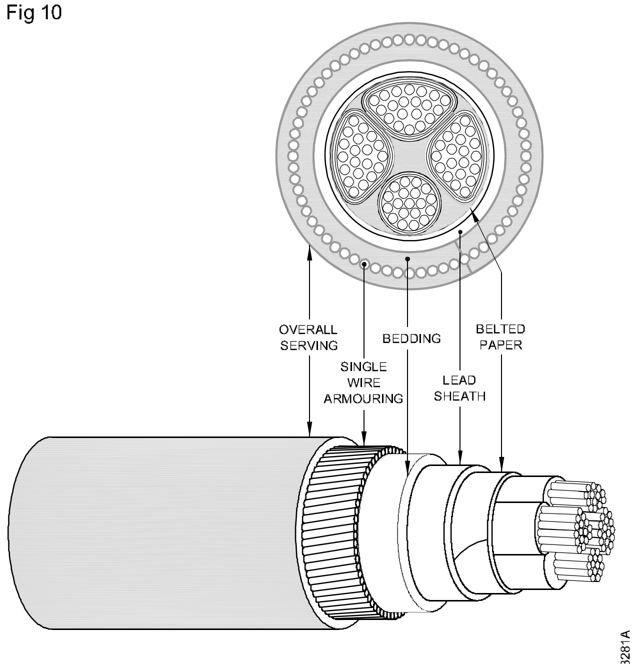
2 Laying in ducts

3 Laying on racks in air.

4 Laying on racks inside a cable tunnel.

5 Laying along buildings or structures.

Fig 10



PAPER INSULATED 3 PHASE 3 ½ CORE CABLE

The choice of any of the systems given above depends on

(i) The actual installation conditions

(ii) Inital cost of laying

(iii) Maintenance and repair charges

(iv) Deisred care in replacement of any cable or adding new cables for the future.

As far as the possible cable should be laid along the roads and streets. Power and communication cables should cross at right angles.

During the preliminary stages of laying the cable, consideration should be given to a proper location of the joints position so that when the cable is actually laid, the joints are made in the most suitable places.

As far as possible water logged locations, carriage ways, pavements, proximity to telephone cables, gas or water mains in accessible places, ducts pipes, racks etc shall be avoided for joint position.

Laying direct in ground:

This method involves digging a trench in the ground and laying cable(s) on a bedding of minimum 75 mm riddled soil or sand at the bottom of the trench, and covering it with additional riddled soil or sand of minimum 75 mm and protecting it by means of tiles, bricks or slabs.

Depth: The desired minimum depth from ground surface to the top of cable is as follows:

a) High voltage cables, 3.3 KV to 11 KV rating : 0.9 m.

b) High voltage cables, 22 KV, 33 KV rating : 1.05 m.

c) Low and medium voltage and control cables : 0.75 m.

d) Cables at road crossings : 1.00 m.

e) Cables at railway level crossings (measured from bottom of sleepers to the top of pipe) : 1.00 m.

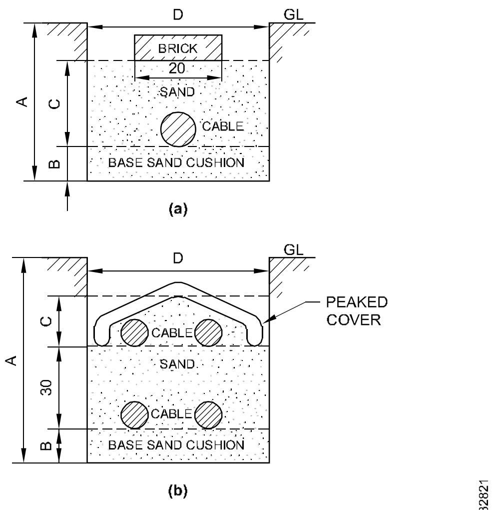
Width: The width of a trench for laying a single cable should be minimum 35 cm. When more than one cable is laid in the same trench in horizontal formation, the width of the trench shall be so increased that the inter-axial spacing between two cables is 20 cm.

Clearance from the terminal cable to the sides of a trench should be 15 cm.

Cable is protected by sand or layer of brick as shown in Fig 1a. Bricks should be second class bricks of a size not less than 20 cm x 10 cm x 10 cm and laid for full length for one cable (bricks to be laid breadthwise).

When more than one cable is to be laid in the same trench, this protective covering shall extend atleast 5 cm. over the sides of the end cables. An alternative to this covering can be earth ware or R.C.C. or fire-bricks of peaked covers section as shown in Fig 1b.

Fig 1



LAYING DIRECT IN GROUND METHOD

It is good practice to leave about 3 metres of cable spare in a loop formation near poles and joints, so that in case joint fails, this additional cable comes to rescue. Cable should be laid 0.4 metre away from water and power mains.

For cable of rating

Ref.	Upto 1.1 kV	Exceeding 1.1 kV
A	75	120
A1	(75+n1x30)	(120+n1x30)
B	8	8
C	17	17
D	35	35
D1	(30+n2x20)	(30+n2x20)
E	15	15

n1 = Number of additional cables in vertical formation.

n2 = Number of additional cables in horizontal formation.

For road crossings cast iron, or 2nd class RCC pipes or M.S/G.I. Pipe of medium class having an appropriate diameter should be laid during construction of the road to avoid damage to the road later on. The top surface of the pipe should be at a minimum depth of 1m. Pipes provided for entry to a building shall slope upward to prevent entry of water into the building. After laying of the cable they should be sealed.

Advantages

1 It is a simple and less costly method.

2 It gives the best conditions for dissipating the heat generated in the cables.

3 It is a clean and safe method as the cable is invisible and free from external disturbances.

Disadvantages

1 The extension of load is possible only by a complete new excavation which may cost as much as the original work.

2 The alterations in the cable network cannot be made easily.

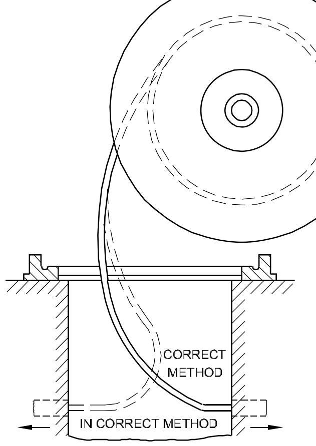
3 The maintenance cost is very high.

4 Localisation of fault is difficult.

5 It cannot be used in congested areas where excavation is difficult.

Drawing the cables into duct pipes: When drawing the cables through ducts, lack of space in the drawing pits usually restricts the distance from the cable drum to the duct mouth. It is essential that the direction of curvature of the cables is not reversed as it enters the duct. If the cable drum is on the same side of the drawing pit, as shown in Fig 2, this condition is fulfilled.

Fig 2



METHOD OF PULLING CABLES INTO DUCTS

Advantages

1 Reparis, alterations or additions to the cable network can be made without opening the ground.

2 As the cables are not armoured, therefore, joints become simpler and maintenance cost is reduced considerably.

3 There are very less chances of fault occurrence due to strong mechanical protection provided by the system.

Disadvantages

1 The initial cost is very high.

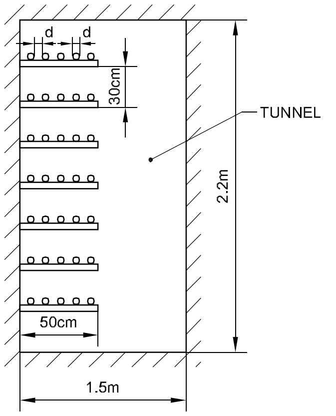
2 The current carrying capacity of the cables is reduced due to the close grouping of cables and unfavourable conditions for dissipation of heat.

This method of cable laying is suitable for congested areas where excavation is expensive and inconvenient, for once the conduits have been laid, repairs or alterations can be made without opening the ground. This method is generally used for short length cable routes such as in workshops, road crossing where frequent digging is costlier or impossible.

Laying cables on racks in air: Inside buildings, industrial plants, generating stations, substations and tunnels, cables are generally installed on racks fixed to the walls or supported from the ceiling. Racks may be ladder or perforated type and may be either fabricated at the site or pre-fabricated. Considerable economy can be achieved by using standard factory made racks. The necessary size of the racks and associated structure has to be worked out taking into consideration the cable grouping and permissible bending radii. Fig 3 shows the method of laying cables inside a tunnel on racks.

Laying cables along buildings or structures: Cables can be routed inside the building along with structural elements or with trenches under floor ducts or tunnels. The route of the proposed cable should be such that intersection with other cables will be minimum. The route should not subject these cables to any vibrations, damage due to heat or other mechanical causes. All adequate precautions should be taken to protect the cables.

Fig 3



LAYING OF CABLE INSIDE TUNNEL

Precautions while handling cables

1 Prevent the cable from dragging on the floor.

2 Prevent kinking of the cable.

3 After laying the cable in the ducts it should be immediately covered or suspended.

Cable jointing methods: This process consists of the following steps.

a) Exact measurement of the cable for insulation removal.

b) Removal of insulation.

c) Replacing of the original insulation with high grade tapes and sleeves.

d) Dressing the cable ends and conductor joints through sleeves/split sleeves.

e) Providing separators between cables.

f) Fixing a cast iron or any other protective shell around the joint and filling the joint boxes with molten bitumen compound.

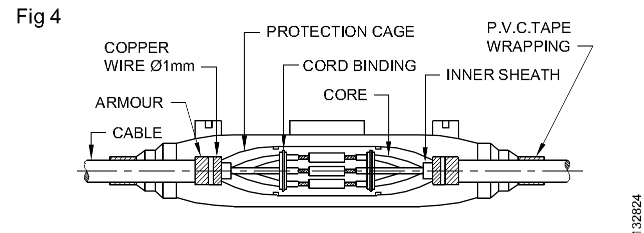
g) Plumbing metallic sleeves or brass glands to the lead sheath of the cable to prevent moisture from entering the joint in case of cast iron joint boxes or tape insulation in case of cast resin kit joint boxes.

Straight through joints

The emphasis should be laid on quality and selection of proper cable, cable accessories, proper jointing techniques. The quality of joint in cable should be such that, it does not add any resistance to the circuit. The material and techniques employed in joining the cables should give adequate mechanical and electrical protection to the joint under all service conditions. The joints should further be resistant to corrosion and other chemical effects.

For PILC cable: For paper insulated lead sheathed cables, straight joints are made either by using sleeve joints or crimping joints up to voltage grade 11 KV. Above 11 KV, compound filled copper or brass sleeves, along with cast iron, fibre glass protection boxes are used.

Fig 4 shows such a joint.

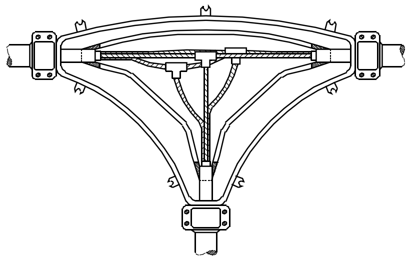


STRAIGHT THROUGH JOINTS FOR CABLES 3.3 KV GRADE

The cast iron protection boxes used up to 11 KV or moulds used for 1.1 KV joints in cast resin joints should conform to the relevant Indian Standard. Above 11 KV cast resin system is not yet standardized.

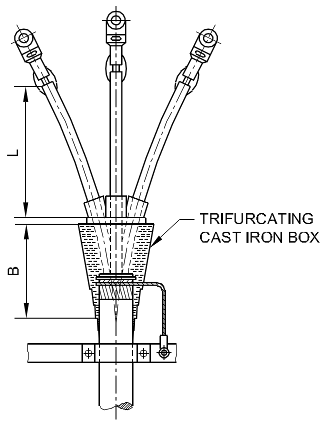
Tee joint: These joints are to be restricted up to 11 KV.

These joints are made either using cast resin kits or C.I. boxes with or without sleeves for PILC cables and cast resin kits for PVC and XLPE cables. (Fig 5)



TEE JOINT OF 11 kV PAPER INSULATED CABLE

Tri-furcating end connections: In order to connect UG cables to the air break switches etc. tri-furcating boxes are used. They can be either cast resin type up to 1.1 KV or cast iron type for 11 KV and above. This type of box is shown in Fig 6.



TERMINATION FOR PVC CABLE

Method of preparing and filling compounds

– Hot pouring

– Cold pouring

Hot pouring compounds: A bituminous compound of melting temperature 90°C and pouring temperature 180°C - 190°C is used for hot pouring.

Properties: The bituminous compound has the following properties.

a) High electrical strength

b) High resistance to moisture

Compounding process: Heat the compound in a special bucket on firewood or charcoal fire, stir with a clean metal rod to have even melting of the compound. Check the temperature with a thermometer and heat the compound up to 180° to 190°C.

Heat the sealing box to 70°C with a blow torch. Open all air escape plugs. Fit a heated funnel to the pouring hole. Pour the compound carefully and evenly in 2 or 3 stages with an interval between them to allow the compound to solidify. Take care that no air bubble is trapped inside.

Cold pouring compound: Cold pouring is used by using cast resin system for PVC cable jointing. This has been developed for application up to 11 KV grade cables. The compound consists of a resin base and a polyamino hardener. The two component liquids are mixed at the site in accordance with the recommendation of the manufacturer.

Typical epoxy straight joint for PVC cable: In this system of jointing the insulation is removed and conductors are joined. The core joints in the case of LV/MV cables should be kept apart to avoid any flash over between them. Spacers are provided between the cores for H.V. cables.

No insulation is applied over the core joints. A cover earth ring is placed tight over the two cut ends of the armour and soldered to the armour wires. The two rings are then jointed by a copper wire and the cut ends of the armouring are bent over the rings to have continuity of armour as earth conductor.

Sandpaper is applied to the inner sheath surface and is cleaned by using methyl chloride. The joint is enclosed by plastic mould, which is in two parts, whose ends are duly cut to match the size of cable. PVC tape is wrapped at the two places where the mould will touch the cables. The two halves are pasted together and kept clamped to avoid any air gap. The mould ends are enclosed with putty which is supplied in the joint kit.

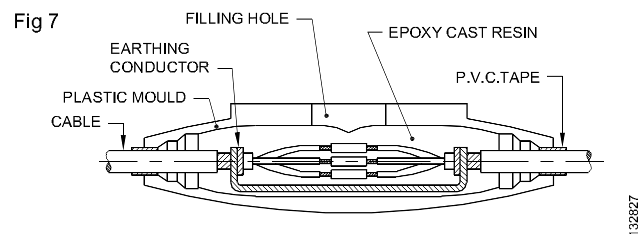
The expiry date of resin is checked and the hardener added to resin. The mixture is churned thoroughly for about 15 to 20 minutes till the colour of the mixed compound becomes grey. The mix is poured slowly into the mould taking care to avoid formation of air bubbles till the mould is filled and it comes out at the risers.

Allow the joint to set for a minimum of three hours till it becomes a solid mass before charging the cable. The mould may be removed, if desired.

Normally all the components required for joints are supplied as kits for various sizes of cables.

Fig 7 illustrates a typical straight through and outdoor termination of PVC cable with epoxy resin respectively.

Fig 7



TYPICAL EPOXY STRAIGHT JOINT FOR PVC CABLE

Types of cable faults and testing procedure

The common faults which are likely to occur in cables are:

1. **Ground fault.** The insulation of the cable may breakdown causing a flow of current from the core of the cable to the lead sheath or to the earth. This is called "Ground Fault".

2. **Short circuit fault.** If the insulation between two conductors is faulty, a current flows between them. This is called a "short circuit fault".

Methods for locating ground and short circuit faults.

The methods used localizing the ground and short circuit faults differ from those used for localizing open circuit faults.

In the case of multi core cables it is advisable, first of all, to measure the insulation resistance of each core to earth and also between cores. This enables us to sort out the core that is earthed in-case of ground fault; and to sort out the cores that are shorted in case of a short circuit fault. Loop tests are used for location of ground short circuit faults. These tests can only be used if a sound cable runs along with the faulty cable or cables.

The loop tests work on the principle of a Wheatstone bridge. The advantage of these tests is that their setup is such that the resistance of fault is connected in the battery circuit and therefore does not effect the result. However, if the fault resistance is high, the sensitivity is adversely affected. In this section only two types of tests viz., Murray and Varley loop tests are being described.

Murray Loop Test. The connection for this test are shown in Fig 8a relates to the ground fault and Fig 8b relates to the short circuit fault.

In both cases, the loop circuit formed by the cable conductors is essentially a wheatstone bridge consisting of resistances P, Q, R and X. G is a galvanometer for indication of balance,

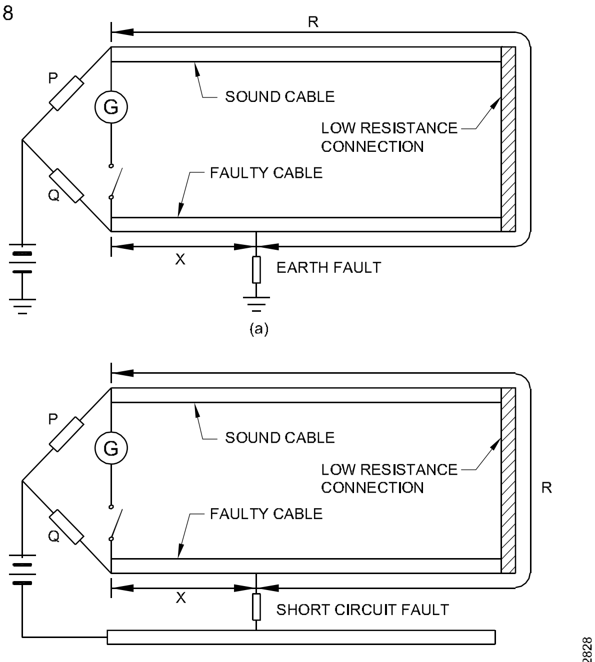
The resistors P, Q forming the ratio arms may be decade resistance boxes or slide wires.

Under balance conditions :

$$\frac{X}{R} = \frac{Q}{P} \text{ or } \frac{X}{R+X} = \frac{Q}{P+Q}$$

$$\therefore X = \frac{Q}{P+Q}(R+X)$$

Fig 8



MURRAY LOOP TEST
(b)

Where (R+X) is total loop resistance formed by the sound cable and the faulty cable. When the conductors have the same cross-sectional area and the same resistivity, the resistance are proportional to lengths. If l_1 represents the length of the fault from the test end and 'l' is the length of each cable. Then

$$l_1 = \frac{Q}{P+Q} \cdot 2l$$

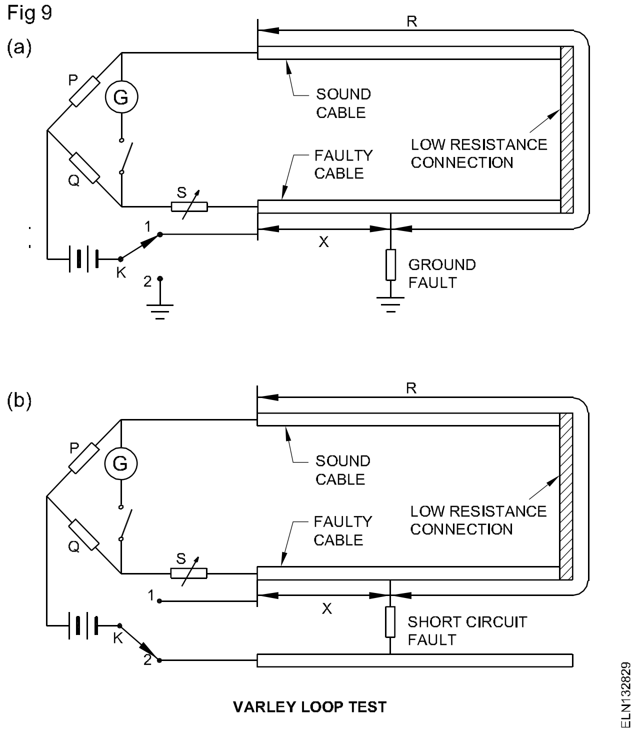
The above relation shows that the position of the fault may be located when the length of the cable is known. Also, the fault resistance does not alter the balance condition because its resistance enter the battery circuit hence effects only the sensitivity of the bridge circuit. However, if the magnitude of the fault resistance is high, difficulty may be experienced in obtaining the balance condition on account of decrease in sensitivity and hence accurate determination of the position of the fault may not be possible.

In such a case, the resistance of the fault may be reduced by applying a high direct or alternating voltage, in consistence with the insulation rating of the cable, on the line so as to carbonize the insulation at the point of the fault.

Varley loop test. In this test we can determine experimentally the total loop resistance instead of calculating it from the known lengths of the cable and its resistance per unit length. The necessary connections for the ground fault are shown in Fig 9a and for the short circuit fault in Fig 9b. The treatment of the problem, in both cases, is identical.

A single pole double throw switch A is used in this circuit. Switch K is first thrown to position 'I' and the resistance 'S' is varied and balance obtained.

Fig 9



VARLEY LOOP TEST

Measurement of resistance

Let the value of S for balance be S. The four arms of the Wheatstone bridge are P, Q, R + X, S_1 at balance:

$$\frac{R+X}{S_1}=\frac{P}{Q}$$

This determines R + X i.e. the total loop resistance as P, Q and S_1 are known.

The switch K is then thrown to position '2' and the bridge is rebalanced. Let the new value of S for balance be S_2. The four arms of the bridge now are P, Q, R, X + S_2.

At balance

$$\frac{R}{X+S_2}=\frac{P}{Q}$$

$$\frac{R+X+S_2}{X+S_2}=\frac{P+Q}{Q}\text{ or } X=\frac{(R+X)Q-S_2P}{P+Q}$$

Hence, X is known from the known value of P, Q, S_2 from this equation and R+X (the total resistance of 2 cables) as determined from Eqn. knowing the value of X, the position of the fault is determined.

Now

$$\frac{X}{R+X}=\frac{l_1}{2l}\text{ or } l_1=\frac{X}{R+X}2l$$

Where

l_1= length of fault from the test end and

l = total length of conductor.

Equations for murrary loop test and varley loop test are valid only when the cable sections are uniform throughout the loop. Corrections must be applied in case the cross-sections of faulty and sound cables are different or when the cross-section of the faulty cable is not uniform over its entire length.

Since temperature affects the value of resistance, corrections must be applied on this account if the temperatures of the two cables are different. Corrections may also have to be applied in case the cables have a large number of joints.

Ohm's law - simple electrical circuits and problems

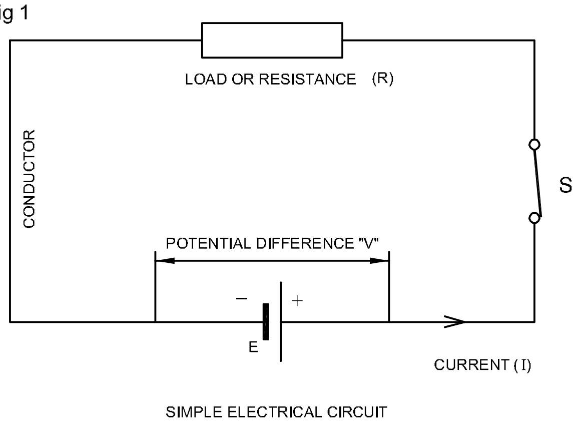
Objectives: At the end of this lesson you shall be able to
- **describe the essential factors in an electrical circuit**
- **state the relation between circuit factors through Ohm's law**
- **apply Ohm's law in an electric circuit.**
- **define electrical power and energy and calculate related problems**

Simple electric circuit

In the simple electric circuit shown in Fig 1, the current completes its path from the positive terminal of the battery via the switch and the load back to the negative terminal of the battery.

The circuit shown in Fig 1 is a closed circuit. In order to make a circuit to function normally the following three factors are essential.

Fig 1



SIMPLE ELECTRICAL CIRCUIT

- Electromotive force (EMF) to drive the electrons through the circuit.
- Current (I), the flow of electrons.
- Resistance (R) - the opposition to limit the flow of electrons.

Ohm's law

In 1826 George Simon Ohm discoverd that for metallic conductor, there is a substantially constant ratio of the potential difference between the ends of the conductor

Ohm's law gives the relation between the voltage, current and resistance of a circuit.

Ohm's law states that the ratio of the voltage (V) across any two points of a circuit to the current (I) flowing through is constant provided physical conditions, namely temperature etc. remain constant. This constant is denoted as resistance (R) of the circuit.

(or)

In simple,

Ohm's law states that in any electrical closed circuit, the current (I) is directly proportional to the voltage (V), and it is inversely proportional to the resistance 'R' at constant temperature.

(ie) $I \alpha V$ (When 'R' is kept constant)

$I \alpha R$ (When 'V' is kept constant)

$I \alpha V/R$ (Relation between I,V and R)

$$I \propto \frac{V}{R}$$

It means I = V/R

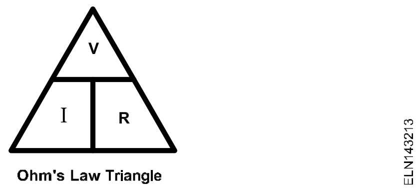
V = Voltage applied to the circuit in 'Volt'

I = Current flowing through the circuit in 'Amp'

R = Resistance of the circuit in Ohm (Ω)

The above relationship can be referred to in a **triangle** as shown in Fig 2. In this triangle whatever the value you want to find out, place the thumb on it then the position of the other factors will give you the required value.

Fig 2



Ohm's Law Triangle

For example for finding 'V' close the value 'V' then readable values are IR, so V = IR.

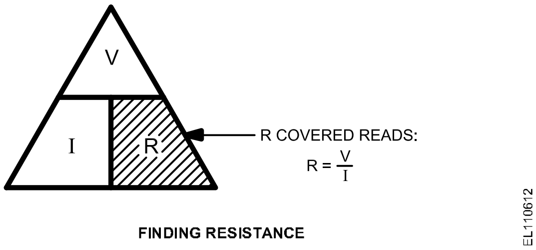
Again for finding 'R', close the value R, then readable values are V/I so R = V/I, like that $I = \frac{V}{R}$.

Written as a mathetical expression, Ohm's Law is

$$\text{Resistance} = \frac{\text{Voltage (V)}}{\text{Current (I)}} \text{ (Refer Fig 3)}$$

$$\text{(or) } R = \frac{V}{I} \text{ (Refer Fig 3)}$$

Fig 3

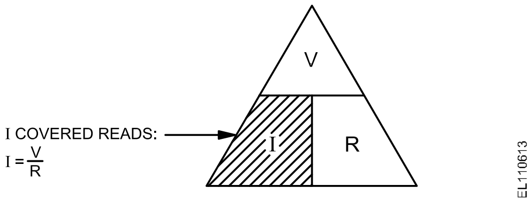


Of course, the above equation can be rearranged as:

$$\text{Current (I)} = \frac{\text{Voltage (V)}}{\text{Resistance (R)}}$$

$$\text{(or) } I = \frac{V}{R} \text{ (Refer Fig 4)}$$

Fig 4

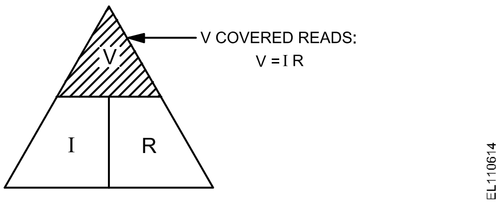


In the same way, ‘V’ can be found by covering ‘V’

Voltage (V) = Current (I) x Resistance (R)

or V - IR (Refer Fig 5)

Fig 5

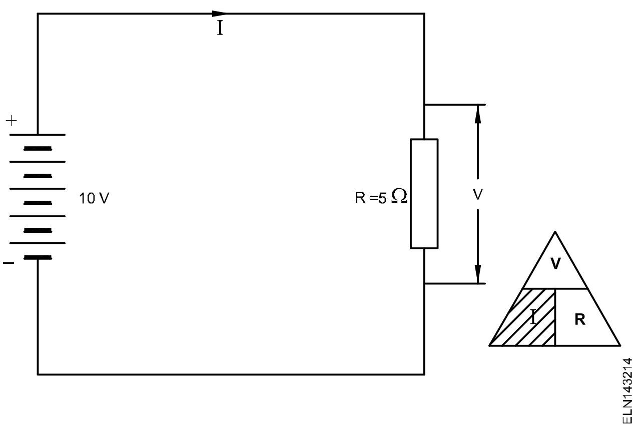


Application of Ohm’s law in circuits

Example 1

Let us take a circuit shown in Fig 6 having a source of 10V battery and a load of 5 Ohms resistance. Now we can find out the current through the conductor.

Fig 6



$$I \propto \frac{V}{R}$$

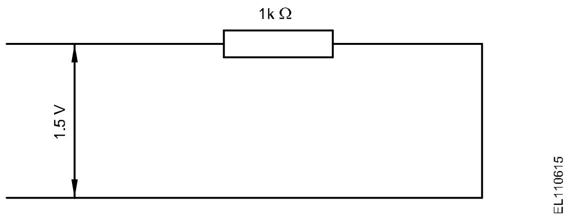
$$I = \frac{V}{R}$$

$$I = \frac{10}{5} = 2 \text{ amp}$$

Example 2

How much current (I) flows in the circuit shown in Fig 7

Fig 7



Given:

Voltage (V) = 1.5 Volts

Resistance (R) = 1 kOhm

= 1000 Ohms

Find : Current (I)

Known

$$I = \frac{V}{R}$$

Solution:

$$I = \frac{1.5 \text{ V}}{1000 \text{ Ohms}} = 0.0015 \text{ amp}$$

Answer:

The current in the circuit is 0.0015 A

or

the current in the circuit is 1.5 milliampere (mA)

(1000 milliamps = 1 ampere)

Problem

Find the value of voltage across a 10 Ohms resistor in the circuit shown in Fig 8. When the current of 2 Amps flows through the 10 Ohm resistor

Solution

Voltage across 10 Ohm

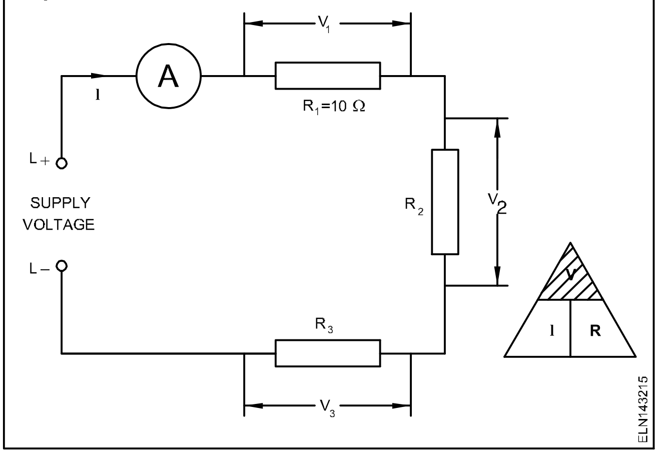
V= I x R

= 2 x 10

= 20 Volt

Similarly if the value of the other resistance is known we can find the voltage drop across them.

Fig 8



Extreme circuit conditions

Two important extreme conditions can occur in a circuit.

Open circuit

In an open circuit, there is an infinitely high resistance in the circuit. This condition can happen in a circuit when the switch is open. Therefore, no current of flow.

For example, a generator is said to be in an open circuit when the switch is open and running without supplying current to the circuit. A wall socket, too, is an open circuit if the control switch of the wall socket is ‘OFF’or 'ON' position provided there is no appliance plugged to the wall socket.

Short circuit

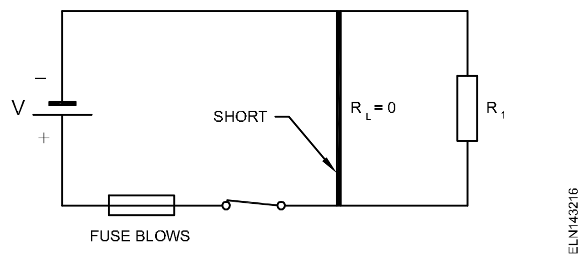
The other important extreme condition is the short circuit. A short circuit will occur, for example, when the two terminals of a cell are joined (Fig 9). A short circuit may also occur if the insulation between the two cores of a cable is defective.

The resulting negligible resistance will cause large currents which can become a hazard. A fuse, if provided in the circuit as shown in Fig 9, could then blow and automatically open the circuit.

Practical application

The knowledge gained by this exercise can be applied to calculate the current drawn by a particular load resistance when the supply voltage is known. This will enable the technician to select a proper size of cable for the circuit.

Fig 9



Electrical Power (P) & Energy (E)

The product of voltage (V) and current (I) is called electrical power. Electrical power (P) = Voltage x Current P=V x I

The unit of Electrical power is 'Watt' It is denoted by the letter 'P' It is measured by Watt meter. The following formulae can also be derived from formula of power (P) as

(i) $P = V \times I$

$= IR \times I$

$P = I^2 R$

(ii) $P = V \times I$

$= V \times \frac{V}{R}$

$$P = \frac{V^2}{R}$$

Electrical Energy (E)

The product of power (P) and time (t) is called as electrical energy (E)

Electrical Energy (E) = Power x time

$E = P \times t$

$= (V \times I) \times t$

$E = V \times I \times t$

The unit of electrical energy is "Watt hour" (Wh)

The commercial unit of Electrical energy is "Kilo watt hour" (KWH) or unit

B.O.T (Board of Trade) unit / KWH/Unit

One B.O.T (Board of Trade) unit is defined as that one thousand watt lamp is used for one hour time, it consumes energy of one kilowatt hour (1kWH). It is also called as **"unit"**

Energy = 1000W x 1Hr = 1000WH (or) 1kWH

Example - 1

How much electrical energy is consumed in an electric iron rated as 750W/250V used for 90 Minutes

Given:

Power (P)	= 750W
Voltage (V)	= 250V
Time	= 90min (or) 1.5Hr

Find:

Electrical Energy (E) = ?

Solution:

Electrical Energy (E)	= P x t
	=750 w x 1.5Hr
	= 1125 WH (or)
E	= 1.125 kWH

Example 2

Calculate the power of a lamp, which takes a current of 0.42 Amp at 240 V supply

Given:

Voltage (V)	= 240 V
Current (I)	= 0.5 A

Find:

Power(P) = ?

Solution:

P	= V X I
	= 240 x 0.42
	= 100.8W
Hence, Power (P)	= 100 W (approx)

Example 3:

Calculate the hot resistance (R) of the 200W/250V rated bulb?

Given:

Power (P)	= 200 W
Voltage (V)	= 250 V

Find:

Resistance (R) = ?

Solution:

$$P = \frac{V^2}{R}$$

$$R = \frac{V^2}{P} = \frac{250 \ X \ 250}{200}$$

(R) Resistance = 312.5 Ohm (Ω)

Example 4

In a house, the following electrical loads are daily used:-

(i) 5 Nos of 40W Tube Lights used for 5 hours/day

(ii) 4 Nos of 80W fans used for 8 hours/day

(iii) 1 No of 120W T.V. receiver used for 5 hours/day

(iv) 4 No of 60W lamps used for 4 hours/day

Calculate the total energy consumed in unit's per day and also the cost of electric bill for the month of January If the cost of energy is 1.50/unit

Given

Load details per day

Electric Device		Power		Numbers		Time in hours
(i) Tube light	-	40W	-	5	-	5 hr/day
(ii) Fans	-	80W	-	4	-	8 hr/day
(iii) T.V.	-	120W	-	1	-	6 hr/day
(iv) Lamps	-	60W	-	4	-	4 hr/day

cost of energy - Rs.1.50/unit

Find:

(i) Energy consumption in unit per day = ?

(ii) Cost of energy for the month of January = ?

Solution

Energy consumption/day

1. Tube light = 40W x 5 x 5 hr /day

$$= \frac{1000 \text{ wh}}{1000} = 1\text{Kwh/day}$$

2. Fans = 80W x 4x8 hr/day

$$= \frac{2560}{1000} = 2.56\text{Kwh/day}$$

3. T.V. = 120W x 1x6 hr/day

$$= \frac{720 \text{ wh}}{1000} = 0.72\text{Kwh/day}$$

4.Lamp = 60W x 4x4 hr/day

$$= \frac{960}{1000} = \text{Kwh} = \frac{0.96\text{kwh/day}}{5.24\text{kwh/day}}$$

(i) Total energy consumption in unit per day
= 5.24 unit

(ii) Total energy consumption for the month of January (i.e 31 days)
= 5.24 x 31
= 162.44 units

Cost of energy = Rs. 1.50/unit

Total electric bill for the month of January = 162.44 x 1.50
= Rs.243.66

Electricity Bill for the month = Rs. 244/-

Assignment :

Note : The instructor may ask the trainees to prepare electric bill for the current month for his house (or) any building.

Work, Power and Energy

Work is said to be done, when a force (F) displaces a body from one distance (s) to another (or)

Work done = Force x distance moved

w.d = F x S

It is generally denoted as "W"

The unit of work done is

(i) In Foot Pound Second (F.P.S) System is "Foot Pound (lb.ft)"

(ii) In Centimetre Gram Second (C.G.S) System "Gram Centimetre (gm.cm)"

or

1 gm.cm = 1 dyne

1 dyne = 10^7 ergs

The smallest unit of work done is **"Erg"**

(iii) In Metre - Kilogram - Second (M.K.S.) System is "Kilogram Metre (Kg-M)'

1 Kilogram = 9.81Newton

(iv) In system of international unit (S.I. Unit) is 'Joule'

1 Joule = 1 Newton Metre (Nw-M)

Power (P)

The rate of doing work is called as Power (P)

Power (P) = work done / time taken

$$P = \frac{F \text{ x } S}{t}$$

It's unit is Lb.ft/sec in FPS system

gm-cm/sec is in C.G.S. System

(or)

Dyne/sec

(or)

Kg-M/sec in M.K.S System (or) NW - M/ sec

(1kg = 9.81 Newton)

Joule/sec in (S.I)

1 Joule/Sec = 1 watt

Electrical Power = VI Watt

The unit of Mechanical power is "Horse Power" (H.P)

Horse Power (HP) further classified into two:

They are:-

Indicated Horse Power - (IHP)

Brake Horse Power - (BHP)

Indicated Horse Power (IHP)

The power developed inside the engine (or) pump (or) motor is called Indicated Horse Power (IHP)

Brake Horse Power (BHP)

The useful Horse Power which is available at the shaft of the engine/motor/pump is called Brake Horse Power (BHP)

So, IHP is always greater than

BHP due to friction losses

IHP > BHP

The relation between Mechanical and Electrical Power

(ie) 1 HP (British) = 746 Watt

1 HP (Metric) = 735.5 Watt

One HP (Metric)

The amount of Mechanical Power required to move/displace a body/substance by force of 75 Kg to one metre distance in one second is called as one HP (metric)

HP (Metric) = 75kg - M/Sec

One HP (British)

The amount of Mechanical power required to move/displace a body/substance of force 550Ib to one foot (ft) distance in one second is called as one HP (British)

1 HP (British) = 550 Ib.ft/sec

Energy

The capacity for doing work is called as electrical Energy

(or)

The product of power and time is known as Electrical energy

(ie) Energy = Power x time

$$t = \frac{\text{workdone}}{\text{time}} \text{xtime}$$

Electric - energy = Power x time

= VI x t

S.I unit of energy is "Joule"

(ie) Energy = (Joule/sec) x sec

$$= \frac{\text{Joulle}}{\text{Sec}} \times \text{Sec} = \text{joule}$$

(ie) The S.I of unit of work done and energy is same (Joule)

The energy can be divided into two main categories (ie)

(i) Potential Energy (eg. Loaded gun, energy (stored in spring etc)

(ii) Kinetic Energy (eg. Moving of car, raining etc).

Kirchhoff's law and its applications

Objectives: At the end of this lesson you shall be able to
- **state Kirchhoff's first law**
- **apply Kirchhoff's first law to find the circuit current**
- **state Kirchhoff's second law and apply the same to find the voltage drop in branches**
- **solve problems by applying Kirchhoff's laws.**

Kirchoff's laws are used in determinig the equivalent resistance of a complex network and the current flowing in the various conductors.

Kirchhoff's laws

Kirchhoff's first law: At each junction of currents, the sum of the incoming currents is equal to the sum of the outgoing currents. (Figs 1 & 2) (or) The algebric sum of all branch currents meeting at a point/node is zero

Fig 1

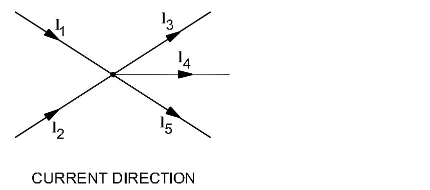
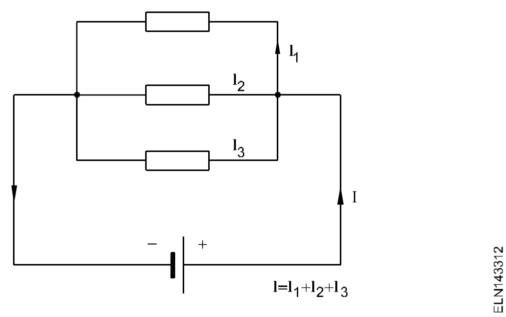


Fig 2



If all inflowing currents have positive signs and all outflowing currents have negative signs, then we can state that

$$I_1 + I_2 = I_3 + I_4 + I_5$$

$$+I_1 + I_2 - I_3 - I_4 - I_5 = 0$$

In the above example the sum of all the currents flowing at the junction (node) is equal to zero.

$$\Sigma I = 0$$

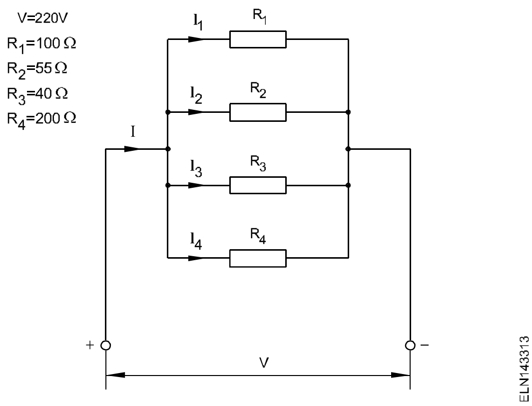
$$I = I_1 + I_2 + I_3 + \ldots\ldots\ldots\ldots\ldots\ldots$$

Example: Apply Kirchhoff's First Law to find the current shown in circuit Fig 3.

Find current

I, I_1, I_2, I_3, I_4

Fig 3



Solution

$$I_1 = \frac{V}{R_1} = \frac{220\text{ V}}{100\text{ ohms}} = 2.2\text{A}$$

$$I_2 = \frac{V}{R_2} = \frac{220\text{ V}}{55\text{ ohms}} = 4\text{A}$$

$$I_3 = \frac{V}{R_3} = \frac{220\text{ V}}{40\text{ ohms}} = 5.5\text{A}$$

$$I_4 = \frac{V}{R_4} = \frac{220\text{ V}}{200\text{ ohms}} = 1.1\text{A}$$

$$I = I_1 + I_2 + I_3 + I_4$$

$$= 2.2\text{A} + 4\text{A} + 5.5\text{A} + 1.1\text{A} = 12.8\text{A}$$

Checking the calculation

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4}$$

$$= \frac{1}{100} + \frac{1}{55} + \frac{1}{40} + \frac{1}{200}$$

$$= \frac{22 + 40 + 55 + 11}{2200} = \frac{128}{2200} = \frac{16}{275}$$

$$\frac{1}{R_{TOT}} = \frac{16}{275}$$

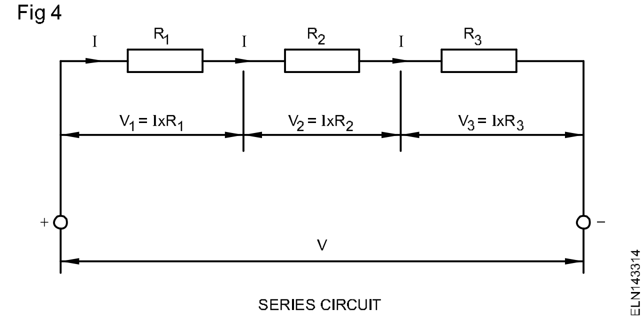
$R_{TOT} \quad = 17.19$ ohms

$$I = \frac{V}{R_{TOT}} = \frac{220V}{17.19 \text{ ohms}} = 12.798 \text{ A}$$

Kirchhoff's second law

A simple case: In closed circuits, the applied terminal voltage V is equal to the sum of the voltage drops V_1+V_2 and so forth. (Fig 4)

Fig 4



If all the generated voltages are taken as positive, and all the consumed voltages are taken as negative, then it can be stated that:

in each closed circuit the sum of all voltages is equal to zero.

$$\Sigma V = 0$$

Example

Given

$V = 220V$
$R_1 = 36$ ohms
$R_2 = 40$ ohms
$R_3 = 60$ ohms
$R_4 = 50$ ohms

Find

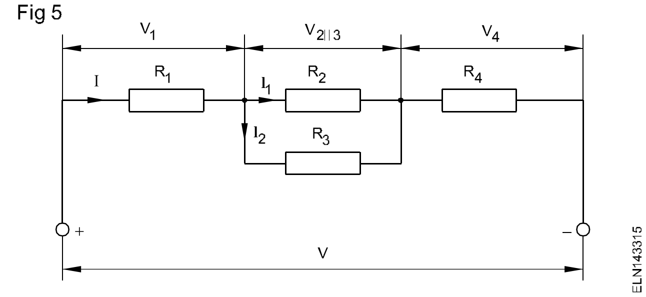
$R, I, I_1, I_2,$

$V_1, V_{2\parallel3}, V_4$

Solution

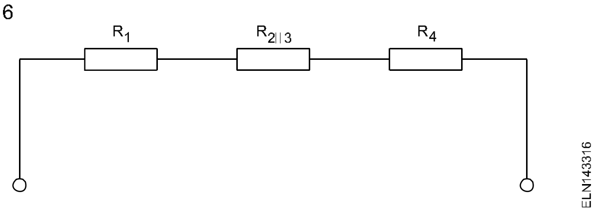
Apply Kirchhoff's First Law to find the voltage drops in the branches (Fig 5).

Fig 5



Calculate the total resistance R of the series circuit according to Kirchhoff's Second Law. (Fig 6)

Fig 6



First simplify by calculating the equivalent resistance for R_2, R_3 according to Kirchhoff's First Law.

$$R_{2\parallel3} = \frac{R_2 \times R_3}{R_2 + R_3} = \frac{40 \text{ ohms} \times 60 \text{ ohms}}{(40+60) \text{ ohms}}$$

$$= 24 \text{ ohms}$$

$$R_{TOT} = R_1 + R_{2\parallel3} + R_4$$

$$= 36 \text{ ohms} + 24 \text{ ohms} + 50 \text{ ohms}$$

$$= 110 \text{ ohms}$$

The total current I can now be calculated by means of Ohm's Law:

$$I = \frac{V}{R_{TOT}} = \frac{220 \text{ V}}{110 \text{ ohms}} = 2A$$

The partial voltages are accordingly:

$$V_1 = I \times R_1 = 2A \times 36 \text{ ohms} = 72 \text{ V}$$

$$V_{2\parallel3} = I \times R_{2\parallel3} = 2A \times 24 \text{ ohms} = 48 \text{ V}$$

$$V_4 = I \times R_4 = 2A \times 50 \text{ ohms} = 100 \text{ V}$$

Checking the calculation

$$V = V_1 + V_{2\parallel3} + V_4$$

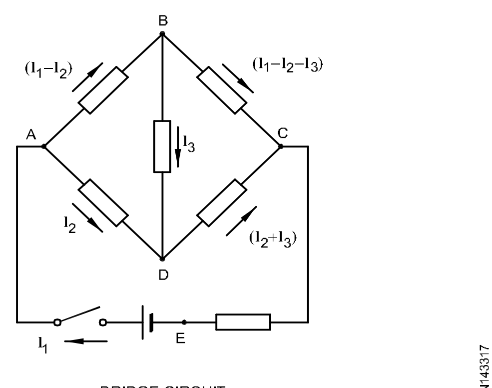
$$220 \text{ V} = 72V + 48V + 100 \text{ V}$$

$$220 \text{ V} = 220 \text{ V}$$

Suggested steps for the application of Kirchhoff's Laws to solve problems.

1 Mark the nodes (junction points) in the given network.
2 Mark the current direction over each element (resistor) in the circuit. The current direction is arbitrary. But it is often convenient to use a direction that goes from –ve to +ve through an emf.
3 Indicate the loop currents with I_1, I_2, I_3 etc. Apply Kirchhoff's First Law to the junction nearer to it. (Fig 7)

Fig 7

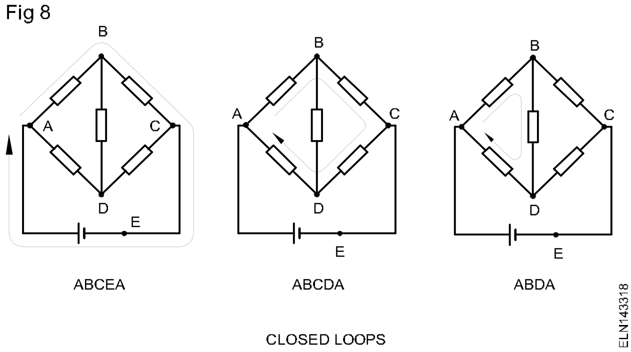


BRIDGE CIRCUIT

4 Once the current and its direction are marked over an element, keep it the same until the problem is solved.

5 Select the windows, (closed loops) in the circuit and name the window. eg. Fig 8.

Fig 8



6 Each element should be included atleast once in any one of the closed loops selected in the above step.

7 Raise in potential is considered as +ve. A drop (fall) in potential is considered as –ve.

8 Trace around each loop and write Kirchhoff's Voltage Law equation. For such tracing to be complete, one should return to the starting point.

9 While tracing, the direction of movement is important.

For the source of emf

A **raise in potential** occurs when moving from the –ve to the +ve terminal of a source. Therefore the value is positive.

A **drop in potential** occurs when moving from a +ve to a –ve terminal of a source. Therefore the value is negative.

The current direction is not considered to fix the potential-raise or potential-drop across a source of emf.

For the resistors

A drop in potential occurs when moving across the resistor in the same direction as that of the current through the resistor. Therefore the value is negative.

A raise in potential occur when moving across the resistor in the opposite direction to that of the current through the resistor. Therefore, the value is positive.

The direction of movement while tracing the loop and related current direction in each element is important. The polarity of the source of emf is not considered to fix the potential raise or drop across a resistor.

10 Solve the equations to determine the current through each element.

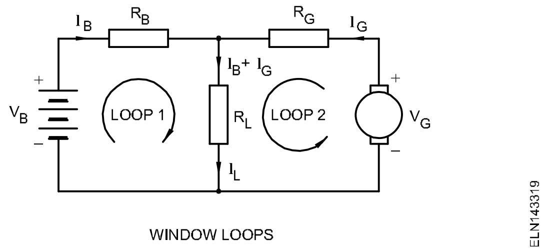
Example 1: A battery of open-circuit voltage V_B and internal resistance R_B is connected in parallel with a generator of open-circuit voltage V_G and internal resistance RG. This combination feeds load resistance R_L. For the following values find the battery current, generator current, load current and load voltage.

V_B = 13.2 V, V_G = 14.5 V, $_{RB}$ = 0.5 Ω and R_L = 2 Ω, R_G = 0.1 - 2 Ω

Solution

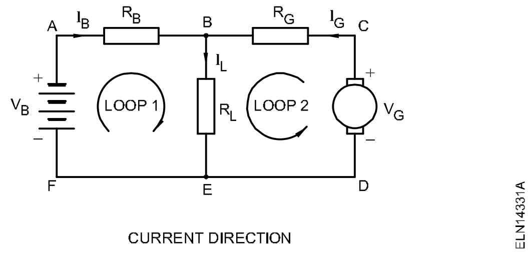
1 Draw a circuit diagram. (Fig 9)

Fig 9



2 It can be seen from Fig 9 that there are two `windows' loops in the circuit. this means that we must show two currents, one in each loop, in any arbitrary direction. (We shall show currents I_B and I_G in the direction we think the current might flow). (Fig 10)

Fig 10



3 Using Kirchoff's Current Law, we can identify the current through the load resistor as

$I_L = I_B + I_G$.

Indicate this current in Fig 10.

4 Show the polarity signs of the voltage drops across each resistor using the assumed directions of the current. (Fig 10)

5 Indicate, in each window, a current loop that goes around a complete circuit. The direction is arbitrary, but it is often convenient to use a direction that goes from - to + through an emf. (See loops 1 and 2 in Fig 8).

6 Trace around each loop, writing Kirchhoff's Voltage Law equation by applying the following basic principles

- If you encounter - V_G of the voltage source first then the +ve of the source while tracing through a loop take the source as +ve.
- If you encounter positive of the source first and then negative of the source while tracing through a loop take the source is negative.
- When you trace a voltage drop in the same direction of current take the voltage drop as negative.
- When you trace a voltage drop in the opposite direction of current take the voltage drop as positive.
- Form clear loops denoting the line of tracing starting with alphabet `A' then after completing the path end with `A'.

Refer Fig 10. Let us start from first loop starting with A and ending with A.

i.e. ABEFA

Applying the above principles

A to B = – $I_B R_B$ (Voltage drop alongwith current direction)

B to E = – $I_L R_L$ -do-

E to F = 0

F to A = $+V_B$ (First negative and then positive of the source in the direction of current)

Hence for first loop, we have

$-I_B R_b - I_L R_L + V_B = 0$ .... Eqn. (1)

OR

$= I_B R_B + (I_B + I_G) R_L$ .... Eqn. (2)

For loop 2 we have C B E D C

$-I_G R_G - I_L R_L + V_G = 0$ .... Eqn. (3)

$-I_G R_G - (I_B + I_G) R_L + V_G = 0$

VG $= I_G R_G + (I_B + I_G) R_L$ .... Eqn. (4)

Insert in eqn. (2) and (4) the numerical values we have

$13.2 = 0.5 I_B + 2(I_B + I_G)$ .... Eqn. (5)

$14.5 = 0.1 I_B + 2(I_B + I_G)$ ... Eqn.(6)

Collect together like terms and solve for I_G I_B

$13.2 = 2.5 I_B + 2 I_G$ .... Eqn. (7)

$14.5 = 2 I_B + 2.1 I_G$ .... Eqn.(8)

Multiply eqn.(7) by 2 and eqn. (8) by 2.5 we have

$26.4 = 5 I_B + 4 I_G$ ..... Eqn.(9)

$36.25 = 5 I_B + 5.25 I_G$ .....Eqn.(10)

Subtract eqn.(9) from eqn. (10) we have

$36.25 = 5 I_B + 5.25 I_G$

$26.4 = 5 I_B + 4 I_G$

$9.85 = 1.25\, I_G$

$$I_G = \frac{9.85}{1.25} = 7.88 \text{ amps}$$

Substituting the value $I_G = 7.88$ in eqn. (9) we have

$26.4 = 5 I_B + 4 \times 7.88$

$= 5 I_B + 31.52$

$26.4 - 31.52 = 5 I_B$

$-5.12 = 5\, I_B$

$$I_B = \frac{-5.12}{5}$$

$= -1.024$ amps

Minus sign in the answer indicates that the battery is not sending any current but receives a charging current of 1.024 amps.

Accordingly current supplied by the generator

$I_G = 7.88$ amps

Current taken by the battery I_B
(Battery in getting charged) $= 1.024$ amps

Load current $I_L = I_B + I_G$

where $I_B = -1.024$ amps

$I_G = +7.88$

$I_L = (-1.024 + 7.88)$

$= 6.856$ amps

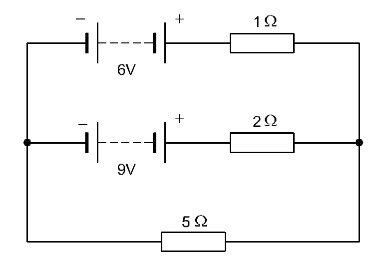
Voltage across the load $= I_L R_L$

$= 6.856 \times 2$

$= 13.712$ volts

Example 2: For the given circuit in Fig 11, determine the following

Fig 11



1 Mark the nodes and name the closed loops.

2 Name and mark the direction of current in the element following Kirchhoff's First Law.

3 Trace around each loop and write Kirchhoff's 2nd law.

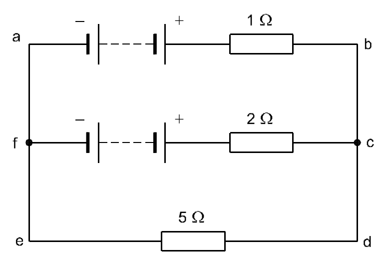
4 Solve the problem using simultaneous equation to find the current delivered or received by the battery 6 V and 9 V.

5 Find the current passing through the 5 ohm resistor.

6 Cross check your calculation.

i The nodes are marked and the closed loops are named (Fig 12)

Fig 12

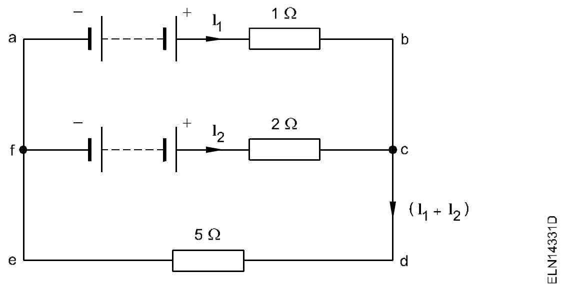


Loop 1 = a b c d e f a

Loop2 = f c d e f

ii Direction of current is marked (Fig 13)

Fig 13



Loop 1 – a b c d e f a

$+6 - 1I_1 - 5(I_1 + I_2) = 0$

$+6 - I_1 - 5I_1 - 5I_2 = 0$

$+6 - 6I_1 - 5I_2 = 0$

$6I_1 + 5I_2 = 6$ .... Eqn.(1)

Loop 2- f c d e f

$+9 - 2I_2 - 5(I_1 + I_2) = 0$

$9 - 2I_2 - 5I_1 - 5I_2 = 0$

$9 - 5I_1 - 7I_2 = 0$

$5I_1 + 7I_2 = 9$ .... Eqn. (2)

iv Multiplying eqn. (2) by 6 and eqn. (1) by 5 we have

$5I_1 + 7I_2 = 9 \times 6$

$6I_1 + 5I_2 = 6 \times 5$

$30I_1 + 42\,I_2 = 54$ .... Eqn. (3)

$30I_1 + 25I_2 = 30$ .... Eqn. (4)

Substracting equation 4 from eqn.3 we have

$17I_2 = 24$

$I_2 = \frac{24}{17} = 1.41$ amps

Substituting I_2 = 1.41 in eqn. 1 we have

$6I_1 + 5(1.41) = 6$

$6I_2 + 7.05 = 6$

$6I_1 = 6 - 7.05 = -1.05$

$I_1 = -0.175$ amps.

As the current value of I_1 is minus sign the current is assumed to flow in opposite direction to the asumed direction

Only the 9V battery delivers current
while the current received by the 6 V battery
= 0.175 amps.

Current delivered by 9 V battery = 1.41 amps

Current passing through 5 ohms resistor

$I_1 + I_2 = -0.175 + 1.41$

$= 1.235$ amps

PD across 5 ohm resistor = 1.235 x 5 = 6.175 V.

Cross check

Taking loop 3 a b c f a

$+6 - I_1 + 2\,I_2 - 9 = 0$

$6 - (-0.175) + 2.82 - 9 = 0$

$8.995 - 9 = 0$

As the values are more or less the same verified by cross checking and found to be corre.

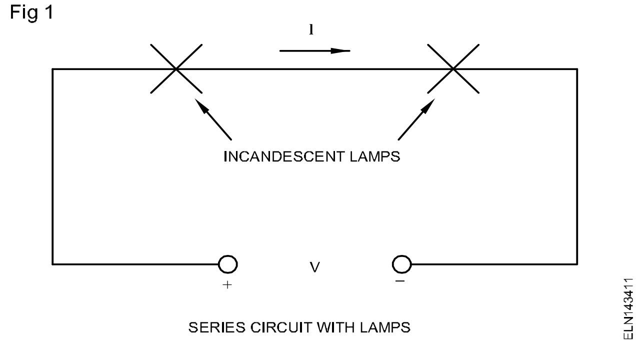
DC series and parallel circuits

Objectives: At the end of this lesson you shall be able to
- **state the characteristics of series circuit and determine the current and voltage across each resistors**
- **determine the total voltage sources in series circuit**
- **state the relation between EMF potential difference and terminal voltage**
- **determine the polarity of voltage drops with respect to ground**

The series circuit

If more than one resistors are connected one by one like a chain and if the current has only one path is called as series circuit. It is possible to connect two incandescent lamps in the way shown in Fig 1. This connection is called a series connection, in which the same current flows in the two lamps.

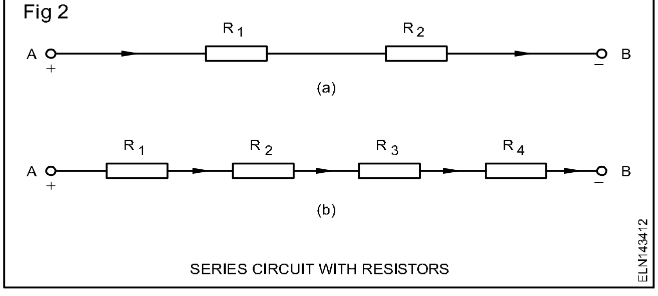
Fig 1



SERIES CIRCUIT WITH LAMPS

The lamps are replaced by resistors in Fig 2. Fig 2 (a) shows two resistors are connected in series between point A and point B. Fig 2(b) shows four resistors are in series. Of course, there can be any number of resistors in a series connection. Such connection provides only one path for the current to flow.

Fig 2



SERIES CIRCUIT WITH RESISTORS

Identifying series connections

In an actual circuit diagram, a series connection may not always be as easy to identify as those in the figure. For example, Fig 3(a), 3(b), 3(c) & 3(d) shows series resistors drawn in different ways. In all the above circuits we find there is only one path for the current to flow.

Current in series circuits

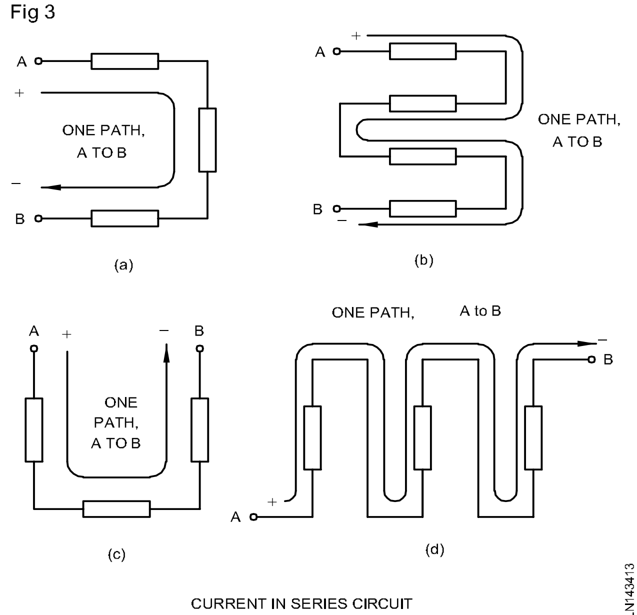
The current will be the same at any point of the series circuit. This can be verified by measuring the current in any two points of a given circuit as shown in Figs 4(a) and 4(b). The ammeters will show the same reading.

The current relationship in a series circuit is

$$I = I_{R1} = I_{R2} = I_{R3}.\ \text{(Refer Fig 4a \& 4b)}$$

We can conclude that there is only one path for the current to flow in a series circuit. Hence, the current is the same throughout the circuit.

Fig 3



CURRENT IN SERIES CIRCUIT

Total resistance in series circuit

You know how to calculate the current in a circuit, by Ohm's law, if resistance and voltage are known. In a circuit consisting of two resistors R_1 and R_2 we know that the resistor R_1 offers some opposition to the current flow. As the same current should flow through R_2 in series it has to overcome the opposition offered by R_2 also.

If there are a number of resistors in series, they all oppose the flow of current through them.

The 2nd characteristic of a DC series circuit could be written as follows (R).

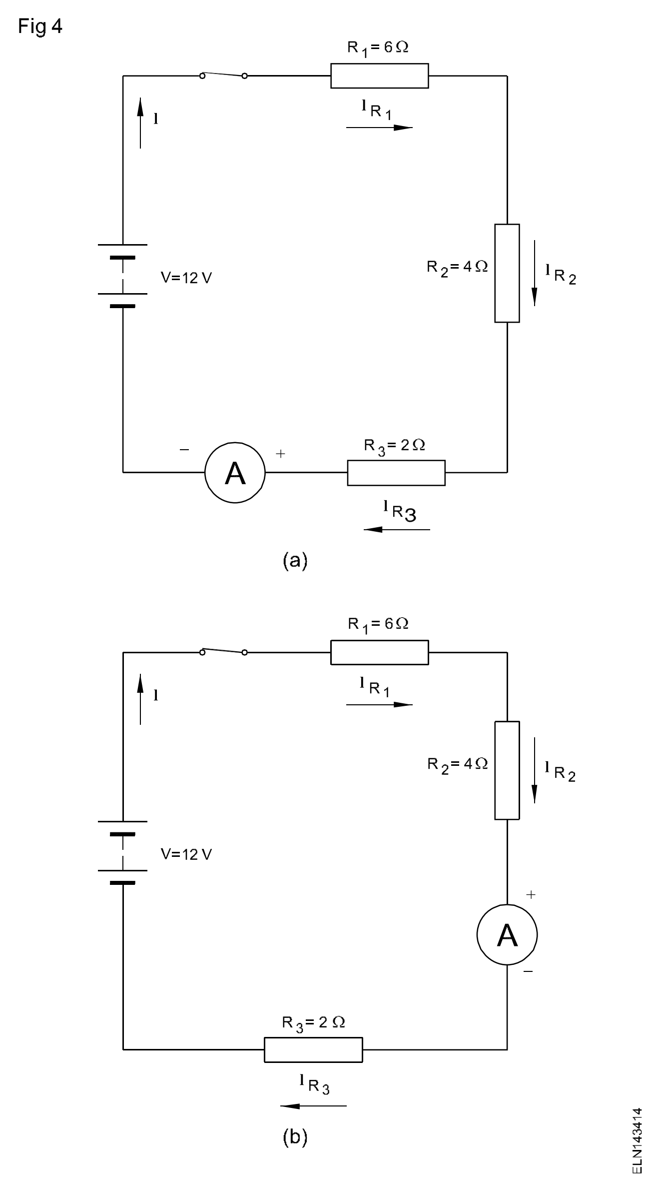
The total resistance in a series circuit is equal to the sum of the individual resistances around the series circuit. This statement can be written as

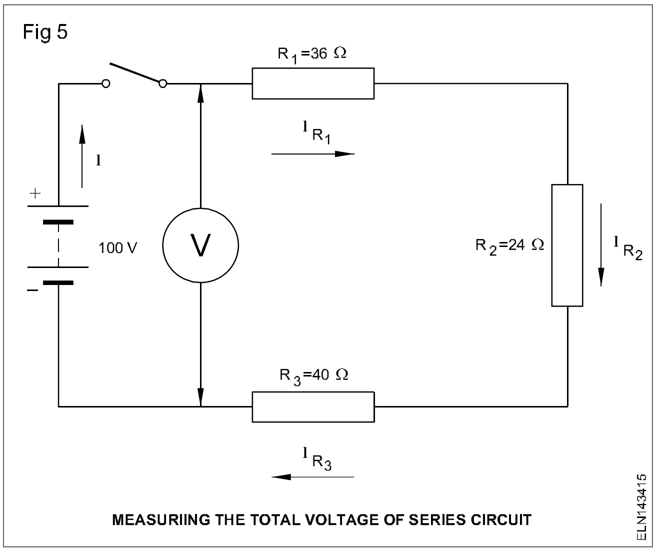
$R = R_1 + R_2 + R_3 + ...R_n$

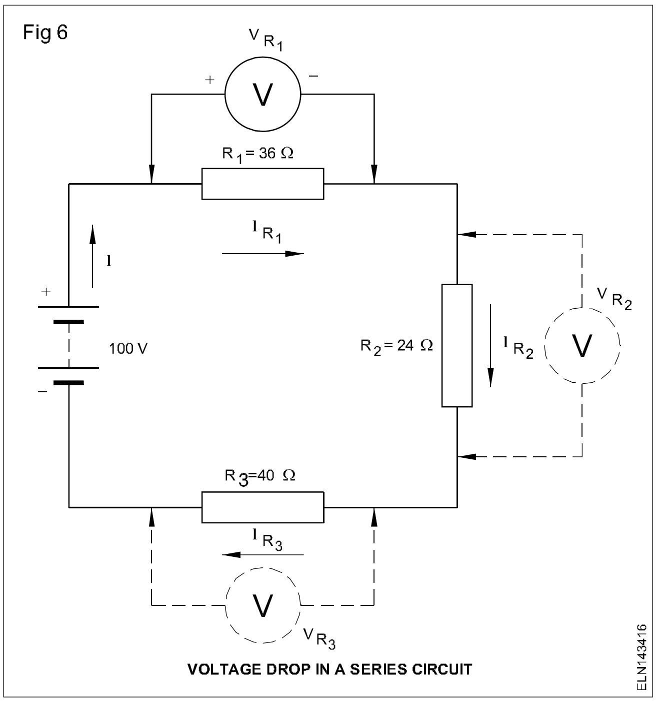
where R is the total resistance

R_1, R_2 , R_3,.......R_n are the resistors connected in series.

When a circuit has more than one resistor of the same value in series, the total resistance is $R = r \times N$







where 'r' is the value of each resistor and N is the number of resistors in series.

Voltage in series circuits

In DC circuit voltage divides up across the load resistors, depending upon the value of the resistor so that the sum of the individual load voltages equals the source voltage.

The 3rd characteristic of a DC circuit can be written as follows.

As the source voltage divides/drops across the series resistance depending upon the value of the resistances

$$V = V_{R1} + V_{R2} + V_{R3} + \ldots\ldots\ldots V_{RH}$$

the total voltage of a series circuit must be measured across the voltage source, as shown in Fig 5.

Voltages across the series resistors could be measured using one voltmeter at different positions as illustrated in Fig 6.

When Ohm's law is applied to the complete circuit having an applied voltage V, and total resistance R, we have the current in the circuit as

$$I = \frac{V}{R}$$

Application of Ohm's law to DC series circuits

Applying to Ohm's law to the series circuit, the relation between various currents could be stated as below

$$I = I_{R1} = I_{R2} = I_{R3}$$

This could be stated as $\frac{V}{R} = \frac{V_{R1}}{R_1} = \frac{V_{R2}}{R_2} = \frac{V_{R3}}{R_3}$

You can use any of the above formulae to calculate current in a series circuit.

We know the total supply voltage

$V = V_{R1} + V_{R2} + V_{R3}$

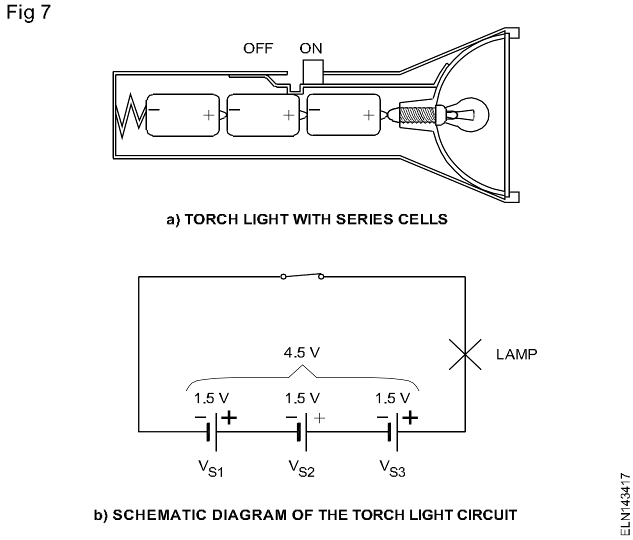
i.e. $IR = R_1 I_{R1} + R_2 I_{R2} + R_3 I_{R3}$

and Total resistance $R = R_1 + R_2 + R_3$.

Voltage sources in series

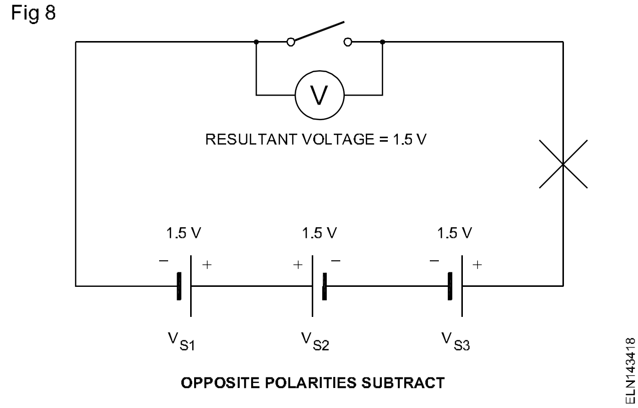
When cells are placed in a torch light, they are connected in series to produce a higher voltage as shown in Fig 7.

Fig 7



Series voltage sources are added when their polarities are in the same direction and or subtracted when their polarities are in the opposite direction. For example, if one of the ends of the cell, say V_{S2} in a torch light is wrongly placed in polarity as indicated in the schematic of Fig 8 its voltage to be subtracted as follows.

Fig 8



$V_{Total} = V_{S1} - V_{S2} + V_{S3}$

$= 1.5\text{ V} - 1.5\text{ V} + 1.5\text{ V}$

$= 1.5\text{ V}$

Use of series connection

1 Cells in torch light, car batteries, etc.

2 Cluster of mini-lamps used for decoration purposes.

3 Fuse in circuit.

4 Overload coil in motor starters.

5 Multiplier resistance of a voltmeter.

Polarity of IR voltage drops

Definitions

Electromotive force (emf)

We have seen that the electromotive force (emf) of a cell is the open circuit voltage, and the potential difference (PD) is the voltage across the cell when it delivers a current. The potential difference is always less than the emf.

Potential difference

PD = emf – voltage drop in the cell

Potential difference can also be called by another term, the terminal voltage, as explained below.

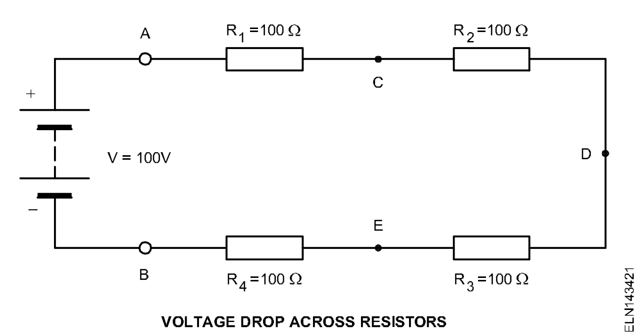
Terminal voltage

It is the voltage available at the terminal of the source of supply. Its symbol is V_T. Its unit is also the volt. It is given by the emf minus the voltage drop in the source of supply,

i.e. $V_T = \text{emf} - IR$

where I is the current and R the resistance of the source.

Fig 1



Voltage drop (IR drop)

The voltage lost by resistance in a circuit is called the Voltage drop or IR drop.

Example 1

The resistances and applied voltage are known. (Fig 1)

The voltage drops across the resistors

The total resistance of the circuit in Fig 1 would be equal to $R_T = 100 + 100 + 100 + 100 = 400$ ohms.

The current flowing through the circuit would be

I = (100/400) = 0.25 amps.

But point A has a potential of 100 volts and point B has zero. Somewhere along the circuit between A and B, the 100 volts have been lost.

To find the voltage drop for each resistor is easy. First find the current, which we have calculated as 0.25 amps, then

$V_{R1} = 0.25 \times 100 = 25$ V

$V_{R2} = 0.25 \times 100 = 25$ V

$V_{R3} = 0.25 \times 100 = 25$ V

$V_{R4} = 0.25 \times 100 = 25$ V.

Add up all the voltage drops and they will total 100 volts which is the applied voltage of the circuit.

25 + 25 + 25 + 25 = 100 volts.

The sum of the voltage drops in a circuit must be equal to the applied voltage.

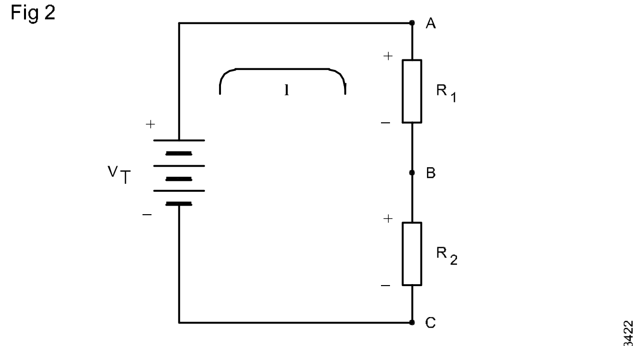
$V_{Total} = V_{R1} + V_{R2} + V_{R3} + V_{R4}$.

Polarity of voltage drops

When there is a voltage drop across a resistance, one end must be more positive or more negative than the other end. The polarity of the voltage drop is determined by the direction of conventional current. In Figure 2, the current direction is through R_1 from point A to B.

Therefore, the terminal of R_1 connected to point A has a more positive potential than point B. We say that the voltage across R_1 is such that point A is more positive than point B. Similarly the voltage of point B is more positive than point C.

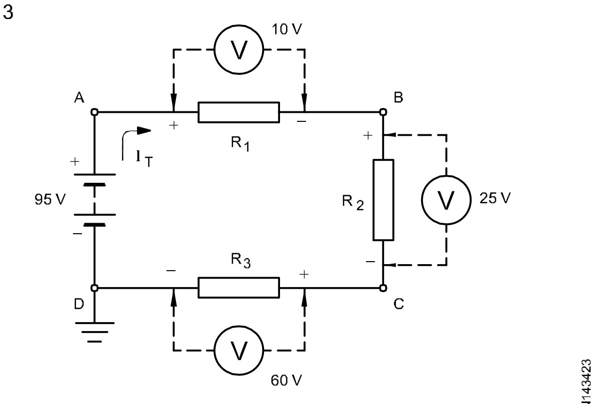
Fig 2



POLARITY OF VOLTAGE SOURCE

Another way to look at polarity between any two points is that the one nearer to the positive terminal of the voltage source is more positive; also, the point nearer to the negative terminal of the applied voltage is more negative. Therefore, point A is more positive than B, while C is more negative than B. (Fig 2)

Fig 3



VOLTAGE DROP AT SERIES CIRCUIT

Example 2

Find the voltage at the points A,B, C and D with respect to ground.

Mark the polarity of voltage drops in the circuit (Fig 3) and find the voltage values at points A, B, C and D with respect to ground.

Trace the complete circuit in the direction of current from the + terminal of the battery to A, A to B, B to C, C to D, and D to the negative terminal. Mark plus (+) where the current enters each resistor and minus (–) where the current leaves each resistor.

The voltage drops indicate (Fig 3) Point A is the nearest point to the positive side of the terminal; so voltage at A with respect to ground is

$V_A = +95$ V.

There is a voltage drop of 10 V across R_1; so voltage at B is

$V_B = 95 - 10 = +85$ V.

There is a voltage drop of 25 V across R_2; so voltage at C is

$V_C = 85 - 25 = +60$ V.

There is a voltage drop of 60V across R_3; so voltage at D is

$V_D = 60 - 60 = 0$ V.

Since the circuit is grounded at D, V_D must equal 0 V.

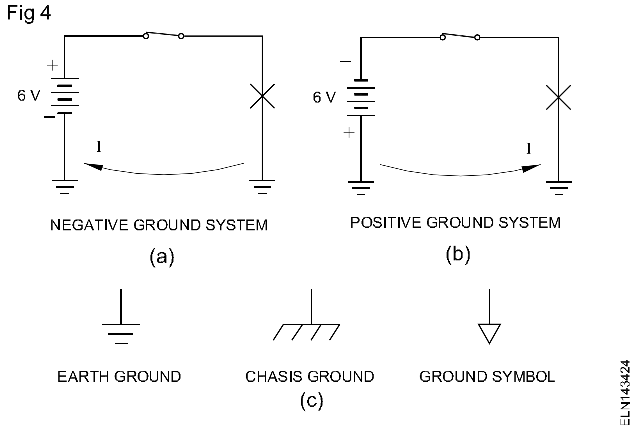
Positive and Negative grounds

In the electrical system of automobiles it is customary to connect one side of the battery to the metal chassis and call it the ground side. In this way metal chassis can be used as the **return path** for any circuit without providing an extra wire.

While most cars have 'negative grounds,' some (European) vehicles have a 'positive-ground' system. In the positive ground system reduced corrosion problems are claimed. Fig 4 shows both the systems.

In the negative ground system all wiring is at a positive potential with respect to the chassis, (as shown in Fig 4a)

Fig 4



whereas in a positive ground system (Fig 4b), all potentials are negative. Current flows in opposite directions in the two systems. But in both systems, the metal chassis is used as a common reference point to state the value of voltage at any point in the system.

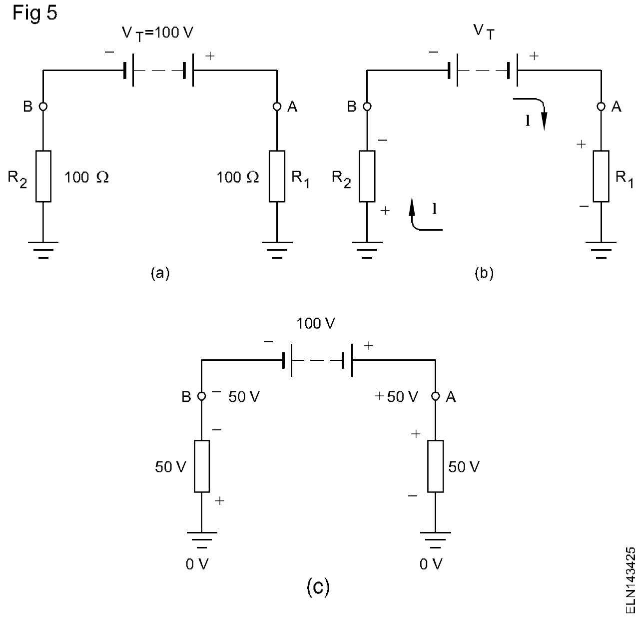
Figure 4c shows symbols for different types of ground systems.

Strictly speaking,the word ground being used for the metal chasis is not correct. A better symbol to use for chassis ground is shown in Fig 4c. This is because ground usually implies a connection to earth ground. (In a car the chassis is insulated from the ground by its rubber tires.) For example, one side of the domestic 240V AC outlet, the neutral is connected to earth by the system earthing method.

Marking the polarity of the voltage drop with respect to ground?

To mark the polarity of the voltage drops across the resistances R_1, R_2, find the voltage drops at points A and B in Fig 5(a), follow the steps as shown in Figures 5(b) and 5(c).

Fig 5



Practical application

The knowledge gained by this lesson will help you to:

- connect resistors in series to limit the current to the required level
- determine the current in the series circuit when PD and resistance value are known
- connect voltage sources like cells in a proper manner to have higher voltage
- determine with polarised meters, the polarity of IR drops, and, thereby, current direction in circuits
- detect faults in series-connected decorative lamp circuits.

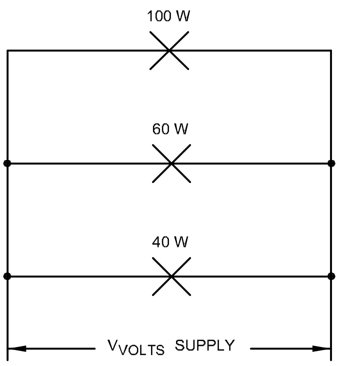
DC parallel circuit

Objectives: At the end of this lesson you shall be able to
- **explain a parallel circuit**
- **determine the voltages in a parallel circuit**
- **determine the current in a parallel circuit**
- **determine the total resistances in a parallel circuit**
- **state the application of a parallel circuit.**

In an electrical circuit, if the current has more than one paths and equal voltage in each branch is called parallel circuit.

It is possible to connect three incandescent lamps as shown in Fig 1. This connection is called parallel connection in which, the same source voltage is applied across all the three lamps.

Fig 1



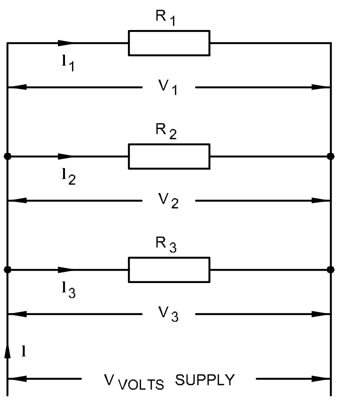
PARALLEL CIRCUIT

Voltage in parallel circuit

The lamps in Fig 1 are replaced by resistors in Fig 2. Again the voltage applied across the resistors is the same and also equal to the supply voltage.

We can conclude that the voltage across the parallel circuit is the same as the supply voltage.

Fig 2

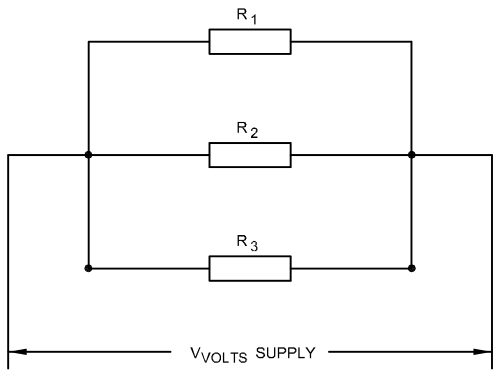


VOLTAGE IN PARALLEL CIRCUIT

Fig 2 could also be drawn as shown in Fig 3.

Mathematically it could be expressed as $V = V_1 = V_2 = V_3$.

Fig 3



PARALLEL CIRCUIT

Current in parallel circuit

Again referring to Fig 2 and applying Ohm's law, the individual branch currents in the parallel circuit could be determined.

Current in resistor $R_1 = I_1 = \frac{V_1}{R_1} = \frac{V}{R_1}$.

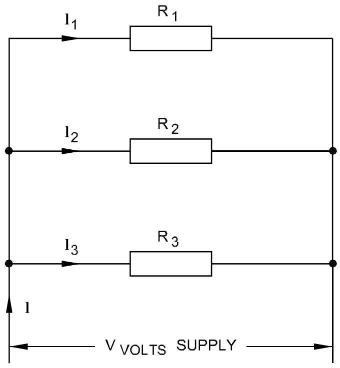
Current in resistor $R_2 = I_2 = \frac{V_2}{R_2} = \frac{V}{R_2}$.

Current in resistor $R_3 = I_3 = \frac{V_3}{R_3} = \frac{V}{R_3}$

as $V_1 = V_2 = V_3$.

Refer to Fig 4 in which the branch currents I_1, I_2 and I_3 are shown to flow into resistance branches R_1, R_2 and R_3 respectively.

Fig 4



The total current I in the parallel circuit is the sum of the individual branch currents.

Mathematically it could be expressed as $I = I_1 + I_2 + I_3 + \ldots\ldots I_n$.

Resistance in parallel circuit

In a parallel circuit, individual branch resistances offer opposition to the current flow though the voltage across the branches will be same.

Let the total resistance in the parallel circuit be R ohms.

By the application of Ohm's law

we can write

$$R = \frac{V}{I} \text{ ohms or } I = \frac{V}{R} \text{ amps.}$$

where

R is the total resistance of the parallel circuit in ohms

V is the applied source voltage in volts, and

I is the total current in the parallel circuit in amperes.

We have also seen

$I = I_1 + I_2 + I_3$

$$\text{or} \quad \frac{V}{R} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$$

As V is the same throughout the equation and dividing the above equation by V, we can write

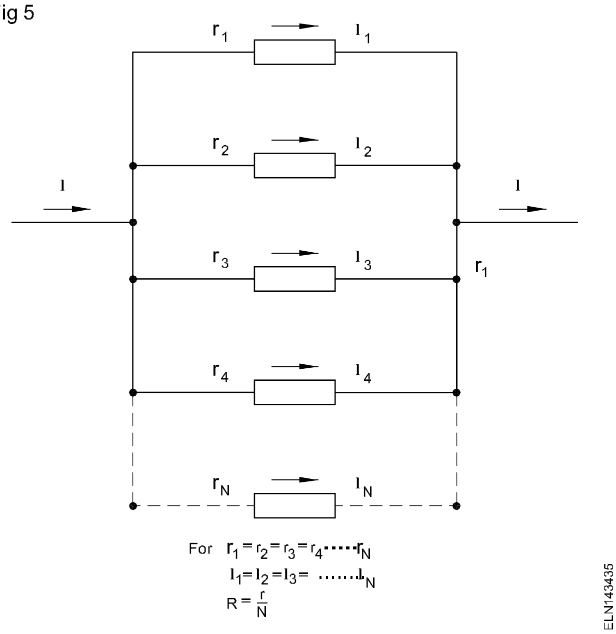
$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

The above equation reveals that in a parallel circuit, the reciprocal of the total resistance is equal to the sum of the reciprocals of the individual branch resistances.

Special case: Equal resistances in parallel

Total resistance R, of equal resistors in parallel (Fig 5) is equal to the resistance of one resistor, r divided by the number of resistors, N.

Fig 5



$$R = \frac{r}{N}$$

Applications of parallel circuits

An electric system in which one section can fail and other sections continue to operate has parallel circuits. As previously mentioned, the electric system used in homes consists of many parallel circuits.

An automobile electric system uses parallel circuits for lights, horn, motor, radio etc. Each of these devices operates independent of the others.

Individual television circuits are quite complex. However, the complex circuits are connected in parallel to the main power source. That is why the audio section of television receivers can still work when the video (picture) is inoperative.

Open and short circuit in series and parallel network

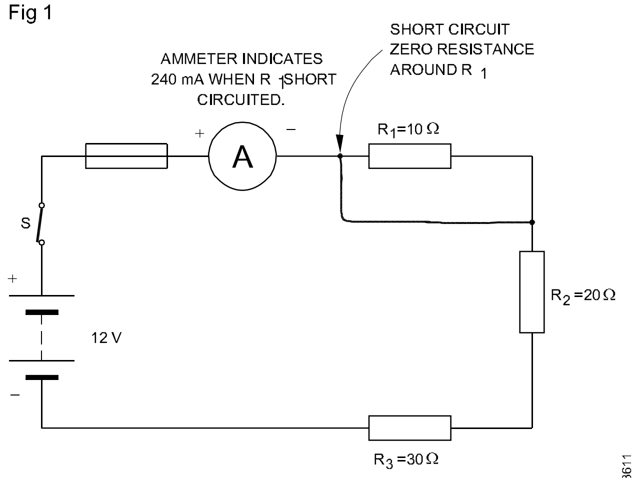
Objectives: At the end of this lesson you shall be able to
- **state about short circuit in series circuit and its effect in series circuit**
- **state the effect of an open circuit in series circuit and its causes**
- **state the effect of shorts and open in parallel circuit.**

Short circuits

A short circuit is a path of zero or very low resistance compared to the normal circuit resistance.

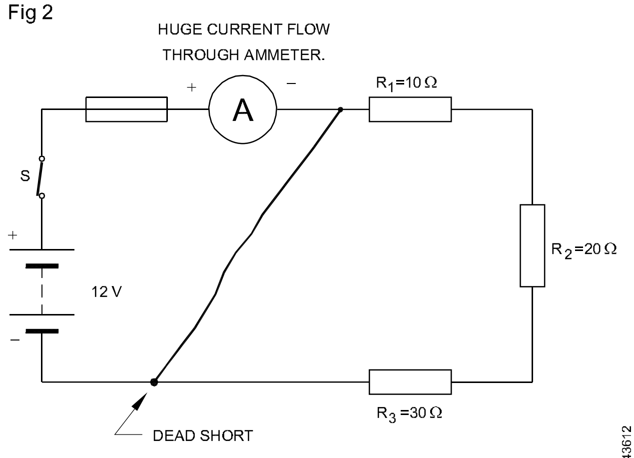
In a series circuit, short circuits may be partial or full (dead short) as shown in Fig 1 and Fig 2 respectively.

Fig 1



PARTIAL SHORT AT R 1

Fig 2



DEAD SHORT ACROSS CIRCUIT

Short circuits cause an increase in current that may or damage the series circuit.

Effects due to short circuit

Excess current due to short circuit can damage the circuit components, power sources, or burn the insulation of connecting wires. Fire is also caused due to intense heat generated in the conductors.

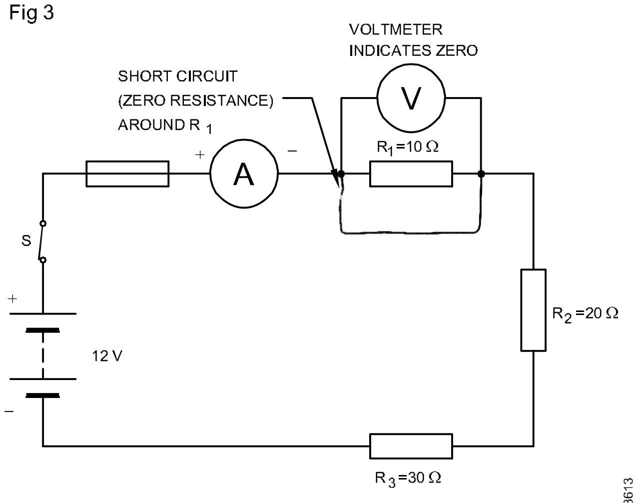
Protection against dangers of short circuit

Dangers of short circuit can be prevented by means of fuses and circuit breakers in series with the circuit.

Detecting short circuit

When the ammeter in the circuit indicates excessive current then it indicates a short circuit in the circuit. The location of short in a circuit can be detected by connecting a voltmeter across each of the elements (resistors) and circuit source. If the voltmeter indicates zero volts or reduced voltage across the element, it is short circuited as shown in Fig 3.

Fig 3



SHORT CIRCUIT IN ONE RESISTANCE

Methods used to protect the circuit in case of a short circuit

As heavy currents flow through the short circuit, the circuit cables should be protected against the large currents. If the short circuit current is allowed to flow through the circuit, the cables which are rated for normal circuit current, will get heated up and become potential fire hazards.

To open the circuit automatically in cases of short circuits, fuses or circuit breakers are used in the circuit. The rating of the fuse wire or setting of the overload relay in circuit breakers will be selected depending upon the lowest rating of any one of the following used in the circuit.

i Load current in the circuit

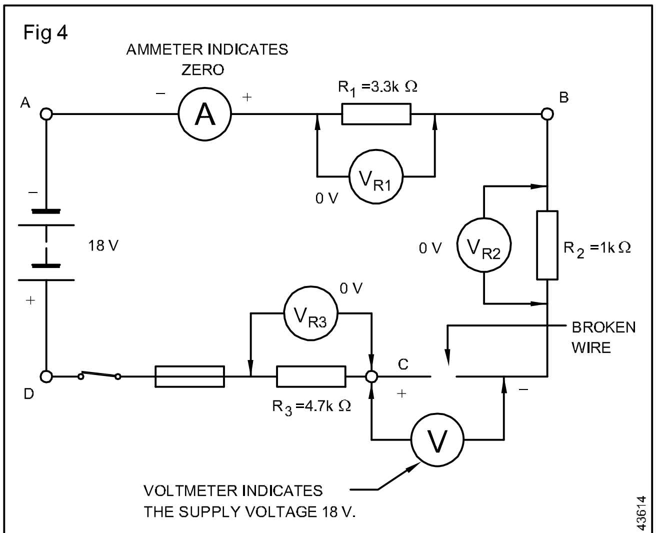
ii Cable rating of the circuit

iii Series meter (ammeter etc.) rating of the circuit.

Open circuit in series circuit

An open circuit results whenever a circuit is broken or is incomplete, and there is no continuity in the circuit.

In a series circuit, open circuit means that there is no path for the current, and no current flows through the circuit. Any ammeter in the circuit will indicate no current as shown in Fig 4.



OPEN CIRCUIT IN SERIES CIRCUIT

Causes for open circuit in series circuit

Open circuits, normally, happen due to improper contacts of switches, burnt out fuses, breakage in connection wires and burnt out resistors etc.

Effect of open in series circuit

a No current flows in the circuit.

b No device in the circuit will function.

c Total supply voltage/ source voltage appear across the open.

Determination the location of break in the circuit has occurred

Use a voltmeter on a range that can accommodate the supply voltage; connect it across each connecting wire in turn. If one of the wires is open as shown in Fig 4, the full supply voltage is indicated on the voltmeter. In the absence of a current, there is no voltage drop across any of the resistors. Therefore, the voltmeter must be reading full supply voltage across the open. part of the circuit

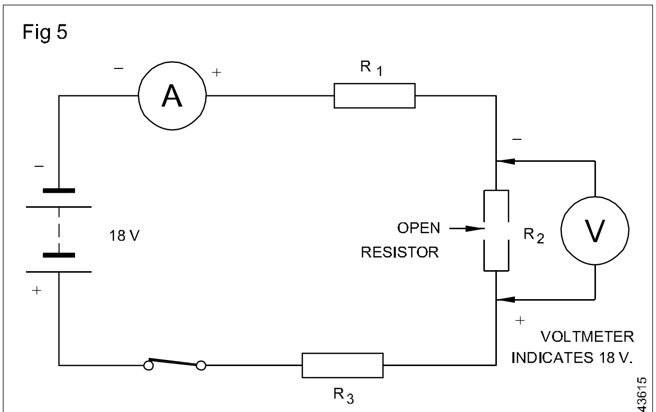
Voltmeter reading

$= 18\ V - V_{R1} - V_{R2} - V_{R3}$

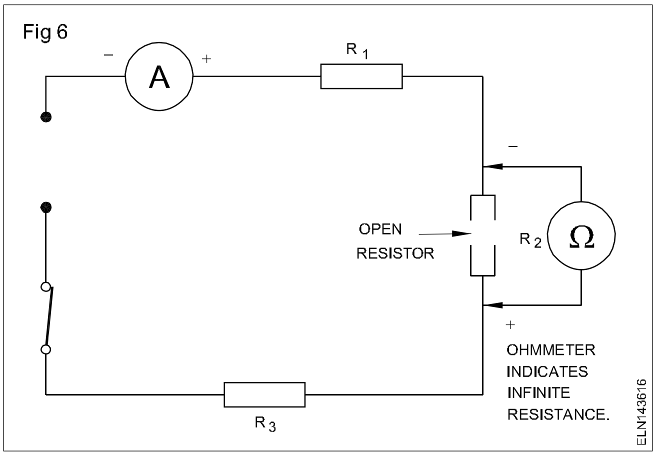
$= 18\ V - O\ V - O\ V - O\ V = 18\ V.$

If the circuit was open due to a defective resistor, as shown in Fig 5 (resistors usually open when they burn out), the voltmeter would indicate 18 V when connected across this resistor, R_2.

Alternatively, the open circuit may be found using an ohmmeter. With the voltage removed, the ohmmeter will show no continuity (infinite resistance), when connected across the broken wire or open resistor. (Fig 6)



OPEN CIRCUIT DUE TO OPEN RESISTOR R 2



Practical application

With the knowledge gained from this exercise:

- locate open and short circuit faults in a series circuit
- repair series-connected decoration bulb sets.

Shorts and opens in parallel circuits

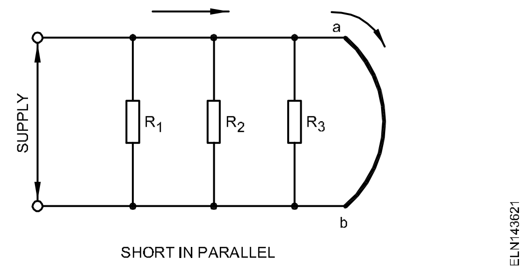
The two possible defects that can occur in an electrical circuit they are:

- short circuit
- open circuit

Shorts in parallel circuit:

Fig 1 shows a parallel circuit with short between points ‘a’ and ‘b’.

Fig 1



This causes reduction of circuit resistance almost to zero.

Therefore, the voltage drop across ‘ab’ will be almost zero (by Ohms law).

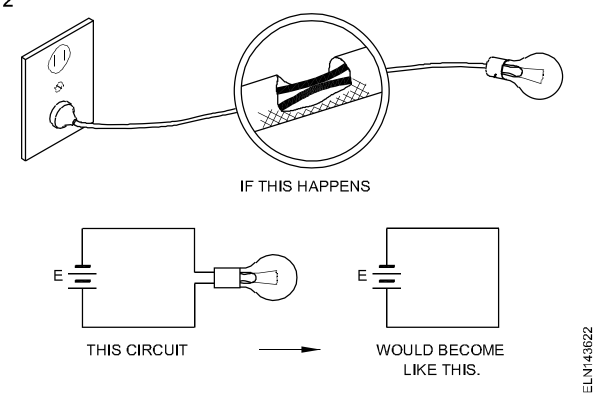
Thus current through the resistors R_1, R_2, R_3 will be negligible and not their normal current.

The result is that a very high current in the order of hundred times of the normal current will flow through the short circuit.

A short circuit exists when current can flow from the positive terminal of the power source through connecting wires and back to the negative terminal of the power source without going through any load. (Fig 2)

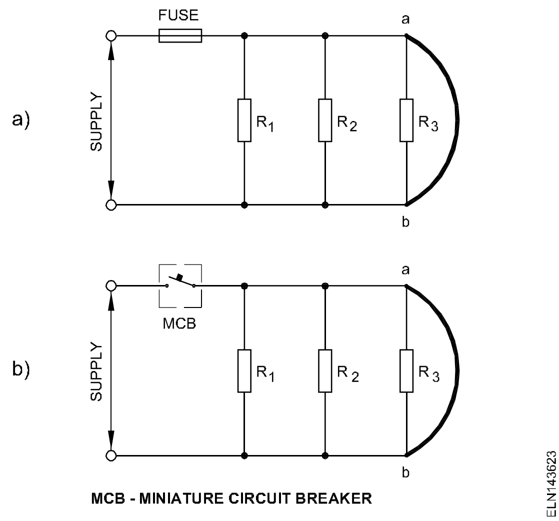
Short circuit may cause burning of the circuit elements like cables, switches etc.

Fig 2



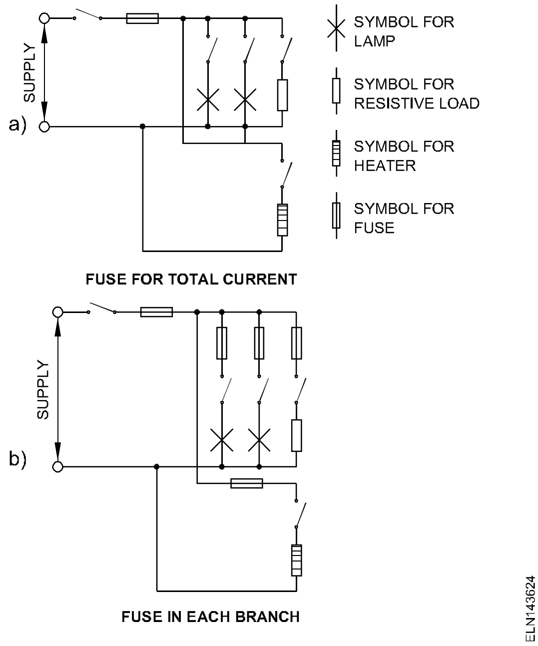
To avoid burning of circuit components safety devices like ‘fuse’, circuit breakers etc. are used to open the circuit.(Figs 3 a and 3b).

Fig 3



For a fuse to protect a parallel circuit, it should be placed in the circuit where the total current flows or else each branch must have a fuse. (Fig 4(a&b))

Fig 4



Opens in parallel circuit

An open in the common line at point A as shown in Fig 5 causes no current flow in that circuit whereas an open in the branch at point B causes no current flow only in that branch. (Fig 6)

However, the current in branches R_1 and R_3 will continue to flow so long as they are connected to the voltage source.

> **Full voltage of the source will be available at open circuit terminals. It is dangerous to meddle with the terminals which are open.**

Practical application

Knowledge gained in this exercise can be applied to identify open circuits or short circuits in wiring installations.

Fig 5

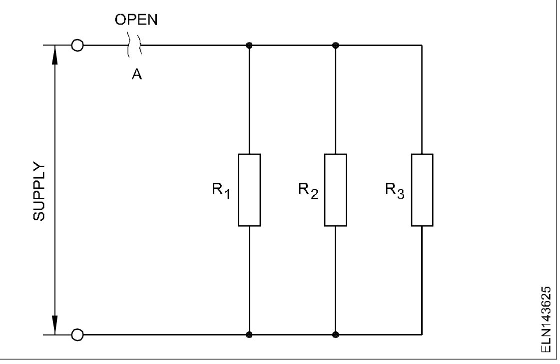
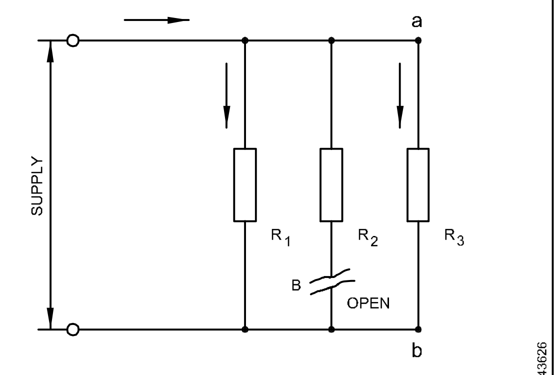


Fig 6



OPEN IN PARALLEL

Laws of resistance and various types of resistors

Objectives: At the end of this lesson you shall be able to
- **state the laws of resistance, compare resistances of different materials**
- **state the relationship between the resistance and diameter of a conductor**
- **calculate the resistance and diameter of a conductor from the given data (i.e. dimensions etc.)**
- **explain various types of resistors.**

Laws of resistance: The resistance R offered by a conductor depends on the following factors.

- The resistance of the conductor varies directly with its length.
- The resistance of the conductor is inversely proportional to its cross-sectional area.
- The resistance of the conductor depends on the material with which it is made of.
- It also depends on the temperature of the conductor.

Ignoring the last factor for the time being,we can say that

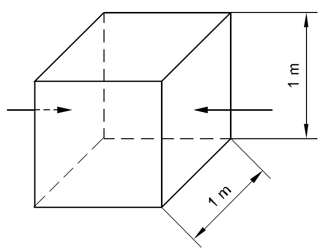
$$R = \frac{\rho L}{a}$$

where 'ρ' (rho - Greek alphabet) - is a constant depending on the nature of the material of the conductor, and is known as its **specific resistance** or **resistivity.**

If the length is one metre and the area, 'a' = 1 m^2, then R = r.

Hence, specific resistance of a material may be defined as `the resistance between the opposite faces of a metre cube of that material'. (or, sometimes, the unit cube is taken in centimetre cube of that material) (Fig 1).

Fig 1



ELN143811

We have $\rho = \frac{aR}{L}$

In the SI system of units

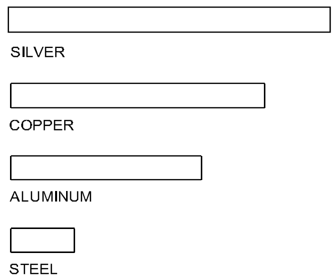
$$\rho = \frac{a\,\text{metre}^2 \times R\,\text{ohm}}{L\,\text{metre}}$$

$$= \frac{aR}{L}\,\text{ohm} - \text{metre}$$

Hence the unit of specific resistance is ohm metre (Ωm).

Comparison of the resistance of different materials: Fig 2 gives some relative idea of the more important materials as conductors of electricity. All the conductors shown have the same cross-sectional area and the same amount of resistance. The silver wire is the longest while that of copper is slightly short and that of aluminium is shorter still. The silver wire is more than 5 times longer than the steel wire.

Fig 2

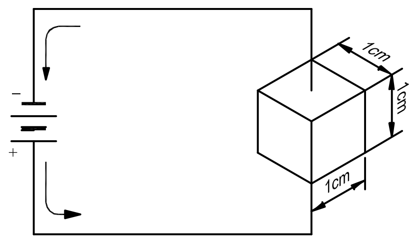


THE CONDUCTANCE OF DIFFERENT MATERIALS

ELN143812

Since different metals have different conductance ratings, they must also have different resistance ratings. The resistance ratings of the different metals can be found by experimenting with a standard piece of each metal in an electric circuit. If you cut a piece of each of the more common metals to a standard size, and then connect the pieces to a battery, one at a time, you would find that different amounts of current would flow. (Fig 3)

Fig 3

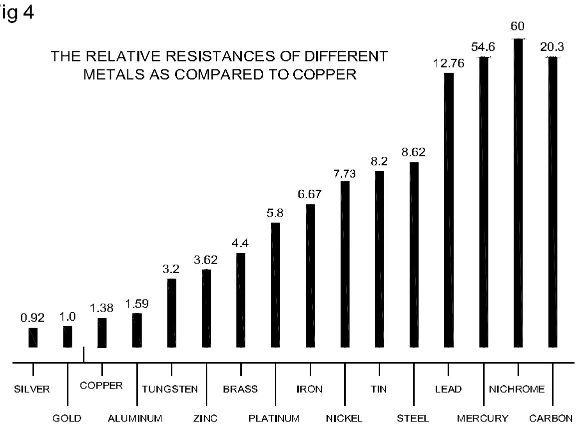


SPECIFIC RESISTANCE CIRCUIT

ELN143813

The bar graph (Fig 4) shows the resistance of some common metals as compared to copper. Silver is a better conductor than copper because it has less resistance. Nichrome has 60 times more resistance than copper, and copper will conduct 60 times as much current as Nichrome, if they were connected to the same battery, one at a time.

Fig 4



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Relationship between the resistance and the diameter of a conductor: For a uniform wire of a given material, the value obtained by dividing the P.D. between any two points by the current is the resistance between those two points, and is directly proportional to the distance between them.

Also if two equal value resistors, each having resistance R, are connected in parallel it's equivalent R_T is given by

$$\frac{1}{R_T} = \frac{1}{R} + \frac{1}{R} = \frac{2}{R}$$

Therefore $R_T = \frac{R}{2}$

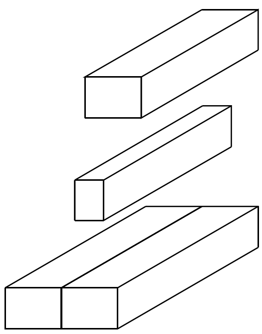
Hence, if two wires of the same material having the same length and diameter are connected in parallel the resistance of the two parallel wires is half that of one wire alone.

But the effect of connecting two wires in parallel is exactly similar to doubling the area of the conductor in just the same way as the effect of connecting, say, five wires in parallel is the same as increasing the cross-sectional area of a wire five times, and the result is to reduce the resistance to a fifth of that of one wire.

In general, we may, therefore, say that the resistance of a given length of a conductor is inversely proportional to its cross-sectional area.

The other factor that influences the resistance is the nature of the material. Hence, we may now say that resistance of a wire (Fig 5 & Fig 6)

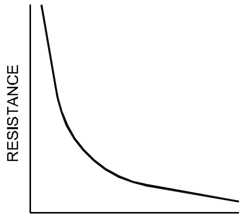
Fig 5



RESISTANCE IS INVERSELY PROPORTIONAL TO THE CROSS-SECTIONAL AREA OF THE CONDUCTOR.

ELN143815

Fig 6



INCREASING THE CROSS-SECTIONAL AREA OF A WIRE DECREASES ITS RESISTANCE

ELN143816

$$= \frac{\text{length}}{\text{area}} \times \text{(a constant) } \rho \text{ given material}$$

$$R(\text{ohms}) = \frac{L\ (\text{metres})}{a\ \text{metre}^2} \times \rho$$

So that $\rho = Ra \div L$ ohm/ meter

where ρ (greek letter, pronounced 'rho') represents the constant.

L is the length of the wire in metres

a is the area in square metres.

Example: Calculate the length of a copper wire of 1.5 mm diameter which is to have a resistance of 0.3 ohms given that resistivity of copper is 0.017 microohm meter.

Solution

Cross-sectional area of wire

$= (\pi/4) \times (1.5)^2 = 1.766 mm^2$

$= 1.766 \times 10^{-6} m^2$

$$R = \frac{\rho L}{a}$$

$$= 0.3 = \frac{0.017 \times 10^{-6} \times L}{1.766 \times 10^{-6}}$$

Ans: Length = 31.2 m.

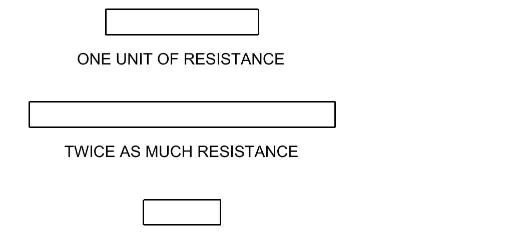
We can reduce all this into a simple statement: the larger the wire, the lower its resistacne; the smaller cross sectional area of the wire, the higher its resistance.

We can summarize with the universal rule: the electrical resistance of any metallic conductor is inversely proportional to its cross-sectional area.

All of this provides us with a useful rule in working with electrical conductors of any kind. Electrical resistance is directly porportional to the length of the conductor, provided, of course, the conductor is of the same diameter and is made of the same material throughout. (Figs 7 & 8)

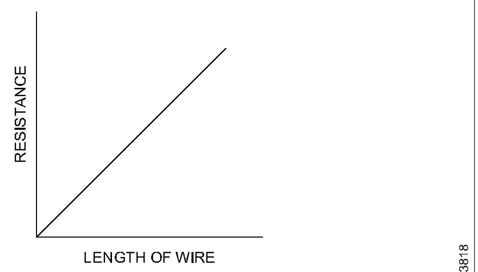
Thus, the length of wire has a considerable influence on its ability to conduct electricity. The longer the wire, the more difficult it is for the current to get through it. In other words, the longer the wire the greater its resistance.

Fig 7



RESISTANCE IS DIRECTLY PROPORTIONAL TO THE LENGTH OF THE CONDUCTOR.

Fig 8



INCREASING THE LENGTH OF A WIRE INCREASES ITS RESISTANCE

Calculation of resistance

Example 1: If a 15m eureka wire 0.14cm in diameter has a resistance of 3.75 ohms find the specific resistance of the material.

Solution

Length of wire L = 15m = 15 x 100 = 1500 cm

Diameter of wire = 0.14cm

Resistance = 3.75 ohm

Cross-sectional area of the wire

$$a = \pi r^2 = \frac{\pi d^2}{4}$$

we know $R = \frac{\rho L}{a}$

Specific resistance = $\rho = \frac{R \times a}{L}$

$$= \frac{3.75 \times 22 \times (0.14)^2}{15 \times 100 \times 7 \times 4} \text{ohm/cm}$$

$$= \frac{3.75 \times 22 \times (0.14)^2 \times 10^6}{15 \times 100 \times 7 \times 4} \text{micro ohm/cm}$$

= 38.5 micro ohm cm

= 38.5 μ ohm cm.

Example 2: Calculate the resistance of a 2 km long wire composed of 19 strands copper conductor, each strand being 1.32mm in diameter. Resistivity of copper may be taken as 1.72 x 10^{-8} ohm-m. Allow 5% increase in length for the `lay' (twist) of each strand in the completed cable.

Solution

Allowing for twist, the length of strands,

= 2000 + 5% of 2000 metre

= 2100m

Area of cross-section of 19 strands of copper conductor is

$$= 19 \text{ x } = \frac{\pi d^2}{4}$$

$$= 19 \times \pi \frac{(1.32 \times 10^{-3})^2 m^2}{4}$$

Now $R = \frac{\rho L}{a} = \frac{1.72 \text{ x } 10^{-6} \text{ x } 2100 \text{ x } 4 \text{ x } 7}{19 \text{ x } (1.32 \text{ x } 10^{-3})^2 \text{ x } 22}$

$$= \frac{1.72 \times 10^{-8} \times 2100 \times 4 \times 7}{19 \times 22 \times (1.32)^2 \times 10^{-6}}$$

= 1.388 ohms.

Example 3: Calculate in mm the dia. of a copper wire; the resistance of 3km of the wire is 14.4 ohms. Specific resistance of copper may be taken as 1.7 micro-ohm per centimetre cube.

Solution

Length = 3km = 3 x 1000 x 100

= 300 000 cm

Resistance = 14.4 ohms

ρ = 1.7μΩ/cm

$$a = \frac{\rho L}{R}$$

$$= \frac{1.7 \times 300\,000}{10^{-6} \times 14.4}$$

$$= \frac{1.7 \times 3}{144} = \frac{5.1}{144} cm^2$$

$$= \frac{51}{1440} = cm^2 = 0.035 \text{ cm}^2$$

Now $a = \frac{\pi d^2}{4}$ or $d^2 = \frac{a \times 4}{\pi}$

$$d = \sqrt{\frac{a \times 4}{\pi}}$$

$$= \sqrt{\frac{0.035 \times 4 \times 7}{22}}$$

$$= \sqrt{0.0445}$$

= 0.21 cm

= 2.1 mm.

Resistors

Objectives: At the end of this lesson you shall be able to
- **explain the construction and characteristics of various types of resistors**
- **explain the functions and applications of the resistors in electrical and electronic circuits.**

Resistors: These are the most common passive component used in electrical and electronic circuits. A resistor is manufactured with a specific value of ohms (resistance). The purpose of using a resistor in circuit is either to limit the current to a specific value or to provide a desired voltage drop (IR). The power rating of resistors may be from fractional walts to hundreds of Watts.

There are five types of resistors

1 Wire-wound resistors

2 Carbon composition resistors

3 Metal film resistors

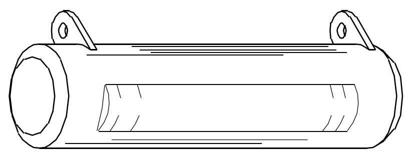
4 Carbon film resistors

5 Special resistors

1 Wire-wound resistors

Wire-wound resistors are manufactured by using resistance wire (nickel-chrome alloy called Nichrome) wrapped around an insulating core, such as ceramic porcelain, bakelite pressed paper etc. Fig 1, shows this type of resistor. The bare wire used in the unit is generally enclosed in insulating material. Wire wound resistors are used for high current application. They are available in wattage ratings from one watt to 100 watts or more. The resistance can be less than 1 ohm and go up to few thousand ohms.

Fig 1



WIRE-WOUND FIXED RESISTOR

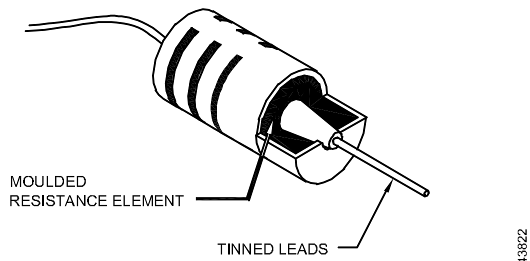
One type of wire-wound resistor is called as fusible resistor enclosed in a porcelain case. This resistor is designed to open the circuit when the current through it exceeds certain limit.

2 Carbon composition resistors

These are made of fine carbon or graphite mixed with powdered insulating material as a binder in the proportion needed for the desired resistance value. Carbon-resistance elements are fixed with metal caps with leads of tinned copper wire for soldering the connection into a circuit. Fig 2 shows the construction of carbon composition resistor.

Carbon resistor are available in values of 1 ohm to 22 megohms and of different power ratings, generally 0.1, 0.125, 0.25, 0.5, 1.0 and 2 watts.

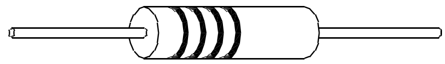
Fig 2



CARBON COMPOSITION RESISTOR

3 Metal film resistors (Fig 3)

Fig 3



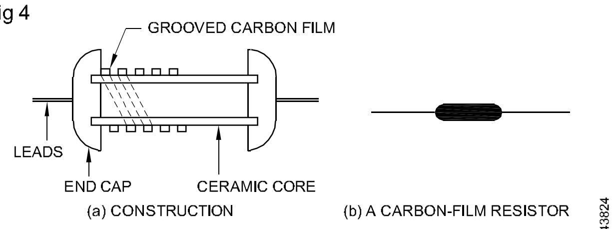
METAL FILM RESISTOR

Metal film resistors are manufactured by two processes. Thick film resistors are pasted with metal compound and powdered glass which are spread on the ceramic base and then backed.

Thin film resistors are processed by depositing a metal vapour on a ceramic base. Metal film resistors are available from 1 ohm to 10 MΩ, upto 1W. Metal film resistors can work from 120°C to 175°C.

4 Carbon film resistors (Fig 4)

Fig 4



CARBON – FILM RESISTOR

In this type, a thin layer of carbon film is deposited on the ceramic base/tube. A spiral groove is cut over the surface to increase the length of the foil by a specialised process.

Carbon film resistors are available from 1 ohm to 10 meg ohm and up to 1 W and can work from 85°C to 155°C.

All the above four types of resistors are coated with synthetic resin to protect them against mechanical damages and climatic influences, It is therefore, difficult to distinguish them from each other externally.

Specification of resistors : Resistors are specified normally with the four important parameters

1 Type of resistor

2 Nominal value of the resistors in ohm (or) kilo ohm (or) mega ohm.

3 Tolerance limit for the resistance value in percentage.

4 Loading capacity of the components in wattage

Example

100 ± 10% , 1W, where as nominal value of resistance is 100Ω.

The actual value of resistance may be between 90Ω to 110 Ω, and the loading capacity is maximum 1 watt.

The resistors can also be classified with respect to their function as

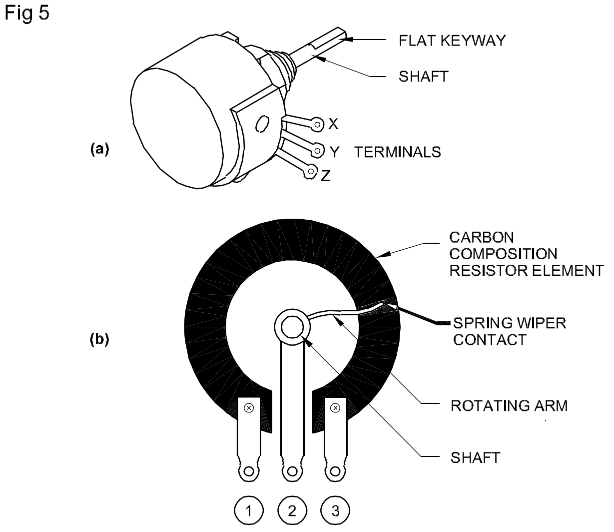
1 Fixed resistors

2 Variable resistors

Fixed resistors : The fixed resistors is one in which the is nominal value of resistance is fixed. These resistors are provided with pair of leads. (Fig 1 to 4)

Variable resistors (Fig 5) : Variable resistors are those whose values can be changed. Variable resistors includes those components in which the resistance value can be set at the different levels with the help of sliding contacts. These are known as potentio meter resistors or simply as a potentio meters.

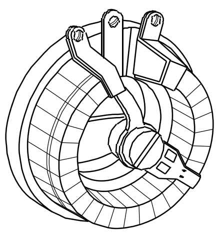
Fig 5



VARIABLE CARBON-RESISTANCE (a) EXTERNAL VIEW
(b) INTERNAL VIEW OF CIRCULAR RESISTANCE ELEMENT

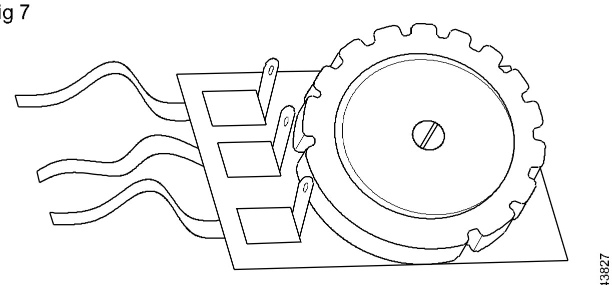
It is provided with 3 terminals as shown in Fig 5 and 6. They are available with carbon tracks (Fig 5) and wire wound (Fig 6) types. Trimmer potentio meters (or) resistor which can be adjusted with the help of a small screw drivers. (Fig 7).

Fig 6



WIRE-WOUND VARIABLE RESISTOR

Fig 7



TRIMMER RESISTOR

Resistance depends upon temperature, voltage, light : Special resistors are also produced whose resistance varies with temperature, voltage, and light.

PTC resistors (Sensistors) : Since, different materials have different crystal structure, the rate at which resistance increases with raising temperature varies from material to material. In PTC resistor (positive Temp. coefficient resistor), as the temp increases, the resistance increases non linearly. For example, the resistance of PTC at room temperature may be of nominal value 100 Ω when the temperature rises say 10°C, it may increase to 150 Ω and with further increase of another 10°C, it may increases to 500 Ω.

NTC Resistors (Thermistors) : In case of NTC resistors (Negative temperature co-efficient resistors) as the temperature increases, the value of resistance decreases non-linearly, For example, NTC resistor, which has nominal value of resistance is 500 Ω at room temperature may decrease to 400 Ω with the rise of 10°C temperature and further decrease to 150 Ω when the temperature rises to another 10°C.

The PTC and NTC resistors can perform switching operation at specific temperature. They are also used for measurements and temperature compensators.

VDR (Varistors) : The VDR (Voltage dependent resistor) resistance falls non-linearly with increasing voltage. For example, a VDR, may have 100 Ω resistance at 10 V, and it may decrease to 90 Ω at rise in 5V. By further increasing the voltage to another 5V, the resistance may fall to 50 Ω. The VDRS are used in voltage stabilisation, arc quenching and over voltage protection.

Light dependent resistor (LDR) : The LDRs are also known as photo- conductors. In LDRs the resistance falls with increase in intensity of illumination. The phenomena is explained as the light energy frees some electron in the materials of the resistors, which are then available as extra conducting electrons. The LDR shall have exposed surface to sense the light. These are used for light barriers in operating relays. These are also used for measuring the intensity of light.

Marking codes for resistors

Objectives: At the end of this lesson you shall be able to
- **interpret the coded marking of colours on the resistors**
- **interpret the letter and digit codes for resistance values**
- **state the tolerance value for resistors.**

Resistance and tolerance value of colour coded resistors

Commercially, the value of resistance and tolerance value are marked over the resistors by colour codes (or) letter and digital codes.

The colour codes for indicating the values to two significant figure and tolerances are given in Table 1 as per IS 8186.

Table 1

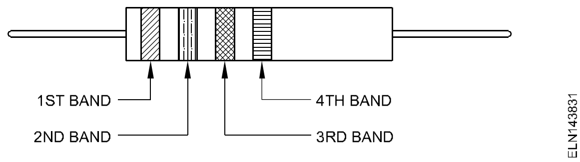
Values to two significant figures and tolerances corresponding to colours

Colour	First Band/ Dot	Second Band/ Dot	Third Band/ Dot	Fourth Band/ Dot
	First Figure	Second Figure	Multiplier	Tolerance
Silver	—	—	10^{-2}	± 10 %
Gold	—	—	10^{-1}	± 5 %
Black	—	0	1	—
Brown	1	1	10	± 1 %
Red	2	2	10^2	± 2 %
Orange	3	3	10^3	—
Yellow	4	4	10^4	—
Green	5	5	10^5	—
Blue	6	6	10^6	—
Violet	7	7	10^7	—
Grey	8	8	10^8	—
White	9	9	10^9	—
None	—	—	—	± 20 %

The two significant figures and tolerances colour coded resistors have 4 bands of colours coated on the body as in Fig.1.

The first band shall be the one nearest to one end of the component resistor. The second, third and four colour bands are shown in Fig 1.

Fig 1



The first two colour bands indicate the first two digits in the numeric value of resistance. The third colour band indicates the multiplier. The first two digits are multiplied by the multiplier to obtain the actual resistance value. The forth colour band indicates the tolerance in percentage.

Example

Resistance value : If the colour band on a resistor are in the order- Red, Green, Orange and Gold, then

First colour	Second colour	Third colour	Fourth colour
Red	Violet	Orange	Gold
2	7	$1000(10^3)$	±5%

the value of the resistor is 27,000 ohms with +5% tolerance.

Tolerance value : The fourth band (tolerance) indicates the resistance range within which is the actual value falls. In the above example, the tolerance is ±5%. ±5% of 27000 is 1350 ohms. Therefore, the value of the resistor is any value between 25650 ohms and 28350 ohms. The resistors with lower value of tolerance (precision) are costlier than normal value of resistors.

Methods of measuring low and medium resistance

Objectives: At the end of this lesson you shall be able to
- **state the different methods of measuring resistance**
- **describe the ammeter & voltmeter method.**

Classification of resistance: Based on the ohmic value of resistance, we name it as low, medium and high resistance.

A resistance is classified on its ohmic value as low, medium, or high.

Ranges

Low resistance - one ohm and below one ohm

Medium resistance - above one ohm up to 100,000 ohms(100 kΩ)

High resistance - above 100 kΩ (i.e 100000Ω)

The above classification is not rigid.

Uses

Low resistance: Armature winding, ammeter shunt, cable length, contact resistance.

Medium resistance: All electrical apparatus normally used have resistance in this range - bulbs, heaters, relay, motor starters.

High resistance: Insulation resistance, carbon composition resistors above 100K in the circuit.

We shall limit for the present to the methods used for measuring low and medium resistances in the following section.

Question

1 The lamp resistance of a mini-torch light, operating on 1.5 volts is classified as ___________ resistance.

Methods of measuring low resistance: The following three methods are used to measure low resistance.

- Voltmeter and ammeter method.
- Comparison of unknown with standard using potentiometer.
- Kelvin bridge
- Shunt type Ohmmeter

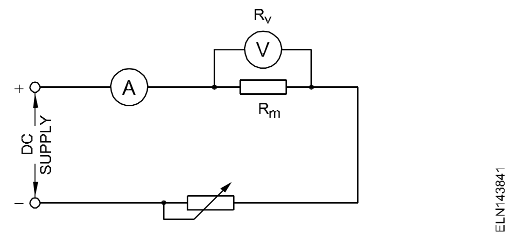
Ammeter and voltmeter method: This method, which is the simplest of all, is very commonly used for the measurement of low resistance.

In Fig 1, R_m is the resistance to be measured and V is a high resistance voltmeter of resistance R_v. A current from a steady direct current supply is passed through R in series with a suitable ammeter. Then assuming the current through the unknown resistance to be the same as that measured by the ammeter A, the formula is given as

$$R_m = \frac{\text{Voltmeter reading}}{\text{Ammeter reading}}$$

R_m = Measured value

Fig 1



If the voltmeter resistance is not very large, compared with the resistor to be measured, the voltmeter current will be an appreciable fraction of the current I, measured by the ammeter, and a serious error may be introduced on this account.

Medium resistance: The following three methods are used to measure medium resistance.

- Series type Ohmmeter
- Voltmeter and ammeter method
- Substitution method
- Wheatstone bridge method

The first method has been considered in the section on low resistance measurement. Substitution method and the wheatstone bridge method is explained subsequently.

Ohmmeter

Objectives: At the end of this lesson you shall be able to
- **classify resistances in terms of their values**
- **explain the principle, construction and use of a series type ohmmeter**
- **explain the principle, construction and use of a shunt type ohmmeter.**

Resistances could be broadly classified according to their values as indicated below.

Low resistance

All resistances of the order of one ohm and below one ohm, may be classified as low resistances.

Example Armature and series field resistances of large DC machines, ammeter shunts, cable resistance, contact resistance etc.

Medium resistances

Resistances above 1 ohm up to 100,000 ohms are classified as medium resistances.

Example Heater resistances, shunt field resistance, relay coil resistance etc.

High resistances

Resistances above 100,000 ohms are classified as high resistances.

Example Insulation resistance of equipment ,cables etc.

Measurement of resistances

Medium resistances could be measured by instruments like Kelvin's bridge, Wheatstone bridge, Slide wire bridge, Post Office box and Ohmmeter. Special designs of the above instruments allow measurement of low resistances, accurately.

However, for measuring high resistances, instruments like megohmmeter or megger are used.

Ohmmeter

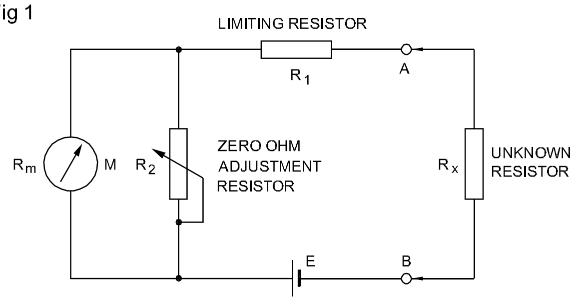
The ohmmeter is an instrument that is used for measuring resistance. There are two types of ohmmeters: the series ohmmeter is used for measuring medium resistances and the shunt type ohmmeter is used for measuring low and medium resistances. The ohmmeter in it basic form consists of an internal dry cell, a PMMC meter movement and a current limiting resistance.

Before using an ohmmeter in a circuit, for resistance measurement, the current in the circuit must be switched off and also any electrolytic capacitor in the circuit should be discharged. Remember that the ohmmeter has its own source of supply.

Series type ohmmeter: construction

A series type ohmmeter shown in Fig 1 essentially consists of a PMMC (Permanent magnet moving coil) ('d' Arsonval) movement 'M', a limiting resistance R_1 and a battery 'E' and a pair of terminals A and B to which the unknown resistance 'R_x' is to be connected. The shunt resistance R_2 connected in parallel to meter 'M' is used for adjusting the zero position of the pointer.

Fig 1



SERIES TYPE OHMMETER

Working

When the terminals A and B are shorted (unknown resistor R_x = zero), maximum current flows in the circuit. The meter is made to read full scale current (I_{fsd})by adjusting the shunt resistance R_2. The full scale current position of the pointer is marked zero(0) ohm on the scale.

When the ohmmeter leads (A & B terminals) are open, no current flows through the meter movement. Therefore, the meter does not deflect and the pointer remains in the left hand side of the dial. The left side of the dial is marked as infinity ($\propto$) resistance which means that there is infinite resistance (open circuit) between the test leads.

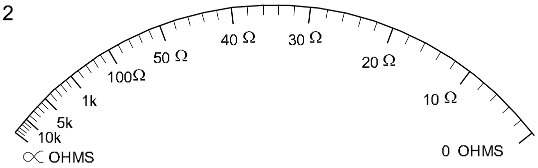
Intermediate marking may be placed in the dial (scale) by connecting different known values of R_x, to the instrument terminals A and B.

The accuracy of the ohmmeter depends greatly upon the condition of the battery. The voltage of the internal battery may decrease gradually due to usage or storage time. As such the full scale current drops and the meter does not read zero when the terminals A and B are shorted.

The variable shunt resistor R_2 in Fig 1 provides an adjustment to counteract the effect of reduced battery voltage within certain limits. If the battery voltage falls below a certain value, adjusting R_2 may not bring the pointer to zero position, and hence, the battery should be replaced with a good one.

As shown in Fig 2, the meter scale will be marked zero ohms at the right end and infinity ohms at the left end.

Fig 2



SERIES TYPE OHMMETER SCALE

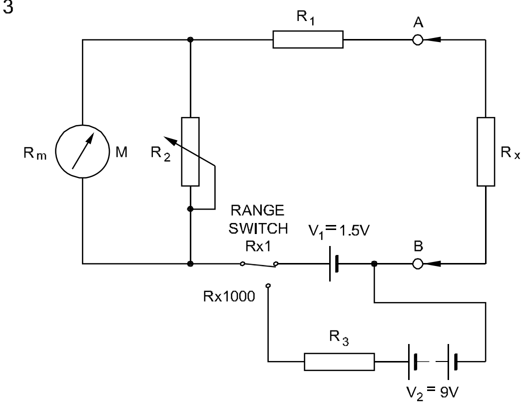
This ohmmeter has a non-linear scale because of the inverse relationship between resistance and current. This results in an expanded scale near the zero end and a crowded scale at the infinity end.

Multiple ohmmeter range

Most of the ohmmeters have a range switch to facilitate measurement of a wide range of resistors, say from 1 ohm up to 100,000 ohms. The range switch acts as the multiplying factor for the ohms scale. To get the actual value of measurement,the scale reading need to be multiplied by the R_x factor of the range switch.

The range switch arrangement is provided either through a network of resistances powered through a cell of 1.5V or through a battery of 9 or 22.5 volts. The arrangement is shown in Fig 3. The resistance value of R_3 is so chosen that the full scale current is passed through the meter at the enhanced source voltage.

Fig 3



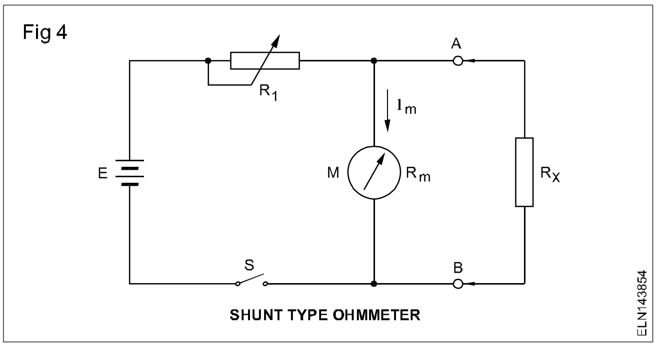
MULTI-RANGE SERIES TYPE OHMMETER

Use

This type of ohmmeter is used for measuring medium resistances only and the accuracy will be poor in the case of very low and very high resistance measurements.

Shunt type ohmmeter

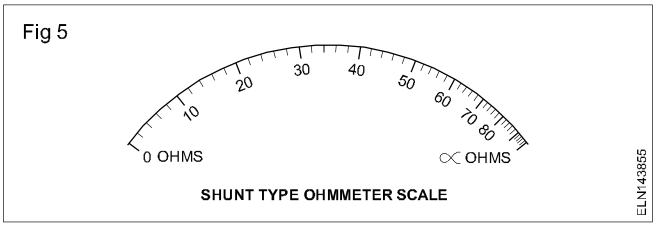
Fig 4 shows the circuit diagram of a shunt type ohmmeter. In this meter the battery 'E' is in series with the zero ohm, adjustment resistor R_1 and the PMMC meter movement. The unknown resistance R_x which is connected across the terminals A and B forms a parallel circuit with the meter. To avoid draining of the battery during storage, the switch S is of a spring-loaded, push-button type.



Working

When the terminals A and B are shorted (the unknown resistance R_x = zero ohm), the meter current is zero. On the other hand if the unknown resistance $R_x = \propto$ =(keeping A and B open) the current flows only through the meter, and by proper selection of the value R_1, the pointer can be made to read its full scale.

The shunt type ohmmeter, therefore, has the zero mark at the left hand side of the scale (no current) and the infinite mark at right hand side of the scale (full scale deflection current) as shown in Fig 5. When measuring the resistance of the intermediate values the current flow divides in a ratio inversely proportional to the meter resistance and the unknown resistance. Accordingly the pointer takes an intermediate position.



Use

This type of ohmmeter is particularly suitable for measuring low value resistors.

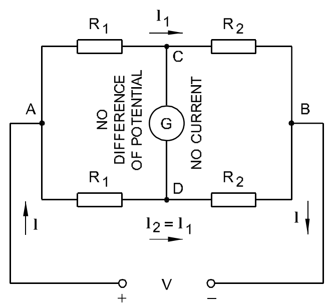
Wheatstone bridge - principle and its application

Objectives: At the end of this lesson you shall be able to
- **describe the method of obtaining equal potential points in two branches of a parallel circuit**
- **state wheatstone bridge circuit, construction, function and uses.**
- **determine the unknown resistance by the wheatstone bridge.**

Points of equal potential in parallel circuits: An electrical current flows only when a potential difference is present. Without a potential difference, current will not flow.

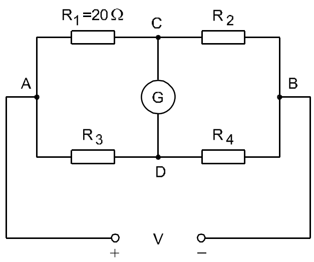
In the Fig 1, the resistances R_1 and R_2 in each of the parallel branches are equal. Therefore, the potential differences across the two resistors R_1 are equal, i.e. from A to C and from A to D. Hence, even when the points C and D are connected with the galvanometer no current will flow.

Fig 1



Four resistors R_1, R_2, R_3 and R_4 are arranged as shown in Fig 2. Select the values of R_2, R_3 and R_4 from the list so that no current flows between points C & D. Resistance values are 20 ohms, 30 ohms, 40 ohms, 70 ohms, 15 ohms.

Fig 2



Equal resistance ratio in parallel circuit: One does not need equal resistances in the parallel circuits to obtain equal potential nodes. It suffices if the resistances are in the same ratio to each other.

In the circuit diagram (Fig 3), the resistances in the top conductor branch are in the ratio 1 : 3.

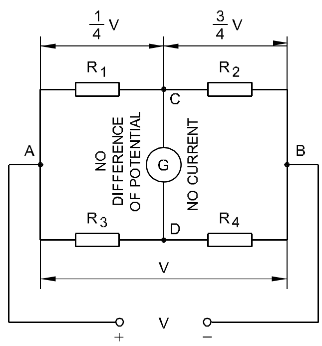
The resistances in the bottom conductor branch are also in the ratio 1:3. The supply emf V, is therefore, divided in the both conductor branches in the same ratio 1:3. The first potential difference is

$$= \frac{1}{4} \text{ V and second} = \frac{3}{4} \text{ V}$$

Again no current can flow in a conductor connected across the points C and D.

A conductor between C and D is called a bridge connection.

Fig 3

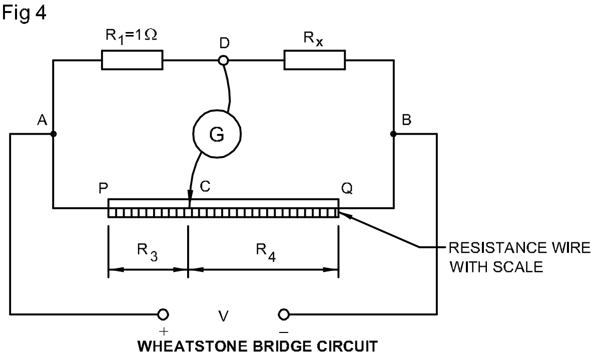


The wheatstone bridge circuit

The equal resistance ratio in parallel circuits can be used for the measurement of resistance.

In the circuit arrangement shown in Fig 4, the sliding contact C slides along a resistance wire.

Fig 4



R_1 is a standard resistor, e.g. 1 ohm.

The sliding contact C is moved along the resistance wire until the detector or bridge galvanometer across C-D reads zero. Then the resistance ratios in the two parallel branches are equal.

$R_x : R_1 = R_4 : R_3$

If R_1 = 1 ohm then

$$R_x = \frac{R_4}{R_3}$$

This circuit arrangement can, therefore, be used to measure an unknown resistance R_x. The resistance can be directly read from a scale on the resistance wire. (Fig 4)

For determining the unknown resistance by Wheatstone Bridge

- The current flowing through the bridge connection should be zero.
- The values of the other three resistances should be precisely known.

How to find no current flows through the bridge connection?: An instrument, that can indicate the flow of even a few micro amperes (millionth of an ampere), called galvanometer, is used. There are galvanometers that give full scale deflection for 25 microamperes.

In the professional Wheatstone bridges, the galvanometer is provided with a parallel resistance and switch. The bridge connection is made only by pressing a push button. This enables the user to check a momentary deflection of the meter. In the case of excessive deflection, adjustment of the variable resistor is done. Final and precise adjustment of the variable resistance is made keeping the shunt resistor of the galvanometer open.

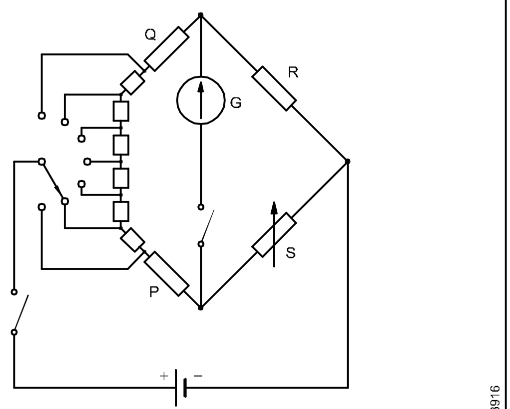
The three arms of the bridge are made of standard/ precision resistors. The contact resistance is kept very very low to increase the accuracy of the measurement made by the Wheatstone bridge.

In short, the use of the galvanometer is to ensure that the current through the bridge connection is zero, i.e. both parallel branches have equipotential points connected by the bridge connector.

This arrangement is named after its inventor and is called the Wheatstone Bridge.

The Wheatstone Bridge is used for measurements in the range of about 1.0 ohm to 1.0 megohm. In Fig 5, resistors P,Q and S are internal to the instrument. R is the resistor of unknown value to be measured.

Fig 5



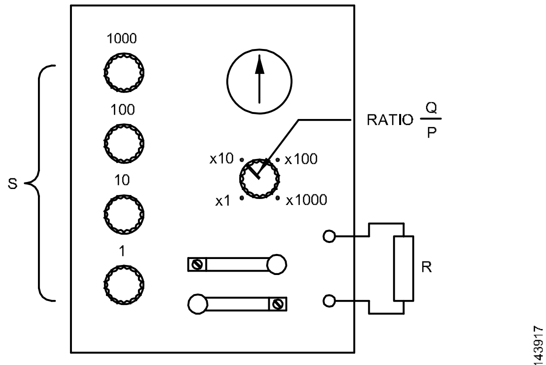
RESISTANCE ARRANGEMENT IN WHEATSTONE BRIDGE

The instrument is adjusted until the ratio $\frac{Q}{P} = \frac{R}{S}$

This is indicated by a zero reading on the galvanometer with its switch in the closed position.

The resistors P and Q are called ratio arms. P and Q are varied in steps to give a range of values and the resistance value of 'S' is set by the decade resistance S.(Fig 6)

Fig 6



FRONT VIEW OF WHEATSTONE BRIDGE

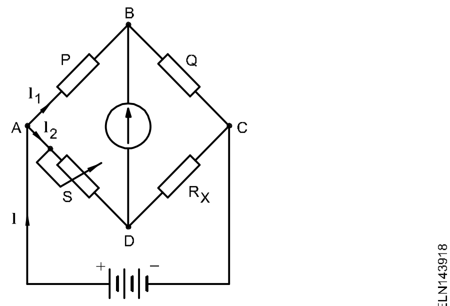
$R = \frac{Q}{P}$ multiplied by S.

The ratio $\frac{Q}{P}$ is arranged to be 1, 10, 100 or 1,000 for ease of calculation.

S is the variable resistance. Four decade resistances are connected in series. The value of S can be set in steps of one ohm from 1.0 ohm to 9999 ohms by suitably setting the four decade resistance units.

Example 1: The Wheatstone Bridge circuit is used to determine the value of the unknown resistor R_x. The bridge is balanced when P = 100 ohms, Q = 1000 ohms and S is adjusted to 130 ohms. Calculate the value of the unknown resistor R_x. (Fig 7)

Fig 7



Solution

At balance $V_{AB} = V_{AD}$

and $V_{BC} = V_{DC}$

therefore, $I_1P = I_2S$

and $I_1Q = I_2 R_X$

$$\frac{I_1}{I_2} = \frac{S}{P} = \frac{I_1}{I_2} = \frac{R_X}{Q}$$

$$\frac{S}{P} = \frac{R_X}{Q}$$

$$R_X = \frac{S}{P} \times Q = \frac{130 \times 1000}{100}$$

$$R_x = 1300\ \Omega$$

Example 2 : In the Wheatstone Bridge network (Fig 8), ABCD is balanced when

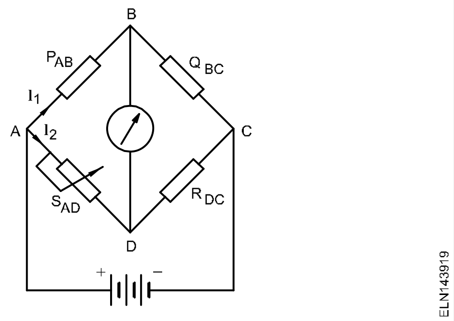
P_{AB} = 500 ohms

Q_{BC} = 250 ohms and

S_{AD} = 12 ohms.

Determine the value of $R_{DC.}$

Fig 8



Solution

At balance $V_{AB} = V_{AD}$

and $V_{BC} = V_{DC}$

$I_1P = I_2S$

and $I_1Q = I_2R$

Therefore,

$$\frac{I_1}{I_2} = \frac{S}{P} = \frac{I_1}{I_2} = \frac{R}{Q}$$

$$\frac{S}{P} = \frac{R}{Q} \text{ and } R = \frac{S}{P} \times Q$$

$$R = \frac{12}{500} \times 250 = 6 \text{ ohms}$$

Effect of variation of temperature on resistance

Objectives: At the end of this lesson you shall be able to
- **explain on what factors electrical resistance of a conductor depends**
- **state the temperature co-efficient of resistance.**

The resistance of material largely depends on temperature and varies according to the material. The phenomenon is used to develop special resistors, PTC & NTC etc., but the overall effect of temperature normally increase the current in that conductor material.

When resistance r is a constant depending on the nature of the material of the conductor and known as its specific resistance or resistivity. Dependency of resistance on temperature is explained in detail below:-

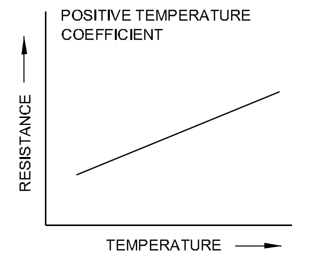
Effect of temperature on resistance: Actually, the relative values of resistance that were given earlier apply to the metals when they are at about room temperature. At higher or lower temperatures, the resistances of all materials change.

In most cases, when the temperature of a material goes up, its resistance goes up too. But with some other materials, increased temperature causes the resistance to go down.

The amount by which the resistance is affected by each degree of temperature change is called the temperature coefficient. And the words positive and negative are used to show whether the resistance goes up or down with the temperature.

When the resistance of the material goes up as temperature is increased, it has a positive temperature coefficient. It is appropriate in the case of pure metals such as silver, copper, aluminium, brass etc. (Fig 1)

Fig 1



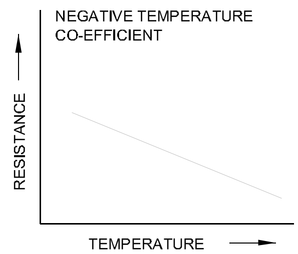
RESISTANCE INCREASES WITH TEMPERATURE

In the case of certain alloys such as eureka, manganin, etc. increase in resistance due to increase in temperature is relatively less and irregular.

When a material's resistance goes down as the temperature is increased, it has a negative temperature coefficient. (Fig 2)

This applies in the case of electrolytes, insulators such as paper, rubber, glass, mica etc. and partial conductors such as carbon.

Fig 2



RESISTANCE DECREASES WITH TEMPERATURE

Temperature coefficient of resistance (a) of a conductor: Let a metallic conductor, having a resistance of R_0 at 0°C, be heated to t°C and let its resistance at this temperature be R_t. Then, considering normal ranges of temperature, it is found that the increase in resistance depends:

- directly on its initial resistance
- directly on the rise in temperature
- on the nature of the material of the conductor

Hence $(R_t - R_o) = R_o t \alpha$ .....(i)

where α (alpha) is constant and is known as the temperature coefficient of resistance of the conductor.

Rearranging Eq.(i), we get

$$\alpha = \frac{R_t - R_0}{R_0 \times t} = \frac{\Delta R}{R_0 \times t}$$

If $R_o = 1\Omega$, t = 1°C, then $\alpha = \Delta R = R_t - R_o$.

Hence, the temperature-coefficient of a material may be defined as: the change in resistance in ohm per °C rise in temperature.

From Eq.(i), we find that $R_T = R_o(1+\alpha t)$ .....(ii)

In view of the dependence of α on the initial temperature, we may define the temperature coefficient of resistance at a given temperature as the change in resistance per ohm per degree centigrade change in temperature from the given temperature.

In case R_o is not given, the relationship between the known resistance R_1 at t_1°C and the unknown resistance R_2 at t_2°C can be found as follows:

$R_2 = R_o(1 + \alpha_o t_2)$ and

$R_1 = R_o(1 + \alpha_o t_1)$.

Therefore $\frac{R_2}{R_1} = \frac{1+\alpha_0 t_2}{1+\alpha_0 t_1}$

Resistivities and temperature coefficients

Material Metals-Alloys	**Resistivity in ohm-metre at 20°C x 10^{-8}**	**Temperature coefficient at 20°C x 10^{-4}**
Aluminimum	2.8	40.3
Brass	6 – 8	20
Carbon	3000 –7000	–(5)
Constant or Eureka	49	(+0.160 –0.4)
Copper (annealed)	1.72	39.3
German silver	20.2	2.7
Iron	9.8	65
Manganin (84% Cu; 25% Mn; 4% Ni)	44 – 48	0.15
Mercury	95.8	8.9
Nichrome (60% Cu;25% Fe; 15% Cr)	108.5	1.5
Nickel	7.8	54
Platinum	9 –15.5	36.7
Silver	1.64	38
Tungsten	5.5	47

Insulators	**Resistivity in ohm-metre at 20°C**	**Temperature coefficient at 20°C**
Amber	5×10^{14}	
Bakelite	10^{10}	
Glass	10^{10}–10^{12}	10^{12}
Mica	10^{15}	
Rubber	10^{16}	
Shellac	10^{14}	
Sulphur	10^{15}	

Example: The resistance of a field coil measures 55 ohms at 25°C and 65 ohms at 75°C. Find the temperature-coefficient of the conductor at 0°C.

$R_t = R_o(1 + \alpha_o t)$

$R_{25} = 55 = R_o(1 + 25\alpha_o)$ Eqn.1

$R_{75} = 65 = R_o(1 + 75\alpha_o)$ Eqn.2

Dividing Eqn.2 by Eqn.1 we get

$$\frac{R_{75}}{R_{25}} = \frac{65}{55} = \frac{1+75\alpha_0}{1+25\alpha_0}$$

$$\frac{13}{11} = \frac{1+75\alpha_0}{1+25\alpha_0}$$

Cross multipling we get

$13[1 + 25\alpha_o] = 11[1 + 75\alpha_o]$

$13 + 325\alpha_o = 11 + 825\alpha_o$

$13 - 11 = 825\alpha_o - 325\alpha_o$

$2 = 500\alpha_o$

$a_o = \frac{2}{500} = 0.004$ per °C.

Series and parallel combination circuit

Objectives: At the end of this lesson you shall be able to
- **compare the characteristics of series and parallel circuits**
- **solve series-parallel circuit problems**

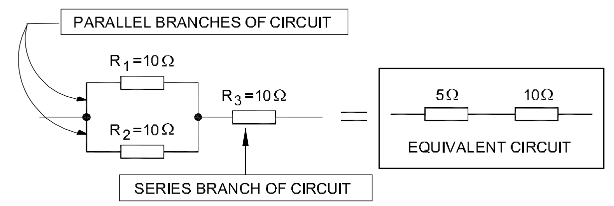
Comparison of characteristics of DC series and parallel ciruits

Sl. No.	Series circuit	Parallel circuit
1	The sum of voltage drops across the individual resistances equals the applied voltage.	The applied voltage is the same across each branch.
2	The total resistance is equal to the sum of the individual resistances that make up the circuit. $R_t = R_1+R_2+R_3+...$ etc combination.	The reciprocal of the total resistance equals the sum of the reciprocal of the resistances. The resultant resis- tance is less than the smallest resistance of the parallel
3	Current is the same in all parts of the circuit. resistance of each branch.	The current divides in each branch according to the resistance of each branch
4	Total power is equal to the sum of the power dissipated by the individual resistances.	(Same as series circuit) Total power is equal to the sum of the power dissipated by the individual resistances.

Formation of series parallel circuit

Apart from the series circuit and parallel circuits, the third type of circuit arrangement is the series-parallel circuit. In this circuit, there is at least one resistance connected in series and two connected in parallel. The two basic arrangements of the series-parallel circuit are shown here. In one, resistor R_1 and R_2 are connected in parallel and this parallel connection, in turn, is connected in series with resistance R_3. (Fig 1)

Fig 1



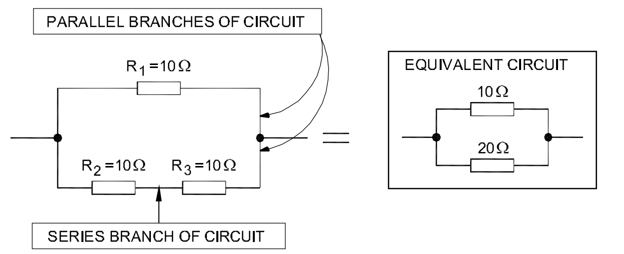
$$R_t = \frac{(R_1 \times R_2)}{(R_1 + R_2)} + R_3 = 5 + 10 = 15\Omega$$

Thus, R_1 and R_2 form the parallel component, and R_3 the series component of a series-parallel circuit. The total resistance of any series-parallel circuit can be found by merely reducing it into a simple series circuit. For example, the parallel portion of R_1 and R_2 can be reduced to an equivalent 5-ohm resistor(two 10-ohm resistors in parallel).

Then it has an equivalent circuit of a 5-ohm resistor in series with the 10-ohm resistor(R_3), giving a total resistance of 15 ohms for the series-parallel combination.

A second basic series-parallel arrangement is shown in Fig 2 where basically it has two branches of a parallel circuit. However, in one of the branches it has two resistances in series R_2 and R_3. To find the total resistance of this series -parallel circuit, first combine R_2 and R_3 into an equivalent 20-ohm resistance. The total resistance is then 20 ohms in parallel with 10 ohms, or 6.67 ohms.

Fig 2



$$R_t = \frac{R_1 \times (R_2 + R_3)}{R_1 + (R_2 + R_3)} = \frac{200}{30} = 6.67\Omega$$

Combination circuits

A series-parallel combination appears to be very complex.

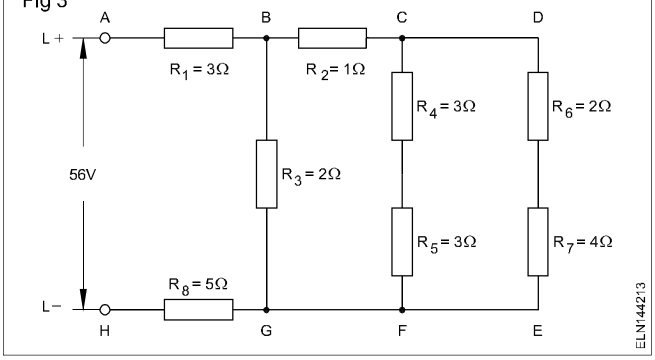
However, a simple solution is to break down the circuit into series/or parallel groups, and while solving problems, each may be dealt with individually. Each group may be replaced by one resistance, having the value equal to the sum of all resistances.

Each parallel group may be replaced by one resistance value equivalent to the combined resistance of that group. Equivalent circuits are to be prepared for determining the current, voltage and resistance for each component.

Example

Determine the combined resistance of the circuit shown in Fig 3.

Fig 3



Procedure

1 Combine R_6 and R_7.

$R_a = R_6 + R_7$

$R_a = 2 + 4$

$R_a = 6$ ohms.

2 Draw an equivalent circuit with resistance Ra. (Fig 4)

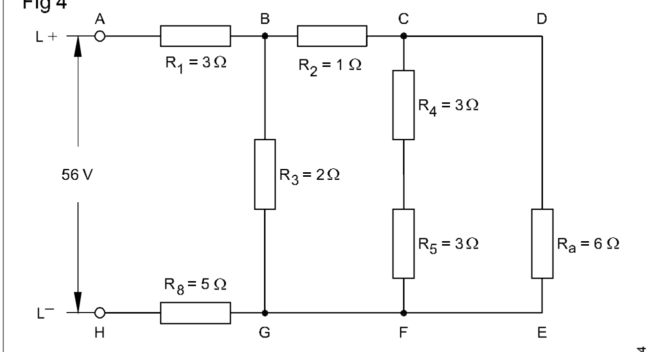
3 Combine R_4 and R_5 of Fig 4.

$R_b = R_4 + R_5$

$R_b = 3 + 3$

$R_b = 6$ ohms.

Fig 4



EQUIVALENT CIRCUIT OF FIG 3. R_6 AND R_7 ARE REPLACED WITH ONE RESISTOR (R_a) OF 6 Ω

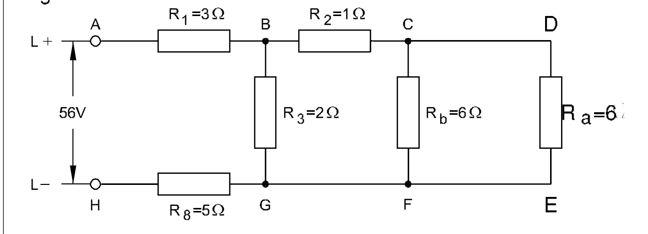
4 Draw an equivalent circuit as per Fig 5.

5 Combine R_a and R_b and call the equivalent resistance value as R_C. (Fig 5)

$$R_c = \frac{R_a \times R_b}{R_a + R_b} = \frac{6 \times 6}{6 + 6}$$

$$= \frac{36}{12} = 3 \text{ ohms}$$

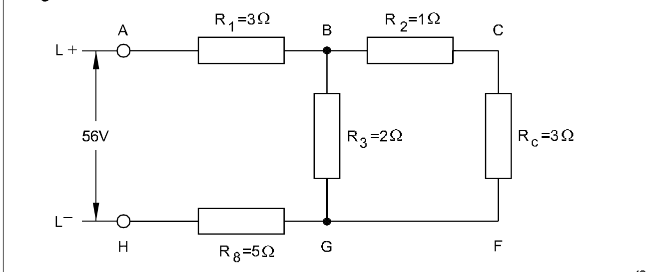
Fig 5



EQUIVALENT CIRCUIT TO FIG 3. R_4 AND R_5 ARE REPLACED WITH ONE RESISTOR (R_b) OF 6 Ω

6 Draw the equivalent circuit. (Fig 6)

Fig 6



EQUIVALENT CIRCUIT TO FIG 3, R_4, R_5, R_6, R_7 ARE REPLACED WITH ONE RESISTANCE (R_c) OF 3 Ω .

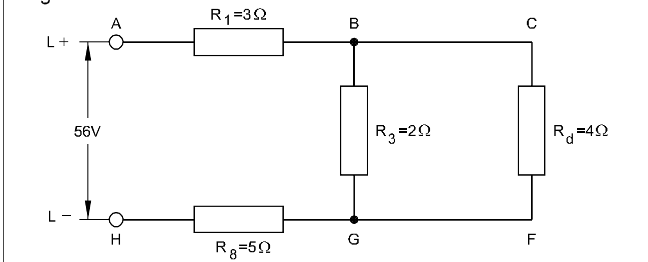
7 Combine R_2 and R_c and call the equivalent resistance R_d.

$R_d = R_2 + R_c$

$R_d = 1 + 3 \quad R_d = 4$ ohms.

8 Draw an equivalent circuit. (Fig 7)

Fig 7



EQUIVALENT CIRCUIT TO FIG 3, R_2, R_4, R_5, R_6, R_7 ARE REPLACED WITH ONE RESISTANCE (R_d) OF 4Ω.

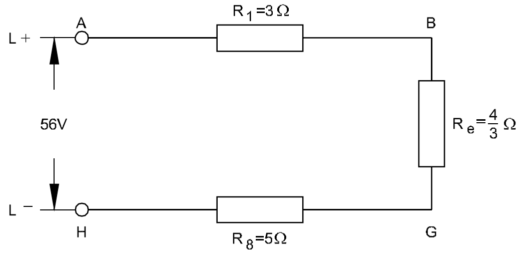
9 Now combine R_3 and R_d and call it R_e

$$R_e = \frac{R_3 \times R_d}{R_3 + R_d} = \frac{2 \times 4}{2 + 4}$$

$$= \frac{8}{6} = \frac{4}{3} = 1\ 1/3 \text{ ohms.}$$

10 Draw an equivalent circuit. (Fig 8)

Fig 8



EQUIVALENT CIRCUIT IN FIG 3, R_2, R_3, R_4, R_5, R_6, AND R_7 ARE REPLACED WITH ONE RESISTANCE (R_e) EQUAL TO $\frac{4}{3}$ Ω.

11 Combine R_1, R_e, and R_8.

$$R_t = R_1 + R_e + R_8$$

$$R_t = 3 + 1\frac{1}{3} + 5$$

$$R_t = 9\frac{1}{3} \text{ ohms.}$$

The total combined resistance of the circuit is $9\frac{1}{3}$ ohms.

Application

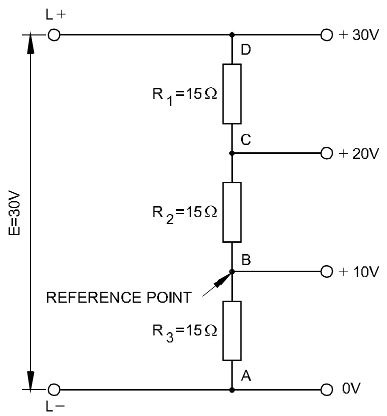
Series-parallel circuits can be used to form a non-standard resistance value which is not available in the market and can be used in the voltage divider circuits.

Voltage divider

If one wants to have different voltages for different parts of a circuit, he can construct a voltage divider. In effect, a voltage divider is nothing more than a series-parallel circuit.

A good voltage divider cannot be designed without first looking at the load resistance. Note in Fig 9 that a voltage divider is made with three 15 ohm resistors to get 10 volts drop across each one.

Fig 9



VOLTAGE VALUES ARE GIVEN FOR VOLTAGE DROP TESTS TAKEN ACROSS RESISTORS FROM A TO B (+10V), B TO C (+10V) AND B TO D (+20V). NOTE THAT THE CIRCUIT IS GROUNDED AT REFERENCE POINT B.

However, as soon as another resistor (load) is added as in Fig 10, there is a further change. The load resistor serves to drop the total resistance of the lower part of the voltage divider. Use this formula for finding the equivalent resistance (R_{eq}) of resistors of equal value in a parallel circuit:

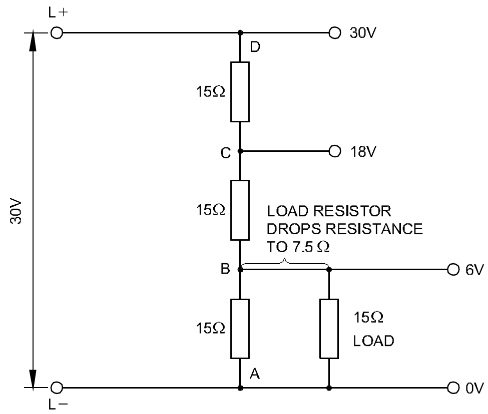
$$R_{eq} = \frac{r}{N}$$

$$R_{eq} = \frac{15}{2} = 7.5 \text{ ohms.}$$

The equivalent resistance of these two 15 ohm resistors in the lower part of the voltage divider is 7.5 ohms. What will happen to the current and voltage in the circuit as a result of this resistance change?

Remember that, as resistance goes down, current goes up. Therefore, with the addition of the load resistor, the circuit will now carry higher amperage but the voltage between points A and B as well as A and C changes. It is important, then, when constructing a voltage divider circuit, to watch the resistance values which change both voltage and current values. Study Fig 10 carefully to make sure you understand how a voltage divider works.

Fig 10



THREE 15 OHMS RESISTORS AND ONE 15 OHM LOAD RESISTOR SERVE AS A VOLTAGE DIVIDER THAT ROUTES DIFFERENT VOLTAGES TO DIFFERENT PARTS OF THE CIRCUIT.

Magnetic terms, magnetic material and properties of magnet

Objectives: At the end of this lesson you shall be able to
- **state the different kinds of magnets and state the classification of magnetic material.**
- **state the molecular theory of magnetism**
- **describe the earth as a magnet**
- **state the classifications of magnets.**

Magnetism and magnets: Magnetism is a force field that acts on some materials and not on other materials. Physical devices which possess this force are called magnets. Magnets attract iron and steel, and when free to rotate, they will move to a fixed position relative to the north pole.

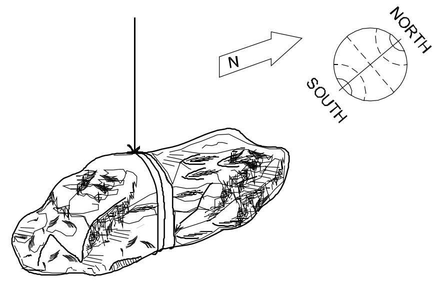
Classification of magnets

Magnets are classified into two groups.

- Natural magnets
- Artificial magnets

Lodestone (an iron compound) is a natural magnet which was discovered centuries ago. (Fig 1)

Fig 1



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There are two types of artificial magnets. Temporary and permanent magnets.

Temporary magnets or electromagnets: If a piece of magnetic material, say, soft iron is placed in a strong magnetic field of a solenoid it becomes magnetised by induction. The soft iron itself becomes a temporary magnet as long as the current continues to flow in the solenoid. As soon as the source producing the magnetic field is removed, the soft iron piece will loose its magnetism.

Permanent magnets: If steel is substituted for soft iron in the same inducing field as in the previous case, due to the residual magnetism, the steel will become a permanent magnet even after the magnetising field is removed. This property of retention is termed retentivenes. Thus, permanent magnets are made from steel, nickel, alnico, tungsten all of which have higher retentiveness.

Molecular theory of magnetism: In magnetic materials such as iron, steel, nickel, cobalt and their alloys, which are ferromagnetic materials, the molecules themselves are tiny magnets, each of them having a north pole and south pole. This is basically due to their special crystalline structure and to the continuous movements of electrons in their atoms.

Under ordinary conditions, these molecules arrange themselves in a disorderly manner, the north and south pole of these tiny magnets pointing in all directions and neutralizing one another. Thus a non-magnetized ferromagnetic bar is one in which there is no definite arrangement of the magnetic poles as shown in Fig 2. When iron or steel is magnetized, the molecules are moved into a new arrangement as shown in Fig 3, which is caused by the force used to magnetize them.

Fig 2

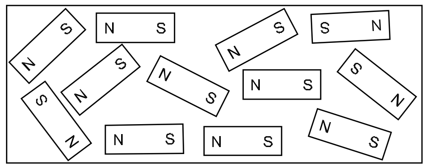

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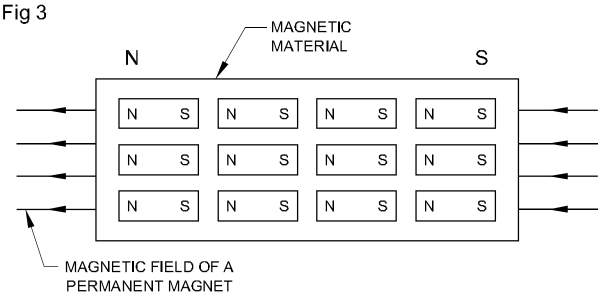
Fig 3



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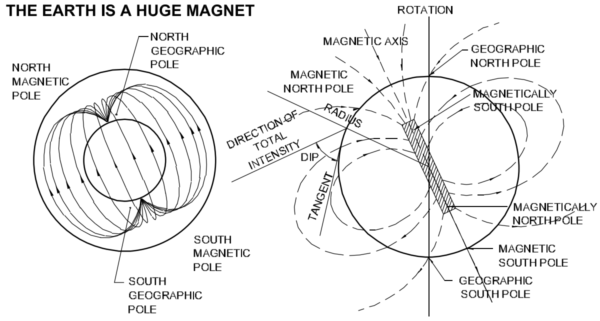
The earth's magnetic field: Since the earth itself is a large spinning mass, it too produces a magnetic field. The earth acts as though it has a bar magnet extending through its centre, with one end near the north geographic pole and the other end near the south geographic pole. (Fig 4)

Fig 4

THE EARTH IS A HUGE MAGNET



APPROXIMATE REPRESENTATION OF THE EARTH'S MAGNETIC FIELD

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Classification of magnetic substances

Materials can be classified into three groups as follows.

Ferromagnetic substances: Those substances which are strongly attracted by a magnet are known as ferromagnetic substances. Some examples are iron, nickel, cobalt, steel and their alloys.

Paramagnetic substances: Those substances which are slightly attracted by a magnet of common strength are called paramagnetic substances. Their attraction can easily be observed with a powerful magnet. In short, paramagnetic substances are similar in behaviour to ferromagnetic materials. Some examples are aluminium, manganese, platinum, copper etc.

Diamagnetic substances: Those substances which are slightly repelled by a magnet of powerful strength only are known as diamagnetic substances. Some examples are bismuth, sulphur, graphite, glass, paper, wood, etc. Bismuth is the strongest of the diamagnetic substances.

There is no substance which can be properly called non-magnetic. It may also be noted that water is a diamagnetic material, and air is a paramagnetic substance.

Magnetic terms and properties of magnet

Objectives: At the end of this lesson you shall be able to
- **define the terms magnetic field, magnetic line, magnetic axis, magnetic neutral axis and unit pole**
- **explain the properties of a magnet**
- **describe magnetic shielding**
- **describe the shape of magnets and the method of magnetizing**
- **state the application, care and maintenance of a permanent magnet.**

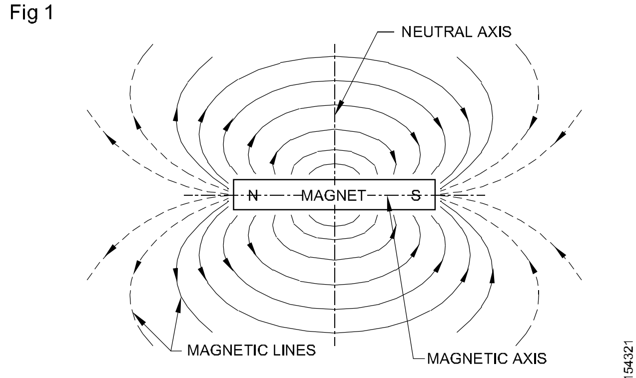
Magnetic fields: The force of magnetism is referred to as a magnetic field. This field extends out from the magnet in all directions, as illustrated in Fig 1. In this figure, the lines extending from the magnet represent the magnetic field.

The space around a magnet in which the influence of the magnet can be detected is called the magnetic field.

Magnetic lines: Magnetic lines of force (flux) are assumed to be continuous loops, the flux lines continuing on through the magnet. They do not stop at the poles.

The magnetic lines around a bar magnet are shown in Fig 1.

Fig 1

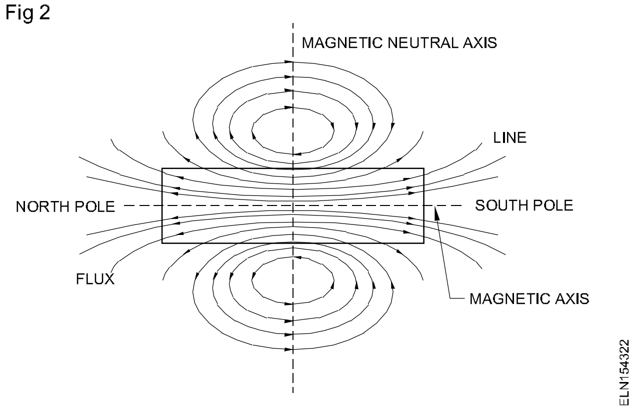


MAGNETIC FIELD OF A MAGNET. THE FLUX IS MOST DENSE AT THE POLES.

Magnetic axis: The imaginary line joining the two poles of a magnet are called the magnetic axis. It is also known as the magnetic equator.

Magnetic neutral axis (Fig 2): The imaginary lines which are perpendicular to the magnetic axis and pass through the centre of the magnet are called the magnetic neutral axis.

Fig 2



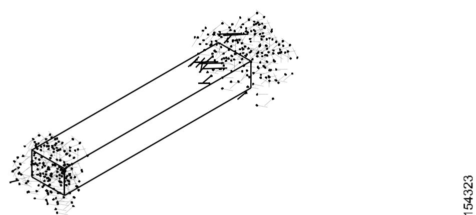
Unit pole: A unit pole may be defined as that pole which, when placed one metre apart from an equal and similar pole, repels it with a force of 10 newtons.

Properties of a magnet

The following are the properties of magnets.

Attractive property : A magnet has the property of attracting magnetic substances (such as iron, nickel and cobalt) and its power of attraction is greatest at its poles. (Fig 3)

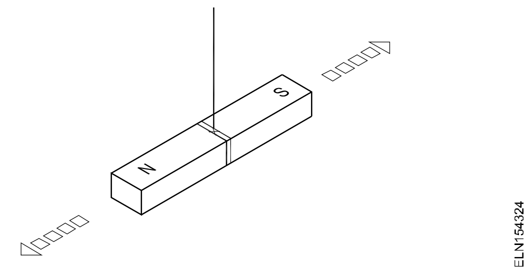
Fig 3



BAR MAGNET

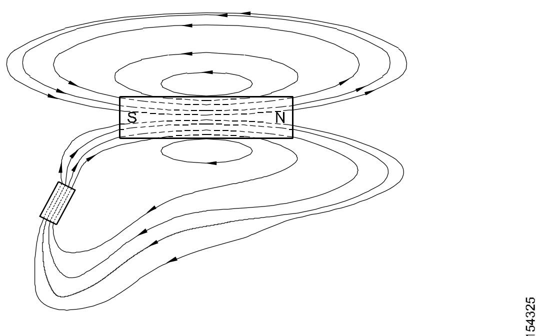
Directive property: If a magnet is freely suspended, its poles will always tend to set themselves in the direction of north and south. (Fig 4)

Fig 4



Induction property: A magnet has the property of producing magnetism in a nearby magnetic substance by induction. (Fig 5)

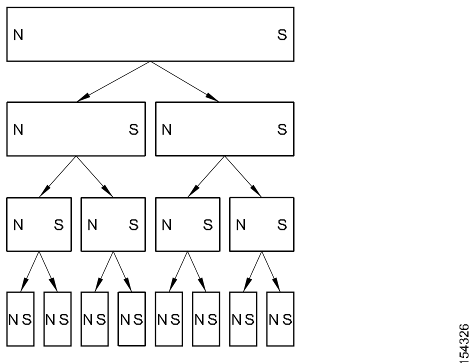
Fig 5



SOFT IRON PROVIDES A PATH FOR MAGNETIC LINES OF FORCE.

Poles-existing property: A single pole can never exist in a magnet. If it is broken into its molecules, each molecule will have two poles. (Fig 6)

Fig 6



MAGNET WHEN DIVIDED

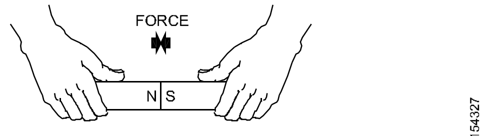
Demagnetising property: If a magnet is handled roughly by heating, hammering, etc. it will lose its magnetism.

Property of strength: Every magnet has two poles. The two poles of a magnet have equal pole strength.

Saturation property: If a magnet of higher strength is further subjected to magnetization, it will never acquire more magnetization due to its being already saturated.

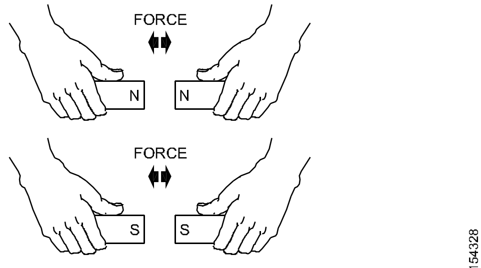
Property of attraction and repulsion: Unlike poles (i.e. north and south) attract each other, (Fig 7) while like poles (north/north and south/south) repel each other. (Fig 8)

Fig 7



ATTRACTION

Fig 8



REPULSION

Assumed physical properties of magnetic lines of force: The lines of force always travel from the north to the south pole outside the magnet through air and from the south to the north pole inside the magnet.

All the magnetic lines of force complete their circuit (form a loop).

The magnetic lines do not cross each other. The lines of force travelling in one direction have a repulsive force between them, and, therefore, do not cross.

The magnetic lines prefer to pass and complete their circuit through a magnetic material.

They behave like a magnetic elastic band.

Magnetic shielding: Magnetic flux lines can pass through all materials. Magnetic materials have a very low reluctance to flux lines. The lines of flux will be attracted through a magnetic material even if they have to take a longer path. (Fig 9) This characteristic allows us to shield things from magnetic lines of force by enclosing them with a magnetic material. This is the way anti-magnetic watches are made. Measuring instruments which are to be shielded are enclosed inside an iron case. (Fig 10)

Shapes of magnets: Magnets are available in various shapes, with the magnetism concentrated at their ends known as poles. The common shapes are listed here.

– Bar magnet

– Horseshoe magnet

– Ring magnet

– Cylindrical type magnet

– Specially shaped magnets

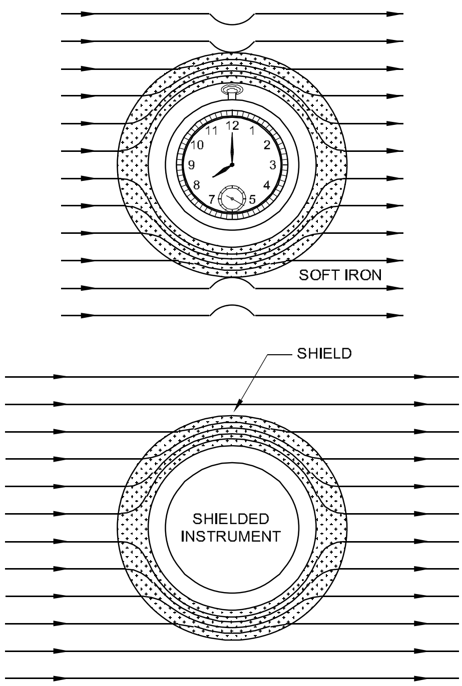
Bar magnet: It is in the form of a rectangular block with the magnetism concentrated at the ends, north pole and south pole. (Fig 11a)

Horseshoe magnet : A rectangular iron rod bent to the shape of a horseshoe with the magnetism concentrated at their ends forming the north pole and south pole. (Fig 11b)

Ring magnet: A ferrous metal formed into a ring as shown in Fig 11c is a ring magnet.

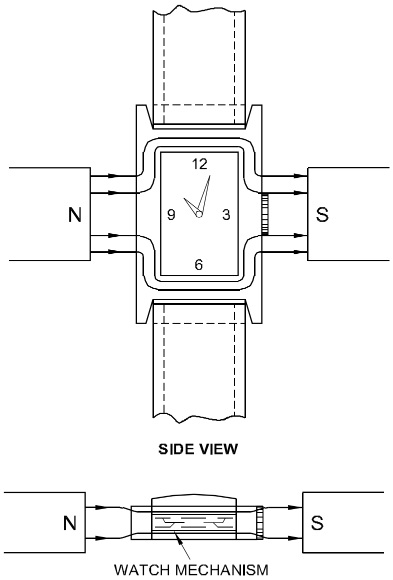
Cylindrical type magnet: It is formed by a cylindrical iron rod with concentration of magnetism at the north and south pole ends as shown in Fig 11d.

Fig 9



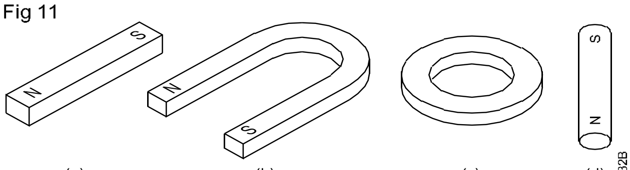
MAGNETIC SHIELD. THE SHIELD PROVIDES A LOW- RELUCTANCE PATH AROUND THE PROTECTED AREA.

Fig 10



MAGNETIC MATERIALS SHIELD A WATCH FROM MAGNETIC FIELDS. THE SHIELD BECOMES ONLY TEMPORARILY MAGNETIZED. THE FLUX LINES CANNOT REACH THIS WATCH MECHANISM.

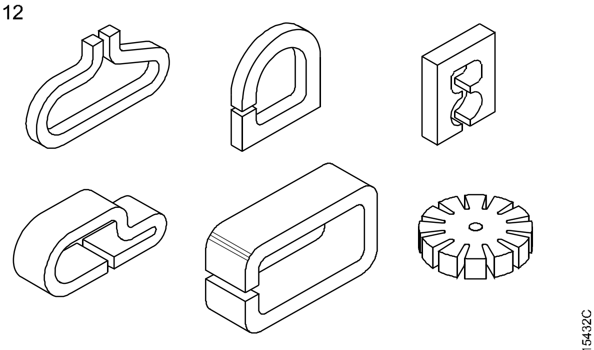
Fig 11



SHAPES OF PERMANENT MAGNETS

Specially shaped magnets: Permanent magnets for special purposes like, for the use of magnet in automobiles, cycle dynamos, electrical instruments and energy meters, are made to special shapes depending upon the purpose for which they are needed. (Fig 12)

Fig 12



SPECIAL SHAPES OF MAGNET

Methods of magnetizing: There are three principal methods of magnetizing a material.

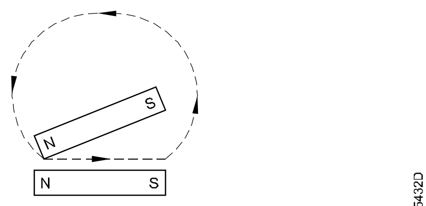
- Touch method
- By means of electric current
- Induction method.

Touch method: This method can be further divided into:

- single touch method
- double touch method, and
- divided touch method

Single touch method: In the single touch method, the steel bar to be magnetized is rubbed with either of the poles of a magnet, keeping the other pole away from it. Rubbing is done only in one direction as shown in Fig 13. The process should be repeated many times for inducing magnetization of the bar.

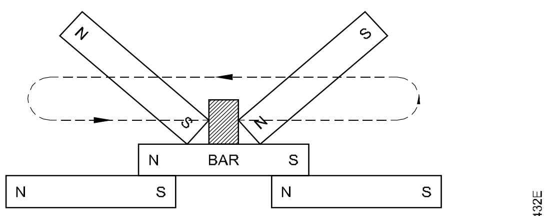
Fig 13



STEEL BAR

Double touch method: In this method the steel bar to be magnetized is placed over the two opposite pole ends of a magnet, and the rubbing magnets are placed together over the centre of the bar with a small wooden piece in between, as shown in Fig 14. They are never lifted off the surface of the steel bar, but rubbed again and again from

Fig 14

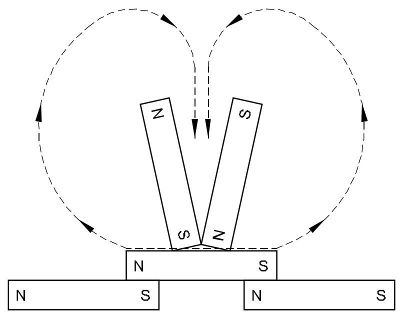


DOUBLE-TOUCH METHOD

end to end, finally ending at the centre where the rubbing was started.

Divided touch method: Here the two different poles of the rubbing magnets are placed as in the previous case. They are then moved along the surface of the steel bar to the opposite ends. The rubbing magnets are then lifted off the surface of the steel bar and placed back in the centre of the bar. The whole process is repeated again and again as shown in Fig 15.

Fig 15

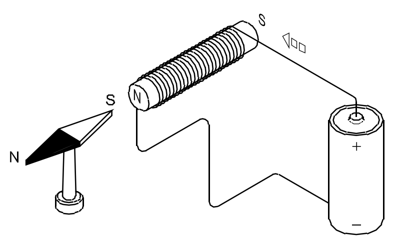


DIVIDED-TOUCH METHOD

The steel bar thus magnetized becomes a permanent magnet but the degree of magnetization is very low.

By electric current: The bar to be magnetized is wound with an insulated copper wire, and then a strong electric current (DC) from a battery is passed through the wire for some time. The steel bar then becomes highly magnetized. If the bar is of soft iron, the magnetism remains as long as the current continues but almost completely disappears as soon as the current ceases. The magnet made by such an arrangement is called an electromagnet and is generally used in laboratories. (Fig 16)

Fig 16

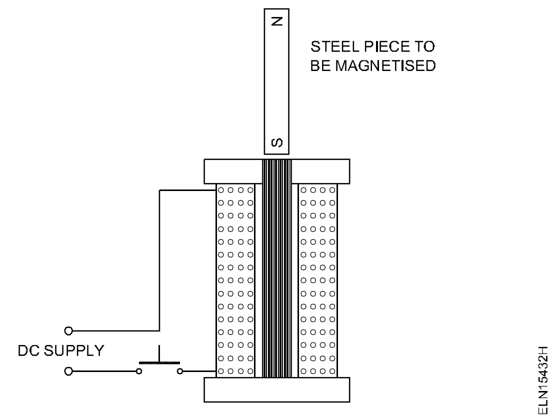


Induction method: This is a commercial method of making permanent magnets. In this method a pole charger is used which has a coil of many turns and an iron core inside it as shown in Fig 17. The direct current supply is fed to the coil through a push-button switch.

The steel piece to be magnetized is placed on the iron core kept inside the coil, and direct current is passed through the coil. The iron core now becomes a powerful magnet, and thus the steel piece is magnetised by induction. The magnetised piece is then removed after switching off the supply.

This is a commercial process for making permanent magnets for speakers, telephones, microphones, earphones, electrical instruments, magnets,compasses etc.

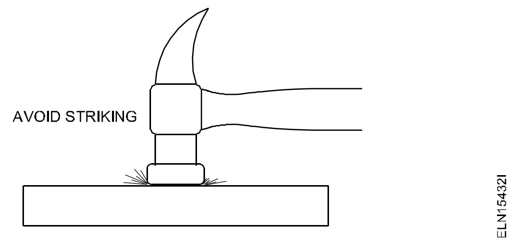
Fig 17



Care and maintenance of permanent magnets: Permanent magnets should not be thrown or dropped.

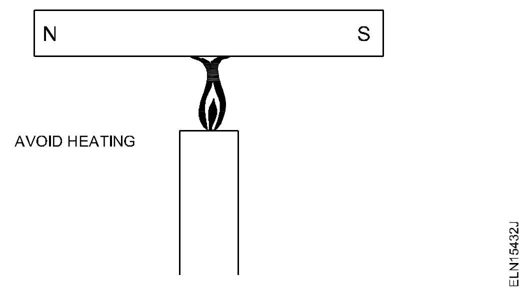
They should not be hammered. (Fig 18)

Fig 18



They should not be heated. (Fig 19)

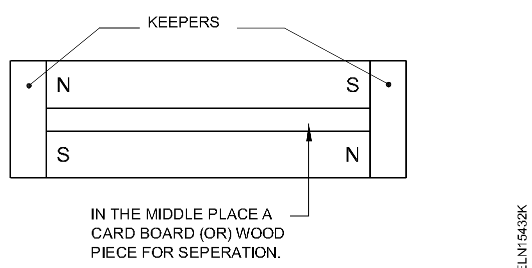
Fig 19



Bar magnets should be placed side by side with their ends facing opposite polarity, with keepers at their ends.

Keepers should be used while storing the magnets. (Fig 20)

Fig 20



As far as possible, the north and south poles of the magnet should be kept in the direction of the south and north directions of the earth respectively.

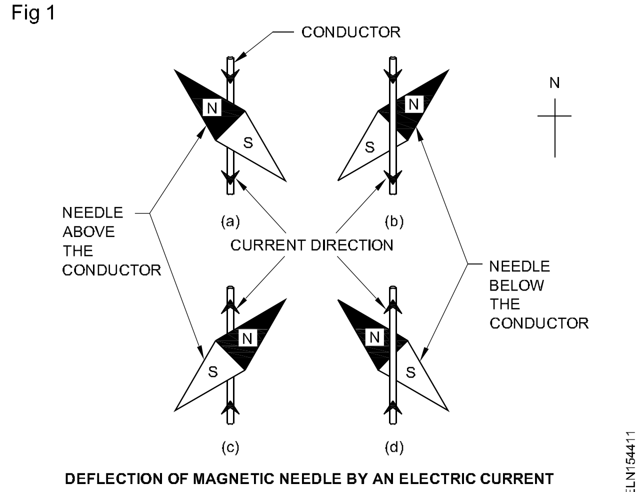
Principles and laws of electro magnetism

Objectives: At the end of this lesson you shall be able to
- **state the oersted principle**
- **explain what is meant by electromagnetism**
- **describe the magnetic field in current-carrying conductors, loop, coil, magnetic core -**
- **state right Hand Grip rule, Corkscrew rule and Right Hand palm rule**
- **state the interaction of the magnetic field**
- **state the magnetic materials for a temporary magnet.**

Oersted's experiment: Oersted, a Danish scientist discovered in 1819, while giving a demonstration lecture, that there is a close relationship between electricity and magnetism. He observed that when a magnetic needle is placed under and parallel to a conductor, and then the current switched on, the needle tends to deflect at right angles to the wire.

Suppose, a wire in which the current is to be passed, is arranged in the direction north to south by placing the needle above the wire as in Fig 1a. Then the north pole of the needle will be deflected to the west, nearly perpendicular to the wire. The deflection will be to the east, as in Fig 1b by placing needle below the wire. When the direction of the flow of current is reversed, the deflections of the needle will be in the opposite direction as shown in Fig 1c and 1d.

Fig 1



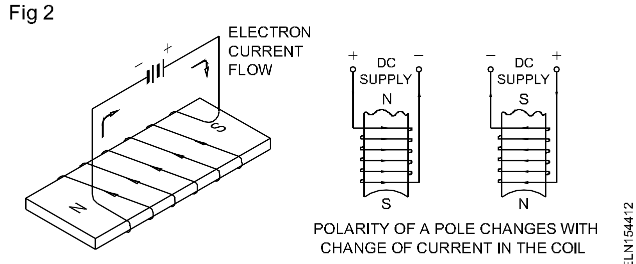
DEFLECTION OF MAGNETIC NEEDLE BY AN ELECTRIC CURRENT

In these cases the deflection of the needle shows that the lines of force are produced around the current-carrying conductor as shown in Fig 3.

Electromagnetism: On passing a current through a coil of wire, a magnetic field is set up around the coil. If a soft iron bar is placed in the coil of wire carrying the current, the iron bar becomes magnetized. This process is known as `electromagnetism'. The soft iron bar remains as a magnet as long as the current is flowing in the circuit. It loses its magnetism when the current is switched off from the coil.

The polarity of this electromagnet depends upon the direction of the current flowing through it. If the direction of the current is altered, the polarity of the magnetic field will also be changed as shown in Fig 2.

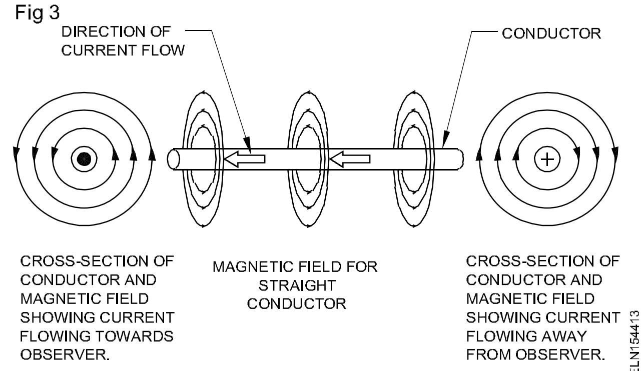
Fig 2



POLARITY OF A POLE CHANGES WITH CHANGE OF CURRENT IN THE COIL

Electromangetism in a wire (current-carrying conductor): A magnetic field is formed around a conductor carrying current. The field is so arranged around the conductor as to form a series of loops. (Fig 3)

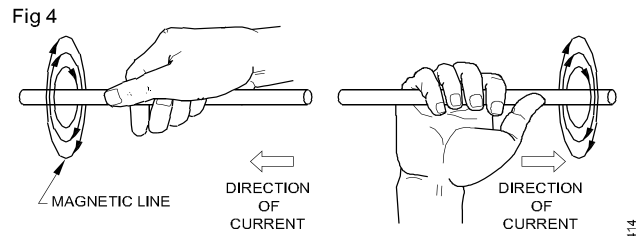
Fig 3



The direction of the magnetic field depends on the direction of the current flow. A compass moved around the wire will align itself with the flux lines.

The Right Hand Grip Rule can be used to determine the direction of the magnetic field. If you wrap your fingers around the wire with your thumb pointing in the direction of current flow, your fingers will point in the direction of the magnetic field as shown in Fig 4.

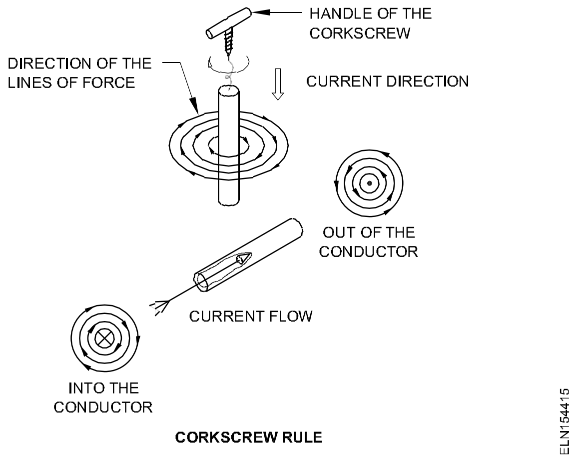
Fig 4



RIGHT HAND GRIP RULE SHOWING THE DIRECTION OF CURRENT AND DIRECTION OF MAGNETIC LINES

Assume a right handed corkscrew to be along the wire so as to advance in the direction of the current. The motion of the handle gives the direction of magnetic lines of force around the conductor (Fig 5)

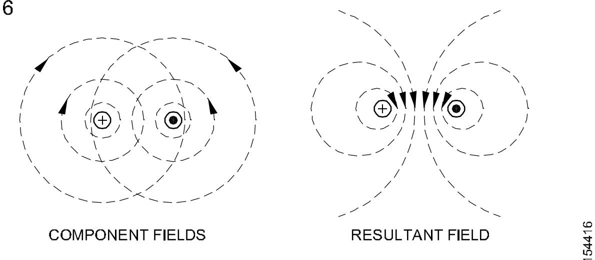
Fig 5



CORKSCREW RULE

If two wires carrying current in opposite directions are brought close to each other, their magnetic fields will oppose one another, since the flux lines are going in the opposite directions. The flux lines cannot cross, and the fields move the wires apart. (Fig 6)

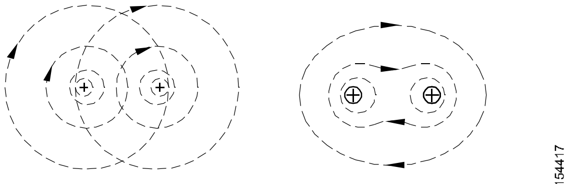
Fig 6



PARALLEL CONDUCTORS CARRYING CURRENT IN OPPOSITE DIRECTION

When wires carrying current in the same direction are brought together, their magnetic fields will aid one another, since the flux lines are going in the same direction. The flux lines join and form loops around both the wires, and the fields bring the wires together. The flux lines of both wires add to make a stronger mangetic field. Three or four wires put together in this way would make a still stronger field. (Fig 7)

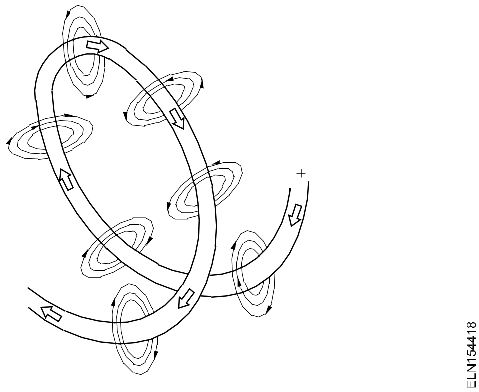
Fig 7



PARALLEL CONDUCTORS CARRYING CURRENT IN SAME DIRECTION

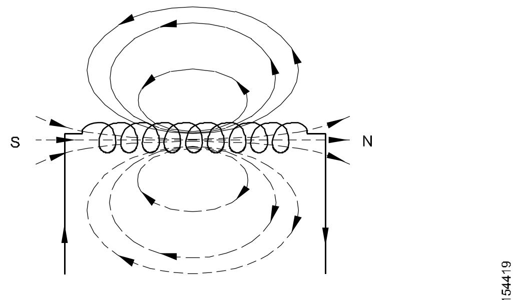
Electromagnetism in a loop: If the wire is made to form a loop, the magnetic fields around the wire will all be so arranged that they each flow into the loop on one side, and come out on the other side. In the centre of the loop, the flux lines are compressed to create a dense and strong field. This produces magnetic poles, with north on the side that the flux lines come out and south on the side that they go in as shown in Fig 8.

Fig 8



Electromagnetism in a coil: If a number of loops are wound in the same direction to form a coil, more fields will add to make the flux lines through the coil even more dense. The magnetic field through the coil becomes even stronger. The greater the number of loops, the stronger the magnetic field becomes. If the coil is compressed tightly, the fields would join even more to produce an even stronger electromagnet as shown in Fig 9.

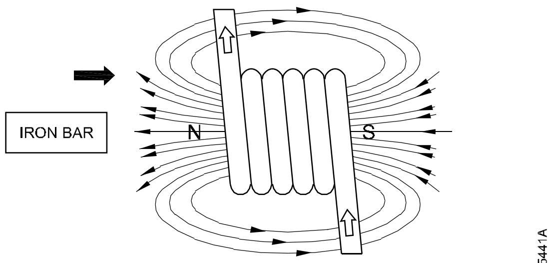
Fig 9



SOLENOID

A helically wound coil that is made to produce a strong magnetic field is called a solenoid. The flux lines in a solenoid act in the same way as in a magnet. They leave the N pole and go around to the S pole. When a solenoid attracts an iron bar, it will draw the bar inside the coil. (Fig 10)

Fig 10

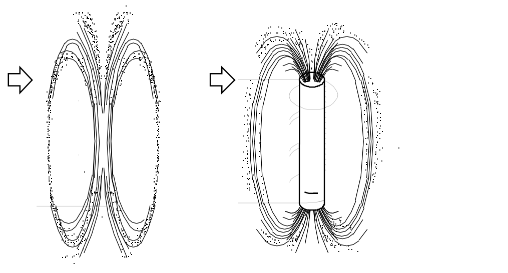


SOLENOID

The magnetic core: The magnetic field of a coil can be made stronger still by keeping an iron core inside the coil of wire. Since the soft iron is magnetic and has a low reluctance, it allows more flux lines to be concentrated in it than it would in the air. The greater the number of flux lines, the stronger the magnetic field. (Fig 11)

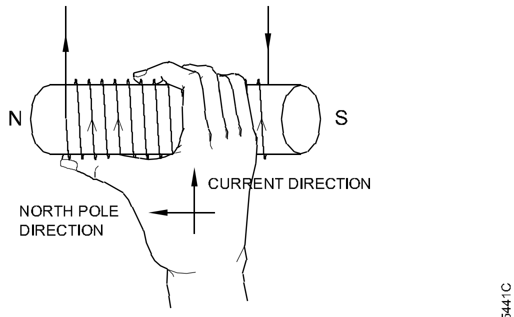
Soft iron is used as a core in an electromagnet because hard steel would become permanently magnetized.

Fig 11



The direction of the magnetic field can be found from palm rule right hand palm rule. (Fig 12)

Fig 12



RIGHT HAND PALM RULE

The Right Hand Palm Rule : Hold the right hand palm over the solenoid in such a way the fingers point in the direction of current in the solenoid conductors then the thumb indicates the direction of magnetic field (North Pole) of the solenoid.

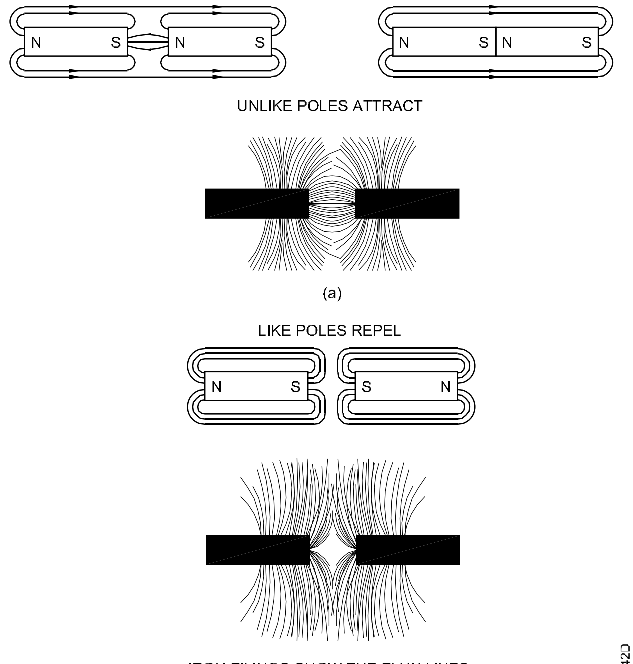
Interaction of magnetic fields: When two magnets are brought together, their fields interact. The magnetic lines of force will not cross one another. This fact determines how the fields act together.

If the lines of force are going in the same direction, they will attract each other and join together as they approach each other. This is why unlike poles attract. (Fig 13a)

If the lines of force are going in opposite directions, they cannot combine. And, since they cannot cross, they apply a force against each other. This is why like poles repel.

The interaction of the flux lines can also be shown with iron filings. (Fig 13b)

Fig 13



Magnetic materials for temporary magnets: Electromagnets are generally known as temporary magnets. The magnetic strength of such magnets can be varied by varying the current passing through them. Soft iron is used in electromagnets as a magnetic core. Silicon steel is very much used in bigger magnets (steel with 2.4% silicon). Nowadays other metals like permalloy, mumetal are also used for some applications.

Permalloy is an alloy of iron and nickel which can be magnetized by a very weak magnetic field and is useful for telephones.

Mumetal is an alloy of nickel, copper, chromium and iron. It has very high permeability and resistivity. Eddy current loss is very low. It is used in instrument transformers and for screening magnetic fields.

The magnetic circuits - self and mutually induced emfs

Objectives: At the end of this lesson you shall be able to
- **define the magnetic terms in a magnetic circuit (like M.M.F., reluctance, flux, field strength, flux density, permeability, relative permeability)**
- **state hysterisis and explain hysterisis loop**
- **describe pulling power of magnet.**

MagnetoMotive Force (MMF): The amount of flux density set up in the core is dependent upon five factors - the current, number of turns, material of the magnetic core, length of core and the cross-sectional area of the core. More current and the more turns of wire we use, the greater will be the magnetising effect. We call this product of the turns and current the magnetomotive force (mmf), similar to the electromotive force (emf). (Fig 1 & 2)

Fig 1

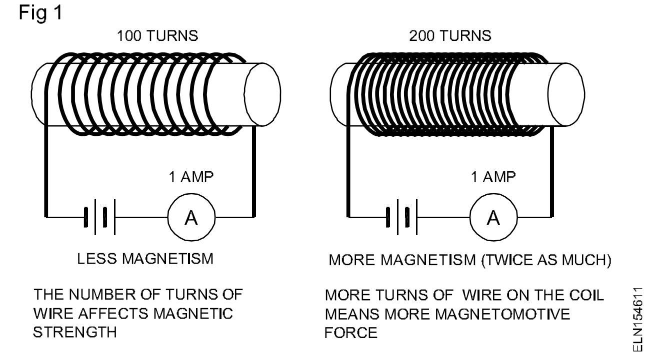
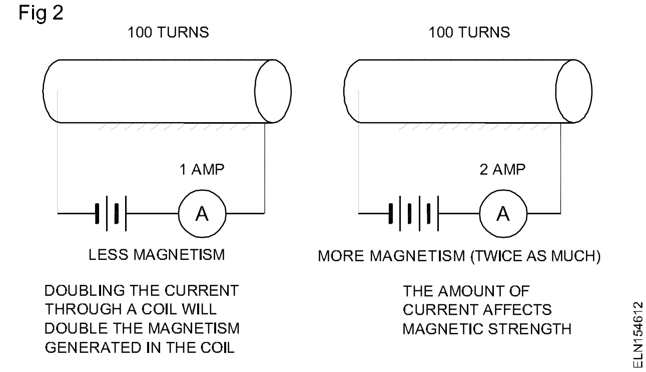


Fig 2



MMF = NI ampere-turns

where mmf - is the magnetomotive force in ampere turns

N - is the number of turns wrapped on the core

I - is the current in the coil, in amperes, A.

If one ampere current is flowing through a coil having 200 turns then the mmf is 200 ampere turns.

Reluctance: In the magnetic circuit there is something analogous to electrical resistance, and is called reluctance, (symbol S). The total flux is inversely proportional to the reluctance and so if we denote mmf by ampere turns. we can write

$\phi = \frac{NI}{S}$ Where ϕ is flux and reluctances $S = \frac{\ell}{\mu_o \mu_r a}$

where S - reluctance

l - length of the magnetic path in metres

μ_o - permeability of free space

μ_r - relative permeability

a - cross-sectional area of the magnetic path in sq.mm.

The unit of reluctance is ampere turns/Wb.

Magnetic flux:The magnetic flux in a magnetic circuit is equal to the total number of lines existing on the cross-section of the magnetic core at right angle to the direction of the flux. Its symbol is Ø and the SI unit is weber.

$$\phi = \frac{NI}{S}$$

$$= \frac{NIa\mu_o\mu_r}{\ell}$$

where

ϕ - total flux

N - number of turns

I - current in amperes

S - reluctance

μ_o - permeability of free space

μ_r - relative permeability

a - magnetic path cross-sectional area in m^2

ℓ - length of magnetic path in metres.

Magnetic field strength: This is also known sometimes as field intensity, magnetic intensity or magnetic field, and is represented by the letter H. Its unit is ampere turns per metre.

$$H = \frac{M.M.F}{\text{Length of coil in meters}} = \frac{NI}{\ell}$$

Flux density (B): The total number of lines of force per square metre of the cross- sectional area of the magnetic core is called flux density, and is represented by the symbol B. Its SI unit (in the MKS system) is tesla (weber per metre square).

$B = \frac{\phi}{A}$ Weber/ m^2

where ϕ - total flux in webers
A - area of the core in square metres
B - flux density in weber/metre square.

Permeability: The permeability of a magnetic material is defined as the ratio of flux created in that material to the flux created in air, provided that mmf and dimensions of the magnetic circuit remain the same. It's symbol is μ and

$\mu = B/H$

where B is the flux density

H is the magnetising force.

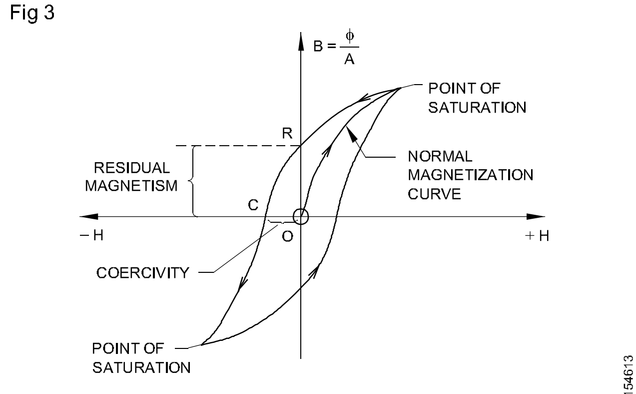
Being a ratio it has no unit and it is expressed as a mere number. The permeability of air μ air = unity. The relative permeability μr of iron and steel ranges from 50 to 2000. The permeability of a given material varies with its flux density.

Hysteresis: Consider the graphical relation between B and H for a magnetic material. Since μ = B/H, the graphical relationship shows how the permeability of a material varies with the magnetizing intensity H.

Assume that the magnetic core is initially completely demagnetised. As we increase the current, $H = \frac{NI}{\ell}$ increases and there will be an increase in the flux density, B. Since the number of turns and the length of core of a coil are fixed, H is directly proportional to the current or ammeter reading. The flux density can be measured by inserting the probe of a flux meter into a small hole drilled in the core.

A plot of the values of B and H gives the normal magnetization curve, as shown in Fig 3.There is evidently a linear portion where B is relatively proportional to H. But then a condition of saturation occurs when a very large increase in H is required to significantly increase B. This point in the curve is called as **saturation point.**

Fig 3



HYSTERESIS LOOP FOR MATERIAL USED IN AN AC CIRCUIT

If the current is now gradually reduced towards zero, H returns to zero, but B does not. The core exhibits retentiveness and retains some residual magnetism. The **retentiveness** is represented by the distance OR.

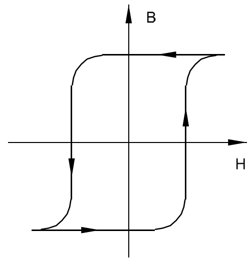
If the connections to the coil are reversed, and the current is again increased, it is found that a certain amount of H is required to bring the magnetism in the core down to zero. This is called the **coercivity** and is represented by the distance OC.

Further, any increase in the current in the opposite direction increases the magnetism in the core as before in the opposite direction, until once again saturation occurs.

Hysteresis loop: Reduction of the current and subsequent reversal of the direction will produce a closed figure called a B-H curve or hysteresis loop. The name comes from the Greek word `hysteros' meaning `to lag behind'. That is, the state of the flux density is always lagging behind the efforts of the magnetising intensity.

The shape of a B-H loop is an indication of the magnetic properties of the material. (Fig 4)

Fig 4



HYSTERSIS LOOP FOR PERMANENT MAGNET

Hysteresis results in the dissipation of energy which appears in the form of heat. The energy wasted in this manner is proportional to the area of the loop. Thus, the energy expanded, in joules per cubic metre of material in one cycle, is equal to the area of the loop in M.K.S. units.

Energy expended/cycle/m^2 in joules= Area of hysteresis loop in m^2.

The shape of the hysteresis loop depends on the nature of the iron or steel. Iron is subject to rapid reversal of magnetism and in this case the area of loop is very small.

Numerically the loss is given by the equation,energy dissipated per second = $\eta f B_m^{1.6}$ joules/m^3

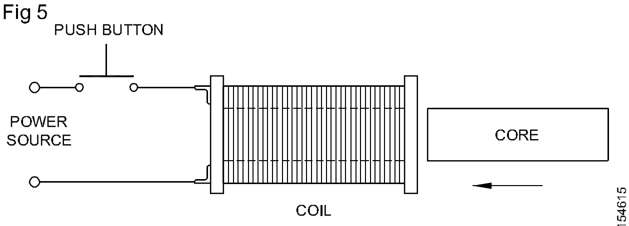
where η - constant, called hysteresis coefficient

B_m - maximum flux density

f - frequency.

Pulling power of solenoid: When the coil is energised, it produces a magnetic field which also magnetises the iron core. The iron core is attracted to the coil and they

Fig 5



CORE MOVES INWARD BY SUCKING ACTION WHEN COIL IS ENERGIZED snap together. Once the core is in the centre of the coil, the magnetic field is concentrated with that core and there is no room for further movement.

The pulling power of a solenoid depends on the number of turns of the coil, the current, material, flux density of the magnetic core, length and cross-sectional area of the core. The strength of an electromagnet depends upon its ability to conduct magnetism. The ability of conduction depends on mmf, reluctance and permeability of the magnetic path. (Fig 5)

Electromagnet applications - Electromagnetic induction

Objectives: At the end of this lesson you shall be able to

- **compare the magnetic circuit and electric circuit**
- **state the applications of an electromagnet (Bell & Buzzer tubelight choke)**
- **state the principle and laws of electromagnetic induction**
- **explain the energy stored in induction coil**
- **explain about the series and parallel connection of inductors and types of inductors**
- **state function of choke in a flourscent light circuit**
- **state the factors that contribute to induced voltage**
- **explain about the counter EMF-induced reactance-time constant.**

Comparison between magnetic and electric circuits

Similarities (Fig 1a & 1b)

	Magnetic Current	Electrical Current
1	Flux = $\frac{\text{mmf}}{\text{reluctance}}$	Current = $\frac{\text{emf}}{\text{resistance}}$
2	M.M.F. (Ampere-turns)	E.M.F. (Volts)
3	Flux ϕ (Webers)	Current I (amperes)
4	Flux density B (Wb/m^2)	Current density (A/m^2)
5	Reluctance $S = \frac{\ell}{\mu A}$ or $S = \frac{\ell}{\mu_0 \mu_r a}$	Resistance $R = \frac{\rho L}{A}$
6	Permeance = (1/reluctance)	Conductance (= 1/resistance)
7	Reluctivity $\mu_o \mu_r A$	Resistivity
8	Permeability (=1/reluctivity)	Conductivity(=1/resistivity)

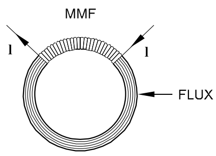


Fig 1a

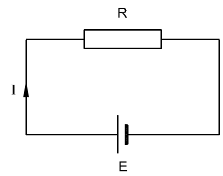


Fig 1b

Practical applications of electromagnets: Electromagnets are used in the manufacture of all types of electrical machines, such as motors, generators, transformers, convertors, some electrical measuring instruments, protective relays, for medical purposes (like removing iron pieces from eyes) and in many other electrical devices like bells, buzzers, circuit-breakers, relays, telegraphic circuits, lifts and other industrial uses. (Figs 2, 3, 4, 5 & 6)

a Bells (Fig 2)

b Buzzers

c Circuit-breakers (Fig 3)

d Relays (Fig 4)

e Telegraphic circuits

f Lifts (Fig 5)

g Industrial uses (Fig 6)

Fig 2

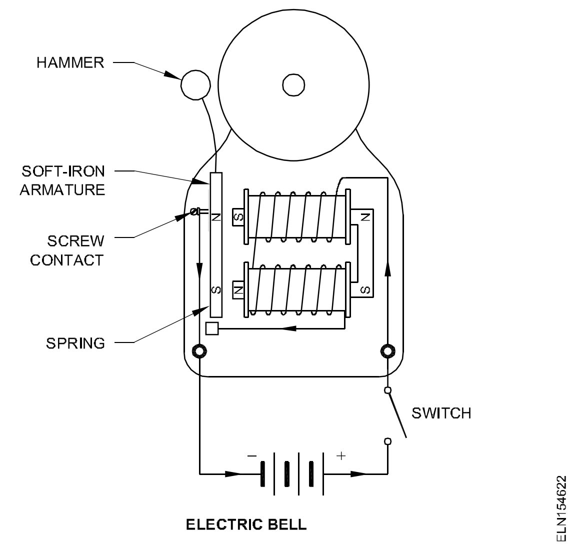


Fig 3

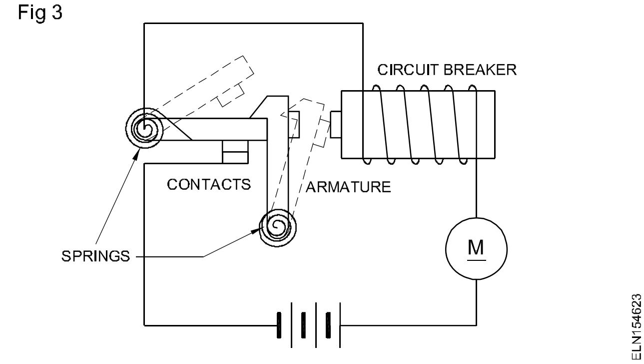
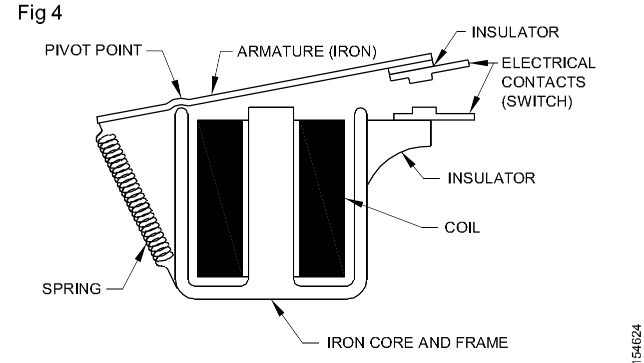
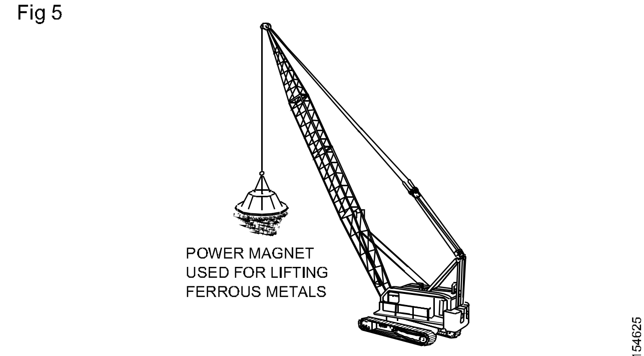


Fig 4



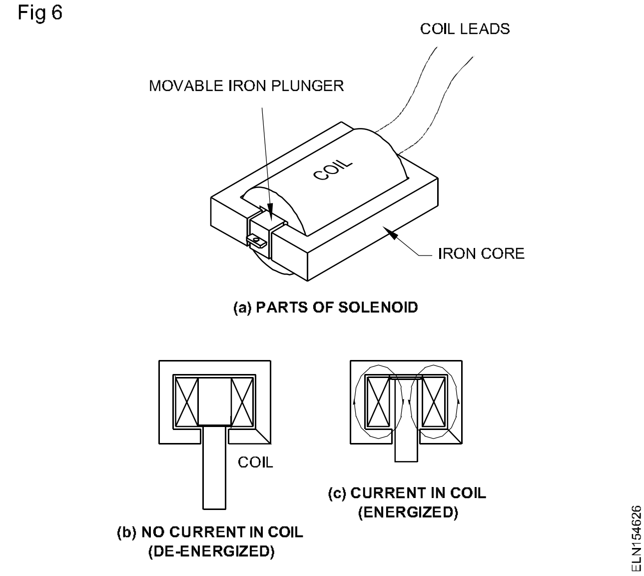
RELAY

Fig 5



MOBILE CRANE

Fig 6



Principles and laws of electromagnetic induction

Faraday's Laws of Electromagnetic Induction are also applicable for conductors carrying alternating current.

Faradays' Laws of Electromagnetic Induction

Faraday's First Law states that whenever the magnetic flux is linked with a circuit changes, an emf is always induced in it.

The Second Law states that the magnitude of the induced emf is equal to the rate of change of flux linkage.

Dyanamically Induced EMF

Accordingly induced emf can be produced either by moving the conductor in a stationery magnetic field or by changing magnetic flux over a stationery conductor. When conductor moves and produces emf, the emf is called as dynamically induced emf Ex. generators.

Statically Induced EMF

When changing flux produces emf the emf is called as statically induced emf as explained below. Ex: Transformer.

Statically induced emf: When the induced emf is produced in a stationery conductor due to changing magnetic field, obeying Faraday's laws of electro magnetism, the induced emf is called as statically induced emf.

There are two types of statically induced emf as stated below:-

1 **Self induced emf** produced with in the same coil

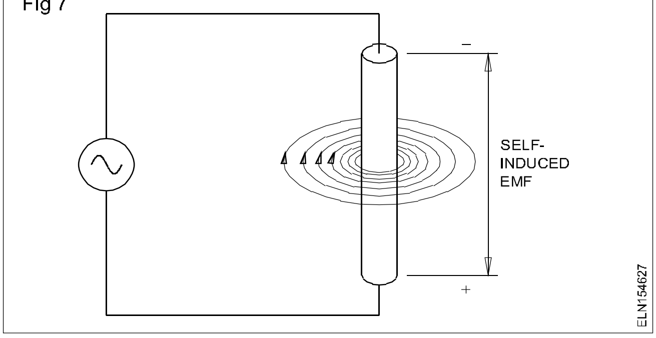
2 **mutually induced emf** produced in the neighbouring coil

Self-induction: The production of an electromotive force in a circuit, when the magnetic flux linked with the circuit changes as a result of the change in a current inducing in the same circuit.

At any instant, the direction of the magnetic field is determined by the direction of the current flow.

With one complete cycle, the magnetic field around the conductor builds up and then collapses. It then builds up in the opposite direction, and collapses again. When the magnetic filed begins building up from zero, the lines of force or flux lines expand from the centre of the conductor outward. As they expand outward, they can be thought of as cutting through the conductor.

Fig 7

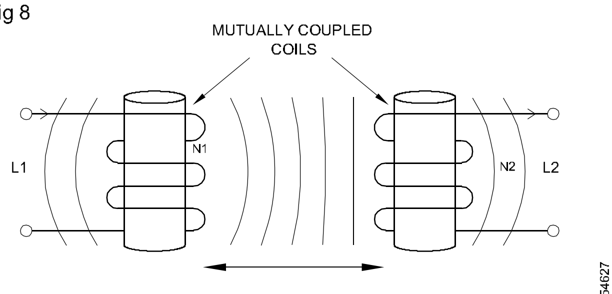


According to Faraday's Laws, an emf is induced in the conductor. Similarly, when the magnetic field collapses, the flux lines cut through the conductor again, and an emf is induced once again. This is called self-induction. (Fig 7)

Mutual Inductance: When two or more coils one magnetically linked together by a common magnetic flux, they are said to have the property of mutual inductance. It is the basic operating principal of the transformer, motor generaters and any other electrical component that interacts with another magnetic field. It can define mutual induction on the current flowing in one coil that induces a voltage in an adjacement coil.

In the Fig,8 current flowing in coil L1 sets up a magnetic field around it self with some of its magnetic field line passing through coil L2 giving in mutual inductance coil one L on has a current of I, and N, turns while coil two L2, has N2 turns therefore mutual inductance M, of coil two that exists with respect to coil one L, depend on their position with inspect to each other.

Fig 8



MUTUAL INDUCTANCE BETWEEN COILS

The mutual inductance M that exists between the two coils can be greately measured by positioning them on a common soft iron cone or by measuring the number of turns of either coil on would he found in a transformer.

The two coils are tightly wound one on top of the other over a common soft iron core unity in said to exist between them as any losses due to the leakage of flux will be extremely small. Then assuring a perfect flux leakage between the two coils the mutual inductance M that exists between them can be given on:

$$M = \frac{M_0 M_r N_1 N_2 A}{L}$$

Value

M_o is the permeability of free space $(4\pi \times 10^{-7})$

M_r - is the relative permability of soft iron cone

N is the no. of turns of coil

A is the cross sectional area in m^2

l is the coil length in meters

Inductance: Inductance (L) is the electrical property of an electrical circuit or device to oppose any change in the magnitude of current flow in a circuit.

Devices which are used to provide inductance in a circuit are called inductors. Inductors are also known as chokes, coils, and reactors. Inductors are usually coils of wire.

Factors determining inductance: The inductance of an inductor is primarily determined by four factors.

- Type of core permeability of the core $m_{r.}$
- Number of turns of wire in the coil 'N'.
- Spacing between turns of wire (Spacing factor).
- Cross-sectional area (diameter of the coil core) 'a' or 'd'.

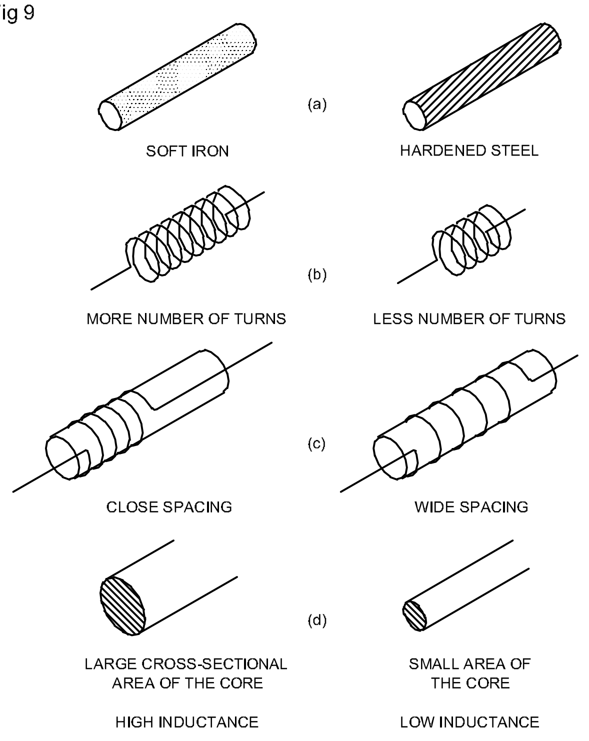
The amount of inductance in a coil of wire is affected by the physical make up of the coil. (Fig 8.)

Core (Fig 9a): If soft iron is used as a core material instead of hardened steel, the coil will have more inductance.

If all the factors are equal, an iron core inductor has more inductance than an air core inductor. This is because iron has a higher permeability, that is, it is able to carry more flux. With this higher permeability there is more flux change, and thus more counter induced emf (cemf), for a given change in current.

Number of turns (Fig 9b): Adding more turns to an inductor increases its inductance because each turn adds more magnetic field strength to the inductor. Increasing the magnetic field strength results in more flux to cut the conductors (turns) of the inductor.

Fig 9



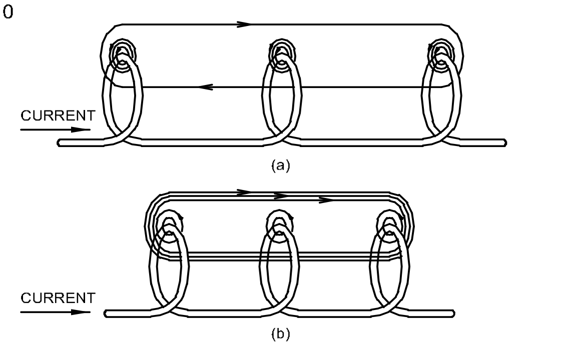
FACTORS DETERMINING INDUCTANCE

Spacing between turns of wire (Fig 9c): When the distance between the turns of wire in a coil is increased, the inductance of the coil decreases. Fig 10 illustrates why this is so. With widely spaced turns Fig 10 many of the flux lines from adjacent turns does not link to gether. Those lines that do not link together produce no voltage in other turns. As the turns come closer together Fig 10 only a fewer lines of flux fail to link up.

Cross sectional area (Fig 9d):For a given material having same number of turns, the inductance will be high with large cross-sectional area and will be low for smaller cross-sectional area.

Symbol and unit of Self-inductance: The property of a coil or conductor to self-induce an emf, when the current though it is changing, is called the coil's (conductor's) self-inductance of simply inductance. The letter symbol for inductance is L; its basic unit is henry, H.

Fig 10



EFFECT OF TURN SPACING

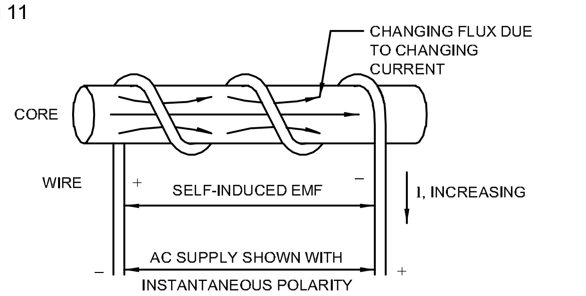
Henry: A conductor or coil has an inductance of one henry if a current that changes at the rate of one ampere per second produces a induced voltage (cemf) of 1 volt.

The inductance of straight conductors is usually very low, and for our proposes can be considered zero. The inductance of coiled conductors will be high, and it plays an important role in the analysis of AC circuits.

What will be the direction of the induced emf? (Lenz's Law): The direction of the self-induced emf is explained by Lenz's Law.

A change in current produces an emf whose direction is such that it opposes the change in current. In other words, when a current is decreasing, the induced emf is in the same direction as the current and tries to oppose the current from decreasing. And when a current is increasing, the polarity of the induced emf is opposite to the direction of the current and tries to prevent the current from increasing (Fig 11).

Fig 11



The magnitude of induced emf:The magnitude of self-induced emf depends on the rate at which the magnetic field changes. However magnetic field is proportional to current.

$$v = L \times \frac{di}{dt}$$

where

- v is the emf induced in volts, V (some times called as counter emf (cemf)
- L is the inductance in henrys, H
- di is the change in current in amperes, A.
- dt is the change in time in seconds s,

$\frac{di}{dt}$ is the rate of change of current in amperes/second, A/s.

Coefficient of self-inductance : It is defined as the flux linkage of weber turns per ampere in the coil.

By definition $L \times \frac{N\phi}{I}$ henry

where 'N' is the number of turns

'f' is the flux in webers

I is the current in amperes

Energy storage: An inductor stores energy in the magnetic field created by the current. The energy stored is expressed as follows.

$$W = \frac{1}{2} LI^2$$

where I is in amperes,

L is in henries and

W is energy in joules or watt-second

To obtain the desired value of inductors, some series and parallel combination of inductors can be used.

Series and Parallel Inductors

Series inductors: When inductors are connected in series, as in Fig 12a, the total inductance L_T is the sum of the individual inductances. The formula for L_T is expressed in the following equation for the general case of n inductors in series.

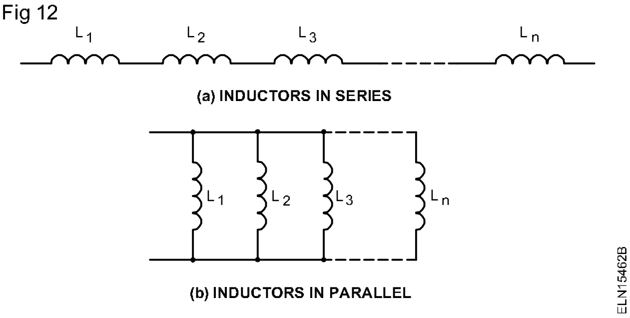
$$L_T = L_1 + L_2 + L_3 + ...L_n$$

Notice that inductance in series to resistance in series.

Parallel inductors: When inductors are connected in parallel, as in Fig 12b, the total inductance is less than the smallest inductance. The formula for total inductance in parallel is similar to that for total parallel resistance.

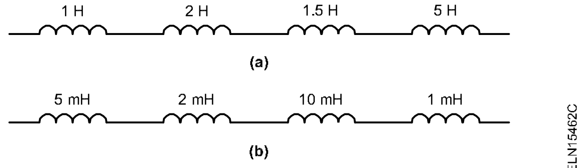
$$\frac{1}{L_T} = \frac{1}{L_1} + \frac{1}{L_2} + \frac{1}{L_3} + \dots\dots\dots\dots \frac{1}{L_n}$$

Fig 12



Example 1: Determine the total inductance for each of the series connections in Fig 13.

Fig 13



Solution

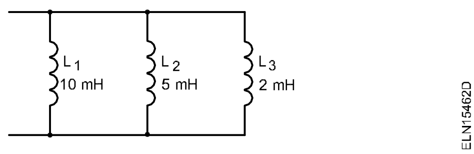
a) L_T = 1H + 2H + 1.5H + 5H = 9.5H

b) L_T = 5mH + 2mH + 10mH + 1mH = 18mH

Note 1000mH = 1 H

Example 2: Determine L_T in Fig 14.

Fig 14



Solution

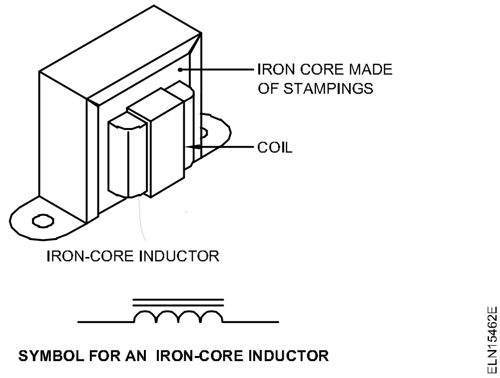
$$L_T = \frac{1}{\left(\frac{1}{10}\text{mH}\right) + \left(\frac{1}{5}\text{mH}\right) + \left(\frac{1}{2}\text{mH}\right)}$$

$$= \frac{1}{0.1 + 0.2 + 0.5}$$

$$L_T = \frac{1}{0.8} = 1.25 \text{ mH.}$$

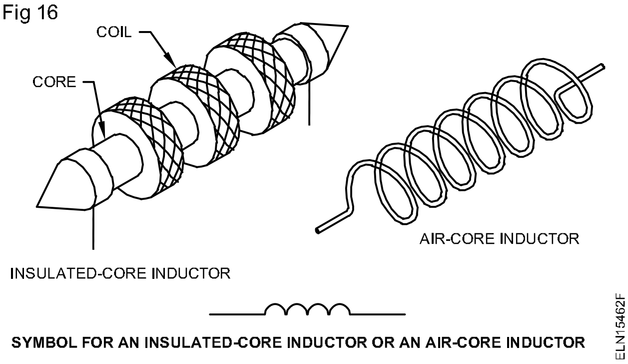
Types of Inductor: Basically, all inductors are made by winding a length of conductor around a core (Fig 15). The conductor is usually a solid copper or aluminum wire coated with enamel insulation, and the core is made either of magnetic material, such as powered iron, or of insulating material.

Fig 15



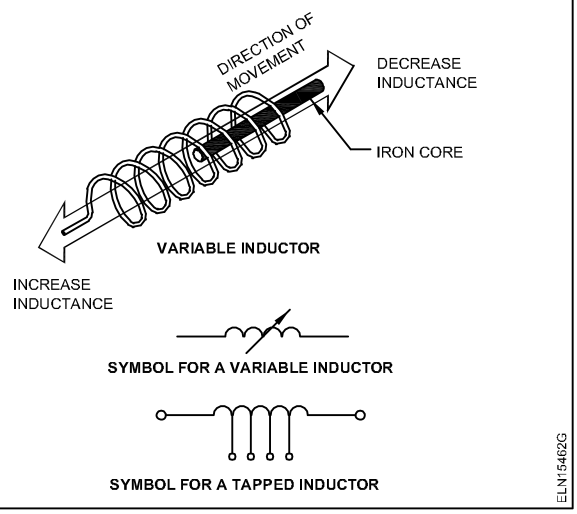
When an inductor is wound around an insulating core, the core is used only for a support, since it has no magnetic properties. If heavy wire is used in making the inductor, a core is actually not needed; the regid loops of wire support themselves. When a magnetic core is not used, the inductor is usually referred to as an air-core inductor. (Fig 16)

Fig 16



Inductor with set values of inductance that cannot be changed are called fixed inductors. Inductors whose inductance can be varied over some range are called variable inductors. Usually, variable inductors are made so that the core can be moved into and out of the winding. The position of the core will determine the inductance value. (Fig 17)

Fig 17



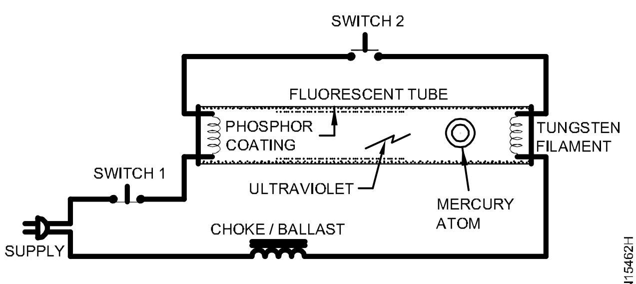
Inductors are also frequently called chokes or coils. All these three terms mean the same thing.

Fixed inductors are used as ballast in gas discharge lamps. They are also used in electronics as power supply filters. Variable inductors and tapped inductors are used for obtaining variation of current in welding transformers to suit the electrode size and weld material.

Function of choke in a fluorescent lamp circuit: Fig 18 shows a fluorescent lamp circuit. The inductor (ballast) is used to induce a momentary high voltage to fire the lamp. The ballast then limits the current through the lamp, after the lamp is lit, because of the coil's inductive reactance. The operation of the lamp circuit is as follows.

The fluorescent lamp is a glass tube with a tungsten filament sealed at each end. The inner surface of the tube is coated with a phosphor material this determines the colour of the light produced. Most of the air is removed during manufacture and a small amount of argon gas and mercury are admitted to the sealed tube.(Fig 18)

Fig 18



SCHEMATIC DIAGRAM OF FLUORESCENT TUBE LAMP

When the momentary contact of the switch 2 is pushed (CLOSED), and held closed for several seconds, a complete series path exists for current to flow through the two filaments to become heated, emitting electrons. A dull glow is observed at each end of the tube. When the switch 2 is released (OPEN), the current through the ballast is interrupted, causing a high voltage to be momentarily induced. This voltage, along with the 240V input, is sufficient to cause the lamp to 'fire'. This means that the current is conducted through the ionized gas in the tube from one filament to the other.

It should be noted that the ballast gets its name from the second function it provides. After the lamp is lit, a typical 40W lamp requires only 110V to maintain proper current through the lamp. The opposition to alternating current caused by the inductance, its inductive reactance, help in the applied 240V dropping to the required value across the lamp.

Flourecent lamps that use a single on/off switch1 in the supply line for control purposes employ a starter inplace of the switch 2.

When a fluorescent lamp circuit is connected to DC supply, the choke serves the first purpose only. An additional resistor is to be connected in series to limit the current through the lamp.

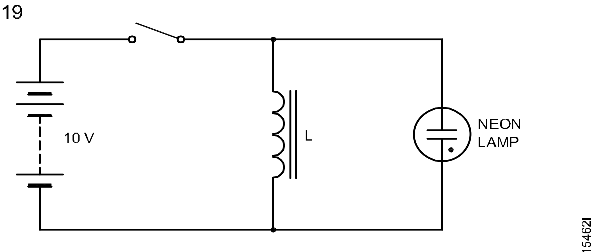
Disadvantage of Inductance:
Inductance increases arcing in switch contact which is a major disadvantage. A large voltage across the contacts, while opening the switch of the inductive circuit, sets an arc, and the stored energy in the magnetic field increases the arcing. Additional measures are required to suppress the arc in such circuits.

Factors that contribute to induced voltage: The ability of a coil to induce high voltage can be observed by connecting a neon lamp across a coil as in Fig 19.

A neon lamp used as an indicator requires a minimum of about 70V to 'fire' or light. It is observed that a battery does not light the lamp as the voltage is only 10V at the time of switching ON. But when the switch is opened the lamp flashes indicating the presence of high voltage, more than 70 V.

A major application of the high voltage induced in a coil by interrupting the current through the coil is in fluorescent lamp circuits and ignitors of petrol engines.

Fig 19



L - CHOKE OF 40W FLUORESCENT TUBELIGHT

Counter emf - inductive reactance - time constant

Objectives: At the end of this lesson you shall be able to
- **explain the term Counter EMF (CEMF)**
- **explain about the inductive reactance**
- **state the reasons for the difference between ohmic resistance and impedance of a coil**
- **explain time constant of an inductive circuit.**

Counter EMF and LENZ's law: The voltage induced in a conductor or coil by its own magnetic field is called a counter electromotive force (cemf). Since the induced emf (voltage) is always opposing, or countering, the action of the source voltage, it is known as cemf. Counter electromotive force is sometimes referred to as back electromotive force (bemf).

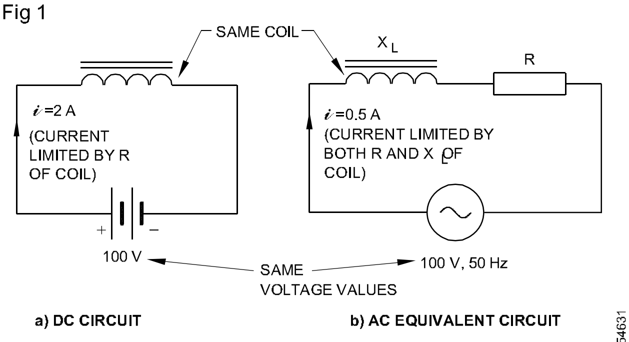
In any type of inductive circuit there is an important relationship between the direction of the current change and the induced voltage. Lenz's law states that a cemf always has a polarity which opposes the force that created it.

The inductance rating of an inductor refers to its ability to generate a counter voltage to a change in current flow. One henry (1H - the SI unit) represents the inductance of a coil in which a current change of one ampere per second (1 A/s) will produce a cemf of one volt (1V).

Inductive reactance:The opposition offered to an AC current flow by the inductive effect is called inductive reactance. Inductive reactance is the result of the cemf of the inductor. The inductor cemf is just equal to (and opposite) the source voltage.

Current flow through a coil connected to a DC source is limited by the wire resistance of the coil only (Fig 1a) Current flow through the same coil connected to an AC source is limited by the wire resistance and the inductive reactance (Fig 1b)

Fig 1



INDUCTANCE CONNECTED TO AN AC AND DC SOURCE

The reactance of an inductor can be calculated with the following formula

$X_L = 2\pi fL = 6.28\ fL$

The inductive reactance is in ohms while the frequency is in hertz and the inductance is in henrys.

From the above formula it can be seen that inductive reactance is directly proportional to both frequency and inductance.

This direct proportional relationship makes sense when one recalls two things.

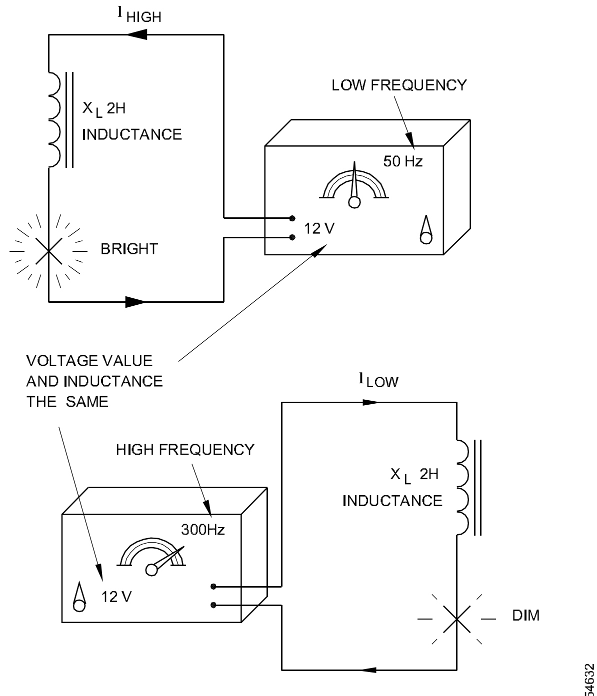
- The higher the frequency, the more rapidly the current is changing. Thus more cemf and more reactance are produced (Fig 2)
- The higher the inductance, the more the flux change per unit of current change. Again more cemf and reactance are produced.(Fig 3)

OHMIC resistance: The DC resistance is the resistance measured with a very accurate ohmmeter. It is the total resistive effect to pure DC.

Effective resistance: In general, a pure resistive circuit reacts in much the same way for both AC or DC. There are, however, some differences that must be considered. These differences vary with the frequency of AC and are generally negligible at low frequencies.

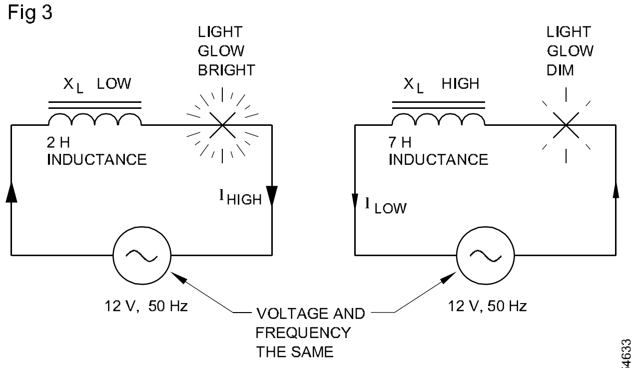
The following five factors affect the amount of current flow in a pure resistive circuit.

Fig 2



INDUCTIVE REACTANCE AND FREQUENCY

Fig 3



COIL-INDUCTANCE AND INDUCTIVE-REACTANCE

- DC resistance
- Skin effect
- Eddy currents
- Hysteresis
- Dielectric stress

The DC resistance is the resistance offered by the conductor (element) to pure DC. The fact that the alternating current changes in value and direction tends to make it flow along the outer surface of the conductor. This phenomenon, known as skin effect, reduces the inner conductive effect of the conducting material and increases the circuit resistance.

Alternating current produces a magnetic flux which changes its polarity with each reversal of current flow. The change in polarity causes the molecules in the metal parts near the circuit to be in motion, thus producing heat. The heat either radiates back into the circuit conductors or retards the dissipation of heat produced by the current flowing in the conductors. The hysteresis effect increases the effective resistance of the circuit.

Eddy currents are caused by voltages induced into the conductors and other surrounding metal parts. They are directly proportional to the frequency of the supply. The heat produced by these currents tends to increase the effective resistance of the circuit.

As the alternating voltage varies in strength, the stress on the conductor insulation increases and decreases. This variation in electric stress also produces heat which increases the circuit resistance.

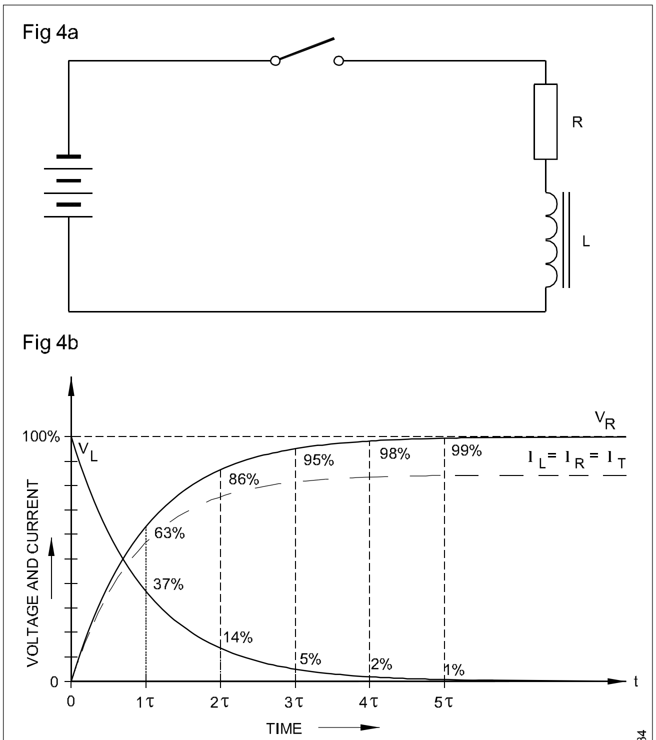
Effect of inductance present in a AC circuit: Coils have various uses in electrical engineering such as

- excitation coils in electric machines or magnets
- relay coils in switching devices
- choke coils for limiting current etc.

If a coil with the current passing through it is compared to a vehicle being moved, then the momentary value of the coil's current I can be compared to the velocity V of the vehicle. An increase in the current corresponds to accelerating the vehicle and a decrease in the current corresponds to braking (retarding) the vehicle. Due to the inertia of the vehicle's mass the velocity cannot suddenly change. The same applies to the coil's current, where a sudden change is prevented by the self-induced emf (voltage).

Time constant for inductors: When a coil with inductance L and resistance R_L is fed by a direct voltage (Fig 4a) the flux increasing with the current induces cemf, so that the current only increases to its final value $I = \frac{V}{R_L}$ with a time delay Fig 4b. The time constant for an RL circuit is defined as the time required for the current through the resistor-inductor to rise to 63.2% of its final value. The time constant of an RL circuit can be calculated using the formula $t = \frac{L}{R}$.

The time constant is in seconds when L is in henry and R is in ohms. The current after the time t = t has reached 63.2% of its final value. The table shows after five time constants have elapsed (t=5t), the current has reached 99.3% of its final value, i.e. it has practically reached its final value.



CURRENT AND VOLTAGE RELATIONSHIPS IN AN INDUCTOR. MAXIMUM INDUCTIVE VOLTAGE OCCURS BEFORE MAXIMUM CURRENT IS REACHED.

Time t =	τ	2τ	3τ	4τ	5τ	6τ	7τ	8τ
Current value I =	63.2%	86.46	95.02	98.10	99.33	99.75	99.9	99.966

Capacitors - types - functions , grouping and uses

Objectives: At the end of this lesson you shall be able to
- **describe capacitor its construction and charging**
- **explain capacitance and the factors determining**
- **state the different types and application of capacitors**
- **state the testing and defects of capacitors**

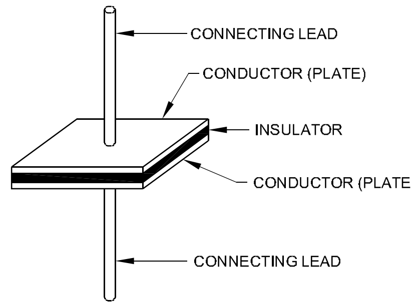
Capacitor:

Capacitor is a passive two terminal electrical/electronic component that stores potential energy in the form of electrostatic field

The effect of capacitor is called as capacitance. It consists of two conducting plates separated by an insulating material called as dielectric. In simple, capacitor is a device designed to store electric charge.

Construction: A capacitor is an electrical device consisting of two parallel conductive plates, separated by an insulating material called the dielectric. Connecting leads are attached to the parallel plates. (Fig 1)

Fig 1



SIMPLE CAPACITOR. THE PLATES OF A CAPACITOR ARE ALWAYS INSULATED FROM EACH OTHER

Function: In a capacitor the electric charge is stored in the form of an electrostatic field between the two conductors or plates, due to the ability of dielectric material to distort and store energy while it is charged and keep that charge for a long period or till it is discharged through a resistor or wire. The unit of charge is coulomb and it is denoted by the letter `C'.

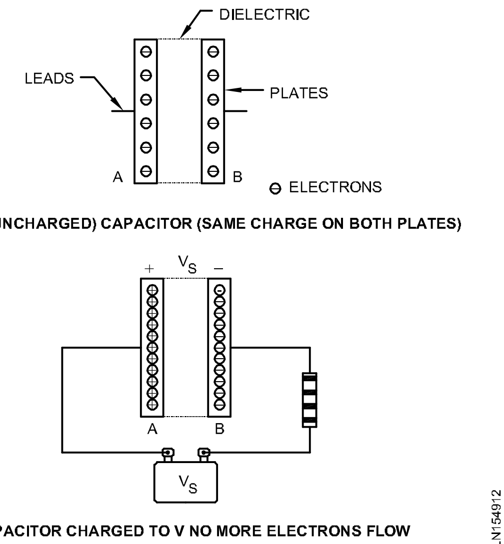
How a capacitor stores charge?: In the neutral state, both plates of a capacitor have an equal number of free electrons, as indicated in Fig 2a. When the capacitor is connected to a voltage source through a resistor, the electrons (negative charge) are removed from plate A, and an equal number are deposited on plate `B'. Plate A becomes positive with respect to plate B as shown in Fig 2b.

The current enters and leaves the capacitor, but the insulation between the capacitor plates prevents the current from flowing through the capacitor.

As electrons flowing into the negative plate of a capacitor have a polarity opposite to that of the battery supplying the current, the voltage across the capacitor opposes the battery voltage. The total circuit voltage, therefore, consists of two series-opposing voltages.

As the voltage across the capacitor increases, the effective circuit voltage, which is the difference between the battery voltage and the capacitor voltage, decreases. This, in turn, causes a decrease in the circuit current.

Fig 2



When the voltage across the capacitor equals the battery voltage, the effective voltage in the circuit is zero, and so the current flow stops. At this point, the capacitor is fully charged, and no further current can flow in the circuit.

Capacitance : The ability or capacity to store energy in the form of electric charge is called capacitance. The symbol used to represent capacitance is C.

Unit of capacitance: The base unit of capacitance is the **Farad.** The abbreviation for **Farad** is **F**. One farad is that amount of capacitance which stores 1 coulomb of charge when the capacitor is charged to 1 V. In other words, a Farad is a coulomb per volt (C/V).

Farad

A farad is the unit of capacitance (C), and a coulomb is the unit of charge(Q), and a volt is the unit of voltage(V). Therefore, capacitance can be mathematically expressed

as $C = \frac{Q}{V}$

This relationship is very useful in understanding voltage distribution in series-capacitor circuits. The other forms of equation are $V = \frac{Q}{C}$

Example 1: What is the capacitance of a capacitor that requires 0.5 C to charge it to 25V?

Given: Charge(Q) = 0.5C

Voltage(V) = 25V

Find :

Capacitance(C)

$$C = \frac{Q}{V}$$

Solution $C = \frac{0.5\,C}{25\,V} = 0.02F$

Answer: The capacitance is 0.02F.

Capacitive reactance

Similar to resistors and inductors, a capacitor also offers opposition to the flow of AC current. This opposition offered to the flow of current by a capacitor is called **capacitive reactance** abbreviated as X_C.

Recall expressions,

$$I = \frac{Q}{t} = \text{and } Q = CV$$

Substituting Q = CV in I = Q/t

$$I = \frac{CV}{t}$$

This means,
$I \alpha C$, $I \alpha V$ and $I \alpha f$ (Because, 1/t = f)

From the above equation, the amount of AC current that a capacitor conducts depends on;

- the frequency (f) of the applied voltage
- the capacitance (C) of the capacitor
- the amplitude of the applied voltage(V).

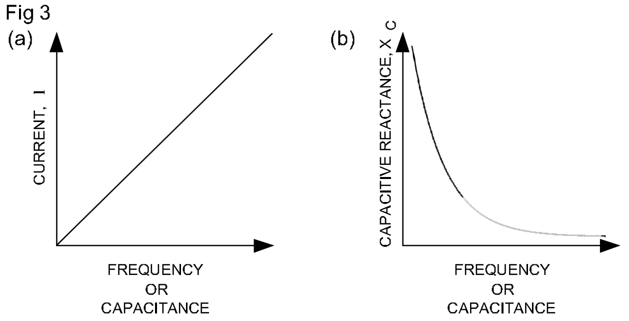
Fig 3a shows the graph of variation of current(I) through a capacitor with frequency or capacitance when the applied voltage is kept constant.

Since current flow through a capacitor is directly proportional to frequency and capacitance, the opposition to current flow by the capacitor is inversely proportional to these quantities.

Capacitive reactance, X_C can be mathematically represented as;

$$X_c = \frac{1}{2\pi fc}$$

Fig 3



where

X_C is the capacitive reactance in ohms

f is the frequency of the applied voltage in Hz

and C is the capacitance in farads.

Fig 3b shows the graph of variation of X_C with frequency or capacitance.

Capacitive reactance, X_C, expressed in ohms, acts just like a resistance in limiting the AC current flow.

Sub-units of a farad: Most capacitors that you will use in electronics work, have capacitance values in microfarads (μF) and picofarads (pF). A microfarad is one-millionth of a farad ($1\mu F = 1 \times 10^{-6}$ F), and a picofarad is one-trillionth of a farad ($1\ PF = 1 \times 10^{-12}{}_{P}F$) one nano farad ($1nF = 1 \times 10^{-9}$ F).

Factors determining capacitance: The capacitance of a capacitor is determined by four factors.

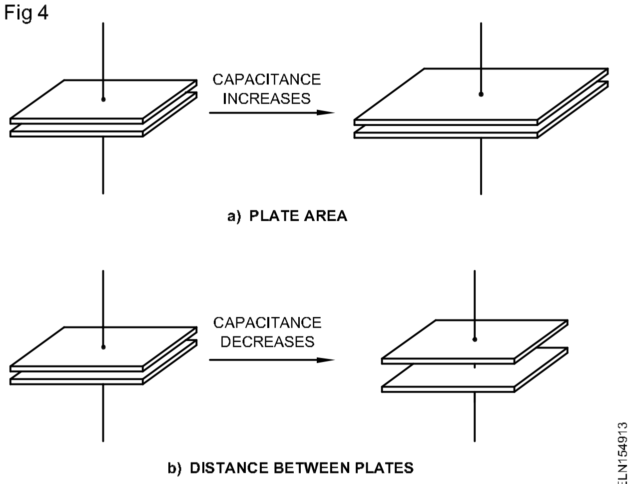
- Area of the plates ($C \alpha A$)
- Distance between the plates ($C \alpha d$)
- Type of dielectric material
- Temperature
- Resistance of the plates

Area of the plates: The capacitance of a capacitor is directly proportional to the area of its plates (or the area of its dielectric). All other factors remaining the same, doubling the plate area doubles the capacitance.

Thus, when the dielectric area is increased, the amount of energy stored in the dielectric is increased and the capacitance is also increased. (Remember, capacitance is defined as the ability to store energy.) (Fig 4a)

Distance between the plates: Other factors being equal, the amount of capacitance is inversely proportional to the distance between the plates. The strength of the electric field between the plates decreases, when the distance between the plates increases. The force on the electrons in the dielectric decreases accordingly. Again the amount of energy stored in the capacitor, for a given voltage applied to the capacitor, would decrease. Thus, the capacitance decreases. (Fig 4b)

Fig 4



Type of dielectric material: In general, those materials which undergo the greatest distortion store the most capacitance. The ability of a dielectric material to distort and store energy is indicated by its **dielectric constant (K)**.

The dielectric constant of a material is a mere number (that is, it has no units). It compares the material's ability to distort and store energy, when in an electric field, with the ability of air to do the same.

Since air is used as the reference, it has been given K equal to 1. Mica, often used as a dielectric, has a dielectric constant approximately 5 times that of air. Therefore, for mica, K = 5 (approximately). Suppose all the other factors (plate area, distance between plates, and temperature) are the same, then a capacitor with a mica dielectric will have 5 times as much capacitance as the one using air as its dielectric.

Dielectric constants for materials commonly used for dielectrics range from 1 for air to more than 4000 for some types of ceramics.

Temperature: The temperature and resistance of the capacitor is the least significant of the four factors. It need not be considered for many general applications of capacitors.

Types of capacitors: Capacitors are manufactured in a wide variety of types, sizes and values. Some are fixed in value, in others the value is variable.

Fixed capacitors

Ceramic capacitors: Ceramic dielectrics provide very high dielectric constants (1200 is typical). As a result, comparatively high capacitance values can be achieved in a small physical size.

Ceramic capacitors are illustrated in Figs 5a) and (b). These discs are made by using ceramic as an insulator with a silver deposit on each side of the plates. These are used for small values of capacitance and an ordinary TV set might contain several dozens in its circuitry.

Ceramic capacitors are typically available in capacitance values ranging from 1μF to 2.2μ F with voltage ratings up to 6 KV. A typical temperature coefficient for ceramic capacitors is 200,000 PPM/°C.

Mica capacitors: There are two types of mica capacitors, stacked foil as shown in Fig 5(c). It consists of alternate layers of metal foil and thin sheets of mica. The metal foil forms the plate, with alternate foil sheets connected together to increase the plate area, thus increasing the capacitance.

The mica foil-stack is encapsulated in an insulating material such as bakelite, as shown in Fig 5d of the figure. The silver-mica capacitor is formed in a similar way by stacking mica sheet with silver electrode material screened on them.

Mica capacitors are available with capacitance values ranging from 1 pF to 0.1 pF and voltgage ratings from 100 to 2500 V DC. Temperature coefficients from −20 to +100 PPM/°C are common. Mica has a typical dielectric constant of 5.

Electrolytic capacitors: Electrolytic capacitors are polarised so that one plate is positive and the other negative.

These capacitors are used for high capacitance values up to over 200,000μ F, but they have relatively low breakdown voltages (350 V is a typical maximum) and high amounts of leakage.

Electrolytic capacitors are available in two types: aluminium and tantalum. The basic construction of an electrolytic capacitor is shown in Figs 5(e) and (f).

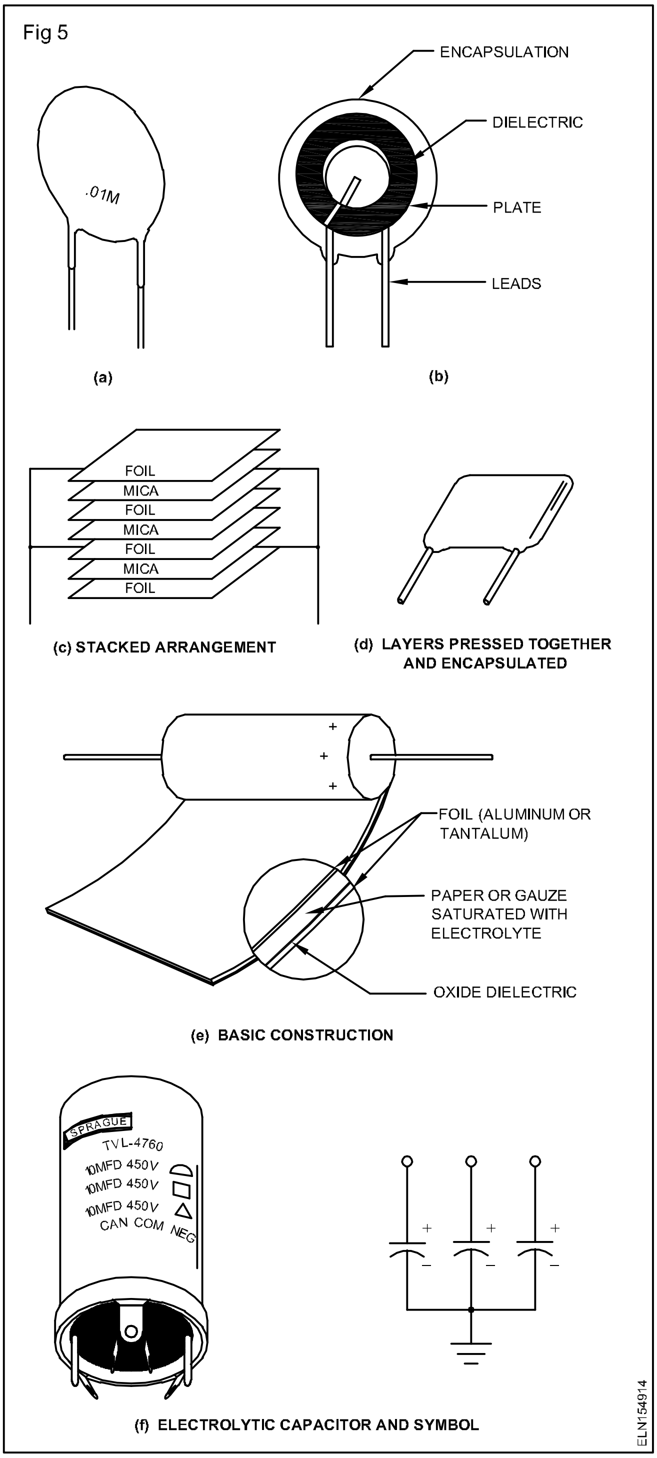
The capacitor consists of two strips of either aluminum or tantalum foil separated by a paper or gauze strip, saturated with an electrolyte. During manufacturing, an electrochemical reaction is induced which causes an oxide layer (either aluminum oxide or tantalum oxide) to form on the inner surface of the positive plate. This oxide layer acts as the dielectric.

One particular point you must always remember about the electrolytic capacitor is that one end is positive (+) and the other negative (−). You must always observe this polarity when connecting in your circuit. The symbol on a drawing will have positive and negative marks. These polarity marks will tell you it is an electrolytic capacitor.

Since an electrolytic capacitor is polarized, the positive plate must always be connected to the positive side of a circuit. Be very careful to make the correct connection and to install the capacitor only in a DC, not AC, circuit.

Reverse polarity on an electrolytic capacitor causes excessively high current in the capacitor. It causes the capacitor to heat up, and possibly to explode. Thus, the common electrolytic capacitor is limited to use in DC circuits.

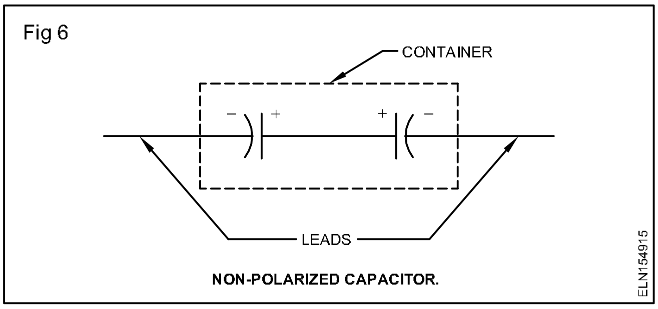
Special electrolytic capacitors are manufactured for use in AC circuits. These capacitors are usually listed in catalogues as `non-polarised' or `AC' electrolytic capacitors. An AC electrolytic capacitor is really two electric capacitors packaged in a single container.(Fig 6)



The two internal capacitors are in series, with their positive ends connected together. Regardless of the polarity on the leads of the AC electrolytic capacitor, one of the two internal capacitors will be correctly polarized.

Paper/plastic capacitors: There are several types of plastic-film capacitors and the older paper dielectric capacitors. Polycarbonate, parylene, polyester, polystyrene, polypropylene, mylar, and paper are some of the more common dielectric materials used. Some of these types have capacitance values up to 100µF.

Fig 7 show a common basic construction used in many plastic-film and paper capacitors. A thin strip of plastic-film dielectric is sandwiched between two thin metal strips which act as plates. One lead is connected to the inner plate and the other to the outer plate as indicated. The strips are then rolled in a spiral configuration and encapsulated in a moulded case. Thus a large plate area can be packaged in a relatively small physical size, thereby achieving larger capacitance values. Fig 7b shows a construction view for one type of plastic-film capacitor.

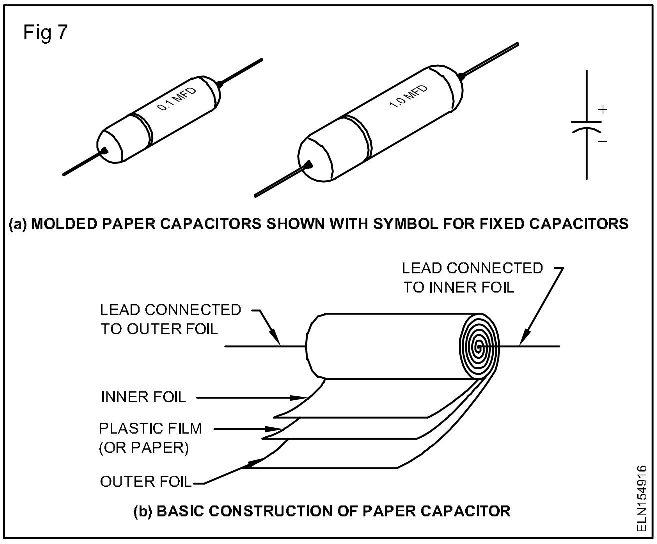


Variable capacitors

Variable capacitors are used in a circuit when there is a need to adjust the capacitance value either manually or automatically. For example, in radio or TV tuners. The major types of variable or adjustable capacitors are now discussed.

Air capacitor: Variable capacitors with air dielectrics, such as the one shown in Fig 8(b), are sometimes used as tuning capacitors in applications requiring frequency selection. This type of capapcitor is constructed with several plates that mesh together. One set of plates can be moved relative to the other, thus changing the effective plate area and the capacitance. The movable plates are linked together mechanically so that they move when a shaft is rotated.

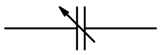
The schematic symbol for a variable capacitor is shown in Fig 8(a).



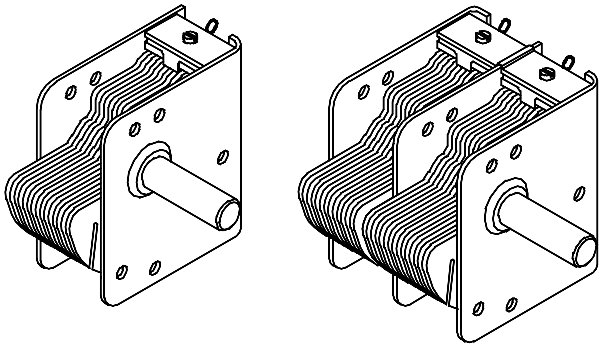
Trimmers and padders: These adjustable capacitors normally have screwdriver adjustments, and are used for very fine adjustments in a circuit. Ceramic or mica is a common dielectric in these types of capacitors, and the capacitance usually is changed by adjusting the plate separation.(Fig 9)

Varactors: A varactor is a semiconductor device that exhibits a capacitance characteristic which is varied by changing the voltage across its terminals. This device is usually covered in greater detail in a course on electronic devices.

Fig 8



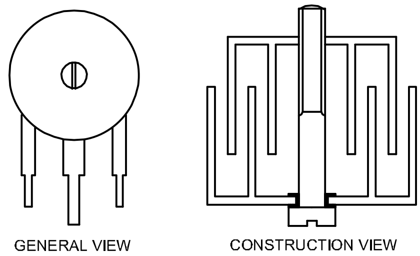
(a) SCHEMATIC SYMBOL FOR A VARIABLE CAPACITOR



(b) SINGLE AND TWO-GANG VARIABLE CAPACITORS WITH AIR DIELECTRIC

ELN154917

Fig 9



TRIMMER CAPACITORS

ELN154918

Application of capacitors with type and ratings - Chart I

Type	Capacitance	Voltage WVDC (Working voltage DC)	Applications
Monolithic	1 pF-10μF	50-200	UHF,RF coupling.
Disc and tube ceramics	1pF - 1μF	50-500	General, VHF.
Paper	0.001-1μF	200-1600	Motors, power supplies.
Film - polypropylene	0.001-0.47μF	400-1600	TV vertical circuits, RF.
Polyester	0.001-1μF	100-600	Enetertainment- electronics.
Polystyrene	0.001-1μF	100-200	General, high stability.
Polycarbonate	0.01 -18μF	50-200	General.
Metallized polypropylene	4-60μF	400 VAC 50Hz	AC motors.
Metallized polyester	0.01-10μF	100-600	Coupling, RF filtering.
Electrolytic-aluminum	1-500,000μF	5-500	Power supplies, filters.
Electrolytic-tantalum	0.1-1000μF	3-125	Small space requirement, high reliability, low leakage.
Electrolytic-Non-polarised (either Al or Ta)	0.47-220μF	16-100	Loudspeaker cross-overs.
Mica	330pF-0.05μF	50-100	High frequency.
Silver-mica	5-820pF	50-500	High frequency.
Variable-ceramic	1-5 to 16-100pF	200	Radio, TV, communications.
Film	0.8-5 to 1.2-30pF	50	oscillators, antenna, RF circuits.
Air	10-365pF	50	Broadcast receivers.
Teflon 0.25-1.5pF		2000	VHF, UHF.

Common defects in capacitors

Short circuited capacitors: In the course of normal usage, capacitors can become short-circuited/shorted. This is because of the deterioration of the dielectric used due to ageing.

Usually such a defect occurs when the capacitor is used over a period of years under the stress of changing voltage across it. This period gets reduced if the capacitor is operated at higher temperatures.

Short-circuiting of capacitors is more common in paper and electrolytic capacitors than in the other types.

Short circuiting of capacitor also occurs due to puncturing of the dielectric when voltages much higher than its rated and applied. A shorted capacitor cannot store energy.

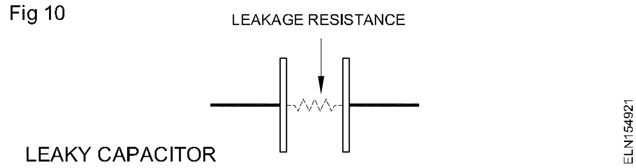
Open capacitors: A capacitor may become open due to loose/broken lead connections or due to the electrolyte. In electrolytic capacitors, the electrolyte develops high resistance with age, particularly when operated at high temperatures. After a few years of usage, the electrolyte may dry up resulting in open-circuit of the capacitor. An open capacitor cannot store energy.

The storage (shelf) life of wet type electrolytic capacitors is small because the electrolyte dries up over period of time.

Leaky capacitors/leakage resistance: Theoretically, the current that flows in a pure capacitive circuit results from the charge and discharge currents of the capacitors. The dielectric, which is an insulator, should prevent any current flow between the plates. However, even the best dielectric conduct very small current.

The dielectric, then has some high value of resistance, known as leakage resistance. This leakage resistance, as shown in Fig 10, allows some leakage current to flow. This leakage current tends to reduce the capacitance value.

Fig 10



In a good capacitor, the leakage resistance is generally of the order of several tens of megohms and hence can be considered negligible for most applications. As the capacitor ages, the leakage resistance could reduce. Generally, the leakage resistance is lower with high value capacitors than with low value capacitors.

The reason for this is that, larger capacitors have larger plate areas that are closer together. Therefore their dielectrics must have large areas and be thin. Recall, resistance reduces as the -sectional area is increased or when the length or thickness is decreased.

So, larger the capacitor, lower the leakage resistance, and higher is the leakage current.

Normal leakage resistance across a good capacitor has to be very high. Depending upon the type of dielectric used, the normal resistance varies.

For paper, plastic, mica and ceramic capacitors the normal resistance will be of the order of 500 to 1000 M or more. For electrolytic capacitors the normal resistance will be of the order of 200 KΩ to 500 KΩ.

A capacitor is said to have become leaky when the resistance across it is less than normal when read with any average quality ohmmeter.

Checking capacitors: The two simple methods to check a capacitor is by carrying out,

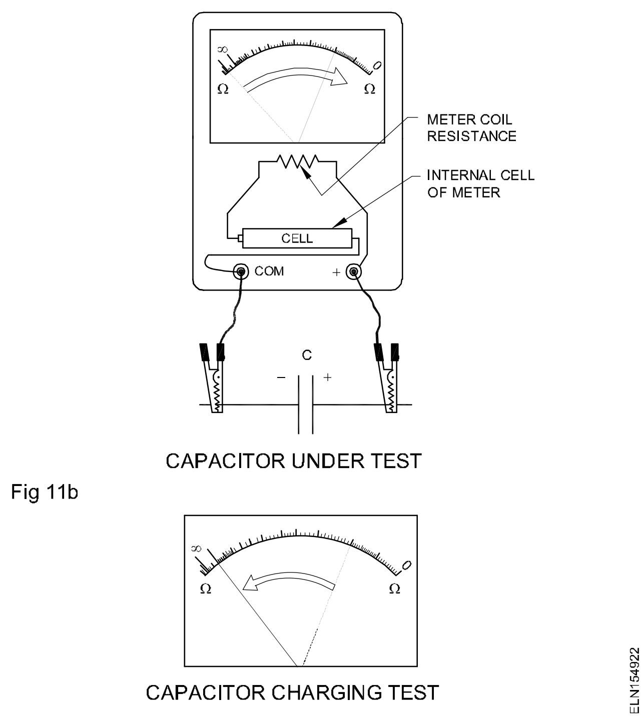
i capacitor action-normal resistance test, using a ohm-meter/multimeter (This test is also referred as quick test)

ii charging-holding test, using a battery and voltmeter/multimeter.

Capacitor action-normal charging test: When an ohmmeter is connected across a fully discharged capacitor, initially, the battery insider the meter charges the capacitor. During this charging, at the first instance, a reasonably high charging current flows.

Since more current through the ohm meter means less resistance, the meter pointer moves quickly towards zero ohms of the meter scale as shown in Fig 11a.

Fig 11



As the initial charging, the charging current to the capacitor slowly decreases (as the voltage across the capacitor increases towards the applied voltage). Since less and less current through the ohmmeter means high and higher resistance the meter pointer slowly moves towards infinite resistance of the meter scale as shown is Fig 11b. Finally, when the capacitor is completely charged to the ohmmeter internal battery voltage, the charging current is almost zero and the ohmmeter reads the normal resistance of the capacitor which is a result of just the small leakage current through the dielectric.

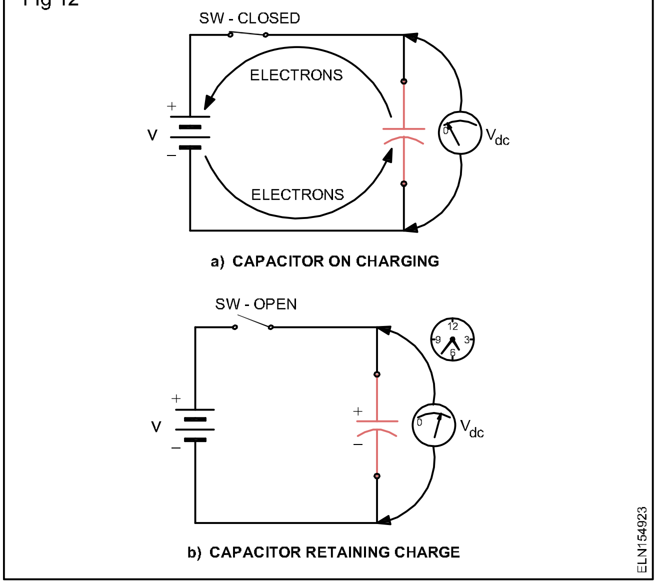
This changing effect commonly known as Capacitor action indicates, whether the capacitor can store charge, whether the capacitor is excessively leaky, whether the capacitor is fully short-circuited or whether the capacitor is fully open-circuited.

The capacitor-action test is most suitable for high value capacitors and specially electrolyte capacitors. When small value capacitors such as ceramic disc or paper capacitors are tested for capacitor-action, due to the extremely low charging current the capacitor-action can not be observed on the meter dial. For such small capacitors the capacitor-charging-holding test is preferred. However, if small capacitors are subjected for the capacitor-action test, if the meter shows high resistance the capacitor can be taken as not shorted and hence may be taken as good.

Charging-holding test on capacitors: In this test, a given capacitor is charged to some voltage level using an external battery as shown in Fig 12a.

Once the capacitor is charged to the applied voltage level, the battery is disconnected and the voltage across the capacitor is monitored as shown in Fig 12b. The voltage is

Fig 12



monitored for a period of time to confirm whether he capacitor is able to hold the charge atleast for a small period of time (of the order of few seconds).

In this test, when the capacitor is tried for charging, if the capacitor does not charge at all even after connecting the battery for a considerable period of time, it can be concluded that the capacitor is either short-circuited or fully open circuited.

If the capacitor is unable to hold the charge even for a considerably small period of time, then it can be concluded that the capacitor is excessively leaky.

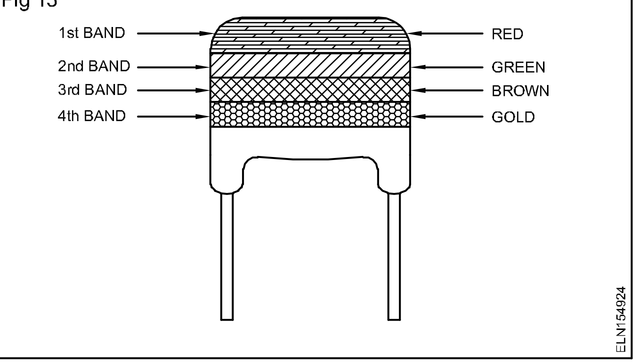
The following points are important and are to be noted to get correct results from the test.

- If the capacitor to be tested is marked + and – at its terminals (polarized-capacitor) then connect the battery with the same polarity. If a polarized capacitor is tried for changing with wrong polarity, the capacitor may get permanently damaged.
- Use a FET input voltmeter or high ohm/volt voltmeter to monitor the holding of voltage across the charged capacitor. This is because a low ohm/volt voltmeter will draw current from the charged capacitor resulting in a early discharge of stored charges on capacitor.

Note: FET voltmeters have input resistance in the order of 6 to 10 Megohms and draws only micro ampere current for full scale deflection.

For determining values of capacitors by colour code of capacitor is given in chart-2 for reference (Fig 13).

Fig 13



Capacitors colour code chart-2

Colour	Significant figures	Multiplier	Tolerance		Dipped tantalum voltage rating
			Over 10pF	Under 10pF	
Black	0	1	±20%	± 2 pF	4 VDC
Brown	1	10	±1%	± 0.1 pF	6 VDC
Red	2	10^2 or 100	±2%	-	10 VDC
Orange	3	10^3 or 1000	±3%	-	15 VDC
Yellow	4	10^4 or 10,000	+100%	-	20 VDC
			- 0%		
Green	5	10^5 or 100,000	±5%	± 0.5 pF	25 VDC
Blue	6	10^6 or 1,000,000	-	-	35 VDC
Violet	7	10^7 or 10,000,000	-	-	50 VDC
Grey	8	10^{-2} or 0.01	+80%	± 0.25 PF	-
		-20%			
White	9	10^{-1} or 0.1	±10%	± 1 pF	3 VDC
Gold	-	-	-	-	-
Silver	-	-	-	-	-
None	-	-	±10%	± 1 pF	-

Note: Main types of fixed value capacitors are given in Chart 3. Constructional details of fixed value capacitors are shown in Chart 4.

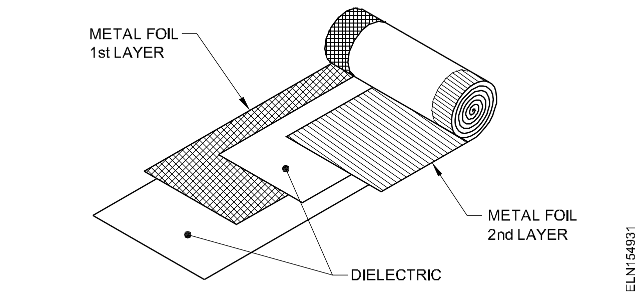
CHART - 3
Main types of fixed value capacitors

Type	Main sub-types	Dielectric used	Construction	Available capacitances	Rated voltage	Applications
Paper	Foil type & Metallized type	Impregnated special craft paper Special tissue paper	Rolled foils	0.001-1μF	200-1600VDC	Motor - starting, PF correction power supply- filters.
Plastic film	Foil type & Metalised type	i) Polystyrene ii) Polyster (Mylar capacitor)- iii) Poly propylene- iv) Poly carbonate v) Metallized polypropyene- vi) Metallized polyester- vii) Polystyrol (Styroflex)	- Rolled foils	0.001-1μF 0.001-1μF 0.001-0.47μF 0.01-18μF 4-60μF 0.01-10μF	100-200VDC 100-600VDC 400-1600 VDC 50-200 VDC 400 VAC, 50 Hz 100-600 VDC	General purpose, high stability. General purpose. RF circuits. General purpose. AC motors. Coupling, RF filtering.
Ceramic	Disc type Tube type Monolithic (chip type) Feed-through-stand-off-button type	Class-1 (Non ferro-electric) -Steatite (Talc) -Mix of MgO, TiO_2 -TiO_2, CaO Class-2 (Ferro-electric) -Barium titanate -Ba, Sr, TiO_2+Mg, Zr	Drawn ceramic films Moulded tubes Substrate-Screening-sintering	1PF -1μF 1PF-1000PF 1pF-10μF	50-500 VDC 500-5K VDC 50-200 VDC	General purpose, RF. General, VHF. VHF, RF coupling. Coupling in VHF range. Decoupling in VHF range. HF circuit feeders.
Electro-lytic	Aluminium (polor, non-polar)(Wet, dry type) Tantalum (polar, non-polar)(Wet, dry type)	Aluminium oxide Tantalum pentoxide	Rolled foil - metallic can Rolled foil - Can/cup/tank	1-500,000μF 0.1-1000μF	5-500 VDC 3-125 VDC	Power supplies, filters. Space electronics. Nonpolar Al and Ta capacitors are used in loudspeaker cross-overs.
Mica	Stacked mica- Silvered mica Button type	White mica, Rose mica, Amber mica	Stacked	5 pF-10,000pF 5pF-3300pF	50-100 50-500	High frequency High frequency H.F line feeders
Glass		Thin layer of glass	Stacked	5 pF-5000pF		VHF applications
Vitreous Enamel		Mixture of silica, Potassium, lead oxide and fluorides	Deposited in layers		50-500	

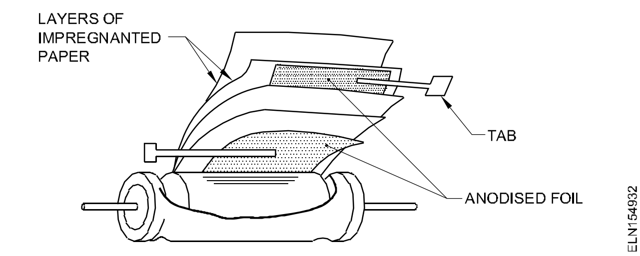
CHART - 4
Constructional details of fixed value capacitors

Paper Capacitors

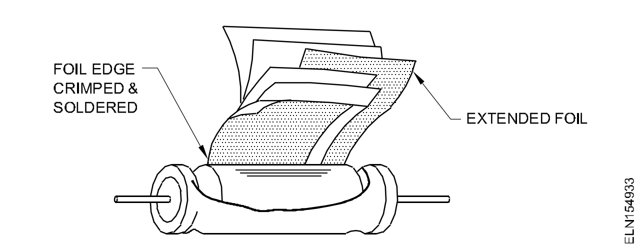
PRINCIPLE



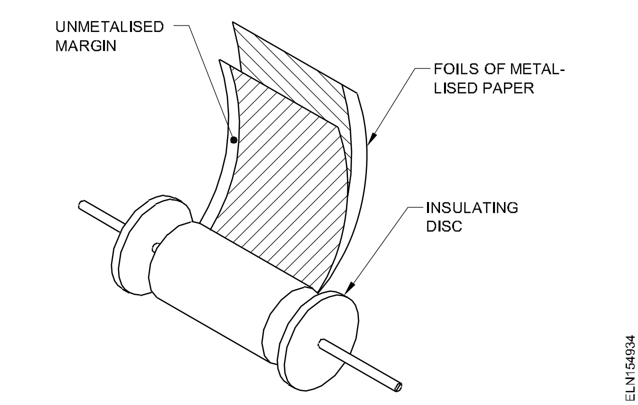
TAD TYPE



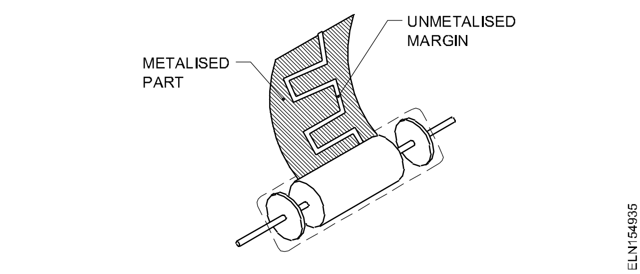
EXTENDED FOIL TYPE



METALISED PAPER CAPACITOR

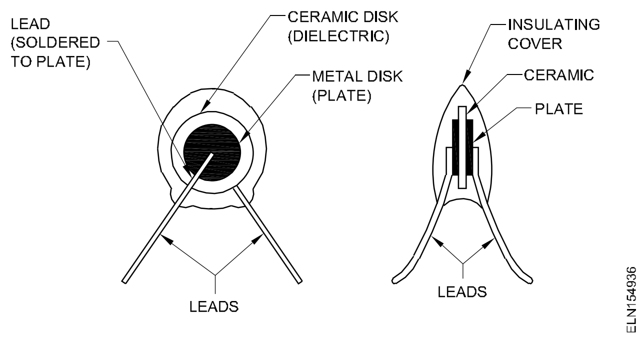


CASTELLATED TYPE PAPER CAPACITOR

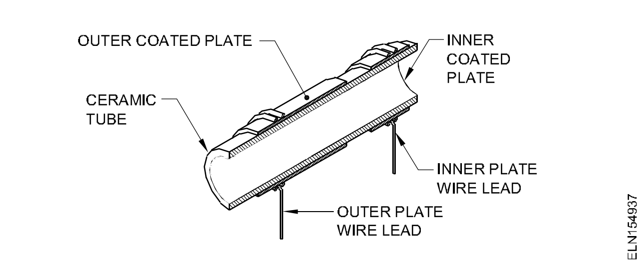


Ceramic Capacitors

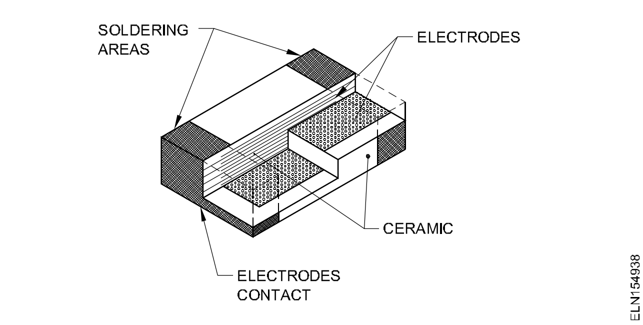
CERAMIC CAPACITORS



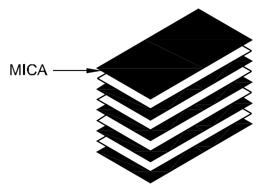
TUBULAR CERAMIC CAPACITOR (CROSS SECTIONAL VIEW)



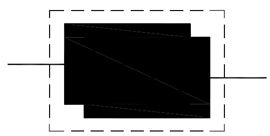
CERAMIC CAPACITOR



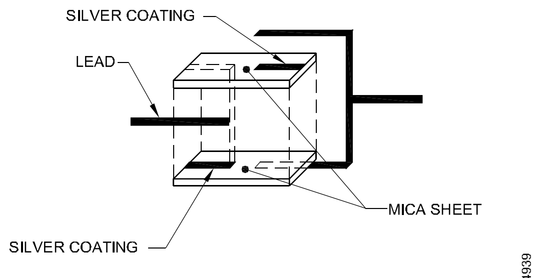
MICA Capacitors



PRINCIPLE

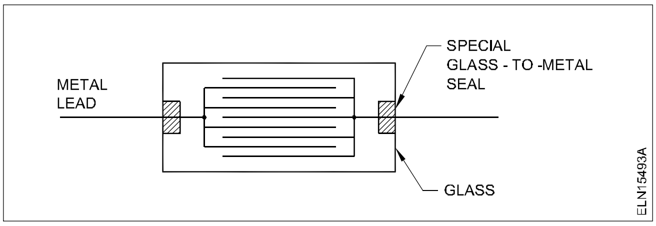


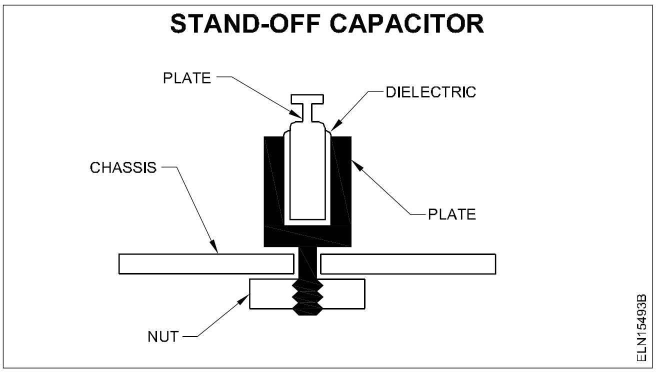
STACKED MICA CAPACITOR

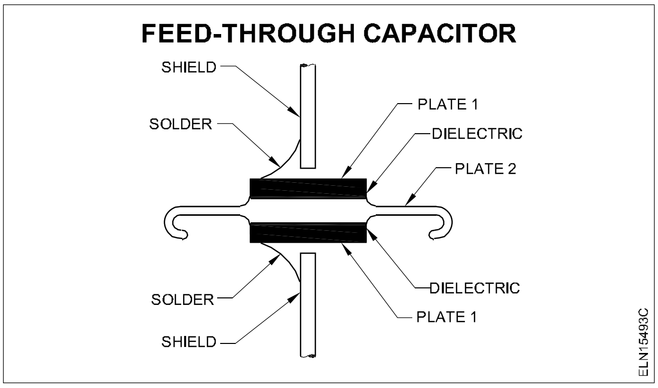


SILVER MICA CAPACITOR

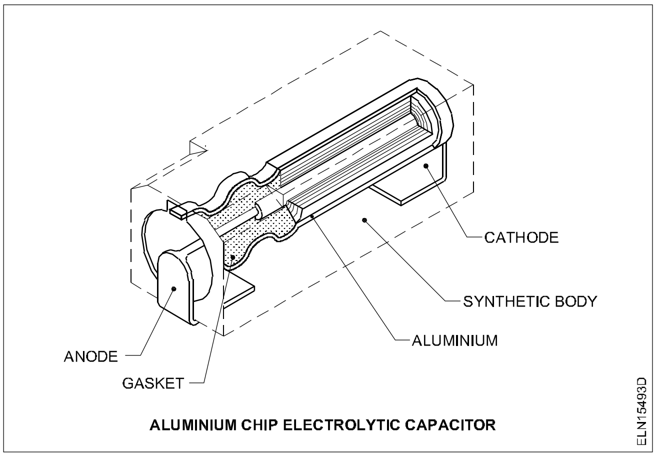
Glass Capacitors

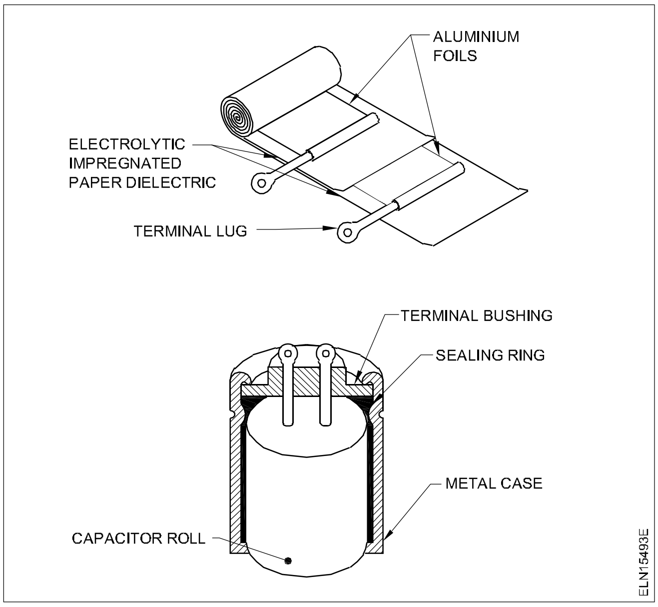




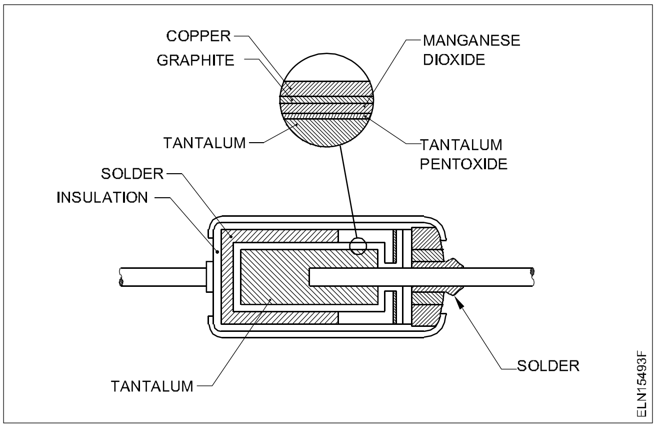


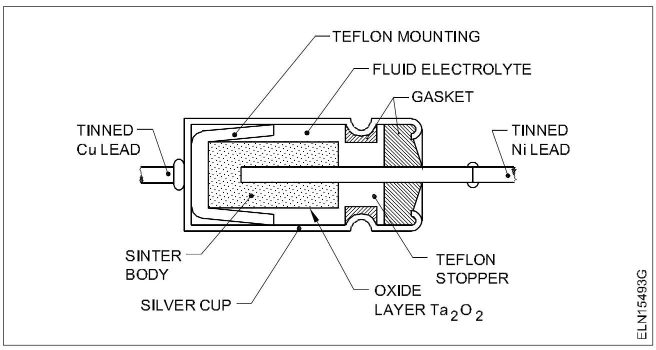
Electrolytic Capacitors Aluminium Type

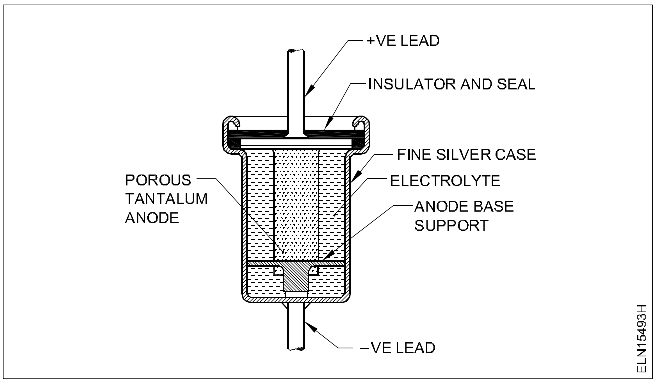


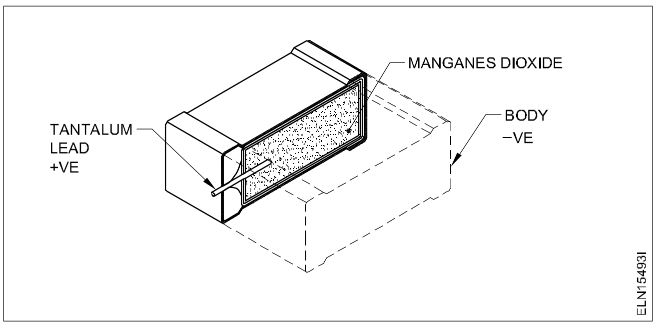


Tantalum Capacitors









Grouping of capacitors

Objectives: At the end of this lesson you shall be able to
- **state the necessity of grouping capacitors and method of connection**
- **state the conditions for connecting capacitors in parallel and in series**
- **explain the values of capacitance and voltage in parallel and series combination**

Necessity of grouping of capacitors: In certain instances, we may not be able to get a required value of capacitance and a required voltage rating. In such instances, to get the required capacitances from the available capacitors and to give only the safe voltage across capacitor, the capacitors have to be grouped in different fashions. Such grouping of capacitors is very essential.

Methods of grouping: There are two methods of grouping.

- Parallel grouping
- Series grouping

Parallel grouping

Conditions for parallel grouping

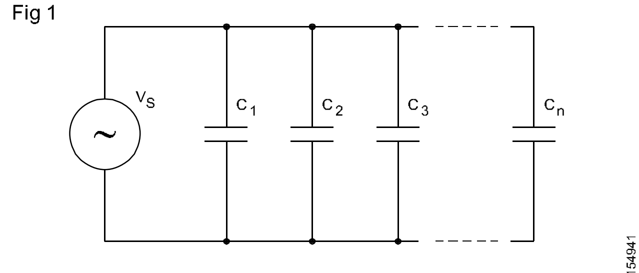
- Voltage rating of capacitors should be higher than the supply voltage Vs.
- Polarity should be maintained in the case of polarised capacitors (electrolytic capacitors).

Necessity of parallel grouping: Capacitors are connected in parallel to achieve a higher capacitance than what is available in one unit.

Connection of parallel grouping: Parallel grouping of capacitors is shown in Fig 1 and is analogous to the connection of resistance in parallel or cells in parallel.

Total capacitance: When capacitors are connected in parallel, the total capacitance is the sum of the individual capacitances, because the effective plate area increases. The calculation of total parallel capacitance is analogous to the calculation of total resistance of a series circuit.

Fig 1



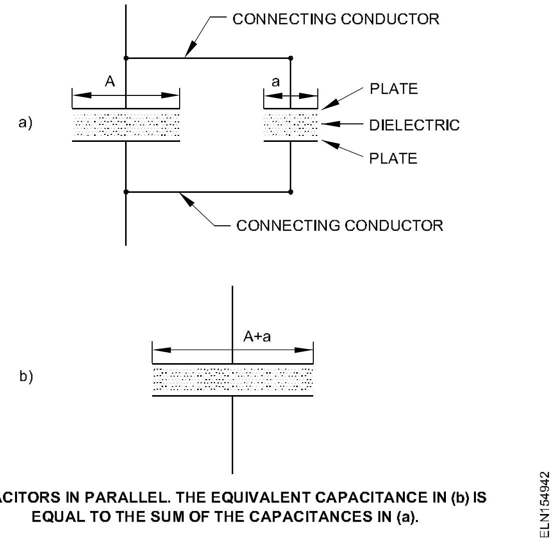
CAPACITORS IN PARALLEL

By comparing Figs 2a and 2b, you can understand that connecting capacitors in parallel effectively increases the plate area.

General formula for parallel capacitance: The total capacitance of parallel capacitors is found by adding the individual capacitances.

$$C_T = C_1 + C_2 + C_3 + \ldots\ldots\ldots\ldots + C_n$$

Fig 2



CAPACITORS IN PARALLEL. THE EQUIVALENT CAPACITANCE IN (b) IS EQUAL TO THE SUM OF THE CAPACITANCES IN (a).

where C_T is the total capacitance,

C_1, C_2, C_3 etc. are the parallel capacitors.

The voltage applied to a parallel group must not exceed the lowest breakdown voltage for all the capacitors in the parallel group.

Example: Suppose three capacitors are connected in parallel, where two have a breakdown voltage of 250 V and one has a breakdown voltage of 200 V, then the maximum voltage that can be applied to the parallel group without damaging any capacitor is 200 volts.

The voltage across each capacitor will be equal to the applied voltage.

Charge stored in parallel grouping: Since the voltage across parallel-grouped capacitors is the same, the larger capacitor stores more charge. If the capacitors are equal in value, they store an equal amount of charge. The charge stored by the capacitors together equals the total charge that was delivered from the source.

$$Q_T = Q_1 + Q_2 + Q_3 + \ldots\ldots + Q_n$$

where Q_T is the total charge

Q_1, Q_2, Q_3.....etc. are the individual charges of the capacitors in parallel.

Using the equation Q = CV,

the total charge $Q_T = C_T V_S$

where V_S is the supply voltage.

Again $C_T V_S = C_1 V_S + C_2 V_S + C_3 V_S$

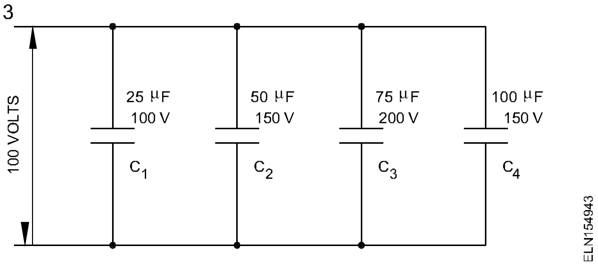
Because all the V_S terms are equal, they can be cancelled.

Therefore, $C_T = C_1 + C_2 + C_3$

Example: Calculate the total capacitance, individual charges and the total charge of the circuit given in Fig 3.

Solution

Fig 3



Total capacitance = C_T

$C_T = C_1 + C_2 + C_3 + C_4$

C_T = 250 micro farads.

Individual charge = Q = CV

$Q_1 = C_1V$

$= 25 \times 100 \times 10^{-6}$

$= 2500 \times 10^{-6}$

$= 2.5 \times 10^{-3}$ coulombs.

$Q_2 = C_2V$

$= 50 \times 100 \times 10^{-6}$

$= 5000 \times 10^{-6}$

$= 5 \times 10^{-3}$ coulombs.

$Q3 = C_3V$

$= 75 \times 100 \times 10^{-6}$

$= 7500 \times 10^{-6}$

$= 7.5 \times 10^{-3}$ coulombs.

$Q_4 = C_4V$

$= 100 \times 100 \times 10^{-6}$

$= 10000 \times 10^{-6}$

$= 10 \times 10^{-3}$ coulombs.

Total charge $= Q_t = Q_1 + Q_2 + Q_3 + Q_4$

$= (2.5\times10^{-3}) + (5\times10^{-3})$

$+(7.5\times10^{-3}) + (10\times10^{-3})$

$= (2.5+5+7.5+10) \times 10^{-3}$

$= 25 \times 10^{-3}$ coulombs.

or $Q_T = C_TV$

$= 250 \times 10^{-6} \times 100$

$= 25 \times 10^{-3}$ coulombs.

Series grouping

Necessity of grouping of capacitors in series: The necessity of grouping capacitors in series is to reduce the total capacitance in the circuit. Another reason is that two or more capacitors in series can withstand a higher potential difference than an individual capacitor can. But, the voltage drop across each capacitor depends upon the individual capacitance. If the capacitances are unequal, you must be careful not to exceed the breakdown voltage of any capacitor.

Conditions for series grouping

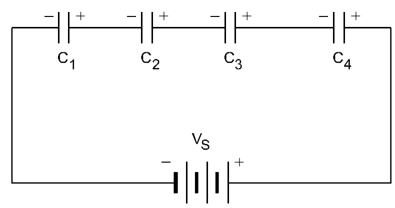
- If different voltage rating capacitors have to be connected in series, take care to see that the voltage drop across each capacitor is less than its voltage rating.
- Polarity should be maintained in the case of polarised capacitors.

Connection in series grouping: Series grouping of capacitors, as shown in Fig 4 is analogous to the connection of resistances in series or cells in series.

Total capacitance: When capacitors are connected in series, the total capacitance is less than the smallest capacitance value, because

- the effective plate separation thickness increases
- and the effective plate area is limited by the smaller plate.

Fig 4

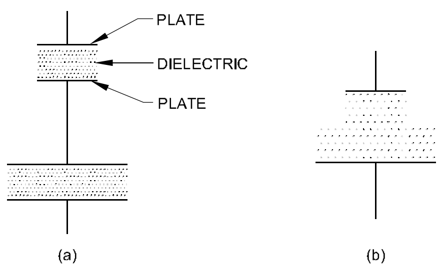


SERIES CONNECTION OF CAPACITORS

The calcualtion of total series capacitance is analogous to the calculation of total resistance of parallel resistors.

By comparing Figs 5a and 5b you can understand that connecting capacitors in series increases the plate separation thickness, and also limits the effective area so as to equal that of the smaller plate capacitor.

Fig 5



THE EQUIVALENT CAPACITANCE IN (b) IS LESS THAN THE LOWER OF THE TWO CAPACITANCES IN (a).

General formula for series capacitance: The total capacitance of the series capacitors can be calculated by using the formula

$$C_T = \frac{1}{\frac{1}{C_1}+\frac{1}{C_2}+\frac{1}{C_3}+.......+\frac{1}{C_n}}$$

or

$$\frac{1}{C_T} = \frac{1}{C_1}+\frac{1}{C_2}+\frac{1}{C_3}+.......+\frac{1}{C_n}$$

If there are two capacitors in series

$$C_T = \frac{C_1 C_2}{C_1 + C_2}$$

If there are three capacitors in series

$$C_T = \frac{C_1 C_2 C_3}{(C_1C_2)+(C_2C_3)+(C_3C_1)}$$

If there are `n' equal capacitors in series

$$C_T = \frac{C}{n}$$

Maximum voltage across each capacitor: In series grouping, the division of the applied voltage among the capacitors depends on the individual capacitance value according to the formula

$$V = \frac{Q}{C}$$

The largest value capacitor will have the smallest voltage because of the reciprocal relationship.

Likewise, the smallest capacitance value will have the largest voltage.

The voltage across any individual capacitor in a series connection can be determined using the following formula.

$$V_X = \frac{C_T}{C_X} \times V_S$$

where V_x - individual voltage of each capacitor

C_x - individual capacitance of each capacitor

V_s - supply voltage.

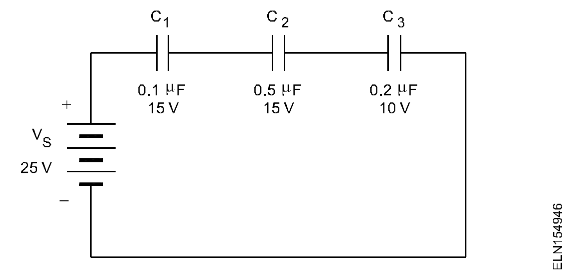
The potential difference does not divide equally if the capacitances are unequal. If the capacitances are unequal you must be careful not to exceed the breakdown voltage of any capacitor.

Example: Find the voltage across each capacitor in Fig 6.

Solution

Total capacitance: C_T

Fig 6



$$\frac{1}{C_T} = \frac{1}{C_1}+\frac{1}{C_2}+\frac{1}{C_3}$$

$$\frac{1}{C_T} = \frac{1}{0.1}+\frac{1}{0.5}+\frac{1}{0.2} \text{ macro farad}$$

$$\frac{1}{C_T} = \frac{10}{1}+\frac{2}{1}+\frac{5}{1}$$

$$\frac{1}{C_T} = \frac{17}{1} \text{ and CT = 0.0588 micro farad}$$

$$V_1 = \frac{C_T}{C_1} \times V_S$$

V_1 = 14.71 V_s

$$V_2 = \frac{C_T}{C_2} \times V_S$$

$$V_2 = \frac{0.0588}{0.5} \times 25$$

V_2 = 2.94 volts

$$V_3 = \frac{C_T}{C_3} \times V_S$$

$$V_3 = \frac{0.0588}{0.2} \times 25$$

V_3 = 7.35 volts

Charge stored in series grouping: Based on previous knowledge, we know that

– the current is the same at all points in a series circuit the current is defined as the rate of flow of charge.

(I = Q/t) or Q = It

The same current is flowing for the same period through the different capacitors of the series circuit. So the charge of each capacitor will be equal (same), and also equal to the total charge Q_T.

$Q_T = Q_1 = Q_2 = Q_3 = ... = Q_n$

But the voltage across each one depends on its capacitance value.

$$\left(V = \frac{Q}{C}\right)$$

By Kirchoff's voltage law, which applies to capacitive as well as to resistive circuits, the sum of the capacitor voltages equals the source voltage.

$V_9 = V_1 + V_2 + V_3 + ... + V_n$

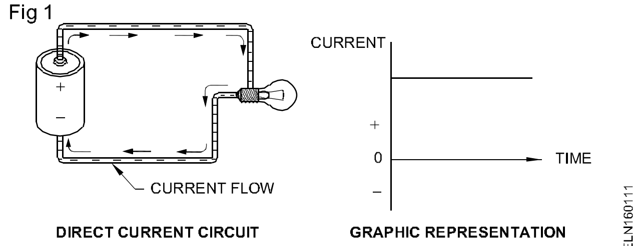
Alternating current - terms & definitions - vector diagrams

Objectives: At the end of this lesson you shall be able to
- **state the features of direct current**
- **list out the advantages of DC over AC**
- **compare the features of DC and AC**
- **explain the generation of alternating current and terms used**
- **state the advantages of AC over DC**

Direct current (DC): Electric current can be defined as the flow of electrons in a circuit. Based on the electron theory, electrons flow from the negative (–) polarity to the positive (+) polarity of a voltage source.

Direct current (DC) is the current that flows only in one direction in a circuit. (Fig 1) The current in this type of circuit is supplied from a DC voltage source. Since the polarity of a DC source remains fixed, the current produced by it flows in one direction only.

Fig 1

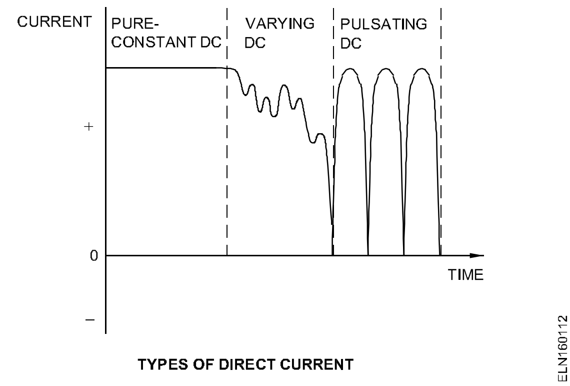


Dry cells are commonly used as a DC voltage source. Both the voltage and polarity of the dry cell are fixed. When connected to a load, the current produced flows in one direction at some steady or constant value.

A direct current flow need not necessarily be constant, but it must travel in the same direction at all times. There are several types of direct current, and all of them depend upon the value of the current in relation to time. (Fig 2)

A constant DC current shows no variation in value over a period of time. Both varying and pulsating DC currents have a changing value when plotted against time. The pulsating DC current variations are uniform, and repeat at regular intervals.

Fig 2



Advantages of DC over AC

1 DC needs only two wires of transmission, while a 3 phase AC may need upto 4 wires.

2 The corona loss associated with DC is negligible while for AC it increases with its frequency.

3 The skin effect is also observed in AC leading to problems in transmission conductor designs.

4 No inductive and capacitive losses.

5 No proximity effect.

Comparison of AC and DC

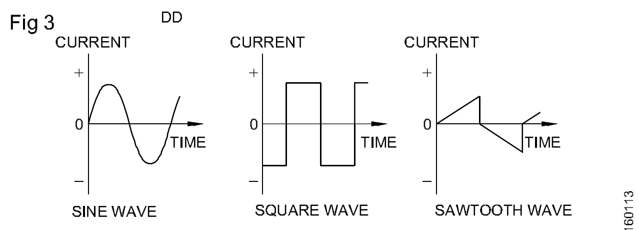
	Alternating current	Direct current
Amount of energy that can be carried	Safe to transfer over longer city distances and can provide more power.	Voltage of DC cannot travel very far until it begins to lose energy.
Cause of the direction of flow of electrons	Rotating magnet along the wire.	Steady magnetism along the wire.
Frequency	The frequency of alternating current is 50Hz or 60Hz depending upon the country.	The frequency of direct current is zero.
Direction	It reverse its direction while flowing in a circuit.	It flows in one direction in the circuit.

	Alternating current	Direct current
Current	It is the current of magnitude varying with time.	It is the current of constant magnitude.
Flow of electrons	Electrons keep switching directions - forward and backward.	Electrons move steadily in one direction or 'forward'.
Obtained from	AC generator and mains.	Cell or battery.
Passive parameters	Impedence.	Resistance only.
Power factor	Lies between 0 to 1.	It is always 1.
Types	Sinusoidal, trapezoidal, triangular, square	Pure and pulsating.

Alternating current (AC): An alternating current (AC) circuit is one in which the direction and amplitude of the current flow change at regular intervals. The current in this type of circuit is supplied from an AC voltage source. The polarity of an AC source changes at regular intervals resulting in a reversal of the circuit current flow.

Alternating current usually changes in both value and direction. The current increases from zero to some maximum value, and then drops back to zero as it flows in one direction. This same pattern is then repeated as it flows in the opposite direction. The wave-form or the exact manner in which the current increases and decreases is determined by the type of AC voltage source used. (Fig 3)

Fig 3



AC WAVE FORMS

Alternating current generation: Alternating current is used wherever a large amount of electrical power is required. Almost all of the electrical energy supplied for domestic and commercial purposes is alternating current.

AC voltage is used because it is much easier and cheaper to generate, and when transmitted over long distances, the power loss is low.

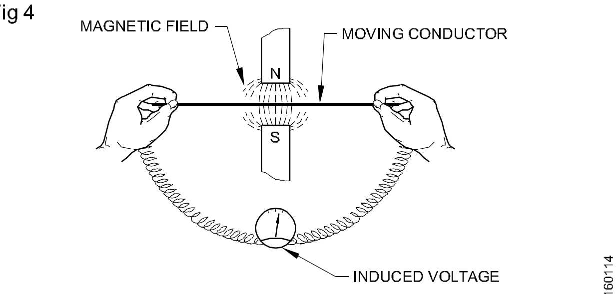
AC equipment is generally more economical to maintain and requires less space per unit of power than the DC equipment.

Alternating current can be generated at higher voltages than DC, with fewer problems of heating and arcing. Some standard values of voltages are 1.1KV, 2.2.KV, 3.3KV for low capacity and 6.6KV (6600V), 11KV(11000V) and 33KV(33000V) for high capacity requirements. The values are increased to 66 000, 110 000, 220 000, 400 000 volts for transmission over long distances. At the load area, the voltage is decreased to working values of 240V and 415V.

The basic method of obtaining AC is by the use of an AC generator. A generator is a machine that uses magnetism to convert mechanical energy into electrical energy. The generator principle, simply stated, is that a voltage is induced in a conductor whenever the conductor is moved through a magnetic field so as to cut the lines of magnetic force.

Fig 4 shows the basic generator principle. A change in a magnetic field around a conductor tends to set electrons in motion. The mere existence of a magnetic field is not enough; there must be some form of change in the field.

Fig 4



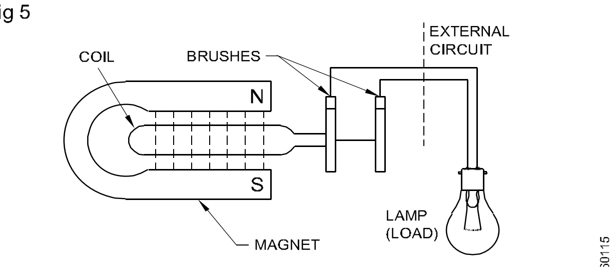
GENERATOR PRINCIPLE

If we move the conductor through the magnetic field, a force is exerted by the magnetic field on each of the free electrons within the conductor. These forces add together and the effect is that voltage is generated or induced into the conductor.

An AC generator produces an AC voltage by causing a loop of wire to turn within a magnetic field. This relative motion between the wire and the magnetic field causes a voltage to be induced between the ends of the wire. This voltage changes in magnitude and polarity as the loop is rotated within the magnetic field. (Fig 5)

The force required to turn the loop can be obtained from various sources. For example, very large AC generators are turned by steam turbines or by the movement of water.

Fig 5



SIMPLIFIED AC GENERATOR

The voltage produced by a single loop generator is too weak to be of much practical value. A practical AC generator has many more turns of wire wound on an armature. The armature is made up of a number of coils wound on an iron core.

The AC voltage induced in the armature coils is connected to a set of slip rings from which the external circuit receives the voltage through a set of brushes. An electromagnet is used to produce a stronger magnetic field.

The sine wave: The shape of the voltage wave-form generated by a coil rotating in a magnetic field is called a sine wave. The generated sine wave voltage varies in both voltage value and polarity.

If the coil is rotated at a constant speed, the number of magnetic lines of force cut per second varies with the position of the coil. When the coil is moving parallel to the magnetic field, it cuts no lines of force.

Therefore, no voltage is generated at this instant. When the coil is moving at right angles to the magnetic field, it cuts the maximum number of lines of force.

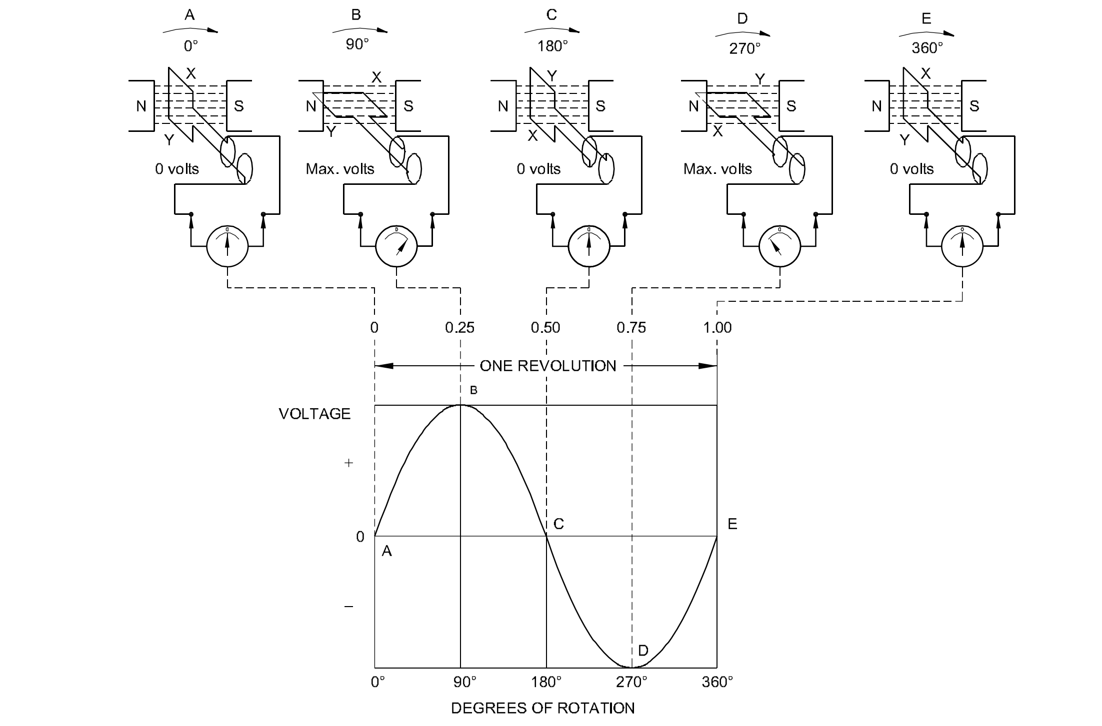
Therefore, maximum or peak voltage is generated at this instant. Between these two points the voltage varies in accordance with the sine of the angle at which the coil cuts the lines of force.

The coil is shown in five specific positions in Fig 6. These are intermediate positions which occur during one complete revolution of the coil position. The graph shows how the voltage increases and decreases in amount during one rotation of the loop.

Note that the direction of the voltage reverses each half-cycle. This is because, for each revolution of the coil, each side must first move down and then up through the field.

The sine wave is the most basic and widely used AC wave-form. The standard AC generator (alternator) produces a voltage of sine wave-form. Some of the important electrical characteristics and terms used when referring to AC sine wave voltage or current are as follows.

Fig 6

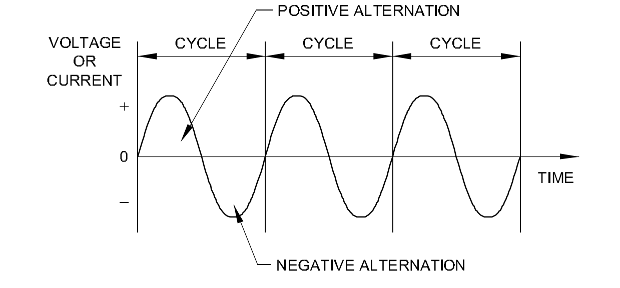


GENERATION OF AN ALTERNATING VOLTAGE: AS THE LOOP ROTATES THROUGH THE MAGNETIC FIELD. THE AMOUNT AND POLARITY OFTHE VOLTAGE CHANGES WITH ANGLE AND DIRECTION OF MOTION.

Cycle: One cycle is one complete wave of alternating voltage or current. During the generation of one cycle of output voltage, there are two changes or alternations in the polarity of the voltage.

These equal but opposite halves of a complete cycle are referred to as alternations. The terms positive and negative are used to distinguish one alternation from the other. (Fig 7)

Fig 7

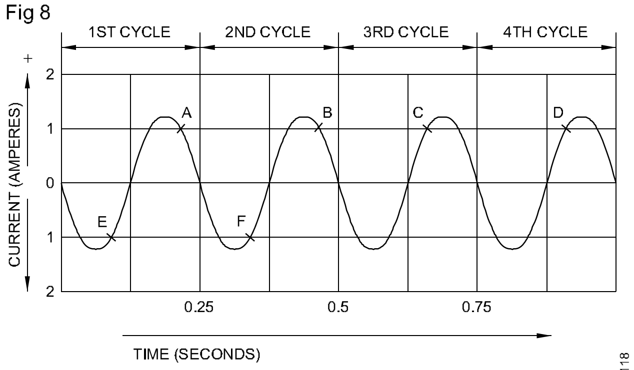


Period: The time required to produce one complete cycle is called the period of the wave-form. In Fig 8, it takes 0.25 seconds to complete one cycle. Therefore, the period (T) of that wave-form is 0.25 seconds.

The period of a sine wave (any symmetrical wave-form) need not necessarily be measured between the zero crossings at the beginning and the end of a cycle. It can be measured from any point in a given cycle to the corressponding point in the next cycle. (See Fig 8-AB, CD or EF.)

Frequency: The frequency of an AC sine wave is the number of cycles produced per second.(Fig 8) The SI unit of frequency is the hertz (Hz). For example, the 240V AC at your home has a frequency of 50 Hz.

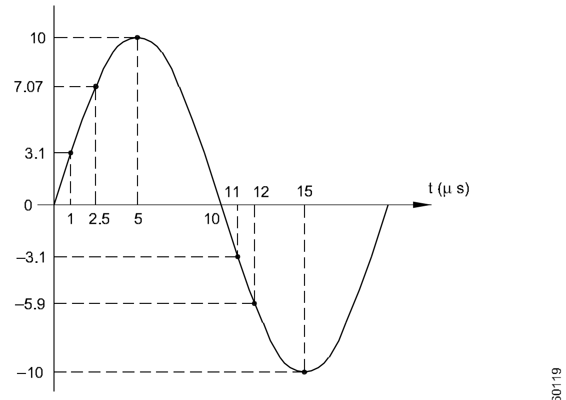
Fig 8



CYCLE, PERIOD, AND FREQUENCY. THE WAVEFORM HAS A PERIOD OF 0.25 SECONDS AND FOUR CYCLES PER SECOND.

Instantaneous value: The value of an alternating quantity at any particular instant is called instantaneous value. The instantaneous values of a sine wave voltage is shown in Fig 9. It is 3.1 volts at 1μs, 7.07 V at 2.5μs, 10V at 5μs, 0V at 10μs, 3.1 volt at 11 μs and so on.

Fig 9

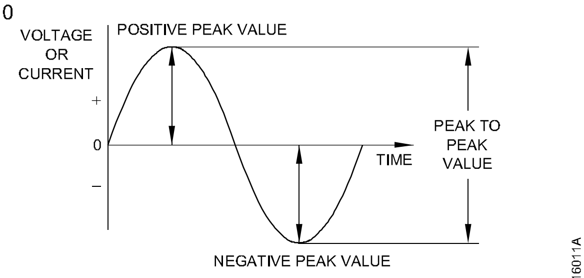


EXAMPLE OF INSANTANEOUS VALUES OF A SINE WAVE VOLTAGE

AC voltage and current values: Since the value of a sine wave of voltage or current continuously changes, one must be specific, while referring to and describing the values of the wave-form . There are several ways of expressing the value of a sine wave.

Peak value or maximum value: Each alternation of the sine wave is made up of a number of instantaneous values. These values are plotted at various heights above and below the horizontal line to form a continuous wave-form. (Fig 10)

Fig 10



PEAK TO PEAK VALUE OF A SINE WAVE

The peak value of a sine wave refers to the maximum voltage or current value. Note that two equal peak values occur during one cycle.

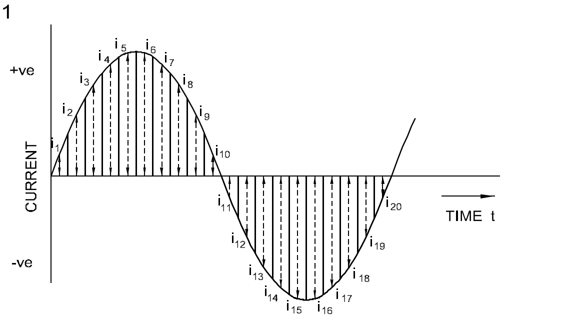
Peak-to-peak value: The peak-to-peak value of a sine wave refers to its total overall value from one peak to the other. (Fig 10) It is equal to two times the peak value.

Effective value: The effective value of an alternating current is that value which will produce the same heating effect as a specific value of a steady direct current. In other words, an alternating current has an effective value of 1 ampere, if it produces heat at the same rate as the heat produced by 1 ampere of direct current, both flowing in the same value of resistance.

Another name for the effective value of an alternating current or voltage is the root mean square (rms) value. This term was derived from a method used to compute the value. The rms is calculated as follows.

The instantaneous values for one cycle are selected for equal periods of time. Each value is squared, and the average of the squares is calculated (values are squared because the heating effect varies as square of the current or voltage). The square root of this is the rms value. (Fig 11)

Fig 11



AVERAGE OF SQUARE OF INSTANTANIOUS VALUES $= \dfrac{i_1^2 + i_2^2 + i_3^2 + \cdots + i_{18}^2 + i_{19}^2 + i_{20}^2}{20}$

By using this method it can be proved that the effective value of a sine wave of current is always equal to 0.707 times its peak value. A simple equation for calculating the effective value of sine wave is:

for voltage, $V = 0.707\ V_m$

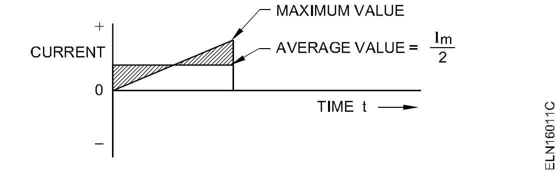
for current, $I = 0.707\ I_m$

where subscript m refers to the maximum value.

When an alternating current or voltage is specified, it is always the effective value that is meant, unless otherwise stated. Standard AC meters indicate effective values only.

Average value: It is sometimes useful to know the average value for one half cycle. If the current is changed at the same rate over the entire half cycle as in Fig 12, the average value would be one half of the maximum value.

Fig 12



However, because the current does not change at the same rate, another method is used. Find the area covered by the curve over the horizontal axis, then divide that area by the base horizontal length. It has been determined that the average value is equal to 0.637 times the maximum value for sine wave-form i.e.

for voltage, $V_{av} = 0.637\ V_m$

for current, $I_{av} = 0.637 I_m$

where subscript av refers to the average value and subscript m refers to the maximum value.

Form factor (k_f): Form factor is defined as the ratio of effective value to average value of half cycle.

For sinusoidal AC

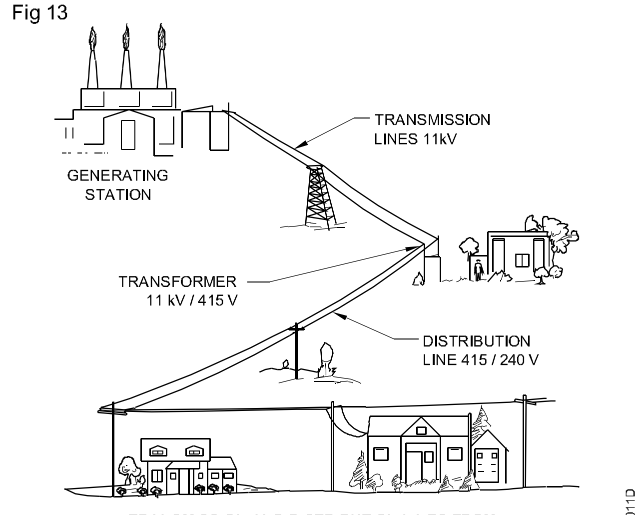
$$k_f = \frac{0.707\ I_m}{0.6637\ I_m} = 1.11$$

where the subscript m refers to the maximum value.

Advantages of AC over DC:

1. AC voltages can be raised or lowered with ease. This makes it ideal for transmission purposes.
2. Large amounts of power can be transmitted at high voltage and low currents with minimum loss.
3. Because the current is low, smaller transmission wires can be used to reduce installation and maintenance costs. (Fig 13)

Fig 13



TRANSMISSION AND DISTRIBUTION LINES FROM GENERATING STATION TO RESIDENCES

DC generators limit their output voltage to 6000V or less. The voltage cannot be raised or lowered through the transformers. Long distance transmission requires heavy cables. AC generators are built with a capacity up to 500000 kilowatts. The DC generators capacity is limited to 10000 kw.

AC motors are less expensive to build, install and maintain than the DC motors. DC motors have one distinct advantage over AC motors: they have better speed control.

- AC is easy to generate than DC.
- It is cheaper to generate AC than DC.
- AC generators take higher efficiency than DC.
- The loss of energy during transmission in negligible for AC in long distance.
- The AC can be easily converted to DC.
- It can easily stepup or stepdown using transformer.
- The value or magnitude of AC can be decreased easily without loss of excess of energy using choke.

Neutral and earth conductors

Objectives: At the end of this lesson you shall be able to
- **describe the purpose of earthing**
- **describe the two types of earthing**
- **differentiate between `neutral' and `earth wire'.**

Earthing: The importance of earthing lies in the fact that it deals with safety. One of the most important, but least understood, considerations in the design of electrical systems is that of earthing (grounding). The word `earthing' comes from the fact that the technique itself involves making a low-resistance connection to the earth or to the ground. The earth can be considered to be a large conductor which is at zero potential.

Purpose of earthing: The purpose of earthing is to provide protection to personnel, equipment and circuits by eliminating the possibility of dangerous or excessive voltage.

There are two distinct considerations in the earthing of an electrical system: earthing of one of the conductors of the wiring system, and earthing of all metal enclosures which contain electrical wires or equipment. The two types of earthing are:

- System earthing
- Equipment earthing.

System earthing: This consists of earthing one of the wires of the electrical system, such as the neutral, to limit the maximum voltage to earth under normal operating conditions.

Equipment earthing: This is a permanent and continuous bonding together (i.e. connecting together) of all non-current carrying metal parts of the electrical equipment to the system earthing electrode.

What is an earthing electrode?: A metal plate, pipe or other conductors electrically connected to the general mass of the earth is known as an earthing electrode. Earth electrodes shall be provided at generating stations, substations and consumer premises (in accordance with the requirements of IS : 3043-1966).

The neutral used in single phase system is to provide return path for load current to the source. Various method of neutral earthing is provided to serve neutral in single phase distribution at substation according to the requirements.

What is an `earth wire'?: A conductor connected to earth and usually situated in proximity to the associated line conductors which is used for equipment earthing is called an earth wire.

The purpose of equipment earthing: By connecting the metal work not intended to carry current to earth, a path is provided for leakage current which can be detected, and, if necessary, interrupted by the following devices.

- Fuses
- Circuit breakers.

Identification: All cores of cables and conductors should be identified at the points of termination, and preferably throughout their length to indicate their function.

Methods of identification may include coloured insulation applied to conductors in manufacture or the application of coloured tape, sleeves or discs (Fig 1). The colours used must be of those specified for the function in Table 52A of IEE wiring regulations.

Fig 1

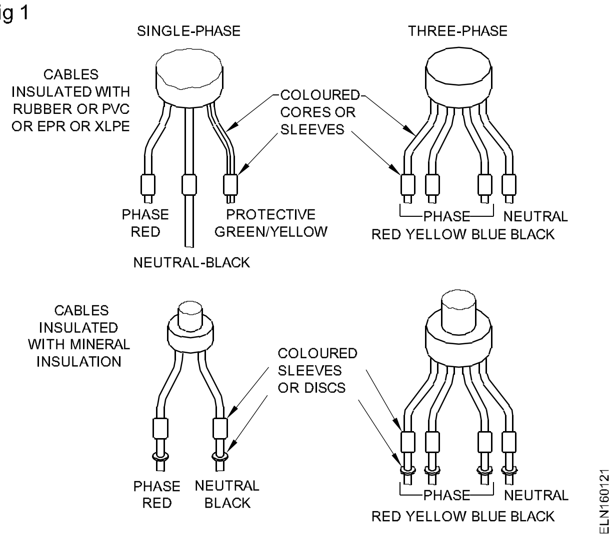


Table 52A of IEE regulations

Colour identification of cores of non-flexible cables and bare conductors for fixed wiring	
Function	**Colour identification**
Protective (including earthing)conductor	Green-and-yellow
Phase of ac. single- or three-phase circuit	Red(or yellow or blue*)
Neutral of ac single- or three-phase circuit	Black
Phase R of 3-phase ac circuit	Red
Phase Y of 3-phase ac circuit	Yellow
Phase B of 3-phase ac circuit	Blue
Positive of dc 2-wire circuit	Red
Negative of dc 2-wire circuit	Black
Outer (positive or negative) of dc 2-wire circuit derived from 3-wire system	Red
Positive of 3-wire dc circuit	Red
Middle wire of 3-wire dc circuit	Black
Negative of 3-wire dc circuit	Blue
As alternatives to the use of red, if desired, in large installations, on the supply side of the final distribution board.	

Flexible cables and flexible cords: Every core of a flexible cable or flexible cord shall be identifiable throughout its length as appropriate to its function, as indicated in Table 52B of IEE Regulations.

Flexible cables or flexible cords having the following core colours shall not be used; green alone, yellow alone, or any bi-colour other than the colour combination green and yellow. When armoured PVC insulated auxiliary cables or paper insulated cables are used an alternative identification system may be used using numbers, where 1, 2 & 3 signify phase conductors and O the neutral conductor. The number 4 is used to identify any special purpose conductor (Fig 2).

Fig 2

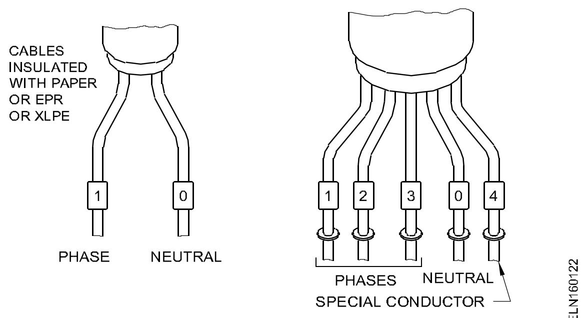


Table 52B of IEE regulations

Colour identification of cores of flexible cables and flexible cords		
No. of cores	**Function of core**	**Colour(s) of core**
1	Phase Neutral Protective (combination)	Brown Blue Green and yellow
2	Phase Neutral	Brown Blue
3	Phase Neutral Protective (combination)	Brown Blue Green and yellow
4 or 5	Phase Neutral Protective	Brown or black Blue Green and yellow (combination)

The colour combination of green and yellow is to be used exclusively for the identification of protective conductors.

Where electrical conduits need to be easily identified from the pipelines of other services such as gas, oil, water, steam, etc. they should be painted orange.

Use of vector diagram

Objectives: At the end of this lesson you shall be able to
- **distinguish between scalar and vector quantity**
- **illustrate the method of drawing vector diagram for two vectors.**

Definition of scalar and vector quantity and phasor

Scalar quantity:A scalar quantity is a quantity which is determined by the magnitude alone, for example energy, volume, temperature etc.

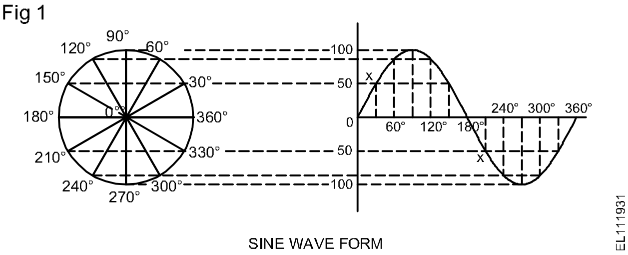
Vector quantity: A vector quantity is a quantity which is represented by straight line with an arrow head to represent the magnitude and direction of it. For example, - force, velocity, weight.

Phasor: Phasor is a vector that is rotating at a constant angular velocity. A straight line with an arrow head is used to represent graphically the magnitude and phase of a sinusoidal alternating quantity (i.e. current, voltage and power) is called phasor.

Plotting a curve of alternating voltage: If the maximum voltage of the alternator is known, the generated voltage can be plotted to form a curve. Draw a circle with the radius representing the maximum value of voltage.

Any convenient scale may be used. Divide the circle into equal parts. (Fig 1) Draw a horizontal line to scale, along which one voltage cycle will be plotted. Divide the line into the same number of equal parts as in the circle. Draw horizontal and vertical lines, as illustrated by the dashed

Fig 1



SINE WAVE FORM

lines in Fig 1. The intersection of the lines represents the value of voltage at that instant. For example, a horizontal and a vertical line intersect at point X.

Using the same scale as used for the radius of the circle, the vlaue of voltage can be measured. This value is the emf produced when the coil is cutting the lines of force at a 30-degree angle.

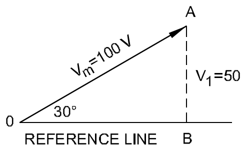
Use of vector diagrams: The change which occurs in the value of an alternating voltage and/or current during a cycle can also be shown by using vector diagrams.

A vector is a line segment that has a define length and direction. A vector diagram is two or more vectors joined together to convey information. Vector diagrams drawn to scale can be used to determine instantaneous values of current and/or voltage.

Scalar quantity	Vector quantity
1. Scalar quantity can be presented by magnitude only, for example - energy, volume etc.	Vector quantity must represent magnitude and direction also, for example - force velocity etc.
2. Addition and substraction of scalar quantities can be done algebraically	Addition and subtraction of vector quantities cannot be done algebracially but by vector summation.

Fig 1 can be analyzed by means of vector diagrams according to the following procedure. Draw a horizontal line as a reference line (Fig 2). Starting at point O and 30 degrees from the reference line, draw OA to scale to represent a maximum voltage (Vm) of 100 volts. From the end of vector OA, draw a vertical dashed line is labelled AB and represents the instantaneous value of voltage (V_i) when the coil is cutting the lines of force at a 30 degree angle. Measure vector AB. It should scale to 50 volts.

Fig 2

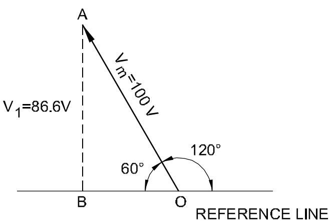


VECTOR DIAGRAM DRAWN TO SCALE TO DETERMINE THE VOLTAGE WHEN THE COIL IS MOVING AT A 30° ANGLE TO THE LINES OF FORCE

ELN160132

The same procedure can be followed for any degree of rotation. The vector diagram shown in Fig 3 is used to determine the value of voltage when the coil has rotated 120 degrees.

Fig 3

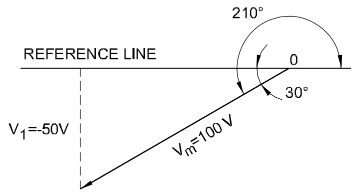


VECTOR DIAGRAM DRAWN TO SCALE. THE COIL HAS ROTATED 120° AND IS CUTTING THE FLUX AT 60°

ELN160133

Although the coil has rotated 120 degrees, the angle it is making with the lines of force is only 60 degrees. It is this angle that determines the value of the instantaneous voltage. For example, if the coil rotates 210 degrees, it cuts the lines of force at angle of 30 degrees. (Fig 4)

Fig 4



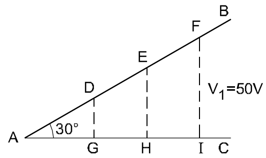
VECTOR DIAGRAM DRAWIN TO SCALE. THE COIL HAS ROTATED 210° AND IS CUTTING THE FLUX AT 30°. THE EMF HAS REVERSED DIRECTION, INDICATED BY THE -VE SIGN.

ELN160134

Referring back to Fig 1, it can be seen that each division of the circle can represent vector OA. Vector AB can be represented by points along the voltage curve. The angle between the horizontal diameter of the circle and the radius v_m is the angle at which the coil is cutting the flux. Although vector diagrams are seldom used alone, they are a simple way of presenting a visual illustration of a problem. Vector diagrams are usually used with trigonometric functions.

Many electrical problems are solved through the use of trigonometry. The vector diagrams used with trigonometric functions are generally in the form of triangles and/or parallelograms.(Fig 5 & 6)

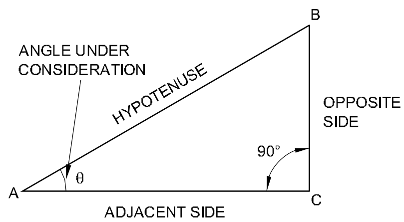
Fig 5



VECTOR DIAGRAM FORMING THREE 30° - 60° - 90° TRIANGLES

ELN160135

Fig 6



ELN160136

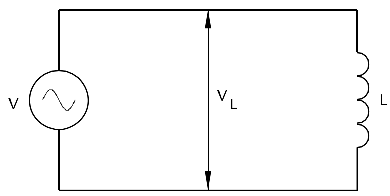
AC simple circuit - with inductance only

Objectives: At the end of this lesson you shall be able to
- **state phase relation between V and I in a pure inductive circuit**
- **state about inductive reactance**
- **state power in pure inductive circuit**
- **define power factor.**

Circuit with pure inductance only: Inductance affects the operation of pure DC circuits only at the instant they are opened and the instant they are closed. In an AC circuit, the current is always changing, and the inductance is always opposing the change. The inductance, therefore, has a constant effect on circuit operation.

A circuit with pure inductance alone can never be formed, because the source, the connecting wires, and the inductor all have some resistance. However, if these resistances are very small and have a much smaller effect on the circuit current than does the inductance, the circuit can be considered as containing only inductance. (Fig 1)

Fig 1



CIRCUIT DIAGRAM

ELN160141

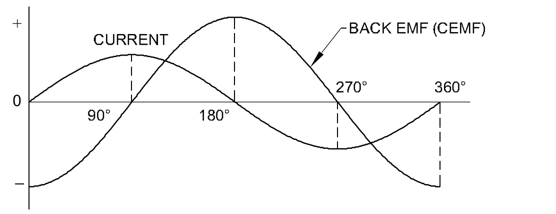
In any AC circuit that contains only inductance, there are three varying quantities. These are (1) the applied voltage, (2) the induced back emf, and (3) the circuit current.

Phase relationship between voltage and current: The phase relationships in an inductance can most easily be understood by considering first the current and the back emf. You know two things about the current and the back emf. One is that the counter emf is maximum when the rate of change of current is the greatest, and is zero when the current is not changing.

The second relationship is that the direction of the cemf is such that it always opposes the current change.

The wave-form in Fig 2 shows one cycle of AC current. The rate of change is greatest where the slope of the wave-form is greatest. You can see that this occurs at those points where the wave-form passes through zero; or at 0,180, and 360 degrees. This means that the highest cemf is generated at 0,180 and 360 degrees, as shown by the wave-forms in Fig 2. Around 90 and 270 degrees, the change is very little; as a matter of fact, at exactly 90 and 270 degrees, where the current change is from rising to falling, the current is momentarily steady. Therefore, the flux lines do not change at those points, and no cemf is induced.

Fig 2



WAVE-FORM OF CURRENT AND BACK EMF

What should be the amount and direction of counter emf (back emf) when the current is passing through zero and in the positive direction?

Since at 0 degrees the current is passing through zero in a positive direction, the cemf must be maximum in the negative direction, in as much as it always opposes the increase in current. Similarly, when the current begins to decrease at 90 degrees, the cemf must be increasing in the positive direction to aid the current flow.

As shown, therefore, the cemf follows Lenz's Law by lagging the current by 90 degrees. You know that the applied voltage is 180 degrees out of phase with the cemf, and so the applied voltage must lead the current by 90 degrees. This is shown in the wave-form in Fig 3. The relationships between the three quantities (current, cemf, and applied voltage) is shown in the wave-forms in Fig 4. We know they are not in phase as in the case of resistive circuits.

Fig 3

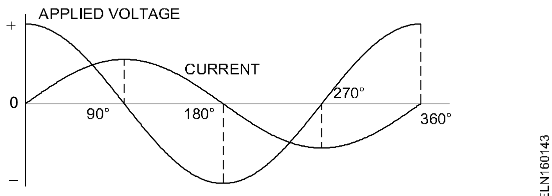
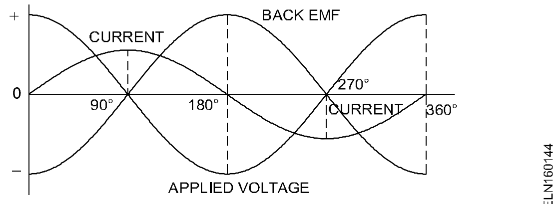


Fig 4



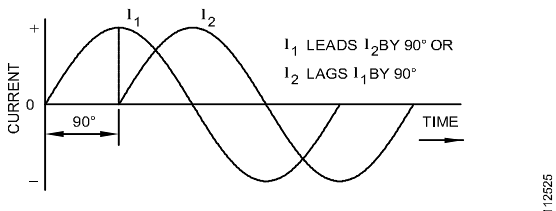
In an inductance: (1) the applied voltage leads the current by 90°; (2) the back emf lags the current by 90° and (3) the applied voltage and the back emf are 180° out of phase.

This is known as 'phase difference'.

Phase difference: If two alternating quantities attain maximum value in the same direction after passing through zero value at different times, they are said to have a phase difference.

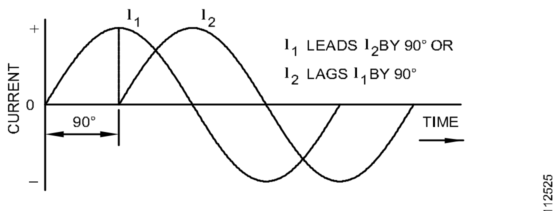
Phase difference can be expressed in fractions of a cycle. For more accuracy, phase difference is given in degrees. The terms `lead' and `lag' are used to describe the relative positions in time of two voltages or currents that are not in phase. The one that is ahead in time is said to lead, while the one behind lags. (Figs 5 and 6)

Fig 5



PHASE DIFFERENCE

Fig 5



PHASE DIFFERENCE

When maximum and minimum points of one voltage or current occur before the corresponding points of another voltage or current, the two are out of phase. When such a phase difference exists, one of the voltages or currents leads, and the other lags.

Phase difference can also be illustrated by a vector diagram. While representing phase difference, the reference quantity is shown on the +ve side of the x axis.(Figs 7 & 8)

Fig 7

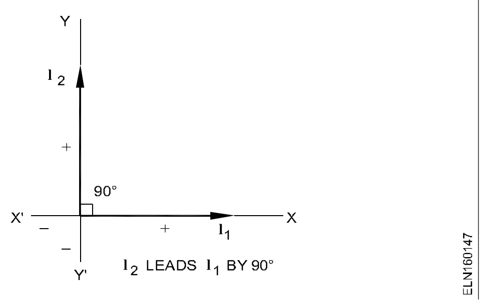
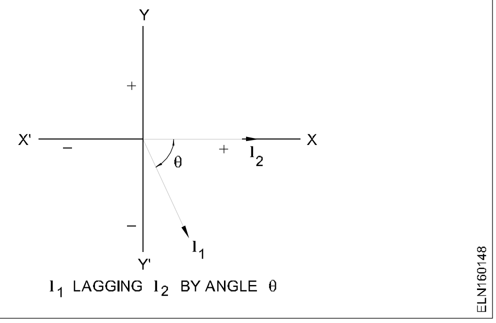


Fig 8



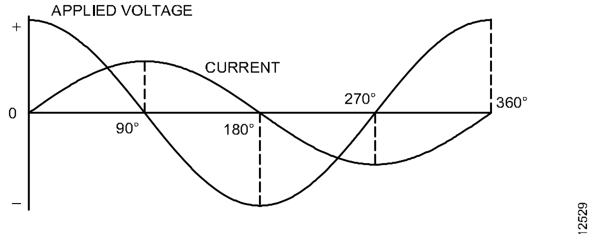
I_1 LAGGING I_2 BY ANGLE θ

The quantity of lead is shown by an angle in an anticlockwise and a lagging quantity is shown by a clockwise angle.

Phase relationship between current and voltage in a circuit with inductance only

When AC voltage is applied to an inductive circuit, the current lags behind the applied voltage by a quarter cycle or by 90°. (Fig 9)

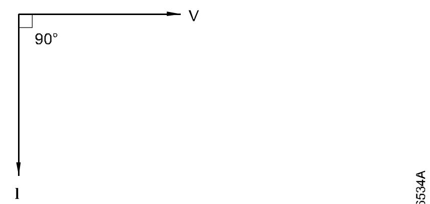
Fig 9



CURRENT LAGS VOLTAGE BY 90°

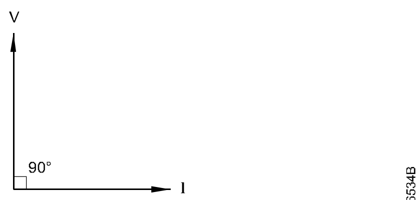
In a purely inductive circuit, the current lags behind the applied voltage by 90°. This is illustrated in the Fig 9 as wave-form. This also can be stated as voltage leads current. The vector diagram for both expressions is given in Figs 10 and 11.

Fig 10



I LAGS BEHIND V BY 90°

Fig 11



V LEADS I BY 90°

Inductive reactance: The cemf acts just like a resistance to limit the current flow. But cemf is discussed in terms of volts, so it cannot be used in Ohm's Law to compute the current. However, the effect of cemf can be given in terms of ohms. This effect is called inductive reactance, and is abbreviated as X_L. Since the cemf generated by an inductor is determined by the inductance (L) of the inductor, and the frequency (f) of the current, the inductive reactance must also depend on these things. The inductive reactance can be calculated by the equation

$$X_L = 2\pi fL$$

where X_L is the inductive reactance in ohms; f is the frequency of the current in cycles per second; and L is the inductance in henrys. The quantity 2π together actually represents the rate of change of the current, usually denoted by the Greek letter `ω' (Omega).

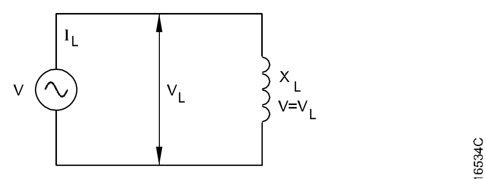
Since 2π = 2(3.14) = 6.28, the Eqn. becomes similarly

$$L = \frac{X_L}{6.28\,f}$$

$$f = \frac{X_L}{6.28\,L}$$

In a circuit containing only inductance, Ohm's Law can be used to find the current and voltage by substituting X_L for R. (Fig 12)

Fig 12



CIRCUIT WITH ONLY X_L

$$I_L = \frac{V_L}{X_L}$$

$$X_L = \frac{V_L}{I_L}$$

$$V_L = I_L X_L$$

where I_L = current through the inductance,in amperes

V_L = voltage across the inductance, in volts

X_L = inductive reactance in ohms

Example: An AC circuit consists of a 20-mH coil operating at a frequency of 1000 kHz. What is the inductive reactance of the coil?

X_L = 6.28fL

= $6.28(1000 \times 10^3)(20 \times 10^{-3})$

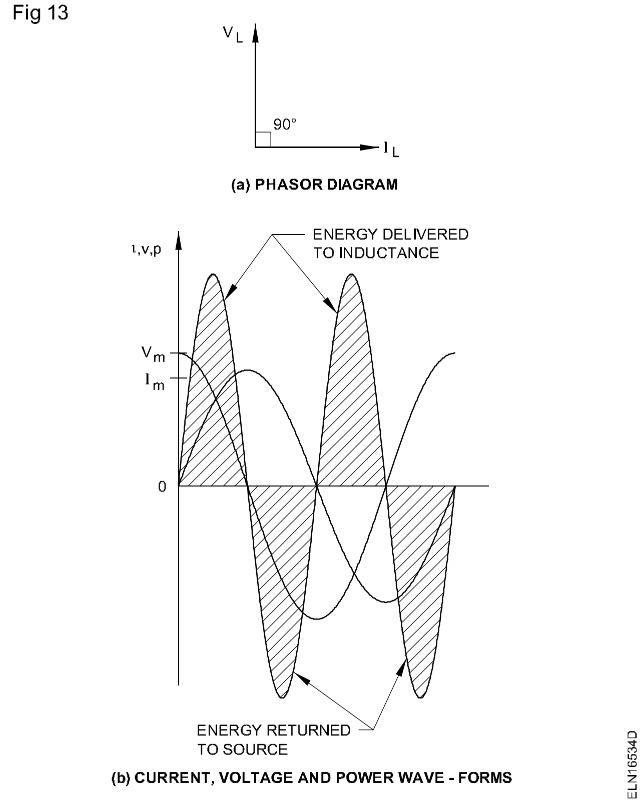
= 12.56×10^4 = 125600 ohms.

Example: What must the inductance of a coil be so that it has a reactance of 628 ohms at a frequency of 40KHz?

$$L = \frac{X_L}{6.28f} = \frac{628}{6.28(40 \times 10^3)} = 2.5 \times 10^{-3} = 2.5\text{ mH}$$

Power in pure inductance: If an AC circuit contains only inductance, the voltage and current are 90° out of phase, as shown by the phasor and wave diagrams in Fig 13. The result of multiplying the V and I wave-forms is a power curve that again has a frequency twice that of the source is as shown in Fig 13. However, over a complete cycle of input voltage, the power curve has an average value of zero. That is, the power curve shows an equal alternation of positive and negative power above and below the zero time axis.

Fig 13



(b) CURRENT, VOLTAGE AND POWER WAVE - FORMS

Positive and negative power: (Fig 13) The shaded portion of the power curve above the zero axis represents energy being delivered to the inductor (or load) from the source. This positive power actually represents a storage of energy in the magnetic field of the inductance.

The shaded portion of the power curve below the zero axis represents energy returned to the source from the inductor. This negative power indicates that a flow of energy is taking place in the opposite direction(from load to source) when the coil's magnetic field collapses.

The average true power, P, is zero, in a pure inductance.

In AC circuits,

Power = VI Cos ϕ watts

where ϕ is the phase angle between voltage and current.

As the phase angle between V & I in pure inductive circuit is 90°, Cos 90° is zero.

Therefore P = V x I x (zero) = zero.

The term Cos ϕ is known as `power factor'.

Reactive power: However, the source must be capable of delivering power for a quarter of a cycle, even though this power will be returned during the next quartercycle. This stored or transferred power is called reactive power, $P_{q.}$

In the case of a purely inductive circuit, the reactive power is given by

$P_q = V_L I_L$ volt-amperes reactive (var)

where P_q is the reactive power in volt-amperes reactive, var

V_L is the voltage across the inductance in volts

I_L is the current through the inductance in ampere.

Since $V_L = I_L X_L$

then $P_q = I_L^2 X_L$ var.

where X_L is the inductive reactance in ohms. Note how the equations for relative power are similar to those for true power with X_L used in place of R. But we must remember to use var for the unit of reactive power, not watts.

Example: Calculate the reactive power of a circuit that has an inductance of 4 H when it draws 1.4 amps from a 50Hz supply.

Solution

X_L = 2πfL = 2π x 50Hz x 4H = 1256 ohms

$P_q = I_L^2 X_L = (1.4A)^2$ x 1256 ohms = 2462 vars

= 2.462 kvar

Note that 1 kvar = 1 kilo-var = 1000 vars.

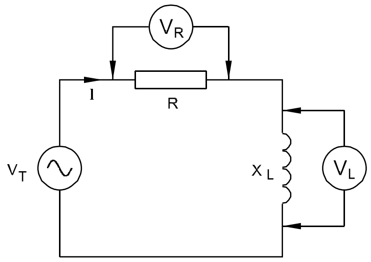
A.C. circuit with R & L in series

Objectives: At the end of this lesson you shall be able to
- **state the voltage and current relationship**
- **determine impedance of a series circuit with RL in series**
- **calculate power in a series circuit (with RL in series)**
- **calculate the power factor in RL series circuit.**

When resistance and inductance are connected in series, or in the case of a coil with resistance, the rms current I_L is limited by both X_L, and R however the current I is the same in X_L and R since they are in series, the voltage drop across R is V_R = IR and the voltage drop across X_L is V_L = IX_L. The current I through X_L must lag V_L by 90° because this is the phase angle between current through an inductance and its self-induced voltage. The current I through R,and its IR voltage drop,are in phase and so the phase angle is 0°.

Now let us apply the principle of phasor representation to a series circuit containing pure resistance and pure inductance. (Fig 1)

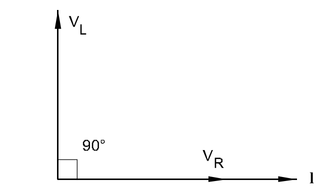
Fig 1



CIRCUIT WITH R & L IN SERIES

Since we are considering a series circuit, it is convenient if we draw the current phasor in the horizontal reference position because it is `common' to both the resistor and inductor. Superimposed upon this phasor is the voltage phasor across the resistor V_R. This is because the current and voltage are always in phase with each other in a pure resistor. (Fig 2)

Fig 2



VECTOR DIAGRAM OF R & L SERIES CIRCUIT

Similarly, the voltage phasor across the inductor V_L is drawn 90° ahead of the current I in other words leading the current phasor. This is because, as we know, the current always lags the inductor voltage by 90° in a pure inductance.

However, these two voltages are 90° out of phase with each other. This means that the total voltage across the series combination cannot be obtained simply by adding V_R to V_L algebraically. We must take into account the angle between them.

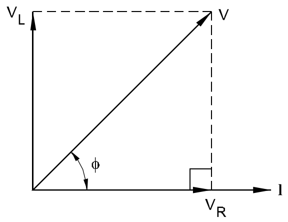
The applied voltage V is the (phasor) sum of V_R and V_L with the phase angle added.

This phasor addition can be carried out simply by constructing a parallelogram (a square in this case) and drawing the diagonal. This is shown in Fig 3. Clearly, the phasor sum V is less than the algebraic sum of V_L and V_R. Also, because V is the hypotenuse of a right-angled triangle, V is given by

$$V^2 = V_R^2 + V_L^2$$

Impedance of a series RL circuit: The total opposition to current in a series, RL circuit, is called the impedance Z. It is the ratio of the total applied voltage V to the current I. Impedance is measured in ohms as are resistance and inductive reactance. But, as shown by the following, impedance is the vector sum of resistance and reactance.

Fig 3

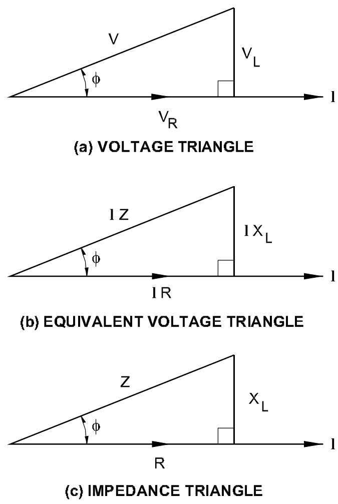


PHASOR DIAGRAM OF R & L SERIES CIRCUIT

Consider the `voltage triangle' for a series, RL circuit, as shown in Fig 4a. This is similar to the phasor diagram in Fig 3 with V_L transferred to make a closed triangle.

Given $V^2 = V_R^2 + V_L^2$ and $V_R = IR$ and $V_L = IX_L$

Fig 4



then $V = \sqrt{(IR)^2 + (IX_L)^2}$

$$= \sqrt{I^2R^2 + (I^2X_L)^2}$$

$$= \sqrt{I^2(R^2 + X_L{}^2)}$$

$$= I\sqrt{R^2 + X_L{}^2} \text{ and } \frac{V}{I} = \sqrt{R^2 + X_L{}^2}$$

But $\frac{V}{I}$ is the impedance Z.

Therefore, $Z = \sqrt{R^2 + X_L{}^2}$ ohms

where Z is the impedance in ohms

R is the resistance in ohms

X_L is the inductive reactance in ohms

and $I = \frac{V}{Z}$ amperes (A).

We can also see from Fig 4b & 4c that, if the impedance and phase angle are known, we can obtain the resistance and inductive reactance.

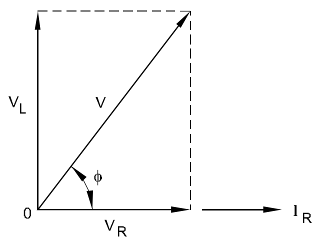
$R = Z \cos \phi$

$X_L = Z \sin \phi$

where ϕ is the angle between Z and R.

Power in a series RL circuit: We have seen that inductance is always accompanied by resistance. Thus coils in motors, generators, relay coils etc. contain both resistance and inductance. When an AC voltage is applied, the current I is neither in phase nor 90° out of phase with the applied voltage V as shown in Fig 5.

Fig 5



CURRENT REFERENCE VECTOR

ELN165355

This means, unlike pure resistance and pure reactance, the product of the voltmeter and ammeter readings in Fig 6 is a combination of the true and (quadrature) reactive power. We call the product of total V and total I apparent power Ps. Since it is neither true power in watts nor reactive power in vars, we use a new unit - the volt ampere, VA to measure the apparent power.

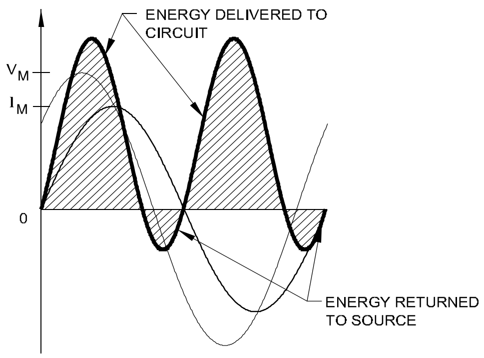
P = V x I volt-amperes (VA)

where P is the apparent power in volt amperes VA,

V is the total applied voltage in volts V,

I is the total circuit current in amperes A.

Fig 6



CURRENT, VOLTAGE, AND POWER WAVE - FORMS

ELN165356

Power triangle: In AC circuit we had identified three types of power.

- True power in watts as in circuit with resistors only.
- Reactive power in vars as in the case of pure inductive or pure capacitive circuit.
- Apparent power in VA as in the case of circuits with R and L or R & C. All the three are interrelated.

We know in a series RL circuit

$$V = \sqrt{V_R^2 + V_L^2}$$

Therefore $V \times I = \sqrt{(V_R \times I)^2 + (V_L \times I)^2}$

But V x I = apparent power in VA

V_R x I = true power in watts

V_L x I = reactive power in vars

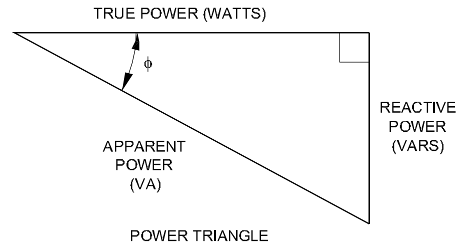
Therefore,

(apparent power)^2 = (true power)^2 + (reactive power)^2

or $VA = \sqrt{(W^2) + (VAR^2)}$

This relation can be represented in a power triangle, as in Fig 7.

Fig 7



POWER TRIANGLE RELATIONS FOR A SERIES RL CIRCUIT

ELN165357

Fig 7 shows the apparent power as represented by the hypotenuse of the right angled triangle. The true power is the product of the current and voltage in phase with each other, and is drawn horizontally. The out-of-phase product of V_L and I gives the reactive power, and is drawn vertically downward. This is a convention used to show a lagging, inductive, reactive power corresponding to a lagging current. (A capacitive reactive power is drawn vertically upward, corresponding to a leading current.)

We can also have other relations.

$W = VA \cos \phi$

$VAR = VA \sin \phi$

Power factor: The ratio of the true power delivered to an AC circuit compared to the apparent power that the source must supply is called the power factor of the load.

If we examine any power triangle, as in Fig 7, we see that the ratio of the true power to the apparent power is cosine of the angle Ø.

$$\text{Power factor} = \frac{W}{VA} = \cos \phi$$

As $W = V_R \times I$ and

$VA = V \times I$ also

$V_R = I \times R$

$= I \times Z$

power factor must also be equal to $\frac{V_R}{V}$ and to $\frac{R}{Z}$

Power factor (PF) $= \frac{W}{VA} = \frac{V_R}{V} = \frac{R}{Z} \cos\phi$

What should be the power factor for a circuit containing pure resistance only?. As the phase angle Ø between current and voltages is $\phi = 0$.

Cos ϕ = 1 and PF = 1.

Similarly the power factor for circuit containing pure inductance or pure capacitance only is zero as

Cos ϕ = Cos 90° = zero.

Example: An inductive coil with a resistance of 10 ohms and inductance of 0.05 henry is connected across 240 volt 50 cycle AC mains.

Calculate

i) current taken by the coil

ii) power factor of the circuit

iii) power consumed, and answer

iv) whether the current in the circuit is lagging or leading.

Solution

X_L = $2\pi fL$ = 2 x 3.142 x 50 x 0.05 = 15.7 ohms

$$Z = \sqrt{R^2 + X_L{}^2} = \sqrt{(10)^2 + (15.7)^2}$$

$$= \sqrt{346.49} = 18.6 \text{ ohms}$$

i I = (240/18.6) = 12.9 Amps

ii Power factor $= \frac{R}{Z} = \frac{10}{18.6} = 0.537$

iii Power consumed = $I^2R = (12.9)^2 \times 10$

= 166.72 x 10

= 1667 W.

iv The current is lagging in the circuit.

Example: An inductive circuit has a resistance of 2 ohms in series with an inductance of 0.015 henry. Find (i) current and (ii) power factor when connected across 200 volt 50 cycles per second supply mains.

Solution

X_L = $2\pi fL$ = 2x3.142x50x0.015 = 4.71 ohms

$$Z = \sqrt{R^2 + X_L{}^2} = \sqrt{(2)^2 + (4.71)^2}$$

$$= \sqrt{4 + 17.39} = \sqrt{26.19}$$

i. $I = \frac{200}{5.11}$ = 39.13 amps

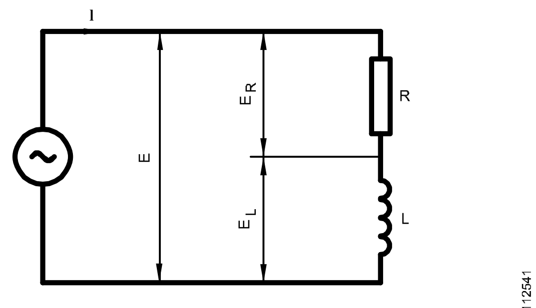
ii. Power factor $= \frac{R}{Z} = \frac{2}{5.11} = 0.39$

Phase relation between V & I in R - L series circuit

Objectives: At the end of this lesson you shall be able to
- **explain how to add and subtract vector quantities**
- **represent voltage of R-L circuit by vector .**

Consider circuit diagram as shown in Fig 1.

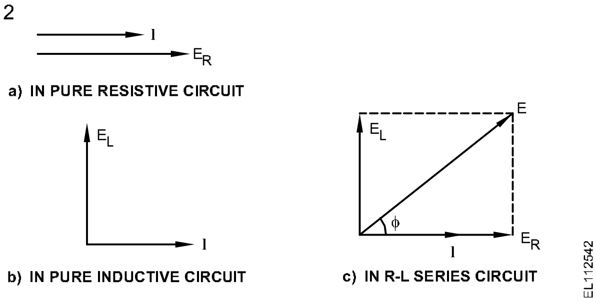
Fig 1



R-L SERIES CIRCUIT

When an alternating voltage is applied to a pure inductor, the resultant alternating current through the inductor is lagging by 90° with the supply voltage due to presence of counter emf. (Fig 2b). As current I is shown first Fig 2(a) the voltage across resistor 'R' i.e. this in phase with current. (Fig 2a & 3b)

Fig 2



The voltage across inductor (L) E_L is 90° leading with current I. (Figs 2b and 3c). Hence the applied voltage E is obviously the resultant of E_R & E_L. It is obtained by simply summing up the instantaneous values of E_R and E_L. (Figs 2c & 3d)

Addition and subtraction of vectors by parallelogram method

Addition of two vectors: Two vectors OA & OB are acting on the same point '0' at an angle a as shown in

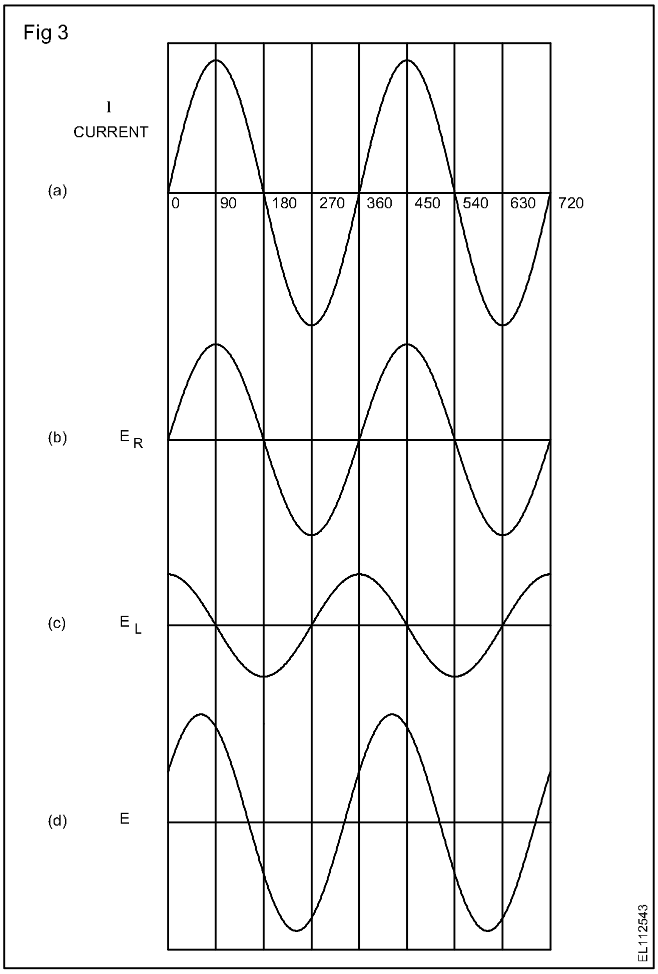
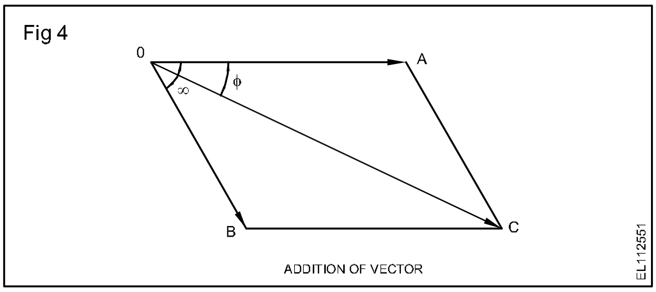


Fig 4. Both vectors can be added by the parallelogram method. On completion of parallelogram OACB, draw the diagonal 'OC' from point 0.

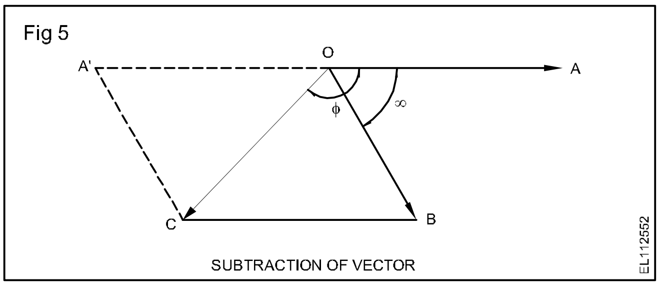


Now 'OC' represents the resultant vector of both vectors.

Subtraction of two vectors: If vector OA is to be subtracted from vector OB (as shown in Fig 5) $(\overline{OB}-\overline{OA})$ then OA is produced backward so that OA' = OA complete parallelogram OBCA'. The diagonal OC drawn from point '0'' of the parallelogram represents the resultant of OA & OB.

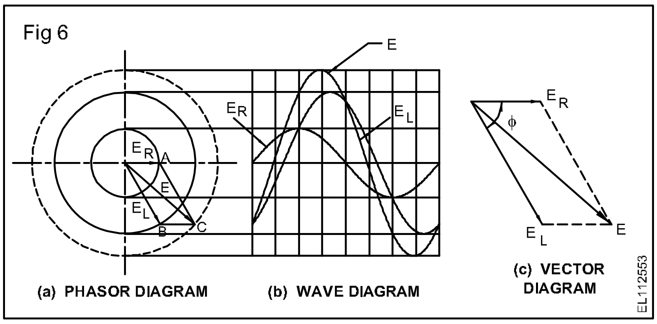
$$\overline{OC}=(\overline{OB}-\overline{OA})$$

Addition of voltage across resistance and inductance connected in series by vector method to compare with supply voltage.



Phasor is representation of sinusoidal quantities. Hence two electrical quantities can be represented by a phase diagram as shown in Fig 6a and wave form a shown by Fig 6b.

Two electrical quantities both (E_R & E_L) voltage can be added by the vector diagram methods as shown in Fig 6c.

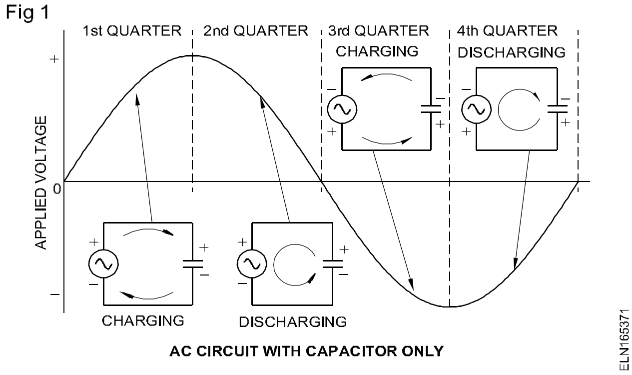


AC Simple circuit - with capacitor only

Objectives: At the end of this lesson you shall be able to
- **explain AC circuit with capacitor only**
- **state phase relation between V and I**
- **state power in pure capacitance only.**

Circuit with capacitance only: In an AC circuit, the applied voltage as well as the current it produces, periodically changes direction. (Fig 1) A capacitor in an AC circuit is first charged by the voltage being applied in one direction. Then, when the applied voltage starts to decrease, less current flows, but the capacitor is still being charged in the same direction. As a result, as the applied voltage continues to drop, the voltage developed across the capacitor becomes greater.

Fig 1



AC CIRCUIT WITH CAPACITOR ONLY

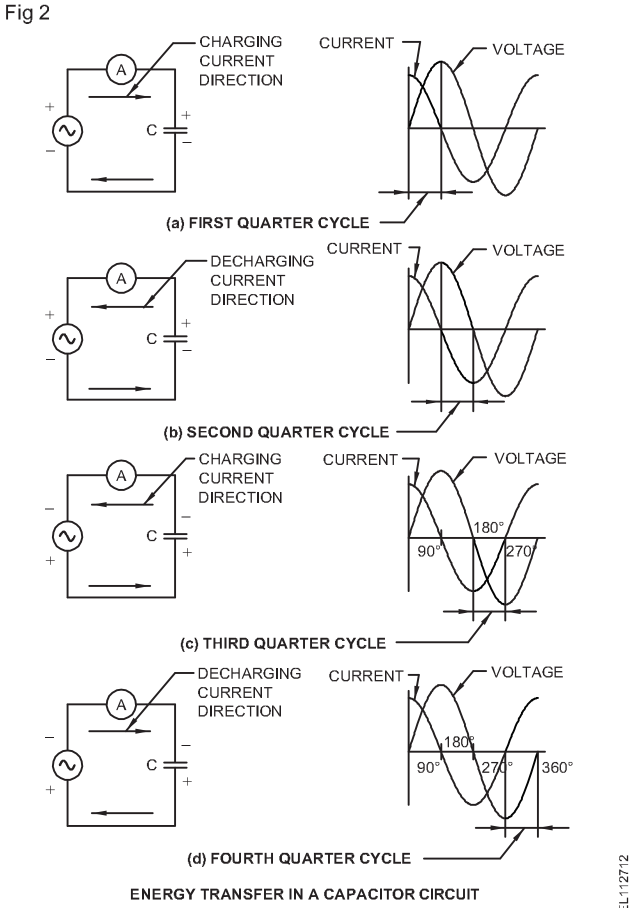
The capacitor then acts as the source, and starts discharging. The capacitor becomes fully discharged when the applied voltage drops to zero and reverses its direction. Then the capacitor starts charging again, but in the same direction in which it was previously discharging.

This continues until the applied voltage again starts to drop, and the events repeat themselves. This alternate charging and discharging, first in one direction, and then in the other, occur during every cycle of the applied AC. An AC current, therefore, flows in the circuit continuously.

It can be said, then, that although a capacitor blocks DC it passes AC.

Voltage and current realtionship: When an AC voltage source is connected across a capacitor, maximum current flows in the circuit the instant the source voltage begins its sinusoidal rise from zero. (Fig 2a)

Fig 2



ENERGY TRANSFER IN A CAPACITOR CIRCUIT

This is because the plates are in neutral state and present no opposing electrostatic forces to the source terminals. Therefore, as you can see by Ohm's Law, if the opposition to the current flow is very, very low, a small applied voltage can cause considerable current to flow.

As the source voltage rises, however, the charges on the capacitor plates, (which result from the current flow) build up. The charge voltage, then, presents an increasing opposition to the source voltage and so the current decreases.

When the source voltage reaches its peak value, the charge voltage across the capacitor plates is maximum. This charge is sufficient to completely cancel the source voltage, so that the current flow in the circuit stops.

As the source voltage begins to decrease, the electrostatic charge on the capacitor plates becomes greater than the potential of the source terminals, and so the capacitor starts to discharge. (Fig 2b)

Is the current flow in the same direction when the voltage decreases?

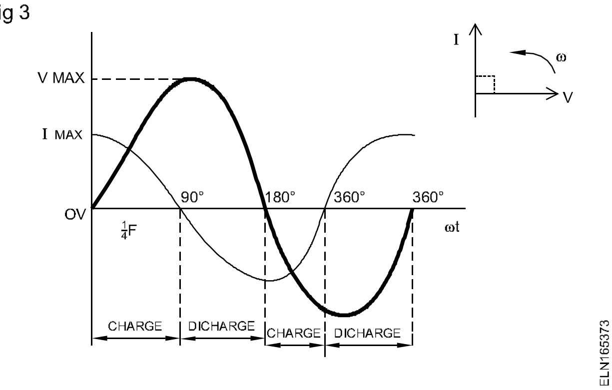
The direction of electron flow is opposite to the direction taken by the electrons during capacitor charging. Thus, at the point that the applied voltage passes through its maximum value and begins decreasing, the current in the circuit passes through zero and changes direction. As can be seen from the graph, this constitutes a 90-degree phase difference, with the current leading the applied voltage.

This 90-degree difference is maintained throughout the complete cycle of applied voltage. When the applied voltage has dropped to zero, the circuit current has increased to its maximum in the opposite direction, and when the voltage reverses the direction, the current begins decreasing. (Fig 2c) Therefore, the voltage applied to a capacitor is said to lag the current through the capacitor by 90 degrees. Or, the current through a capacitor leads the applied voltage by 90 degrees.

Hence the current increases from zero to maximum when voltage starts decreasing from the peak value in the opposite direction to zero. (Fig 2d)

The phase relation between voltage and current in a pure capacitor circuit is shown in the wave-form and vector diagram. (Fig 3)

Fig 3



Capacitive reactance: The opposition offered to the flow of current by a capacitor is called capacitive reactance, and is abbreviated Xc. Capacitive reactance can be calculated by:

$$X_C = \frac{1}{2\pi fC} = \frac{1}{\omega c}$$

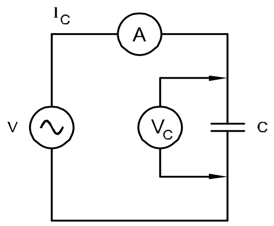
where 2π is approximately 6.28

f is the frequency in Hz

C is the capacitance in farad and $\omega = 2.\pi.f.$

Like its inductive counterpart - inductive reactance, capacitive reactance is expressed in ohms. Ohm's Law can also be applied to a circuit containing capacitive reactance only. (Fig 4)

Fig 4



PURE CAPACITIVE CIRCUIT

$$V_C = I_c X_c$$

$$I_c = \frac{V_c}{X_c}, \qquad X_c = \frac{V_c}{I_c}$$

where, I_c is current through capacitor in amps

V_C is the voltage across the capacitor in volts

X_C is the capacitive reactance in ohms.

Example: A 10 micro-farad capacitor is connected to a 200V 50Hz supply. Find the current taken.

Solution

$$I_c = \frac{V_c}{X_c}, \qquad V_c = V$$

where X_c is the capacitive reactance.

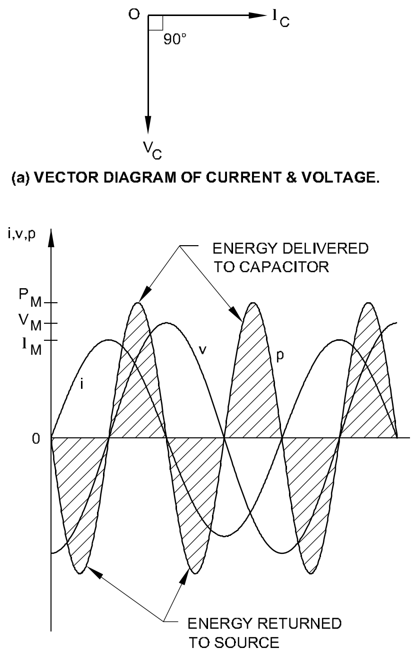
$$X_c = \frac{1}{2\pi fc} = \frac{10^6}{2\pi \times 50 \times 10}$$

$$X_c = \frac{1000}{\pi} = 318.4 \text{ ohms}$$

$$I_C = \frac{200}{318.4} = 0.628 \text{ amps}$$

Power in pure capacitance: For pure capacitance, the voltage and current are 90° out of phase with each other, the current leading as shown by the phase diagram in Fig 5a.

Fig 5



(a) VECTOR DIAGRAM OF CURRENT & VOLTAGE.

(b) CURRENT, VOLTAGE AND POWER FORMS.

The product of v and i gives a power curve as shown in Fig 5b. We see that the energy delivered to the capacitor and stored in the electric field is represented as a positive quantity. A quarter of a cycle later, all of this energy is returned to the source, as the capacitor discharges. Thus the average true power, P, is zero in a pure capacitance.

However, reactive power P_q is drawn by the capacitor, and the source must be able to supply this power.

For a purely capacitive circuit, the reactive power is given by

$P_q = V_c I_c$ volt-amperes reactive (var)

where

P_q is the reactive power in volt-amperes reactive, var

V_c is the voltage across the capacitance in volts

I_c is the current through the capacitance in amperes.

Since $V_c = I_c X_c$

then $P_q = I_c^2 X_c$ var

and $P_q = \dfrac{V_c^2}{X_c}$

where X_c is the capacitive reactance in ohms.

Again the equations for reactive and true power are similar with X_c used in place of R. We must use vars, not watts, for the reactive power.

As in the case of pure inductive circuit, the power factor of the pure capacitive circuit is also zero.

Why is it so?

This is because the angle between the current and voltage in a capacitive circuit is 90°. Result cos ϕ = 0.

Example: A reactive power of 100 vars is drawn by a 10 micro farad capacitor due to a current of 0.87A. Calculate the frequency.

Solution

$$X_c = \frac{P_q}{I_c^2} = \frac{100 \text{ vars}}{(0.87)^2} = 132 \text{ ohms}$$

Therefore, $f = \frac{1}{2.\pi.X_c.C}$

$$= \frac{1}{2\pi \times 132 \text{ ohms} \times 10 \times 10^{-6} F}$$

= 120 Hz.

Power and power factor in AC single phase circuit

Objective: At the end of this lesson you shall be able to

- **calculate power and power factor of a single phase AC circuit from the given relevant values.**

Power in pure resistance circuit: Power can be calculated by using the following formulae.

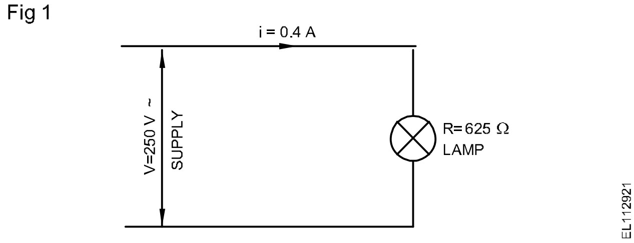
1) $P = V_R x\ I_R$ watts

2) $P = I^2_R\ R$ watts

3) $P = \frac{E^2}{R}$ watts

Example 1: Calculate the power taken by an incandescent lamp rated 250V when it carries a current of 0.4A if the resistance is 625 ohms.(Fig 1)

Fig 1



$P = V_R x\ I_R$

= 250 x 0.4

= 100 watts.

Alternately

$P = I^2R$

= 0.4 x 0.4 x 625

= 100 watts

$$\text{or } P = \frac{E^2}{R} = \frac{250^2}{625}$$

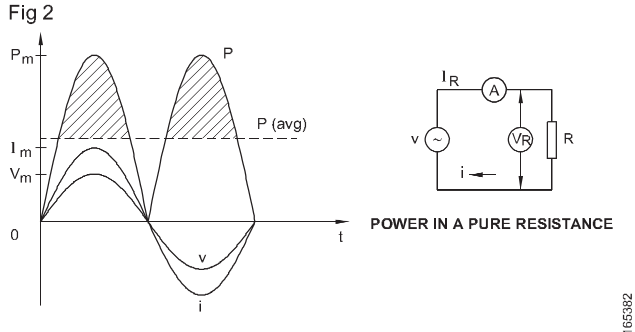
$$P = \frac{250 \times 250}{625}$$

= 100 watts.

Since the current and voltage are in phase, the phase angle is zero and the power factor is unity. Therefore, the power can be calculated with voltage and current itself.

Example 2: A wattmeter connected in an AC circuit indicates 50W. The ammeter connected in series with the load reads 1.5A. Determine the resistance of the load.

Fig 2



CURRENT, VOLTAGE, AND POWER WAVEFORMS

Solution

Known: $P = I_R^2R$

The circuit arrangement and wave-forms of I, V and P are shown in Fig 2.

Given: I = 1.5 amperes

P = 50 watts.

Therefore,

$$R = \frac{P}{I^2R} = \frac{50W}{(1.5)^2} = 22.2 \text{ ohms}$$

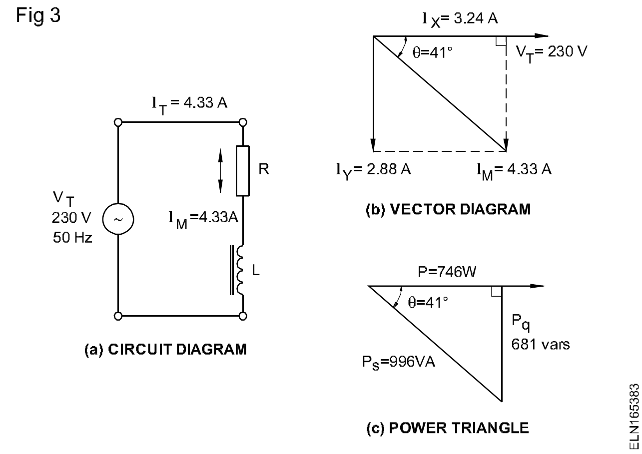
Power in pure inductance: If an AC circuit contains only inductance, the voltage and current are 90° out of phase, and the circuit of the instantaneous values of voltage and current gives with positive and negative power. Net result is the power consumed in a pure inductive circuit is zero.

Power in pure capacitance: If an AC circuit contains only capacitor, the voltage and current are 90°. Out of phase and the product of instantaneous values of voltage and current gives both positive and negative power. Net result is the power consumed in a pure capacitive circuit is zero.

Most industrial installations have a lagging PF because of the large number of AC induction motors that are inherently inductive.

Effect of a low power factor: To show the important effect of the power factor, let us consider a 240V, 50 Hz, 1 hp motor. Let us assume that it is 100% efficient so that it draws a true power of 746 W. Such a motor has a typical power factor of 0.75 lagging. (Fig 3)

Fig 3



To deliver 746 W from 240V at a power factor of 0.75 requires a current of

$$I = \frac{P}{V \times \cos\theta} A$$

$$= \frac{746W}{240V \times 0.75} = 4.144 \text{ A}$$

Now let us assume that we can modify the motor in some way to make the power factor unity (I). The current now required is

$$I = \frac{P}{V \times \cos\theta}$$

$$I = \frac{746W}{240V \times 1} = 3.108A$$

Evidently, it requires a higher current to deliver a given quantity of true power if the power factor of the load is less than unity. This higher current means that more energy is wasted in the feeder wires serving the motor. In fact, if an industrial installation has a power factor less than 85% (0.85) overall, a `power factor penalty' is assessed by the electric utility company. It is for this reason that power factor correction is necessary in large installations.

Power factor correction: In order to make the most efficient use of the current delivered to a load we desire a high PF or a PF that approaches unity.

A low PF is generally due to the large induction loads such as discharge lamps, induction motors, transformers etc. which take a lagging current and produce heat which returns to the generating station without doing any useful work as such it is essential to improve or correct the low PF so as to bring the current as closely in phase with the voltage as possible. That is the phase angle θ is made as small as possible. This is usually done by placing a capacitor load which produces a leading current.

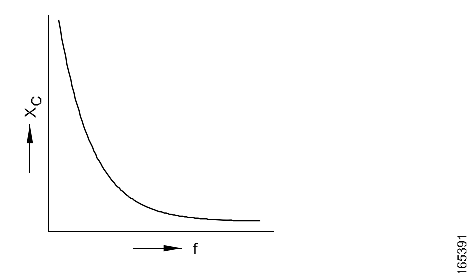
The capacitor is to be connected in parallel with the inductive load.

R - C Series circuit

Objectives: At the end of this lesson you shall be able to
- **state the effect of frequency on capacitive reactance in R-C series circuit**
- **calculate power factor**
- **determine the power factor and phase angle**
- **state the R-C time constant while charging and discharging**

In a circuit with capacitance, the capacitive reactance (X_C) decreases when the supply frequency (f) increases as shown in Fig 1.

Fig 1



RELATION BETWEEN FREQUENCY AND CAPACITIVE REACTANCE

$$X_C \propto \frac{1}{f}$$

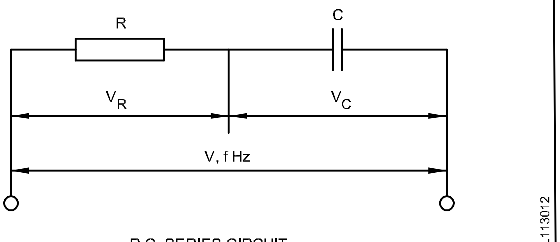
When the capacitive reactance X_C increases the circuit current decreases.

$$I \propto \frac{1}{X_C}$$

Therefore the increase in frequency (f) results in the increase of the circuit current in the capacitive circuit. When resistance (R), capacitance (C) and frequency f are known in a circuit, the power factor cos q can be determined as follows. (Fig 2)

$$X_C = \frac{1}{2\pi fC}$$

Fig 2



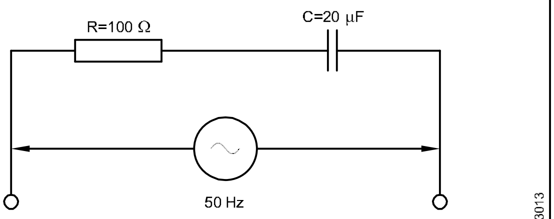
R.C. SERIES CIRCUIT

$$Z = \sqrt{R^2 + X_C^2}$$

$$\text{Power factor, } \cos\theta = \frac{R}{Z}$$

Example 1: A capacitance of 20 µ f and a resistance of 100Ω are connected in series across a supply frequency of 50 Hz. Determine the power factor. (Fig 3)

Fig 3



R.C, SERIES CIRCUIT

Solution

$$X_C = \frac{1}{2\pi fC} = \frac{1}{2 \times \frac{22}{7} \times 50 \times 20 \times 10^{-6}}$$

$$= \frac{7 \times 10^{-6}}{2 \times 22 \times 50 \times 20}$$

$$= \frac{7000000}{44000}$$

= 159.1 Ω, say 160 Ω.

$$Z = \sqrt{R^2 + X_C^2}$$

$$= \sqrt{10000 + 25600}$$

$$= \sqrt{36600} = 191.3\Omega$$

$$\text{P.F.} = \frac{R}{Z} = \frac{100}{191.3} = -.522$$

Capacitive reactance X_C in a capacitive circuit can be determined with the formula

$$X_C = \frac{1}{2\pi fC}$$

where X_C = capacitive reactance in ohm

f = frequency in Hz

C = Capacitance in farad

Power consumed in a R-C series circuit can be determined using the formula

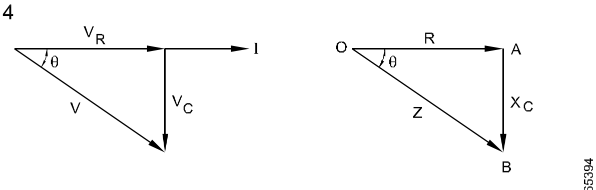
P = VI cos θ where P = power in watts

I = current in ampere

cos θ = power factor.

Vector diagram of voltages and their use to determine pf angle θ. (Fig 4)

Fig 4



a) VOLTAGE TRIANGLE b) IMPEDENCE TRIANGLE

$V_R = I_R$ drop across R (in phase with I)

$V_C = IX_C$ drop across capacitor (lagging I by 90°)

$$V = \sqrt{V_R^2 + V_C^2} = \sqrt{(IR)^2 + (IX_C)^2} = I\sqrt{R^2 + X_C^2}$$

$$\therefore I = \frac{V}{\sqrt{R^2 + X_C^2}} = \frac{V}{Z}$$

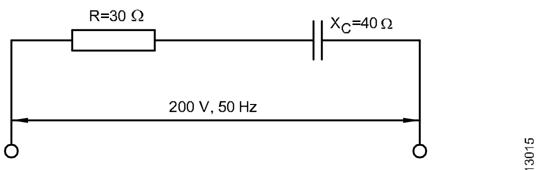
$\therefore Z = \sqrt{R^2 + X_C^2}$ where Z is the impedance of the circuit.

Power factor, cos θ = R/Z.

From pf cos θ the angle θ can be known referring to the Trignometric table.

Example 2: In RC series circuit shown in the diagram (Fig 5) obtain the following.

Fig 5



R.C. SERIES CIRCUIT

- Impedance in ohms
- Current in amps
- True power in watts
- Reactive power in var
- Apparent power in volt amp.
- Power factor

Solution

1 Impedence (Z)

$$= \sqrt{R^2 + X_C^2} = \sqrt{30^2 + 40^2} = \sqrt{2500} = 50\Omega$$

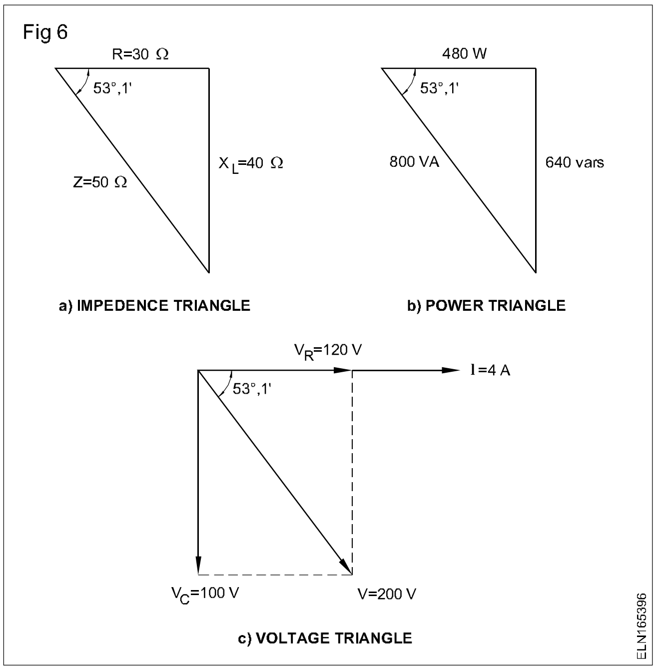
2 Current $I = \frac{V}{Z} = \frac{200}{50} = 4A$

3 True power $W = I^2R = 4^2 \times 30 = 480W$
(Power consumed by capacitoir = zero)
$V_C = IX_C = 4 \times 40 = 160$ V

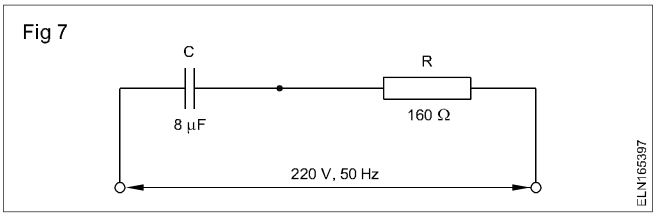
4 Reactive power $VAR = V_C I = 160 \times 4 = 640$ VAR
Apparent power $VI = 200 \times 4 = 800$ VA

PF $\cos\theta = \frac{R}{Z} = \frac{30}{50} = 0.6$

The impedance triangle, power triangle and voltage triangle for exercise 2 are showm in Fig 6



Example 3: An 8 μf capacitor is connected in series with an ohmic resistance of 160 Ω. A voltage of 220V AC, 50 Hz is applied to the circuit (Fig 7)



Calculate

a) the capacitive reactance

b) the impedance

c) the current

d) the active power

e) the reactive power.

Solution

a) $X_C = \frac{1}{2\pi fC} = \frac{10^6}{314 \times 8} = 400\Omega$

b) $Z = \sqrt{R^2 + X_C^2} = \sqrt{160^2 + 400^2}$

$= \sqrt{185600} = 430\,\Omega$

c) $I = \frac{V}{Z} = \frac{220}{430} = 0.51A$

d) $W = I^2R = 0.51^2 \times 160 = 41.62W$

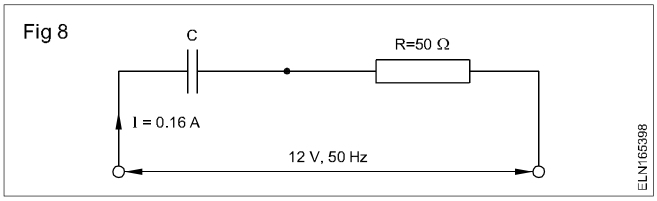
e) $VAR = V \times I \sin\theta = 220 \times 0.51 \times 0.9291$

$= 102.2$ VAR

$\cos\theta = \frac{R}{Z} = \frac{160}{430} = 0.37$

($\theta = 18°18'$,Referring to the sine table,

$\sin\theta = \sin 18°18' = 0.9291$.



Example 4: In the circuit shown in Fig 8, calculate a) the capacitive reactance and b) the capacitance of the capacitor.

Solution

$V_R = IR = 0.16 \times 50 = 8V$

$V_C = \sqrt{V^2 - V_R^2} = \sqrt{12^2 - 8^2} = \sqrt{80} = 9V$ (App)

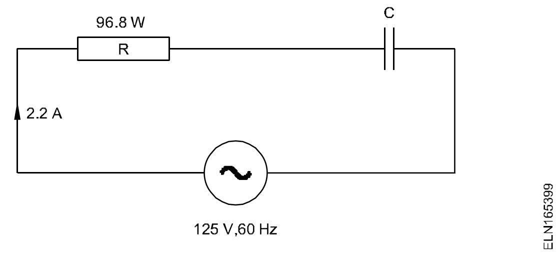
$X_C = \frac{V}{I} = \frac{9}{0.16} = 56\Omega$

$X_C = \frac{1}{2\pi fC}$

$C = \frac{1}{2\pi fX_C} = \frac{1}{314 \times 56} = \frac{10^6}{314 \times 56} = 57\,\mu F$

Example 5: A voltage of 125V at 60Hz is applied across a non-inductive resistance connected in series with a condenser. The current in the circuit is 2.2A. The power loss in the resistor is 96.8W and that in the condenser is negligible. Calculate the resistance and capacitance. (Fig 9)

Fig 9



Solution : Power loss I^2R = 96.8W

$$\therefore R = \frac{96.8}{I^2} = \frac{96.8}{2.2^2} = 20\Omega$$

Impedence $Z = \frac{V}{I} = \frac{125}{2.2} = 56.82\Omega$

Capacitance reactance $X_C = \sqrt{Z^2 - R^2}$

$$= \sqrt{56.82^2 - 20^2}$$

$= 53.2\Omega$

$X_C = 1 / (2\pi fC)$

$2\pi fC = 1 / X_C$

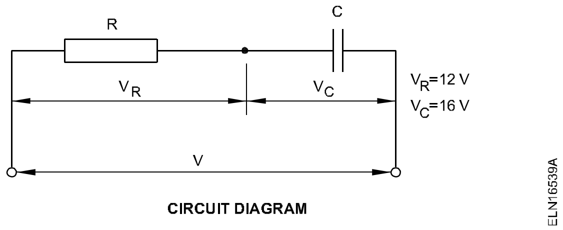
2 x 3.14 x 60 x C = 1/53.2

C = 1 / (53.2 x 2 x 3.14 x 60)

= 0.00005 F = 50 mF

Example 6: In the circuit shown (Fig 10)

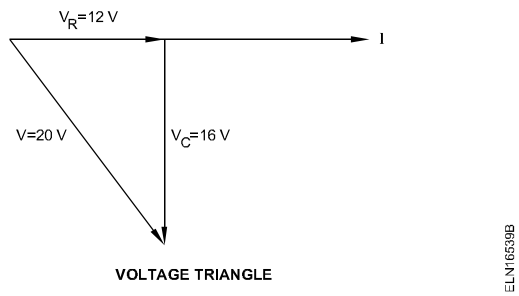
Fig 10



a) calculate the voltage V

b) draw the voltage triangle (Fig 11).

Fig 11



Solution

a) $V = \sqrt{V_R^{\ 2} + V_C^{\ 2}} = \sqrt{12^2 + 16^2} = \sqrt{144 + 256}$

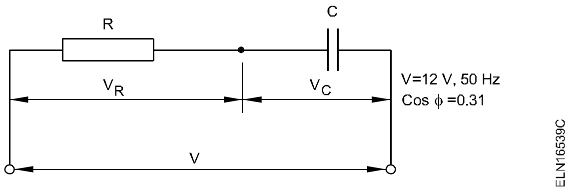
$= \sqrt{400}$ = 20V

Example 7: In the circuit shown, Fig 12 calculate

a) the resistor voltage

b) the capacitor reactance voltage.

Fig 12



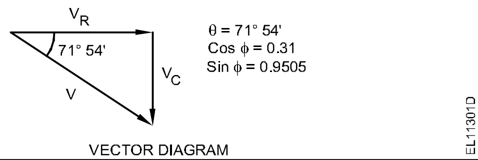
Solution

a) $V_R = V \cos\theta$ = 12 x 0.31 = 3.72V

b) $V_C = V \sin\theta$ = 12 x 0.9595 x 11.4V

Vector diagram Fig 13

Fig 13



'Time constant': One time constant is that time in seconds required for a completely discharged capacitor to charge 63% of the source voltage (charging voltage).

τ = R x C

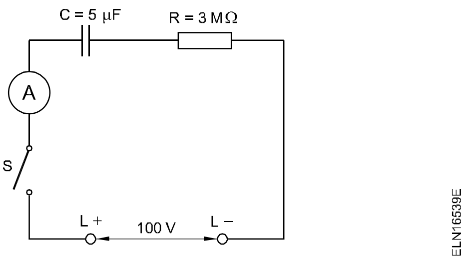
where τ = one time constant in seconds

R = resistance in ohms

C = capacitance in farad.

As shown in the (Fig 14), if

Fig 14



C= 5 μF, R = 3 M Ω, then

$\tau = 5 \times 10^{-6} \times 3 \times 10^6$ = 15 seconds

charging voltage = 100 V

one time (τ) constant = 15 seconds. V_e= 63V

After 5 time constant a capacitor is 99.3% charged, for practical purposes it is taken that the capacitor is fully charged. A capacitor charges in 5 time constant.

A charging curve is shown in Fig 15.

During discharging, a fully charged capacitor discharges in five time constant. A discharging curve is shown in Fig 16.

Fig 15

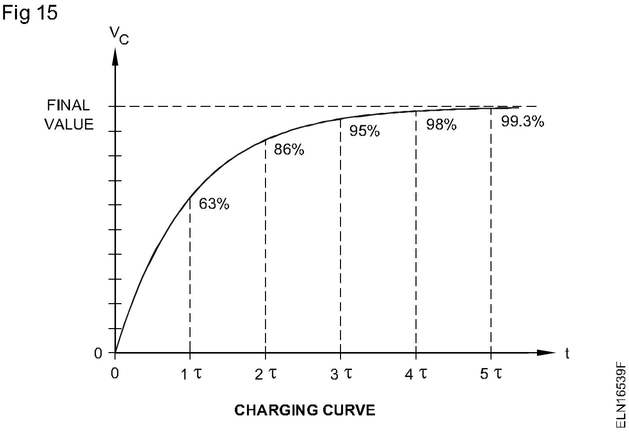
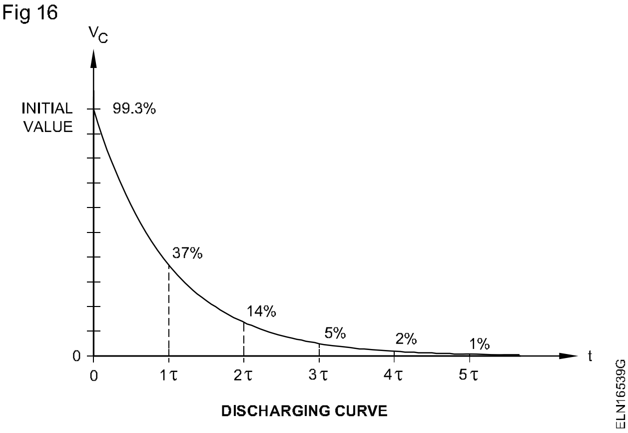


Fig 16



τ (sec)	**Time taken** (V)	**Charging voltage plates** (V)	**Voltage across the capacitor**
At the time of switching on		100	0
1τ	15	63% of 100 = 63	0 + 63 = 63
2τ	30	63% of (100-63) = 23.3 say 23	63 + 23 = 86
3τ	45	63% of (100-86) = 8.82 say 9	86 + 9 = 95
4τ	60	63% of (100-95) = 3.15 say 3	95 + 3 = 98
5τ	75	63% of (100-98) = 1.26 say 1.3	98 + 1.13 = 99.3

R L C series circuit

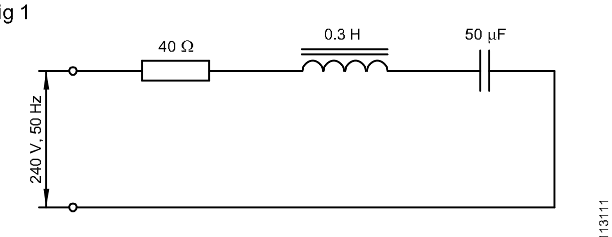
Objectives: At the end of this lesson you shall be able to

- **calculate the resultant reactance and impedance of the RLC series circuit**
- **state the impedance, voltage and power triangle.**
- **explain the necessary conditions for series resonance.**

Assume an AC single phase circuit consisting a resistance, inductor and capacitor in series. Various parameters could be calculated as shown in the example.

Example : The value of the components shown in Fig 1 is R = 40 ohms L = 0.3 H and C = 50µf. The supply voltage is 240 V 50 Hz. Calculate the inductive reactance, capacitance reactance, net reactance, impedance, current in the circuit, voltage drops across the R, L and C power factor, active power, reactive power and apparent power. Also draw the impedance triangle, voltage triangle and power triangle.

Fig 1



R L C SERIES CIRCUIT

Calculate the resultant reactance in RLC circuit : Inductance and capacitance have directly opposite effects in an AC circuit. The voltage drop caused by the inductive reactance of the coil leads the line current by 90°. The voltage drop across the inductor coil and the capacitor are 180 degrees apart and oppose each other. To calculate the net reactance in the above example:

Inductive reactance

$X = 2\pi fL = 314 \times 0.3 = 94.2\Omega$

Capacitive reactance

$$X = \frac{1}{2\pi fC} = \frac{1}{314 \times 0.00005} = \frac{1}{0.0157} = 63.69\ \Omega$$

Net reactance - X_L - X_C = 94.2 - 63.69 = 30.51Ω

Calculate the impedance: From the circuit given above the impedance can be found. The impedance is the resultant combination resistance and reactance. In this circuit, the impedance is the combination of the 40 ohms resistance and 30.51 Ω resultant reactance. The impedance for this circuit is

$$Z = \sqrt{R^2 + (X_L - X_C)^2} = \sqrt{40^2 + 30.51^2}$$

$$= \sqrt{1600 + 930.86} = \sqrt{2530.86} = 50.30\,\Omega$$

Draw the impedance triangle: Draw the horizontal line (X axis) indicating the circuit current.

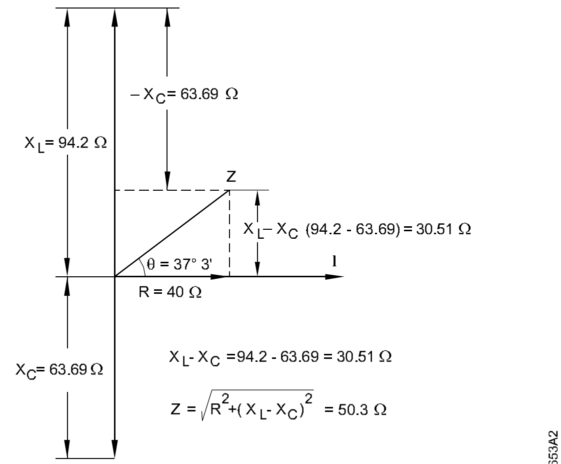
Draw along with current vector the value of R to a suitable scale i.e. 1cm = y ohm.

draw the vertical line perpendicular to the current vector in +y axis indicating the value of inductive reactance to the scale selected (1cm = y ohm)

draw a vertical the perpendicular to the current vector in _y axis indicating the value of capacitive reactance to the scale selected (1cm = y ohm).

Substract the value of X_C from, X_L as shown in Fig 2 the net reactance value is equal to 30.51 ohms. Complete the vectors by closing the parallelogram the reactance of the parallelogram is the impedance of the series RLC circuit.

Fig 2



IMPEDANCE TRIANGLE

Mathematically what we determined the values of net reactance and impedance could also be determined by the above vectorial method.

Measurement of current and voltage drop in RLC circuit. The voltage drop across R =E_R across L = E_L and drop across C = E_C and the formula for finding their values and given below.

E_R = IR

E_L = IX_L

E_C = IX_C

Current in given RLC series circuit: Current in this series circuit is I = E/Z = 240/50.3 = 4.77 amps.

Identifying whether the current flow is leading or lagging the voltage in a RLC series circuit: As this is a series circuit, the current is the same in all parts of the circuit, but the voltage drop across the resistor, the inductor coil and capacitor are

E_R = IR = 4.77 x 40 = 190.8 volts

E_L = IX_L = 4.77 x 94.2 Ω = 449.33 volts

E_C = IX_C = 4.77 x 63.69 = 303.80 volts.

The vector sum of the voltage of 190.8 volts across the resistor and 145.53 volts across the net reactance of 30.51Ω is equal to the line voltage of 240 volts as shown below.

$$E = \sqrt{E^2R + (E_L - E_C)^2}$$

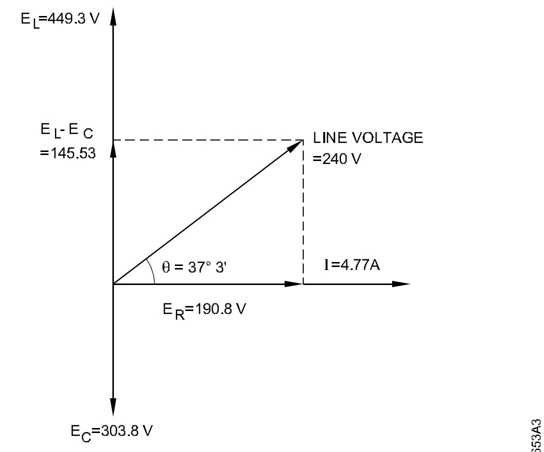
$$= \sqrt{190.8^2 + (449.33 - 303.80)^2}$$

$$= \sqrt{190.8^2 + 145.53^2}$$

E = 240 volts.

The voltage vector diagram could be drawn as shown in Fig 3.

Fig 3



VECTOR DIAGRAM

In this type of series circuit, the current is used as a horizontal reference line. The voltage value of 145.53 volts across the portion of the inductive reactance which is not cancelled out by the voltage across the capacitive reactance. The PF = E_R/E = 190.8/240 = 0.795 lag or PF = R/Z = 40/50.30 = 0.795 lag PF. In this circuit the phase angle is 37.3° lagging. This means that current lags the line voltage.

In an RLC series circuit, if X_L is greater then the voltage appearing across the inductor is high and that can be found out by IX_L. In the same way if the X_C value is greater in an RLC series circuit, the voltage appearing across the capacitor is more and can be found out by IX_C.

In the example given above, the voltage drop across resistance 40 Ω = 190.8 volts.

Voltage drop across inductance 0.3 H = 449.33 volts. Voltage drop across capacitor of 50 mf = 303.80 volts.

From these values it is clear that the voltage drop across the inductor and capacitor is higher than the supply voltage. Hence while connecting the meter to measure the voltage drop across inductor and capacitor it should be noted that the range of this should be high (in this case 0 - 500 volts)

Calculate the power factor: Power factor of the RLC series circuit can be found from the impedance triangle or voltage triangle as shown below

$$\text{Power factor} = \text{Cos}\,\theta = \frac{R}{Z} \text{ or } \frac{E_R}{V}$$

$$\text{Power factor} = \frac{R}{Z} = \frac{40}{50.3} = 0.795$$

$$= \frac{E_R}{V} = \frac{190.8}{240} = 0.795$$

Calculate the active power (R_A): Active power can be calculated by using any one of the formulae given below

P = EI Cos θ = I^2R

= EI Cos θ = 240 x 4.77 x 0.795

= 910 walts

= $I^2R = 4.77^2 \times 40$

= 910 watts.

Calculate the reactive power P_q: Reactive power can be calculated using the formula

P_q = EI sin θ Vars

= 240 x 6.77 x 0.6074

= 695 Vars

Cos θ = 0.795

θ = 37°3'

Sin θ = Sin 37°3'

= 0.6074

Calculate the apparent power (P_{APP}): Apparent power can be calculated using the formula

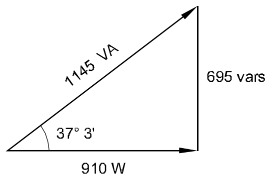
P_{APP} = EI volt-amperes

= 240 x 4.77

= 1145 Volt-amperes.

Draw the power triangle: Power triangle is shown in Fig 4.

Fig 4



POWER TRIANGLE

Resonance circuit: When the value of X_L and X_C are equal, the voltage drop across them will be equal and hence they cancel each other. The value of voltage drops V_L and V_C may be much higher than the applied voltage.

The impedance of the circuit will be equal to the resistance value. Full value of applied voltage appears across R and the current in the circuit is limited by the value of resistance only. Such circuits are used in electronic circuits like radio/TV turning circuits. When $X_L = X_C$ the circuit is said to be in resonance.

As current will be maximum in series resonant circuits it is also called acceptor circuits. For a known value of L and C the frequency at which this occurs is called as resonant frequency. This value can be calculated as follows when $X_C = X_L$

$$2\pi fL = \frac{1}{2\pi fC}$$

$$\text{Hence resonant frequency } f = \frac{1}{2\pi\sqrt{LC}}$$

Power factor angle is commonly denoted by Theta θ. In some pages of this text it is denoted by Phi ϕ. As such these terms are used alternatively in this text.

Series resonance circuit

Objectives: At the end of this lesson you shall be able to
- **explain the impedance of series resonance circuit**
- **state the condition for series resonance and its expression**
- **state the resonance frequency and its formula**
- **state about the 'Q' factor (selectivity) of RLC circuit from graph.**

Series resonance circuit

Impedance of series resonance circuit

A simple series LC circuit shown in Fig 1. In this series LC circuit,

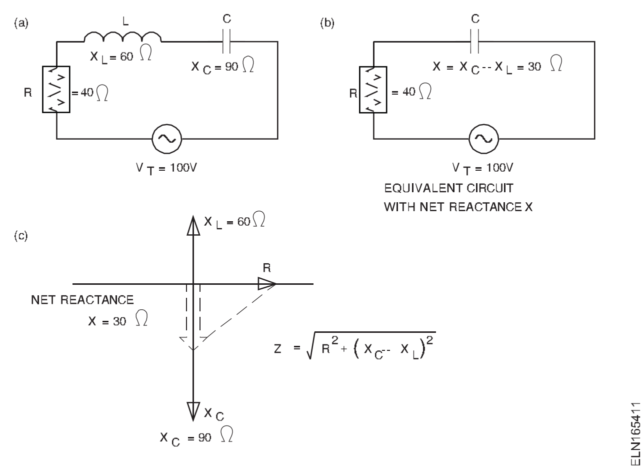
– resistance R is the total resistance of the series circuit(internal resistance) in ohms,

– X_L is the inductive reactance in ohms, and

– X_C is the total capacitive reactance in ohms.

In the circuit at Fig 1a, since the capacitive reactance(90Ω) is larger than inductive reactance(60Ω), the net reactance of the circuit will be capacitive. This is shown in Fig 1b.

Fig 1



> **Note: If the capacitive reactance was smaller than inductive reactance the net reactance of the circuit would have been inductive.**

All though the unit of measure of reactance and resistance is the same(ohms), the impedance, Z of the circuit is not given by the simple addition of R, X_L and X_C. This is because, X_L is +90° out of phase with R and X_C is -90° out of phase with R.

Hence the impedance Z of the circuit is the phasor addition of the resistive and reactive components as shown by dotted lines in Fig 1c. Therefore, Impedance Z of the circuit is given by,

$$Z = \sqrt{R^2 + (X_C - X_L)^2}$$

If X_L were greater than X_C, then the absolute value of impedance Z is will be,

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

For the circuit in Fig 2(a), total impedance Z is,

$$Z = \sqrt{R^2 + (X_C - X_L)^2}$$

$$Z = \sqrt{40^2 + 30^2}$$

Z = 50Ω, Capacitive (because $X_C > X_L$)

Current I through the circuit is given by,

$$I = \frac{V}{Z} = \frac{100}{50\Omega} = 2 \text{ Amps}$$

Therefore, the voltage drop across the components will be,

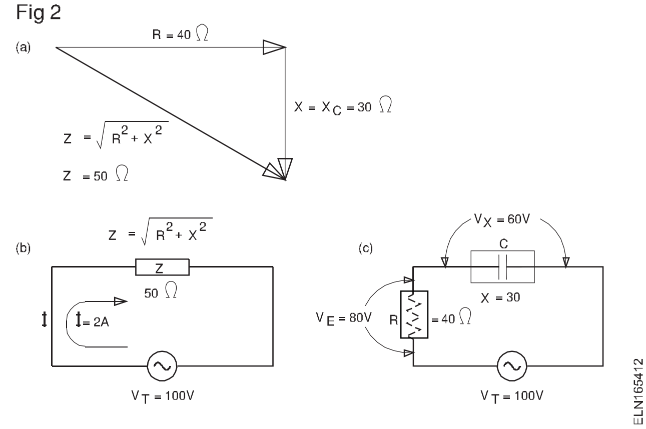
V_R = voltage drop across R = I.R = 2x40 = 80 volts

V_L = voltage drop across L = I.X_L = 2x60 = 120 volts

V_C = voltage drop across C = I.X_C = 2x90 = 180 volts.

Since V_L and V_C are of opposite polarity, the net reactive voltage V_X is = 180 - 120 = 60V as shown in Fig 2.

Fig 2



Note that the applied voltage is not equal to the sum of voltage drops across reactive component X and resistive component. This is again because the voltage drops are not in phase. But the phasor sum of V_R and V_X will be equal to the applied voltage as given below,

$$V_T = \sqrt{V_R^2 + V_X^2}$$

$$= \sqrt{V_R^2 + (V_L - V_C)^2}$$

$$= \sqrt{80^2 + 60^2} = 100 \text{ volts(applied voltage).}$$

Phase angle θ of the circuit is given by,

$$\theta = \tan^{-1} \frac{X_C - X_L}{R}$$

Condition at which current through the RLC Series circuit is maximum

From the formula,

$Z = \sqrt{R^2 + (X_C - X_L)^2}$ it is clear that the total impedance Z of the circuit will become purely resistive when,

reactance $X_L = X_C$

In this condition, the impedance Z of the circuit will not only be purely resistive but also minimum.

Since the reactance of L and C are frequency dependent, at some particular frequency say f_r, the inductive reactance X_L becomes equal to the capacitive reactance X_C. In such a case, since the impedance of the circuit will be purely resistive and minimum, current through the circuit will be maximum and will be equal to the applied voltage divided by the resistance R.

Series resonance

From the above discussions it is found that in a series RLC circuit,

Impedance $Z = \sqrt{R^2 + (X_L - X_C)^2}$

Current $I = \frac{V}{Z}$

and,

Phase angle $\theta = \tan^{-1} \frac{X_L - X_C}{R}$

If the frequency of the signal fed to such a series LC circuit (Fig 1a) is increased from 0 Hz, as the frequency is increased, the inductive reactance($X_L = 2\pi fL$) increases linearly and the capacitive reactance ($X_C = 1/2\pi fL$) decreases exponentially as shown in Fig 3.

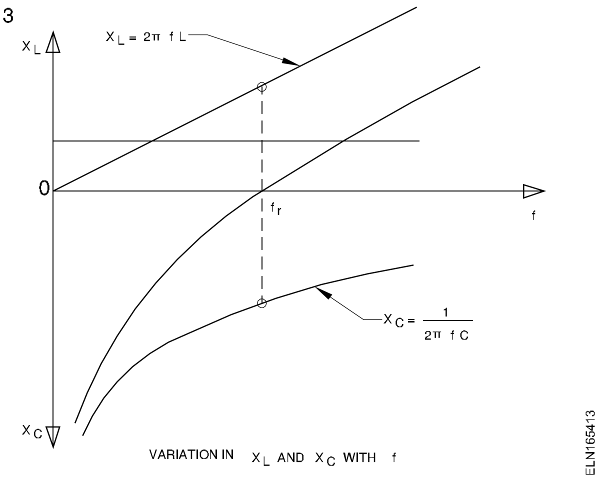
As shown in Fig 3, at a particular frequency called the resonance frequency, f_r, the sum of X_L and X_C becomes zero($X_L - X_C = 0$).

From Fig 3 above, at resonant frequency ,

- Net reactance, X = 0 (i.e, $X_L = X_C$)
- Impedance of the circuit is minimum, purely resistive and is equal to R
- Current I through the circuit is maximum and equal to V/R
- Circuit current, I is in-phase with the applied voltage V (i.e. Phase angle = 0).

At this particular frequency f_r called resonance frequency, the series RLC is said to in a condition of series resonance.

Fig 3



Resonance occurs at that frequency when,

$X_L = X_C$ or $2\pi fL = 1/2\pi fC$

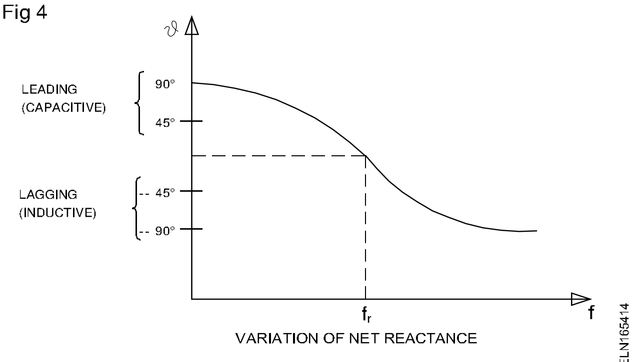
Therefore, **Resonance frequency, f_r** is given by,

$$f_r = \frac{1}{2\pi\sqrt{LC}} \text{ Hz} \qquad ....[1]$$

Reactance of series RLC above and below resonance frequency f_r

Fig 4 shows the variation of net reactance of a RLC circuit with the variation in frequency.

Fig 4



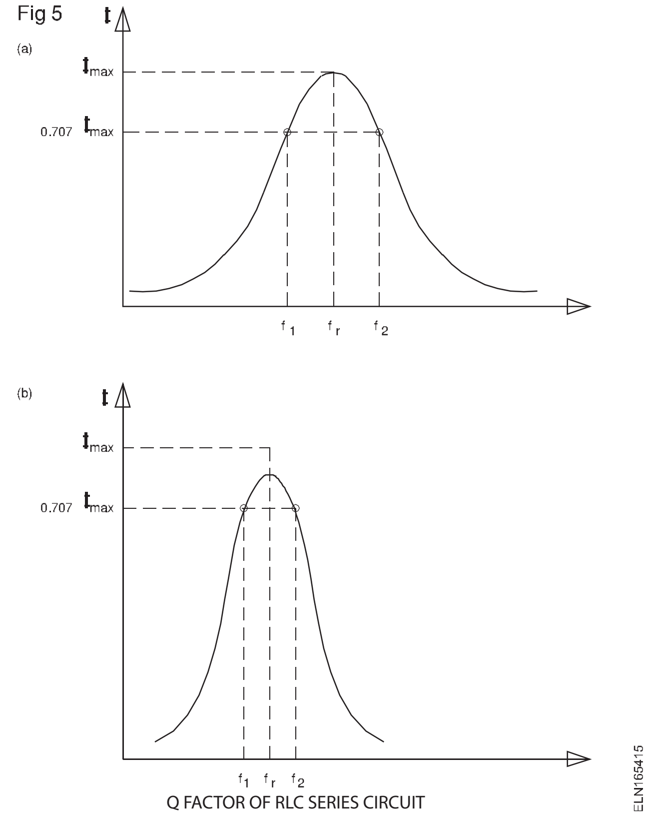
From Fig 4 above,it can be seen that the,

- net reactance is zero at resonant frequency f_r
- net reactance is capacitive below the resonant frequency f_r
- net reactance is inductive above the resonant frequency f_r.

Selectivity or Q factor of a series RLC circuit

Figs 5a and 5b two graphs showing the current through series two different RLC circuits for frequencies above and below f_r. f_1 and f_2 are frequencies at which the circuit current is 0.707 times the maximum current,I_{max} or the -3dB points.

Fig 5



Q FACTOR OF RLC SERIES CIRCUIT

Fig 5 indicates that series RLC circuits select a band of frequencies around the resonant frequency, f_r. This band(f_1 to f_2 is called the **band width** f of the series RLC circuit.

Bandwidth = $\Delta f = f_2 - f_1$ Hz.

where, f_2 is called the upper cut off frequency and f_1 is called the lower cut off frequency of the resonant circuit.

Comparing Figs 5a and 5b, it is seen that the bandwidth of 5b is smaller than that of 5a. This is referred to as the **selectivity** or **quality factor, Q** of the resonance circuit. The RLC circuit having the response shown in Fig 5b is more selective than that of Fig 5a. The quality factor, Q of a resonance circuit is given by,

$$\text{Quality factor} = Q = \frac{f_r}{\Delta f} = \frac{f_r}{f_2 - f_1} \qquad ...[2]$$

If Q is very large, the bandwidth f will be very narrow and vice-versa. The Q factor of the series resonance circuit depends largely upon the Q factor of the coil(inductance) used in the RLC circuit.

Therefore,

$$\text{Q of coil} = \frac{X_L}{R} = \frac{2\pi f_r L}{R}$$

since,

$$f_r = \frac{1}{2\pi\sqrt{LC}}$$

Q of the series RLC circuit is given by,

$$Q = \frac{1}{R} \cdot \frac{\sqrt{L}}{\sqrt{C}} \qquad ...[3]$$

Application of series resonance circuits

A series resonance circuit can be used in any application where it is required to select a desired frequency. One such application is radio receiver.

R-L, R-C and R-L-C parallel circuits

Objectives: At the end of this lesson you shall be able to
- **explain the admittance triangle and the relationship between conductance, susceptance and admittance**
- **explain susceptance, conductance and admittance by symbols.**

R-L Parallel circuit

When a number of impedances are connected in parallel across an AC voltage, the total current taken by the circuit is the phasor sum of the branch currents (Fig 1).

There are two methods for finding the total current.

- Admittance method
- Phasor method

Admittance method

The current in any branch $I = \frac{E}{Z}$

$$= E \times \left|\frac{1}{Z}\right| \text{ where } \left|\frac{1}{Z}\right|$$

is called the **admittance** of the circuit i.e. admittance is the reciprocal of impedance. Admittance is denoted by 'Y' (Fig 2).

$$I = E \times \left|\frac{1}{Z}\right| = EY \quad \text{or} \quad Y = \frac{I}{E}$$

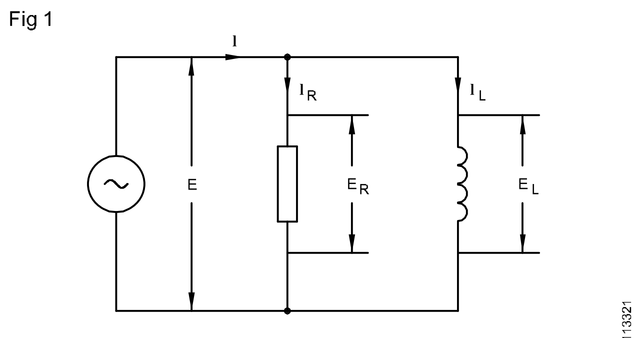
$$\therefore \text{Total admittance } (Y_T) = \frac{\text{total current}}{\text{common applied voltage}}$$

$$= \frac{\text{phasor sum of branch currents}}{\text{common applied voltage}}$$

= phase sum of separate admittance

Note: Supply voltage is referred as V or E interchangeably.

Fig 1

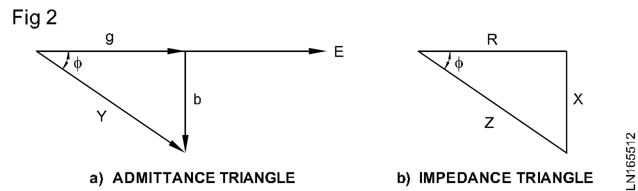


R.L. PARALLEL CIRCUIT

An admittance may be resolved into two components.

- A component in phase with the applied voltage called the conductance denoted by g.
- A component in quadrature (at right angle) with the applied voltage called **susceptance,** denoted by b.

Fig 2



a) ADMITTANCE TRIANGLE b) IMPEDANCE TRIANGLE

$$g = Y \cos\phi = \frac{1}{Z} \times \frac{R}{Z}$$

$$= \frac{R}{Z^2} = \frac{R}{R^2 + Z^2}$$

$$b = Y \sin\phi = \frac{1}{Z} \times \frac{X}{Z} = \frac{X}{Z^2}$$

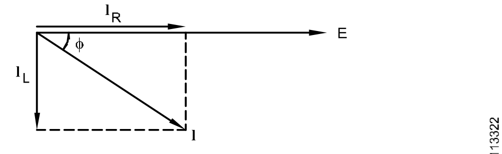
$$= \frac{X}{R^2 + X^2}$$

The unit of admittance, conductance and susceptance is called the mho symbol ℧.

Relationship between branch current and supply voltage

In a R-L parallel circuit, the voltage across resistor (E_R) and inductor (E_L) are the same and equal to the supply voltage E. Hence E is the reference vector. The current through resistor (I_R) in phase with E_R is E. (Fig 3) The current through inductor (I_L) is lagging the E_L is E by 90^o. In short the current through resistor I_R is in phase and the current through inductor I_L, lags with applied voltage (E) by 90° . The power factor of R-L parallel circuit is cos ϕ where ϕ is the angle in between the total current and applied voltage.

Fig 3



R.L. PARALLEL CIRCUIT VECTOR

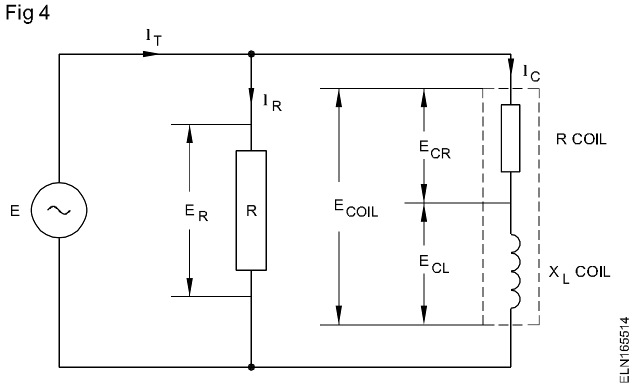
Representation of two branch currents and total current in the circuit containing R, R coil, X_L coil and supply voltage

I_R = branch current through resistor

I_C = branch effective current through coil

In a parallel circuit, the voltage across R (E_R) and across coil (E_C) is the same. Due to the applied voltage across coil (E_C) the coil current (I_C) flows through the coil. The current flowing through the coil is the effective current. The same current flows through the resistance and inductance of the coil (Fig 4).

Fig 4

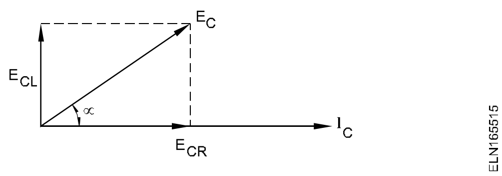


I_C = current flow through the resistance and inductance of the coil

E_{CR} = voltage drop in the coil due to resistance and in phase with I_C

E_{CL} = voltage drop in the coil due to inductance and leads the current by 90° (Fig 5).

Fig 5

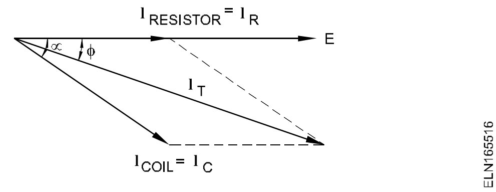


I_R = current through resistor in phase with E

I_C = current through coil lagging with E by α

I_T = total current lagging E by an angle ϕ.

Fig 6



The power factor of the above circuit is cos ϕ where ϕ is the phase angle between the applied voltage and total current (Fig 6).

Assignment

1 A coil of resistance 15 ohms and inductance 0.05H is connected in parallel with a non-inductive resistance of 20 ohms. Find (a) the current in each branch and (b) the phase angle between the total current of the whole arrangement and the applied voltage of 200 V at 50 Hz.

2 The load on a 250 V supply system is -

a) 12 A at 0.8 power factor lagging

b) 5 A at unity power factor.

Find the total load in kVA and its power factor.

3 The load on a 250 V supply system is -

a) 10 A at 0.5 power factor lagging

b) 5 A at unity power factor

c) 12 A at 0.866 power factor lagging.

Draw the vector diagram. Find the total load in kVA and its power factor.

4 A coil of resistance 15 ohms and inductance 0.05 H is connected in parallel with a non-inductive resistor of 40 ohms. Find the total current when a voltage of 200 V at 50 Hz. is applied. Give the phasor diagram.

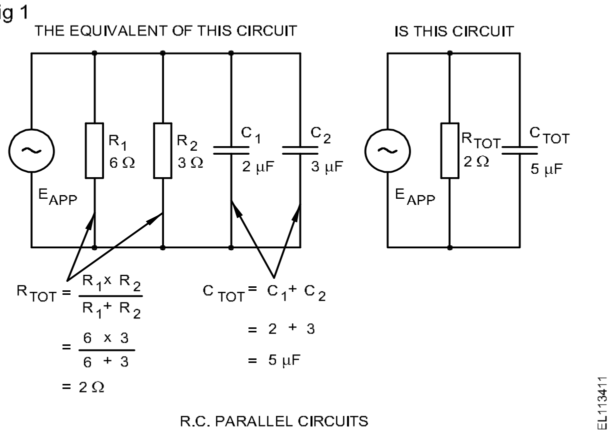
AC Parallel circuit (R and C)

Objectives: At the end of this lesson you shall be able to
- **state the relationship between branch current, voltage in a parallel circuit**
- **solve problems in RC parallel circuit by admittance method**
- **compare the charecteristics of A.C series and parallel circuits**
- **state the R-L-C parallel circuit vector diagram**

Parallel RC circuits: In a parallel RC circuit, one or more resistive loads and one or more capacitive loads are connected in parallel across a voltage source. Therefore, resistive branches, containing only resistance and capacitive branches, containing only capacitance. (Fig 1) The current that leaves the voltage source divides among the branches; so there are different currents in different branches. The current is, therefore, not a common quantity, as it is in the series RC circuits.

Voltage: In a parallel RC circuit, as in any other parallel circuit, the applied voltage is directly across each branch. The branch voltages are, therefore, equal to each other, as well as to the applied voltage, and all three are in

Fig 1

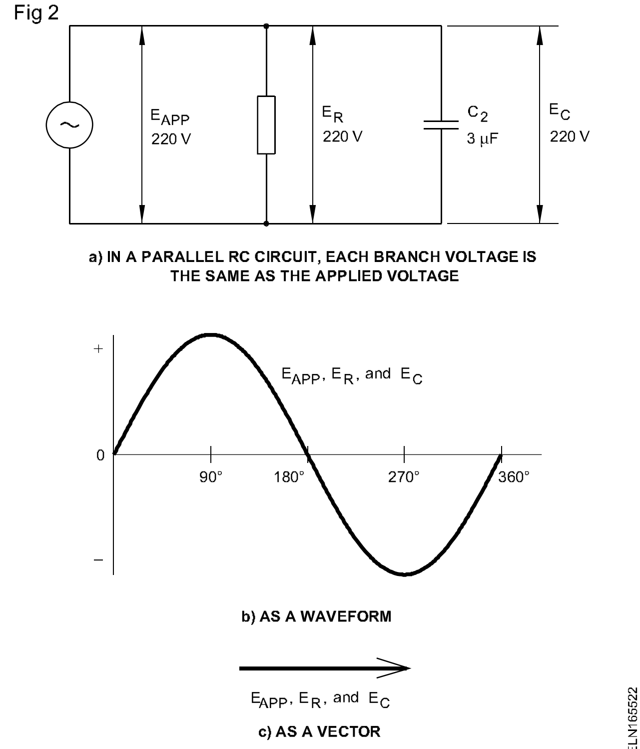


phase. (Fig 2) So if you know any one of the circuit voltages, you know all of them.

Since the voltage is common throughout the circuit, it serves as the common quantity in any vector representation of the parallel RC circuits. This means that on any vector diagram, the reference vector will have the same direction, or phase relationship, as the circuit voltage.

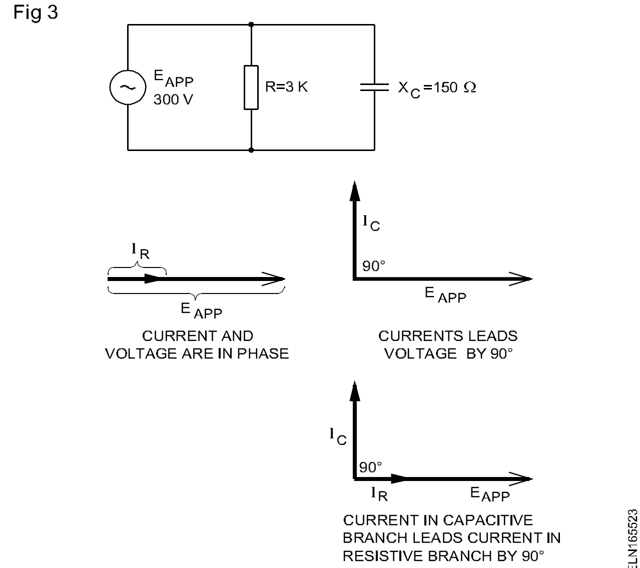
The two quantities that have this relationship with the circuit voltage, and whose vectors, therefore, have a direction of zero degrees, are the capacitor voltage and the current through the resistance.

Fig 2



Branch current: The current in each branch of a parallel RC circuit is independent of the current in the other branches. The current within a branch depends only on the voltage across the branch, and the resistance or capacitive reactance contained in it. (Fig 3)

Fig 3

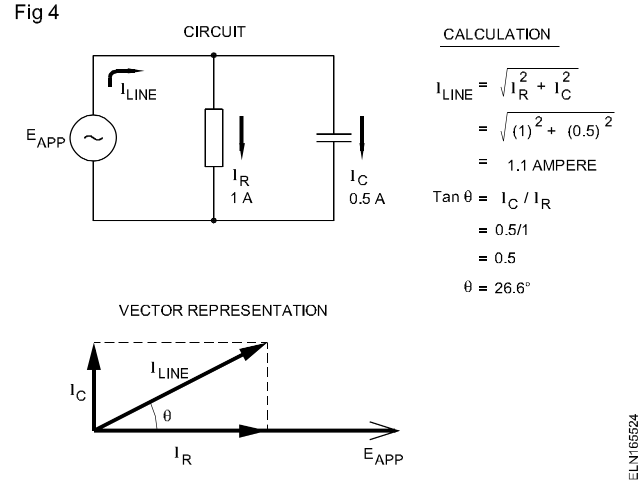


The current in the resistive branch is calculated from the equation: $I_R = E_{APP}/R$.

The current in the capacitive branch is found with the equation: $I_C = E_{APP}/X_C$.

The current in the resistive branch is in phase with the branch voltage, while the current in the capacitive branch leads the branch voltage by 90 degrees. Since the two branch voltages are the same, the current in the capacitive branch (I_C) must lead the current in the resistive branch (I_R) by 90 degrees. (Fig 4)

Fig 4



Line current: Since the branch currents in a parallel RC circuit are out of phase with each other, they have to be added vectorially to find the line current (Fig 5).

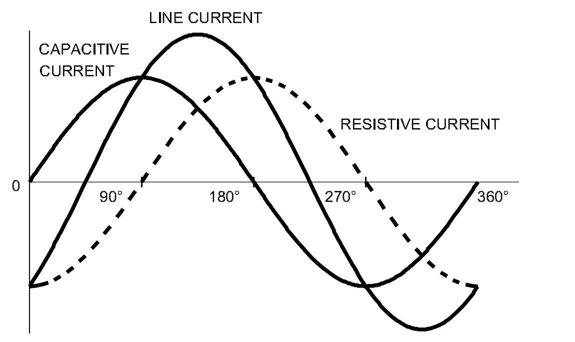
The two branch currents are 90 degrees out of phase, so their vectors form a right triangle, whose hypotenuse is the line current. The equation for calculating the line current, I_{LINE}, is

$$I_{LINE} = \sqrt{I_R^2 + I_C^2}$$

If the impedance of the circuit and the applied voltage are known, the line current can also be calculated from Ohm's Law.

$$I_{LINE} = \frac{E}{Z}$$

Fig 5



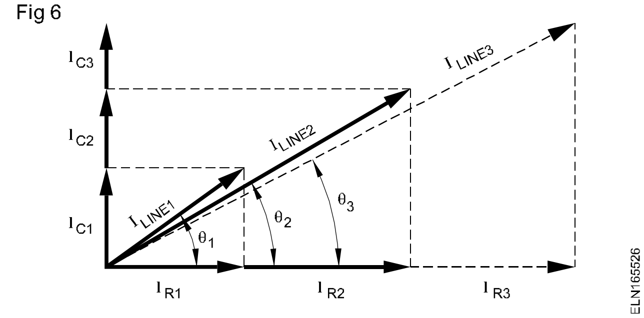
CAPACITIVE CURRENT LEADS THE RESISTIVE CURRENT BY 90°
THE LINE CURRENT IS THE VECTOR SUM OF THE RESISTIVE AND CAPACITIVE CURRENTS

In as much as the current in the resistive branch of a parallel RC circuit is in phase with the applied voltage, while the current in the capacitive branch leads the applied voltage by 90 degrees, the sum of the two branch currents, or line current, leads the applied voltage by some phase angle less than 90 degrees but greater than 0 degrees.

The exact angle depends on whether the capacitive current or resistive current is greater. If there is more capacitive current, the angle will be closer to 90 degrees; while if the resistive current is greater, the angle is closer to 0 degrees.

In cases where one of the currents is 10 or more times greater than the other, the line current can be considered to have a phase angle of 0 degrees if the resistive current is the larger (Fig 6). The value of the phase angle can be calculated from the values of the two branch currents with the equation:

Fig 6



$$\tan\theta = \frac{I_C}{I_R}$$

By substituting the quantitites $I_C = E/X_C$ and $I_R = E/R$ in the above equation, two other useful equations for calcualting the phase angle, θ, can be derived, they are:

$$\tan\theta = \frac{R}{E_C} \qquad \text{Cos}\,\theta = \frac{R}{Z}$$

Once you know the line current and the applied voltage in a parallel RC circuit, you can find the circuit power using the same equations you learned for parallel RL circuits. These are:

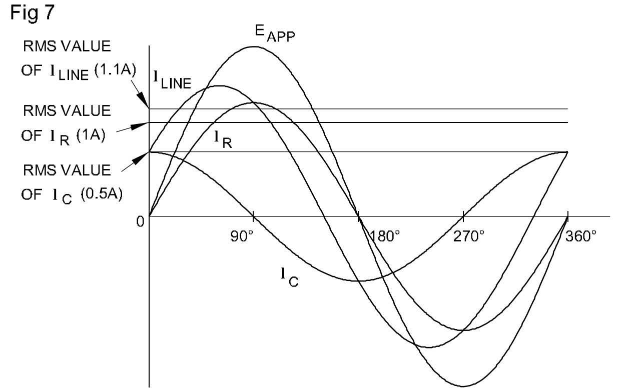
$$P_{APPARENT} = E_{APP} . I_{LINE}$$

$$P_{TRUE} = E_{APP} . I_{LINE} . \text{Cos}\ \theta$$

where cos θ is the power factor.

Current wave-forms: Since the branch currents in a parallel RC circuit are out of phase, their vector sum rather than their arithmetic sum equals the line current. This is the same condition that exists for the voltage drops in a series RC circuit. By adding the currents vectorially, you are adding their instantaneous values at every point, and then finding the average or effective value of the resulting current. This can be seen from the current wave-forms shown (Fig 7). They are the wave-forms for the circuit solved on the previous page.

Fig 7



EVERY POINT ON THE LINE CURRENT WAVEFORM (I_{LINE}) IS THE ALGEBRAIC SUM OF THE INSTANTANEOUS VALUES OF THE I_R AND I_C WAVEFORMS. THE RMS VALUE OF THE LINE CURRENT WAVEFORM IS THUS SHOWN TO BE EQUAL TO THE VECTOR SUM OF THE I_R AND I_C WAVEFORMS

Impedance: The impedance of a parallel RC circuit represents the total opposition to the current flow offered by the resistance of the resistive branch and the capacitive reactance of the capacitive branch. Like the impedance of a parallel RL circuit, it can be calculated with an equation that is similar to the one used for finding the total resistance of two parallel resistances.

However, just as you learned for parallel RL circuits, two vector quantities cannot be added directly, vector addition must be used. Therfore, the equation for calculating the impedance of a parallel RC circuit is

$$Z = \frac{RX_C}{\sqrt{R^2 + X_C^2}}$$

where $\sqrt{R^2 + X_C^2}$ is the vector addition of the resistance and capacitive reactance.

In cases where you know the applied voltage and the circuit line current, the impedance can be found simply by using Ohm's law in the form:

$$Z = \frac{E_{APP}}{I_{LINE}}$$

The impedance of a parallel RC circuit is always less than the resistance or capacitive reactance of the individual branches.

The relative values of X_C and R determine how capacitive or resistive the circuit line current is. The one that is the smallest, and therefore, allows more branch current to flow, is the determining factor.

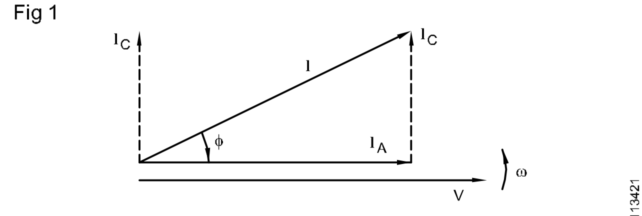
Thus, if X_C is smaller than R, the current in the capacitive branch is larger than the current in the resistive branch, and the line current tends to be more capacitive.

The opposite is true if R is smaller than X_C. When X_C or R is 10 or more times greater than the other, the circuit will operate for all practical purposes as if the branch with the larger of the two did not exist.

RC Parallel circuit - Admittance method

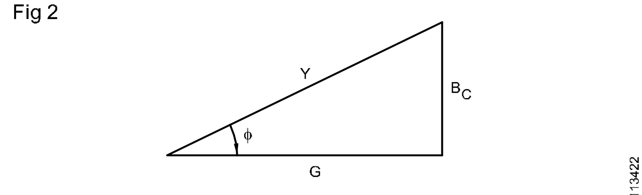
Admittance: In order to derive the admittance of a parallel circuit consisting of a resistance R and a capacitive reactance X_C we use the phasor diagram representation of the currents, I_A, I_C and I (Fig 1), and the corresponding admittance triangle (Fig 2).

Fig 1



PHASOR DIAGRAM

Fig 2



ADMITTANCE TRIANGLE

Admittance $Y = \sqrt{G^2 + B_C{}^2}$

Total current I = VY

The current triangle gives

Active current $I_A = I \cos \theta$

Reactive current $I_C = I \sin \theta$

Total current $I = \sqrt{I_A^2 + I_C^2}$

From both triangles, the phase relationship is given by

$$\tan \phi = \frac{I_C}{I_A} = \frac{B_C}{G} = \frac{R}{X_C}$$

We can derive the values of R and X_C if we know the voltage V, the current I and the phase angle ϕ.

$Y = \frac{V}{I}$ conductance $G = Y \cos \phi$

susceptance $B_C = Y \sin \phi$

$R = \frac{1}{G}$ and $X_C = \frac{1}{B_C}$.

Parallel connection of R and X_C (Fig 3)

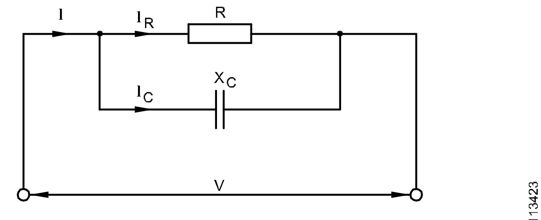
Graphic solution:

1 V as common vector

2 I_R in phase with V

3 I_C leads by 90^o

Fig 3



R.C. PARALLEL CIRCUIT

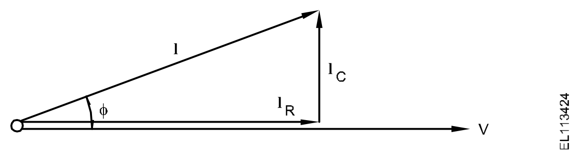
4 I as resultant (Fig 4)

5 f between V and I.

$$\frac{1}{Z} = \sqrt{\left(\frac{1}{R}\right)^2 + \left(\frac{1}{X_C}\right)^2}$$

$$Y = \sqrt{G^2 + B_C^2} \text{ (Refer Fig 4)}$$

Fig 4



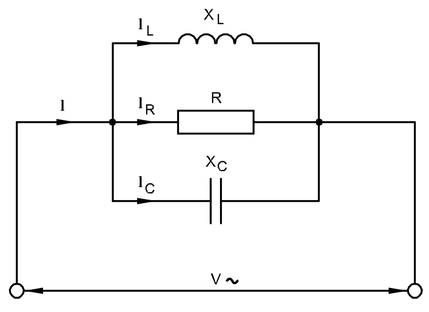
Comparison of series and parallel RC circuits

Quantity	Series RC circuit	Parallel RC circuit
Current	It is the same everywhere in circuit. Currents through R and C are, therefore, in phase.	It divides between resistive and capacitive branches. $I_{TOT} = \sqrt{I_R{}^2 + I_C{}^2}$ $I_R = \frac{E_{APP}}{R}$ $I_C = \frac{E_{APP}}{X_C}$ Current through C leads current through R by 0°
Voltage	Vector sum of voltage drops across R and C equals applied voltage (Fig 5). $E_{APP} = \sqrt{E_R{}^2 + E_C{}^2}$ Voltage across C lags voltage across R by 90°.	Voltage across each branch is the same as applied voltage. Voltages across R and C are, therefore, in phase. $E_R = E_C = E_{APP}$
Impedance	It is the vector sum of resistance and capacitive reactance. used. $Z = \sqrt{R^2 + X_C{}^2}$	It is calculated the same way as parallel resistances are, except that vector addition is $Z = \frac{RX_C}{\sqrt{R^2 + X_C{}^2}}$
Phase angle θ	It is the angle between the circuit current and the applied voltage. $\tan\theta = \frac{E_C}{E_R} = \frac{X_C}{R}$ $\cos\theta = \frac{R}{Z}$	It is the angle between line current and applied voltage. $\tan\theta = \frac{I_C}{I_R} = \frac{R}{X_C}$ $\cos\theta = \frac{R}{Z}$
Power	Power delivered by source is apparent power. Power actually consumed in the circuit is true power. Power factor determines what portion of apparent power is true power. $P_{APP} = E_{APP} I$	$P_{TRUE} = E_{APP} I \cos\theta$ P.F. = Cos θ
Effect of increasing frequency	X_C decreases, which in turn causes the circuit current to increase. Phase angle decreases,which means that the circuit is more resistive.	X_C drecreases, the capacitive branch current increases, and so line current also increases. phase angle increases, which means that the circuit is more capacitive.
Effect of increasing resistance	Phase angle decreases, which means that the circuit is more resistive	Phase angle increases, which means that the circuit is more capactive
Effect of increasing capacitance	Phase angle decreases, which means that the circuit is more resistive	Phase angle increases, which means that the circuit is more capactive

R, L and C Parallel circuit - Vector diagram

Parallel connection of R, X_L and X_C: X_L and X_C oppose each other, that is to say, I_L and I_C are in opposition, and partly oppose one another (Fig 1).

Fig 1



R, L & C PARALLEL CIRCUIT

$I_X = I_C - I_L$ or $I_L - I_C$, depending on whether the capacitive or inductive current dominates.

Graphic solution: when $I_L > I_C$

1 V as common value

2 I_R in phase with V

3 I_C leads by 90°

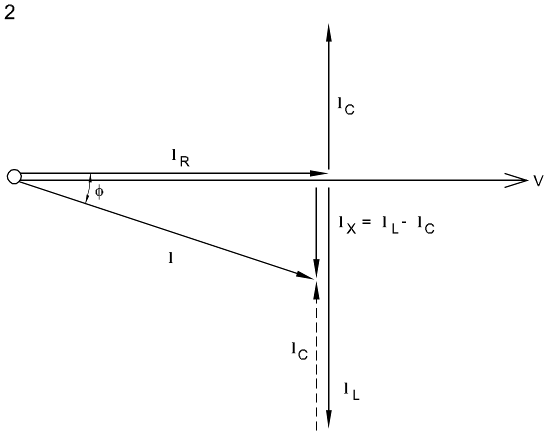
4 I_L lags by 90°

5 $I_X = I_L - I_C$

6 I as resultant

ϕ in this case inductive, I lags (Fig 2)

Fig 2



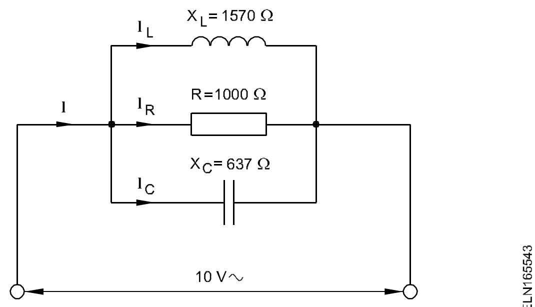
Particular case: X_L and X_C are equally large - I_L and I_C cancel each other. Z = R; parallel resonance occurs.

Currents in the reactances may be greater than the total current.

The calculation of the resonant frequency is the same as for the series connection.

Example: Calculate the value of I_T Z power factor and power for the circuit in Fig 3.

Fig 3



Given

$V_T = 10V$

$R = 1000\ \Omega$

$X_L = 1570\ \Omega$

$X_C = 637\ \Omega$

Known: Ohm's Law

$$I_T = \sqrt{(I_C - I_L)^2 + I_R^{\,2}}$$

Solution

$$I_C = \frac{10\text{ V}}{637\ \Omega} = 0.0157\text{ A} = 15.7\text{ mA}$$

$$I_L = \frac{10\text{ V}}{1570\ \Omega} = 0.0064\text{ A} = 6.4\text{ mA}$$

$$I_R = \frac{10\text{ V}}{1000\ \Omega} = 0.01 = 10\text{ mA}$$

$$I_T = \sqrt{(0.0157 - 0.0064)^2 + (0.01)^2}$$

$$= 0.0137\text{A} = 13.7\text{ mA}$$

$$Z = \frac{10\text{V}}{0.0137\text{ A}} = 730\ \Omega$$

$$\text{P.F} = \frac{Z}{R} \quad Y = \frac{1}{Z} \quad \text{and} \quad g = \frac{1}{R}$$

$$= \frac{730}{1000} = 0.73$$

$$= \frac{g}{Y} = \frac{1}{R} \times \frac{1}{1/Z} = \frac{Z}{R}$$

Parallel resonance circuits

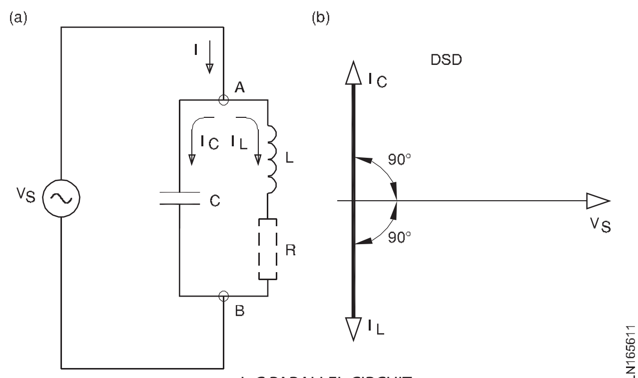
Objectives: At the end of this lesson you shall be able to
- **state the characteristics of R-L-C parallel circuits at resonance**
- **explain the term band-width in parallel LC circuits**
- **explain the storage action in parallel LC circuits**
- **list a few applications of parallel LC circuits**
- **compare the properties of series and parallel resonance circuits**

Parallel resonance

The circuit at Fig 1, having an inductor and a capacitor connected in parallel is called parallel LC circuit or parallel resonance circuit. The resistor R, shown in dotted lines indicate the internal DC resistance of the coil L. The value of R will be so small compared to the inductive reactance, that it can be neglected.

From Fig 1a, it can be seen that the voltage across L and C is same and is equal to the input voltage V_S.

Fig 1



L-C PARALLEL CIRCUIT

By Kirchhoff's law, at junction A,

$I = I_L + I_C$.

The current through the inductance I_L (neglecting resistance R), lags V_S by 90°. The current through the capacitor I_C, leads the voltage V_S by 90°. Thus, as can be seen from the phasor diagram at Fig 1b, the two currents are out of phase with each other. Depending on their magnitudes, they cancel each other either completely or partially.

If $X_C < X_L$, then $I_C > I_L$, and the circuit acts capacitively.

If $X_L < X_C$, then $I_L > I_C$, and the circuit acts inductively.

If $X_L = X_C$, then $I_L = I_C$, and hence, the circuit acts as a purely resistive.

Zero current in the circuit means that the impedance of the parallel LC is infinite. This condition at which, for a particular frequency, f_r, the value of $X_C = X_L$, the parallel LC circuit is said to be in parallel resonance.

Summarizing, for a parallel resonant circuit, at resonance,

$X_L = X_C$,

$Z_p = \infty$

$I_L = I_C$

$$f_r = \frac{1}{2\pi\sqrt{LC}}$$

$$I = \frac{V}{Z_P} \approx 0$$

In a parallel resonance circuit, with a pure L(no resistance) and a pure C(loss-less), at resonance the impedance will be infinite. In practical circuits, however small, the inductor will have some resistance. Because of this, at resonance, the phasor sum of the branch currents will not be zero but will have a small value I.

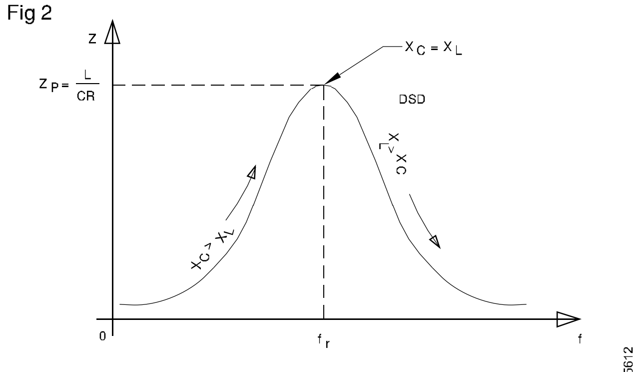
This small current I will be in phase with the applied voltage and the impedance of the circuit will be very high although not infinite.

Summarizing, the three main characteristics of parallel resonance circuit at resonance are,

- phase difference between the circuit current and the applied voltage is zero
- maximum impedance
- minimum line current.

The variation of impedance of a parallel resonance circuit with frequency is shown in Fig 2.

Fig 2



FREQUENCY VERSES IMPEDENCE OF A PARALLEL RESONANT CIRCUIT

In Fig 2, when the input signal frequency to the parallel resonance circuit is moved away from resonant frequency f_r, the impedance of the circuit decreases. At resonance the impedance Z_p is given by,

$$Z_P = \frac{L}{CR}$$

At resonance, although the circuit current is minimum, the magnitudes of I_L & I_C will be much greater than the line current. Hence, a parallel resonance circuit is also called current magnification circuit.

For further details on current magnification in parallel resonance refer reference books at the end of this book.

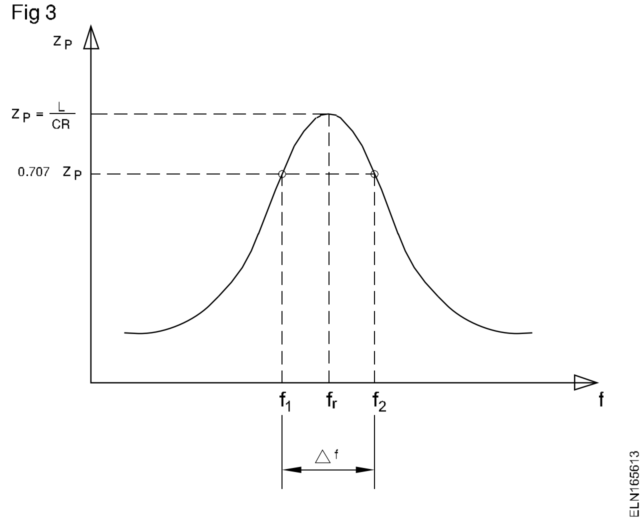
Bandwidth of parallel resonant circuits

As discussed in series resonance, all resonant circuits have the property of discriminating between the frequency at resonance(f_r), and those not at resonance. This discriminating property of the resonant circuit is expressed in terms of its **bandwidth(BW).**

In the case of series resonant circuits the response of the circuit at resonance frequency(f_r) is in terms of the line current(which is maximum), and in a parallel resonant circuit, it is in terms of the impedance(which is maximum).

The bandwidth of a parallel resonant circuit is also defined by the two points on either side of the resonant frequency at which the value of impedance Z_p drops to 0.707 or $1/\sqrt{2}$ of its maximum value at resonance, as shown Fig 3.

Fig 3



From Fig 3, the bandwidth of the parallel resonance circuit is,

Bandwidth, BW = $\Delta f = f_2 - f_1$

As can be seen in Fig 3, the value of Z_p is dependent on the resistance R of the coil (Z_p = L/CR). If R is less Z_p will be larger and vice versa.

Since the bandwidth depends on Z_p and Z_p depends on R, we can say that the bandwidth of a resonant circuit depends upon the resistance associated with the coil. The resistance of the coil in turn decides the Q of the circuit. Thus, the Q of the coil decides the band width of the resonant circuit and is expressed as,

$$\text{Bandwidth(BW)} = (f_2 - f_1) = \frac{f_r}{Q}$$

Storage action of parallel resonance circuit

At parallel resonance, though the circuit current is minimum(ideally zero), I_L and I_C will still be there. This I_L and I_C will be a circulating current in the closed loop formed by L and C.

This circulating current will be very high at resonance. This circulating current flip-flops between the capacitor and inductor, alternately charging and discharging each. When a capacitor or an inductor is charged, it stores energy. When it is discharged it gives up the energy stored in it. The current inside the LC circuit switches the stored energy back and forth between L and C. If the inductor had no resistance and if the capacitor was loss-free, then, no more external energy would be required to retain this flip-flop or oscillation of charging and discharging.

But, in a practical circuit, since ideal L and C cannot be obtained, some amount of the circulating energy is lost due to the resistance of the coil and the loss due to capacitor. This lost energy is the only energy the power supply source(V_S) must supply in the form of circuit current,I.

This current, therefore, is called as **make-up current.** It is this storage action of the parallel-resonant circuit which gives rise to the term **tank circuit**, often used with parallel resonant circuits. Hence, parallel resonant circuits are also called tank circuits.

Application of parallel resonant circuits

Parallel resonance circuits or tank circuits are commonly used in almost all high frequency circuits. Tank circuits are used as collector load in class-C amplifiers instead of a resistor load as shown in Fig 4.

Fig 4

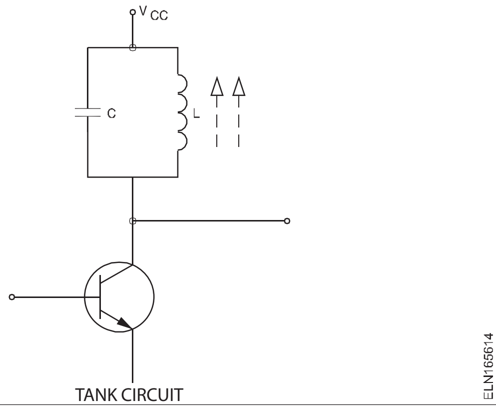


Table below gives a comparison between series resonant and parallel resonant circuit at frequencies above and below their resonant frequency f_r.

Property	Series circuit	Parallel circuit
	At resonant frequency	
Resonant frequency, f_r	$= \frac{1}{2\pi\sqrt{LC}}$	$= \frac{1}{2\pi\sqrt{LC}}$
Reactance	$X_L = X_C$	$X_L = X_C$
Impedance	Minimum (Z_r = R)	Maximum (Z_r = L/CR)
Current	Maximum	Minimum
Quality factor	$\frac{X_L}{R}$	$\frac{X_L}{R}$
Bandwidth	$\frac{X_L}{R}$	$\frac{X_L}{R}$
	Above resonant frequency	
Reactance	$X_L > X_C$	$X_C > X_L$
Impedance	Increases	Decreases
Phase difference	The current lags behind the applied voltage.	The current leads the applied voltage.
Type of reactance	Inductive	Capacitive
	Below resonant frequency	
Reactance	$X_C > X_L$	$X_L > X_C$
Impedance	Increases	Decreases
Phase difference	The current leads the applied voltage.	The current lags behind the applied voltage.
Type of reactance	Capacitive	Inductive

Power, energy and power factor in AC single phase system - Problems

Objectives: At the end of this lesson you shall be able to
- **state the relationship between power and power factor in single phase circuits**
- **state the connection diagram for measuring power factor using a direct reading meter.**
- **calculate the problem related to P.F and power in A.C circuits**

The power in a DC circuit can be calculated by using the formulae.

- $P = E \times I$ watts
- $P = E^2/R$ watts.

The use of the above formulae in AC circuits will give true power only if the circuit contains pure resistance. Note that the effect of reactance is present in AC circuits.

Power in AC circuit: There are three types of power in AC circuits.

- Active power (True power)
- Reactive power
- Apparent power

Active power (True power)**:** The calculation of active power in an AC circuit differs from that in a direct current circuit. The active power to be measured is the product of $V \times I \times \cos\theta$ where $\cos\theta$ is the power factor (cosine of the phase angle between current and voltage). This indicates that with a load which is not purely resistive and where the current and voltage are not in phase, only that part of the current which is in phase with the voltage will produce power. This can be measured with a wattmeter.

Reactive power (P_r): With the reactive power (wattless power)

$$P_r = V \times I \times \sin\theta$$

only that part of the current which is 90° out of phase (90° phase shift) with the voltage is used in this case. Capacitors and inductors, on the other hand, alternatively store energy and return it to the source. Such transferred power is called reactive power measured in volt/ampere reactive or vars. Unlike true power, reacitve power can do no useful work.

Apparent power: The apparent power, $P_a = V \times I$.

The measurement can be made in the same way as for direct current with a voltmeter and ammeter.

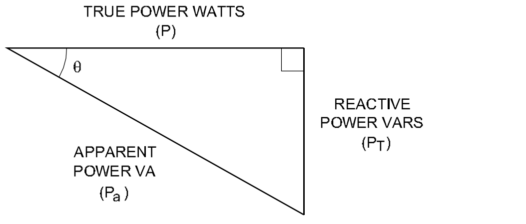
It is simply the product of the total applied voltage and the total circuit current and its unit is volt-ampere (VA).

The power triangle: A power triangle identifies three different types of power in AC circuits.

- True power in watts (P)
- Reactive power in vars (P_r)
- Apparent power VA (P_a)

The relationship among the three types of power can be obtained by referring to the power triangle. (Fig 1)

Fig 1



POWER TRIANGLE

Therefore

$$P_a^2 = P^2 + P_r^2 \text{ volt-amperes (VA)}$$

where `P_a' is the apparent power in volt-ampere (VA)

`P' is the true power in watts (W)

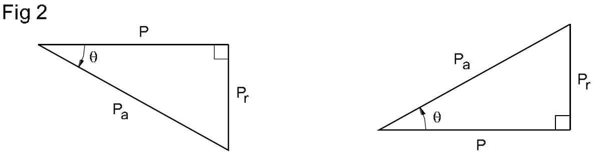
P_q is the reactive power in volt-amperes reactive. (VAR)

Power factor: The ratio of the true power delivered to an AC circuit compared to the apparent power that the source must supply is called the power factor of the load. If we examine any power triangle (Fig 2), you may see the ratio of the true power to the apparent power is the cosine of the angle θ.

$$\text{Power factor} = \frac{P}{P_a} = \cos\theta$$

From the equation, you can observe that the three powers are related and can be represented in a right-angled power triangle, from which the power factor can be obtained as the ratio of true power to apparent power. For inductive loads, the power factor is called lagging to distinguish it from the leading power factor in a capacitive load. (Fig 2)

Fig 2



(a) POWER TRIANGLE FOR A SERIES OR PARALLEL RL CIRCUIT.
(b) POWER TRIBNGLE FOR A SERIES OR PARALLEL RC CIRCUIT.

POWER TRIANGLES SHOWING THAT $\frac{P}{P_a}$=COS θ

A circuit's power factor determines how much current is necessary from the source to deliver a given true power. A circuit with a low power factor requires a higher current than a unity power factor circuit.

Single phase energy

The product of true power and time is known as energy.

(ie) Energy = T.Power x time

= Voltage x current x power factor x time

= VI Cos θ x t (time is in hour)

The unit of energy is watt hour and commercial unit is represented in 'KWH' (or) unit. (Board of trade unit. B.O.T)

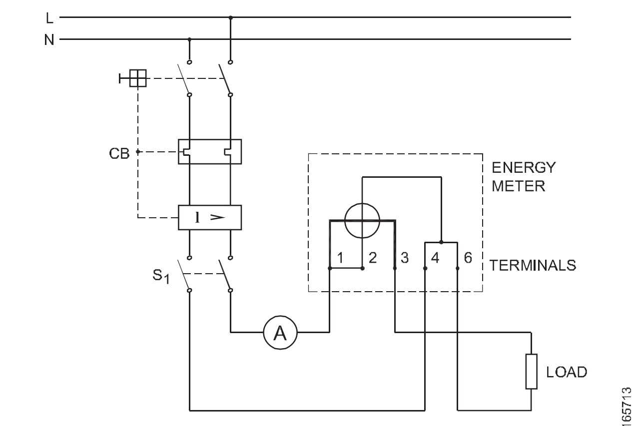
The energy depends upon the following factors:

- Voltage
- Current
- Power factor (load)
- Time

Single phase energy can be measured by energy meter. It contains 4 terminals (Incoming 2 and outgoing 2 common neutral)

The connection is shown in Fig 3.

Fig 3

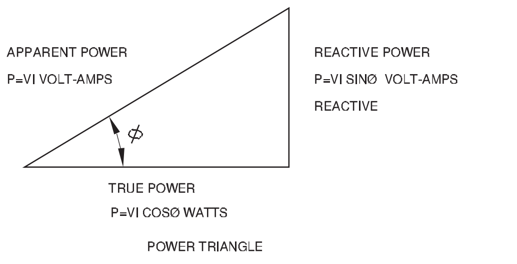


SINGLE PHASE ENERGY METER CONNECTION

Power in AC circuit having R L and C in series

As we have already studied, the power triangle has three components as shown in Fig 1.

Fig 1



POWER TRIANGLE

The above formula could be used in any AC single phase circuit. But the value of capacitive reactance and the inductive reactance decides whether the circuit is capacitive or inductive. When the value of the capacitive reactance is more than the value of inductive reactance, the PF will be leading or vice versa.

A series AC circuit consisting of 100 ohms, an inductance of 0.2 H and a capacitance of 120 μF are connected across 200 V 50c/s. Calculate the impedance, current, power factor and power absorbed.

The capacitive reactance = 1/ 2πfc ohms.

$$X_C = \frac{1 \times 10^6}{2 \times \pi \times 50 \times 120} = 26.53 \text{ ohms}$$

The inductive reactance

$X_L = 2\pi fL.$

$X_L = 2 \times \pi \times 50 \times 0.2 = 62.83$ ohms.

Therefore, $X_L - X_C = 62.83 - 26.53 = 36.30$ ohms.

$$\text{The impedance} = \sqrt{R^2 + (X_L - X_C)^2}$$

$$= \sqrt{100^2 + (62.83 - 26.53)^2}$$

$$= \sqrt{100^2 + (36.3)^2} = 106.4\text{ohms}$$

$$\text{The current} = \frac{\text{Voltage}}{\text{Impedence}} = \frac{200}{106.4} = 1.88\text{A}$$

$$\text{The power factor} = \frac{R}{Z} = \frac{100}{106.4} = 0.94 \text{ (lagging)}$$

As the value of X_L is greater than that of X_c the circuit is having a lagging PF.

The power absorbed = V I cos θ

= 200 x 1.88 x 0.94 = 353.4 W.

Example 1

Calculate the current and its power factor when a resistance of 10 ohms, an inductance of 0.1 H and a condenser of 100μF capacitance are connected in series across 220 V 50 c/s supply mains.

Solution

R = 10 ohms

L = 0.1 H

C = 100 μF

$X_C = 1/ 2\pi fC$

$$X_C = \frac{10^6}{2 \times 3.14 \times 50 \times 100}$$

= 31.85 ohms.

$X_L = 2\pi FL$

= 2 x 3.14 x 50 x 0.1

= 31.4 ohms.

$X = X_C - X_L = 31.85 - 31.4$

= 0.45 ohms.

$$Z = \sqrt{10^2 + (0.45)^2} = 10 \text{ ohms (approx.)}$$

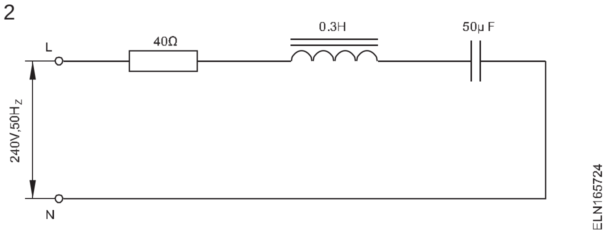
I = 220/ 10 = 22 A

PF = cos θ = R/Z = 10/10 = 1.Unity PF approx.

Example 2

In the circuit given in Fig 2.

Fig 2



Calculate:-

a the resulting reactance

b the impedance

c the current

d voltage drop across R,L&C

e draw the vector diagram

f Compare the calculated supply voltage with the applied supply voltage

g power factor

h power factor angle.

Solution

a Inductive reactance

$X_L = 2\pi fL$ = 2 x 3.14 x 50 x 0.3 = 94.2 ohms

$X_c = 1/2\pi fC$

$$X_C = \frac{1}{2\pi \times 50 \times 50 \times 10^{-6}} = \frac{10^6}{15714} = 63.69 \text{ ohms}$$

Net reactance = $X_L - X_C$ = 94.2 – 63.69 = 30.51 ohms.

The impedance for this circuit is Z

b $$Z = \sqrt{R^2 + (X_L - X_C)^2} = \sqrt{40^2 + (30.51)^2}$$

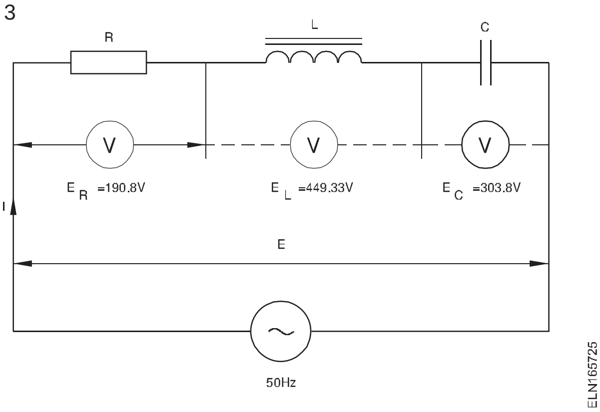
$$= \sqrt{1600 + 930.86} = \sqrt{2530.86} = 50.30 \text{ ohms}$$

c Current in given RLC series circuit

Current in this series circuit is I = E/ Z = 240/50.3= 4.77 amps.

d Voltage drop across R, L and C. (Fig 3)

Fig 3



E_R = IR = 4.77 X 40 = 190.8 volts

$E_L = IX_L$ = 4.77 X 94.2 ohms = 449.33 volts

$E_C = IX_C$ = 4.77 X 63.69 = 303.80 volts.

The vector sum of the voltage of 190.8 volts across the resistor and the difference between the drops across inductor and the capacitor ($E_L - E_C$) 145.53 volts is equal to the line voltage of 240 volts where

$$E = \sqrt{E_R^2 + (E_L - E_C)^2} = \sqrt{190.8^2 + (449.33 - 303.80)^2}$$

Therefore E = 240 volts.

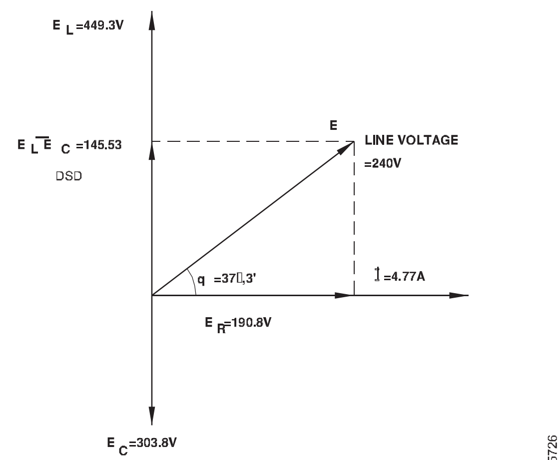
e Vector diagram is shown in Fig 4.

f The calculated voltage and the applied voltages are equal i.e say 240V

g The power factor Cos θ = E_R/ E = 190.8/240 = 0.798.

h The power factor angle is 37º3'.(Refer to Natural cosine table.)

Fig 4



VECTOR DIAGRAM

Application

These AC circuits having R, L and C in series are used in electronic tuning circuits in radio or TV to select the desired station/channel. A variable condenser called gang condenser is used to change the value of X_C equal to X_L at a desired station/channel frequency allowing only resistance in the circuit which, in turn, allows maximum current to flow in the circuit.

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

when $X_L = X_C$

$Z = R$

Current I = V/ R which is maximum.

At this condition the circuit is said to be resonant.

The frequency at resonance

$$f_R = \frac{1}{2\pi\sqrt{LC}}$$

as $X_L = X_C$

$2\pi f_R L = 1/2\pi/RC$

Hence

$$f_R = \frac{1}{2\pi\sqrt{LC}}$$

AC Parallel circuit problem

In practice all industrial and domestic electrical circuits are connected in parallel as we follow the constant voltage system. In a parallel circuit, the voltage across any branch circuit is the same as the supply voltage. However, the arithmetical sum of the branch currents does not necessarily equal the total current. This is true because the branch current values may be out-of-phase due to the fact that the loads connected may be resistive, inductive, (V lead I) or capacitive (I lead V).

Therefore, the total current must be obtained by adding or subtracting vectors of the branch currents either mathematically (admittance method) or graphically (vector method).

Vector method of solving AC parallel circuit

While drawing vectors for the AC parallel circuit, the following rules need to be followed.

i Draw the line voltage as the horizontal reference line as this voltage is the same across all branch circuits (X axis).

ii Draw the current in the pure resistive branch circuit in phase with the reference vector (X axis) to a scale.

iii Draw the current in the pure inductive branch circuit at 90º lagging the reference vector (Y axis) to the same scale as in I .

iv Draw the current in the pure capacitive branch circuit at 90º leading the reference vector (Y axis) to the same scale as in I.

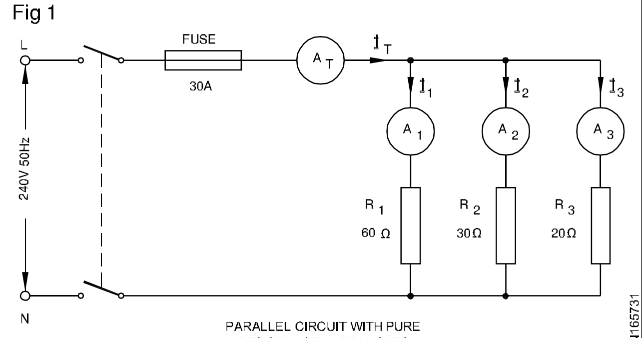
v Use vector subtraction and addition methods to obtain the total current.

Example 1

Parallel circuit with pure resistance

Let us consider an AC parallel circuit having three branches of pure resistance as shown in Fig 1.

Fig 1



PARALLEL CIRCUIT WITH PURE RESISTANCE IN BRANCHES

Determine the following for the circuit shown in Fig 1.

i The current taken by each branch (I_1, I_2 & I_3).

ii Vector diagram of branch currents and voltage.

iii The line current I_T.

iv The combined resistance.

v The power factor angle and the power factor.

vi The total power taken by the parallel circuit.

solution

i The branch current $I_1 = \frac{V}{R_1}$

$$= \frac{240}{60} = 4 \text{ amps}$$

Pure resistive, hence, in phase with the voltage.

The branch current $I_2 = \frac{V}{R_2}$

$$= \frac{240}{30} = 8 \text{ amps}$$

Pure resistive, hence, in phase with the voltage.

The branch current $I_3 = \frac{V}{R_3}$

$$= \frac{240}{20} = 12 \text{ amps}$$

Pure resistive, hence, in phase with the voltage.

ii Now draw the vector diagram following the rules mentioned above.

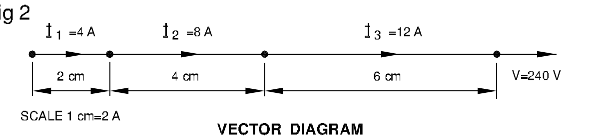
Decide a scale 1cm = 2 amps. (Fig 2)

iii Total current I_T is the sum of the branch currents I_1, I_2 and I_3 as they are in phase with each other.

$I_T = I_1 + I_2 + I_3$

$= 4 + 8 + 12 = 24$ amps.

Fig 2



VECTOR DIAGRAM

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iv As all branches have pure resistance load, the total resistance R_T is equal to the total impedance Z.

The total resistance $R_T = Z = \frac{V}{I_T}$

$= \frac{240}{24} = 10$ ohms.

v The power factor angle between the applied voltage and the current is found to be zero as per the vector diagram.

Power factor angle $= 0$

Power factor $= \cos ø$

$= \cos 0 = 1$ unity.

vi Total power taken by the circuit

$I_T^2 R_T = VI_T \cos ø = 24^2 \times 10$

$= 240 \times 24 = 5760$ watts.

(Total current I_T is in phase with the voltage.)

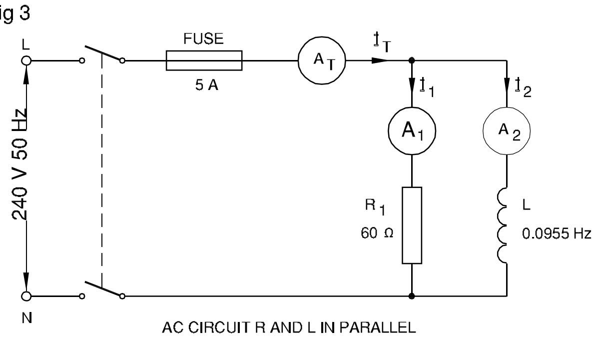
Example 2

Parallel circuit with R and X_L in branches

Now consider a parallel circuit having one branch consisting of a pure resistance and the other branch having pure inductance.

Determine the following for the circuit shown in Fig 3.

Fig 3



AC CIRCUIT R AND L IN PARALLEL

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i The branch currents.

ii Draw the vector diagram.

iii The total current.

iv The power factor angle and the power factor.

v The combined impedance.

vi The power in the circuit.

SOLUTION

i The branch current $I_1 = \frac{V}{R_1}$

$= \frac{240}{60} = 4$ amps

Pure resistive, hence, in phase with the voltage.

To calculate the branch current I_2 first find out the inductive reactance X_L.

$X_L = 2\pi FL = 2 \times \frac{22}{7} \times 50 \times 0.0955$

$= 30$ ohms.

So the branch current $I_L = \frac{V}{X_L} = \frac{240}{30} = 8$ amps.

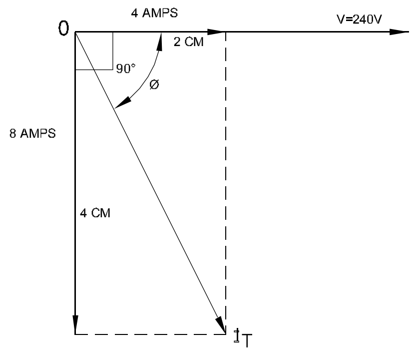
Pure inductive, hence, lags the applied voltage by 90°.

ii Draw the vector diagram by following the rules: Scale 1 cm = 2 amps. (Fig 4)

Complete the parallelogram to find the total current I_T.

Measure the angle ø and the length of $0I_T$.

Fig 4



VECTOR DIAGRAM - R AND L IN PARALLEL

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iii Measured angle is 63º 26'

Power factor = Cos 63º 26'

= 0.447 lagging.

iv Length of $0I_T$ = 4.47 cm.

Hence, I_T = 4.47 x 2 = 8.94 amps.

The combined impedance of the circuit = Z.

v Power taken by the circuit

$P = VI \cos \phi = I_1^2 R$

$= 240 \times 8.94 \times 0.447 = 4^2 \times 60$

= 959 watts approx. 960 watts.

Example 3

Parallel circuit with R and X_C

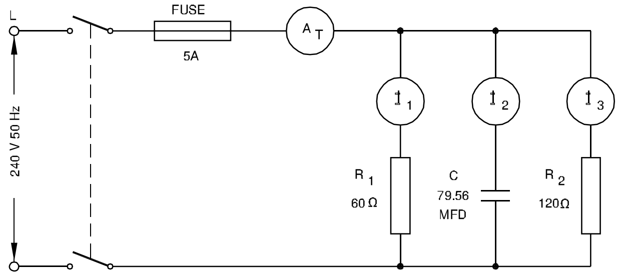
Now consider a parallel circuit having pure resistance in two branches and a pure capacitance in the third branch.

Find the following for the circuit shown in Fig 5.

i The branch currents.

ii Vector diagram of the branch currents.

Fig 5



AC CIRCUIT - R, L AND C IN PARALLEL

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iii Total current I_T.

iv Power factor angle.

v Power factor.

vi Power in the circuit.

Solution

i The branch current $I_1 = \dfrac{V}{RI} = \dfrac{240}{60}$ = 4 amps

Pure resistive, hence, in phase with the voltage.

To calculate the branch current I2 first find out the capacitive reactance X_C.

$$X_C = \frac{1}{2\pi FC} = \frac{1}{2 \times 3.142 \times 50 \times 79.56 \times 10^{-6}} = 40\Omega$$

So the branch current $I_2 = \dfrac{V}{X_C} = \dfrac{240}{40}$ = 6 amps

Pure capacitive, hence, current leads the applied voltages by 90º.

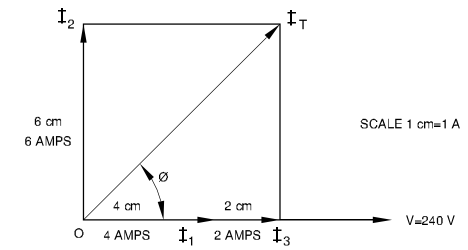
The branch current $I_3 = \dfrac{V}{R} = \dfrac{240}{120}$ = 2 amps

ii Draw the vector diagram to scale.

Complete the parallelogram to find the total current I_T. (Fig 6)

iii Measured length OI_T = 8.5cm.

Fig 6



VECTOR DIAGRAM - R, L AND C IN PARALLEL

ELN165736

Total current I_T. = 8.5 x 1 = 8.5 amps.

iv Measure the angle between the total current and the voltage.

Measured angle θ = 45º leading.

v Power factor cos ø = cos 45º = 0.707.

vi Power taken by the circuit.

$P = VI \cos\theta = (I_1^2 R_1 + I_3^2 R_2) = 240 \times 85 \times 0.707$

$= (4^2 \times 60 + 2^2 \times 120)$

1442 approx.1440 watts.

Example 4

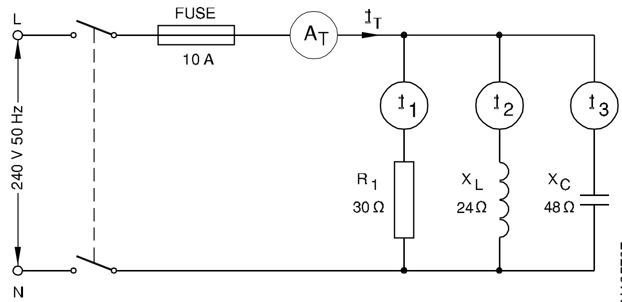
Parallel circuit with R, X_L and X_C

Now consider a parallel circuit having pure resistance in one branch, pure inductance in the 2nd branch and a pure capacitance in the 3rd branch as shown in Fig 7.

Find the following for the circuit shown in Fig 7.

i The branch currents.

Fig 7



ELN165737

ii The vector diagram.

iii Total current I_T.

iv Power factor angle.

v Power factor.

vi Power taken by the circuit.

vii Impedance of the circuit.

SOLUTION

i The branch current

$$I_1 = \frac{V}{R_1} = \frac{240}{30} = 8 \text{ amps in phase with V.}$$

The branch current

$$I_2 = \frac{V}{X_L} = \frac{240}{24} = 10 \text{ amps lagging 'V' by } 90^o.$$

The branch current

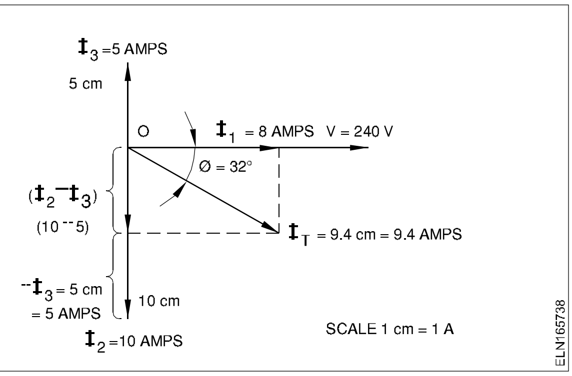
$$I_3 = \frac{V}{X_C} = \frac{240}{48} = 5 \text{ amps leading 'V' by } 90^o.$$

ii Draw the vector diagram to scale.

Scale 1 cm = 1 ampere

Complete the parallelogram to find the total current I_T (Fig 8).

Fig 8



iii Measured OI_T = 9.4 cm.

Total current

I_T = 9.4 x 1 = 9.4 amps.

iv Measure the angle between voltage and the total current.

Measured angle = 32º lagging.

v Power factor $\cos\theta = \cos 32^o = 0.85$.

vi Power taken by the circuit

$VI\cos\theta = I_1^2R$

$= 240 \times 9.4 \times 0.85 = 8^2 \times 30$

$= 1918$ approx.1920 watts.

vii Combined impedance Z

$$Z = \frac{V}{I_T} = \frac{240}{9.4} = 25.5 \text{ ohms}$$

Admittance method of solving AC parallel circuit

In solving problems in AC circuit of parallel groups either the vector or the admittance method could be used. However, there will be considerable difficulty in solving problems by vector method if series parallel combination groups are to be dealt with.

Though admittance method requires simple knowledge of mathematics, the numbers to be handled are decimals, their addition, subtraction, square and roots will make the solutions a little more cumbersome.

Let us find how this method could be used to solve problems in parallel AC circuits.

When several impedances say Z_1, Z_2 and Z_3 are connected in parallel, their combined impedance Z could be found by

$$Z = \frac{1}{\frac{1}{z_1}+\frac{1}{z_2}+\frac{1}{z_3}} \text{(Equation .... 1)}$$

$$\frac{1}{z} = \frac{1}{\frac{1}{z_1}+\frac{1}{z_2}+\frac{1}{z_3}} \ldots\ldots\ldots\ldots\ldots + \frac{1}{z_n} \text{ (Vector sum)}$$

Alternatively

$$Y = Y_1 + Y_2 + Y_3 \quad \text{Where } \frac{1}{Z} = Y$$

where the reciprocal impedance is called admittance, the unit is Siemens and the symbol is Y.

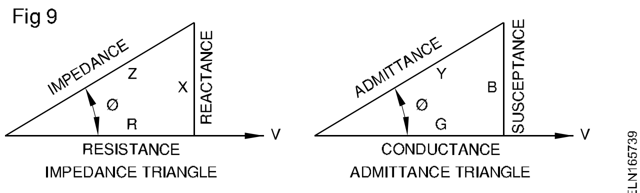
Just like impedance, the admittance also has two components as shown in Fig 9.

One component which is in phase with the voltage is called conductance, the unit is Siemens, and the symbol is G.

The other component which is in quadrature with the applied voltage V is called susceptance, the unit is Siemens and the symbol is B.

Admittance $Y = Y_1 + Y_2 + Y_3$ vectorially.

Fig 9



From the admittance triangle we have

$$Y = \sqrt{G^2 + B^2} \text{ .... Eqn.}$$

$$G = Y \cos\theta \text{ .... Eqn.}$$

Where $Y = \frac{1}{Z}$ and $\sin\theta = \frac{R}{Z}$

Hence G = Y x $\frac{R}{Z} = \frac{R}{Z^2} = \frac{R}{R^2 + X^2}$ .... Eqn.

B = Y Sin θ .... Eqn.

Where Y = $\frac{1}{Z}$ and sin θ = $\frac{X}{Z}$

Hence B = $\frac{1}{Z}$ x $\frac{X}{Z} = \frac{R}{Z^2} = \frac{R}{R^2 + X^2}$ .... Eqn.

Further when several resistances, reactances are connected in parallel the conductances of individual branches can be added to get the total conductance

$G = G_1 + G_2 + G_3 + ... + G_m$

Likewise when several reactances are connected in parallel, the susceptance of individual branches can be added algebraically to get the total susceptance. The susceptance due to inductive reactances are taken as +ve sign where the susceptance due to capacitive reactances are taken as –ve sign.

$B = b_1 + b_2 + (-b_3)$ ....

Example 1

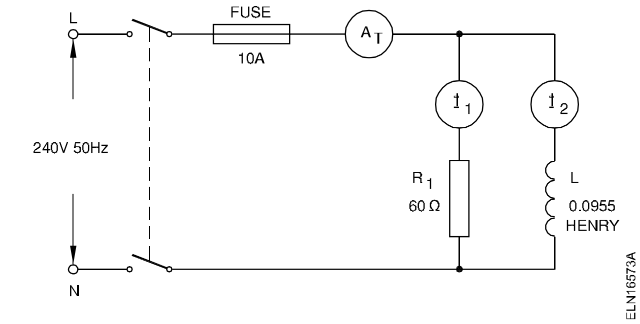
Parallel circuit with R and XL in branches.

Determine the following for the circuit shown in Fig 10.

i Conductance in branch circuits:

The conductance $G = g_1 + g_2$

Fig 10



where g_1 and g_2 are the conductance of branch 1 and 2 respectively.

In branch 1

$$g_1 = \frac{R_1}{R_1^2 + X_1^2} = \frac{60}{60^2 + 0^2}$$

$$= \frac{60}{60^2} = \frac{1}{60} = 0.01667 \text{ Siemens}$$

$$b_1 = \frac{X}{R_1^2 + X_1^2} = \frac{0}{60^2 + 0^2}$$

In branch 2

$$X_L = 2\pi fL = 2 \infty \frac{22}{7} \infty 50 \infty 0.0955 = 30 \text{ ohms}$$

$$g_2 = \frac{R_1}{R_2^2 + X_2^2} = \frac{0}{0^2 + 30^2} = 0$$

$$b_2 = \frac{X}{R_L^2 + X^2} = \frac{30}{0^2 + 30^2} = \frac{1}{30} = 0.033 \text{Siemens}$$

Admittance $Y = \sqrt{G^2 + B^2}$

where $G = g_1 + g_2 = 0.01667 + 0 = 0.01667$ Siemens

and $B = b_1 + b_2 = 0 + 0.0333 = 0.0333$ Siemens

i.e $Y = \sqrt{0.01667^2 + 0.0333^2} = 0.0372$ Siemens

= 0.0372 Siemens

The branch current $I_1 = \frac{V}{Z_1}$

$$\frac{V}{R} = \frac{240}{60} = 4 \text{amps in phase with the voltage}$$

The branch current $I_2 = \frac{V}{Z_2}$

$$\frac{V}{X_L} = \frac{240}{30} = 8 \text{amps}$$

lagging behind the applied voltage by 90°.

Total current = $I_T = \sqrt{I_1^2 + I_2^2}$

$$= \sqrt{4^2 + 8^2} = \sqrt{16 + 64}$$

= 8.94 amps

Alternatively, $I = \frac{V}{Z}$ = VY = 240 x 0.0372

= 8.94 amps.

Power factor $= \frac{G}{Y} = \frac{I_1}{I_T}$

$$= \frac{0.01667}{0.0372} = \frac{4}{8.94} = 0.448 \text{ approx. } 0.447.$$

So power factor angle = 63° 26'.

Impedance of the circuit $Z = \frac{1}{Y} = \frac{1}{0.0372} = 26.88$ ohms

Power taken by the circuit = VI cos ø

= 240 x 8.94 x 0.447

= 959 watts.

Example 2

In Fig 11, Parallel circuit with R, X_L and X_c

Find the following.

i Conductance and susceptance of each branch.

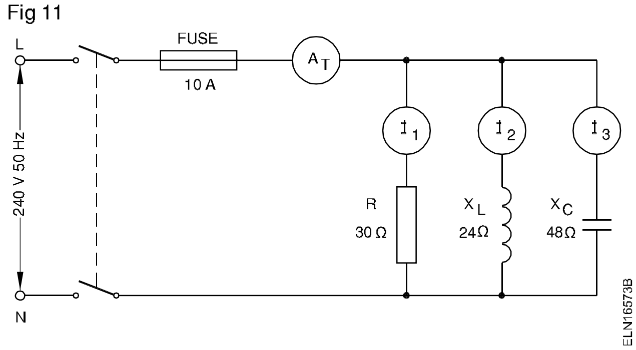
ii Total G, B and Y.

iii Branch currents.

iv PF and PF angle.

v Power taken by the circuit.

Fig 11



i Conductance in branch circuits

$$g_1 = \frac{R_1}{Z_1^2} = \frac{30}{30^2} = \frac{1}{30}$$

= 0.0333 siemens

$$g_2 = \frac{R_2}{Z_2^2} = \frac{0}{24^2} = 0$$

$$g_3 = \frac{R_3}{Z_3^2} = \frac{0}{48^2} = 0$$

Susceptance in branch cirucits

$$b_1 = \frac{X_1}{Z_1^2} = \frac{0}{30^2} = 0$$

$$b_2 = \frac{X_2}{Z_2^2} = \frac{24}{24^2} = \frac{1}{24}$$

= 0.04167 siemens

$$b_3 = \frac{-X_3}{Z_1^2} = \frac{-48}{-48^2} = -\frac{1}{48}$$

= - 0.02083 siemens

ii Total conductance G = $g_1 + g_2 + g_3$

= 0.0333 + 0 + 0

= 0.0333 Siemens.

Total susceptance B = $b_1 + b_2 + b_3$

= 0 + 0.04167 + (– 0.02083)

= 0.02084 Siemens.

$$Y = \sqrt{G^2 + B^2}$$

$$= \sqrt{0.333^2 + 0.02084^2}$$

= 0.03928 Siemens.

iii The branch current $I_1 = \frac{V}{Z_1}$

$$= \frac{V}{R} = \frac{240}{30} = 8 \text{ amps in phase with V}$$

The branch current $I_2 = \frac{V}{Z_2}$

$$\frac{V}{X_L} = \frac{240}{24} = 10 \text{ amps lagging } 90° \text{ with V}$$

The branch current $I_3 = \frac{V}{X_3}$

$$= \frac{240}{48} = 5 \text{ amps lagging } 90° \text{ with V}$$

Total current

$$I_T = \sqrt{I_1^2 + (I_2 - I_3)^2}$$

$$= \sqrt{8^2 + (10-5)^2} = \sqrt{89}$$

= 9.43 amps

Alternatively

I_T = VY = 240 X 0.03928

= 9.43 amps.

iv Power factor $= \frac{G}{Y} = \frac{I_R}{I_T}$

$$= \frac{0.0333}{0.03929} = \frac{8}{9.43}$$

= 0.848.

v Power factor angle = 32° lagging.

Power taken by the circuit = VIcos ø

= 240 x 9.43 x 0.848

= 1919 watts.

Total impedance = Z = $\frac{1}{Y}$

$$\frac{1}{0.03929} = 25.5 \text{ ohms}$$

Check these answers with the answers obtained by the vector method.

Power factor - improvement of power factor

Objectives: At the end of this lesson you shall be able to
- **define power factor - explain the causes of low power factor**
- **list out disadvantage of low power factor and advantage of higher power factor in a circuit**
- **explain the methods to improve the power factor in an AC circuit**
- **illustrate the importance of power factor improvement in industries**
- **distinguish between leading, lagging and zero PF**
- **state the recommended power factor as per ISI 7752 (Part I) 1975 for electrical equipment.**

Power Factor (P.F.)

The power factor is defined as the ratio of true power to apparent power and it is denoted by Cos θ.

$$\text{i. e. Power Factor} = \frac{\text{True Power }(W_T)}{\text{Apparent Power}(W_a)} = \text{Cos } \theta$$

$$\text{or Cos } \theta = \frac{W_T}{V \times I}$$

Where W_T is the real power (true power) and is measured in watts or some times in kilowatts (kW). Similarly the product VI is known as the apparent power measured in volt amperes or sometimes in kilo-volt amperes written as kVA.

The majority of AC electrical machines and equipment draw from the supply the apparent power (kVA) which exceeds the required useful power (KW). This is due to the reactive power (kVAR) necessary to produce the alternating magnetic field in motors and transformers.

The ratio of useful power (kW) to apparent power (kVA) is termed the PF of the load. The reactive power is indispensable and constitutes an additional demand on the system.

The principal cause of a low power factor is due to the reactive power flowing in the circuit. The reactive power mostly due to inductive load rather than capacitive load.

Variation in power factor and the type of circuits

The following are the different conditions of the power factor in different circuits.

Unity power factor

A circuit with a unity power factor will have equal real and apparent power, so that the current remains in phase with the voltage, and hence, some useful work can be done. (Fig 1a)

Leading power factor

A circuit will have a leading power factor if the current leads voltage by an angle q of electrical degrees and the true power will be less than the apparent power. Mostly capacitive circuits and synchronous motors operated at over excitation contribute for leading power factor. (Fig 1b)

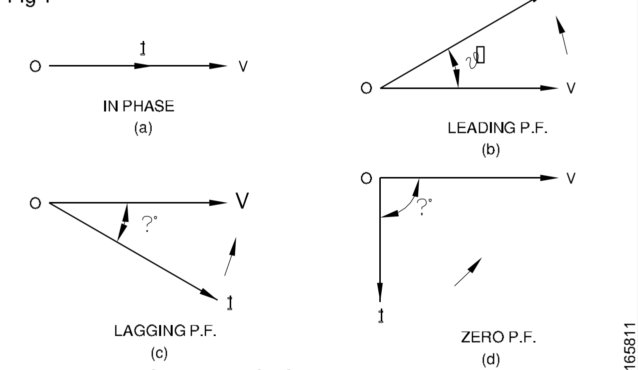
Lagging power factor

In such a circuit the true power is less than the apparent power and current lags behind the voltage by an angle, in electrical degrees. Mostly inductive loads like induction motors and induction furnaces account for lagging power factor. (Fig 1c)

Zero power factor

When there is a phase difference of 90° between the current and voltage, the circuit will have zero power factor and no useful work can be done. Pure inductive or pure capacitive circuits account for zero power factor. (Fig 1d)

Fig 1



PHASE RELATIONSHIP BETWEEN V AND I

> **The power factor can be one or less than one but can never be greater than one.**

Table 1 shows the most common electrical appliances used, the power in watts and the average power factor.

TABLE 2 shows the natural power factor of the various installations used in the industries.

TABLE 1

Power factor for single phase electrical appliances and equipment (Reference IS 7752 (Part I) - 1975)

Sl.No.	Appliance/Equipment	Power output		Average natural power factor
		Min.(W)	Max.(W)	
1	Neon sign	500	5000	0.5 to 0.55
2	Window type air- conditioners	750	2000*	0.75 to 0.85 0.68 to 0.82 0.62 to 0.65
3	Mixer	150	450	0.8
4	Coffee grinder	200	400	0.75
5	Refrigerator	200	800	0.65
6	Freezer	600	1000	0.7
7	Shaver	80	250	0.6
8	Table fan	25	120	0.5 to 0.6
9	Ceiling fan	60	100	0.5 to 0.7
10	Exhaust fan	150	350	0.6 to 0.7
11	Sewing machine	80	120	0.7 to 0.8
12	Washing machine	300	450	0.6 to 0.7
13	Radio	25	450	0.8
14	Vacuum cleaner	200	450	0.7
15	Tube light	40	100	0.5
16	Clock	5	10	0.9

* Starts dropping when compressor motor is not in circuit.

TABLE 2

Power factor for three-phase electrical installations (Reference IS 7752 (Part I) - 1975)

Sl.No.	Type of installation	Natural power factor
1	Cold storage and fisheries	0.7 to 0.80
2	Cinemas	0.78 to 0.80
3	Confectionery	0.77
4	Dyeing and printing (Textile)	0.60 to 0.87
5	Plastic moulding	0.57 to 0.73
6	Film studios	0.65 to 0.74
7	Heavy engineering works	0.48 to 0.75
8	Pharmaceuticals	0.75 to 0.86
9	Oil and paint manufacturing	0.51 to 0.69
10	Printing press	0.65 to 0.75
11	Food products	0.63
12	Laundries	0.92
13	Flour mill	0.61
14	Textile mills	0.86
15	Oil mill	0.51 to 0.59
16	Woolen mills	0.70
17	Cotton press	0.63 to 0.68
18	Foundries	0.59
19	Tiles and mosaic	0.61
20	Chemicals	0.72 to 0.87
21	Rolling mills	0.72 to 0.60
22	Irrigation pumps	0.50 to 0.70

Causes of low power factor

The following are the reasons.

i In industrial and domestic fields, the induction motors are widely used. The induction motors always take lagging current which results in low power factor.

ii The industrial induction furnaces have low power factor.

iii The transformers at substations have lagging power factor because of inductive load and magnetising currents.

iv Inductive load in houses like fluorescent tubes, mixers, fans etc.

The disadvantages of low power factor are as follows.

a For a given true power, a low power factor causes increased current, thereby, overloading of the cables, generators, transmission and distribution lines and transformers.

b Decreased line voltage at the point of application (voltage drop at consumer end) due to voltage drop and power losses in the supply system.

c Inefficient operation of plant and machine (efficiency drops due to low voltage).

d Penal power rates (increased electricity bills).

The advantages of high power factor are as follows.

As the higher PF for a given load, reduces the current, there will be:

a a possibility of connecting extra load on existing generators and transmit additional power through the same lines

b lesser losses and voltage drop in lines; thereby, transmission efficiency is high and the voltage at the point of application will be normal without much drop

c normal voltage improves the efficiency of operation of plants and machinery

d reduction in electricity bills for the given load during the given time.

Method of improving the power factor

To improve the power factor of a circuit, two methods are used:

i to run a lightly loaded synchronous motor with over-excitation on that line in which the PF is to be improved

ii to connect capacitors in parallel with the load.

Usually the capacitor method is used in Indian factories.

Synchronous condenser method

The synchronous motor is used in certain industries as well as in receiving end substations to drive a mechanical load and also to correct the power factor. An over-excited synchronous motor draws leading current to compensate the lagging current taken by the other loads.

The leading volt-ampere reactive power taken by a synchronous motor, when over- excited will be opposite in nature to the lagging voltage pure reactive due to inductive loads, and, thereby, reduces the volt-ampere reactive component to improve the power factor.

Example

A factory is having a load of 100 kW working at 0.6 PF lagging. A synchronous motor is connected in the factory and is made to run over-excited to improve the power factor. The synchronous motor is of 30 kW and is working at 0.8 PF leading. Calculate the following:

i the true power in watt, aspperent power in VAR for the factory load at 0.6p.f lagging.

ii The true power in watt, apparent power in volt- ampere and leading reactive power in VAR for the synchoronous motor at 0.8P.F lagging.

iii The true power in watt, reactive power in VAR and apparent power in Volt - ampere and PF supplied by the feeder lines.

i Factory Load

Load in kW = 100 kW

Load in watts = 100×10^3 watts

Load in volt-amperes = $\dfrac{\text{True power}}{\text{PF}} = \dfrac{100\times10^3}{0.6}$

= 167×10^3 volt - amperes

Load in vars = Volt ampere x $\sin\theta$

= $\cos\theta = 0.6$

= $\theta = 53.1^o$

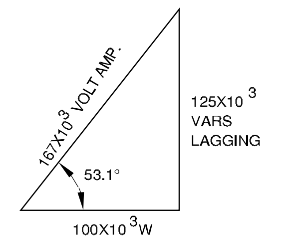
= $\sin\theta = \sin 53.10 = 0.8$

Load in vars = $167 \times 10^3 \times 0.8$

= 133.6×10^3 vars lagging

Refer to Fig 2.

Fig 2



FACTORY LOAD - VECTOR REPRESENTATION

ii Synchronous motor

Motor load in kW = 30 kW = 30×10^3 watts

Motor load in volt - amperes= $\dfrac{\text{True power}}{\text{PF}} = \dfrac{30\times10^3}{0.8}$

= 37.5×10^3 volt - amperes

Motor load in vars $= \text{Volt ampere} \sin\theta$

$\cos\theta = 0.8$

$\theta = 36.1^o$

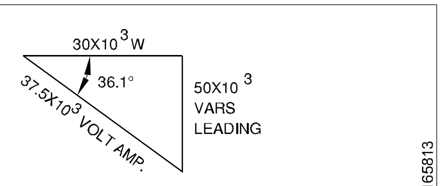
$\sin\theta = \sin 36.1^o = 0.6$

Motor load in vars $= 37.5 \times 10^3 \times 0.6$

$= 22.5 \times 10^3$ vars lagging

Refer to Fig 3.

Fig 3



SYNCHRONOUS MOTOR - VECTOR REPRESENTATION

iii Feeder line

Condition: Combined load condition for improvement of PF by the synchronous motor

Total load in watts = Factory true power + true power taken by synchronous motor

$= 100 \times 10^3 + 30 \times 10^3$

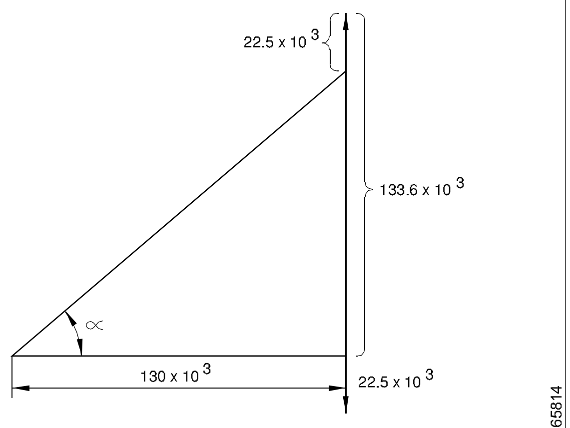
$= 130 \times 10^3$ watts

Total load in V_{ARS} = factory reactive power (Inductive) – syn. motor reactive power (Capacitance)

$= 133.6 \times 10^3 - 22.5 \times 10^3\ V_{ARS}$ lagging

$= 111.1 \times 10^3\ V_{ARS}$ lagging

Fig 4



LOAD + SYNCHRONOUS MOTOR
(VECTOR REPRESENTATION)

This could be represented by a vector diagram as shown in the Fig 4.

$$\text{Now } \tan\alpha = \frac{\text{Opp. side}}{\text{Adj. side}} = \frac{111.1\text{x}10^3}{130\text{x}10^3} = 0.8546$$

Angle $\alpha = 40.5^o$

Power factor of the factory after the connection of synchronous motor $= \cos\theta = \cos 40.5^o = 0.7604$

The PF has improved from 0.6 to 0.7604 by the use of the synchronous motor.

Present volt-amperes supplied by the factory

$$= \frac{\text{True power}}{\text{PF}} = \frac{\text{Truepower}}{\cos\alpha}$$

$$= \frac{130 \times 10^3}{\cos 40.5^o} = \frac{130 \times 10^3}{0.7604}$$

$= 171 \times 10^3$ Volt amperes

Condenser method

Capacitors when used for PF improvement are connected in parallel to the supply. In three-phase circuits the capacitors are connected in delta across the load lines. Now automatic devices are available which can be connected to the supply lines to detect low power factor and to switch on the required capacity of capacitors in the line to improve the power factor.

Normally these capacitors are provided with discharge resistances to discharge the stored energy. However, no capacitor terminal should be touched to avoid shock.

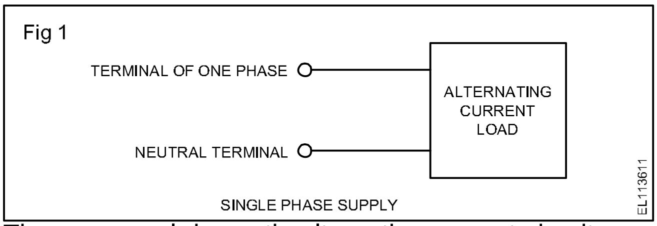
3-Phase AC fundamentals

Objectives: At the end of this lesson you shall be able to
- **state and describe the generation of 3-phase system with single loops**
- **state the advantages of the 3-phase system over a single phase system**
- **state and explain the 3-phase, 3-wire, and 4-wire system**
- **state and explain the relation between phase and line voltage.**

Introduction

When a piece of electrical equipment is plugged into the socket of a normal alternating current supply (e.g. a ring main circuit), it is connected between the terminal of one phase and the neutral wire. (Fig 1)

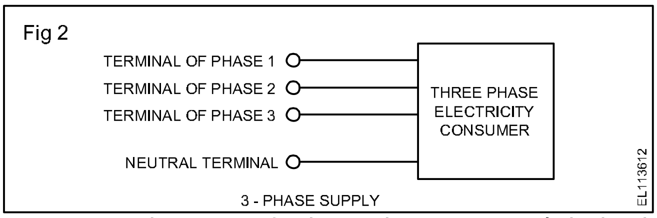
Fig 1



Thus a normal domestic alternating current circuit may also be described as a single-phase circuit.

Similarly, a three-phase power consumer is provided with the terminals of three phases. (Fig 2)

Fig 2



One great advantage of a three-phase AC supply is that it can produce a rotating magnetic field when a set of stationary three-phase coils is energized from the supply. This is the basic operating principle for most modern rotating machines and, in particular, the three-phase induction motor.

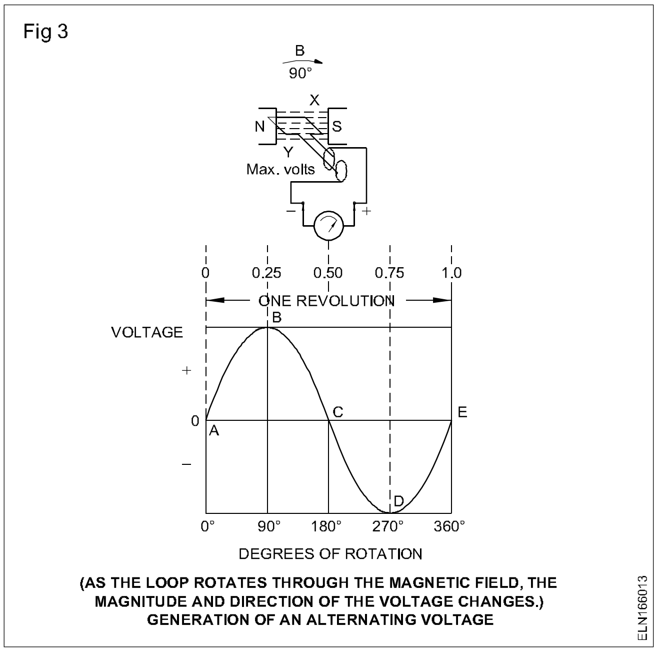
Further, lighting loads can be connected between any one of the three phases and neutral.

Review: Further to the above two advantages the following are the advantages of polyphase system over single phase system.

- 3-phase motors develop uniform torque whereas single phase motors produce pulsating torque only
- Most of the 3-phase motors are self starting whereas single phase motors are not
- Power factor of 3-phase motors are reasonably high when compared to single phase motors
- For a given size the power out put is high in 3-phase motors whereas in single phase motors the power output is low.
- Copper required for 3-phase transmission for a given power and distance is low when compared to single phase system.
- 3-phase motor like squirrel cage induction motor is robust in construction and more are less maintenance free.

The basic principle used in generating an alternating voltage is that of rotating a wire loop at a constant angular speed in a uniform magnetic field. (Fig 3) The alternating voltage thus produced varies sinusoidally with time.

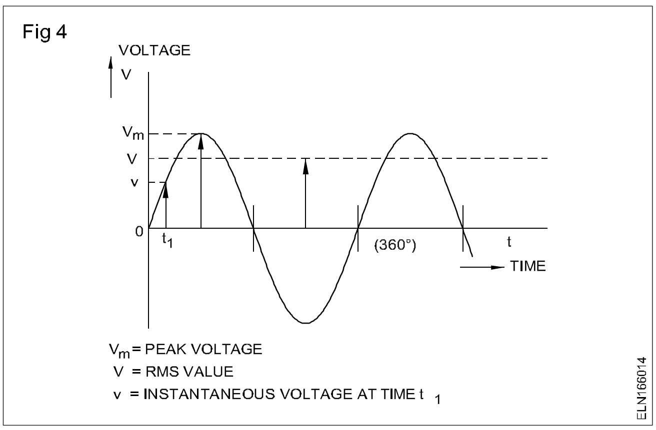
Fig 3



(AS THE LOOP ROTATES THROUGH THE MAGNETIC FIELD, THE MAGNITUDE AND DIRECTION OF THE VOLTAGE CHANGES.) GENERATION OF AN ALTERNATING VOLTAGE

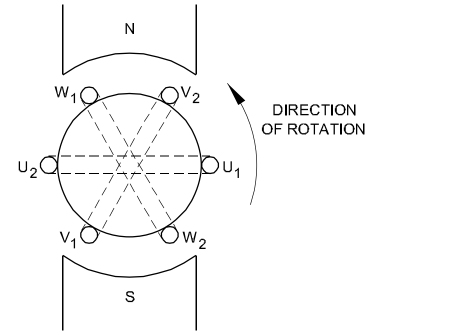
The effective (RMS) value is the same as that of a direct current that would produce the same heating effect, RMS voltage and frequency are usually quoted for a sinusoidal alternating voltage (Fig 4).

Fig 4



Three-phase generation: To generate three-phase voltages, a similar method to that used for generating single-phase voltages is employed but with the difference that, this time, three wire loops U_1, U_2, V_1, V_2 and W_1, W_2 rotate at a constant angular speed about the same axis in the uniform magnetic field. U_1, U_2, V_1, V_2 and W_1, W_2, are displaced 120° in position with respect to each other, permanently. (Fig 5)

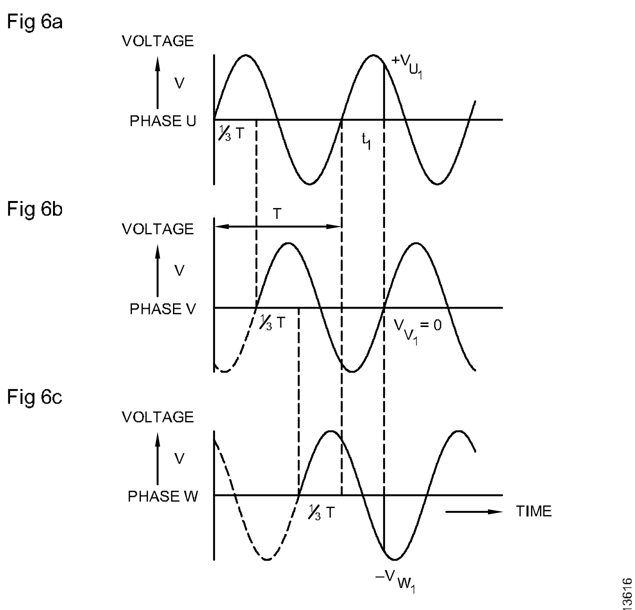
Fig 5



SIMPLIFIED THREE – PHASE ALTERNATOR

For each wire loop, the same result is obtained as for the alternating voltage generator. This means that an alternating voltage is induced in each wire loop. However, since the wire loops are displaced by 120° from each other, and a complete revolution (360°), takes one period, the three induced alternating voltages are delayed in time by a third of a period with respect to each other.

Because of the spatial displacement of the three wire loops by 120°, three alternating phase voltages result, which are displaced by one third of a period, T, with respect to each other. (Fig 6)



PHASE DISPLACEMENT OF 3 - PHASE

To distinguish between the three phases, it is a common practice in (heavy current) electrical engineering to designate them by the capital letters U,V and W or by a colour code red, yellow and blue. At a time 0, U is passing through zero volts with positively increasing voltage. (Fig 6a) V follows with its zero crossing 1/3 of the period later (Fig 6b), and the same applies to W with respect to V. (Fig 6c)

In three-phase networks, the following statements can be made about the three-phase voltages.

- The three-phase voltages have the same frequency.
- The three-phase voltages have the same peak value.
- The three-phase voltages are displaced by one third of a period in time with respect to each other.
- At every instant in time, the instantaneous sum of the three voltages

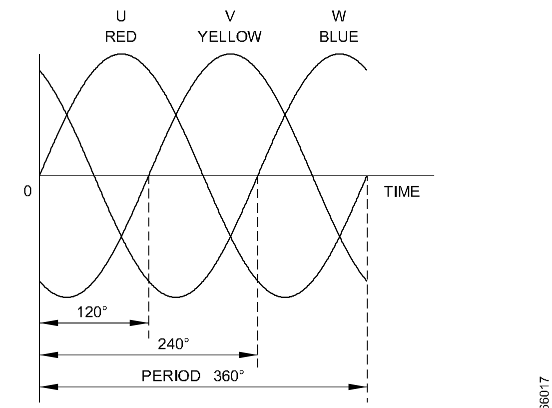
$$V_U + V_V + V_W = 0.$$

The fact that the sum of the instantaneous voltages is zero is illustrated in Fig 6. At time t_1, U has the instantaneous value V_U. At the same time, $V_V = 0$, and the instantaneous value for W is $-V_W$. Because V_U and V_W have the same value but are opposite in sign, it follows that

$$V_{U1} + V_{V1} + V_{W1} = 0.$$

The three voltages of the same amplitude and frequency are shown together in Fig 7.

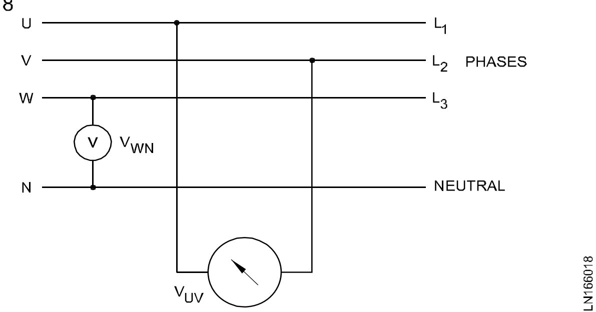
Fig 7



COMBINED WAVE - FORMS OF THREE PHASE SUPPLY

Three-phase network: A three-phase network consists of three lines or phases. In Fig 8, these are indicated by the capital letters U, V and W.

Fig 8

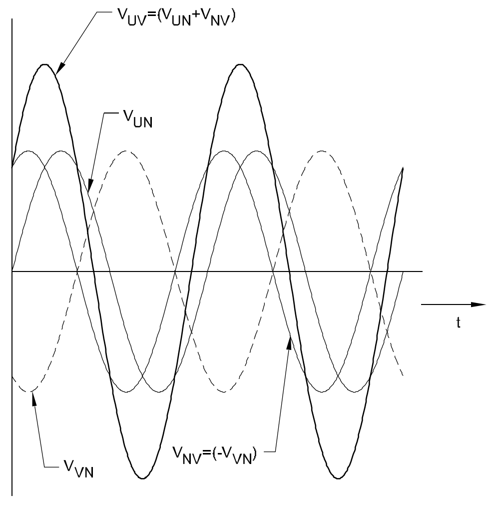


The return lead of the individual phases consists of a common neutral conductor N, which is described later in more detail. Voltmeters are connected between each of the lines U, V and W, and the neutral line N. They indicate the RMS (effective) values of the voltages between each of the three phases and neutral.

These voltages are designated as phase voltages V_{UN}, V_{VN} and V_{WN}.

The individual, phase voltages all have the same magnitude. They are simply displaced from each other by one third of a period in time. (Fig 9)

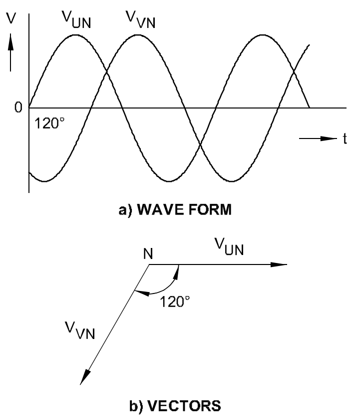
Fig 9



The individual instantaneous, peak and RMS values are the same as for a single-phase alternating voltage.

Line and phase voltage: If a voltmeter is connected directly between line U and line V (Fig 10), the RMS value of the voltage V_{UV} is measured, and this is different from any of the three phase voltages.

Fig 10



Its magnitude is directly proportional to the phase voltage. The relationship is shown in Fig 9, where the time-variation wave- forms of V_{UV} and the phase voltages V_{UN} and V_{VN} are drawn.

V_{UV} has a sinusoidal wave-form and the same frequency as the phase voltages. However, V_{uv} has a higher peak value since it is computed from the phase voltages V_{UN} and V_{VN}. The varying positive and negative instantaneous values of V_{UN} and V_{VN} at a particular time produce the instantaneous value of V_{UV}. V_{UV} is the phasor sum of the two phase voltages V_{UN} and V_{NV}.

This combination of phase-displaced alternating voltages is called phasor addition.

The voltage across phase-to-phase is called the line voltage.

Relationship between line and phase voltage: The possibility of combining pairs of phases in a generator is a basic property of three-phase electricity. The understanding of this relationship will be enhanced by studying the following illustrative example which explains the concept of phase difference in a very simple way.

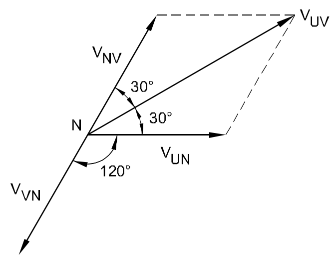
The phase voltages V_{UN} and V_{VN} are separated in phase by one third of a period, or 120° between the two phasors. (Fig 10)

The phasor sum of the two phase voltages V_{UN} and V_{NV} can be obtained geometrically, and the resultant phasor so obtained is the line voltage V_{UV} through the relation $V_{UV} = V_{UN} + V_{NV}$.

Note that to obtain the line voltage V_{UV} the measurement is made from the U terminal through the common point N to the V terminal, for a star connection.

This fact is illustrated in Fig 11. Starting with the phasors V_{UN} and V_{VN} (Fig 10), the phasor $-V_{VN} = V_{NV}$ is produced from the point N. The diagonal of the parallelogram with sides V_{UN} and V_{NV} is the phasor representing the resulting line voltage V_{UV}.

Fig 11



It can be concluded, therefore, that in a generator the line voltage V_L is related to the phase voltage V_P by a multiplying factor. This factor can be shown to be $\sqrt{3}$, so that

$V_L = \sqrt{3} \times V_P$

In a three-phase generating system, the line voltage is always $\sqrt{3}$ times the phase-to-neutral voltage. The factor relating the line voltage to the phase voltage is $\sqrt{3}$.

It was shown that the line voltage is greater than the phase voltage. Here is a numerical example.

The RMS phase voltage in a three-phase system is 240V. Since the ratio of line voltage to phase voltage is $\sqrt{3}$ the RMS line voltage is

$V_L = \sqrt{3} \times V_P = \sqrt{3} \times 240$

$= 415.68V$

or rounded down, $V_L = 415V$.

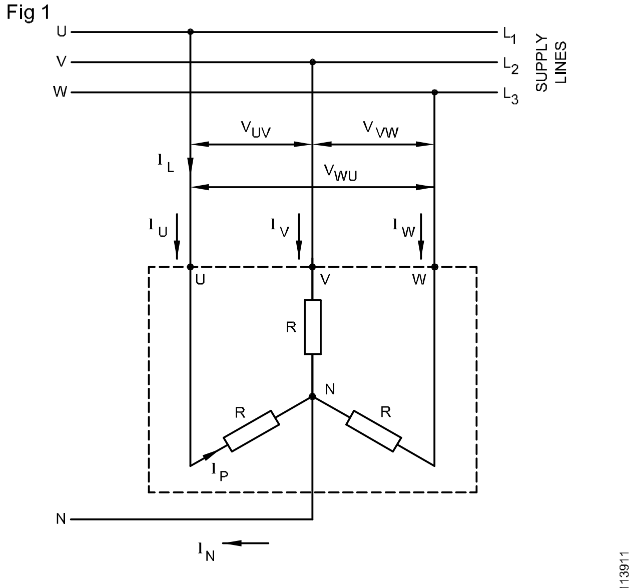
Systems of connection in 3-phase AC

Objectives: At the end of this lesson you shall be able to
- **explain the star and delta systems of connection**
- **state phase relationship between line and phase voltages and current in a star connection delta connection**
- **state the relationship between phase and the voltage and current in star and delta connection**

Methods of 3-phase connection: If a three-phase load is connected to a three-phase network, there are two basic possible configurations. One is `star connection' (symbol Y) and the other is `delta connection' (symbol Δ).

Star connection: In Fig 1 the three-phase load is shown as three equal magnitude resistances. From each phase, at any given time, there is a path to the terminal points U, V, W of the equipment, and then through the individual elements of the load resistance. All the elements are connected to one point N: the `star point'. This star point is connected to the neutral conductor N. The phase currents i_U, i_V, and i_W flow through the individual elements, and the same current flows through the supply lines, i.e. in a star connected system, the supply line current (I_L) = phase current (I_P).

Fig 1



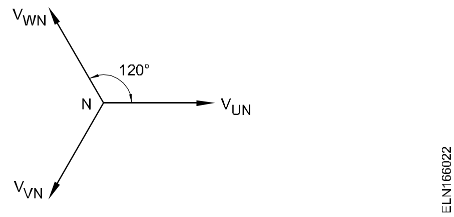
STAR CONNECTION

The potential difference for each phase, i.e. from a line to the star point, is called the phase voltage and designated as V_P. The potential difference across any two lines is called the line voltage V_L. Therefore, the voltage across each impedance of a star connection is the phase voltage V_P. The line voltage V_L appears across the load terminals U-V, V-W and W-U and designated as V_{UV}, V_{VW} and V_{WU} in the Fig 1. The line voltage in a star-connected system will be equal to the phasor sum of the positive value of one phase voltage and the negative value of the other phase voltage that exist across the two lines (Fig 2).

Thus

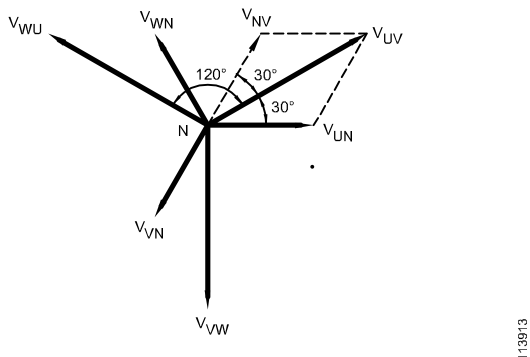
$$V_L = V_{UV} = (\text{phasor } V_{UN}) - (\text{phasor } V_{VN})$$
$$= \text{phasor } V_{UN} + V_{VN}.$$

Fig 2



In the phasor diagram (Fig 3)

Fig 3



PHASOR DIAGRAM

$$V_L = V_{UV} = V_{UN} \cos 30^o + V_{NV} \cos 30^o$$

But $\cos 30^o = \dfrac{\sqrt{3}}{2}$.

Thus as $V_{UN} = V_{VN} = V_P$

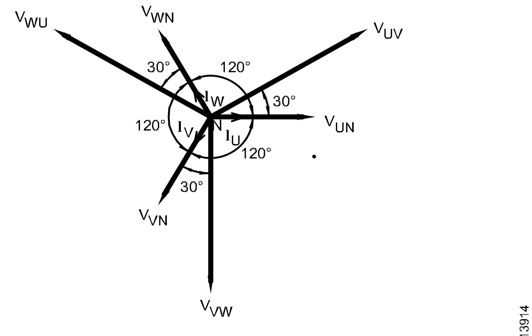
$$V_L = \sqrt{3}\, V_P.$$

This same relationship is applied to V_{UV}, V_{VW} and V_{WU}.

> **In a three-phase star connection, the line voltage is always $\sqrt{3}$ times the phase-to-neutral voltage. The factor relating the line voltage to the phase voltage is $\sqrt{3}$ (Fig 3).**

The voltage and current relationship in a star connection is shown in the phasor diagrams. (Fig 4) The phase

Fig 4



PHASOR DIAGRAM OF STAR CONNECTION

voltages are displaced 120° in phase with respect to each other.

Derived from these are the corresponding line voltages. The line voltages are displaced 120^0 in phase with respect to each other. Since the loads in our example are provided by purely resistive impedances, the phase currents I_P (I_U, I_V, I_W) are in phase with the phase voltages V_P (V_{UN}, V_{VN} and V_{WN}). In a star connection, each phase current is determined by the ratio of the phase voltage to the load resistance R.

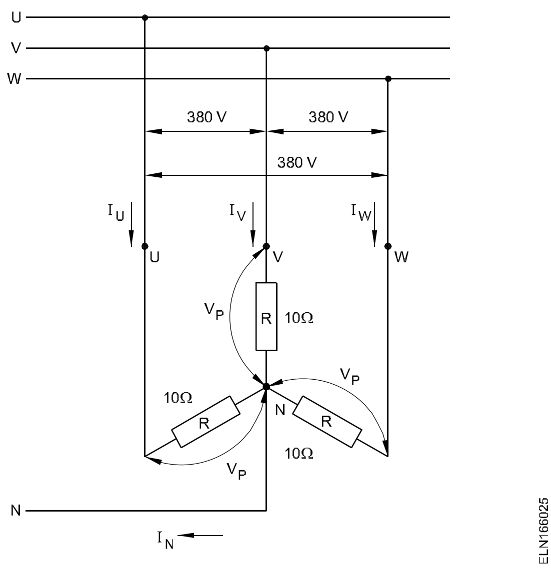
***Example 1**:* What is the line voltage for a three-phase, balanced star-connected system, having a phase voltage of 240V?

$$V_L = \sqrt{3}V_P = \sqrt{3} \text{ x } 240$$

$$= 415.7V$$

***Example 2**:* What is the magnitude of each of the supply line currents for the circuit shown in Fig 5?

Fig 5



Because of the arrangements of a star connection there is a voltage

$$V_P = \frac{380}{173} = 220 \text{ V}$$

across each of the purely resistive loads R.

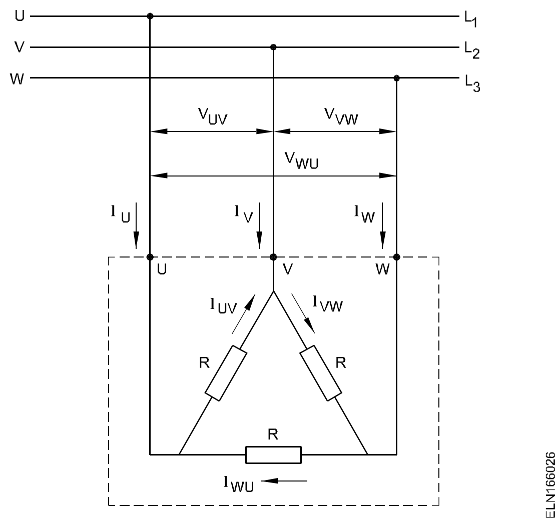
The three-supply line currents have the same magnitude since the star-connected load is balanced, and they are given by

$$I_U = I_V = I_W = \frac{V_P}{R} = \frac{220}{10} = 22A = I_L = I_P$$

Delta connection: There is a second possible arrangement for connecting a three-phase load in a three-phase network. This is the delta or mesh connection (Δ).(Fig 6)

The load impedances form the sides of a triangle. The terminals U, V and W are connected to the supply lines of the L_1, L_2 and L_3.

Fig 6



In contrast to a star connection, in a delta connection the line voltage appears across each of the load phases.

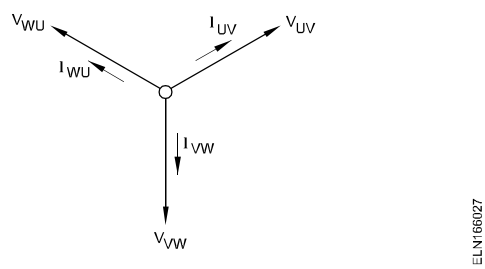
The voltages, with symbols V_{UV}, V_{VW} and V_{WU} are, therefore, the line voltages.

The phase currents through the elements in a delta arrangement are composed of I_{UV}, I_{VW} and I_{WU}. The currents from the supply lines are I_U, I_V and I_W, and one line current divides at the point of connection to produce two phase currents.

The voltage and current relationships of the delta connection can be explained with the aid of an illustration. The line voltages V_{UV}, V_{VW} and V_{WU} are directly across the load resistors, and in this case, the phase voltage is the same as the line voltage. The phasors V_{UV}, V_{VW} and V_{WU} are the line voltages. This arrangement has already been seen in relation to the star connection.

Because of the purely resistive load, the corresponding phase currents are in phase with the line voltages. (Fig 7)

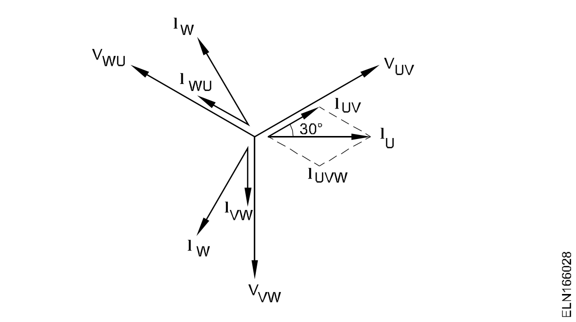
Fig 7



Their magnitudes are determined by the ratio of the line voltage to the resistance R.

On the other hand, the line currents I_U, I_V and I_W are now compounded from the phase currents. A line current is always given by the phasor sum of the appropriate phase currents. This is shown in Fig 8. The line current I_U is the phasor sum of the phase currents I_{UV} and I_{UW}. (See also Fig 8)

Fig 8



Hence, $I_U = I_{UV} \cos 30^o + I_{UW} \cos 30^o$

But $\cos 30^o = \frac{\sqrt{3}}{2}$.

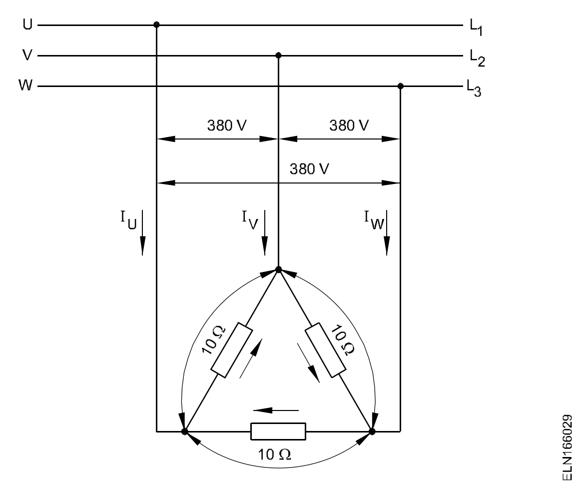
Thus $I_L = \sqrt{3}\, I_{ph}$

Thus, for a balanced delta connection, the ratio of the line current to the phase current is $\sqrt{3}$.

Thus, line current = $\sqrt{3}$ x phase current.

Example 3: What are the values of the line currents, I_U,

Fig 9



I_V and I_W in the above example? (Fig 9)

Solution

Since the load is balanced (i.e. the resistance of each phase is the same), the phase currents are of equal magnitude, and are given by the ratio of the line voltage to the load phase resistance

$$I_{UV} = I_{VW} = I_{WU} = \frac{V_P}{R} = \frac{V_L}{R} = \frac{380}{10} = 38A.$$

Thus, the phase current in the case of delta is 38A. Expressed in words:

$$\text{Phase current} = \frac{\text{line or phase voltage}}{\text{phase resistance}}$$

The line current is $\sqrt{3}$ times the phase current.

Therefore the line current is

$$I_U = I_V = I_W = \sqrt{3} \times 38A = 1.73 \times 38A = 66A.$$

***Example 4**:* Three identical coils, each of resistance 10 ohms and inductance 20mH is delta connected across a 400-V, 50Hz, three-phase supply. Calculate the line current.

For a coil,

reactance $X_L = 2\pi fL = 2 \times 3.142 \times 50 \times \frac{20}{1000} = 6.3$ ohms.

Impedance of a coil is thus given by

$$Z = \sqrt{(R^2 + X^2} = \sqrt{(10^2 + 6.3^2)} = 11.8 \text{ ohms}.$$

For a delta connected system, according to equation

$V_L = V_P$.

Thus $V_P = 400V$.

Hence the phase current is given by

$$I_P = \frac{V_P}{Z} = \frac{400}{118} = 33.9 \text{ A}.$$

But for a delta connected system, according to equation,

$$I_L = \sqrt{3} I_P = \sqrt{3} \times 33.9 = 58.7A.$$

Application of star and delta connection with balanced loads

An important application is the `star-delta change over switch' or star-delta starter.

For a particular three-phase load, the line current in a delta connection is three times as great as for a star connection for a given line voltage, i.e. for the same three-phase load (D line current) = 3 (Y - line current).

This fact is used to reduce the high starting current of a 3-phase motor with a star-delta change over switch.

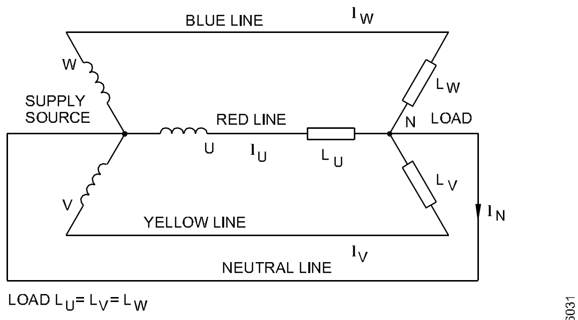
Application of star connection: Alternators and secondoary of distribution transformers, have their three, single-phase coils interconnected in star.

Neutral in 3-phase system

Objectives: At the end of this lesson you shall be able to
- **explain the current in neutral of a 3-phase star connection**
- **state the method of producing artificial neutral in a 3-phase delta connection**
- **state the method of earthing the neutral**
- **explain the behaviour of 3ϕ system when neutral open.**

Neutral: In a three-phase star connection, the star point is known as neutral point, and the conductor connected to the neutral point is referred as neutral conductor (Fig 1).

Fig 1



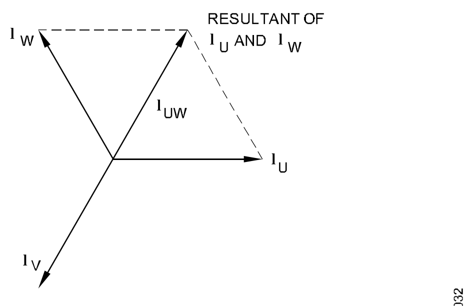
THREE-PHASE SUPPLY AND LOAD

Current in the neutral conductor: In a star-connected, four-wire system, the neutral conductor N must carry the sum of the currents I_U, I_V and I_W. One may, therefore, get the impression that the conductor must have sufficient area to carry a particularly high current. However, this is not the case, because this conductor is required to carry only the phasor sum of the three currents.

I_N = phasor sum of I_U, I_V and I_W

Fig 2 shows this phasor addition for a situation where the loads are balanced and the currents are equal. The result is that the current in the neutral line I_N is zero. This can also be shown for the other instantaneous values.

Fig 2

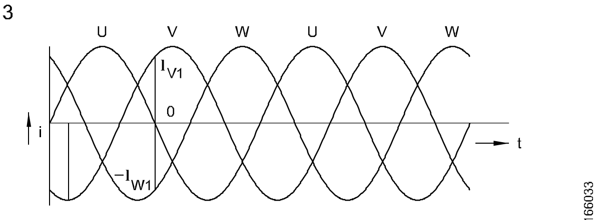


FOR A BALANCED LOAD THE RESULTANT OF I_W AND I_U IS EQUAL IN MAGNITUDE BUT OPPOSITE TO I_V.

At a particular instant in time, t_1, the instantaneous value i_U= 0 (Fig 3), i_V and i_W, have equal magnitudes, but they have opposite signs,i.e. they are in opposition and the phasor sum is zero. Taking the other values of t, it can be seen that the sumof the three phase currents to equal to zero.

Therefore, for a balanced load the neutral conductor carries no current.

Fig 3



RESULTANT OF THREE-PHASE CURRENTS

With unequal value the phase currents are different in magnitude and the neutral current is not zero. Then a `neutral' current I_N does flow in the neutral conductor, but this, however, is less than any of the supply line currents. Thus, neutral conductors, when they are used, have a smaller cross-section than the supply lines.

Effect of imbalance: If the load is not balanced and there is no neutral conductor, there is no return path for the sum of the phase currents which will be zero. The phase voltages will not now be given by the line voltage divided by $\sqrt{3}$, and will have different values.

Earthing of neutral conductor: Supply of electrical energy to commercial and domestic consumers is an important application of three-phase electricity. For `low voltage distribution' - in the simplest case, i.e. supply of light and power to buildings - there are two requirements.

1 It is desirable to use conductors operating at the highest possible voltage but with low current in order to save on expensive conductor material.

2 For safety reasons, the voltage between the conductor and earth must not exceed 250V.

A voltage distribution system according to criterion 2, only possible with a low line voltage below 250 V. However, this is contrary to criterion 1. On the other hand, with a star connection, a line voltage of 415V is available. In this case, there is only 240V between the supply line and the neutral conductor. Criterion 1 is satisfied and, to comply with 2, the neutral conductor is earthed.

Indian Electricity Rules: I.E.Rules insist that the neutral conductor must be earthed by two separate and distinct connections to earth. Rule No.61(1)(a), Rule No.67(1)(a) and Rule No.32 insist on the identification of neutral at the point of commencement of supply at the consumer's premises, and also prevent the use of cut outs or links in the neutral conductor. BIS stipulate the method of earthing the neutral. (Code No.17.4 of IS 3043-1966)

Cross-sectional area of neutral conductor: The neutral conductor in a 3-phase, 4-wire system should have a smaller cross-section. (half of the cross-section of the supply lines).

Artificial neutral: Normally neutral conductors are available with a 3-phase, 4-wire system only. Neutral conductors are not drawn for a 3-phase, 3-wire system. Neutral conductors are also not available with the delta-connected supply system.

A neutral conductor is required for measuring phase voltage, energy, power to connect indicating lamps, etc. An artificial neutral for connecting indicating lamps can be formed by connecting them in star. (Fig 4) Artificial neutral for instruments can be formed by connecting additional resistors in star. (Fig 5)

Fig 4

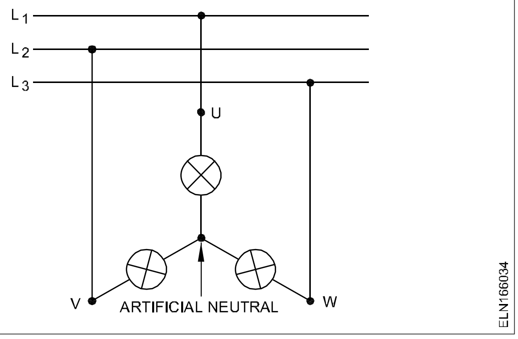
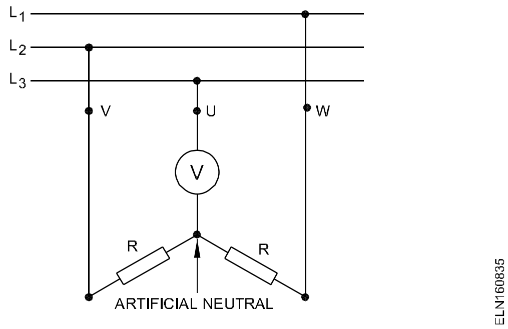


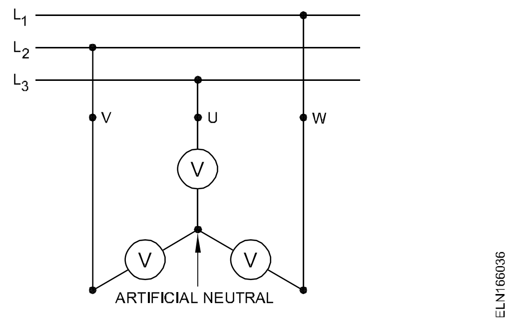
Fig 5



In this method, the value of R must be equal to the resistance of the voltmeter. The same method can be used while measuring power or energy by connecting resistors of equal resistance as of potential coil.

When three instruments of a similar kind are in use, their pressure coils can be connected to form an artificial neutral. (Fig 6)

Fig 6



This type of neutral cannot allow a large current. When earthing of a delta-connected system is required, neutral earthing compensators are used. These can sink or source large currents while keeping neutral to phase voltages constant.

IS 3043 Code No.17, provide a method to obtain neutral for earthing purposes by an earthing compensator.

Power in star and delta connections

Objectives: At the end of this lesson you shall be able to
- **explain active, appparent and reactive power in AC 3 phase ϕ**
- **explain behaviour of unbalanced and balance load**
- **state the method of earthing the neutral**
- **determine the power in 3-phase star and delta connected balanced load.**

Fig 1 shows the load of three resistances in a star connection. So the power must be three times as great as the single phase power.

$$P = 3V_pI_p.$$

If the quantities V_P and I_P in the individual phases are replaced by the corresponding line quantities V_L and I_L respectively, we obtain:

$$P = 3\frac{V_L}{\sqrt{3}}I_L.$$

(Because $V_P = V_L$, $\sqrt{3}$ and $I_p = I_L$)

Since $3 = \sqrt{3} \times \sqrt{3}$, this equation can be simplified to the form

$$P = \sqrt{3}\, V_LI_L$$

Note that power factor in resistance circuit is unity. Hence power factor is not taken into account.

Quantity	P	V_L	I_L
Unit	W	V	A

The power in this purely resistive load(ϕ=0°, cosϕ= 1) is entirely active power which is converted into heat. The unit of active power is the watt (W).

As the last formula shows, three-phase power in a star-connected load circuit can be calculated from the line quantities, and there is no need to measure the phase quantities.

$P = \sqrt{3} \times V \times I$ (Formula holds good for pure resistive load)

It is always possible, in practice, to measure the line quantities but the accessibility of the star point cannot always be guaranteed, and so it is not always possible to measure the phase voltages.

Three-phase power with a delta-connected load:

Fig 1

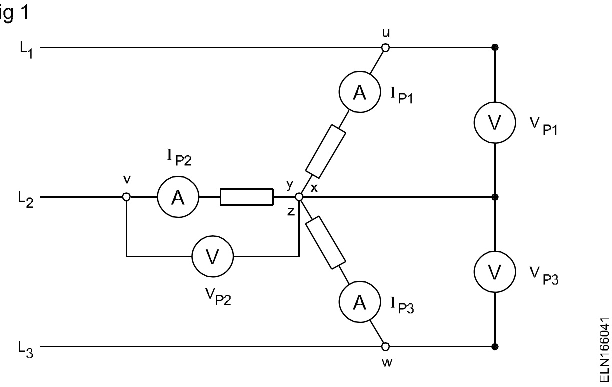
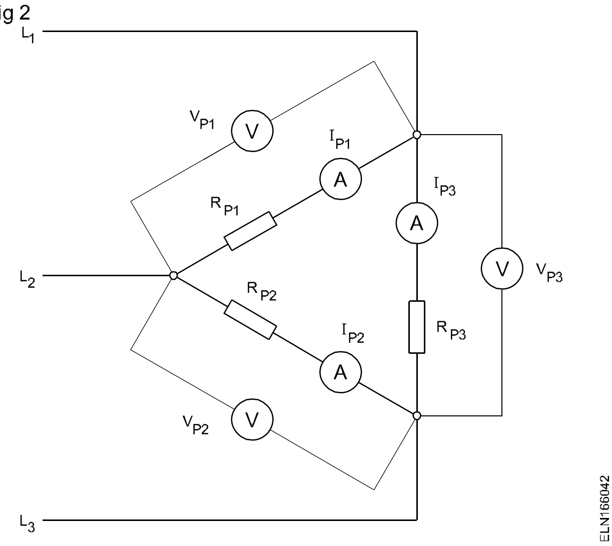


Fig 2 shows the load of three resistances connected in delta. Three times the phase power will be dissipated.

Fig 2



$$P = 3P_P = 3V_P I_P$$

If the quantities V_P and I_P are replaced by the corresponding line quantities V_L and I_L, we obtain:

Since, $V_L = V_P$

$$I_L = \sqrt{3} I_P \text{ and } I_P = \frac{I_L}{\sqrt{3}}$$

but since $3 = \sqrt{3} \times \sqrt{3}$, this equation can be simplified to the form:

$P = \sqrt{3}\, V_L I_L$. (Formula holds good for pure resistive load)

If we compare the two power formulae for the star and delta connections, we see that the same formula applies to both. In other words, the way in which the load is connected has no effect on the formula to be used, assuming that the load is balanced.

Active,reactive and apparent power: As you already know from AC circuit theory, load circuits which contain both resistance and inductance, or both resistance and capacitance, take both active and reactive power because of the phase difference existing between the voltage and current in them. If these two components of power are added geometrically, we obtain the apparent power. Precisely the same happens in each phase of the three-phase systems. Here we have to consider the phase difference f between the voltage and current in each phase.

Applying the factor $\sqrt{3}$, the components of power in a three-phase system follow from the formulae derived for single-phase, AC circuits, namely:

Apparent power	$S=VI$	$S = \sqrt{3} V_L I_L$	VA
Active power	$P=VI \cos\phi$	$P = \sqrt{3}\, V_L I_L \cos\phi$	W
Reactive power	$Q=VI \sin\phi$	$Q = \sqrt{3} V_L I_L \sin\phi$	var

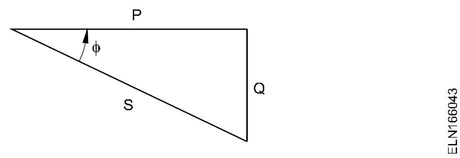
Finally, the well known relationships found in single-phase AC circuits apply also to three-phase circuits.

$$\cos\phi = \frac{\text{activepower}}{\text{apparentpower}} = \frac{P}{S}$$

$$\sin\phi = \frac{\text{reactivepower}}{\text{apparentpower}} = \frac{Q}{S}$$

This can also be seen from Fig 3.

Fig 3



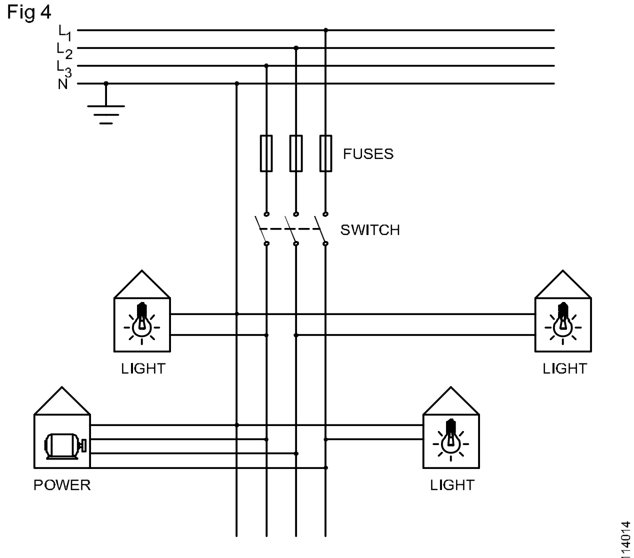
$\cos\phi$ is called the power factor, while $\sin\phi$ is sometimes called the reactive power factor.

Unbalanced load: The most convenient distribution system for electrical energy supply is the 415/240 V four-wire, three-phase AC system.

This offers the possibility of supplying three-phase, as well as single-phase current, to users simultaneously. Supply to buildings can be arranged as in the given example. (Fig 4)

The individual houses utilize one of the phase voltages. L_1, L_2 and L_3 to N are distributed in sequence (light current). However, large loads (eg.three-phase AC motors) may be fed with the line voltage (heavy current).

Fig 4

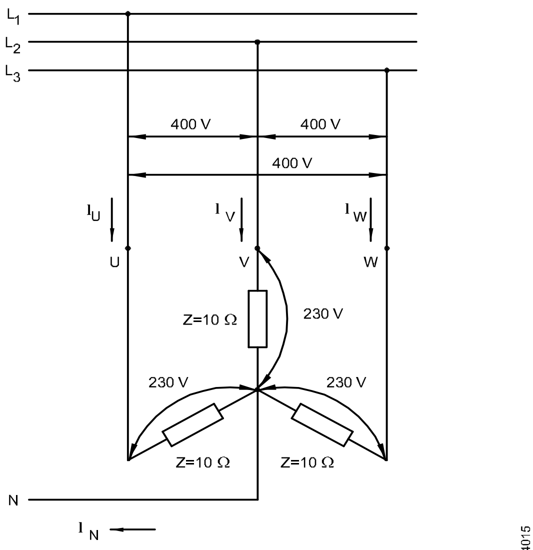


UNBALANCED LOAD

However, certain equipment which needs single or two phase supply can be connected to the individual phases so that the phases will be differently loaded, and this means that there will be unbalanced loading of the phases of the four-wire, three-phase network.

Balanced load in a star connection: In a star connection, each phase current is determined by the ratio of phase voltage and load impedance `Z'.

Fig 5



BALANCED STAR CONNECTED LOAD

This fact will now be confirmed by a numerical example.

A star-connected load consisting of impedances `Z' each of 10 ohms, is connected to a three-phase network with line voltage V_L = 415V. (Fig 5)

Because of the arrangements of a star connection, the phase voltage is 240V (415/$\sqrt{3}$).

The three load currents taken froms supply have the same magnitude since the star-connected load is balanced, and they are given by

$$I_U = I_V = I_W = V_P \div Z.$$

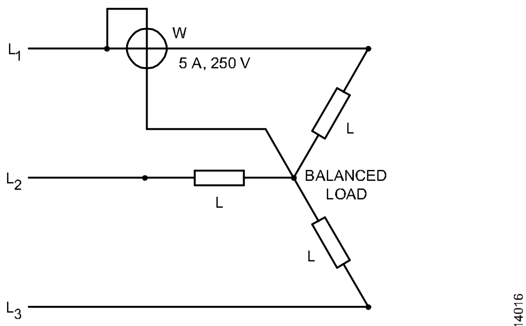
The measurement of power: The number of wattmeters used to obtain power in a three-phase system depends on whether the load is balanced or not, and whether the neutral point, if there is one, is accessible.

- Measurement of power in a a star-connected balanced load with neutral point is possible by a single wattmeter.
- Measurement of power in a star or delta-connected, balanced or unbalanced load (with or without neutral) is possible with two wattmeter method.

Single wattmeter method: Fig 6 shows the circuit diagram to measure the three-phase power of a star-connected, balanced load with the neutral point accessible the current coil of the wattmeter being connected to one line, and the voltage coil between that line and neutral point. The wattmeter reading gives the power per phase. So the total is three times the wattmeter reading.

$$\text{Power/phase} = 3V_P I_P \cos\theta = 3P = 3W.$$

Fig 6



POWER MEASUREMENT - SINGLE WATTMETER

The two-wattmeter method of measuring power

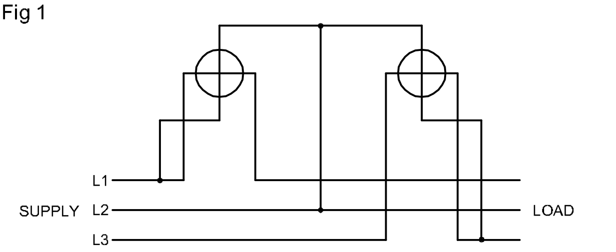
Objectives: At the end of this lesson you shall be able to:
- **measure 3-phase power using two single phase wattmeter**
- **calculate power factor from meter reading.**
- **explain the `two-wattmeter' method of measuring power in a three-phase, three-wire system**

Power in a three-phase, three-wire system is normally measured by the `two-wattmeter' method. It may be used with balanced or unbalanced loads, and separate connections to the phases are not required. This method is not, however, used in four-wire systems because current may flow in the fourth wire, if the load is unbalanced and the assumption that $I_U + I_V + I_W = 0$ will not be valid.

The two wattmeters are connected to the supply system as shown in Fig 1. The current coils of the two wattmeters are connected in two of the lines, and the voltage coils are connected from the same two lines to the third line. The total power is then obtained by adding the two readings:

$$P_T = P_1 + P_2.$$

Fig 1



TWO WATTMETER - POWER MEASUREMENT

Consider the total instantaneous power in the system $P_T = P_1 + P_2 + P_3$ where P_1, P_2 and P_3 are the instantaneous values of the power in each of the three phases.

$$P_T = V_{UN} i_U + V_{VN} i_V + V_{WN} I_W$$

Since there is no fourth wire, $i_U + i_V + i_W = 0$; $i_V = -(i_U + i_W)$.

$$\begin{aligned} P_T &= V_{UN} i_U - V_{VN}(i_U + i_W) + V_{WN} i_W \\ &= i_U(V_{UN} - V_{VN}) + i_W(V_{WN} - V_{UN}) \\ &= i_U V_{UV} + i_W V_{WV} \end{aligned}$$

Now $i_U V_{UV}$ is the instantaneous power in the first wattmeter, and $i_W V_{WV}$ is the instantaneous power in the second wattmeter. Therefore, the total mean power is the sum of the mean powers read by the two wattmeters.

It is possible that with the wattmeters connected correctly, one of them will attempt to read a negative value because of the large phase angle between the voltage and current for that instrument. The current coil or voltage coil must then be reversed and the reading given a negative sign when combined with the other wattmeter readings to obtain the total power.

At unity power factor, the readings of two wattmeter will be equal. Total power = 2 x one wattmeter reading.

When the power factor = 0.5, one of the wattmeter's reading is zero and the other reads total power.

When the power factor is less than 0.5, one of the wattmeters will give negative indication. In order to read the wattmeter, reverse the pressure coil or current coil connection. The wattmeter will then give a positive reading but this must be taken as negative for calculating the total power.

When the power factor is zero, the readings of the two wattmeters are equal but of opposite signs.

Self-evaluation test

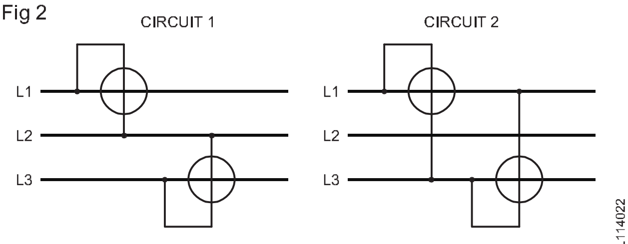
1 Draw a general wiring diagram for the two-wattmeter method of three-phase power measurement.

2 Why is it desirable, in practice, to use the two-wattmeter method? (Fig 2)

3 Why can the two-wattmeter method not be used in a three-phase, four-wire system with random loading?

4 Which of the above circuits is used for the two-wattmeter method of power measurement?

Fig 2



TWO WATTMETER - POWER MEASUREMENT

Power factor calculation in the two-watmeter method of measuring power

As you have learnt in the previous lesson, the total power $P_T = P_1 + P_2$ in the two-wattmeter method of measuring power in a 3-phase, 3-wire system.

From the readings obtained from the two wattmeters, the tan f can be calculated from the given formula

$$\tan\phi = \frac{\sqrt{3}(P_1 - P_2)}{(P_1 + P_2)} = \frac{\sqrt{3}\,(W_1 - W_2)}{(W_1 + W_2)}$$

from which f and power factor of the load may be found.

***Example 1**:* Two wattmeters connected to measure the power input to a balanced three-phase circuit indicate 4.5 KW and 3 KW respectively. Find the power factor of the circuit.

Solution

$$\tan\phi = \frac{\sqrt{3}(P_1 - P_2)}{(P_1 + P_2)}$$

$P_1 = 4.5$ KW

$P_2 = 3$ KW

$P_1 + P_2 = 4.5 + 3 = 7.5$ KW

$P_1 - P_2 = 4.5 - 3 = 1.5$ KW

$$\tan\phi = \frac{\sqrt{3} \times 1.5}{7.5} = \frac{\sqrt{3}}{5} = 0.3464$$

$\phi = \tan^{-1} 0.3464 = 19^0 6'$

Power factor Cos $19^0 6' = 0.95$

***Example 2**:* Two wattmeters connected to measure the power input to a balanced three-phase circuit indicate 4.5 KW and 3 KW respectively. The latter reading is obtained after reversing the connection of the voltage coil of that wattmeter. Find the power factor of the circuit.

Solution

$$\tan\phi = \frac{\sqrt{3}(P_1 - P_2)}{(P_1 + P_2)}$$

$$= \frac{\sqrt{3}(4.5 - (-3))}{(4.5 + (-3))}$$

$$= \frac{\sqrt{3}(4.5 + 3)}{(4.5 - 3)}$$

$$= \frac{\sqrt{3} \times 7.5}{1.5} = \sqrt{3} \text{ x } 5$$

$$= 1.732 \times 5 = 8.66.$$

$\phi = \tan^{-1} 8.66 = 83^o.27'$

since power factor (Cos $83^o 27'$) = 0.114.

Question 1: The reading on the two wattmeters connected to measure the power input to the three-phase, balanced load are 600W and 300W respectively.

Calculate the total power input and power factor of the load.

Question 2: Two wattmeters connected to measure the power input to a balanced, three-phase load indicate 25KW and 5KW respectively.

Find the power factor of the circuit when (i) both readings are positive and (ii) the latter reading is obtained after reversing the connections of the pressure coil of the wattmeter.

Solution

1 Total power = $P_T = P_1 + P_2$

P_1 = 600W.

P_2 = 300W.

P_T = 600 + 300 = 900 W

$$\tan \phi = \frac{\sqrt{3}(P_1 - P_2)}{(P_1 + P_2)} = \frac{\sqrt{3}(600 - 300)}{600 + 300} = \frac{\sqrt{3} \times 300}{900}$$

$$= \frac{\sqrt{3}}{3} = \frac{1}{\sqrt{3}} = 0.5774$$

$\phi = \tan^{-1} 0.5774 = 30^o$

Power factor = Cos 30^o = 0.866.

2 a) P_1 = 25 KW

P_2 = 5 KW

$$\tan \phi = \frac{\sqrt{3}(P_1 - P_2)}{(P_1 + P_2)} = \frac{\sqrt{3}(25 - 5)}{25 + 5}$$

$$= \frac{\sqrt{3} \times 20}{30} = \frac{\sqrt{3} \times 2}{3} = \frac{2}{\sqrt{3}} = 1.1547$$

$\phi = \tan^{-1} 1.1547 = 49^o 6'$

Power factor (Cosϕ) = Cos $49^o 6'$ = 0.6547

b) P_1 = 25 KW

P_2 = –5 KW

$$\tan \phi = \frac{\sqrt{3}(P_1 - P_2)}{(P_1 + P_2)} = \frac{\sqrt{3}(25 - (-5))}{25 + (-5)}$$

$$= \frac{\sqrt{3}\ (25 + 5)}{25 - 5} = \frac{\sqrt{3} \times 30}{20}$$

$$= \frac{\sqrt{3} \times 3}{2} = 2.5980$$

$\phi = \tan^{-1} 2.5980 = 68^o 57'$

Power factor = Cos $68^o 57'$ = 0.3592

Phase-sequence indicator (Meter)

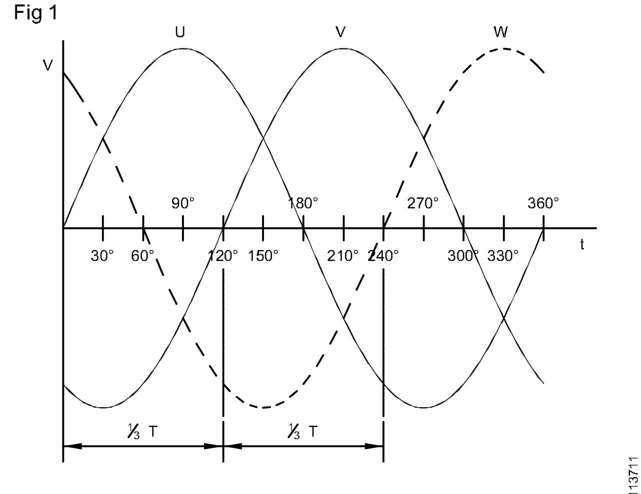
Objectives: At the end of this lesson you shall be able to
- **describe the method of finding the phase sequence of a 3-phase supply using a phase-sequence indicator**
- **explain the methods of finding phase sequence using lamps.**

Review

A three-phase alternator contains three sets of coils positioned 120^o apart and its output is a three-phase voltage as shown in Fig 1. A three-phase voltage consists of three voltage waves, 120 electrical degrees apart.

At a time 0, phase U is passing through zero volts with positively increasing voltage. (Fig 1) V follows with its zero crossing 1/3 of the period later and the same applies to W with respect to V. The order in which the three-phases attain their maximum or minimum values is called the phase sequence. In the illustration given here the phase sequence is U,V,W.

Fig 1



3 - PHASE OUTPUT VOLTAGE

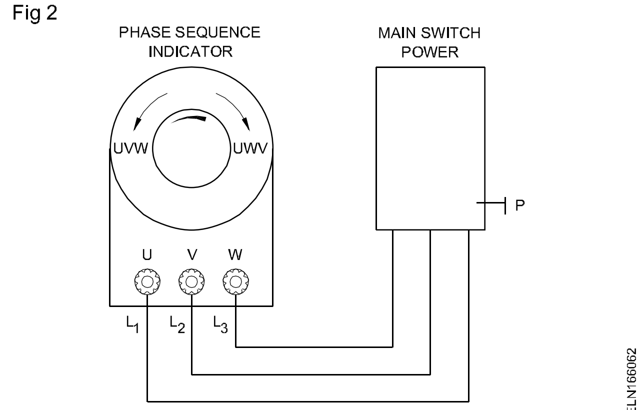
Importance of correct phase sequence: Correct phase sequence is important in the construction and connection of various three-phase systems. For example, correct phase sequence is important when the outputs of three-phase alternators must be paralleled into a common voltage system. The phase `U' of one alternator must be connected to phase `U' of another alternator. The phase `V' to phase `V' and phase `W' to phase `W' must be similarly connected to each other.

In the case of an induction motor, reversal of the sequence results in the reversal of the direction of motor rotation which will drive the machinery the wrong way.

Phase-sequence indicator(meter)**:** A phase-sequence indicator (meter) provides a means of ensuring the correct phase-sequence of a three-phase system. The phase-sequence indicator consists of 3 terminals `UVW' to which three-phases of the supply are connected. When the supply is fed to the indicator a disc in the indicator moves either in the clockwise direction or in the anticlockwise direction. The direction of the disc movement is marked with an arrowhead on the indicator. Below the arrowhead the correct sequence is marked. (Fig 2)

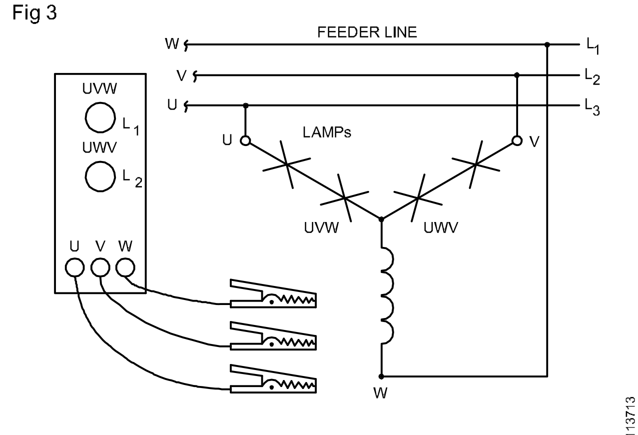
The phase sequence of the three-phase system may be reversed by interchanging the connections of any two of the three phases.

Fig 2



Phase-sequence indicator using choke and lamps: The phase-sequence indicator consists of four lamps and an inductor connected in a star formation (Y). A test lead is connected to each leg of the `Y'. One lamp is labelled U-V-W, and the other is labelled U-W-V. When the three leads are connected to a three-phase line, the brighter lamp indicates the phase sequence. (Fig 3)

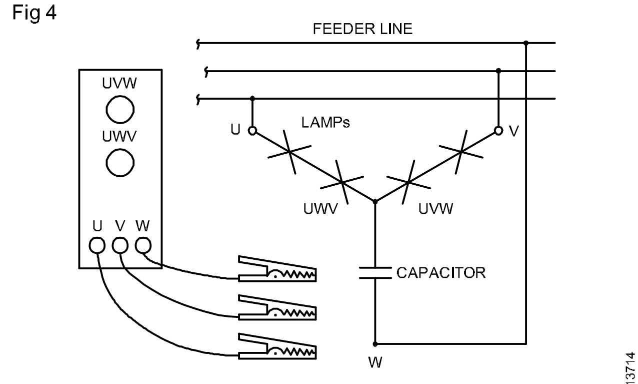
Fig 3



PHASE SEQUENCE INDICATOR USING CHOKE & LAMPS

Phase-sequence indicator using capacitor & lamps: The phase-sequence indicator consists of four lamps and a capacitor connected in a star formation (Y). A test lead is connected to each leg of the `Y'. One pair of lamps are labelled U-V-W,and the other pair are labelled U-W-V. When the three leads are connected to a 3-phase line, the brighter lamp indicates the phase sequence. (Fig 4)

Fig 4



PHASE SEQUENCE INDICATOR USING CAPACITOR & LAMPS

Project Work

Objectives: At the end of this lesson you shall be able to

- **prepare project report of the project selected**
- **draw circuit diagram/layout diagram**
- **list the specification of the material/component to be procured**
- **list the plan of action to be executed**
- **develop the project, complete and submit it.**

Selection of project & its execution

- Discuss in details of the project - necessity, marketting facility , cost involvement, availability of material and hope of future development and expansion.
- Collect all material and tools required to start the work.
- The project has to be agreed by all members involved and get the approval of the concerned.
- Prepare an action oriented plan to execute the work with in a stipulated time table, accepted by all member and approval of instructor concerned.
- Complete the project as per the expectation.
- Test, calibrate and finish the project as per the plan and execution
- Keep the project with optimum finish and good workman ship

Preparation of project report

- Report should be started with a intreductory infoprmation connected with a known subject and highlight its importance in present conditions
- A survey to be conducted regarding the marketing and its commercial application
- A brief working principle and its operation has to be illustarted in the report
- Highlight the maintenance, repair and periodic servicing etc in the report
- Costing should be so competitive and affordable to the concerned without any reservations
- Further expansion to an advanced version without any much changes and cost to be an added attraction to your project
- Report shall be followed with ref. books and websiite details