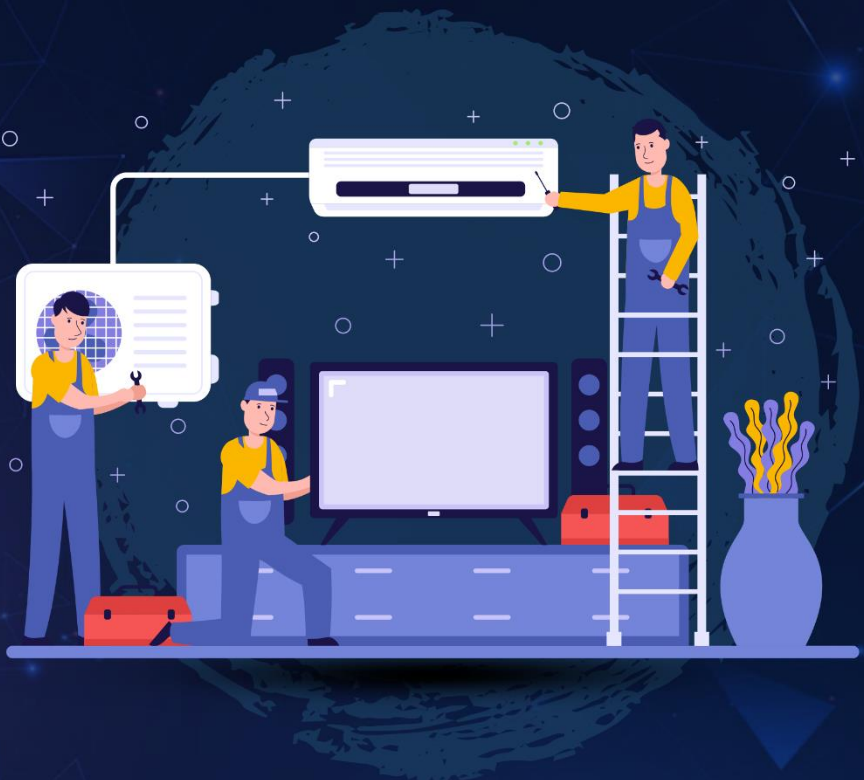
Draft Study Material

# Field Technician – Air Conditioner

(Job Role)

(Qualification Pack: Ref. Id. ELE/Q3102)
Sector: Electronics

(Grade XI)



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# Preface

Vocational Education is a dynamic and evolving field, and ensuring that every student has access to quality learning materials is of paramount importance. The journey of the PSS Central Institute of Vocational Education (PSSCIVE) toward producing comprehensive and inclusive study material is rigorous and time-consuming, requiring thorough research, expert consultation, and publication by the National Council of Educational Research and Training (NCERT). However, the absence of finalized study material should not impede the educational progress of our students. In response to this necessity, we present the draft study material, a provisional yet comprehensive guide, designed to bridge the gap between teaching and learning, until the official version of the study material is made available by the NCERT. The draft study material provides a structured and accessible set of materials for teachers and students to utilize in the interim period. The content is aligned with the prescribed curriculum to ensure that students remain on track with their learning objectives.

The contents of the modules are curated to provide continuity in education and maintain the momentum of teaching-learning in vocational education. It encompasses essential concepts and skills aligned with the curriculum and educational standards. We extend our gratitude to the academicians, vocational educators, subject matter experts, industry experts, academic consultants, and all other people who contributed their expertise and insights to the creation of the draft study material.

Teachers are encouraged to use the draft modules of the study material as a guide and supplement their teaching with additional resources and activities that cater to their students' unique learning styles and needs. Collaboration and feedback are vital; therefore, we welcome suggestions for improvement, especially by the teachers, in improving upon the content of the study material.



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# Module 1 Basic Mechanical Systems

## Module Overview

Understanding mechanical systems begins with a foundational overview of simple machines, which are the fundamental building blocks of both, simple and complex mechanical systems. Simple machines, such as the lever, inclined plane and wheel, play a crucial role in manipulating mechanical forces such as distance and friction to achieve desired mechanical outputs. A thorough understanding of the simple machines is essential for working with any kind of machinery. Knowledge of how these machines operate, their components, functions, and mechanical advantages provides the groundwork for more advanced mechanical concepts. This foundational understanding helps in recognizing how complex systems are constructed from these basic principles.

Mechanical Concepts:

Fitting: This involves the precise assembly of machine components to ensure that they work together properly. Proper fitting is essential for the efficient and reliable operation of mechanical systems.

Tools and Equipment: Familiarity with various tools and equipment is critical for mechanical work. This includes hand tools like wrenches and screwdrivers, as well as more specialized machinery for cutting, shaping, and assembling parts.

Sheet Metal Work: This process involves forming and shaping metal sheets into various components used in mechanical systems. Techniques include cutting, bending, and stamping.

Welding: Welding is the process of joining two or more metal pieces by melting the edges and applying heat. It is crucial for creating strong, durable connections in mechanical assemblies.

Brazing: Similar to welding, brazing involves joining metals using a filler material that melts at a lower temperature than the base metals. It is used for creating strong bonds in components that cannot withstand the high temperatures of welding.

Soldering: Soldering is the process of joining metal components together by melting a filler metal, called solder, which has a lower melting point than the base metals. Soldering is commonly used in electronics and precision work to make connections in circuit boards and delicate assemblies. It provides a less permanent bond compared to welding or brazing, but it is essential for creating reliable electrical connections and joining small components.

Without a solid grasp of these fundamental principles and processes, learners would struggle to understand and work with more advanced mechanical systems. Mastery of basic mechanical systems forms the bedrock for tackling more complex machinery and engineering challenges.

## Learning Outcomes

After completing this module, you will be able to:

- Demonstrate identify and properly use basic tools and equipment in fitting operations.
- Analyse and solve basic electric circuits using fundamental electrical laws and

theorems.

- We understand the processes and techniques involved in welding, brazing, and soldering, and their applications in electrical work.

| Module Structure |
|---|
| Session 1. Fitting, Tools and Equipment |
| Session 2. Electric Circuit Analysis |
| Session 3. Welding, Brazing and Soldering |

## Session 1. Fitting, Tools and Equipment

**Fitting**

Fitting involves a large number of hand operations to finish the work to desired shape, size and accuracy. The various operations performed are marking, chipping, sawing, filing, scraping, drilling, tap (Internal threading) and die (External threading). By performing these operations, students acquire skills in using tools and basic fitting equipment, identifying materials, describing and demonstrating various bench vices, holding devices, and files, as well as drilling and threading tools.

The fittings shops are equipped with mechanized hydraulic bending attachment in which the operations like drilling, reaming, boring, counter sinking, tapping, threading and grinding etc. are performed.

### 1.1 Tools and Equipment

Tools and measuring instruments have made routine tasks much easier. In our daily lives, we frequently use common hand tools and measuring instruments for various household needs. Additionally, different types of tools are essential for opening and repairing electrical and electronic gadgets. For example, installing refrigerators and air conditioners requires tools such as screwdrivers, phase testers, strippers, pliers, and more. In this chapter, you will learn about and practice using the basic tools and equipment commonly found in mechanical workshops. Some of the most common hand tools and equipment are shown in Figure 1.1.


**Fig. 1.1 Common hand tools and equipment**

## 1.2 Hand, Power and Testing tools and safety precautions

### 1.2.1 Hand tools

A tool is any instrument or simple piece of equipment that can be held in the hand and used for a specific task. Examples of tools include spades, hammers, and knives. Tools are generally categorized into two types: hand tools and power tools.

Hand tools, which are operated manually without electricity, include items such as hammers, screwdrivers, wrenches, clamps, pliers, sledges, and measuring tools. They are further classified based on their functions, such as Holding Tools (e.g., clamps and pliers), Striking Tools (e.g., sledges and hammers), Measuring Tools, and Metal Cutting Tools (e.g., reamers, files, and drills).

Power tools, in contrast, are electrically powered and include equipment like drills, saws, and sanders, which are used for more demanding tasks.

**Commonly used hand tools are explained below.**

**1. Screwdrivers** – A screwdriver is a hand tool used to attach or remove screws. The two most common types are the flat-blade and Phillips. The flat-blade screwdriver is used on screws that have a slot in the screw head.

**Philips Screw Driver –** It is a screwdriver with a cross-driving end. It is used to attach or remove screws that have two slots crossing at right angles in the centre of the screw head as shown in Figure 1.3 and Figure 1.4.

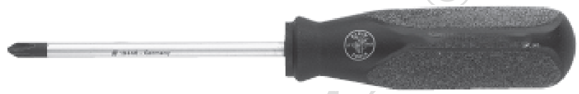


**Fig 1.3 Flat-blade screwdriver**

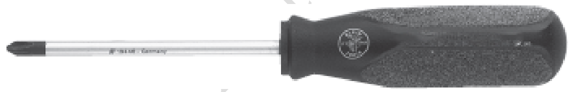


**Fig 1.4 Philip Screw Driver**

When using a Phillips screwdriver, exert more pressure downward to keep the tool in the slots. Always use the largest Phillips size that fits snugly into the slots, just as with the flat-blade screwdriver.

Never use worn-out screwdrivers when working on appliances. A worn screwdriver may damage the head of the screw. It can also damage the product on which you are working.

**flat-blade screwdriver –** It is available in many sizes and shapes. Always use the largest blade size that fits snugly into the slot on the screw head so that it will not slip off the screw. The screwdriver should never be used as a pry bar or a chisel, as it was not designed for that purpose. As shown in Figure 1.5.

**Fig. 1.5 Combination screwdriver set**

**2. Nut Drivers –** Many manufacturers use metal screws with hexagonal heads. A nut driver is a hand tool similar to a screwdriver. It is a handheld driver to drive or remove hex nuts or bolts.

Mostly applicable to deep down places where our hand is not able to reach. Each size nut requires a different-sized driver as shown in Figure 1.6.

**Fig. 1.6 Hex-nut drivers**

**3. Wrenches –** Wrenches are used to remove and fasten nuts and bolts. There are many different types and sizes of wrenches. Their purpose is to hold and turn nuts, bolts, cap screws, plugs, and various threaded parts. Wrenches are generally available in five different types as shown in Figure 1.7. They are available in socket wrench, box, open-end, adjustable, and Allen types.

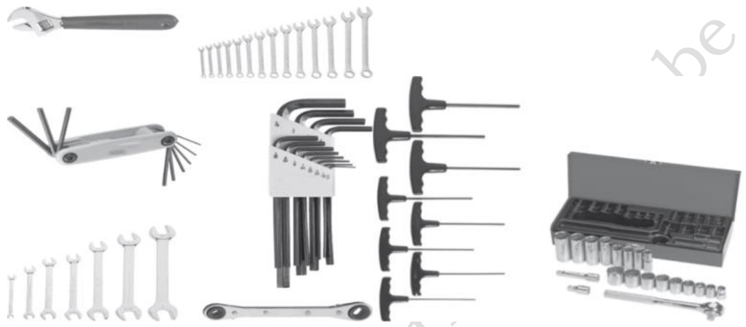


**Fig. 1.7 Wrenches**

**Socket wrenches –** Socket wrenches are used to slip over bolt heads, as opposed to other wrenches, which are used at right angles to the nut or bolt. This arrangement allows more leverage to be applied to loosen or tighten the nut or bolt as shown in Figure 1.8. It is used in the repair and maintenance of the air conditioner.

**Fig. 1.8 Socket wrench**

**Box wrenches –** It is a tool (Figure 1.9), used for assembling and disassembling mechanical parts. Box wrenches, also known as "ring spanners" or "box-end wrenches," are tools used to tighten or loosen bolts and nuts. They have a closed, circular end that fits snugly around the bolt or nut, providing a better grip than an open-end wrench. The closed design of the box wrench also helps prevent rounding or stripping of the corners of the bolt or nut. Box wrenches come in a variety of sizes to fit different bolt and nut sizes. They may have a single box-end or a double box-end, with two different size wrenches on each end.

**Fig. 1.9 Box wrench**

**Open-end wrenches –** Open-end wrenches are tools used for tightening or loosening nuts and bolts. They feature an open, U-shaped end that fits around the nut or bolt, as shown in the figure 1.10. Unlike box wrenches, which have a closed, circular end, open-end wrenches are particularly useful in tight spaces where a box wrench cannot fit.

However, the open design of the wrench makes it more likely to slip off the nut or bolt, and excessive force can round off the corners. Open-end wrenches are available in various sizes to fit different nuts and bolts. Some have different sizes on each end, while others have the same size on both ends.

**Fig. 1.10 Open wrench**

**Adjustable wrenches –** It has a jaw, which can be adjusted as shown in Figure 1.11. It is used to loosen or tighten nuts or bolts of different sizes. Adjustable wrenches, also known as crescent wrenches, are versatile tools used for tightening or loosening nuts and bolts of varying sizes. They have an adjustable jaw that can be moved up or down along a threaded shaft to accommodate different sizes of nuts or bolts.

**Fig. 1.11 Adjustable wrenches.**

The adjustable jaw of the wrench is opened or closed by turning a thumbwheel or knurled knob on the shaft of the wrench as illustrated in Figure 1.12. When the wrench is positioned around the nut or bolt, the jaw is tightened by turning the thumbwheel or knurled knob to provide a secure grip. One of the advantages of an adjustable wrench is that it can be used on a variety of different-sized nuts and bolts with just one tool.

(a) (b) (c)

**Fig. 1.12 Using (a) socket wrench (b) adjustable wrench (c) open-end wrench**

Select the size and type of socket to fit the nut with the proper drive size for the load. See Table 1.1 for the proper drive size loading recommendations.

Table 1.1 Drive Size and Hex Size Loading Recommendations

| **Hex Size** | **1/4" Drive** | **3/8" Drive** | **1/2" Drive** | **3/4" Drive** | **1" Drive** |
|---|---|---|---|---|---|
| 1/8" to 7/32" | USE | DO NOT USE | DO NOT USE | DO NOT USE | DO NOT USE |
| 1/4" to 11/32" | USE | USE | DO NOT USE | DO NOT USE | DO NOT USE |

| Hex Size | 1/4" Drive | 3/8" Drive | 1/2" Drive | 3/4" Drive | 1" Drive |
|---|---|---|---|---|---|
| 3/8" to 9/16" | USE | USE | USE | DO NOT USE | DO NOT USE |
| 19/32" to 11/16" | DO NOT USE | USE | USE | DO NOT USE | DO NOT USE |
| 3/4" to 1" | DO NOT USE | DO NOT USE | USE | USE | DO NOT USE |
| 1 1/16" to 1 1/4" | DO NOT USE | DO NOT USE | USE | USE | USE |
| 1 1/2" | DO NOT USE | DO NOT USE | DO NOT USE | USE | USE |
| 1 9/16" to 3 1/2" | DO NOT USE | DO NOT USE | DO NOT USE | DO NOT USE | USE |

Always select the appropriate wrench for the task at hand. Box wrenches are best suited for heavy-duty applications and tight spaces. Open-end wrenches are ideal for medium-duty tasks or when it's difficult to use a socket or box wrench on a nut, bolt, or fitting from above. Adjustable wrenches are useful for light-duty jobs, accommodating odd-sized nuts and bolts, and can replace a regular open-end wrench in many cases. They can be adjusted to fit various sizes within their maximum range. Allen wrenches, which have a six-pointed flat face on each end, are specifically used for adjusting and removing components secured with Allen set screws, such as fan blades.

Practical activity 1.1 demonstrates the way to use an adjustable wrench for the fitting of a bracket for an air conditioner.

**Practical Activity 1.1** Demonstrate the use of an adjustable wrench for fitting an air conditioner.

**Material Required –**

Adjustable wrench

**Procedure**

**Step 1.** Identify the nut or bolt you want to tighten/loosen.

**Step 2.** Open the adjustable wrench by turning the screw mechanism. This will open the jaw of the wrench, as shown in Figure 1.13

**Fig. 1.13 Opening adjustable wrench**

**Step 3.** Check if you opened it enough for the nut to fit in, or if it needs to be opened more. Make sure it is open a bit more than the size of the nut as illustrated in Figure 1.14

**Fig. 1.14 Inserting adjustable wrench into nut**

**Step 4.** Slip the open jaw over the nut and hold it in place. Turn the screw mechanism so that it clamps tightly around the nut, the opening of the nut is illustrated in Figure 1.15.

**Fig. 1.15 Opening nut using an adjustable wrench**

**Step 5.** Turn the wrench in a clockwise direction to tighten it, or counter-clockwise to loosen it. Keep on turning it, untill the nut is tight or loose as desired. Tightening of the nut is illustrated in Figure 1.16.

**Fig. 1.16 Tighten the nut using an adjustable wrench**

**Step 6.** Remove the wrench by loosening the screw mechanism.

**4. Hammers –** A hammer is a tool designed for striking and is available in many sizes and styles, as illustrated in Figure 1.17. Hammers are used for tasks such as driving nails, breaking objects, or hitting surfaces. They typically feature a handle, or shaft, and a weighted metal head, usually made of steel. The hammer's head is used to strike objects, while the handle provides the user with a secure grip.

Different types of hammers serve various purposes. For example, the claw hammer is commonly used in appliance repairs for driving and removing nails. Engineer hammers are suited for heavy-duty tasks like breaking concrete, while ball-peen hammers are ideal for shaping metal.


**Fig. 1.17 Hammers**

**5. Pliers –** Pliers are among the most commonly used tools and are designed for gripping or cutting, depending on the type. They are not typically used for tightening or unscrewing heavy nuts and bolts. Pliers come in various sizes and shapes, as shown in Figure 1.18. It is important to select the right type of pliers for the specific task at hand. Some common types of pliers include slip-joint pliers, adjustable slip-joint pliers, vise-grip pliers, needle-nose pliers, and diagonal-cutting pliers.


**Fig. 1.18 Pliers**

**Long Nose Plier –** Long nose pliers, also known as needle-nose or snipe-nose pliers, feature a long, tapered nose that ends in a point, as shown in Figure 1.19. These pliers are ideal for gripping, bending, and cutting small objects in tight spaces. The extended nose provides precise control and manipulation of small parts, while the cutting edge allows for snipping wires or other materials. They are versatile tools commonly used by electricians, HVAC technicians, and other professionals who work with small components or in confined areas.

**Fig. 1.19 Long nose plier**

**Slip Joint Plier –** Slip joint pliers, also known as adjustable pliers, are mechanical pliers with an adjustable pivot point that allows the jaw opening to be resized to accommodate various objects. The jaws, typically flat and serrated, are used for gripping, holding, twisting, and bending materials such as wires, pipes, and nuts, as shown in Figure 1.20. These pliers are commonly employed for loosening and tightening nuts and bolts, as well as for holding and bending wires in electrical work.

**Fig. 1.20 Slip joint plier**

**Pump pliers –** Pump pliers, also known as slip-joint adjustable pliers, are versatile tools used for general tasks, particularly with larger objects. Unlike standard slip-joint pliers, pump pliers feature jaws that can be adjusted to multiple positions, providing greater adaptability. They typically have long handles, which are designed to grip, hold, and turn large items such as pipes, fittings, and nuts, as shown in Figure 1.21. The extended handles offer increased leverage, making pump pliers ideal for tasks that require significant force, such as loosening and tightening nuts and bolts or handling pipes during plumbing work.

**Fig. 1.21 Pump plier**

**Vise grip pliers –** Vise grip pliers, also known as locking pliers or mole grips, combine the functions of a clamp, pipe wrench, hand vise, and pliers into a single tool. Designed to lock onto a workpiece, these pliers allow users to hold objects securely without continuous manual pressure. The lever mechanism locks the jaws in position, providing up to one ton of clamping force.

Vise grip pliers typically feature serrated jaws that can be adjusted to accommodate different sizes of objects. The jaws are spring-loaded and can be locked in place using a trigger mechanism, which ensures a consistent grip on the workpiece, as shown in Figure 1.22. Some models also include additional features such as wire cutters, adjustable handles, and swivel pads for enhanced versatility.

**Fig. 1.22 Vise grip plier**

**Diagonal cutting pliers** - Diagonal cutting pliers, also known as diagonal cutters or side cutters, are designed specifically for cutting wire, cables, and other materials. They feature sharp cutting edges angled relative to the pliers' axis, enabling them to cut flush with a surface, as shown in Figure 1.23.

Available in various sizes and styles, diagonal cutting pliers can be made from materials such as steel or aluminium. They are commonly used in electrical work, jewellery making, and other applications that require precise cutting of wires or small components.

**Fig. 1.23 Diagonal cutting pliers**

**Cutting Tools –** Various cutting tools are designed for cutting different materials, and choosing the right tool for each task is essential. Chisels, for instance, are used for cutting both metal and wood. Made from high-carbon steel, they are durable enough to carve through metal, as illustrated in Figure 1.24. Chisels are particularly useful for removing rusted bolts and nuts. They come in a range of sizes and types, including wood chisels, metal chisels, and concrete chisels, each suited to specific cutting tasks.

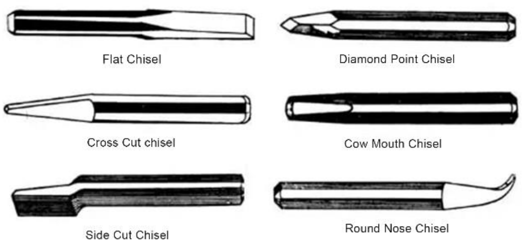



**Fig. 1.24 Chisels**

**Hacksaws –** A hacksaw is a cutting tool equipped with a fine-toothed blade, ideal for cutting through metal, wood, plastic, and other materials, as shown in Figure 1.25. The hacksaw comprises a handle, a frame, and a blade. The frame is adjustable, allowing it to accommodate blades of various lengths. Additionally, blades come with different numbers of teeth per inch, enabling users to apply appropriate force for making precise cuts.

**Fig. 1.25 Hacksaws**

**File –** Files are tools used to smooth rough edges on metals, wood, and plastic by removing small amounts of material to shape or refine surfaces, a process known as filing. To use a file, hold it by its handle and press the teeth against the material's surface. Move the file back and forth, applying pressure primarily on the forward stroke. The file's teeth cut into the material, gradually removing it with each pass.

Files come in various sizes and shapes, as illustrated in Figure 1.26. For example, a flat file is used for filing flat surfaces, a round file is designed for round or curved surfaces, and a half-round file can handle both flat and curved areas.


**Fig. 1.26 Files**

**Flat File –** A flat file is a hand tool designed for shaping, smoothing, and removing small amounts of material from flat surfaces. It features a rectangular cross-section with teeth cut into one or both sides of the flat surface. The teeth are typically angled in one direction, allowing the file to effectively remove material when moved in that direction while resisting movement in the opposite direction.

Flat files are used to eliminate rough edges, burrs, and other imperfections on a variety of materials, including wood, metal, and plastic. They come in different sizes and are commonly made of high-carbon steel, ensuring durability and longevity, as shown in Figure 1.27.

**Fig. 1.27 Flat file**

**Round File –** A round file is a hand tool used for shaping and smoothing round or curved surfaces. It has a cylindrical shape with teeth cut into its surface, angled in one direction, as illustrated in Figure 1.28. Round files come in various sizes and are available in two forms: half-round and full-round. They are typically made of high-carbon steel, ensuring durability and longevity.

Round files are ideal for working on surfaces such as pipes, tubes, and dowels. They are also useful for removing burrs and sharp edges from drilled holes and other circular openings.

**Fig. 1.28 Round file**

**Drill bits –** Drill bits are cutting tools used for creating holes in materials such as metal, wood, and concrete. A general-purpose twist drill set can meet most technicians' needs. For specialized tasks, wood bits and masonry drill bits are commonly used. Drill bits come in various sizes, shapes, and materials, each tailored to specific drilling applications, as shown in Figure 1.29.

The most common types of drill bits include:

**Twist Drill Bits:** Made from high-speed steel with a helical shape, these are versatile and suitable for drilling in metal, wood, and plastic.

**Masonry Drill Bits:** Featuring a tungsten carbide tip, these are designed for drilling into brick, concrete, and stone.

**Forstner Bits:** Used to create flat-bottomed holes in wood.

**Spade Bits:** Ideal for drilling larger holes in wood.

**Auger Bits:** Designed for drilling deep holes in wood.


**Fig. 1.29 Drill bits**

**Assignment 1**

Identify the name of hand tools used during the installation of an air conditioner

| Picture of the tool | Name of the tool |
|---|---|
|  Fig. 1.30 | Name ............................... |
|  Fig. 1.31 | Name ............................... |
|  Fig. 1.32 | Name ............................... |
|  Fig. 1.33 | Name ............................... |

| | | | |
|---|---|---|---|
| |  Fig. 1.34 | Name ................................ | |
| |  Fig. 1.35 | Name ................................ | |
| |  Fig. 1.36 | Name ................................ | |

### 1.2.2 Power Tools

Power tools perform the same tasks as hand tools but are designed to complete them more quickly and efficiently. These tools can be powered either by electricity through a wired connection or by batteries. Power tools, which include electric and pneumatic devices, are used for functions such as cutting, drilling, grinding, sanding, and polishing. They enhance efficiency, accuracy, and speed across various industries, including construction, woodworking, metalworking, and automotive.

When using power tools, it is essential to follow safety precautions to prevent injury. This includes wearing protective gear such as gloves, goggles, and ear protection, adhering to proper operating procedures, keeping the work area clean and well-lit, and ensuring that the tools are in good working condition before use.

There are various power tools available such as a Power drill, Circular saw, Angle grinder, Power jigsaw, Impact driver, Reciprocating saw, and Power sander. some of which are shown in Figure 1.37


**Fig. 1.37 Power tools**

**Power drill -** A power drill, also known as an electric drill, is a tool powered by electricity rather than manual effort. It is versatile and can be used for various tasks, including drilling holes, driving screws, and mixing paint or other materials.

Power drills come in two main types: corded and cordless. Corded drills are generally more powerful and do not require a battery, but they are less portable. Cordless drills, on the other hand, offer greater mobility but rely on a rechargeable battery. Examples of both types are shown in Figure 1.38 (a) and (b), respectively.

**Fig. 1.38 Power drills (a) Corded electric drill (b) Cordless electric drill**

**Circular saw -** A circular saw is a powerful handheld tool designed for making straight or angled cuts through various materials, including wood, metal, and plastic. It features a robust electric motor, which can be either AC or DC.

Circular saws come in a range of sizes, from small, lightweight models suitable for home use to heavy-duty versions intended for professional applications. It's crucial to select the appropriate blade for the material being cut and to ensure that the blade is correctly installed and adjusted. A typical circular saw is shown in Figure 1.39.

**Fig. 1.39 Circular saw**

**Angle grinder -** An angle grinder, also referred to as a disc grinder or side grinder, is a versatile handheld power tool designed for cutting, grinding, and polishing various materials, including metal, stone, and concrete. The tool's name reflects the angle at which the abrasive disc is mounted on its head. Angle grinders are equipped with a motor that drives a rotating abrasive disc or wheel. The choice of disc depends on the specific task, as shown in Figure 1.40. These discs are commonly made from abrasive materials such as diamond, aluminium oxide, or silicon carbide. They are used for tasks such as cutting metal, smoothing welds, removing rust and paint, and shaping or polishing surfaces.

**Fig. 1.40 Angle grinder**

**Power jigsaw -** A power jigsaw is a versatile handheld tool designed for cutting various materials, such as wood, metal, plastic, and ceramic. It excels in making straight, curved, and bevel cuts.

The power jigsaw operates with a motor that drives a reciprocating blade up and down. The blade is mounted on a guide plate that can be adjusted to achieve different types of cuts. Typically, the blade is made from high-carbon steel or tungsten carbide and features various tooth configurations depending on the material being cut, as shown in Figure 1.41.

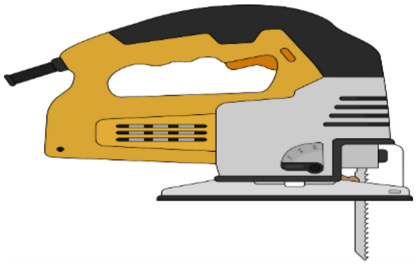


**Fig. 1.41 Power jigsaw**

**Impact driver -** An impact driver is a powerful tool designed for driving screws and bolts into various materials, including wood and metal. Unlike a standard cordless drill, an impact driver delivers higher torque and faster rotational speed using a distinct mechanism.

The impact driver features a motor that drives a rotating shaft to strike an internal anvil. This process generates a series of rapid, high-torque blows to the tool's chuck, making it particularly effective for driving long screws and bolts into tough materials, as shown in Figure 1.42.

Impact drivers are available in both corded and cordless models, with cordless versions being more popular due to their convenience. They typically use hexagonal driver bits and can accommodate a wide range of screw and bolt sizes.

**Fig. 1.42 Impact driver**

**Reciprocating saw -** A reciprocating saw, often referred to as a "recip saw" or "sawzall," is a versatile handheld power tool that uses a push-and-pull motion to make cutting strokes. Its blade moves rapidly back and forth, enabling it to cut through a wide range of materials, including wood, metal, PVC, and drywall, as illustrated in Figure 1.43.

Reciprocating saws can be equipped with various blades, each designed for specific tasks, such as metal-cutting blades, wood-cutting blades, and pruning blades. Many reciprocating saws also feature adjustable speed controls, allowing users to modify the cutting speed based on the material being worked on.

**Fig. 1.43 Reciprocating saw**

**Power sander** - A power sander is a handheld tool designed to sand and smooth surfaces more efficiently than traditional hand-held sandpaper. It is powered by electricity, batteries or air compressors. Power sanders are used for working on wood, metal, and other materials.

The most common types of power sanders include:

**Belt Sanders:** Ideal for heavy-duty sanding and removing large amounts of material quickly.

**Orbital Sanders:** Used for finer sanding tasks and achieving a smooth finish.

**Random Orbit Sanders:** Combine the features of orbital and random motion for a versatile sanding approach with minimal swirl marks. A typical power sander is illustrated in Figure 1.44.

**Fig. 1.44 Power sander**

### 1.2.3 Specialty Tools

Specialty tools are designed for specific tasks and provide precise servicing for various appliances. They are essential for operations such as installing or removing unique screws and nuts, servicing bearings in air conditioners, and adjusting switch contacts. Figure 1.45 depicts different types of specialty screws and the corresponding drivers needed for their removal.

Common types of specialty tools include:

**Wire Stripper:** Used for removing insulation from electrical wires.

**Alligator Jumpers:** Electrical connectors used for temporary connections.

**Flashlight:** Provides illumination in dim or inaccessible areas.

**Copper Tube Benders:** Used for bending copper tubing in plumbing or HVAC systems.

**Allen Keys:** Also known as hex keys, used for driving hexagonal screws.

**Phase Tester:** Checks the presence of electrical voltage in circuits.

**Combination Pliers:** Versatile pliers used for gripping, twisting, and cutting.

**Measuring Tape:** Essential for taking accurate measurements.

**Electric Drill Guns:** Powered tools used for drilling holes and driving screws.

These tools facilitate precise and efficient work in various servicing scenarios.

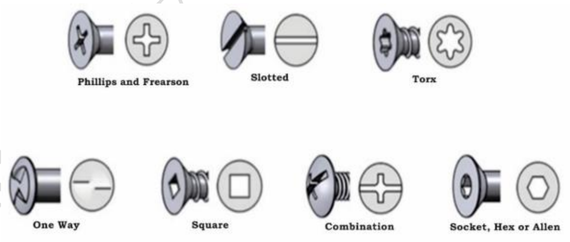



**Fig. 1.45 Speciality screws**

In addition to the basic hand tools, several special-purpose tools are used in appliance servicing as shown in Figure 1.46.

**Fig. 1.46 Special-purpose tools**

**Wire stripper –** A wire stripper is a hand tool used to remove insulation from electrical wires without damaging the conductive core. This tool is crucial for electricians and electronics technicians.

Wire strippers come in various sizes and designs but generally feature cutting jaws with notches tailored to specific wire sizes. To use the tool, insert the wire into the correct notch and squeeze the handles to close the jaws around the wire. The insulation is then stripped away easily by pulling the tool away from the wire, leaving the wire intact. Figure 1.47 illustrates the typical appearance of a wire stripper.

**Fig. 1.47 Wire stripper**

**Alligator jumper –** An alligator jumper, also known as an alligator clip jumper, is a type of electrical cable used for temporarily connecting two points within an electrical circuit. This tool features alligator clips at both ends of a length of insulated wire.

Alligator clips are spring-loaded clamps designed to attach securely to wires or other conductive surfaces. They are commonly employed in electrical testing and troubleshooting for making temporary connections between circuit components. Figure 1.48 shows the typical appearance of an alligator jumper.

This flexible and convenient tool is useful for testing circuits, diagnosing electrical issues, and establishing temporary connections across various applications. For example, an alligator jumper can connect a power source to a circuit board for testing or link a multimeter to measure voltage or current.

**Fig. 1.48 Alligator jumper**

**Flash light –** A portable hand-held electric lamp is an essential tool used in the repair and maintenance of air conditioners. It provides illumination for viewing and working on the internal components of the air conditioner. This type of lamp is particularly useful for inspecting and servicing areas that are otherwise difficult to see. Figure 1.49 illustrates a typical hand-held electric lamp used for these purposes.

**Fig. 1.49 Flashlight**

**Copper tube bender –** A copper tube bender is a specialized tool used to bend copper pipes or tubing into specific shapes or angles. It is commonly employed in plumbing and HVAC (heating, ventilation, and air conditioning) systems to create precise bends for routing pipes around obstacles or fitting them into tight spaces. Figure 1.50 illustrates a typical copper tube bender.

Copper tube benders come in various shapes and sizes, generally featuring a set of rollers or mandrels that fit around the copper tubing. A bending arm or lever is used to apply force, bending the tube to the desired angle. To use the tool, insert the tube into the rollers or mandrels and operate the bending arm or lever to achieve the desired bend. The angle of the bend can be adjusted by repositioning the mandrels or rollers.

**Fig. 1.50 Copper tube bender**

**Allen key –** An Allen key, also known as a hex key or Allen wrench, is a hand tool used to tighten or loosen screws and bolts with hexagonal sockets. It consists of a small, L-shaped metal bar with a hexagonal end that fits into the corresponding hexagonal socket on the screw or bolt head, as shown in Figure 1.51.

Allen keys come in various sizes to match different screw and bolt sizes. To use the tool, insert the hexagonal end into the socket on the screw or bolt head, and turn it to either tighten or loosen the fastener. The L-shaped design allows for easy manoeuvrability in tight or hard-to-reach areas.

**Fig. 1.51 Allen key**

**Phase tester –** A phase tester, also known as a voltage tester, neon screwdriver, or test pin, is a tool used to detect the presence of AC voltage, although some models can also measure DC voltage. It is commonly used by electricians and homeowners to verify the presence or absence of electrical current before performing maintenance, repairs, or installations.

A typical phase tester features a pointed probe at one end and a display or light indicator at the other end. To use the tester, insert the probe into an electrical outlet. If voltage is present, the display or indicator will light up, as shown in Figure 1.52.

**Fig. 1.52 Phase tester**

**Measuring Tape –** A measuring tape, also known as a tape measure, is a hand-held tool used to measure distances, lengths, and widths. It consists of a long, flexible ribbon or blade made of metal or fiberglass, marked with measurement increments, and housed in a plastic or metal case. A typical measuring tape is illustrated in Figure 1.53.

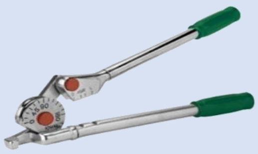
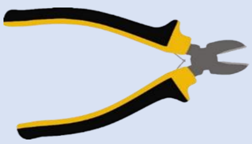
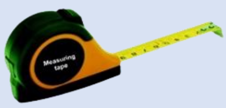
To use a measuring tape, extend the tape to the desired length, placing the end of the tape at one point of the measurement. Read the measurement from the tape at the other end of the measurement to obtain the distance. Proper use of a measuring tape ensures accurate measurements.


**Fig. 1.53 Measuring tape**

Practical activity 1.3 demonstrates the use of tools for the installation of the air conditioner.

**Assignment 1**

Match the correct tool with its name.

| Picture of the tool | Name of the tool |
|---|---|
|  Fig. 1.54 | Name ................................ |
|  Fig. 1.55 | Name ................................ |
|  Fig. 1.56 | Name ................................ |
|  Fig. 1.57 | Name ................................ |
|  Fig. 1.58 | Name ................................ |
|  Fig. 1.59 | Name ................................ |

### 1.2.4 TESTING TOOLS

Testing appliances are crucial for ensuring customer satisfaction, which is a top priority for manufacturers. Before an appliance is launched into the market, it undergoes rigorous testing across various parameters such as temperature and pressure to ensure that it meets quality standards. Over time, however, the performance of an appliance may decline. To maintain optimal performance, regular testing is necessary.

Various test equipment is employed by technicians for performance testing and repair of appliances. These tools are essential for monitoring, maintaining, and repairing air conditioners and their components. Test instruments play a key role in diagnosing issues that may arise with appliances, helping ensure they function efficiently and effectively.

**Ammeter –** An ammeter is a device used to measure the electrical current flowing through a circuit. It is typically a compact, portable instrument connected in series with the circuit under measurement. The ammeter measures current in amperes (A), which is the unit of electrical current. It is designed to measure the circuit's current without interrupting the flow of electricity, as shown in Figure 1.60.

Ammeters come in two main types: analog and digital. Analog ammeters use a pointer and a scale to indicate the current, while digital ammeters provide a numeric readout of the current on a display. Some ammeters are calibrated to measure very small currents, whereas others are capable of handling very high current levels.

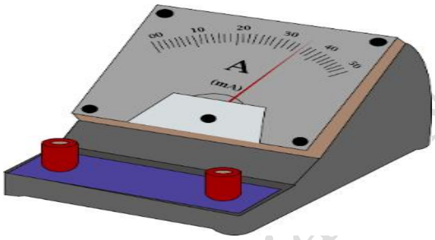



**Fig. 1.60 Ammeter**

**Wattmeter –** A wattmeter is a device used to measure the electrical power consumed by a circuit or electrical device. It calculates the power by measuring the product of the voltage and current flowing through the circuit, with the result expressed in watts (W). Wattmeters are widely used in industrial, commercial, and residential settings to monitor and manage energy consumption, as illustrated in Figure 1.61.

The operation of a wattmeter involves measuring both the voltage and current in a circuit and then multiplying these values to determine the power consumption. This is typically done using a combination of current and potential transformers, which reduce the voltage and current to safe levels for measurement. The wattmeter then displays the total power consumed by the appliance or circuit.

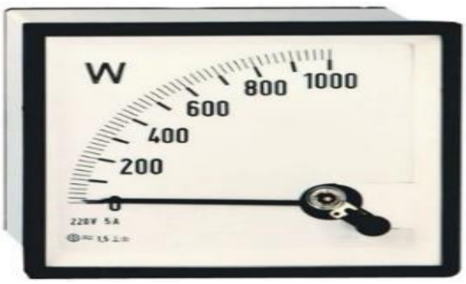



**Fig. 1.61 Wattmeter**

**Temperature tester –** A temperature tester is a device used to measure the temperature of an object or substance. It can be either digital or analog, and it measures temperature either through direct contact or by using infrared radiation. Temperature testers are versatile tools commonly used to monitor temperatures in various applications, such as measuring the temperature inside a washer tub or checking the inlet temperature of water supply. A typical temperature tester is illustrated in Figure 1.62.


**Fig. 1.62 Temperature tester**

**Clamp Meter –** A clamp meter is a measuring instrument used to measure the amount of electrical current flowing through a wire. It operates by clamping around the wire without needing to disconnect it from the circuit. The meter then automatically measures and displays the current value. This tool is highly convenient for measuring current in live wires. A typical clamp meter is illustrated in Figure 1.63.


**Fig. 1.63 Flexible charging line**

**Digital Multimeter –** A multimeter is a versatile instrument used to measure various electrical parameters, including voltage, current, resistance, and continuity. It is available in two forms: manual and auto-ranging. The device displays readings as numerical values on an LCD screen, making it easy to interpret. While similar in function to an analog meter, the digital multimeter provides more precise and easy-to-read measurements. A typical multimeter is illustrated in Figure 1.64.


**Fig. 1.64 Multimeter**

**Tachometer –** A tachometer is an instrument used to measure the rotational speed of a motor, typically in revolutions per minute (RPM). It is commonly used to check the RPM of wash motors and spin motors in appliances. A typical tachometer is illustrated in Figure 1.65.

**Fig. 1.65 Tachometer**

Practical activity 1.2 demonstrates the measurement of AC or DC current supply using a clamp meter in the air conditioner.

**Practical Activity 1.2.** To demonstrate the measurement of AC or DC current supply using a clamp meter in the air conditioner.

**Material Required –**

Clamp meter, Electric wire

**Procedure**

**Step 1.** Set the rotary selector on the clamp meter to the correct function and range, as shown in Figure 1.66.


**Fig. 1.66 Setting the rotary selector on the clamp meter**

**Step 2.** Set the clamp meter to the voltage symbol "V" to read the voltage on the conductor, as shown in Figure 1.67. Connect the black probe to the COM jack and the red probe to the V/O jack.


**Fig. 1.67 Setting the clamp meter to voltage**

**Step 3.** Push the trigger on the device to open the jaw. Clamp the device around the conductor and close it as shown in Figure 1.68, making sure that the electrical conductor is connected to a power source.

**Fig. 1.68 Clamp the device around conductor**

**Step 4.** Note the reading on the display of the clamp meter, as shown in Figure 1.69.

**Fig. 1.69 Taking the reading on the clamp meter**

Practical activity 1.3 demonstrates the use of a multimeter to measure various electrical quantities of the air conditioner.

**Practical activity 1.3.** Demonstrate the use of a multimeter to measure various electrical quantities of the air conditioner

**Material required –**

Digital multimeter, resistor, AC and DC power source, connecting cords.

**Procedure**

**A. Measuring the resistance using a digital multimeter.**

**Step 1.** Insert the black probe into the common terminal and the red probe into the terminal marked for measuring volts and ohms. Figure 1.70 illustrates that The Digital multimeter has two probes.

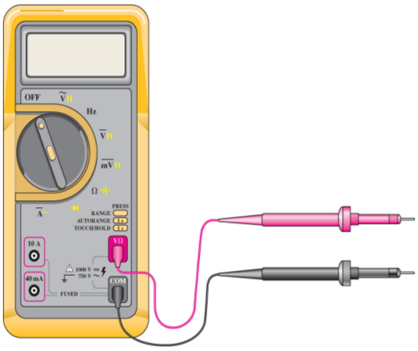


**Fig. 1.70 Volt/ohm terminal and common terminal of multimeter**

**Step 2.** Twist the selector knob to set the multimeter to measure resistance, as shown in Figure 1.71. This may be represented by the Greek letter Omega Ω, which stands for ohms, the unit for measurement of resistance.

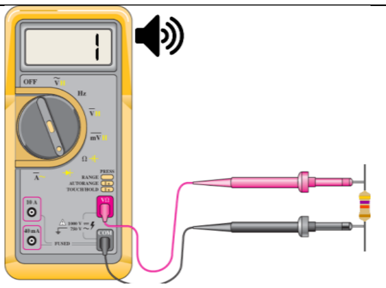


**Fig. 1.71 Multimeter knob set measure the resistance value**

**Step 3.** Touch the tips of the probes to sides of the resistor, as shown in Figure 1.72.

**Fig. 1.72 Measuring the resistance of resistor by touching the resistor terminal to the red and black probes**

**Step 4.** Read the display, as shown in Figure 1.73, taking care to note the units. A reading of 10 may indicate 10 ohms, 10 kilo-ohms or 10 mega-ohms.

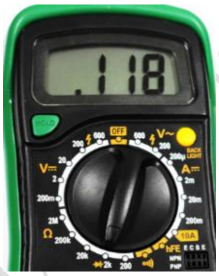


**Fig. 1.73 Resistance value in Kilo-ohm**

**B. Measuring AC and DC voltage using a digital multimeter.**

**Step 1.** The Digital multimeter has two probes, as shown in Figure 1.74. Using these probes measurement of voltage can be done. Put the black probe in the common terminal and the red probe in the terminal marked for measuring volts and ohms.

**Fig. 1.74 Connecting the red probe to the volt terminal and black probe to the common terminal**

**Step 2.** Set the multimeter to measure the voltage, as shown in Figure 1.75. You can measure volts DC, millivolts DC or volts AC. If your multimeter has an auto-range function, it is not necessary to select the voltage you are measuring.

**Fig. 1.75 (a) Turning the knob to measure the DC voltage**

**Fig. 1.75 (b) Turning the knob to measure the AC voltage**

**Step 3.** Measure AC voltage by placing the probes across the component. In case of AC it is not necessary to observe polarity, as demonstrated in Figure 1.76


**Fig. 1.76 Measuring AC voltage using multimeter**

**Step 4.** Observe polarity when measuring DC voltage or millivolt. Place the black probe on the negative side of the DC source and the red probe on the positive side of the DC source, as demonstrated in Figure 1.77.

**Fig. 1.77 Measuring DC voltage using multimeter**

**Step 5.** Read the display, as shown in Figure 1.78. If you prefer, you can use the touch-hold feature to keep the reading on the display after removing the probes. The multimeter will beep each time a new voltage is detected.


**Fig. 1.78 Holding the value in the display using hold button**

Practical activity 1.4 demonstrate measuring the rotation speed of the motor using a tachometer

**Practical activity 1.4** Demonstrate measuring the rotation speed of the motor using a tachometer.

**Material required –**

Optical tachometer, contact tachometer, reflecting tape.

**Procedure**

Follow the following steps to measure the speed of the motor.

**A. Measuring the speed using an optical tachometer.**

**Step 1.** First, unplug the electric motor, and stick the reflecting tape on the shaft of the electric motor as shown in Figure 1.79.

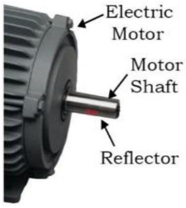



**Fig. 1.79 Reflecting tape on the motor shaft**

**Step 2.** Turn on the supply of the electric motor and press the test button, as shown in Figure 1.80.

**Fig. 1.80 Pressing the test button of a tachometer**

**Step 3.** On pressing the test button, an optical ray will come out from the end of the tachometer as shown in Figure 1.81.


**Fig. 1.81 Optical ray coming out from tachometer**

**Step 4.** Focus the light ray on the reflecting tape and observe the reading in RPM on the tachometer as shown in Figure 1.82.


**Fig. 1.82 Reading in RPM**

**Step 5.** Wait for the reading to get stabilized. Take three to four readings and calculate the mean for accuracy.

**B. Measuring the speed using a contact tachometer.**

**Step 1.** Turn on the supply of electric motors. Now, touch the contact of the tachometer to the shaft of the electric motor as shown in Figure 1.83.


**Fig. 1.83 Touch the contact of tachometer to the shaft of electric motor**

**Caution:** Do not apply too much pressure on the tachometer contact, while touching the shaft of the electric motor.

**Step 2.** Press the test button of the tachometer. You will observe the reading in RPM on the tachometer as shown in Figure 1.84.


**Fig. 1.84 Reading in RPM**

**Step 3.** Wait for the reading to get stabilized. Take three to four readings for accuracy.



## 1.3 Safety Guidelines for Fitting Work

### 1.3.1 Safety Precautions

When using tools for the installation, repair, and maintenance of an air conditioner, it is crucial to take safety precautions, as safety begins with accident prevention. Without a proper understanding of basic tools and their safety, one should not attempt these tasks. Improper installation, maintenance, or repair can lead to personal injury and property damage.

Here are the safety precautions to follow to prevent injuries when using basic tools:

1. Always wear gloves when handling tools.
2. Avoid loose clothing when working with power tools.
3. Wear safety glasses to protect your eyes from flying debris.
4. Use tools according to the manufacturer's instructions and never modify their intended use.
5. Keep tools clean and in good working condition.
6. Use each tool only for its intended purpose.
7. Ensure that the power cord is kept away from the working end of power tools.
8. Check that any shields or guards are functioning properly and always use them.
9. Use an extension cord in good condition; do not use it if bare wires are visible. Ensure it is heavy-gauge to provide adequate voltage for the tool.
10. Make sure the extension cord is properly grounded.
11. Grip tools firmly during use.
12. Never use worn-out tools, as they have a higher risk of causing injury. For example, a worn screwdriver is more likely to slip, potentially leading to injury.
13. If a power tool malfunctions, unplug it before attempting any repairs or adjustments.
14. Use insulated hand tools when working with electricity or electrical components.

### 1.3.2 Safety Guidelines for Fitting Work

Safety is paramount when performing fitting work, and it is essential to adhere to safe working practices at all times. Ignoring safety rules can lead to losing the privilege to work in the fitting shop.

Improper or careless use of tools can make them dangerous, so working safely is a fundamental skill for any fitter. The safe way is the only correct way. Before operating any machine tools, one must first learn the safety regulations and precautions specific to each tool or machine. Most accidents occur due to failure to follow these prescribed procedures.

**1. Eye Protection**

Wearing eye protection in the machine shop is the most crucial safety rule. Metal chips and shavings can be ejected at high speeds and over long distances, posing a significant risk of serious eye injury.

Safety glasses must always be worn when using hand-cutting tools. These tools, typically made of hardened steel, can break or shatter if not used correctly, making eye protection essential.

There are various types of safety glasses available, but those with side shields offer the best protection. For individuals who wear prescription glasses, safety goggles should be worn over them, as demonstrated in Figure 1.85.

**Fig. 1.85 Eye Protection**

**2. Foot Protection**

The floor in a machine shop is often littered with razor-sharp metal chips, and heavy materials may be accidentally dropped, posing a risk to your feet. To protect against these hazards, safety shoes or solid leather shoes must be worn at all times.

Safety shoes are equipped with a steel plate over the toe area, designed to withstand impacts and protect your feet from injury. Some safety shoes also feature an in-step guard for added protection, as illustrated in Figure 1.86.

**Fig. 1.86 Foot Protection**

**3. Grinding Dust and Hazardous Fumes**

Grinding dust from abrasive wheels consists of extremely fine particles of both the metal being worked on and the abrasive wheel itself. Some grinding machines come with a vacuum dust collector to help manage this dust. When operating a grinder without a vacuum system, it's crucial to wear an approved respirator to avoid inhaling the dust, which can be harmful to your health.

Using coolant while grinding is highly recommended, as it helps in controlling dust and reducing the risk of inhalation. This is especially important when grinding materials like beryllium or components used in nuclear systems, where the dust requires meticulous control due to its hazardous nature, as illustrated in Figure 1.87.

**Fig. 1.87 Face cover**

**4. Electrical safety**

Machine operators are generally focused on the on/off switch of the machine they are using. However, if any adjustments or repairs need to be made, it's essential to disconnect the power source. For machines that are permanently wired, the circuit breaker should be switched off and tagged with a clear warning statement to prevent accidental re-energization.

While the power source is often not disconnected for routine adjustments, such as changing machine speeds, caution is still necessary. If the speed change requires adjusting belts or pulleys, ensure that no one else can turn on the machine while the operator's hands are in contact with these moving parts. This precaution is vital to avoid accidents.

### 1.4 Hazards

Hazards refer to conditions that pose a threat to the lives of humans and animals in their surroundings. These hazards can lead to severe consequences such as nuclear fallout, the release of poisonous gases into the atmosphere, oil or grease spills that can cause slips and falls, or even fire accidents. Such hazards can result in serious health issues.

There are three primary types of hazards:

**Chemical Hazard:** Involves exposure to harmful chemicals that can cause health problems or environmental damage.

**Physical Hazard:** Includes physical conditions or objects in the environment that can cause harm, such as noise, radiation, or extreme temperatures.

**Ergonomic Hazard:** Arises from improper workstation setup, poor posture, or repetitive movements, leading to musculoskeletal injuries and strain.

#### 1.4.1 Chemical Hazards

The entry of foreign substances into the human body through various means is termed a chemical hazard. Chemicals can enter the human body through the following pathways:

**Inhalation:** This is the most common way for chemicals to enter the body. When a person breathes, chemicals can be inhaled and enter the respiratory system, leading to potential harm.

**Ingestion:** Chemicals can enter the body through swallowing, often occurring when eating, drinking, or accidentally consuming contaminated food or liquids.

**Absorption:** This process involves chemicals entering the body through the skin or eyes. Direct contact with hazardous substances can lead to absorption, causing adverse effects.

#### 1.4.2 Physical Hazards

There are of different types of physical hazards that are harmful for the workers:

i. Noise

ii. Vibration

iii. Temperature Extremes

**Noise:** When working with machinery, exposure to high noise levels can lead to temporary hearing loss. Several factors significantly impact workers in this regard:

**Simultaneous Operation of Multiple Machines:** When several machines generating high noise levels are used at the same time.

**Enclosed or Partially Enclosed Spaces:** These environments can amplify noise, increasing exposure levels.

**Poorly Maintained or Malfunctioning Equipment:** Machines that are not properly maintained or are malfunctioning can produce excessive noise, further contributing to hearing risks.

**Vibration:** While working with large equipment such as drillers, air mallets, pile drivers, tractors, bulldozers, earth-moving equipment etc., hand-arm vibration usually occurs such as while using power tools, like pneumatic drills, grinders, etc.

**Temperature Extremes –** A transformation in body temperature due to risky work environmental conditions could incorporate stress or illness from heat or cold. If not treated in time, both heat and cold stress/illness can develop into life-threatening situations.

**Heat illnesses causes and injuries:** Substantial amount of work in very high temperatures could lead to muscle cramps, dehydration and unconsciousness. A few symptoms of heat illnesses are as follows:

- Heat rash
- Fainting
- Heat cramps
- Heat exhaustion
- Heat stroke
- Wearing resistant protective clothing when doing heavy work.

**Cold illnesses cause and injuries:** A cold temperature majorly causes tiredness, breathing difficulties and lack of consciousness (hypothermia). A few symptoms of heat illnesses are as follows:

- Frost nip
- Immersion injury (trench foot)
- Frost bite
- Hypothermia

### 1.4.3 Ergonomic Hazards

These hazards lead to aching & disabling injuries mainly in muscles and joints. These injuries are due to following factors:

- Repeating chores more than twice
- Wrong way of holding a tool, wrong body language (gestures or movements) while working
- Lifting heavy weight tools, regular lifting, or wrong method of lifting
- Using unnecessary force
- Using improperly maintained tools
- Using wrong tools for the job
- Hand-intensive work

**The Ergonomic hazards also lead to musculoskeletal disorders (MSDs) and injuries.**

Following are the correct lifting procedures that must be followed at work to avoid Ergonomic hazards:

- Chin tucked in
- Comfortably straight back
- Leaning slightly forward
- Arms close to body
- Secure grip
- Bent knees
- Proper foot position

**Fig. 1.88 The correct lifting procedures**

**1.5 Common hazards that can lead to an accident:**

Slip & fall at the work place due to spill of liquids, oils, water at the floors. To prevent this, non-slip floor surfaces & fatigue mats must be provided at the shop floor.

**Fig. 1.89 Spill of liquids, oils, water at the floor**

Use of faulty, defective & improperly maintained equipment to perform some operations leads to accidents. A proper maintenance of equipment is recommended. Lifting heavy objects manually leads to muscle tension & spinal injuries.

Improper store of chemicals & some dangerous substances leads to fire hazards & in few cases it leads to explosions also. This can be prevented by make use of fire extinguisher.

**Worn out hoses:**


**Fig. 1.90**

**Damaged power tools:**

**Fig. 1.91**

**Precautionary Measures to Prevent from Workplace Hazards**

- Wear an appropriate PPE.
- Ensure that all tools, equipment's, extension leads are in safe working conditions.
- Ensure the machine and its tools are secured at all times. Also, check the work area is kept free from any hazards.
- Carry out regular maintenance of tools & equipment.

**Fig. 1.92 Safety equipment to be used in workplaces**

**Summary**

- The tools and measuring instruments made human routine work easy.
- Hand tools are simple pieces of equipment that you hold in your hands and use to do a particular kind of work.
- A measuring tape, also known as a tape measure, is a hand-held tool used for measuring distances, lengths, and widths.
- Drill bits are also cutting tools used with drill machines.
- A round file is a hand tool that is used for shaping and smoothing round or curved surfaces.
- A wattmeter is a device used to measure the electrical power consumed by a circuit or an electrical device.
- Phase tester is used for the detection of AC voltage.
- Clamp meter is a measuring instrument, used to measure the amount of current flowing in a wire.
- Techo meter is used to measure the rotation of motors in air conditioner.
- Power tools are used for installation work so fast and easily.
- Allen key is a simple hand tool used to tighten or loosen screws and bolts with hexagonal sockets.
- An impact driver is a powerful tool used for driving screws and bolts into wood, metal, and other materials.

## CHECK YOUR PROGRESS

**A. Multiple Choice Question**

1. A screw is usually made up of ___. (a) Treads (b) Springs (c) Threads (d) Strings
2. Which of the following equipment is used to measure the current without breaking the circuit? (a) Ammeter (b) Voltmeter (c) Clamp meter (d) Multimeter
3. Which of the following equipment is used to measure the AC voltage? (a) Power meter (b) Galvanometer (c) Ammeter (d) Megger meter
4. Which of the following tool is used for the removal of the insulation of wire? (a) Plier (b) Wrench (c) Wire stripper (d) Hammer

5. Which of the following is used to test the phase in the wire? (a) Phase tester (b) Screwdriver (c) Wire stripper (d) Combination plier
6. Wire ________is a portable handheld tool used by workers, especially electricians, for removing the protective coating of an electric wire. (a) stripper (b) cutter (c) holder (d) breaker
7. Combination Plier can perform number of operations. It enables the user to perform the ______operation such as cutting and gripping using a single tool. (a) combine (b) single (c) double (d) Triple
8. Tong Tester/Clamp meter is a tool used to measure ________flowing in a wire. (a) current (b) voltage (c) Temperature (d) Power
9. A typical screwdriver has (a) has only shaft (b) has only handle (c) has a flat end at its tips (d) a handle and a shaft
10. Multimeters are available in ________form. (a) digital and analog (b) digital only (c) analog only (d) Voltmeter

**B. Fill in the blanks**

1. Combination plier is used for _____ and _______.
2. Tong meter is also known as _____ meter.
3. In Phase tester _____ bulb is used for the indication of live wire.
4. Multimeter is used for the measurement of resistance, voltage, and ____.
5. Clamp meter measure the _______.
6. The flaring tool is a tool for ____________________ piping for flaring that expands the pipe opening of air conditioning piping.
7. Drill Machine is a tool primarily used for making _______________ or driving fasteners
8. Hammer is a tool consisting of a piece of metal with a ________________ that is fixed onto the end of a long, thin, usually wooden handle, used for hitting things, shaping of _________________.
9. Phase Tester is a tool, which is used to identify or ____________________conductor.
10. Metallic rod and mouth are a ____________________ metal rod. The flat end (mouth) is used as a ____________________

**C. State whether the following statements are True or False**

1. Clamp meter is used to measure the current flowing inside the wire.
2. Multimeter is used for the testing of diode.
3. Combination plier is used for the stripping of the insulation in the wire.
4. Line tester is used for testing Resistance.
5. Multimeter can measure AC and DC voltage.
6. A screwdriver has a handle and a shaft.
7. A clamp meter requires unnecessary procedure of breaking the circuit to measure current.
8. The jaws of combination pliers open and close along with the handles.
9. Wire Stripper is a non-portable handheld tool used by workers, especially electricians, for removing the protective coating of an electric wire.
10. Neon Bulb is used as phase indicator bulb.

**D. Short Answer Questions**

1. List out the uses of screwdriver.

2. Does screwdriver have insulator and conductor. If yes, mention the parts, which are insulator and conductor.
3. Write down the electrical quantities, which can be measure using multimeter?
4. Write down the different parts of combination plier. Mention its specific use.
5. What is the purpose of line tester in electrical network?

## Session 2. Sheet Metal

**Sheet Metal**

Sheet metal refers to metal and metal alloys that have been rolled into thin sheets, typically ranging from 10 S.W.G. (Standard Wire Gauge) and thinner. It holds significant importance in the manufacturing industry, playing a crucial role in meeting various everyday needs. Sheet metal products are essential in numerous fields, including agriculture, construction, household items, office and laboratory equipment, heating and air conditioning, transportation, decorative work, toys, and more.

Using specialized tools, various processes are applied, from surface development to actual fabrication. Key operations in sheet metal work include cutting, rolling, bending, and shaping. Common tasks involve creating seam joints, lap joints, fabricating cylinders and trays, as well as performing riveting and soldering applications.

**Process of Metal working**

Metalworking involves shaping and assembling metals to create individual parts, assemblies, and structures. Hand tools play a crucial role in this process, allowing for the precise and skilled manipulation of metal to achieve desired outcomes. These tools are indispensable in producing a wide range of products, from intricate jewellery pieces to large-scale construction components.

Metalworking hand tools are specifically designed for tasks such as cutting, shaping, joining, and finishing metal materials. Their primary characteristics include durability, precision, and ergonomic design, ensuring effective and comfortable use. Additionally, features like non-slip grips, adjustable settings, and compatibility with safety equipment enhance both the performance and safety of these tools across various metalworking applications.

In the following sections, we'll explore some of the most essential metalworking hand tools, highlighting their features and specific uses.

**Types of Metal Work Hand Tools**

Along with all the high-tech, electric, and pneumatic power tools used for metal fabricating, you will need specific hand tools as well. Here are some types of metalwork hand tools:

| **Types of Metal Work Hand Tools** | |
|---|---|
| Hacksaw | A fine-toothed cutting tool, designed for cutting metal such as steel and pipe. |
| Cold Chisel | Used for cutting metals in a cold state and designed to cut or shape thick metal. |

| | |
|---|---|
| Hammers | Ranging from lightweight taper to a heavyweight sled, hammers are used for shaping, forming, and striking metal surfaces during fabrication and forging processes. |
| Mallet | Generally used for shaping, forming, and pounding metal. |
| Snips (Shears) | Metalworking scissors that are able to cut metal roofing, flashing, metal sheets, and thin metal plates. |
| File | A bar of metal covered with serrations that is used for smoothing, shaping, and removing metal. |
| Bolt Cutters | Designed for cutting through materials like bolts, chains, wire, and other metals. |

**Hacksaw**

When considering metalworking hand tools, hacksaws are among the most essential. These fine-toothed cutting tools are specifically designed for cutting metal, such as steel pipes, but they can also be quite effective for cutting plastic when a specialized tool is unavailable.

Typically, hacksaws feature a C-shaped frame that holds a blade under tension, making it easier to cut through tubing and sheet metal. For optimal cutting results, you can adjust and use different blade sizes depending on your needs. A great example of this is the Ronix RH-3611 hacksaw, which features an ergonomic ABS grip and a sharp Bi-Metal blade, as illustrated in Figure 2.1. This tool is designed for both comfort and precision, making it a reliable choice for various cutting tasks.


**Fig. 2.1 Hacksaw**

**Cold Chisel**

Another essential metalworking hand tool worth highlighting is the cold chisel. These tools are primarily used for cutting and shaping metals in a cold state, particularly when the material is thick, making them a go-to option when other tools like hacksaws or tin snips are less effective.

Cold chisels are made from hardened steel and feature a beveled cutting edge along with an octagonal handle, offering both durability and control. They are especially useful for tasks such as chopping through metal screws, bolts, rivets, brackets, and nails, as illustrated in Figure 2.2. Their robust design allows for precise cutting and shaping in various metalworking applications.

**Fig. 2.2 Cold Chisel**

**Hammers**

A reliable hammer is a fundamental tool in any metalworking toolkit. When assembling your collection of metalworking hand tools, a high-power hammer should be at the top of your list.

Hammers are available in various shapes and sizes, each tailored to specific tasks or metal thicknesses. From lightweight hammers for delicate work to heavy-duty sled hammers for stubborn metal pieces, the right hammer can make a significant difference in your project.

For instance, the Ronix RH-4726 and RH-4751 Claw Hammers are excellent choices for metalworking. They feature non-slip rubber grip handles for enhanced control, and their heads are made from drop-forged polished steel, ensuring maximum strength and a long service life, as shown in Figure 2.3. These hammers are designed to meet the demands of various metalworking applications.


**Fig. 2.3 Cold Chisel**

**Mallet**

Mallets are among the most crucial metalworking hand tools, primarily used for shaping, forming, and pounding metal in various work environments. These tools can have faces made of wood, plastic, metal or rubber, depending on the specific application.

It's important to distinguish between hammers and mallets. Hammers typically have smaller, metal heads designed to deliver blunt force, making them ideal for tasks requiring significant impact. On the other hand, mallets feature larger, round heads made from softer materials like wood, rubber, or metal. This design allows mallets to be used on surfaces without leaving marks, making them suitable for more delicate work.

Mallets are generally crafted from soft materials, which prevent damage to the workpiece, while hammers are made of pure steel, enabling them to strike with maximum force. This difference is visually represented in Figure 2.4.

**Fig. 2.4 Mallet**

**Snips (Shears)**

Snips, also known as shears, are essential hand tools in metalworking, specifically designed for cutting through metal sheets and other tough materials. These tools come in various types, each suited for different applications and metal thicknesses. Snips are versatile and can be used to cut metal roofing, flashing, thin metal plates, and another sheet metal.

There are two primary types of snips:

**Tin Snips:** These snips have long handles and short blades, making them ideal for cutting low-carbon tin or mild steel.

**Compound Action Snips:** These snips, designed for cutting through steel or softer materials, use a compound mechanism that enhances cutting power. While they are primarily used on mild steel, they can occasionally be used on stainless steel without causing damage.

For those seeking a professional-grade tool, the Ronix RH-3901 Aviation Snip is an excellent choice. It is capable of cutting through cold-rolled steel and stainless steel, featuring a high-leverage design and an ergonomic TPR handle for comfort and efficiency, as shown in Figure 2.5.

**Fig. 2.5 Snips**

**Files**

A file is a crucial hand tool in metalworking, primarily used for the material removal process. It is designed to remove fine amounts of material from a workpiece, allowing for precise shaping, smoothing, and finishing of metal surfaces. A file is typically a metal bar covered with serrations or sharpened scales, which effectively cut and shape the material as it is moved across the surface.

Files come in a wide range of types and are available in various lengths and shapes, including cylindrical, triangular, and rectangular profiles, each suited for different applications.

For anyone starting in metalworking, whether a beginner or a DIY enthusiast, having the right hand tools is essential. These tools are particularly valuable as they are more affordable than electric or advanced metalworking tools, making them accessible even on a low budget. Equipping yourself with these basic hand tools can be easily done at any tool shop, ensuring you have what you need to carry out metalworking tasks effectively.

**Bolt Cutters**

Bolt cutters are specifically designed to cut through tough materials such as bolts, chains, wires, and other metals. In metalworking, they are especially useful for cutting through metal rods, bolts, and other items that require significant force to cut.

Bolt cutters feature two long handles, often equipped with rubber or plastic grips to enhance comfort and control. At the end of these handles are leveraged cutting jaws, which are typically made from hardened steel for maximum durability and cutting efficiency. These jaws come in various designs to accommodate different types and sizes of materials, making bolt cutters versatile tools for a range of metalworking tasks.

**Hand Tools for Sheet Metal Work**

Sheet metal work requires hand tools that are specifically designed to meet the unique demands of working with thin metal sheets. Essential tools in this category include aviation snips (shears) and sheet metal hammers, which are crucial for cutting and shaping the metal. Aviation snips are perfect for making precise cuts, while sheet metal hammers help in forming and shaping the material. Additionally, bench anvils play a vital role by providing a stable surface for secure joining and forming operations, making these tools indispensable in any sheet metal workshop.

**Hand Tools for Cutting Metal**

Among Hand tools used for metal work, the following are specifically used for cutting the workpiece.

Hacksaws

Snips

Bolt cutters

Metal shears

Files

Hacksaws are versatile tools ideal for cutting thin metal sheets, pipes, and rods. Aviation snips are specifically designed for cutting sheet metal into various shapes with precision. Bolt cutters are used for cutting through thick metal rods or bolts, providing significant cutting power. Metal shears are excellent for making clean, straight cuts in thin to medium-thick metal sheets. Files are used for shaping and smoothing metal surfaces to achieve a refined finish.

**Summary**

A fine-toothed cutting tool ideal for cutting metal, typically featuring a C-shaped frame with an adjustable blade.

Used for cutting and shaping thick metal in a cold state, made of hardened steel.

Available in different sizes for various metal-shaping tasks, from lightweight for delicate work to heavy-duty sled hammers.

Similar to a hammer but with softer heads, often used for shaping metal without damaging the surface.

Used for cutting metal sheets and thin metal plates. Tin snips and compound action snips are common types.

Used for smoothing, shaping, and removing fine amounts of metal from workpieces.

Designed to cut through tough materials like bolts and chains, featuring long handles for greater leverage.

Hacksaws are crucial for cutting thin metal sheets and pipes with adjustable blade sizes for different needs.

Cold Chisels are vital for cutting through thick metal, screws, bolts, and nails when more delicate tools are insufficient.

Hammers are versatile, with various types like claw hammers for shaping and striking metal surfaces.

Mallets are essential for shaping metal without causing surface damage, useful for delicate applications.

Snips (Shears) are specialized for precise cutting of metal sheets, with tin snips for softer metals and compound action snips for tougher materials.

Files smooth and shape metal surfaces, an essential step for finishing work.

Metal cutting tools include hacksaws, snips, bolt cutters, metal shears, and files. Each serves different purposes, from making precise cuts to shaping metal surfaces for a clean finish.

## CHECK YOUR PROGRESS

**A. Multiple Choice Question: -**

1. What gauge of sheet metal is typically used in manufacturing? a. 5 S.W.G. b. 10 S.W.G. c. 15 S.W.G. d. 20 S.W.G.

2. Which of the following is not a common application of sheet metal products? a. Agriculture b. Construction c. Painting d. Household items

3. What is the purpose of a mallet in metalworking? a. Cutting metal b. Shaping and forming metal c. Smoothing metal surfaces d. Riveting metal

4. Which metalworking tool is designed for cutting metal rods, bolts, and chains? a. Hacksaw b. Cold Chisel c. Bolt Cutters d. Snips

5. Files are typically used for: a. Shaping and smoothing metal surfaces b. Cutting metal sheets c. Riveting metal parts d. Welding

6. Which of the following tools uses a compound mechanism to increase cutting power? a. Tin Snips b. Cold Chisel c. Hacksaw d. Compound Action Snips

7. What type of hammer is often used in delicate metalworking tasks? a. Sled hammer b. Claw hammer c. Ball-peen hammer d. Mallet

8. Which tool is primarily used to cut metal in a cold state? a. Hacksaw b. Cold Chisel c. Snips d. Mallet

9. In metalworking, what is the main feature of a hacksaw? a. Adjustable tension blade b. Compound cutting mechanism c. Beveled cutting edge d. Large round head

10. Which tool is typically used for making straight cuts in sheet metal? a. File b. Hammer c. Metal shears d. Bolt cutter

**B. Fill in the blanks**

1. Sheet metal typically ranges from ............. S.W.G. and thinner.
2. **............** joints are commonly used in sheet metal fabrication.
3. The tool used to cut bolts, chains, and wires is called **..................**
4. ............... are designed for shaping and forming metal without leaving marks.
5. A **............** is a fine-toothed tool used for cutting metal pipes and sheets?
6. **................** are used to cut metal roofing and flashing.
7. The tool with a beveled cutting edge used to cut thick metal is called a **.............**
8. A file is used for **...........** and **............** surfaces.
9. **.................** are designed for making straight cuts in thin metal sheets.
10. The handles of bolt cutters are often equipped with **............** grips for comfort and control.

**C. State whether the following statements are True or False**

1. A cold chisel is used for cutting metal in a heated state.
2. Hacksaws can be used to cut both metal and plastic.
3. Bolt cutters are primarily used for shaping metal surfaces.
4. Mallets are generally used for shaping metal without leaving marks.

5. Files are used for cutting metal sheets into various shapes.
6. Snips, or shears, are used to cut through metal roofing, flashing, and thin metal plates.
7. Tin snips are used to cut stainless steel regularly.
8. The shape of a hammer is not important in metalworking.
9. Files come in various shapes and are essential for smoothing metal surfaces.
10. A hacksaw's frame holds the blade under tension, making it easier to cut through sheet metal.

**D. Short/Long Questions: -**

1. What is the primary function of a cold chisel in metalworking?
2. Describe the main difference between a hammer and a mallet in metalworking.
3. What are snips used for in sheet metal work?
4. Explain the role of bolt cutters in metalworking.
5. What is the purpose of using a file in metalworking

# Session 3. Welding, Brazing and Soldering

### 3.1 Welding

Welding is a fabrication technique that joins materials, such as metals, by applying heat at high temperatures. Unlike soldering and brazing, which do not melt the base metal, welding involves melting the base metal along with the filler material to form a strong bond. Once cooled, both the base metal and filler material fuse together, creating a solid joint.

The development of welding can be traced back to the quest for efficient methods to shape iron. Early welding efforts produced hardened steel blades through carburization of iron. Initially, these blades were brittle, but the technique evolved with the interlaying of rigid and soft iron with high-carbon material and hammer forging, leading to tougher and more durable blades.

In welding, filler material is crucial; it forms a molten pool that bridges the base metal and creates a robust connection. After the welding process, shielding techniques protect the weld from oxidation and contamination. Various energy sources are used in welding, including gas flames, electron beams, electric arcs, LASERs, and friction. Understanding the different types of welding processes can help in selecting the appropriate method for specific applications.

### 3.2 Types of Welding

There are many types of welding used for various purposes under different situations.

1. Arc welding
    a) Shielded metal arc welding
    b) Gas metal arc welding
    c) submerged arc welding
    d) flux-cored arc welding
2. Electroslag welding
3. Laser beam welding
4. Electron beam welding
5. Magnetic pulse welding
6. Friction stir welding

7. Forge welding

8. Oxy-fuel welding

**1. Arc Welding**

Arc welding is a highly prevalent welding technique used today. It operates by generating an electric arc between an electrode and the metal workpieces, creating intense heat that melts both the electrode and the base metal. This melting allows the materials to fuse together.

During arc welding, small droplets of molten metal are transferred from the electrode to the weld joint, which solidify to form a durable bond. This versatile method can be applied to various metals and thicknesses, utilizing the focused heat of the arc to achieve efficient and effective welding, as shown in Figure 3.1.

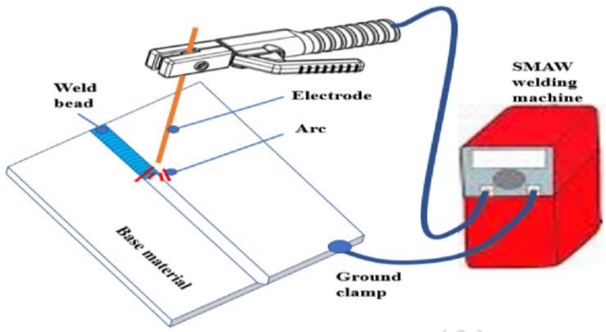



**Fig. 3.1 Arc Welding**

**a). Shielded Metal Arc Welding**

Shielded Metal Arc Welding (SMAW), also known by various names such as flux shielded arc welding, manual metal arc welding, or stick welding, is a manual welding process. It involves using an electrode coated with flux to carry out the welding operation, as depicted in Figure 3.2.

In SMAW, either an AC or DC power supply creates an electric arc between the electrode and the metals being joined. The arc generates the necessary heat to melt both the electrode and the base metal, facilitating the welding process.

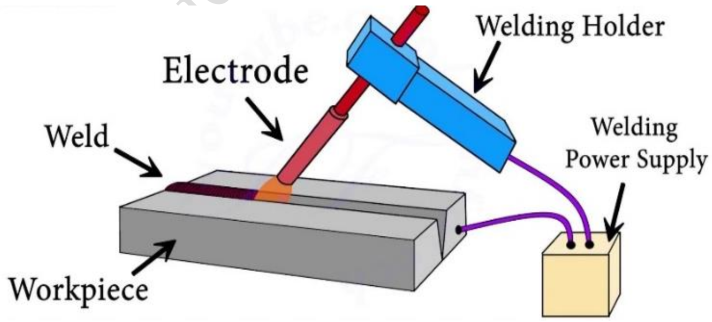



**Fig. 3.2 Shielded Metal Arc Welding**

**b). Gas Metal Arc Welding**

Gas metal arc welding in which an electric arc is formed between a consumable metal inert gas wire electrode and the workpiece metal. The generated heat melts the workpiece metal and is then joined. It is a semi-automatic or automatic process which uses AC or DC from the power supply as shown in Figure 3.3.

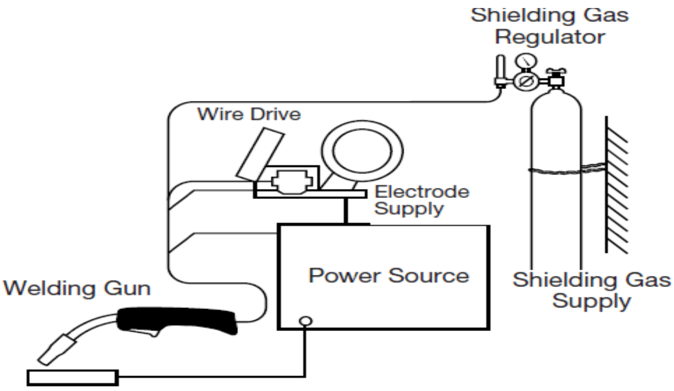



**Fig. 3.3 Gas Metal Arc Welding**

**c). Submerged Arc Welding**

Submerged arc welding is a type of arc welding process that involves forming an arc between the electrode and the workpiece. A blanket of granular fusible material shields the arc on the work as shown in Figure 3.4.

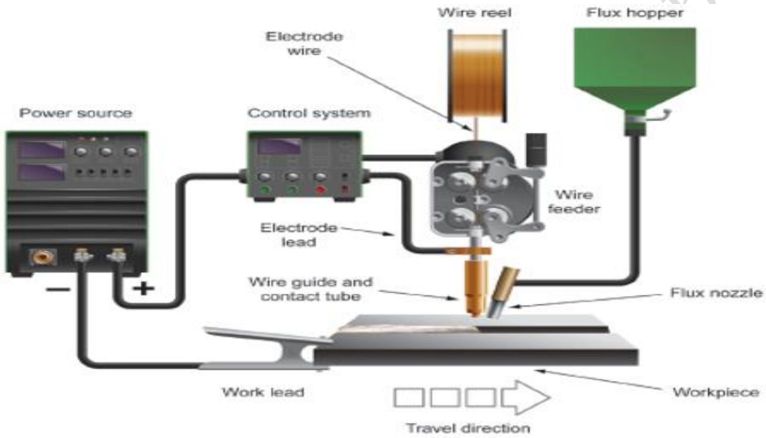



**Fig. 3.4 Submerged Arc Welding**

**d). Flux-Cored Arc Welding**

Flux-cored arc welding is a semi-automatic or automatic arc welding process. Flux-cored arc welding is similar to the metal active gas welding process. It uses a continuous wire fed electrode and a constant-voltage welding power supply as shown in Figure 3.5.

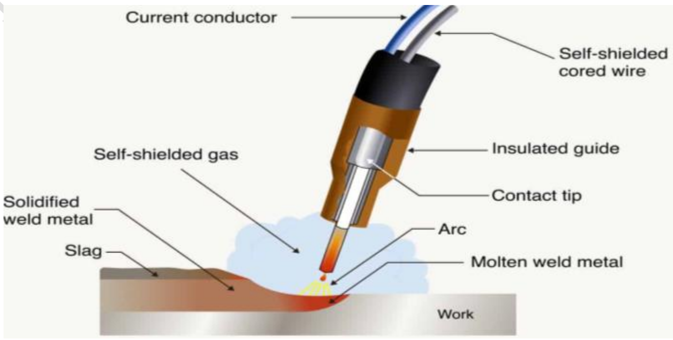



**Fig. 3.5 Flux-Cored Arc Welding**

**2. Electroslag Welding**

Electroslag welding is the most effective welding used to weld materials more significant than 25 mm up to about 300 mm. In electro slag welding, heat is generated by passing electricity between the filler metal and the workpiece through a molten slag covering the weld surface as shown in Figure 3.6.

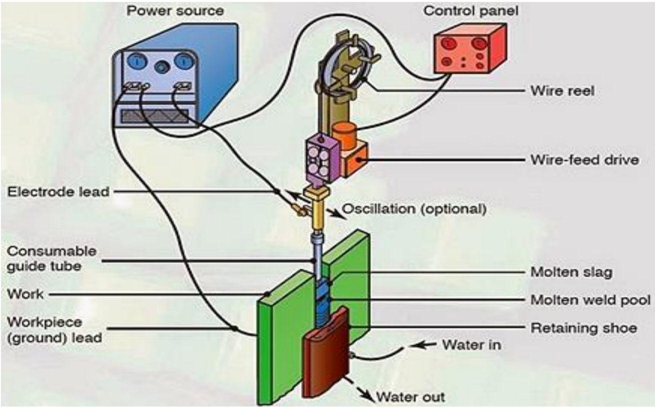



**Fig. 3.6 Electroslag Welding**

**3. Laser Beam Welding**

Laser beam welding is the process in which the metal or thermoplastic materials are joined together with the aid of LASER (Light Amplification by Stimulated Emission of Radiation). It is an efficient technique that can perform deep welds. Laser beam welding is a non-contact process requiring access to the weld zone from one side of the welded parts. Since the LASER beam is monochromatic and single phased, without any divergence, high energy light produced is channelized to perform welding as shown in Figure 3.7.

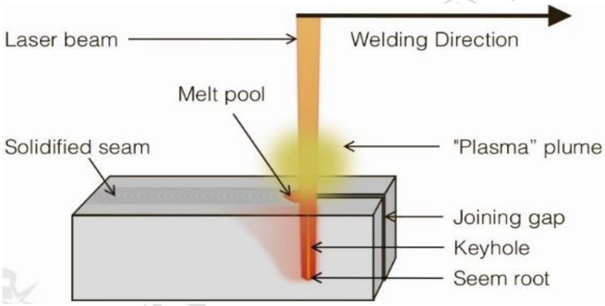



**Fig. 3.7 Laser Beam Welding**

**4. Electron Beam Welding**

Electron beam welding is a technique in which high-velocity electrons are applied to the materials to be welded. Electron beam welding is undertaken under vacuum conditions to prevent dissipation of the electron beam. The kinetic energy from the electrons is transformed into heat, and the materials are welded. The electron gun is used to generate electrons, and the electron gun helps control the flow of the electrons. Electron beam welding is performed in a vacuum condition to avoid the scattering of electrons as shown in Figure 3.8.

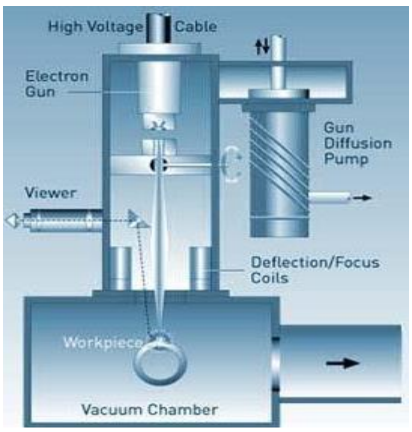



**Fig. 3.8 Electron Beam Welding**

**5. Magnetic Pulse Welding**

Magnetic pulse welding is a technique that uses magnetic force to weld two materials together. It is the solid-state welding developed in 1970 and is used extensively in automotive industries. It is the fastest way of welding, which consumes only microseconds without the need for welding consumables or shielding gases as shown in Figure 3.9.

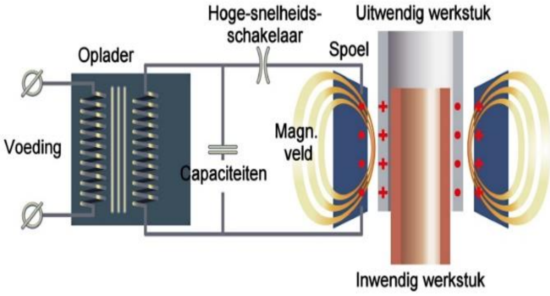



**Fig. 3.9 Magnetic Pulse Welding**

**6. Friction Stir Welding**

Friction stir welding is also a solid-state welding process that uses frictional heat generated by a rotating tool to join materials.

The tool, equipped with a profiled probe and shoulder, is rotated and plunged into the interface between two workpieces. The tool, when moved along the joint line, causes the material to heat and soften. The shoulder also acts to contain this plasticized material, which is mechanically mixed to create a solid phase weld as shown in Figure 3.10.

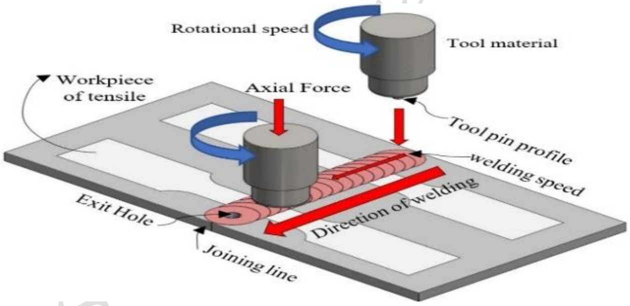



**Fig. 3.10 Friction Stir Welding**

**7. Forge Welding**

Forge welding is the early version of welding where it was used to join the small iron pieces to make larger valuable pieces. It is the simplest welding method where two metals are heated and joined, and later hammered for the finishing purpose as shown in Figure 3.11.

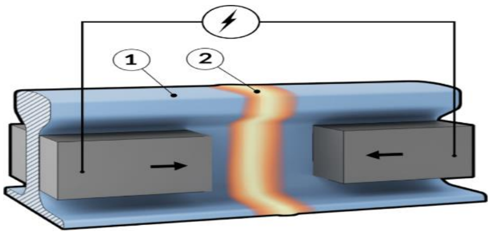



**Fig. 3.11 Forge Welding**

**8. Oxy-Fuel Welding**

Oxy-Fuel Welding, also known as oxy welding, gas welding, or oxy-acetylene welding, utilizes the combustion of fuel gases such as acetylene and oxygen to weld or cut metals. Developed by French engineers Edmond Fouché and Charles Picard in 1903, this process involves mixing acetylene and oxygen in specific ratios within a hand-held torch or blowpipe. The resulting flame can reach temperatures of up to 3,200 degrees Celsius. By adjusting the oxygen-to-acetylene ratio, the flame's intensity can be controlled, making it suitable for various welding tasks, as shown in Figure 3.12.

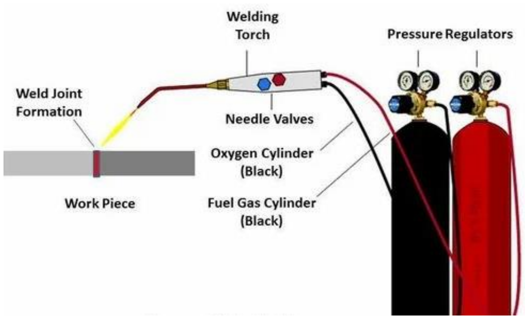



**Fig. 3.12 Oxy-Fuel Welding**

### 3.3 Advantages and Disadvantages of Welding

**Advantages**

- Welding establishes strong, durable, and permanent joint links.
- It is a simple process that results in a great finish.
- The technique, when used with filler material, produces a stronger weld than the base material.
- It can be performed at any place
- It is an economical and affordable process
- It is used in various sectors like construction, automobile, and many more industries.

**Disadvantages**

- It is hazardous when performed under the safety and security guidelines.
- It is a difficult task to dismantle the joined material through welding.
- Requires skilled labour and electric supply.

### 3.4 Step by step Guide to Welding and Repairs

Repair welding is a vital process in constructing and maintaining components and structures. This technique ensures that the repaired sections achieve the same static strength, impact resistance, ductility, and tensile stress levels as the original base material. Repair welding is considered a standard practice, where the damaged or cracked portion of a component is removed using arc gouging, and the material on both sides of the crack is then welded together to restore the integrity of the component.

Repaired components are more serviceable than the original parts as it is possible to reinforce them. Moreover, weld repairs are frequently more cost-effective because the expense of a replacement part generally exceeds the cost of repairing the damaged part.

**Systematic process for Successful Repair Welding**

Repair welding can be approached in a methodical way to ensure the creation of a functional and reliable component. Alternatively, it can be done sporadically, but this often leads to poor construction quality, which can result in hardware failure, warranty repair claims, and customer complaints. To prevent these negative outcomes, it's crucial to follow a systematic process for successful repair welding:

**1. Welding Procedure:** All welders must be able to access the welding procedure, which should include detailed information about the methods that will apply. The following techniques are the four most commonly used in the welding industry.

- Gas metal Arc welding
- Gas Tungsten Arc welding
- Shielded Metal Arc welding
- Fluxed Cored Arc Welding

**Fig. 3.13**

**2. Welding Equipment:** Securing the appropriate and sufficient welding equipment is critical to avoid potential delays. There should also be equipment on standby, including holders, grinders, wire feeders, cables, and other welding accessories.

**Fig. 3.14**

**3. Materials:** Welders must ensure that adequate materials are available through the repair welding process. These materials include properly-stored filler metals and insert and reinforcement pieces. The method also requires shielding gasses, fuel for temperature control, and another fuel type for engine-powered welding equipment.

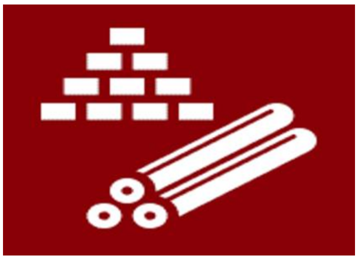


**Fig. 3.15**

**4. Alignment Markers:** Alignment markers are indicators used before the welding process for easy setting. They can be as simple as center draw marks placed throughout the joint.

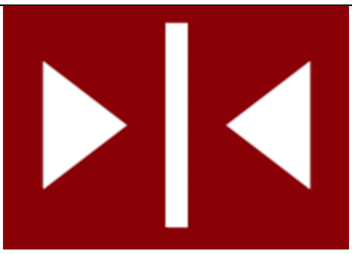


**Fig. 3.16**

**5. Welding sequence:** The welding sequence is the order in which the weld beads are deposited in the workpiece. It can affect the weldment's strength, coverage, and heat distribution, selecting an appropriate sequence for the application is critical.

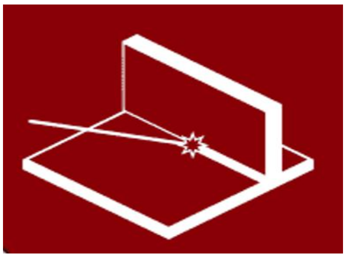


**Fig. 3.17**

**The following are the most common welding sequences:**

- Stringer Beads
- Skip Welding
- Staggered Welding

**6. Safety:** You should not neglect safety throughout the welding process. For example, when fuel gasses are used for preheating, ventilation is required to ensure that air contaminants are removed from the welder's breathing zone.

**Fig. 3.18**

**7. Weld Quality:** You must check the weld quality regularly to ensure smoothness and the absence of notching and reinforcing. It must also flow as smoothly as possible throughout the existing structure to be usable. In addition, grinding is applied to keep the contours smooth and flowing.

**Fig. 3.19**

**3.5 Brazing:** Brazing is a joining process in which metals are bonded using a filler material that has a melting (liquidus) temperature above 450°C (840°F) but below the melting point of the base metals being joined. During the process, the molten filler metal is drawn into the narrow gap between the closely aligned surfaces of the parts to be joined, utilizing capillary action to create a strong bond.

**3.6 Types of Brazing**

Braze welding is a brazing technique used when the surfaces to be joined have a gap greater than 0.5 mm. Due to the larger distance between the surfaces, the filler metal used must have a higher strength than the parent material to ensure the joint's durability. It's important not to significantly exceed the filler metal's liquidus temperature to prevent it from seeping out of the joint. The seam preparation and working methods in braze welding are similar to those used in gas welding. This technique is particularly useful for joining galvanized steel pipes, as depicted in Figure 3.20.

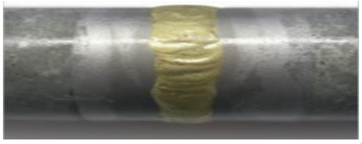


**Fig. 3.20**

**3.6.1 Gap Brazing**

In gap brazing, the workpieces are carefully prepared to create narrow capillary gaps at the joints. These gaps are uniformly heated to the brazing temperature along their entire length. The liquid filler metal is then drawn into the gap by capillary action, ensuring a strong and precise bond, as illustrated in Figure 3.21. Gap brazing is the predominant method used in most brazing operations due to its effectiveness in creating robust joints.

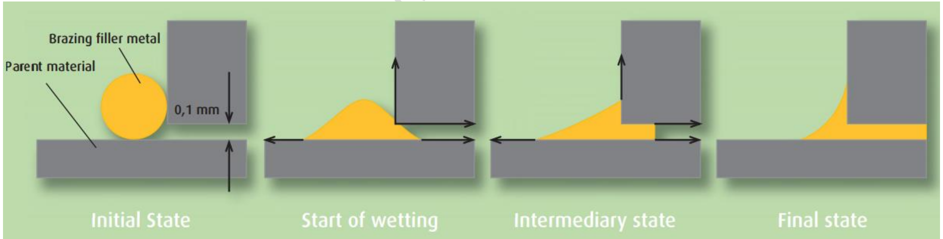



**Fig. 3.21 Flow of filler metal during gap brazing**

When brazing a joint in an open atmosphere with the use of flux, the filler metal must be capable of displacing the flux from the gap as it penetrates. In gap brazing, it's common to exceed the liquidus temperature of the filler metal by 20 to 50 °C to ensure that the gap is uniformly filled with the molten metal, leading to a strong and complete bond.

**3.6.1.1 Capillary Attraction**

The narrower the joint gap, the greater the capillary attraction will be. For instance, with a parallel gap of 0.1 mm, the capillary pressure can reach approximately 100 mbar (10 kPa), which corresponds to a filler metal rise height of about 10 cm (assuming a filler metal density of 10 g/cm$^3$), as illustrated in Figure 3.22. These theoretical rise heights have been validated through practical testing, confirming the effectiveness of capillary action in filling narrow gaps during the brazing process.

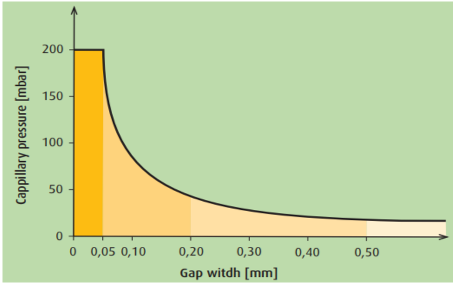



**Fig. 3.22 Capillary pressure dependent on gap width**

Properly dimensioning joint gaps and ensuring the cleanliness of brazing surfaces are critical for optimizing capillary attraction during brazing. If the gaps are too large or the surfaces are not adequately cleaned, the capillary pressure decreases, which can result in only partial filling of the brazing gaps. For brazing in protective gas atmospheres or vacuum, gaps smaller than 0.05 mm are ideal due to the high capillary pressure they generate. In mechanized brazing with fluxes, a gap range of 0.05 to 0.2 mm is recommended, as this range provides sufficient capillary attraction to ensure that the filler metal penetrates and fills the gap adequately. Gaps wider than 0.2 mm are challenging to fill and are not suitable for mechanized brazing. Manual brazing can handle gaps up to 0.5 mm, but beyond this size, the low capillary pressure makes it difficult to achieve reliable and uniform filling of the gaps with filler metal.

The minimum gap size for brazing with flux is determined by the need to draw enough flux into the gap to remove any oxides present on the surfaces. The appropriate gap width ranges for different brazing techniques are illustrated in Figure 3.23.

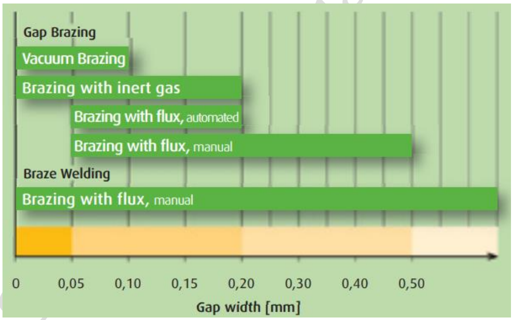



**Fig. 3.23 Gap with for various brazing technique**

Besides the gap size, the geometry of the gap plays a crucial role in capillary attraction and, consequently, the quality of brazing results. The capillary pressure in a fillet joint is 4.5 times higher than in a regular parallel gap between flat surfaces, as illustrated in Figure 3.24. This increased pressure in fillet joints enhances the capillary action, leading to more efficient filling of the brazing gap and better overall brazing performance.

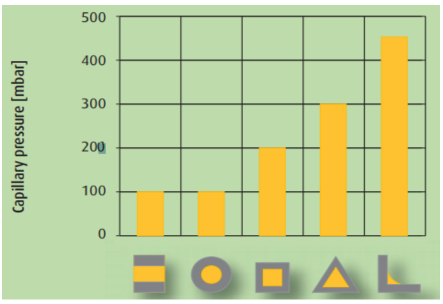



**Fig. 3.24 Capillary pressure dependent on gap geometry**

**3.6.2 Surface Brazing**

Surface brazing is used to enhance the properties of component surfaces rather than joining parts. In this process, filler metals and optional additives are applied to the surfaces of the parent material to improve hardness and provide protection against wear and corrosion. Components that experience high stress, such as ventilator fan blades, mill housings, heavy-duty transport pumps, and hydraulic and pneumatic cylinders, pistons, and piston rods, are coated with a hard material brazing layer. This layer is then melted in a furnace to create a compact, smooth surface with minimal porosity, offering increased durability and resistance to wear, as shown in Figure 3.25.

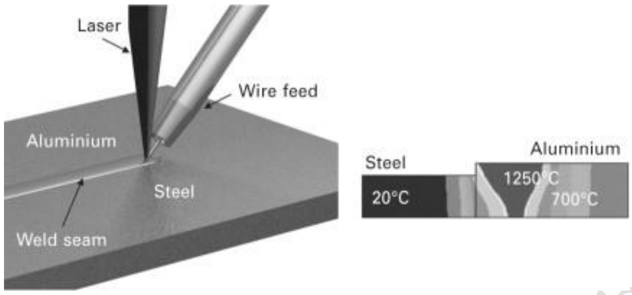



**Fig. 3.25 Surface Brazing**

### 3.6.3 Torch brazing

A heating source for brazing can be supplied by a fuel gas flame, with gases such as butane, acetylene, or propane being commonly used. This method often employs copper-phosphorus or silver brazing fillers, making it versatile for both single and multiple joints. However, the process is operator-sensitive, requiring careful control to achieve optimal results, as depicted in Figure 3.26.

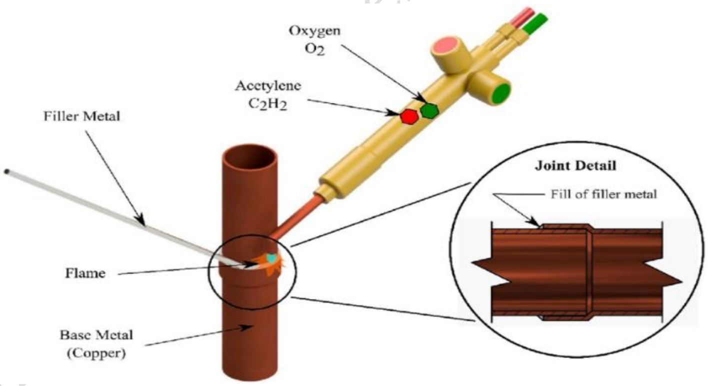



**Fig. 3.26 Torch brazing**

### 3.6.4 Induction brazing

Electric coils, tailored for specific joint geometries, are employed to heat both the part and the brazing filler material until the molten metal flows into the joint through capillary attraction. This method is commonly used for brazing with copper-phosphorus and silver alloys. It provides rapid heating cycles, especially effective for ferrous metals, as illustrated in Figure 3.27.

**Fig. 3.27 Induction brazing**

### 3.7 Working temperature

When a brazing material is heated to its solidus temperature, it begins to melt. As the temperature continues to rise, more of the alloy turns into a liquid until, at the liquidus temperature, the alloy is entirely liquid. Throughout this melting range, the proportion of the liquid phase increases relative to the solid phase as the temperature increases.

To achieve a successful brazed joint, the brazing alloy must reach a temperature where it is sufficiently fluid to flow into the capillary gap between the joined surfaces. This temperature is known as the 'working temperature' of the brazing alloy. It is typically higher than the solidus temperature but lower than the liquidus temperature of the alloy. For example, the Phos series alloys produced by Tesco Limited have a solidus temperature around 645°C and a liquidus temperature near 800°C. However, these alloys become sufficiently fluid for brazing at temperatures as low as 700°C, allowing for effective capillary flow and joint formation.

### 3.8 Differentiation Between Welding and Brazing

In welding, materials of the same type, such as steel with steel or aluminum with aluminum, are typically bonded together. The weld metal used has a similar composition to the parent material, making it specific to the material being welded.

In contrast, brazing and soft soldering allow for the joining of both similar and dissimilar metals, such as steel with copper or copper with brass. The filler metal used in these processes, known as the brazing alloy or solder, is generally not specific to the parent materials. The composition of the filler materials can vary significantly from that of the parent materials, as illustrated in Figure 3.28.

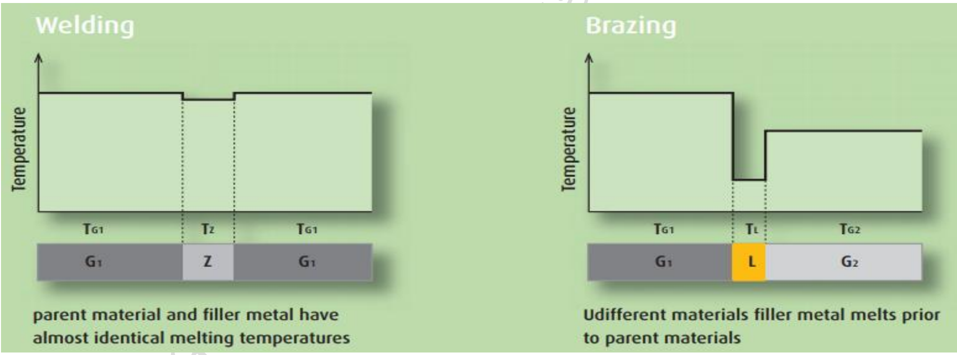



**Fig. 3.28 Schematic comparison of temperature of welding and brazing**

### 3.9 Soldering

Soldering is a process of connecting any two metallic surfaces such as copper, brass and alloys of these metals. Some types of solder joints are shown in Figure 3.29.

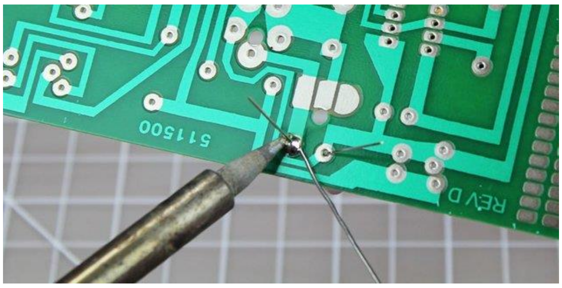


**Fig. 3.29 Soldering**

**There are two types of soldering**

1. Hard soldering or Brazing- used for joining large metal parts.

2. Soft soldering – used to form good electrical joints/connection between electrical/electronic parts.

Soft soldering is used extensively for electronic circuit wiring

**Need for soldering**

Requirements of an electrical joint

1. The electrical joint must provide ideally zero resistance or at least a very low resistance path, for the flow of current.
2. The electrical joint made should be strong enough to with stand vibrations, physical shock, bumps etc, without causing any deterioration to the quality and strength of the joint.
3. The electrical joint should be able to withstand corrosion and oxidation due to adverse atmospheric conditions.

All the above requirements of an electrical joint can be achieved by making a solder joint.

### 3.9.1 Solder

In a soldered joint, the solder typically consists of a mixture of metals, usually tin (Sn) and lead (Pb). This alloy is designed to melt at a specific temperature and acts as a filler material between the parts of the joint, creating a continuous, low-resistance metallic path for electrical conduction.

During the soldering process, the liquid solder wets the metal surface, ensuring a free flow over it. This interaction initiates a complex chemical reaction that bonds the solder to the metal surface. As the solder cools, the tin (Sn) content diffuses into the metal surface, forming a layer of a new alloy. This alloy maintains the structural properties of the constituent metals, providing the necessary metallic properties and strength for the joint.

### 3.9.2 Soldering and soldering irons

During soldering, the solder is melted between the metallic surfaces of the joint using a soldering iron, as depicted in the figure. A soldering iron is a tool designed to generate the necessary heat for soldering.

Soldering irons are available in various wattage ratings, ranging from 10 watts to over 150 watts. The choice of wattage depends on the type, size, and heat sensitivity of the components being soldered. Most soldering irons operate on a 240V, 50Hz AC mains supply, although there are specialized models that function on DC supply as well. For soldering delicate components, soldering irons with temperature control features, known as soldering stations, are used to ensure precise temperature regulation.

### 3.9.3 Soldering iron tips

Soldering irons come with a range of tip sizes and shapes, allowing for versatility in various soldering tasks. The selection of the soldering iron and tip should be based on the specific requirements of the joint to be soldered. Choosing the right combination is crucial for achieving a high-quality soldered joint. Additionally, to ensure effective soldering, it is essential to keep the tip of the soldering iron clean at all times.

### 3.9.4 Soldering FLUX

Most metals develop a protective oxide layer on their exposed surfaces, which forms quickly on newly exposed metal and thickens over time. This oxide layer can interfere with the soldering process, so it must be removed before making a soldered joint.

Flux is used to address this issue by first dissolving the thin layer of oxide from the metal surfaces to be joined. It then forms a protective blanket over the metal to prevent further oxidation until the solder can flow over and bond with the joint surface. However, for thicker oxide layers, an abrasive method may be necessary, as some fluxes are not effective at removing these more substantial oxide layers.

### 3.9.5 Basics of Soldering

#### 3.9.5.1 Materials required for Soldering

**A. Soldering Iron**

- A soldering iron is used to heat the connections to be soldered.
- For electronic circuits, you should use a 25- to 40-watt (W) soldering iron.
- Higher wattage soldering irons are not necessarily hotter; they are just able to heat larger components.
- A 40-W soldering iron makes joints faster than a 25-W soldering iron does.

**B. Solder/Soldering Lead (Rosin Core Solder)**

Melting Point: Solder has a lower melting point than the metals being joined. When heated by the soldering iron, the solder melts while the metals remain solid.

**Flux:** The rosin core in solder acts as a flux, preventing oxidation of the metals being connected and enhancing the solder's ability to wet the surfaces and form a strong bond.

**Core Types:** Solder used for copper pipes typically has an acid core, which is suitable for plumbing but can corrode electronic connections. For electronics, use solder with a rosin core.

**Diameter:** For most electronics work, solder with a diameter of 0.75 mm to 1.0 mm is ideal. Thicker solder can make it challenging to work on small joints and increases the risk of solder bridges between copper pads.

**Alloy Composition:** A common solder alloy for electronics is 60/40 (60% tin, 40% lead). Lead-free solders are also available for those who prefer or require them.

**C. Soldering Stand**

- There are a variety of stands available. It is important to always keep the hot iron in its stand when not in use.

**D. Sponge**

- The damp sponge is used to clean the tip of the iron.

**E. Solder Braid**

- This is used to remove solder.
- To use the braid, place it over the solder to be removed and heat it from above with the iron. The solder will flow into the braid.
- Solder braid is used to extract an electronic component that is soldered onto a board.
- It is also used to reduce the amount of solder on a connection.

**F. Prototype Board**

- A prototype board is used to assemble the circuit.
- Prototype boards have copper tracks or pads for connecting components.

**G. Steel wool or Fine Sandpaper**

- This is used to clean connections prior to soldering.
- Solder will not flow over a dirty connection as shown in Figure 3.30

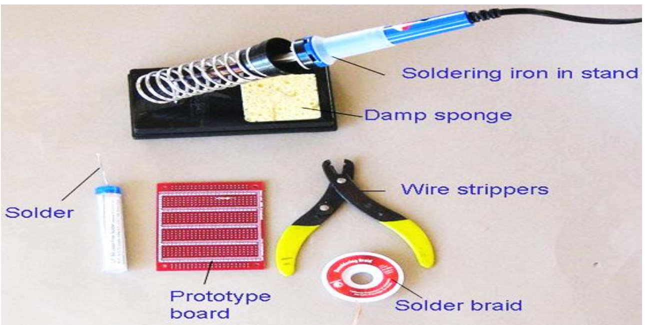



**Fig. 3.30 Materials of Soldering**

### 3.10 Process of Soldering

**1. Solder needs a clean surface on which to adhere.**

- Buff the copper foil of a PC board with steel wool before soldering.
- Remove any oil, paint, wax, etc. with a solvent, steel wool, or fine sandpaper.

**2. To solder, heat the connection with the tip of the soldering iron for a few seconds, then apply the solder.**

- Heat the connection, not the solder.
- Hold the soldering iron like a pen, near the base of the handle.
- Both parts that are being soldered have to be hot to form a good connection.

**3. Keep the soldering tip on the connection as the solder is applied.**

- Solder will flow into and around well-heated connections.
- Use just enough solder to form a strong connection as shown in Figure 3.31.

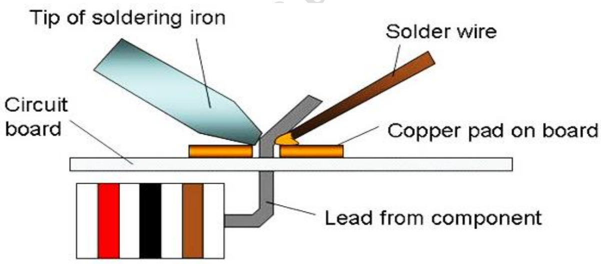



**Fig. 3.31 Process of Soldering**

**4. Remove the tip from the connection as soon as the solder has flowed where you want it to be. Remove the solder, then the iron.**

**5. Don't move the connection while the solder is cooling.**

**6. Don't overheat the connection, as this might damage the electrical component you are soldering.**

- Transistors and some other components can be damaged by heat when soldering. A crocodile clip can be used as a heat sink to protect these components as shown in Figure 3.32.

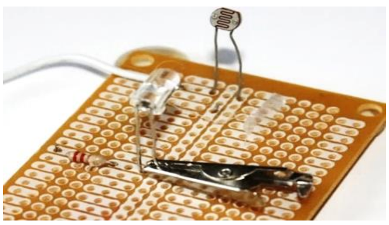


**Fig. 3.32 A crocodile clip for heat sink**

**7. Soldering a connection should take just a few seconds.**

**8. Inspect the joint closely. It should look shiny.**

- If you are soldering a wire (called the lead) onto a PC board (on the track), it should have a volcano shape.
- If the connection looks bad, reheat it and try again as shown in Figure 3.33.

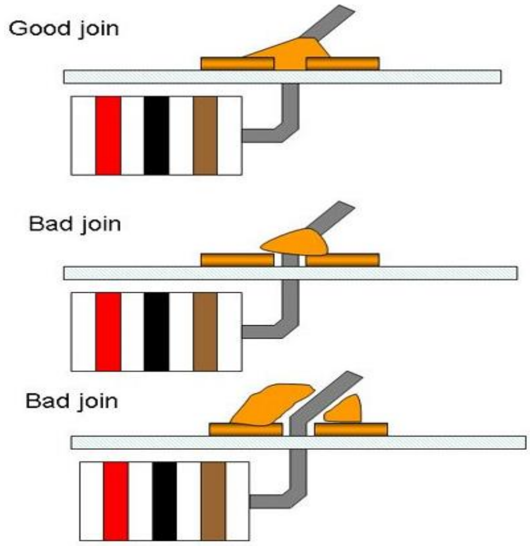



**Fig. 3.33 Inspect the joint closely**

**9. Wipe the tip of the iron on a damp sponge to clean it. The tip should now be shiny.**

**10. Unplug the soldering iron when it is not in use.**

### 3.11 Desoldering

The reverse process of soldering is desoldering. It is a process of removal of solder and components mounted on circuit boards. The soldered joint is removed by the process of desoldering. For this purpose, a small vacuum pump is used to remove solder from the plated through holes. The lead over which the desoldering tip was placed is moved in a circular motion for rounded leads and back and forth for flat leads as shown in Figure 3.34.

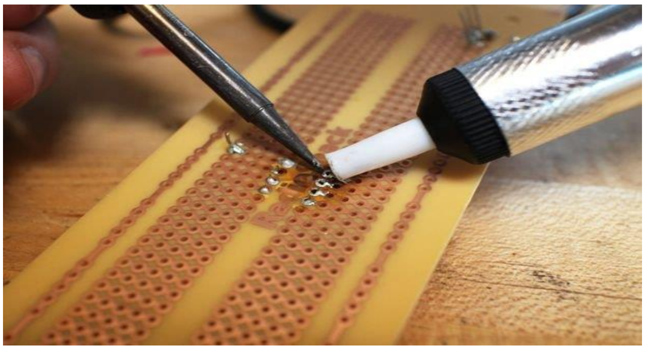


**Fig. 3.34 Desoldering**

#### 3.11.1 Basics of Desoldering and Materials Needed for Desoldering

**Solder Sucker/ Desoldering Pump**

The most commonly used and convenient equipment needed for desoldering is the desoldering pump. A good manual solder sucker like this one works pretty well for selectively removing through holes parts from a PCB. Cheaper and smaller units do not work as well. They're marketed as compact but they don't work as well due to the limited stroke length and smaller cylinders as shown in Figure 3.35.

**Fig. 3.35 Solder Sucker/ Desoldering Pump**



**Desoldering Process**

One of the nicest ways to desolder a component involves using a desoldering pump. A desoldering pump is essentially a small, high pressure vacuum. After heating up the solder, you can use the desoldering pump to suck the solder up and out of the way. Here are the basic steps for using a hand-powered desoldering pump as shown in Figure 3.36.


**Fig. 3.36 Desoldering process**

1. Heat up the solder you want to remove with a soldering iron (some desoldering pumps also come with attached irons).
2. Press down on the plunger (If your pump has a bulb, just squeeze the bulb).
3. Once the solder is molten, place the tip of the desoldering pump against the solder that you want to remove as shown in Figure 3.37.

**Fig. 3.37 Solder remove**

4. Release the plunger or bulb. Some desoldering pumps have a release button so that you don't have to hold it the whole time as shown in Figure 3.38

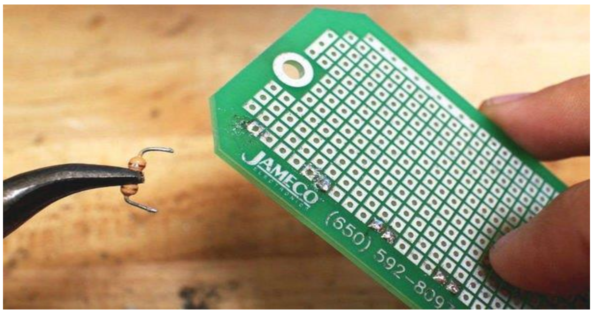



**Fig. 3.38 Release the plunger or bulb**

**5.** Remove free component.

**6.** Repeat steps 1-4 to remove any excess solder.

**7.** Dispose of the solder inside the pump by repeatedly pressing down and releasing the plunger.

**Know more…**

- Soft soldering with filler metals having a liquidus temperature under 450 °C.
- Brazing with filler metals which have a liquidus temperature above 450 °C.
- High-Temperature Brazing in a vacuum or protective atmosphere with filler metals having a liquidus Temperature above 900 °C.



## Check Your Progress

**A. Multiple Choice Question**

1. What is the main difference between welding and soldering? (a) Welding involves melting the base metal; soldering does not (b) Soldering requires high temperatures; welding does not (c) Welding uses flux; soldering does not (d) Soldering creates a stronger bond than welding
2. Which welding technique uses an electric arc between an electrode and the workpiece? (a) Laser Beam Welding (b) Electron Beam Welding (c) Shielded Metal Arc Welding (d) Magnetic Pulse Welding
3. In which welding process is a blanket of granular fusible material used to shield the arc? (a) Gas Metal Arc Welding (b) Submerged Arc Welding (c) Oxy-Fuel Welding (d) Friction Stir Welding
4. Which welding technique requires a vacuum environment? (a) Laser Beam Welding (b) Electron Beam Welding (c) Electroslag Welding (d) Flux-Cored Arc Welding
5. What is a key characteristic of Flux-Cored Arc Welding? (a) It uses a non-consumable electrode (b) It requires shielding gases (c) It uses a continuous wire-fed electrode (d) It operates in a vacuum environment
6. Which welding process is known for using frictional heat generated by a rotating tool? (a) Forge Welding (b) Magnetic Pulse Welding (c) Friction Stir Welding (d) Gas Metal Arc Welding
7. What type of welding is commonly used in the automotive industry due to its speed? (a) Submerged Arc Welding (b) Laser Beam Welding (c) Magnetic Pulse Welding (d) Electroslag Welding

8. Which welding process was developed by Edmond Fouche and Charles Picard in 1903? (a) Oxy-Fuel Welding (b) Gas Metal Arc Welding (c) Shielded Metal Arc Welding (d) Electron Beam Welding
9. What is a common disadvantage of welding? (a) It can be performed at any place. (b) It requires skilled labour and electric supply (c) It is a simple process with a great finish (d) It is used in various sectors like construction and automobiles
10. Which welding technique uses the principle of carburization of iron to produce steel blades? (a) Arc Welding (b) Forge Welding (c) Laser Beam Welding (d) Electroslag Welding

**B. Fill in the blanks**

1. Welding involves melting both the base metal and .......... material to create a strong bond.
2. In Gas Metal Arc welding, an electric arc is created between a consumable ........... and the workpiece metal.
3. .................. welding is performed under vacuum conditions to prevent the scattering of electrons.
4. The ................ process uses frictional heat generated by a rotating tool to join materials.
5. In ................... arc welding, a blanket of granular fusible material shields the arc from the environment.
6. The primary advantage of welding is that it creates ...............and durable joint links.
7. Welding is considered a ................... process when it comes to cost-effectiveness compared to replacement parts.
8. The ............. beam welding process requires access to the weld zone from one side of the welded parts.
9. .............. welding involves heating and hammering small iron pieces to form larger items.
10. To protect the weld from oxidation and contamination, ............... techniques are used.

**C. State whether the following statements are True or False**

1. Welding does not melt the base metal, only the filler material.
2. Flux-Cored Arc Welding is similar to Gas Metal Arc Welding but uses a continuous wire-fed electrode.
3. Electroslag Welding is best used for materials thinner than 25 mm.
4. Laser Beam Welding requires the weld zone to be accessible from one side of the welded parts.
5. Friction Stir Welding is a solid-state welding process that uses a high-velocity electron beam.
6. Oxy-Fuel Welding was developed in the 20th century and utilizes acetylene and oxygen gases.
7. Magnetic Pulse Welding is a slow process that requires welding consumables and shielding gases.
8. Shielded Metal Arc Welding requires an electrode coated with flux and either AC or DC power supply.

9. Electron Beam Welding can be performed in open air without any vacuum conditions.
10. Forge Welding is a modern welding technique developed in the last century.

**D. Short/Long Questions**

1. Explain the main difference between welding and soldering.
2. Describe the process and advantages of Shielded Metal Arc Welding (SMAW).
3. What is the role of filler material in welding, and why is it important?
4. How does Electron Beam Welding work, and what are the conditions required for it?
5. What are the main advantages and disadvantages of welding compared to other fabrication techniques?

# Module 2 Basic Electrical

## Module Overview

Electricity is a cornerstone of modern life, enabling a vast array of applications that are integral to daily activities and industrial processes. It powers lighting, providing illumination in homes, offices, and public spaces, and drives heating systems that maintain comfortable temperatures in residential and commercial environments. In transportation, electricity fuels electric vehicles and supports railway systems, enhancing mobility and reducing reliance on fossil fuels.

In the realm of communication, electricity is essential for operating telecommunication networks, including telephones, internet services, and broadcasting systems, facilitating global connectivity and information exchange. Medical devices, ranging from life-support systems to diagnostic equipment, rely on electricity to function, underscoring its importance in healthcare and patient safety.

Manufacturing processes also depend on electricity for machinery and automation, driving productivity and efficiency in various industries. Additionally, electricity powers entertainment devices such as televisions, computers, and gaming consoles, enriching leisure and recreational experiences.

At its core, electricity involves the flow of electrical charge through conductors, representing a critical form of energy that can be easily converted into other types of energy, such as light, heat, and mechanical work. Its versatility and significance in numerous applications highlight its role as a fundamental and transformative force in contemporary society.

**Key Concepts in Electricity Generation are presented in Table 2.1**

| Parameter | Definition | Details | Unit of Measurement |
|---|---|---|---|
| Electric Charge | The intrinsic property of matter responsible for electrical interactions | Positive and negative charges | Coulombs (C) |

| | | | |
|---|---|---|---|
| Current | The movement of electric charge through a conductor | Direct Current (DC) and Alternating Current (AC) | Amperes (A) |
| Voltage | The potential difference between two points in an electrical circuit | Drives the flow of current through a conductor | Volts (V) |
| Resistance | The opposition to the flow of electric current through a conductor | Material, length, cross-sectional area, and temperature are the factors that affect the resistance | Ohms (Ω) |
| Power | The rate at which energy is transferred or converted | Power (P) = Voltage (V) × Current (I) | Watts (W) |

In this Module, we will cover the foundational principles of electricity generation, various electrical laws, the operation of electrical motors and components, and their roles within electrical circuits.

## Learning Outcomes

After completing this module, you will be able to:

- The basic principles of electricity, including charge, voltage, current, and resistance.
- Analyze electrical circuits and apply circuit laws to solve for unknowns in circuits.
- Identify and describe the function of common electrical components such as resistors, capacitors, inductors, and diodes.

## Module Structure

Session 1. Electricity

Session 2. Electric Circuit Analysis

Session 3. Electrical Components

# Session 1. Electricity

One day Pinky is combing her hair. After combing she found that a few pieces of paper were attracted to the comb. She wondered what to see. She asked her teacher about that incident. The teacher told her this happens due to static electricity. Figure 1.1 illustrates that the teacher is demonstrating pinky about static electricity.

**Fig. 1.1 Teacher is demonstrating the static electricity**

Electricity holds a crucial role in contemporary society, powering nearly all modern appliances and even fueling advancements such as electric cars. Despite its ubiquity, electricity is silent, invisible, and has no physical form. Understanding electrical theory is essential for safely managing and troubleshooting electrical devices, as it helps us recognize and address potential hazards associated with their use.

In this chapter, we will learn the basic concepts of electricity, its generation, conductor and insulators, electrical quantities, types of electricity, and magnetic fields.

## 1.1 ELECTRICITY

Everything around us is made up of matter. Matters have three states: solid, liquid, and gas. Typical states of matter are shown in Figure 1.2.

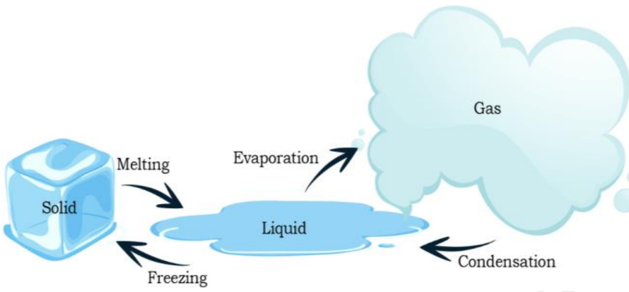



**Fig. 1.2 States of matter**

Every state of matter is composed of atoms, which have a central core known as the nucleus. Atoms are made up of three types of subatomic particles: protons, electrons, and neutrons. Protons and electrons carry electrical charges, with protons having a positive (+) charge and electrons carrying a negative (-) charge. Neutrons, however, do not have any charge and are electrically neutral. Electrons orbit the nucleus, where the positive charge of the protons attracts the negatively charged electrons, thus maintaining the stability of the atom. For example, silicon, depicted in Figure 1.3, has an atomic number of 14, indicating it has 14 protons and 14 electrons.

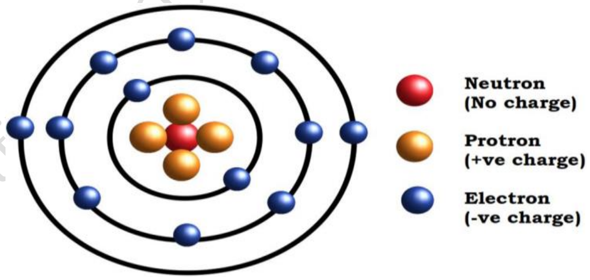



**Fig. 1.3 Atomic structure**

**Know More....**

Opposite charges attract each other and the same charges repel each other. The measuring unit of charge is coulomb 'C'. One coulomb of charge represents the charge on $6x10^{18}$ electrons. A charge is represented using the letter 'Q'.

Natural lightning, commonly seen during thunderstorms, serves as a vivid demonstration of electricity in action. Inside a storm cloud, strong winds cause the distribution of positive and negative charges. Figure 1.4 (a) illustrates that positive charges generally accumulate at the top of the cloud, while negative charges concentrate at the bottom. Figure 1.4 (b) demonstrates how these negative charges in the cloud are drawn toward the positively charged ground, resulting in a lightning strike.

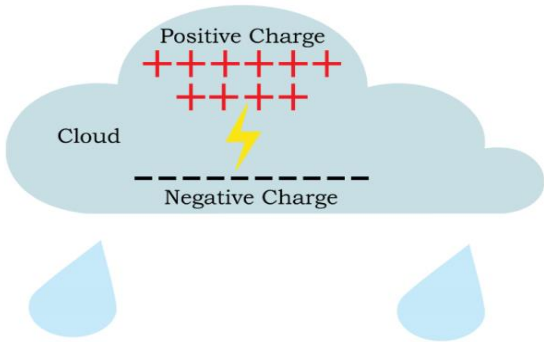



**Fig. 1.4 (a) Lightning within the cloud**

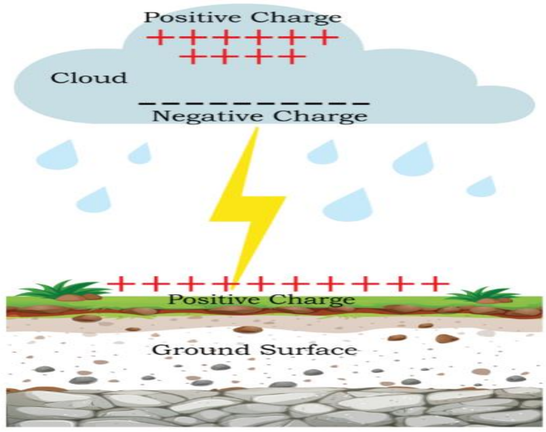



**Fig. 1.4 (b) Lightning between cloud and ground**

So, we can say that the presence of electricity is due to the presence or flow of electric charges.

## 1.2 ELECTRICAL NETWORK

An electrical network is a system of interconnected elements designed to transmit electrical energy from power sources to various electrical loads. It typically includes generators, transformers, transmission lines, distribution lines, and other key components that work together to deliver electricity to consumers.

This network is crucial for supplying power to homes, businesses, and industries globally and can be divided into three main sections: **Generation, Transmission, and Distribution**.

**Know More…**

Have you ever imagined how this electric power comes to our home? By observing the steps mentioned below. You can know the steps that pass through them when electric power reaches you.

**Source → Generating station → Turbine → Generator → Step-up Transformer → High Voltage Transmission Line → Substation → Step-down transformer → Low Voltage Transmission Line → Residential/ Industrial Area**

### 1.2.1 Conductors and Insulators

When electrons move among the atoms in a matter, a flow of electricity will take place. Based on the structure of an atom, materials can be categorized as conductors and insulators.

**Conductors –** In conductive materials, electrons are loosely attached to their nuclei, allowing them to move freely between atoms when a small external electric field is applied. These materials, known as conductors, include metals like copper and aluminium, which are highly effective at conducting electricity. Figure 1.17 demonstrates how electrons can easily flow through such conductors.

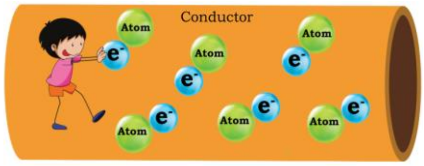



**Fig. 1.17 Easy to move electrons in a conductor**

**Insulators –** In insulating materials, electrons are tightly bound to their atomic nuclei, making it nearly impossible for them to move between atoms even when subjected to a high external voltage. These materials, known as insulators, include substances like rubber, plastic, cloth, and glass. Figure 1.18 shows how electrons are unable to flow through an insulator.

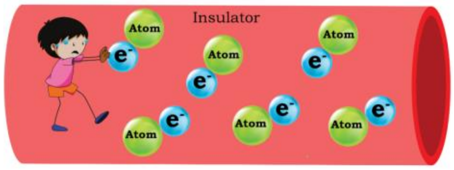



**Fig. 1.18 Tough to move electrons in an insulator**

A typical example of conductors and insulators in practical use is the electric wiring found in homes. Electrical wires consist of both a conductor and an insulator. Figure 1.19 demonstrates that the conductor carries the electric current, while the insulator provides protection by preventing short circuits and electrical hazards.

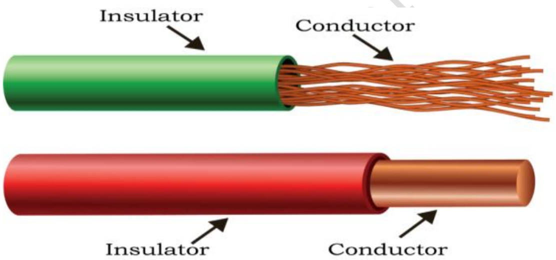



**Fig. 1.19 Electrical wire having conductor and insulator**

## 1.3 TYPE OF ELECTRICITY

As previously mentioned in this chapter, while lightning is a natural electrical phenomenon, it is not harnessed for energy production. To understand electricity better, it's helpful to distinguish between its two main types: static and dynamic electricity. Let's explore these concepts further.

**Static Electricity** Materials are composed of atoms, which are electrically neutral due to the balance between positive and negative charges. Static electricity occurs when there is a separation of these charges, leading to an imbalance. Unlike dynamic electricity, where electrons flow through a conductor, static electricity involves charges remaining stationary. This type of electricity is characterized by a stationary electric field between positive and negative charges. An example of static electricity is the energy stored in an electric cell or battery.

Practical activity 1.1 demonstrate the concept of electricity

| |
|---|
| **Practical Activity 1.1 –** Demonstrate the concept of electricity |
| **Material Required –** a plastic comb, a few pieces of paper |
| **Procedure** |
| **Step 1 –** Take a plastic comb. Figure 1.20 illustrates a comb and it is made up of plastic which is an insulator. Insulators have a positive charge and it is difficult to extract electrons from the insulator. |

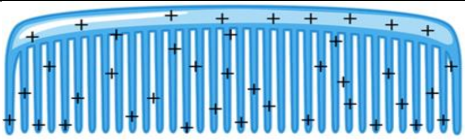


**Fig. 1.20 Comb having positive charge**

**Step 2 –** Rub the comb in your head hair three or four times. Figure 1.21 illustrates that a boy is rubbing a plastic comb on his head hairs.

**Fig. 1.21 Comb rubbing on the hairs**

**Step 2 –** Place the piece of paper near this comb. When we rub a comb on our head hair, it will get negatively charged, because our body is a conductor. Through rubbing the negative charge of the body will get transferred to the comb. Figure 1.22 illustrate that the negative charge accumulated on the bottom of the comb and is placed near the piece of paper

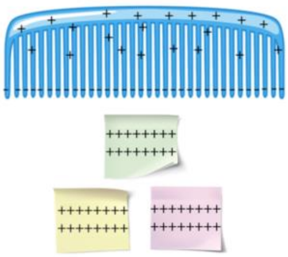


**Fig. 1.22 Comb with Negative charge on the bottom of the comb placed near the piece of paper**

**Step 3 –** A piece of paper, which is an insulator, can become positively charged. When a charged comb is placed near the paper, it will attract the paper. Figure 1.23 demonstrates how the charged comb pulls the piece of paper towards itself.

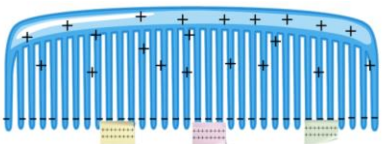


**Fig. 1.23 Piece of the paper attracted towards the comb**

**Dynamic or Current Electricity –** As the term "dynamic" implies, this type of electricity involves the movement of charges. Dynamic electricity, or current electricity, flows through conductors such as wires and delivers energy to various devices. This flow of electricity is facilitated by moving charged particles, typically electrons. Unlike static electricity, dynamic electricity cannot be stored directly; it must be converted into static electricity for storage. Examples of dynamic electricity include the current flowing through electrical wires and powering appliances. Figure 1.24 shows an LED connected to a cell, illustrating the flow of current electricity.

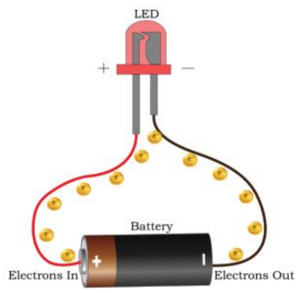



**Fig. 1.24 Electrons motion in an electric circuit**

**Assignment 2**

1. List the various conductors and insulators used in our day-to-day life.
2. List the source of static electricity.

### 1.3.1 Electrical Quantities

Current, voltage, and resistance are the three basic building blocks of an electric circuit, called electrical quantities.

An electric circuit is formed when a closed path is formed to allow free electrons to move continuously. This continuous movement of free electrons in a conductor of a circuit is called a current, and it is often referred to in terms of the "flow of electrons", just like the flow of a liquid through a hollow pipe. Figure 1.25 illustrates the flow of current in the circuit.

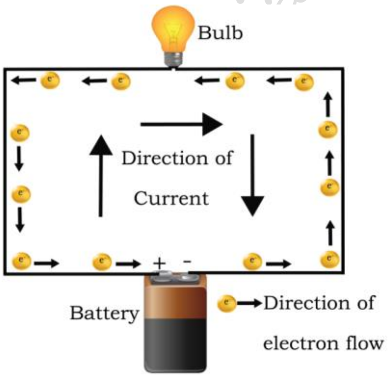



**Fig. 1.25 Electric circuit showing electrical quantities**

Electrons require an external force to propel their movement through a conductor, and this force is known as voltage or electromotive force (EMF). Voltage drives the electrons to flow through the circuit. However, as electrons move, they encounter opposition, called resistance, which impedes their flow. The current in a circuit is directly influenced by the applied voltage and the resistance present. Essentially, voltage motivates the electrons to move, while resistance acts to oppose this flow. The standard units of measurement for electrical current, voltage, and resistance are summarized in Table 1.1.

Table 1.1 Measuring Units and Symbols of electrical quantities

| Electrical Quantity | Symbol | Unit of Measurement |
|---|---|---|
| Current | I | ampere (A) |
| Voltage | V | volt (V) |
| Resistance | R | ohm (Ω) |

The symbols used for electrical quantities are standardized alphabetical letters representing these quantities in algebraic equations. The units of measurement for electrical quantities are named in honour of key figures in the field of electricity: André-Marie Ampère, Alessandro Volta, and Georg Simon Ohm.

**Voltage –** Let us understand the concept of voltage. Consider a situation, a person needs to pick a stone from point A and drop it at point B. To complete this task, he must do some work. Figure 1.26. demonstrate the person is moving from point A to B.

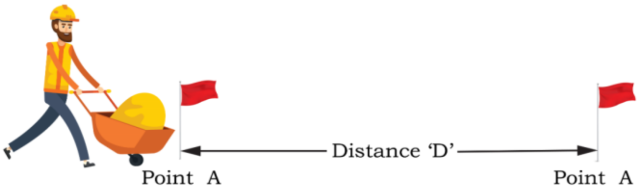



**Fig. 1.26 Work to be done to move the raw material from point A to point B**

In the same way, voltage is the amount of work required to move one-coulomb charge from point A to point B. The mathematical expression for voltage is written as

V=W/Q

where,

'V' is the voltage,

'W' is the work in joule,

'Q' is the charge in coulomb.

Alessandro Volta (1745–1827)

Voltage establishes a potential difference in an electric circuit between two points i.e. one point is at a higher potential and the other at a lower potential.

In an electric circuit, a battery is used as a source of electric potential. Inside a battery, a chemical reaction provides the energy required to move electrons. A typical, general-purpose battery is shown in Figure 1.27.


**Fig. 1.27 General-purpose battery**

When a voltage source such as a battery is connected to an electric circuit, negatively charged particles are pulled towards a higher potential (+), while positively charged particles are pulled towards a lower potential (-). Therefore, the current in a wire or resistor always flows from higher voltage towards the lower voltage as shown in Figure 1.28.

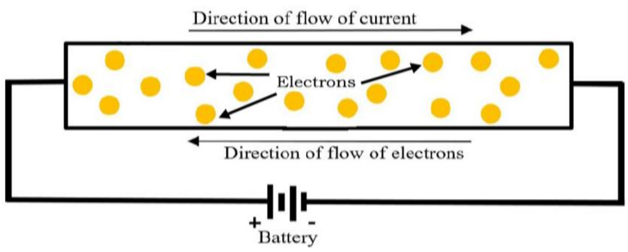



**Fig. 1.28 Flow of electrons on the application of DC supply**

A voltmeter is used to measure the voltage or potential difference between two points in an electric circuit. The value of voltage is measured in volts or joules per coulomb. The symbolic representation of voltage is **'V'** or **'v'**. When one joule of work is done to move one-coulomb charge from one point to another point the potential difference between two points is said to be one volt. Sources of AC and DC voltages are shown in Figure 1.29 and Figure 1.30.

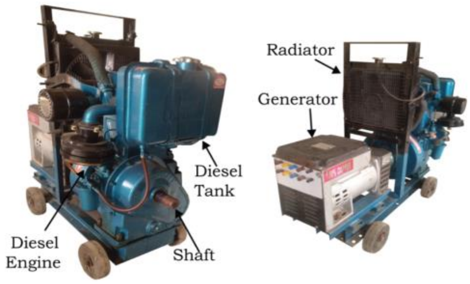



**Fig. 1.29 Diesel AC voltage generator used as AC voltage source**

**Fig. 1.30 Battery source of DC voltage**

**Example 1.1** How much work has to do to move a charge of 2 C across two points having a potential difference of 12 V?

**Solution** Given, the amount of charge Q, that flows between two points at potential difference V (= 12 V) is 2 C. Thus, the amount of work W, done in moving the charge is

W = VQ

= 12 V × 2 C

= 24 J

**Assignment 3**

1. Calculate the amount of work required to move a 10 C charge between the two points having a potential difference 24V.
2. Calculate the amount of charge required when the 12 J of work is performed to move a charge under the potential difference of 10V.

**Electric Current –** The flow of electric charges is called electric current. The electrons carry charges with them. The electrons flow from one place to another. The amount of current flowing from one place to another determines the amount of charge flowing through a section of the conductor at a specific time. The measuring unit of current is ampere (A). The symbolic representation of the current is 'I'. Mathematically, it can be written as,

$I = Q/t$

Where,

'I' is current,

'Q' is the amount of charge in coulombs

't' is the time in seconds

André-Marie Ampère (1775–1836)

**Note** Coulomb is the unit of charge.

If a 1-coulomb charge passes through a cross-section area A in 1 second, then it will represent the current of 1 ampere. Conventionally, the direction of current is taken as opposed to the flow of electrons.

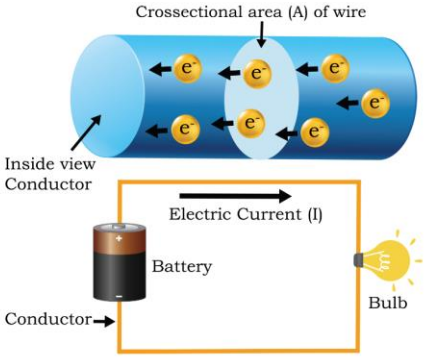



**Fig. 1.31 Flow of charge through a cross section 'A'**

> **Example 1.2** Calculate the amount of current flowing through a wire. When the amount of charge is 5 coulombs and the time is 10 seconds.
>
> **Solution** The relation between the current, charge and time.
>
> I= Q/t
>
> I= 5/10
>
> I= 0.5 Ampere

**The flow of Charge inside a Wire –** Inside the conductor free electron randomly moves from one point to another. Due to this random flow, the net electric charge of a conductor is zero. When an external power source is attached across it, the net flow of electrons is in one direction. This movement of electrons results in a current. If there is a current of 1 ampere passing through a wire, it theoretically means that 6 x $10^{18}$ electrons are moving from one point to another in 1 second. Figure 1.32 illustrates that when the electrons inside the conductor experience the force they align in the same direction.

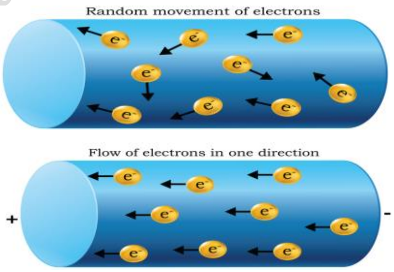



**Fig.1.32 Flow of charge**

> **Assignment 4**
>
> 1. Calculate the amount of current drawn by radio when the amount of charge flow is 120 coulombs in 1 minute.
> 2. Consider an electric circuit in which LED is used for indication. While observing it was found that the rate of charge used by the LED is 180 coulombs in 2.5 minutes. Calculate the current drawn by the LED.
> 3. What are the basic elements required to form an electric circuit?
> 4. Does electric current is dynamic in nature? how?

**Classification of Current –** Depending upon the movement of electrons in an electric circuit, current can be classified as – (i) Direct current (DC) and (ii) Alternating current (AC)

**(i) Direct Current –** It is unidirectional, that is movement of electrons takes place only in one direction. This means that current flows only in one direction. Figure 1.33 illustrates the typical electric circuits having a DC voltage source and current are shown in.

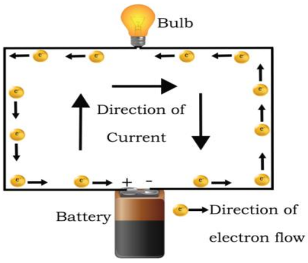



**Fig. 1.33 DC voltage and current in an electric circuit**

DC voltage sources such as batteries and cells produce direct current. Figure 1.34 illustrates typical DC voltage sources are shown in. Direct current is used in wall clocks, remote control, motor vehicles, cell phones, and many more.


**Fig. 1.34 Various sources of DC voltage source**

**(ii) Alternating Current –** It is bidirectional, that is movement of electrons takes place in two directions. This means that the current flows in two directions. Figure 1.35 illustrates the typical AC source applied in an electric circuit is shown in.

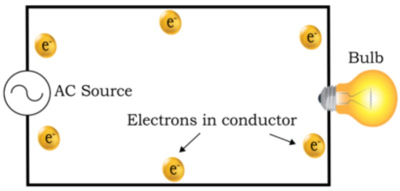



**Fig. 1.35 AC source is applied in an electric circuit**

During the positive half cycle of the AC signal, the upper part of the AC source becomes positive and the lower part becomes negative. Observe the direction of the flow of current in Figure 1.36.

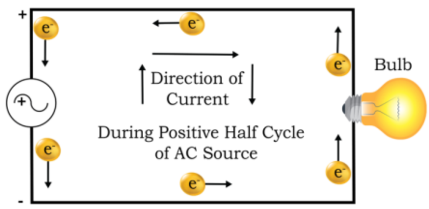



**Fig. 1.36 Positive half of the AC source is applied in an electric circuit**

During the negative half cycle of the AC signal the upper part of the AC source becomes negative and the lower part becomes positive. Observe the direction of the flow of current in Figure 1.37.

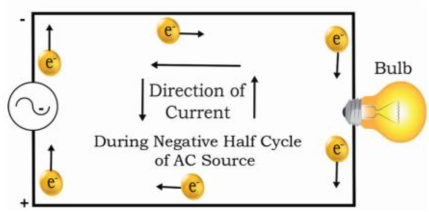



**Fig. 1.37 Negative half of the AC source is applied in an electric circuit**

An AC voltage source like an AC generator produces alternating current. Hydel power plants, thermal power plants, and many more are the places where AC voltage is generated. In India, the standard AC generating frequency (f) of alternating current is 50 hertz. Generators at the power plants work continuously to produce AC voltage. As a backup for a few hours' diesel generators are used to provide power supply for appliances in case of power cuts or unavailability of generating power supply. Alternating current is used in ceiling fans, coolers, washing machines, and many more. Various AC generators are shown in Figure 1.38.


**Fig. 1.38 Various AC generators**

**Know More...**

Frequency can be defined as "the number of cycles in one second". In Figure 1.39, point A to point B represents one cycle. Hertz (Hz) is the measuring unit of frequency.

Example 50 Hz represents 50 cycles in 1 second.

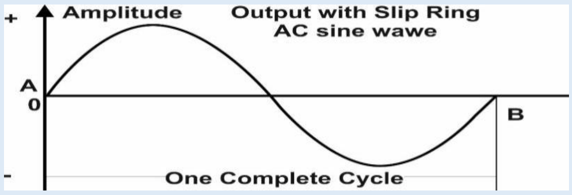



**Fig. 1.39 Cycle of AC signal**

The main difference between AC and DC is the directionality in the flow of electrons. In alternating current (AC), the movement of electric charge periodically reverses direction. In direct current (DC), the flow of electric charge is only in one direction. The usual waveform which is generated by the AC generator is sinusoidal in nature i.e. sine wave. In certain applications, different waveforms are used, such as triangular or square waves. Waveforms of various shapes are shown in Figure 1.40.

Frequency can be defined as "the number of cycles in one second". From point A to point B represents one cycle. Hertz (Hz) is the unit of frequency.

**Example 1.3** Represent 50 Hz with the help of various type of waveform

**Solution –** 50 Hz represents 50 cycles in 1 second.

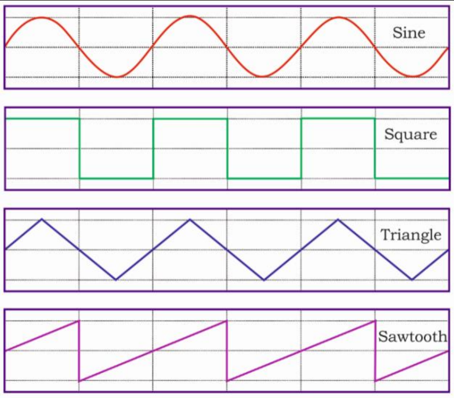



**Fig. 1.40 Various waveform**

**Assignment 5**

Prepare a list of gadgets in tabular form. This table will have two columns. In the first column, list out the gadgets which works on the alternating current and in the second column list out the gadgets which works on the direct current.

**Resistance –** We know that in conductors, electrons are loosely held and can move very easily. In insulators, electrons are tightly bound to the nucleus of atoms. Therefore, they do not move very easily. A very high voltage is required to move the electrons in an insulating material. On the other hand, a very small voltage is required to move the electrons in any conductor. Conductors such as copper, and aluminium offer the least resistance, while insulators such as rubber, and plastic offer high resistance as shown in Figure 1.41 and 1.42 respectively. Therefore, it can be said that Resistance resists the flow of electrons and hence, electric current in the circuit. Conceptually, the resistance controls the flow of electric current. The resistance is represented by the symbol "R". The SI unit of electrical resistance is the ohm (Ω).

Georg Simon Ohm (1789 - 1854)

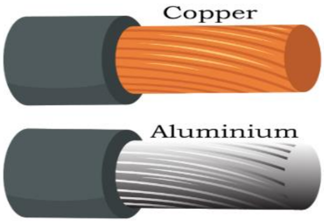



**Fig. 1.41 Copper and aluminium wire used as a conductor**

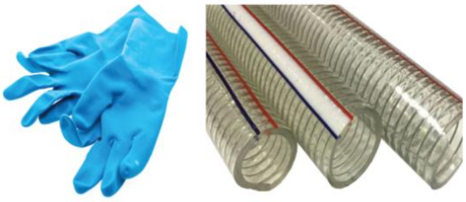



**Fig. 1.42 Rubber and PVC plastic used as insulators**

In household applications, we use various appliances for our daily use. To control the amount of current flowing into the appliance resistors are used. If the resistor is not used in the circuit, then the excessive current may damage the appliance.

**Electric Power –** Electric power is the rate of doing work, which means the "amount of work done in one second". It is represented by the symbol "P". The SI unit of power is the **watt** (W). It is named in honour of Scottish inventor James Watt (1736-1819). One Watt is equal to one joule per second.

P = Work done per unit time = QV/t = V x I

Where,

'Q' is electric charge in coulombs

't' is time in seconds

'I' is electric current in amperes

'V' is electric potential or voltage in volts

P =W/t or P= $I^2R$

James Watt (1336 - 1819)

Where,

'W' is the work done in joules

't' is the time in seconds

**Know More...**

Consider an object on the ground surface, if you lift the object 1m above the ground surface with a force of 1 newton, the amount of energy required represents 1 joule as shown in Figure 1.43.

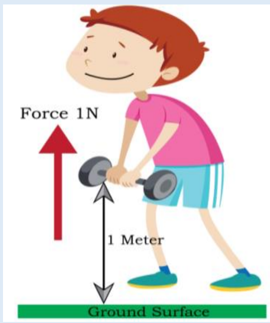



**Fig. 1.43 Person lifting the object**

Consider an electric bulb in the circuit, if it is of 60 watt that means that it will do 60 joules of work in one second. Likewise, some of the appliances with wattage are shown in Figure 1.41.


**Fig.1.44 Electric appliances with their wattage**

**Assignment 6**

1. What do you understand by wattage of appliances, suppose we have a television, ceiling fan, electric iron, refrigerator of 120-watt, 75-watt, 800 watts, 150watt respectively?

Electric horsepower (HP) is another measuring unit of power. One horsepower is equal to 746 watts. In Indian Railways, the locomotive engine series WAP-5 is of 5400HP and WAP-7 is of 6000 HP. Typical locomotives WAP-7 and WAP-5 are shown in Figure 1.45 and Figure 1.46.


**Fig.1.45 WAP-7 locomotive engine**


**Fig.1.46 WAP-5 locomotive engine**

Watt is a small measuring unit of power, in actual practice we need a much larger unit i.e. kilowatt (kW), which is equal to 1000 watts.

Since the product of power and time gives electrical energy; therefore, the measuring unit of electrical energy is watt-hour or kilowatt-hour. One-watt hour of energy is consumed when 1 watt of power is used for 1 hour. The commercially measuring unit of electric energy is kilowatt-hour (kWh). Single-phase meter i.e. energy meter in our home measures power consumption in kWh. A typical energy meter is shown in Figure 1.47.

1kWh = 1000watt x 3600 second

= 3.6 x $10^6$ watt second or 3.6 x $10^6$ joule

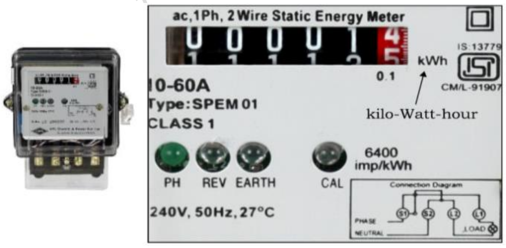



**Fig.1.47 Single-phase energy meter**

**Example 1.4 –** What is the meaning of 9 watts written on the domestic household LED bulb

**Solution –** The meaning of 9 watts written on the LED bulb means that the power of LED is 9 watts. This 9-watt defines it will do 9 joules of work in 1 second. A typical LED is shown in Figure 1.48.


**Fig. 1.48 Domestic Efficiency Lighting Program (DELP) 9-Watt LED**

In our home, every electrical or electronic appliance consumes electrical energy. We can calculate the amount of energy consumption by the appliances. To understand that let us do the activity, which will help to provide a basic formula for the energy consumption calculations.

Considering the above derived expression, we can calculate the following.

**Example 1.5 –** Calculate the amount of energy consumed by the Ceiling Fan. **If a ceiling fan power of 200 watts runs four hours per day, and for 120 days per year, what would be the annual energy consumption?**

**Solution –**

**Given,**

**Ceiling fan = 200 watts, Fan works for 4 hours per day; it works for 120 days per year.**

Formula used

Energy consumption/day (kWh) = Power consumption (Watt/1000) x hours used/Day

Energy consumption per day (kWh) = (200/1000) x 4 (hours used/day). Energy consumption per day (kWh) = (1/5) x 4 energy consumption per day (kWh) = 4/5 or 0.8 so the energy consumption **per day** is 0.8 kWh. To find out energy for 120 days, do simple multiplication 0.8 x 120 = 96 kWh.

**Assignment 7**

1. Calculate the amount of energy consumed in tube light. If you use a tube light of 40 watts for eight hours per day, and for 365 days, what would be the annual energy consumption?
2. Calculate the amount of energy consumed by television. If you use a television 100 watt for six hours per day, and for 200 days per year, what would be the annual energy consumption?
3. Calculate the electric power, when the voltage across an electric motor is 440V and the current drawn by the motor is 2A.
4. Calculate the amount of charge flowing through the machine in 10 seconds, when the applied voltage to the 1000-watt machine is 220V.
5. Calculate the applied voltage to the machine, when the current and power are 10A and 1500 watts respectively.

A 100-watt electric bulb is lighted for two hours daily, and four 40-watt bulbs are lighted for four hours daily. Calculate the energy consumed (in kWh) in 30 days.

**Know More…**

The government of India has launched a national program for LED-based home and street lighting for energy conservation. Along with this program, the Government of India launched a scheme for Light Emitting Diode (LED) bulb distribution under the Domestic Efficient Lighting Programme (DELP).

Fig.1.49 Logo of DELP scheme

In our home, every electrical and electronic appliance requires an AC supply. For convenience, we use a power socket. They provide the desired power to the appliance. Let us learn the representation of different ports in the power sockets.

Practical activity 1.2 demonstrates analysis of the live, neutral, and earth ports of the power socket.

**Practical Activity 1.2 –** Demonstrate analysing the live, neutral, and earth ports of the power socket.

**Material Required**

Phase tester, five-pin socket.

**Procedure**

**Step 1.** Turn ON the switch of the socket. Figure 1.50 illustrate to switch ON the supply

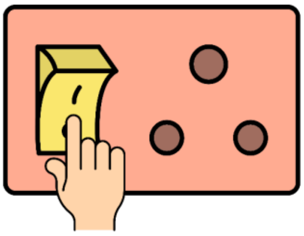


**Fig. 1.50 Switch on the power supply**

**Step 2.** Take a phase tester, and hold it in such a way that the forefinger of your right hand must touch the head of the tester. Figure 1.51 illustrates holding the phase tester.

**Fig. 1.51 Holding of phase tester**

**Step 3.** Place the tip of the tester into the ports of the socket. Figure 1.52 illustrate that Placing the tip of the phase tester near the ports

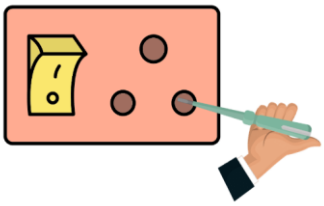


**Fig. 1.52 Place the tip of the phase tester near the ports**

**Step 1.** Observe the neon bulb in the tester, which will indicate the phase terminal. If the neon bulb turns ON it shows the phase terminal in the socket. Opposite to it will then be considered a neutral terminal. Figure 1.53 illustrates the verification of phase and neutral.

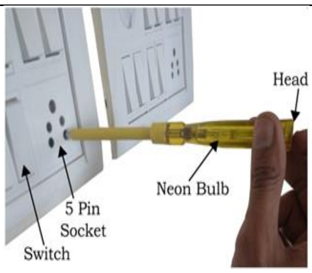



**Fig. 1.53 Verification of phase and neutral ports using the phase tester**

**Step 5.** Observe the phase, neutral and ground terminal of the socket, which is at the top of the socket. Figure 1.54 illustrates the various terminals of the socket.

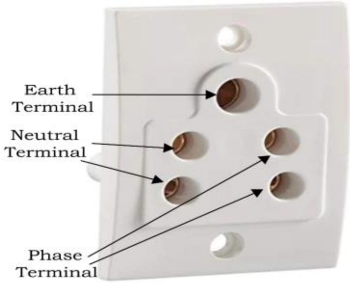



**Fig. 1. 54 Various terminals in the socket**

**Caution –** Do not touch the metal or uninsulated part of the phase tester.

### 1.3.2 Magnetic Field

A magnetic field is the area around a magnet or magnetic object. In this area, magnetic lines exert force on the object placed in this area. These lines are called magnetic lines of force. Typical bar magnets with lines of force are shown in Figure 1.55.

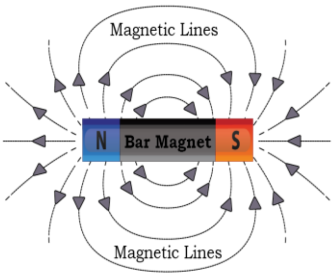



**Fig. 1.55 Natural magnet**

Our earth also acts as a magnet. The nature of Earth as a magnet is shown in Figure 1.56.

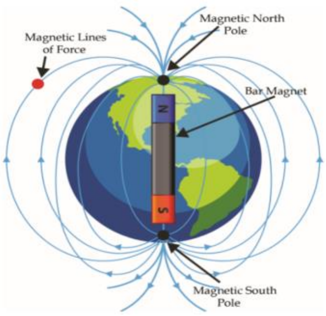



**Fig.1.56 Earth as a magnet**

Magnets play an important role in electrical and mechanical machinery. Let us perform an activity to form a magnet. Practical activity 1.3 Demonstrate to prepare an electromagnet.

**Practical Activity 1.3 –** Demonstrate to prepare an electromagnet.

**Material Required**

Battery, Iron nail, single copper wire of 1m length

**Procedure**

**Step 1.** Take a nail and wound a copper wire around it. Figure 1.57 illustrates copper wire wound around an iron nail.

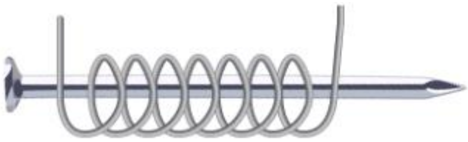


**Fig. 1.57 Copper wire is wound around the iron nail**

**Step 2.** Connect the two terminals of wire to a battery. Figure 1.58 illustrates copper wire is connected to the battery.

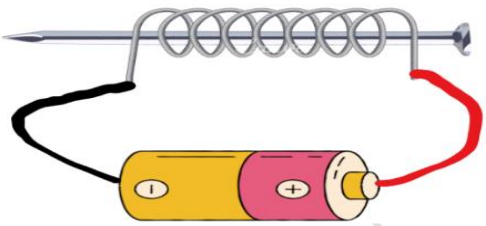


**Fig. 1.58 Coil is connected to the battery**

**Step 3.** Now, bring any magnetic material such as a piece of iron near the nail, a force of attraction can be observed. Figure 1.59 illustrates that another iron nail is near the system.

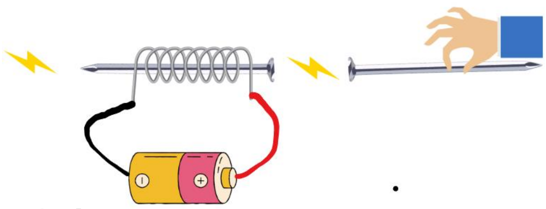


**Fig. 1.59 Iron nail is placed near the system**

**Step 1.** This presence of force shows a magnetic field of an electromagnet. Figure 1.60 illustrate that it become an electromagnet

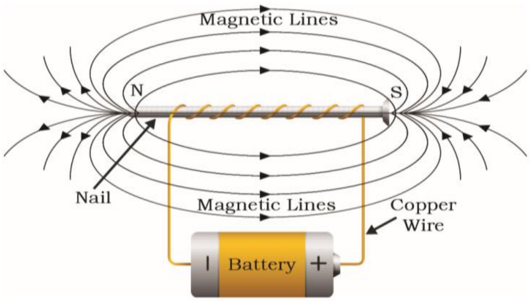



**Fig. 1.60 Artificial Magnet or Electromagnet**

This type of magnet which was prepared in practical activity 1.3 is called an electromagnet. It is formed when a voltage source i.e. battery is applied to generate the magnetic field. It is frequently used in mechanical equipment such as in lifting heavy machinery as shown in Figure 1.61.

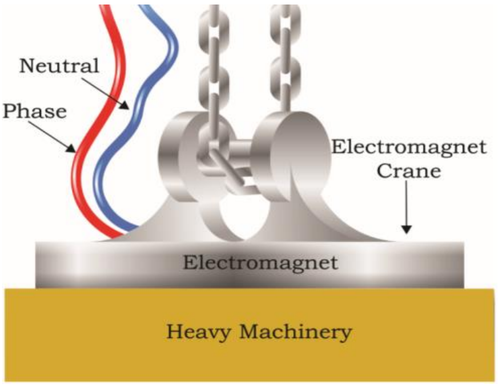



**Fig. 1.61 Application of electromagnet as crane**

**Electromagnetic Induction -** To understand electromagnetic induction first we need to understand the changing magnetic field. Changing magnetic fields defines the variation in the density of magnet lines of force. This variation can be performed by varying the applied voltage as shown in Figure 1.62. If we apply a large amount of voltage, the magnetic field density will be high and vice-versa.

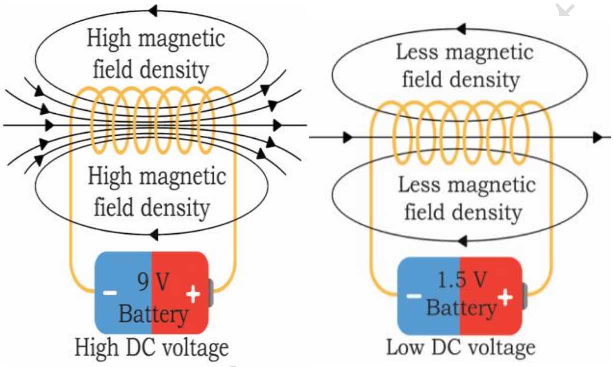



**Fig. 1.62 Variation in magnetic field density on the application of voltage**

If the applied voltage changes frequently, it will result in a varying magnetic field. If we place the conductor in this field, then due to the varying magnetic field a voltage will get generated across the terminals of the conductor. This voltage is called induced voltage. Therefore, it can be said that voltage will get induced, if we place a conductor in a varying magnetic field.

## Check Your Progress

**A. Multiple Choice Questions**

1. Which of the following is not state of matter? (a) Solid (b) Liquid (c) Plasma (d) Gas
2. In electromagnetic, magnetic field cannot be vary by (a) Applied voltage (b) Applied current (b) Applied heat (d) Resistance
3. Earth acts a _______ (a) Insulator (b) Conductor (c) Semiconductor (d) Magnet
4. Which of the following ports are available in the electric power socket? (a) Neutral (b) Live (c) Earth (d) All of the above
5. Which of the following component is used to provide resistance (a) Heat (b) Energy (c) Product (d) Resistor
6. In India Frequency (f) of alternating current is. (a) 45 (b) 60 (c) 50 (d) 55

7. Amount of work in one second is (a) Power (b) Current (c) Voltage (d) Charge
8. Amount of charge flowing through a point in one second is called (a) Voltage (b) Current (c) Power (d) Charge
9. Amount of work required to move a unit coulomb charge from point A to point B called as (a) Current (b) Charge (c) Voltage (d) Power
10. What are the basic building blocks that all matters? (a) Electrons, neutrons, and protons (b) Electrons, proton and ions (c) Neutrons, protons and ions (d) Electrons, neutrons, and charged ions
11. Electric charge can be produced by (a) Sticking (b) Rubbing (c) Oiling (d) Passing ac current
12. An electron has _______charge (a) Positive (b) Negative (c) Zero (d) Sometime positive, sometimes negative
13. A proton has _______ charge. (a) Positive (b) Negative (c) Zero (d) Sometimes positive, sometimes negative
14. A neutron has _______ charge. (a) Positive (b) Negative (c) Zero (d) Sometimes positive, sometimes negative
15. Unit of electric current is _______ (a) Ampere (b) Volt (c) Watt (d) Joule

**B. Fill in the blanks**

1. The ___________ done in one second is called power.
2. Magnet have _______ pole and _______ pole.
3. Proton has _______ charge.
4. Unit of electrical _______ is watt.
5. 1kWh = _______ watt x _______ second.
6. Electrons have _______ charge.
7. Alternating current is _______ in nature.
8. Direct current is _______ in nature.
9. Number of cycles in one second is called as _______.
10. Battery is an example of _______ voltage source.

**C. State whether the following statements are True or False**

1. Frequency (f) of alternating current is 60 hertz in India. ( )
2. Electrons are electrically neutral. ( )
3. Due to rubbing of two bodies, electric charge is produced. ( )
4. Earth is an electromagnetic. ( )
5. Unit of current is ampere. ( )
6. Resistor easily passes current. ( )
7. Unit of voltage is watt. ( )
8. Unit of power is joule/second. ( )
9. Rubber is a good conductor of electricity. ( )
10. 1kWh = 1000-watt x 3600 second. ( )

**D. Short answer questions**

1. What is the residential voltage supply in India?
2. What do you understand by the term one volt?
3. What is the supply frequency of AC voltage?

4. What is an electric current?
5. What does 10 A mean?
6. How AC and DC currents are different from each other?
7. List the appliances, which use DC power.
8. Write the steps to prepare an electromagnet?
9. What are insulators and conductors?
10. Differentiate between AC and DC voltage.

# Session 2. Electric Circuit Analysis

In an electrical system, there are several circuits. To analyse and monitor the electrical quantities like voltage, and current in the electric circuits, students need to know some basic laws. While repairing the appliances, these basic laws are used to determine the required value of electrical quantities. In this chapter, students will learn the basic laws used in the circuit analysis of electrical systems such as Ohm's Law, Kirchhoff's Law, and Electromagnetic induction.

## 2.1 ELECTRIC CIRCUIT

An electric circuit provides a path through which electrical energy can move forward from the source to the load and can reverse back to the source. The load can be any appliance, which consumes electrical energy such as bulbs, tube lights, fans, television, and many more. These loads can be easily operated if the electric circuit has a complete path. Figure 2.2 illustrates the symbolic representation of close connections between the electrical load and the electrical source.

The close path is made up of wires or cables. Consider a situation in which we plugin the power cord of the television in the socket. Once we switch ON the button, electric current enters through a phase or live wire into the television set and returns to the socket through a neutral wire. In this way, it completes the circuit.

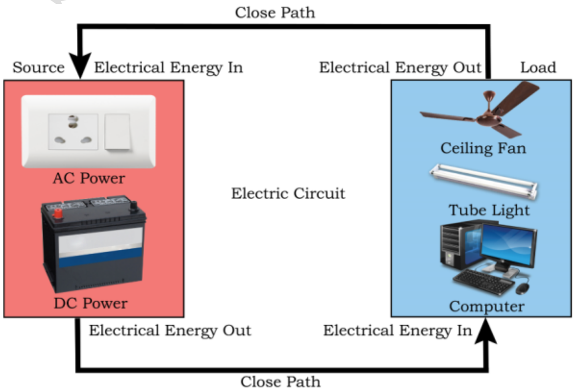
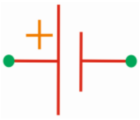
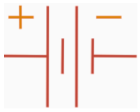
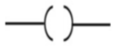
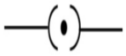
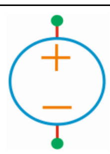
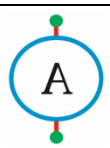
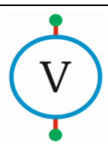



**Fig. 2.1 Logical closed path in electrical network between source to load and back to the source**

An electric circuit is an interconnection of electrical and electronic components. They are arranged in such a way that electric charges are made to flow along a closed path. Electric circuits are designed to execute specific functions. Circuit diagrams are used to check the connectivity of components on the printed circuit board (PCB). In a circuit diagram, components are represented by their respective symbols. Some of the commonly used symbols in circuit diagrams are given in Table 2.1.

Table 2.1 Symbolic representation of the components

| S.No. | Components | Symbol |
|---|---|---|
| 1. | Electric cell |  |
| 2. | Battery or a combination of cells |  |
| 3. | Plug key or switch (open) |  |
| 4. | Plug key or switch (closed) |  |
| 2. | A wire joint |  |
| 6. | Wires crossing without joining |  |
| 7. | A resistor of resistance R |  |
| 8. | Variable resistance or rheostat or |  |
| 9. | AC voltage source |  |
| 10. | DC voltage source |  |
| 11. | Ammeter |   |
| 12. | Voltmeter |   |

In Figure 2.2, a battery is connected to a resistor to form a simple electric circuit. The battery provides a current 'I' to the circuit, delivering electrical energy into the resistor 'R'. After passing through the resistor, the current again returns to the source. Hence, completes the electric circuit. This is an example of a simple electric circuit. In complex electric circuits, various components can be used such as resistors, capacitors, switches, transformers, and many more. The components in the circuit can be active or passive.

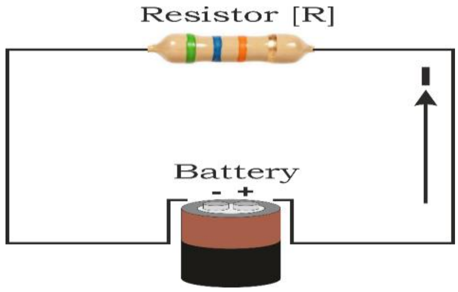
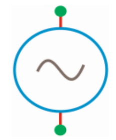
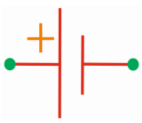
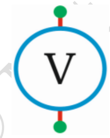
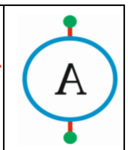



**Fig. 2.2 Basic Electric Circuit**

**Assignment 2.1 –** Identify and name the following symbols.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
|  |  |  |  |  |  |  |  |
| | | | | | | | |

## 2.1.1 Open and Closed Circuit

A circuit is a path or loop around which an electric current flow. If the circuit is complete, it is called **closed.** In this state, the device or load will get the power and execute its function. If this circuit is broken, it is called open**.** In this state, the device or load will not get the power and cannot execute its function. Figure 2.3 (a), and Figure 2.3 (b) illustrate the states of the closed and open circuits.

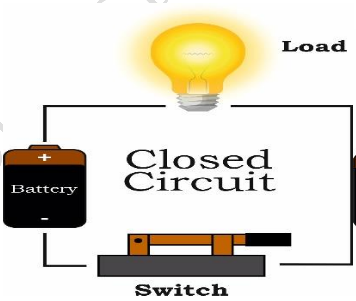



**Fig. 2.3 (a) Closed circuit**

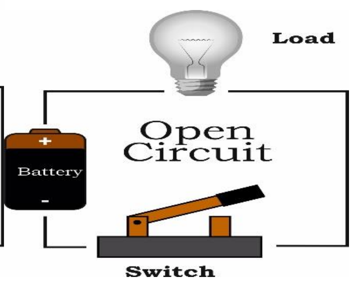



**Fig. 2.3 (b) Open circuit**

Practical activity 2.1 demonstrates a closed and open circuit. A closed circuit is a complete loop where the current can flow continuously without any interruption. In a closed circuit, there is a continuous path for the electric current to follow, connecting the power source to the load. An open circuit is a circuit that has a gap or a break in the path, preventing the current from flowing.

**Practical Activity 2.1 –** To prepare an electric circuit to analyse the state of open and closed circuits.

**Material Required –**

9 volts battery, connecting wire, resistor, lamp, wire stripper, wire cutter, and switch.

**Procedure**

**Step 1 –** Take a battery and check the positive and negative terminals of the battery or cell which is already marked on it. Figure 2.4 illustrates the positive and negative terminal of the battery.


**Fig. 2.4 Cell or battery**

**Step 2 –** Cut the required length of wire using a wire cutter and then strip the insulation of ends using a wire stripper. Figure 2.5 illustrates the wire stripper is cutting the wire into two pieces.

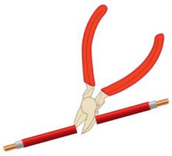


**Fig. 2.5 Cut the wire with the help of a wire stripper**

**Step 3 –** Take a lamp, observe its two terminals, and connect stripped wire to both terminals. Figure 2.6 illustrate the two terminals is ready

**Fig. 2.6 Bulb terminals are connected with wires**

**Step 4 –** Take one of the terminals of the lamp and connect one end of a resistor to the stripped wire of the lamp.

**Fig. 2.7 Resistor is connected to the wire**

**Step 5 –** Then, again cut and strip the required length of wire, then using this stripped wire connect another end of the resistor to the positive terminal of the battery via switch. Figure 2.8 illustrates the switch is connected between the circuits.

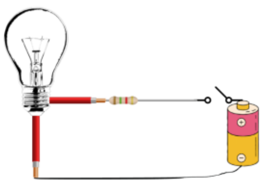


**Fig. 2.8 Cell positive terminal is connected via a switch**

**Step 6 –** Then connect the other end of the switch to the negative terminal of the battery.

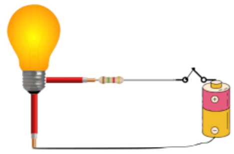


**Fig. 2.9 Cell negative terminal is connected via a switch**

**Step 7 –** Turn ON the lamp using a switch and observe that the circuit is working properly. Figure 2.10(a) illustrates the open circuit and Figure 2.10(b) illustrates the closed circuit respectively.

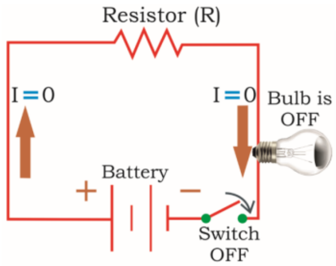



**Fig. 2.10(a) Open circuit**

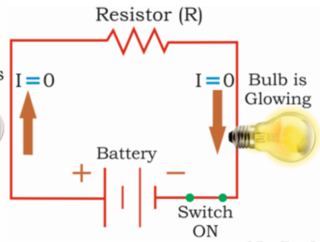



**Fig. 2.10(b) Close circuit**

While repairing electric appliances, one needs to test the continuity of various electrical and electronic components. To test the components, a test lamp can be used.

Practical activity 2.2 demonstrates the design for a Series test lamp. A series test lamp, also known as a test light or test lamp, is a simple electrical device used to test the presence of voltage in a circuit. It consists of a bulb or an LED connected in series with a probe or a long wire. The probe is typically a pointed metal tip or a clip that can be attached to the circuit being tested. The series test lamp works based on the principle that when voltage is present in a circuit, it causes current to flow through the lamp, making it light up. It provides a simple and quick indication of the presence or absence of voltage.

**Practical Activity 2.2 –** To construct a Series test lamp.

**Material Required –**

A bulb, a bulb holder, wire, wire cutter, wire stripper, plug

**Procedure**

**Step 1 –** Cut the wire into two pieces using a wire cutter, making each two meters long.

**Step 2 –** Now, you have two pieces of wire. Each wire is two meters in length. Strip the insulation of the wire terminals.

**Step 3 –** Connect these wires to the bulb holder.

**Step 4 –** Now, you have a bulb holder to which wires are connected. Figure 2.11 illustrates an AC Electric bulb with two terminals.

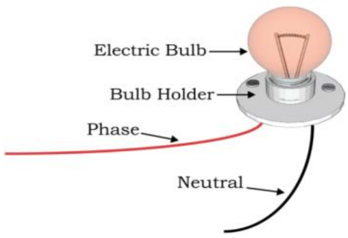



**Fig. 2.11 Electric AC bulb with two terminals**

**Step 2.** Connect the terminal of one wire to the plug. Figure 2.12 illustrate that phase wire is connected with a plug.

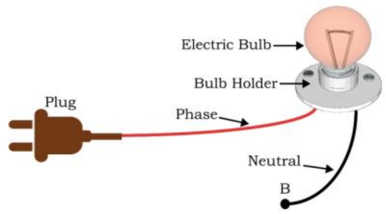



**Fig. 2.12 Electric plug is connected to a phase wire**

**Step 6.** Leave one wire-free for testing i.e. terminals A and B are used for testing Figure 2.13 illustrate that neutral wire is having two terminals.

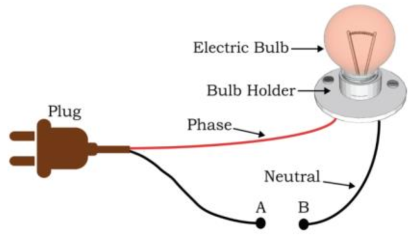



**Fig. 2.13 Neutral terminal have two terminal A and B**

**Step 7.** Insert the plug in the socket. Figure 2.14 illustrate that the electric plug is connected to the socket.

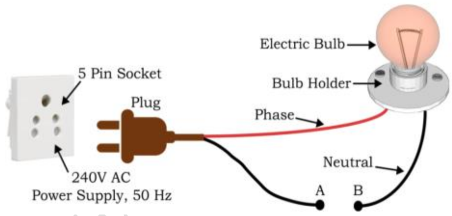



**Fig. 2.14 Electric Plug is connected to the AC socket**

**Step 8.** Now, check the continuity of the path in a circuit or component using points A and B. If the bulb is ON that means, the circuit is complete or continues.

**Assignment 2.1**

Take a battery of 9V, a fixed resistor of 3 ohms, and a bulb or LED of 5 watts to connect them as per the circuit diagram shown in Figure 2.12. Find out the voltage, current, resistance, and power in a given circuit.

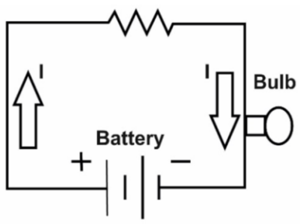



**Fig. 2.15 Electric circuit**



### 2.1.2 Series and Parallel Circuit

In electric circuits, various components are connected. They can be arranged in many ways. The circuit is named based on the way components are connected. There are two forms of circuits known as Series and Parallel.

**Series Circuit –** Suppose, a battery and two electric bulbs are connected along a single path in such a way that it will form a close circuit. Therefore, the current flowing through each bulb remains the same, whereas voltage will get divided across each bulb Figure 2.16(a) illustrates the series circuit. Suppose, if one of the bulbs is fused, the electric path becomes incomplete, and another bulb is also turned off. Referring to this condition, it can be concluded that in series circuits the same number of current passes through the bulbs, but voltage divides across the bulbs Figure 2.16(b) illustrates that if any bulb is fused other bulbs will not glow.

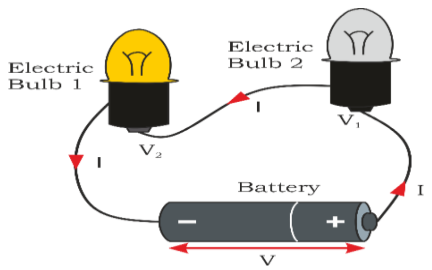



**Fig.2.16 (a) Bulbs connected in series along with battery**

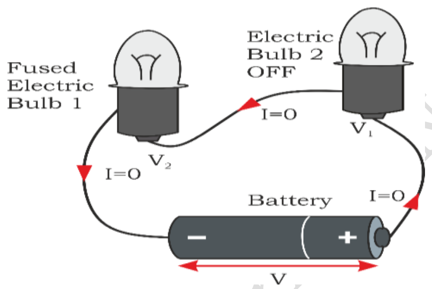



**Fig.2.16 (b) Fused bulb incomplete the electric circuit**

**Parallel Circuit –** Suppose, a battery is connected to two electric bulbs in such a way that each bulb is placed in a separate path forming a close circuit with a common battery. Therefore, the current flowing through each bulb divides, whereas the voltage across each bulb remains the same. Figure 2.17(a) illustrates the parallel circuit. Suppose, if one of the bulbs is fused, only one electric path breaks and another bulb connected in another path will not get affected. Figure 2.17(b) illustrates that if any bulb is fused other bulbs will glow. Referring to this condition, it can be concluded that in parallel circuits different amounts of current pass through the bulbs. But, the voltage remains the same.

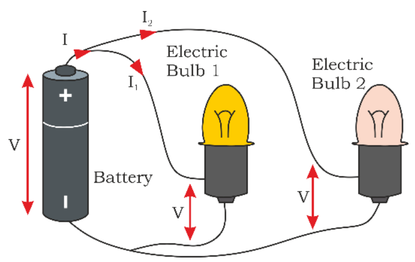



**Fig. 2.17 (a) Bulbs connected in parallel**

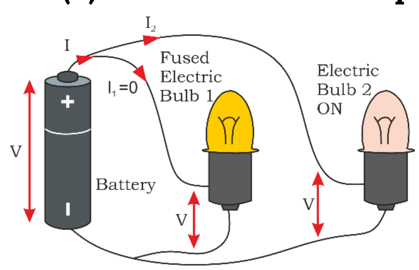



**Fig. 2.17 (b) Fused bulb incomplete only the single path**

## 2.2 OHM'S LAW

We have already discussed the potential difference, current, and resistance but is there any relationship between the potential difference across a conductor and the current through it?

Practical activity 2.3 demonstrate the relationship between potential difference across a conductor and the current through it.

**Practical Activity 2.3 –** To verify the relationship between potential difference across a conductor and the current through it.

**Material Required –**

Nichrome wire of length 0.5m, ammeter, voltmeter, four cells of 1.5 V each, plug key, connecting wires, and a piece of sandpaper.

**Circuit diagram –**

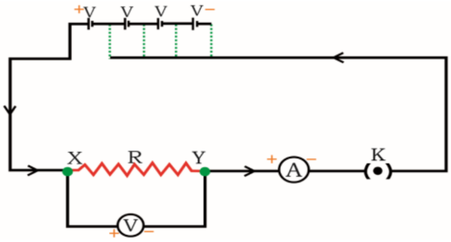



**Fig. 2.18 Circuit diagram of Ohm's law**

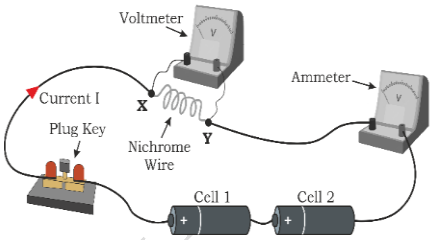



**Fig. 2.19 Ohm's law setup**

**Procedure –**

**Step 1.** Set up a circuit as shown in Figure 2.18, consisting of a nichrome wire XY of length, say 0.5 m, an ammeter, a voltmeter, and four cells of 1.5 V each. **(Nichrome is an alloy of nickel, chromium, manganese, and iron metals.)**

**Step 2.** First, use only one cell as the source in the circuit. Note the reading in the ammeter I, for the current and the reading of the voltmeter V for the potential difference across the nichrome wire XY in the circuit. Tabulate them in the Table given.

**Step 3.** Next, connect two cells in the circuit and note the respective readings of the ammeter and voltmeter for the values of current through the nichrome wire and potential difference across the nichrome wire. Figure 2.19 illustrates the practical setup of Ohms law.

**Step 4.** Repeat the above steps using three cells and then four cells in the circuit separately.

**Step 2.** Calculate the ratio of **V** to **I** for each pair of potential difference V and current I.

Table 2.2

| S. No. | Number of Cells used in the circuit | Current through the nichrome wire, I (ampere) | Potential difference across the nichrome wire, V (volt) | V/I (volt/ampere) |
|---|---|---|---|---|

| | | | | |
|---|---|---|---|---|
| 1. | One | 0.06 | 0.75 | 12.5 |
| 2. | Two | 0.08 | 1.0 | 12.5 |
| 3. | Three | 0.09 | 1.2 | 12.5 |
| 4. | Four | 0.13 | 1.6 | 12.5 |

**Step 6.** Plot a graph between V and I, and observe the nature of the graph.

**Result**

Here the value of V/I is constant for all the values is found to be 12.2. Hence, we can say that the value of resistance of Nichrome wire is 12.5Ω.

The VI graph is found to be an almost 45° inclined line.

**Precautions**

1. All the electrical connections must be neat and tight.
2. Voltmeter and ammeter must be of proper range.
3. The key should be inserted only while taking readings.

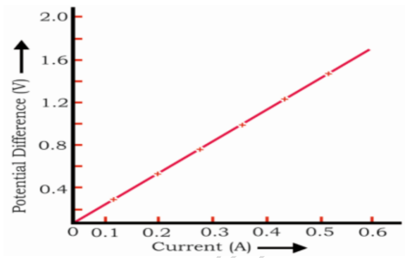



**Fig. 2.20 V–I graph for a nichrome wire.**

In this activity, you will find that approximately the same value for V/I is obtained in each case. Thus, Figure 2.20 illustrates that the V–I graph is a straight line that passes through the origin of the graph. It also describes that **as the current through a wire increases, the potential difference across the wire increases linearly – this is Ohm's law.**

In 1827, German physicist Georg Simon Ohm (1787–1854) found the relationship between the current I, flowing in a metallic wire, and the potential difference across its terminals.

**The current flowing through a given metallic wire in an electric circuit is directly proportional to the applied potential difference V, provided room temperature remains the same. This is called Ohm's law**. In other words, it can be

$V \propto I$

or $V/I = \text{constant} = R$

or $V = IR$

R is a constant for the given metallic wire at a given temperature and is called its resistance.

According to Ohm's law,

$R = V/I$

In the above expression, it is obvious that the current through a resistor is inversely proportional to its resistance. If the resistance is doubled the current gets halved. In many practical cases, it is necessary to increase or decrease the current in an electric circuit. A component used to regulate current without changing the voltage source is called variable resistance. In an electric circuit, a rheostat and potentiometer are often used to change the resistance in the circuit. Figure 2.21 illustrates the variable resistance or a potentiometer

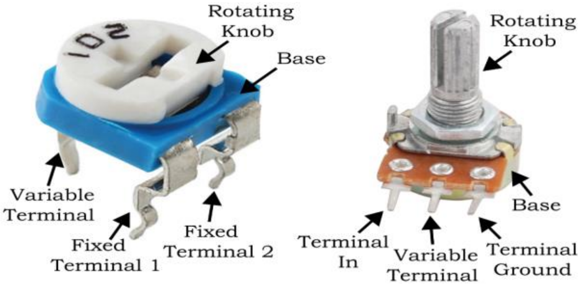



**Fig. 2.21 Potentiometer**

Figure 2.22 illustrates the rheostat, a kind of variable resistance used to vary resistance.

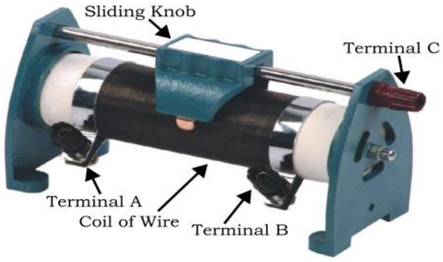



**Fig. 2.22 Rheostat**

In an electrical network, every material has its resistance value. The resistance value of the material must be known because it is used in the analysis of electric circuits.

Practical activity 2.4 demonstrates the determination of the resistance value of the material. It is a measure of how strongly it resists the flow of electric current. The resistance of a material depends on factors such as its physical properties, dimensions, and temperature.

**Practical Activity 2.4 –** To study about electrical resistance of a conductor.

**Material Required –**

Nichrome wire, a torch bulb, a 10 W bulb and an ammeter (0 – 5 A range), a plug key, and some connecting wires.

**Procedure**

**Step 1 –** Set up the circuit by connecting four dry cells of 1.5 V each in series with the ammeter leaving a gap XY in the circuit, Figure 2.23 illustrates the various components required.

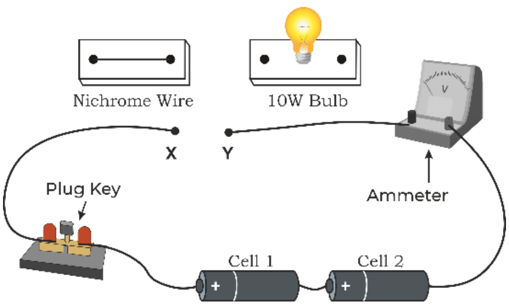



**Fig. 2.23 Experimental setup**

**Step 2 –** Complete the circuit by connecting the nichrome wire in the gap XY. Plug the key. Note down the ammeter reading. Take out the key from the plug.

**[Note – Always take out the key from the plug after measuring the current through the circuit.]**

**Step 3 –** Replace the nichrome wire with the 10W bulb in the circuit and find the current through it by measuring the reading of the ammeter.

**Step 4 –** Repeat this activity by keeping any material component in the gap. Observe the ammeter readings in each case.

**Result**

The value of current is different for different components

In the above Practical activity, it is observed that the current is different for different components because Certain components offer an easy path for the flow of electric current while others resist the flow.

The motion of electrons in an electric circuit constitutes an electric current. The electrons, however, are not completely free to move within a conductor. They are restrained by the attraction of the atoms among which they move. Thus, the motion of electrons through a conductor is retarded by its resistance.

A component of a given size that offers a low resistance is a good conductor. A conductor having some appreciable resistance is called a resistor. A component of identical size that offers a higher resistance is a poor conductor. An insulator of the same size offers even higher resistance.

**Example 2.1 –** A 10 V battery is connected to an electric bulb having a resistance 20 Ω. Find the current flowing through the electric bulb.

**Solution** Given,

$V = 10\ V$
$R = 20\ \Omega$

The current flowing through an electric bulb is given by
$V = I\ R$
$I = V/R$
$I = 10/20$
$I = 0.5\ A$
So, the current flowing through the bulb is 0.5 A.

**Example 2.2 –** An electric iron having resistance 40 Ω is connected to a supply voltage. The current flowing through the electric iron is 6 A. Find the voltage applied to the electric iron.

**Solution** Here, I = 6 A, R = 40 Ω

The voltage equation is given by

$V = I\ R$
So, Voltage is expressed as $V = 6 \times 40$,
$V = 240\ V$

**Example 2.3 –** A 110 V voltage source supplies power to a halogen light. The current flowing through the halogen light is 5 A. Find the resistance of the halogen light.

**Solution** Here, V=110V, I=5A

The resistance is given by

$R = V / I$
$R = 110/5$
$R = 22\ \Omega$
so, the resistance of halogen light is 22 Ω.

**Assignment 2.1**

**Solve the problems based on Ohm's law.**

**1.** A 9 V is applied across a 3 Ω resistor. What is the current flowing?

**2.** A 6 Ω resistor passes a current of 2 A. What is the voltage across it?

**3.** What is the voltage of a circuit with a resistance of 255 Ω and a current of 3 A?

**4.** A small electrical pump is labelled with a rating of 5 A and a resistance of 30 Ω. At what voltage is it designed to operate?

**2.** A 9 V battery is hooked up to a light bulb with a rating of 2 Ω. How much current passes through the light?

**6.** A lamp is plugged into the wall outlet, which is providing 110 V. An ammeter attached to the lamp shows 2 A flowing through the circuit. How many ohms of resistance is the lamp providing?

**7.** If your body resistance is 9000 Ω and you touch a 9 V battery, what amount of current will flow through you?



**Assignment 2.2**

a) Fill in the following Table

Table 2.3

| | **Current** | **Voltage** | **Resistance** |
|---|---|---|---|
| **Symbol** | | | |
| **Unit** | | | |

b) In the following table, from the given quantities, calculate the unknown quantities. The unit 'k' stands for kilowatt (kW), which means 1000 W.

Table 2.4

| **Voltage** | **Current** | **Resistance** | **Power** |
|---|---|---|---|
| 100 V | 5A | | |
| 12 V | | 1 Ω | |
| | 5A | 8 Ω | |
| 230 V | 13A | | |
| | 3A | 150 Ω | |
| 50 V | | 20 Ω | |
| | | 40 Ω | 1 kW |
| | 0.5 A | | 2.5 W |
| 250 V | | | 62.5 W |

## 2.3 KIRCHHOFF'S LAW

Kirchhoff's law is named after Gustav Kirchhoff, he was a German physicist. Kirchhoff defined the basic relation between voltage (V), and current (I) in an electric circuit. These laws of Kirchhoff are used for circuit analysis. Kirchhoff's laws are related to the conservation of energy, which concludes that energy cannot be created or destroyed, it only changes its form.

Kirchhoff's laws represent the conservation of voltage and current. Kirchhoff's stated two laws namely

1. Kirchhoff's Current Law
2. Kirchhoff's Voltage Law

### 2.3.1 Kirchhoff's Current Law (KCL)

Kirchhoff's current law states, "Sum of the incoming current at a junction is equal to the sum of the outgoing current". It can be understood by an example, considering current $I_1$, $I_2$, $I_3$, and point A. Current $I_1$ and $I_2$ are incoming currents as they are coming towards point A. Current $I_3$ is outgoing current w.r.t point A as shown in Figure 2.24. According to the KCL, the sum of incoming current $I_1$ and $I_2$ are equal to the outgoing current $I_3$.

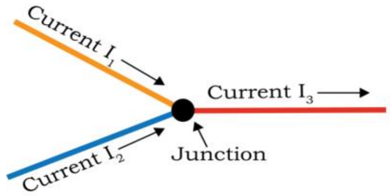



**Fig. 2.24 Line diagram to analyse Kirchhoff's current law**

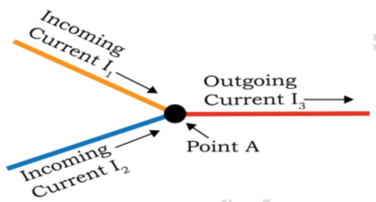



**Fig. 2.25 Point A representing the junction**

Mathematically, at point A

$I_1 + I_2 = I_3$

### 2.3.2 Kirchhoff's Voltage Law (KVL)

Kirchhoff's voltage law states, "Sum of voltage drops across the loads in the circuit are equal to the total voltages applied to the circuit" or "the algebraic sum of the products of currents and resistance plus the algebraic sum of the E.M.F. in that closed path (or mesh) in a network is equal to zero".

Mathematically, $\sum IR + \sum E.M.F. = 0$

In the earlier chapter, we studied that current always flows from higher potential toward lower potential, and also it flows from positive polarity to negative polarity. Figure 2.26 illustrates that a resistor of fixed value is attached with the higher potential +5 V and the other terminal of the resistor is attached with low potential +1V in that case the direction of current will always be from higher potential to lower potential. This condition is called a voltage drop. Let us consider a resistor, and a point at which current enters the resistor becomes positive and the point at which it leaves becomes negative.

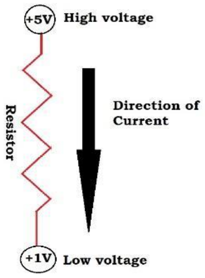



**Fig. 2.26 Fixed value resistor is connected to high higher potential to lower one**

Observe the circuit, if the direction of analysis is from positive to negative polarity across a resistor or any other component, then the voltage drop across the resistor will be V=-IR, here minus sign symbolizes a fall in voltage. Figure 2.27 illustrates the concept of a fall in voltage.

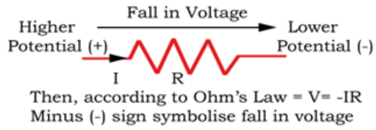



**Fig. 2.27 Concept of fall in voltage**

Observe the circuit, if the direction of analysis is from negative to positive polarity across a resistor or any other component, then the voltage drop will be V=+IR here positive sign symbolizes a rise in voltage. Figure 2.28 illustrates the concept of a rise in voltage.

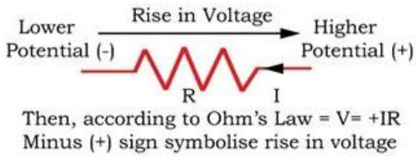



**Fig. 2.28 Concept of rise in voltage**

**For writing the equation using Kirchhoff's Voltage Law.**

**Step 1 –** Start from any point in the closed circuit, and move completely around the circuit, note down the "voltage drops" and the "voltage rises".

**Step 2 –** Remember that is defined as "**minus to plus"** constitutes a **rise** in voltage and "**plus to minus"** constitutes a **drop**-in voltage).

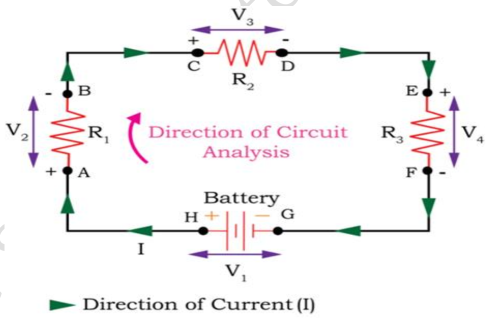



**Fig. 2.29 Circuit diagram for KVL analysis**

In the circuit diagram shown in Figure 2.29, for current I point A is the entering point of resistor $R_1$. Therefore, it is considered positive. Point B is the leaving point of resistor R1. Therefore, it is considered negative. Similarly, for resistor $R_2$, point C is positive and point D is negative. For resistor $R_3$, point E is positive and point F is negative.

In battery ($V_1$), points H and G are the positive and negative terminals of the battery. We can start the circuit analyses from any of the points, let us start from point H. Moving from point H towards point A of the resistor $R_1$, through point A current is entered in the resistor $R_1$, which will consider positive, and point B through which the current leave resistor $R_1$, it will consider as negative. In the same way, points C and D of resistor R2, and point E and F of resistor $R_3$. Now, we will determine the voltage across the resistors, across resistor $R_1$ fall in voltage

$V_2=-IR_1$

across resistor $R_2$ fall in voltage

$V_3=-IR_2$

across resistor $R_3$ fall in voltage

$V_4$=-$IR_3$

After pointing F of resistor $R_3$, point G of the battery is negative and H is positive. The voltage will be considered as a rise in voltage i.e. +$V_1$.

Combining all the expressions as per the KVL

$(-IR_1) + (-IR_2) + (-IR_3) + V_1 = 0$

Or $V_1 = IR_1 + IR_2 + IR_3$

In the above equation, it is observed that "voltage drops" on the right-hand sides of our equations, and all the "voltage rises" on the left-hand sides

We can conclude that, **Summation of applied voltages in a circuit = Summation of dropped voltages across components in a circuit**.

**Example 2.4 –** In a Circuit with 3 A of current running through the 4 Ω resistors as indicated in Figure 2.30.

1. Determine the current through each of the other resistors.
2. Determine the voltage of the battery on the left.
3. Determine the power delivered to the circuit by the battery on the right.

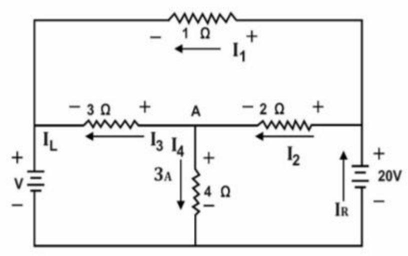



**Fig. 2.30 Circuit diagram**

Start with the 2Ω resistors. Apply KVL on the lower right of the circuit.

$20 = I_2(2\Omega) + (3A)(4\Omega)$

$\mathbf{I_2}$=4A

Start the circuit analysis from 3 Ω resistors. Apply the KCL at junction B in the circuit.

$I_2 = I_3 + I_4$

$4A = I_3 + 3\ A$

$\mathbf{I_3}$ = 1A

The current through the 1 Ω resistor certainly runs from right to left. If we apply the KVL to the top part of the circuit, we will have to run against that current.

$I_1\ (1\Omega) = (4A)\ (2\Omega) + (1A)\ (3\Omega)$

$\mathbf{I_1}$=5A

Applying the KVL in the lower left of the circuit.

$V + 1\ (3\Omega) = 3\ (4\Omega)$

V = 9V

The power delivered to the circuit by the battery can be calculated by multiplying voltage and current in the circuit. We already have the voltage (it's given in the problem) all that remains is to determine the current. Apply the junction rule to the junction on the left.

$I_L = I_1 + I_3$

$I_L = 5A + 1A$

$I_L$ = 12A

And again, to the junction at the bottom

$I_R = I_L + I_4$

$I_R$ = 12A+3A

$I_R$ = 15A

To find the power of the battery on the right

P = VI

P = (20V) (15A)

P = 300W

**Assignment 2.3**

Determine the current through each resistor in the circuit shown below.

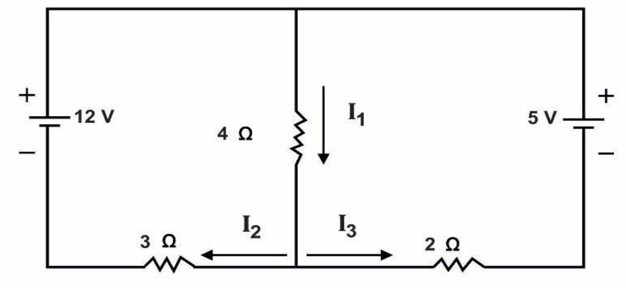



**Fig. 2.31 Circuit diagram**

## 2.4 ELECTROMAGNETIC INDUCTION

Electromagnetic induction was discovered by Michael Faraday in the 1830s. It is the phenomenon of generating an electric current or voltage.

Whenever a conductor is placed in a magnetic field in a particular position and the magnetic field keeps changing or the magnetic field is kept constant and the conductor is moving, this process will produce a voltage of EMF across the electrical conductor.

When the magnet comes near the coil which is connected to the galvanometer as shown in Figure 2.32. A deflection is observed in the galvanometer.

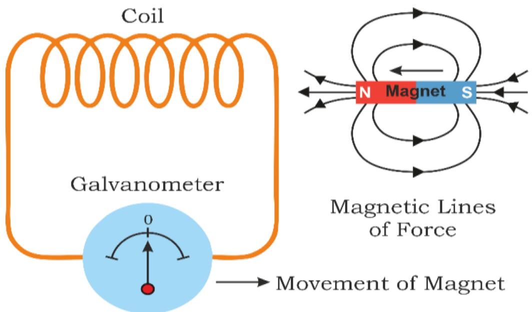



**Fig. 2.32 Experimental setup to observe the electromagnetic induction**

### 2.4.1 Faraday's Law of Electromagnetic Induction

Faraday's law of electromagnetic induction is a basic law of electromagnetism. It describes that magnetic field when it interacts with an electric circuit to produce an electromotive force (EMF). This phenomenon is known as electromagnetic induction. (Figure 2.33)

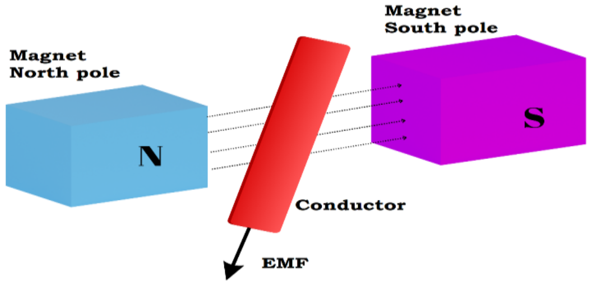



**Fig. 2.33 Faraday's Law of electromagnetic induction**

**First law –** Whenever a conductor is placed in a varying magnetic field, EMF induces and this emf is called an induced emf if the conductor is a closed circuit then the induced current flows through it.

**Second law –** The magnitude of the induced EMF is equal to the rate of change of flux linkages. The induced EMF is generally denoted by "e".

$e = N.d\varphi.dt$

Where,

e = induced EMF

N = Number of turns in the coil

$\varphi$ = Magnetic Flux

T = Time

Table 2.5 Concept of Faraday's Electromagnetic Induction

| **Position of Magnet** | **Deflection in Galvanometer** |
|---|---|
| Magnet at rest | No deflection in the galvanometer |
| The magnet moves toward the coil | Deflection in galvanometer in one direction |
| The magnet is held stationary at the same position (near the coil) | No deflection in the galvanometer |
| The magnet moves away from the coil | Deflection in galvanometer but in the opposite direction |
| The magnet is held stationary at the same position (away from the coil) | No deflection in the galvanometer |

### 2.4.2 Lenz Law of Electromagnetic Induction

Lenz's law is a consequence of Faraday's law and provides information about the direction of the induced current. It states that the induced current will always flow in such a way as to oppose the change in the magnetic field that produced it. In other words, the polarity or direction of that induced emf is such that it opposes the cause of its production. This law is based on the principle of conservation of energy. Figure 2.34 illustrates the coil repulses the magnet when it is inserted inside the coil. And the coils attract the magnet when it is removed from the coil.

According to the Lenz law

$e = N.(d\varphi/dt)$ volts

Where,

e = induced EMF

N = Number of turns in the coil

φ = Magnetic Flux

T = Time

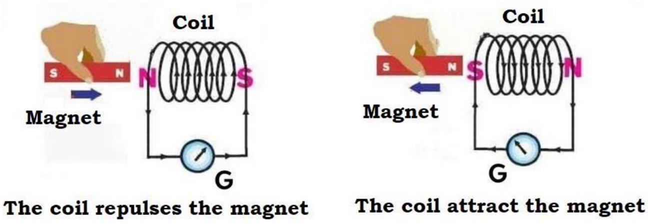



**Fig. 2.34 Lenz law**

### 2.4.3 Application of Electromagnetic Induction

Electromagnetic induction has numerous practical applications, some of the commonly used practical examples are described below –

**Electric generators –** Electric power generators utilize electromagnetic induction to convert mechanical energy into electrical energy. Rotating a coil of wire within a magnetic field induces an alternating current (AC) in the wire, which can then be used to power devices. Figure 2.35 illustrates the typical electrical generator.

**Fig. 2.35 Electric generator**

**Transformers –** Transformers are devices that use electromagnetic induction to transfer electrical energy between two or more coils of wire. By varying the number of turns in each coil, transformers can step up or step-down voltage levels for efficient transmission and distribution of electricity. Figure 2.36 illustrates the typical electrical transformer used in the distribution of electricity.

**Fig. 2.36 Electric transformer**

**Induction cooktops –** Induction cooktops use electromagnetic induction to heat cookware directly. An alternating current pass through a coil beneath the cooktop's surface, generating a rapidly changing magnetic field. This field induces eddy currents in the metal cookware, which in turn produces heat. Figure 2.37 illustrates the typical induction cooktop used for making food.

**Fig. 2.37 Induction cooktop**

**Wireless charging –** Electromagnetic induction is also utilized in wireless charging systems. An alternating current in a charging pad generates a changing magnetic field. When a compatible device with a receiving coil is placed on the pad, the changing magnetic field induces a current in the receiving coil, allowing for wireless charging. Figure 2.38 illustrates the typical Wireless charger of a mobile phone.

**Fig. 2.38 Wireless charger of mobile phone**

## Check Your Progress

**A. Multiple Choice Questions**

1. Which of the following component is used to close or break the circuit . (a) Bulb (b) Switch (c) Wire (d) Electric Cell
2. In series circuit current remains ________ and voltage ________ (a) Divide, same (b) Same, same (c) Divide, divide (d) Same, divide
3. In parallel circuit current remains ________ and voltage ________ (a) Divide, same (b) Same, same (c) Divide, divide (d) Same, divide
4. Ohms law states that ________ (a) Voltage is directly proportional to the applied voltage (b) Voltage is directly proportional to the applied current (c) Current is directly proportional to the applied voltage (d) Current is directly proportional to the applied current.
5. The statement which correctly represents ohm's law: (a) V = IR (b) V = R/I (c) R = VI (d) I = R/V
6. If V = 50 V and I = 5 A, then R = ___ (a) 50 Ω (b) 5 Ω (c) 10 Ω (d) 2 Ω
7. If P = 50 watt and R = 2 Ω, then I = ___ (a) 50 A (b) 5 A (c) 10 A (d) 2 A
8. A current of 3A flow through a conductor whose end are at a potential difference of 6V. Calculate the resistance of the conductor. (a) 4 Ω (b) 5 Ω (c) 1 Ω (d) 2 Ω
9. A current of 2A flows through a 12V bulb then Calculate the resistance (a) 6 (b) 16 (c) 24 (d) 20
10. Conductors which do not obey the ohms law are called as: (a) Un-ohmic conductor (b) Non-ohmic conductor (c) Low-ohmic conductor (d) Less-ohmic conductor

**B. Fill in the blanks**

1. In __________circuit current remains same and voltage divides.
2. In __________circuit current divides and voltage remains same.
3. A component which is used to close or break a circuit is __________.
4. "Current is directly proportional to the applied voltage" this law is given by __________
5. Switch is used for __________and __________ of circuit.
6. An electric circuit is an interconnection ____________ and ________________ of components.
7. An electric circuit is formed, when a closed path is formed to allow ______________ to move continuously

**C. State whether the following statements are True or False**

1. Kirchhoff's law gives relation between voltage, current, resistances. ( )
2. Ohm's law defines the direction of current at the junction. ( )
3. Current flow in closed circuit. ( )
4. Switch completes or in completes the electric circuit. ( )
5. Kirchhoff's voltage law used in the analysis of electric circuit. ( )
6. This continuous movement of free electrons in a conductor of a circuit is called a current. ( )
7. When electrons are in motion, electricity is called as dynamic or current electricity. ( )
8. Current, voltage, and resistance are the three basic building blocks of an electric circuit, called as electrical quantities. ( )
9. The amount of current in a circuit depends on the amount of applied voltage. ( )
10. Measuring units of electrical quantities are named after the famous invention in the field of electricity Frenchman Andre M. Ampere, Italian Alessandro Volta, and German Georg Simon Ohm. ( )

**D. Short answer questions**

1. Explain diagrammatically, how the components are connected in series circuits?
2. Explain diagrammatically, how the components are connected in parallel circuits?
3. What will happen to the series circuit if a bulb is fused? Will the circuit be close in this case?
4. State Kirchhoff's Ccurrent Law and Kirchhoff's Voltage Law.
5. State Ohm's law.

# Session 3. Electrical Components

One day, Sonu found a tiny bulb and was filled with excitement. He quickly connected two wires to its terminals and attempted to plug it into an AC socket. Seeing this, his father shouted and halted him.

His father explained that this small bulb only requires a 6V DC supply, not a 220V AC supply to make it illuminate. To make it work, He requires a few electrical components like a transformer, diode, capacitor, and wires. He also told him that these electrical components are the fundamental building block of the electrical network. This incident enlightened Sonu about the importance of electrical components.

Electrical components are commonly found in electric circuits. In this chapter, the students will learn about the various electrical components and their applications.

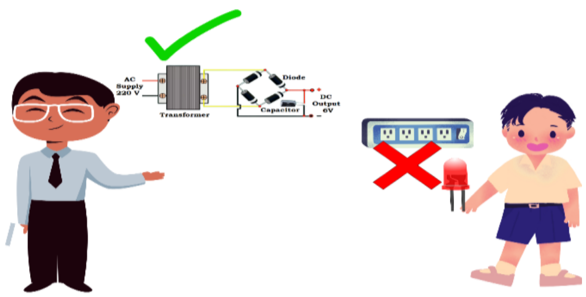



**Fig. 3.1 Sonu's father explains the use of electrical components**

## 3.1 ELECTRICAL CIRCUIT COMPONENTS

Electric circuits consist of various components that work together to control the flow of electric current. There are two categories of electric circuit components i.e. Active and Passive. Both these categories of electric circuit components are different from each other. Figure 3.2 illustrates a few basic electrical components.

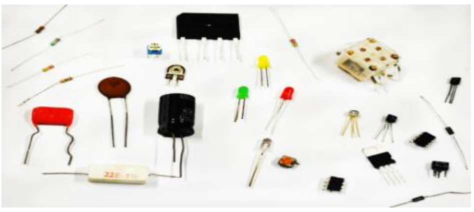


**Fig. 3.2 Electrical components**

**Active Components –** In an electrical circuit, the elements which can work as a power source or can supply power to the circuit in the form of voltage or current are known as active components. These components required an external source for their operation. There are various active components available in electrical circuits as well as electronic circuits. Some of the common examples of active components are diodes, Transistors, Operational amplifiers, and many more. Let us consider the example of a silicon diode for understanding the active component. Whenever we connect to a voltage source it will not conduct current either in forward bias or reverse bias until it reaches its threshold voltage which is 0.7 volts for a silicon diode. Figure 3.3 shows a few active components available.

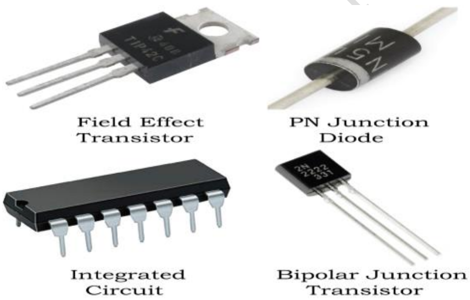



**Fig. 3.3 Active components**

**Passive Components –** Passive components do not produce energy in the form of voltage or current. These components do not require external sources for their operation. Some of the common examples of passive components are resistors, capacitors, inductors, and many more. Like a silicon diode, a resistor does not require at least 0.7 V for its operation i.e. when we connect a resistor to the supply voltage, it starts working as soon as we connect the voltage without waiting to cross any threshold voltage value. In simple words, passive components are energy acceptors. Figure 3.4 shows some of the passive components.

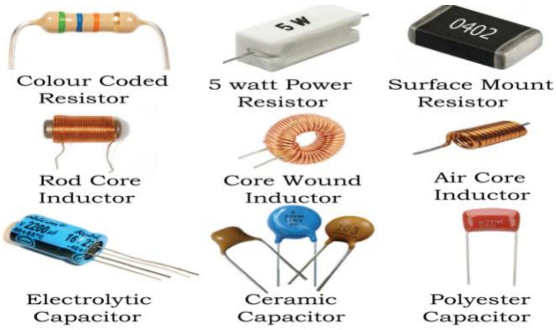



**Fig. 3.4 Passive components**

### 3.1.1 Resistor

It is a basic electrical component. It opposes the movement of electrons in a circuit, hence, it controls the electric current. This opposition is called resistance. It also drops the voltage, thus lowering the voltage level within the circuits. It has two or three terminals. Resistors can have fixed or variable resistance values. Resistors whose resistance value does not change are called fixed resistors. Resistors whose value can be changed are called variable resistors. These variable resistors are used to control different parameters such as voltage, and current. For example, in radio circuits variable resistors are used as a volume control component. Figure 3.5 illustrates the fixed-type and variable-type resistors. The SI unit of measuring the resistance is ohms denoted by a symbol Ω.

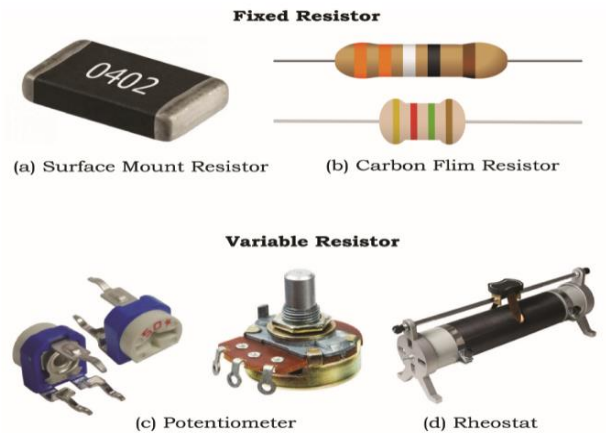



**Fig. 3.5 Various fixed and variable resistor**

In a carbon film resistor or axial resistor, the resistance value is in the form of bands of colours. They are available in four or five bands of colour code. In the case of a 4-band resistor, the first two bands represent significant digits, the third band represents the multiplier and the fourth band represents tolerance. Figure 3.6 illustrates the four-band axial resistor.

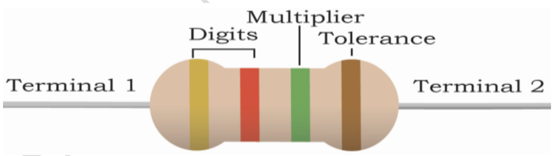



**Fig. 3.6 Four-band axial resistor**

In the case of a 5-band resistor, the first three bands represent significant digits, the fourth band represents the multiplier and the fifth band represents tolerance. Figure 3.7 illustrates the five-band axial resistor.

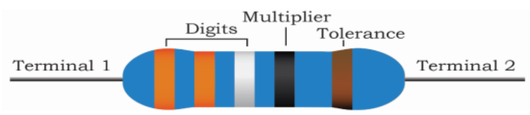



**Fig. 3.7 Five-band axial resistor**

Table 3.1 Colour Code Chart

| **Color** | **Number** |
|---|---|
| Black | 0 |
| Brown | 1 |
| Red | 2 |
| Orange | 3 |

| | |
|---|---|
| Yellow | 4 |
| Green | 5 |
| Blue | 6 |
| Violet | 3 |
| Grey | 8 |
| White | 9 |

**Tolerance of the resistor –** The tolerance of a resistor is a measure of its deviation from the ideal resistance value. It indicates the range within which the actual resistance of the resistor can vary from its stated or nominal value. Tolerance is typically expressed as a percentage.

For example, if a resistor has a nominal value of 100 ohms with a 5% tolerance, it means that the actual resistance of the resistor can be 5% higher or 5% lower than the stated value. In this case, the actual resistance can vary between 95 ohms (100 ohms - 5% of 100 ohms) and 105 ohms (100 ohms + 5% of 100 ohms).

Resistors with higher tolerances have a greater allowable deviation from their nominal values. Common tolerance values for resistors include 1%, 5%, and 10%. Precision resistors, used in more demanding applications, may have tighter tolerances such as 0.1% or 0.01%. It's important to consider the tolerance of resistors, especially in applications where precise resistance values are critical. In other words, tolerance defines the upper and lower limit of resistance value. Consider a 100Ω resistor its tolerance value can be defined in the following table 3.2.

Table 3.2 Tolerance value of the resistor

| **Tolerance** | **Colour** | **Stated** | **Allowed Upper Value** | **Allowed Lower Value** |
|---|---|---|---|---|
| +/- 1% | Brown | 100Ω | 101Ω | 99Ω |
| +/- 2% | Red | 100Ω | 102Ω | 98Ω |
| +/- 5% | Gold | 100Ω | 105Ω | 95Ω |
| +/- 10% | Silver | 100Ω | 50Ω | 90Ω |

Practical activity 3.1 demonstrates to calculate the value of an axial resistor

**Practical Activity 3.1 –** To calculate the resistance value of a four Band axial resistor.

**Material Required –** Few axial resistors, Notepad.

**Procedure –**

**Step 1**. In a 4-band resistor, three colour bands are at the left side of the resistor, and some distance away, the remaining single band is at the right.

**Step 2**. The first colour band of the resistor is considered the first numeric digit of the resistance value. Figure 3.8 illustrates the first band is yellow, so the first number is 3.

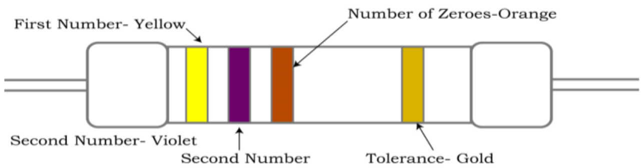



**Fig. 3.8 Four-band Resistor Specification**

**Step 3.** The second colour band gives the second number. This band is violet in colour making the second digit 7.

**Step 3.** The third colour band is called the multiplier and gives the number of zeros, in this case, it will be 1000 (three zeros because the colour code is orange).

**Step 5**. Therefore, the value of the resistor is 47000Ω or 47kΩ.

**Step 3.** The fourth colour band gives tolerance. Which is gold and hence its tolerance is +/- 5%

When resistors are combined in circuits, they can be connected in either series or parallel configurations. These configurations affect the overall resistance and current flow in the circuit.

**Series connection of resistors –** When resistors are connected in series, they are arranged one after the other, so that the current passes through each resistor in succession. The total resistance $R_{equivalent}$ of a series combination is equal to the sum of the individual resistances R1, R2, R3,.....

In this connection, the current remains the same in each resistor, but voltage divides across each resistor. Figure 3.9 illustrates the series combination 4 resistor

$R_{equivalent} = R_1 + R_2 + R_3 + R_4.....$

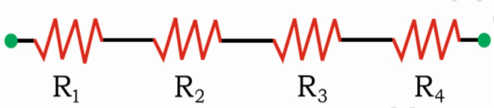



**Fig. 3.9 Series connection of resistors**

**Parallel connection of resistors –** When resistors are connected in parallel, they are connected across the same two points, effectively creating multiple paths for current flow. The total resistance $R_{equivalent}$ of a parallel combination can be calculated using the formula $1/R_{equivalent} = 1/R_1 + 1/R_2 + 1/R_3 + .....$

In this connection, the voltage across each resistor remains but the current divides in each branch. Figure 3.10 illustrates the parallel combination of 4 resistors

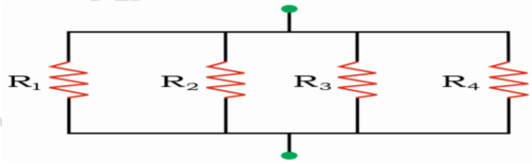



**Fig. 3.10 Parallel connection of resistors**

**Assignment 3.1**

1. Calculate the value of equivalent resistance in parallel and series, where the value of resistors are $R_1$= 10 & $R_2$ = 20 ohms.

2. Search on the internet for different types of resistors and note down their specification.

Table 3.3

| **Picture** | **Specification of resistor** |
|---|---|
|   Fig.3.11 | Name............................. Operating voltage..................... Resistance value................ |

| | | |
|---|---|---|
|  Fig.3.12 | Name............................<br>Operating voltage ....................<br>Resistance value................ | |
|  Fig.3.13 | Name............................<br>Operating voltage ....................<br>Resistance value................ | |
|  Fig.3.14 | Name............................<br>Operating voltage ....................<br>Resistance value................ | |

### 3.1.2 Capacitor

The word capacitor specifies the capacity. It represents the capacity to store energy. In a capacitor, energy is stored in the form of an electric field. Capacitors have two parallel sections, between these sections' energy is stored. It consists of two metallic conducting plates separated by a dielectric material. The metallic conductor can be made up of aluminium, or copper. A dielectric can be ceramic, mica, electrolyte, air, and or paper. It stores the charges on its metallic plates, these charges generate the electric field between the plates. In this way, it stores the energy in the form of an electric field. Figure 3.15 illustrates various types of capacitors.

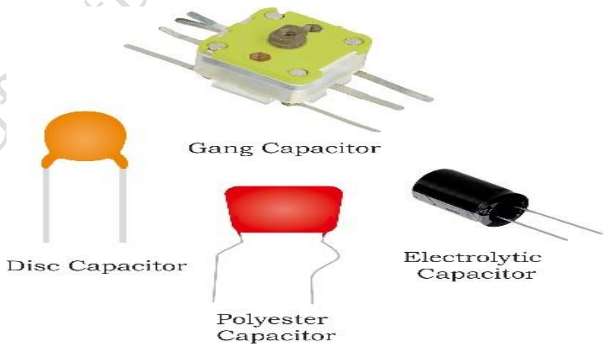



**Fig. 3.15 Various capacitors**

Capacitors have parameters such as maximum voltage they can withstand without damage, charge store capacity, and polarity of terminals i.e. positive and negative terminals. These parameters are mentioned in the body of a capacitor.

Mathematically,

Q= C x V

Where,

Q= Charge in coulomb

C= Capacitance in farad

V= Voltage in volt

Smaller SI units of capacitors are farad (F); they are available in mili farad (mF), Microfarad (µF), Nano farad (nF), and Pico farad (pF).

**Example 3.1 –** Calculate the charge produced on a capacitor. when the 250V is applied across the capacitor of 10 µF,

the amount of charge stored by it is given by

Q = C x V

Q = 10 x $10^{-6}$ x 250

Q = 2.5 mC

**Assignment 3.2**

1. Determine the applied voltage across a 1000 pF capacitor, which can store the 2C of charges.
2. The charge on the plates of a capacitor is 6 mC when the potential between them is 2.4 kV. Determine the capacitance of the capacitor.
3. For how long must a charging current of 2 A be fed to a 5 F capacitor to raise the potential difference between its plates by 500 V.(Hint I=Q/t)
4. A direct current of 10 A flows into a previously uncharged 5 µF capacitor for 1 mS. Determine the potential difference between the plates. (Hint I=Q/t).

### 3.1.3 Inductor

An inductor is an electrical component that stores and releases energy in the form of a magnetic field. It consists of a coil of wire wound around a core made of a magnetic material such as iron or ferrite. When an electric current flow through the coil, a magnetic field is generated around it.

The inductor stores the energy in the form of a magnetic field along the coil. If the current flowing through the inductor changes, a changing magnetic field appears across the wire. This changing magnetic field develops a voltage across the two ends of the wire. The inductor opposes the change in the electric current passing through it. This property of opposition is known as inductance is illustrated in Figure 3.16

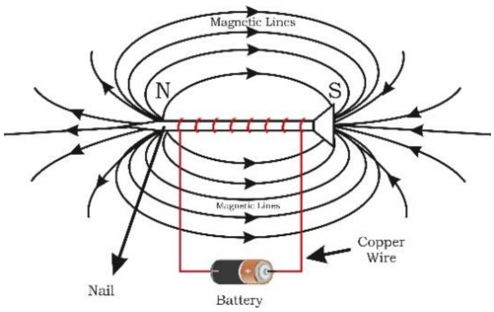



**Fig. 3.16 Current flows through the coil**

The fundamental property of an inductor is its inductance denoted by the alphabet letter L, which is a measure of its ability to store magnetic energy. Inductance is determined by factors such as the number of turns in the coil, the cross-sectional area of the coil, the material of the core, and the length of the coil. The SI unit of inductance is the Henry denoted by the alphabet letter H, but smaller units such as millihenries (mH) and microhenries (µH) are commonly used. Figure 3.17 illustrates the various available inductors.

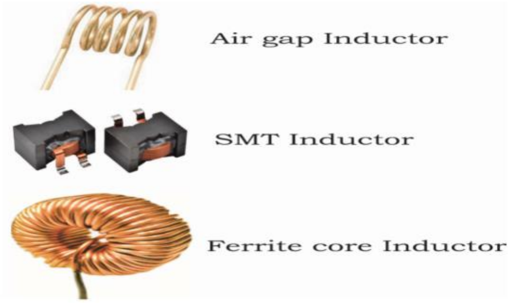
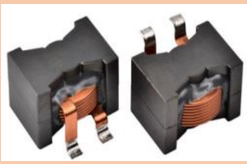



**Fig. 3.17 Various types of inductors Air gap inductors, Ferrite core inductors, SMT inductors**

**Assignment 3.3**

Identify and name the inductors, which are shown in the picture in Table 3.3

Table 3.3

| **Picture** | **Name of inductor** |
|---|---|
|  Fig. 3.18 | ………………………… |
|  Fig.3.19 | ………………………… |
|  Fig.3.20 | ………………………… |



**3.2 TRANSFORMER**

A transformer is an electrical device that is used to transfer electrical energy between two or more circuits through electromagnetic induction. It consists of two or more coils of wire, known as windings, which are wound around a common magnetic core. The primary winding receives electrical energy from a power source, while the secondary winding delivers the transferred energy to the load.

The basic operation of a transformer relies on Faraday's law of electromagnetic induction. When an alternating current (AC) flows through the primary winding, it creates a changing magnetic field in the core. This changing magnetic field induces a voltage in the secondary winding, which is proportional to the turn ratio between the primary and secondary windings. As a result, the transformer can step up or step down the voltage and current levels, depending on the winding configuration.

A transformer is a static unit. It simply transforms the voltage level of an AC signal. It either step-up or step down the AC voltage. It works on the principle of electromagnetic induction. The transformer does not change the frequency of the applied AC signal.

Transformers have two main components they are core and winding

**Core –** The magnetic core provides a low-reluctance path for the magnetic flux generated by the windings. It is typically made of laminated iron or other magnetic materials to minimize energy losses.

**Windings –** The primary winding is connected to the input voltage source, while the secondary winding is connected to the load. The turn ratio between the windings determines the voltage transformation ratio of the transformer.

Figure 3.21 illustrates the general configuration of the transformer.

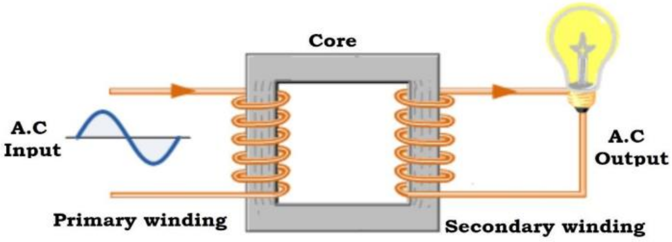



**Fig. 3.21 Transformer**

A step-up transformer and a step-down transformer are two types of transformers that provide voltage transformation in opposite directions.

### 3.2.1 Step-Up Transformer

A step-up transformer is designed to increase the voltage level from the primary winding (input side) to the secondary winding (output side). The number of turns in the secondary winding is greater than the number of turns in the primary winding, resulting in a higher output voltage compared to the input voltage. The step-up transformer is commonly used in power transmission and distribution systems to increase the voltage for long-distance transmission, which reduces power losses and allows for efficient power transfer. It is also used in applications where a higher voltage is required, such as in high-voltage power supplies or electrical equipment. Figure 3.22 illustrates the number of turns in primary winding is lower than in secondary winding.

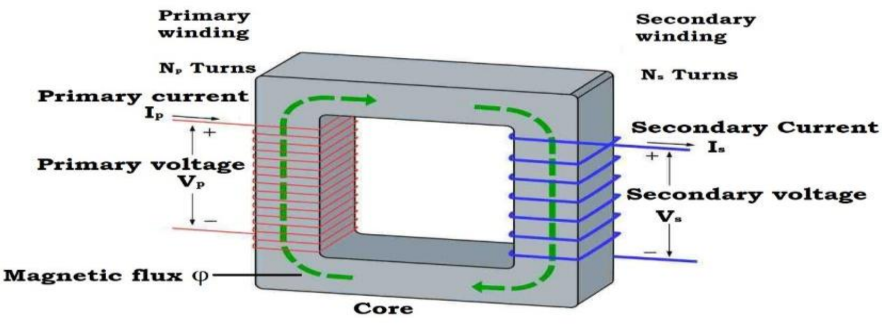



**Fig. 3.22 Step-up transformer**

### 3.2.2 Step-Down Transformer

A step-down transformer, as the name suggests, is designed to decrease the voltage level from the primary winding to the secondary winding. The number of turns in the secondary winding is lower than the number of turns in the primary winding. Due to this a lower output voltage compared to the input voltage is received.

The step-down transformer is widely used in various applications, such as electrical power distribution, where the voltage needs to be reduced to a safe and usable level for residential, commercial, and industrial purposes. It is also utilized in electronic devices and appliances to provide the appropriate voltage levels required for their operation. Figure 3.23 illustrates the number of turns in primary winding is greater than in secondary winding.

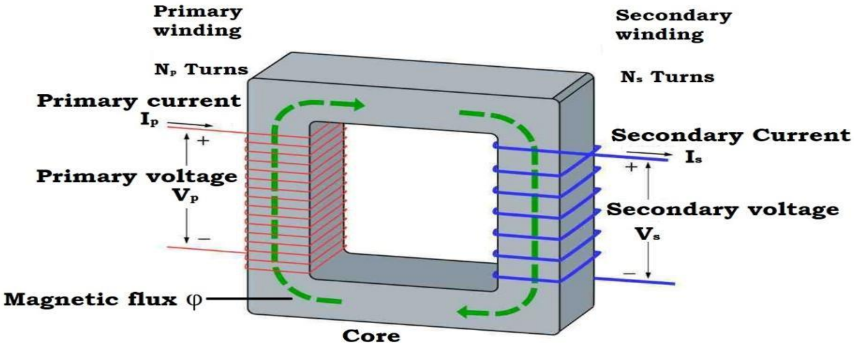



**Fig. 3.23 Step-down transformer**

The turn ratio of a transformer determines the voltage transformation ratio. For example, a transformer with a turn's ratio of 1:2 (primary to secondary) in a step-up configuration would double the input voltage, while a transformer with a turn's ratio of 2:1 in a step-down configuration would halve the input voltage. Figure 3.24 shows a typical power distribution transformer

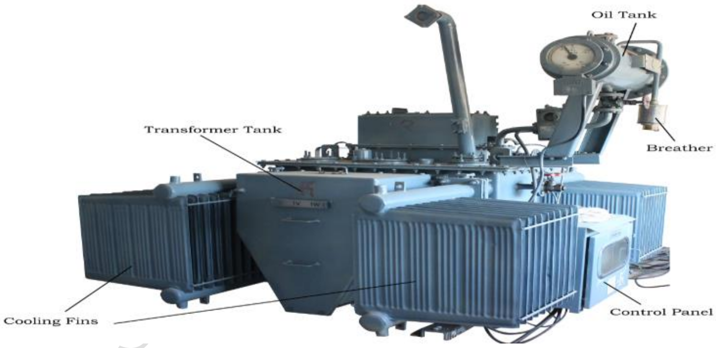



**Fig. 3.24 Transformer for power distribution**

### 3.2.3 Application of Transformer

Transformers are widely used in various applications, including –

**Power Distribution –** Transformers play a crucial role in power distribution systems, stepping up the voltage at power plants for long-distance transmission and then stepping it down to safer levels for local distribution.

**Power Supplies –** Transformers are used in power supplies to convert voltage levels required for different electronic devices.

**Electronics –** Transformers are utilized in audio equipment, televisions, computers, and other electronic devices for signal isolation, impedance matching, or voltage transformation.

**Industrial Applications –**Transformers are employed in various industrial processes, such as motor control, welding, and heavy machinery, to provide the required voltage levels.

**Assignment 3.4**

Visit the nearest power distribution substation and identify and name the different parts of high voltage transformers

**Multi meter: -** A multi meter is a versatile electronic instrument that is essential for technicians and engineers. It is primarily used to measure voltage, current, and resistance, and it can also test continuity in electrical circuits (Figure 3.25).

A multimeter functions as an ammeter, voltmeter, and ohmmeter. It is a handheld device featuring positive and negative indicator needles over a numeric LCD digital display. Multimeters are commonly used to test batteries, household wiring, electric motors, and power supplies.


**Fig. 3.25 Multi meter**

**Operate Multi meter**

**AC Voltage Measurements**

1. Turn the Range Selector Switch to 750 ACV setting, always start with the highest range if the voltage is unknown.

2. Plug the red lead into the VΩmA (centre) jack. Plug the black lead into the COM (Bottom) Jack. Switch the Multi meter ON as shown in Figure 3.23.

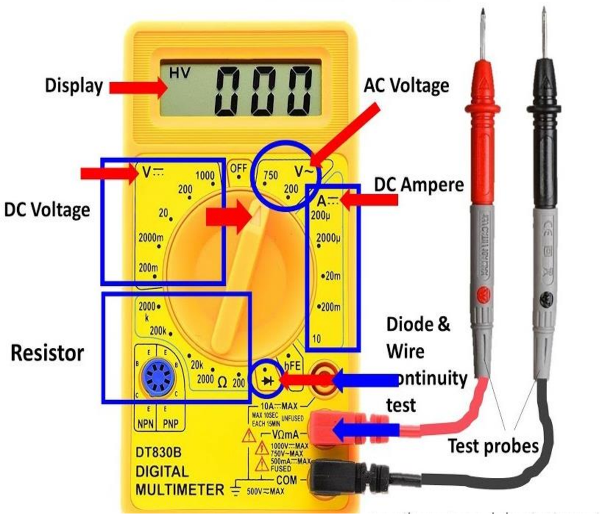



**Fig. 3.26 Multi meter ON**

3. Carefully touch the exposed conductors with the tips of the probes to measure the voltage (not amperes).

4. Read measurements. If the voltage is less than 200 volts, set the Range Selector Switch to the lower range.

5. When testing is complete, remove Test leads and store the multimeter.

**DC Voltage Measurements**

1. Turn the Range Selector Switch to 1000 DC setting.

2. Follow the directions discussed above under "AC Voltage Measurements" only use the DC setting instead.

**DC Current Measurements**

1. Turn the Range Selector Switch to the 10 A position always start with the highest range if the Amperage is unknown.

2. Plug the red lead into the 10A (Top) Jack. Plug the black lead into the COM (Bottom) Jack Switch the Multimeter.

3. Carefully touch the exposed conductors with the tips of the probes to measure the amperage.

**Note:** Amperage is always tested in series with the circuit under test.

4. Read measurement. If the reading is less than 2 AMPs switch the red lead to the VΩmA (centre) Jack and set the Range Selector Switch to the 200-mA setting.

5. when testing is complete, remove Test Leads and store the multimeter.

**Resistance Measurements**

Never measure resistance on a circuit with voltage running thread it.

1. Turn the Range selector switch to the 200mA position.

2. Plug the red Test Lead into the VΩmA (centre) jack. Plug the black Test lead into the Com (Bottom) jack. Switch the Multimeter ON. Shot the test Leads together. The meter should read "0" Ohms.

**Ammeter –** An ammeter is a device used to measure the electrical current flowing in a circuit. It is typically a small, portable instrument that is connected in series with the circuit being measured. The ammeter measures the current in amperes (A), which is a unit of electrical current. It is a test instrument that is connected into a circuit to measure the current of the circuit without interrupting the electrical current. A typical ammeter is shown in Figure 3.27. The ammeters can be analog or digital. Analog ammeters use a pointer on a scale to indicate the current, while digital ammeters display the current as a numeric value on a screen. Some ammeters are designed to measure very small currents, while others can handle very high currents.

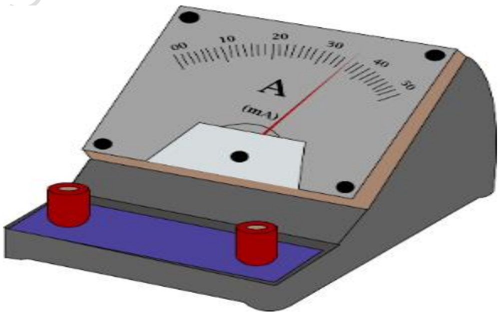



**Fig. 3.27 Ammeter**

**Use Ammeter and check current**

1. Take the required length wire and connect 01 Hp motor with phase & neutral.

2. Connect Ammeter 0-30 A series with the phase line (in between the phase line).

3. Connect voltmeter parallel to the supply.

4. Switch on the supply and check the current drawn by the motor in Ammeter.

5. Switch off the supply & remove connections after taking the readings.

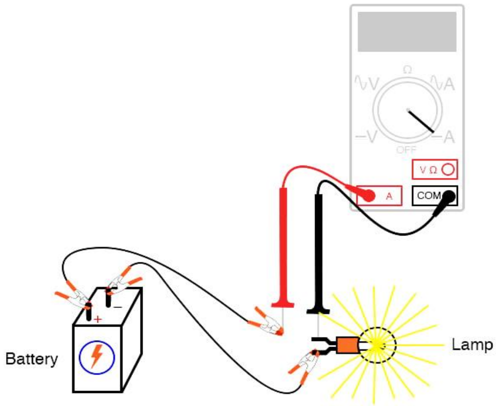



**Fig. 3.28 Using Ammeter and check current**

**Voltmeter -** A voltmeter, or voltage meter, is an instrument designed to measure the voltage or potential difference between two points in an electronic or electrical circuit. It is commonly used for both Alternating Current (AC) and Direct Current (DC) circuits. Additionally, specialized voltmeters can measure Radio Frequency (RF) voltage as shown in Figure 3.29.

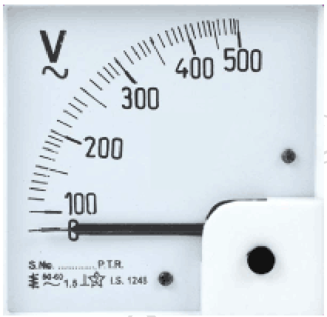



**Fig. 3.29 Voltmeter**

**Use Voltmeter and check voltage**

1. Take the required length wire & skin the ends.
2. Connect the lamp holder with phase & neutral wire (prepare test lamp).
3. Connect voltmeter parallel to the supply.
4. Connect voltmeter terminals with phase and neutral connection.
5. Fix the 200W bulb & Switch on the Supply.
3. Check the voltage in voltmeter & record.
7. Switch off the supply & remove the connections after talking the readings.

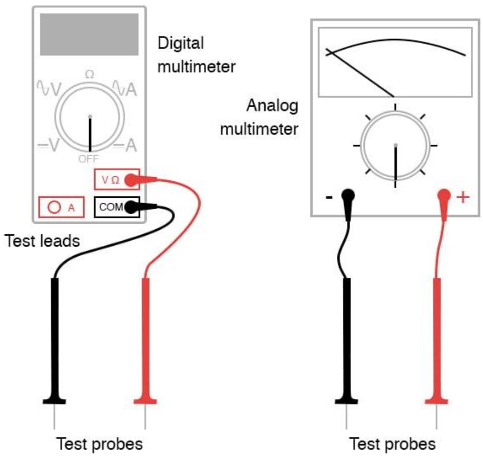



**Fig. 3.30 Using Voltmeter and check voltage**

**Practical activity 3.2 Demonstrate measuring the voltage at the primary and secondary winding of the transformer**

**Practical Activity 3.2 –** Demonstrate measuring the voltage at the primary and secondary winding of the step-down transformer.

**Material Required –**

Transformer (230V to 12V), multimeter, single phase input power supply, Bulb, bulb holder, wire.

**Procedure**

**Step 1**. Carefully, provide the input power supply to the primary winding of a transformer using a wire.

**Step 2**. Switch 'ON' the power supply.

**Step 3.** Measure the voltage using a multimeter at the primary and secondary winding. Figure 3.31 illustrates the measurement at input side of transformer

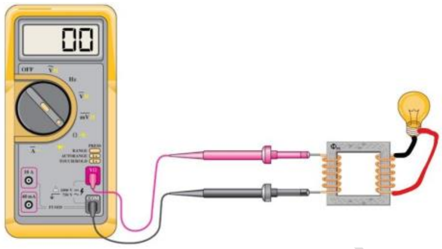


**Fig. 3.31 Measurement of input voltage in the primary side of the Transformer**

**Step 4 –** Now connect the probes of the multimeter to the secondary winding and measure the voltage on the secondary side. Figure 3.32 illustrates the secondary winding voltage

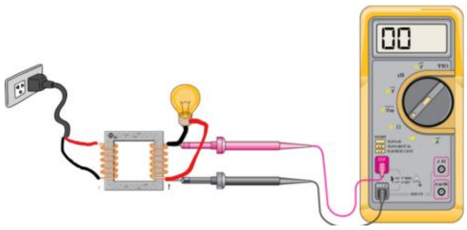


**Fig. 3.32 Measurement of input voltage in the secondary side of the Transformer**

**Step 5**. Observe the reading displayed on the screen of a multimeter.

**Step 3.** Note down the readings in the following table.

| S.No. | Reading at Primary Winding | Reading at Secondary Winding |
|---|---|---|
| 1. | **230 V** | **12 V** |
| 2. | **230 V** | **11.6 V** |
| 3. | **230 V** | **11.7 V** |
| 3. | **230 V** | **11.8 V** |
| 4. | **230 V** | **11.9 V** |

**3.3 RELAYS**

A relay is an electromechanical device that is commonly used to control or switch electrical circuits by using a low-power signal to control a higher-power circuit. It works on the principle of an electromagnetic coil that generates a magnetic field when current flows through it, which in turn actuates a set of contacts to open or close an electrical circuit. Figure 3.33 illustrates a typical relay.

**Fig. 3.33 Relay**

### 3.3.1 Components of relays

The basic components of a relay include:

**Electromagnetic Coil –** The coil is typically made of copper wire wound around a core. When current flows through the coil, it creates a magnetic field.

**Contacts –** Relays have one or more sets of contacts, which can be either normally open (NO) or normally closed (NC). When the relay is energized, the contacts change their state. For example, in a normally open (NO) relay, the contacts close when the coil is energized, completing the circuit. In a normally closed (NC) relay, the contacts open when the coil is energized, interrupting the circuit

**Armature –** The armature is a movable part of the relay that is connected to the contacts. When the coil is energized, the magnetic field attracts the armature, causing it to move and change the state of the contacts.

### 3.3.2 Principle of operation of relays

Relay can be classified into two types according to their working principle as an electromechanical and solid-state relay

**Electromechanical relay –** This type of relay can transfer its signals between its contact by mechanical operation. This relay has two sections, the first is an electromagnet and the second one is the armature including the mechanical contact section.

The electromagnet has a coil that is mounted over a zero magnetic core material. Whenever the input signal which is equal to a rated voltage of a coil reaches the coil, it gets magnetized and attracts the armature. When the armature is attracted to the electromagnet the contacts become closed and when the input signal is removed the armature returns to its original position via spring. Figure 3.34 illustrates the working principle of the electromagnetic relay.

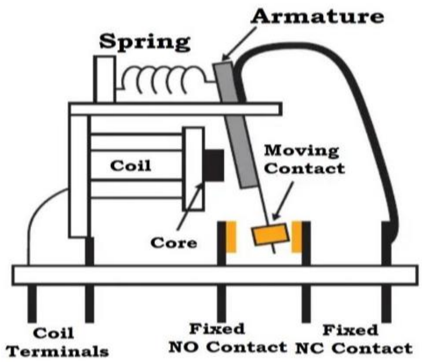



**Fig. 3.34 Principle of electromagnetic relay**

**Solid state relay –** This is another type of relay commonly known as the SSR. They do not have any moving mechanical parts. It consists of a semiconductor device with some electronic components. The electromagnet is replaced by an optocoupler and a few required circuits to drive the relay. The contact section is replaced by the TRIC circuit.

## 3.4 MOTOR

An electric motor is an electrical machine, which provides rotational force. It converts electrical energy into mechanical energy. Electric motors are used as an important part of electric fans, refrigerators, mixers, washing machines, computers, MP3 players, and many more. Conceptually, we can say that energy transformation takes place in an electric motor i.e. electrical to mechanical energy. Figure 3.35 illustrates the typical electrical motor representing its concept.

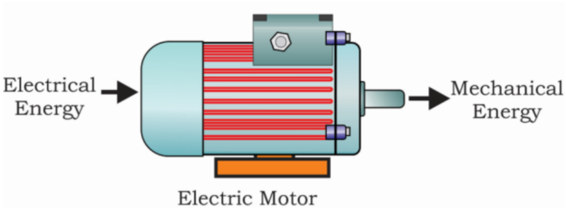



**Fig. 3.35 Conceptual representation of energy conversion in motor**

### 3.4.1 Fleming's Left-Hand Rule

If we stretch our left hand in such a way that the forefinger, middle finger, and thumb are perpendicular to each other, then the forefinger represents the magnetic field, the middle finger represents the direction of current, and the thumb represents the direction of force. (Figure 3.36)

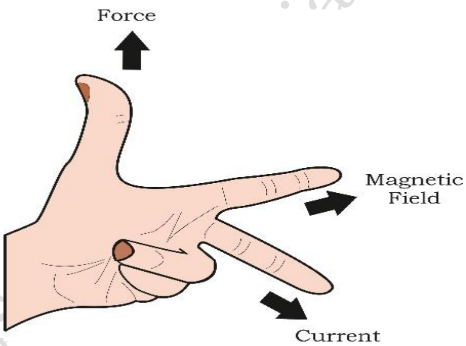



**Fig. 3.36 Fleming's left-hand rule**

### 3.4.2 Working Principle of Motor

The electric motor operates based on the principle of electromagnetic induction. This principle states that when a conductor carrying an electric current is placed in a magnetic field with the current perpendicular to the field, a force is exerted on the conductor, causing it to rotate.

An electric motor typically consists of a rectangular coil ABCD made of insulated copper wire. (Figure 3.37) This coil is positioned within a magnetic field such that its sides AB and CD are perpendicular to the direction of the magnetic field. The ends of the coil are connected to two halves, P and Q, of a split ring. These halves are insulated on their inner surfaces and mounted on an axle. The external conducting edges of P and Q contact stationary brushes X and Y, respectively. In operation, current flows from the source battery through brush X into the coil and returns to the battery through brush Y. In the coil, the current flows from A to B in arm AB and from C to D in arm CD, which is opposite to the direction in arm AB.

According to Fleming's left-hand rule, the force on the current-carrying conductor in the magnetic field causes arm AB to move downward, while arm CD moves upward. This results in the coil and axle rotating in an anti-clockwise direction. As the coil completes half a rotation, the split ring causes the current to reverse direction, changing its path to DCBA. This reversal is achieved by the commutator, which is the split ring in this case. When the current direction reverses, the forces on arms AB and CD are also reversed. Consequently, the previously downward-moving arm AB now moves upward, and the previously upward-moving arm CD moves downward, continuing the anti-clockwise rotation of the coil and axle. The reversing of the current is repeated at each half-rotation, giving rise to a continuous rotation of the coil and to the axle.

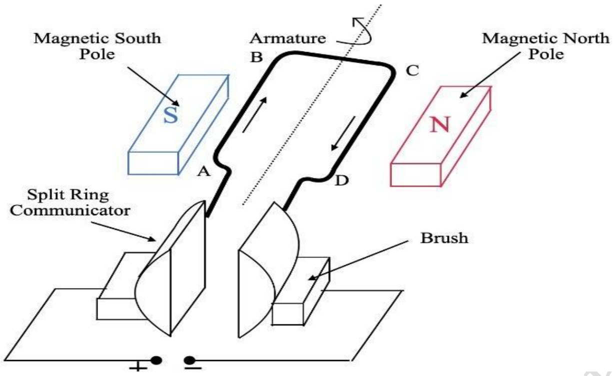



**Fig. 3.37 Working principle of motor**

**Assignment 1**

1. Search on the internet, which motor is used in electric locomotives, lifts, and escalators.
2. Where do we apply Fleming's left-hand rule? What is its importance?

### 3.4.3 Parts of Motor

A motor is an electrical machine, which includes stationary and rotary parts. Armature, stator, outer body cover, commutator, carbon brush, and cooling fan are the main parts of an electric motor.

**Armature –** It is a rotating part of the motor. The wire is wound over the metallic shaft, which will form the armature winding. Figure 3.38 illustrates the armature and its parts.

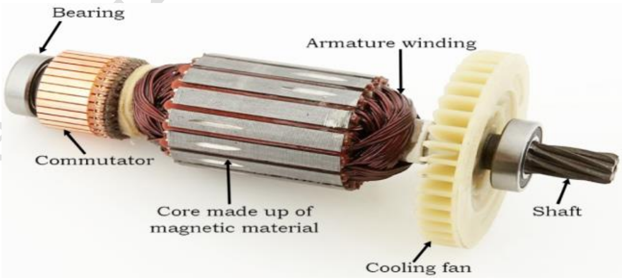



**Fig. 3.38 Parts of the armature**

**Stator –** It is a static part of the motor. The wire is wound on the slots of the stator body. Figure 3.39 illustrates the stator and its parts.

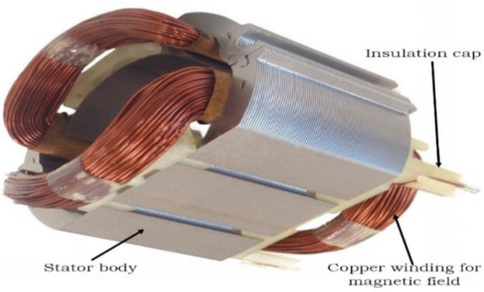



**Fig. 3.39 Parts of the stator**

**Outer body –** It is the outer cover of the motor. It is like a house for armature and stator. Its presence ensures the protection of the armature and stator from external damage. Figure 3.40 illustrates the Outer body parts of the motor.

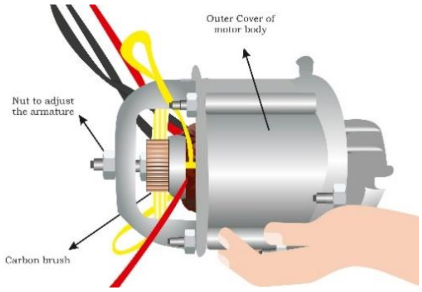



**Fig. 3.40 Outer body parts of the motor**

| **Assignment 2** |
|---|
| 1. List the parts of the motors. |
| 2. Prepare a working model of the motor. |

### 3.4.4 Types of Motors

Based on operating power, the motor can be classified as alternating current (AC) or direct current (DC). Figure 3.41 illustrates the flowchart having the classification of motors.

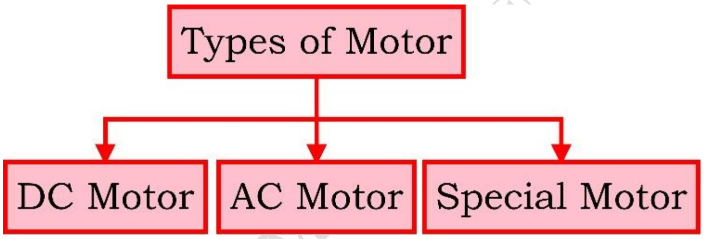



**Fig. 3.41 Classification of motors**

**DC Motor –** As we know, that motor converts electrical energy into mechanical energy. DC motors require a DC supply for their operation. It works on the principle that "when a current-carrying conductor is placed in a magnetic field, that current-carrying conductor experiences a force". This rotating force is called torque. DC motors can be further classified as Brushed DC motors and Brushless DC motor

A. **Brushed DC Motor –** A brushed DC motor is a type of electric motor that uses a rotating armature or rotor along with a stationary set of magnets to convert electrical energy into mechanical energy. It is called a "brushed" motor because it uses brushes and a commutator to control the flow of current in the motor windings. Figure 3.42 illustrates the various parts of the brushed DC motor.

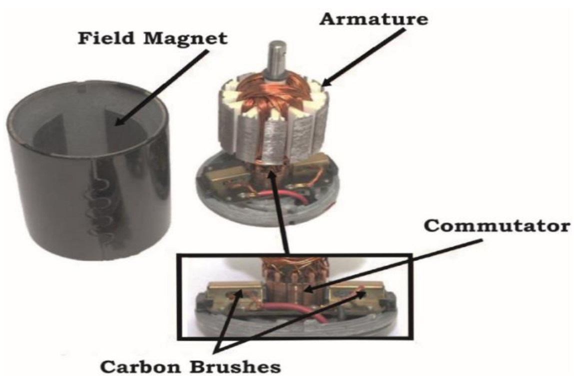



**Fig. 3.42 Brushed DC motors**

A carbon brush, also known as a motor brush, is a small part of the motor. It is used to pass electric current from stationary windings to armature windings of a motor or generator. Figure 3.43 illustrates the commutator with a carbon brush.

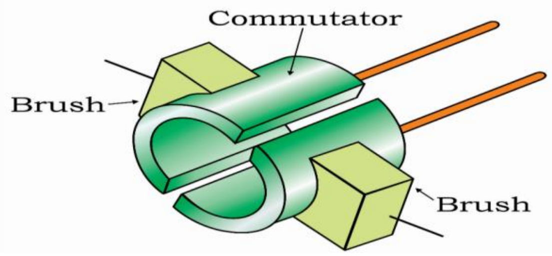



**Fig. 3.43 Commutator with brush**

B. **Brushless DC Motor –** A brushless DC or BLDC motor, also known as an electronically commutated motor (ECM) or a synchronous DC motor. It is an electric motor that operates using electronic commutation instead of brushes and a commutator. Figure 3.44 illustrates the various parts of a brushless DC motor.

BLDC motors offer several advantages over brushed DC motors, including improved efficiency, higher reliability, and reduced maintenance requirements.

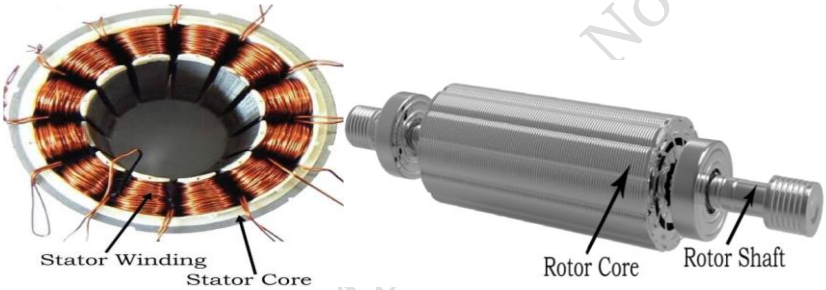



**Fig. 3.44 Brushless DC motors**

**AC Motor –** As we know that motor converts electrical energy into mechanical energy. AC motors required an AC power supply for their operation. It works on the principle that "when a current-carrying conductor is placed in a magnetic field, that current-carrying conductor experiences a force". This rotating force is called torque. AC motors are classified as follows – Synchronous motor and Asynchronous motor

A. **Synchronous Motor –** It is a type of motor in which the rotating speed of the rotor is the same as the rotating speed of the magnetic field. Suppose, the magnetic field is rotating at a speed of 1000 rotations per minute (RPM) and the rotor is rotating around 998 rotations per minute (RPM), in such case, the motor is said to be synchronized. Figure 3.45 illustrates the various parts of a synchronous motor.

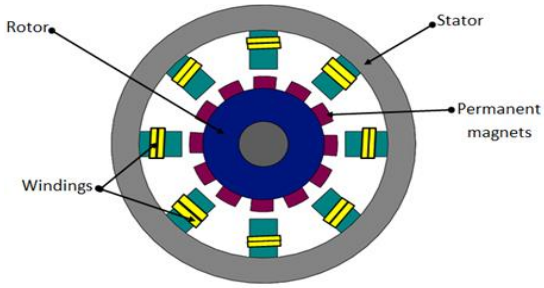



**Fig. 3.45 Various parts of synchronous motors**

B. **Asynchronous Motor –** A synchronous motor is a type of motor in which the rotating speed of the rotor is less than the rotating speed of the magnetic field. Suppose, the magnetic field is rotating at a speed of 1000 rotations per minute (RPM) and the rotor is rotating at 800 rotations per minute (RPM). In such a case, the motor is said to be asynchronous. An asynchronous motor is also known as an induction motor. Figure 3.46 illustrates the various parts of an asynchronous motor.

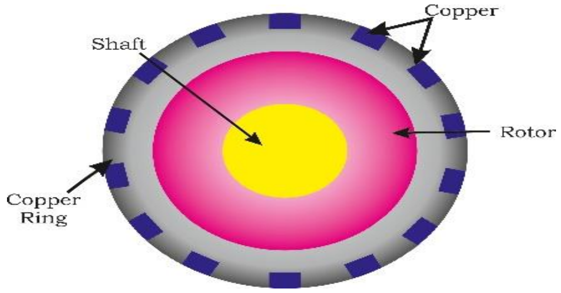



**Fig. 3.46 Asynchronous motor**

**Special Motors –** These are motors designed for some specific task. Some of the special motors can run on both AC and DC power supplies. Some of the commonly available special motors are universal motors, stepper motors, and servo motors.

A. **Universal motor –** It is a series-wound motor. In these motors, the stator's field coils are connected in series with the rotor windings through a commutator. Universal motors are used in mixers, grinders, juicers, hand drill machines, and many more. Figure 3.47 illustrates the various parts of a universal motor.

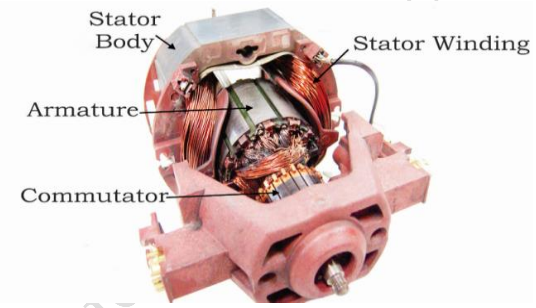



**Fig. 3.47 Parts of universal motor**

B. **Stepper motor –** This motor also known as a step motor or stepping motor, is a brushless DC electric motor that divides a full rotation into several equal steps. Stepper motors are used in robots and in those places where one wants angular rotation of the motor shaft. Figure 3.48 illustrates the typical stepper motor

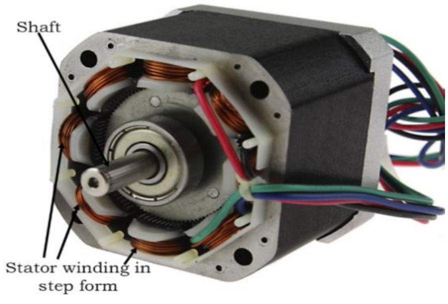



**Fig. 3.48 Stepper motor**

C. **Servomotor –** It is a rotary actuator or linear actuator that allows for precise control of angular or linear position, velocity, and acceleration. It consists of a suitable motor coupled to a sensor for position feedback. A servo motor is used in robots and in those places, where one requires accurate rotation of the motor shaft. Figure 3.49 illustrates the typical servomotor

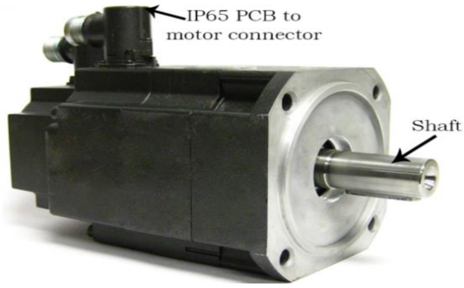



**Fig. 3.49 Servomotor**

## Check Your Progress

**A. Multiple Choice Questions**

1. Resistor whose resistance value can vary is known as ____. (a) Rheostat (b) Fixed Resistor (c) Variable Resistor (d) Thermistor
2. Which of the following consist of a coil or a wire loop? (a) Inductor (b) Capacitor (c) Resistor (d) Diode
3. Transformers are used to _____. (a) Step up the voltage (b) Step down the voltage (c) Both A and B (d) None of these
4. Transformer works on ____. (a) AC (b) DC (c) Both AC and DC (d) None of these
5. Which of the following device stores energy in the form of electric field? (a) Capacitor (b) Inductor (c) Resistor (d) Diode
6. Which of the following factors can affect the resistance of wire? (a) Length of wire (b) Temperature (c) Thickness of wire (d) All of these
7. What is the ohmic value for the colour code of orange, orange, orange? (a) 22 kΩ (b) 33 kΩ (c) 3300 Ω (d) 44000 Ω
8. Which of the following is true for resistance? (a) Symbolized by R, measured in ohms, and directly proportional to conductance (b) Represented by the flow of fluid in the fluid circuit (c) Directly proportional to current and voltage (d) The opposition to current flow accompanied by the dissipation of heat
9. A colour code of Brown, Brown, Red, Gold is for what ohmic value? (a) 1.2k Ω 5% (b) 1.1k Ω 5% (c) 1.3k Ω5% (d) 1.5k Ω 5%
10. A colour code of Black, Brown, green, Gold is for what ohmic value? (a) $1x10^5Ω$ 5% (b) $1x10^4Ω$ 5% (c) $1x10^5Ω$ 10% (d) $1x10^4Ω$ 10%

**B. Fill in the blanks**

1. Transformer works on _________ voltage.
2. Capacitor stores energy in the form of ___________ field.
3. Inductor stores energy in the form of ____________ field.
4. Green, Orange, Orange, Violet colour coded resistor is ________.
5. Violet, brown, Orange, Silver colour coded resistor is __________.
6. The ________ of a resistor is a measure of its deviation from the ideal resistance value.
7. Resistors are connected in ________ they are arranged one after the other.
8. Resistors are connected in __________ they are connected across the same two points.
9. Capacitor represents the capacity to store ___________.

10. SI units of capacitors are ______________.

**C. State whether the following statements are True or False.**

1. Transformer works on the principle of electromagnetic induction. ( )
2. Low voltage is used for transmission and high voltage is used in home/office. ( )
3. The base unit of capacitance is the farad. ( )
4. Green, Orange, Orange, Violet colour coded resistor is 62 kΩ 5%. ( )
5. Violet, Green, Orange, Silver colour coded resistor is 75 kΩ 10%. ( )
6. Blue, Red, Orange, Gold colour coded resistor is 62 kΩ 5%. ( )
7. Orange, Orange, Yellows, Gold colour coded resistor is 330 kΩ 5%. ( )
8. Black, Red, green, Silver colour coded resistor is 300 kΩ 5%. ( )
9. Semiconductors are materials whose conductivity lies between conductors and insulators. ()
10. Inductor store energy in the form of electric field. ( )

**D. Short answer questions**

1. Write short notes on: Resistor, Capacitor, Inductor
2. Define transformer.
3. Write down the specification of capacitor.
4. What is an inductance?
5. What is a capacitor?

**Exercise:** Identify and name the parts of transformer in the Figure 6.50.

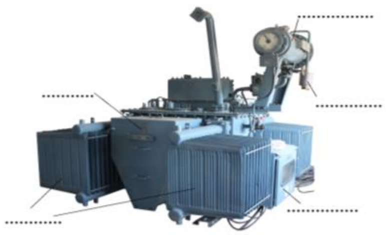


Fig. 6.50

**E. Match the column**

| Name of components | Related terms |
|---|---|
| A. Capacitor | 1. Magnetic field |
| B. Inductor | 2. Opposition in the flow of current |
| C. Resistor | 6. Works on AC power supply |
| D. Transformer | 4. Electric field |

| Module 3 | Basic Electronics |
|---|---|

## Module Overview

Basic electronics involves the fundamental principles and components of electronic circuits, focusing on how electronic devices, circuits, and systems manipulate electrical currents and voltages to perform various functions. It serves as the foundation for more advanced electronics concepts and applications and is essential for anyone working with or troubleshooting electronic devices or designing circuits.

At the core of basic electronics is the study of semiconductor materials, which are crucial for the operation of various electronic components. Semiconductors, such as silicon and germanium, have electrical conductivity that falls between conductors and insulators. They are fundamental to the creation of electronic devices because their conductive properties can be controlled through doping, a process that introduces impurities to alter their electrical behavior.

Semiconductors can be categorized into two main types: intrinsic and extrinsic. Intrinsic semiconductors are pure materials without any impurities, while extrinsic semiconductors have been doped with specific elements to enhance their electrical properties. This doping process results in two types of extrinsic semiconductors: n-type (which has an excess of electrons) and p-type (which has a deficit of electrons or "holes").

These semiconductors form the basis for creating various electronic components, including diodes and transistors. A diode, made from a p-n junction of semiconductors, allows current to flow in only one direction, providing rectification. Transistors, which can be bipolar junction transistors (BJTs) or field-effect transistors (FETs), are crucial for amplification and switching in electronic circuits. They work by using a small input current or voltage to control a larger output current or voltage, thereby enabling signal amplification and electronic switching.

Further advancement in electronics leads to the creation of integrated circuits (ICs), where numerous electronic components like resistors, capacitors, diodes, and transistors are combined into a single chip. ICs are essential for modern electronics, providing compact, efficient, and reliable circuit solutions for a wide range of applications.

In addition to these components, understanding analog and digital electronics is crucial. Analog electronics deal with continuously variable signals, such as audio or temperature measurements, whereas digital electronics handle discrete signals represented by binary values (0s and 1s). Both types of electronics play distinct but complementary roles in modern technology.

Sensors and transducers are also key elements in basic electronics. Sensors detect physical quantities like temperature, light, or pressure and convert them into electrical signals. Transducers, on the other hand, convert one form of energy into another, such as converting electrical energy into mechanical motion. Both components are integral to interfacing electronics with the physical world, allowing for practical applications and interactions in various systems.

## Learning Outcomes

After completing this module, you will be able to:

- Identify and explain the function of fundamental electronic components such as diodes, transistors, and ICs.
- Understand the working principles and applications of sensors, transducers, and signal generating equipment in electronic circuits.
- We learn the basics of digital electronics, including logic gates, binary systems, and combinational circuits.
- The operation and applications of Zener diodes, Silicon Controlled Rectifiers (SCR), Unijunction Transistors (UJT), and full-wave bridge rectifiers.

## Module Structure

| |
|---|
| Session 1. Electronic Components |
| Session 2. Sensors, Transducers, and Signal Generating Equipment |
| Session 3. Digital Electronics |
| Session 4. Zener Diode, SCR/UJT & Full wave Bridge Rectifier |

# Session 1. Electronic Components

One day Shantanu was playing with his toy car and suddenly he found that the car stopped responding to the commands from his remote control. He was surprised and worried about that situation. He picked up his toy car and remote to his dad. His dad took a screwdriver and opened the screws of the remote he found that the transmitter section situated in the remote burned, then his father took the solder station and replaced the transmitter section while doing this Shantanu's father explains the need and use of electronic components. Figure 1.1 illustrates that Shantanu's father replaced the transmitter of the remote control.

**Fig. 1.1 Basic electronic components**

### 1.1 SEMICONDUCTOR

Semiconductors are materials that have electrical conductivity between that of conductors and insulators. They are essential in the creation of electronic devices. Silicon and germanium are the most commonly used semiconductors in the production of circuits and components. Semiconductors can be classified into two types: intrinsic and extrinsic.

**Intrinsic Semiconductor –** An intrinsic semiconductor is a pure form of a semiconductor material, meaning it contains no impurity atoms. For instance, pure silicon consists solely of silicon atoms, without any other types of atoms mixed in. This lack of impurities results in lower electrical conductivity. To enhance the conductivity of intrinsic semiconductors, impurity atoms must be introduced, a process that is further explained in the context of extrinsic semiconductors.

**Extrinsic Semiconductor –** An extrinsic semiconductor, or doped semiconductor, is a modified form of a semiconductor in which impurity atoms have been intentionally introduced into the pure (intrinsic) material. This process, known as doping, is done to alter the electrical properties of the semiconductor. By adding impurities, the conductivity is enhanced through the creation of additional free charge carriers, allowing better control over the semiconductor's behaviour.

There are two types of extrinsic semiconductors based on the type of impurities added (P type and N-type). Silicon, with an atomic number of 14, has an electronic configuration of 2, 8, 4, meaning it has 4 electrons in its outermost shell. To enhance silicon's conductivity, additional free charge carriers can be introduced. Given that silicon has 4 valence electrons, it is beneficial to introduce impurity atoms with either 5 valence electrons (pentavalent) or 3 valence electrons (trivalent). Pentavalent atoms, having 5 electrons in their outer shell, and trivalent atoms, with 3 electrons, can significantly influence the conductivity of silicon. Figure 1.2 illustrates how semiconductors are classified based on these properties.

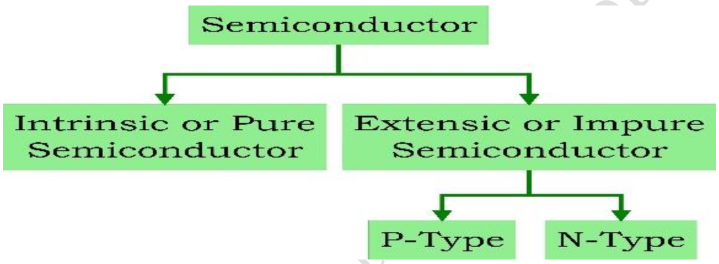



**Fig. 1.2 Classification of semiconductor**

**N-type semiconductor –** When a pentavalent impurity atom is added an extrinsic semiconductor is formed which is known as an N-type semiconductor.

**P-type semiconductor –** When a trivalent impurity atom is added an extrinsic semiconductor is formed which is known as a P-type semiconductor.

Figure 1.3 illustrates that in an N-type semiconductor, a donor impurity creates an electron that plays a role in the current flow, and in the case of a P-type semiconductor acceptor impurity creates a hole that plays a role in the current flow.

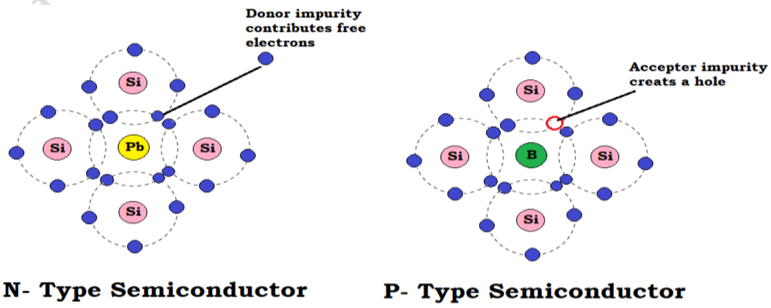



**Fig. 1.3 Adding Impurity to Semiconductors**

**Know More...**

Valence defines the number of electrons present in the outermost shell of an atom.

### 1.1 PN JUNCTION DIODE

When two semiconductors i.e. P-type and N-type semiconductors are combined, it will form a component known as a diode. “Di” defines two, hence diodes have two terminals. Diode is used in switching applications as it passes current only in one direction. Figure 1.4. illustrates that the P-side is called the anode and the N-side is called the cathode.


**Fig. 1.4 Terminals of diode**

Figure 1.5 illustrates the symbolic representation of the PN junction diode.

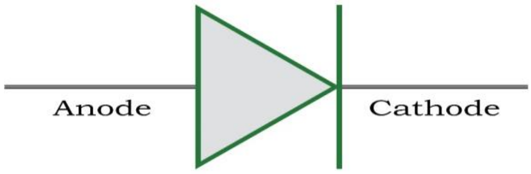



**Fig. 1.5 Symbol of diode**

Figure 1.6 illustrates that the PN junction diode has a silver ring to physically identify the N-side or cathode of a diode

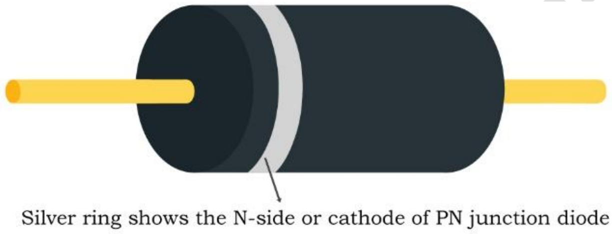



**Fig. 1.6 Ring over the diode**

The depletion region is a region around the PN junction in a PN junction diode where there are no mobile charge carriers (electrons or holes). It is also sometimes referred to as the space charge region or the transition region. The formation of the depletion region is a result of the diffusion and recombination of charge carriers when a P-type and an N-type semiconductor are brought together.

In an N-type semiconductor, there is an abundance of electrons, whereas in a P-type semiconductor, there is an abundance of holes. When these two regions come together to form a PN junction, the excess electrons from the N-type region diffuse into the P-type region, and the excess holes from the P-type region diffuse into the N-type region. This diffusion continues until the electrons and holes near the junction recombine.

As a result of this recombination, a region near the junction becomes depleted of free charge carriers, creating what is known as the depletion region. This region acts as a barrier, preventing the further flow of charge carriers and blocking current in the reverse-biased condition of the diode. The width of the depletion region depends on the doping concentrations of the P and N regions and the magnitude of the applied voltage across the diode. A higher doping concentration results in a narrower depletion region, while a higher reverse bias voltage widens the depletion region.

A PN junction diode can be connected in two configurations: forward bias and reverse bias. In a forward bias configuration, the anode (positive terminal) of the diode is connected to the positive terminal of an external voltage source, while the cathode (negative terminal) is connected to the negative terminal of the source. Under this condition, the diode is said to be **forward-biased**, and it operates in conduction mode, acting like a closed switch, meaning it is "ON." In this state, the diode allows current to flow through the circuit. Figure 1.7 depicts a circuit where a PN junction diode is connected in a forward bias configuration, allowing current to pass through it.

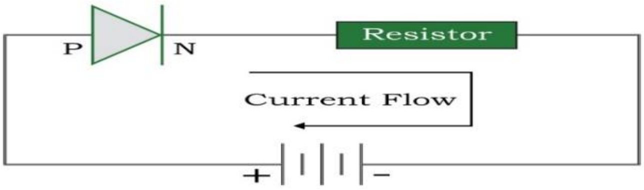



**Fig. 1.7 Forward bias circuit current**

When the P-side of a PN junction diode is connected to the negative terminal of a battery and the N-side is connected to the positive terminal, the diode is said to be in **reverse bias**. In this configuration, the diode behaves like an open switch, meaning it is "OFF." Under reverse-biased conditions, the PN junction diode prevents current from flowing through the circuit. Figure 1.8 illustrates a circuit where the PN junction diode is connected in reverse bias, resulting in no current flow.


**Fig. 1.8 Reverse bias circuit**

Practical activity 1.1 illustrates the procedure for identifying the proper working of a PN junction diode.

**Practical Activity 1.1 –** To identify the working of a PN junction diode using a multimeter.

**Material required –**

PN junction diode, multimeter.

**Procedure –**

**Step 1–** First set the multimeter in diode mode. Figure 1.9 illustrates the knob is in the diode mode of a multimeter.


**Fig. 1.9 Switch the knob to diode mode**

**Step 2 –** Keep the positive probe of the multimeter in the anode of the diode and the negative probe in the cathode. Observing the reading in the multimeter display, it will show the forward voltage drop of the diode. Figure 1.10 illustrates anode and cathode knobs are connected to the terminals of the diode.


**Fig. 1.10 Multimeter in diode mode which shows the forward bias in diode**

**Step 3 –** Reverse the polarity of the probes of the multimeter. the multimeter will not show the value on its display. Figure 1.11 illustrates the diode is in reverse bias by changing its polarity.

**Fig. 1.11 Multimeter in diode mode which shows the reverse bias in diode**

**Step 4 –** Forward bias current and no current in reverse bias condition will show the proper working of the PN junction diode.

## 1.2 TRANSISTOR

The transistor is a three-layer semiconducting device. Transistors act as switches or can be used for signal amplification. Transistor acts as a switch, which is controlled by an external electrical signal. In addition, it can also be used for enhancing the strength applied signal.

There are two members in the transistor family i.e. Bipolar Junction Transistor (BJT) and Field Effect Transistor (FET). Figure 1.12 (a) shows a typical bipolar junction transistor and Figure 1.12 (b) illustrates a typical field effect transistor.

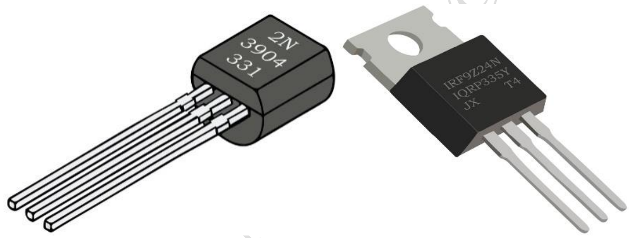



**Fig. 1.12 (a) Bipolar Junction Transistor (b) Field Effect Transistor**

### 1.2.1 Bipolar Junction Transistor

The bipolar junction transistor (BJT) has three layers i.e. emitter, base, and collector. The point where the two layers touch each other is called a junction. The junction where the emitter and base layer touches each other is called an emitter-base junction (EB junction). The junction where the collector and base layer touches each other is called a collector-base junction (CB junction). Figure 1.13 illustrates the two junctions of the transistor and three terminals of the bipolar junction transistor.

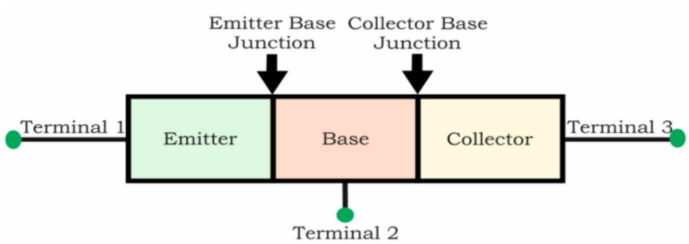



**Fig. 1.13 Layers and junctions in BJT**

There are two types of BJTs – NPN (Negative-Positive-Negative) and PNP (Positive-Negative-Positive). In an NPN transistor, the majority of carriers are electrons, while in a PNP transistor, the majority of carriers are holes.

**NPN Bipolar Junction Transistor –** It is a type of bipolar junction transistor where the majority of carriers are electrons. It consists of three layers of semiconductor material – the emitter, base, and collector. The NPN BJT is commonly used in electronic circuits for amplification and switching purposes. It consists of three terminals: emitter, base, and collector.

a) **Emitter (E) –** This is the heavily doped region of the transistor, and it emits the majority of carriers (electrons) into the base region.

b) **Base (B) –** The base is lightly doped and located between the emitter and collector. It controls the transistor's operation by controlling the flow of electrons from the emitter to the collector.

c) **Collector (C) –** The collector is moderately doped and collects the majority of carriers (electrons) from the emitter region.

NPN BJTs are widely used in various electronic circuits, such as audio amplifiers, voltage regulators, oscillators, and digital logic gates. They offer good linearity, high gain, and high switching speeds, making them versatile components in the field of electronics.

**PNP Bipolar Junction Transistor –** It is another type of bipolar junction transistor, where the majority of carriers are holes. Similar to an NPN BJT, a PNP BJT consists of three layers of semiconductor material: the emitter, base, and collector. The PNP BJT is commonly used in electronic circuits for amplification and switching. This transistor also consists of three terminals: emitter, base, and collector.

a) **Emitter (E) –** The emitter is heavily doped and emits the majority of carriers (holes) into the base region.

b) **Base (B) –** The base is lightly doped and positioned between the emitter and collector. It controls the transistor's operation by regulating the flow of holes from the emitter to the collector.

c) **Collector (C) –** The collector is moderately doped and collects the majority of carriers (holes) from the emitter region.

PNP BJTs find applications in various electronic circuits, such as audio amplifiers, voltage regulators, oscillators, and digital logic gates. They possess similar characteristics to NPN BJTs, including good linearity, high gain, and high switching speeds. However, their current flow and voltage polarities are opposite to those of NPN BJTs.

BJT can be of NPN or PNP type. Figure 1.14 illustrates the symbols of NPN and PNP transistors.

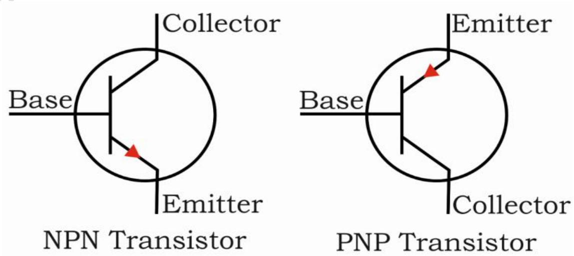



**Fig. 1.14 BJT symbol.**

Figure 1.15 illustrates the physical appearance of the transistor. NPN and PNP are the types of BJT. Both are similar in physical appearance. Physically, they cannot be differentiated.

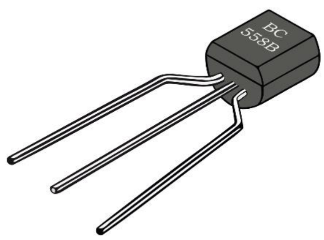



**Fig. 1.15 BJT terminals**

A multimeter is used to identify the type of BJT. The BJT has two junctions (NPN ≡ N - P - N ≡ NP Junction + PN Junction and PNP ≡ P - N - P ≡ PN Junction + NP Junction).

Emitter to the base is one PN junction (diode) and the base to the collector is another PN junction (diode). In total in a single transistor two diodes can be formed logically. Let us perform the activity to better identify the transistor.

Practical activity 1.2 demonstrates identifying whether the transistor is an NPN or not. It is said that the Emitter (E) is made up of an N-type terminal, Base (B) is made up of a P-type terminal, and Collector (C) is made up of an N-type terminal.

**Practical Activity 1.2 –** To identify the working of an NPN transistor using a multimeter.

**Material required –**

NPN transistor, multimeter.

**Procedure –**

**Step 1 –** Connect the red cord to the voltage measuring point, which is shown in Figure 1.16.


**Fig.1.16 Voltage measuring point on the multimeter**

**Step 2 –** Connect the black cord to the common point, which is shown in Figure 1.11.


**Fig. 1.17 Common point on the multimeter**

**Step 3 –** Rotate the knob of the multimeter in the diode mode as shown in Figure 1.18.


**Fig. 1.18 Selector knob at diode mode**

**Step 4 –** Touch the red probe to the center pin (base) of the transistor, and the black probe to either of the two pin-1 (emitter) or pin-3 (collector) of BJT as shown in Figure 1.19.

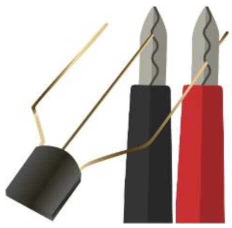


**Fig. 1.19 Multimeter probes connected to the transistor terminals**

**Step 5 –** Check the display of the multimeter. If it shows a forward voltage drop in terms of voltage between pin number 1 and pin number 2 as illustrated in Figure 1.20 then this transistor is an NPN transistor. Also, if connections are interchanged it will not show any value.


**Fig. 1.20 Forward voltage drop in the diode**

**Step 6 –** The following observation is found that pin number 1 is Emitter (E), Pin no 2 is Base, and pin number 3 is Collector (C) pin

Practical activity 1.3 demonstrates identifying whether the transistor is an NPN or not in the case of a PNP transistor. It is said that the Emitter (E) is made up of a P-type terminal, Base (B) is made up of an N-type terminal, and Collector (C) is made up of a P-type terminal.

**Practical Activity 1.3 –** To identify the working of a PNP transistor using a multimeter.

**Material required –**

PNP transistor, multimeter.

**Procedure –**

**Step 1 –** Connect the red cord to the voltage measuring point. Figure 1.16 illustrates a voltage measuring point in a multimeter.

**Step 2 –** Connect the black cord to the common point, Figure 1.17 illustrates a common point in a multimeter.

**Step 3 –**Turn the multimeter in the diode mode. Figure 1.18 illustrates that the selector is in diode mode.

**Step 4 –** Touch the black probe to the center pin (Base) of the transistor, the red probe to either of the two pin – 1 (Collector) or pin- 3 (emitter) of BJT as shown in Figure 1.19.

**Step 5 –** The multimeter display shows the forward voltage drop. Shows it is a PNP transistor. If the connections are interchanged, it will not show any value. Figure 1.21 illustrates the forward voltage drop in the case of a PNP transistor.


**Fig. 1.21 Forward voltage drop in the diode**

**Step 6 –** The following observation is found that pin number 1 is Collector (C) pin no 2 is Base, and pin number 3 is Emitter (E) pin.

**1.2.2 Field Effect Transistor** FET has three layers i.e. Source, Gate, and Drain. The point where the two layers touch each other is known as a junction. The junction where the source and gate touch each other is named a source-gate junction. The junction where the drain and gate layer touch each other is named a drain-gate junction. The field effect transistor is of two types N-channel FET and P-channel FET. Figure 1.22 illustrates the typical field effect transistor.

**Fig. 1.22 Field Effect Transistor**

The most common types of FETs are the metal-oxide-semiconductor field-effect transistor (MOSFET) and the junction field-effect transistor (JFET).

**Metal-Oxide-Semiconductor Field-Effect Transistor (MOSFET) –** It is a type of field-effect transistor that is widely used in electronic devices and integrated circuits. It is a three-terminal device with a gate, source, and drain. The structure of a MOSFET typically consists of a silicon substrate, a thin insulating layer (oxide) typically made of silicon dioxide ($SiO_2$), and a metal gate electrode. The MOSFET can be classified into two main types based on the conductivity type of the substrate namely N channel MOSFET and P channel MOSFET.

a) **N-channel MOSFET (NMOS) –** In an N-channel MOSFET, the substrate is made of p-type silicon, and the channel is formed by an n-type region. The gate terminal controls the flow of electrons (hence the name N-channel) in the channel region. When a positive voltage is applied to the gate relative to the source, it creates an electric field that attracts electrons from the source to the channel, allowing current to flow from the drain to the source.

b) **P-channel MOSFET (PMOS) –** In a P-channel MOSFET, the substrate is made of n-type silicon, and the channel is formed by a p-type region. The gate terminal controls the flow of holes (positive charge carriers) in the channel region. When a negative voltage is applied to the gate relative to the source, it creates an electric field that attracts holes from the source to the channel, allowing current to flow from the source to the drain.

The operation of a MOSFET is based on the voltage applied to the gate terminal, which creates an electric field that controls the conductivity of the channel between the source and drain terminals. MOSFETs have high input impedance, and low power consumption, and can be fabricated in large quantities on a single integrated circuit.

MOSFETs are commonly used in various applications, including digital integrated circuits (ICs), power amplifiers, switching circuits, voltage regulators, motor control, and many other electronic devices. Their ability to provide fast switching speeds, high current handling capabilities, and low power dissipation has made them essential components in modern electronics.

Practical activity 1.4 demonstrates identifying the working of NMOS transistor

**Practical Activity 1.4 –** To identify the working of an NMOS transistor using a multimeter.

**Material required –**

NMOS transistor, multimeter.

**Procedure –**

**Step 1 –** Set the multimeter to the diode test mode as illustrated in Figure 1.18

**Step 2 –** Connect the positive lead of the multimeter to the drain terminal of the NMOS transistor and the negative lead to the source terminal. Figure 1.23 illustrates that the MOSFET is connected by a probe of a multimeter.

**Fig. 1.23 Multimeter probes connected to the MOSFET terminals**

**Step 3 –** If the NMOS transistor is functioning correctly, you should see a relatively high resistance reading or an open circuit. This indicates that the channel between the source and drain is off or blocked. Figure 1.24 illustrates the multimeter showing high resistance.

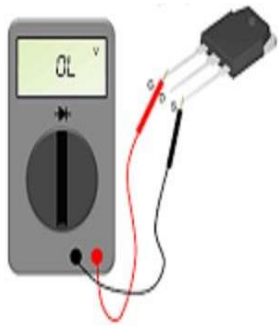



**Fig. 1.24 Multimeter showing high resistance value**

**Step 4 –** Reverse the connections of the multimeter leads, with the positive lead connected to the source terminal and the negative lead connected to the drain terminal. a relatively low resistance reading or a conductive path. This indicates that the channel between the source and drain is on or conducting current. Figure 1.25 illustrates the multimeter showing low resistance.


**Fig. 1.25 Multimeter showing low resistance value**



**Junction Field-Effect Transistor (JFET) –** It is a type of field-effect transistor that operates based on the voltage-controlled modulation of current flow through a semiconductor channel. JFETs are primarily used in analog applications due to their high input impedance, low noise characteristics, and simplicity. A JFET consists of a doped semiconductor channel with two regions at either end called the source and drain. The channel is usually made of a single type of semiconductor material either n-type or p-type, and it is connected to the source and drain regions by junctions.

JFETs are classified into two main types based on the conductivity type of the channel namely N-channel JFET (NJFET), P-channel JFET (PJFET)

a) **N-channel JFET (NJFET) –** In an NJFET, the channel is made of n-type semiconductor material, and the source and drain regions are p-type.

b) **P-channel JFET (PJFET) –** In a PJFET, the channel is made of p-type semiconductor material, and the source and drain regions are n-type.

The JFET operates by applying a voltage to the gate terminal relative to the source. The gate-source voltage controls the width of the depletion region in the channel, which affects the resistance and current flow through the channel. JFETs are depletion-mode devices, meaning that current flows through the channel when the gate-source voltage is at or near zero bias. By applying a reverse bias voltage to the gate, the channel can be pinched off, reducing or blocking the current flow.

JFETs are commonly used in low-noise amplifiers, analog switches, voltage-controlled resistors, and impedance converters. They are also utilized in audio applications, sensors, and instrumentation circuits.

### 1.2.3 Integrated Circuit (IC)

An integrated circuit is a combination of electronic components on a single piece (or "chip") of semiconductor material such as silicon. Integrated circuit has large numbers of tiny transistors onto a small chip. This will form a circuit. This integrated circuit is smaller, cheaper, and faster. Figure 1.26 illustrates the Integrated circuit with 8 pins.

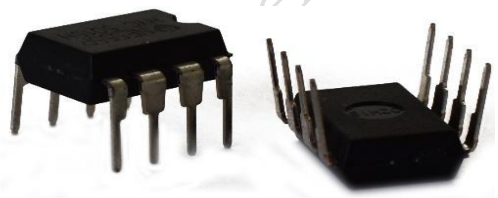


**Fig. 1.26 Integrated Circuit**

Integrated circuit has a number of pins. Each pin defines inputs or outputs. Datasheets are required when using an integrated circuit chip. Datasheets give complete information about a particular integrated circuit. Figure 1.27 illustrates the internal structure of IC.

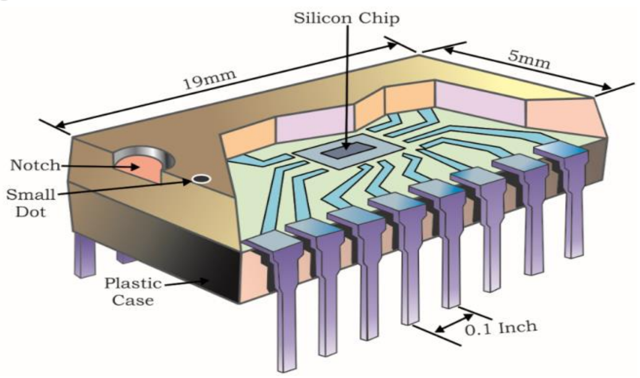



**Fig. 1.27 Internal structure of IC**

Figure 1.28 illustrates a full wave bridge rectifier IC 2KBP10 and DF04S. These ICs are used in the power supply or mobile charging circuit to convert the AC voltage to DC voltage.

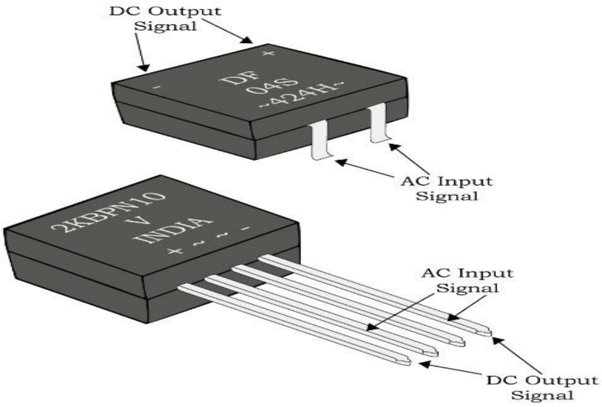



**Fig. 1.28 Full wave rectifier integrated circuit**

**Classification of Integrated Circuit –** All the IC's have interconnected discrete devices inside the chip and have corresponding external pins. Each pin has different functionality, which may vary according to the manufacturer's design.

A. **Classification of integrated circuits based on their applications.**
   1. Linear Integrated Circuits
   2. Digital Integrated Circuits

B. **Classification of integrated circuits based on the chip size.**
   1. Small scale integration (SSI) — It contains 3 to 30 gates/chips.
   2. Medium scale integration (MSI) — It contains 30 to 300 gates/chips.
   3. Large scale integration (LSI) — It contains 300 to 3,000 gates/chips.
   4. Very large-scale integration (VLSI) — It contains more than 3,000 gates/chips.

C. **Classification of integrated circuits based on the fabrication techniques used.**
   1. Monolithic integrated circuit
   2. Thick and thin film integrated circuit
   3. Hybrid or multi chip integrated circuit

### 1.2.4 Light Emitting Diode

Light-Emitting Diode (LEDs) comprises several layers of semiconducting material. When DC voltage is applied to LEDs, the layer produces light. This light is of particular colour and this colour is dependent on the type of semiconductor material used in its manufacturing. LED emits light in red, green, yellow, or blue colours depending on the composition of the crystal compounds. Figure 1.29. illustrates a typical LED's internal parts.

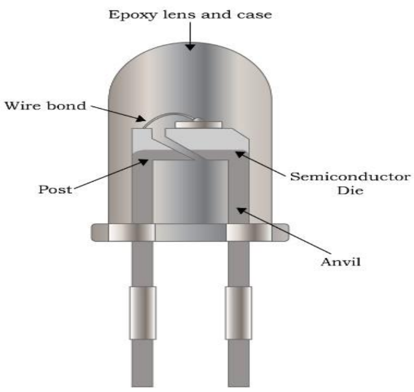



**Fig. 1.29 Internal parts of Light Emitting Diode**

Figure 1.30 illustrates the Symbolic representation of Light emitting diodes.

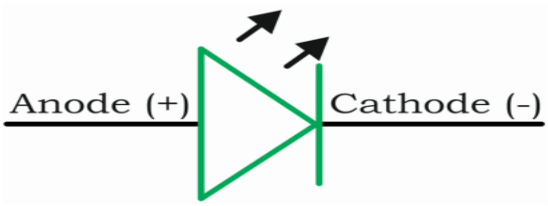
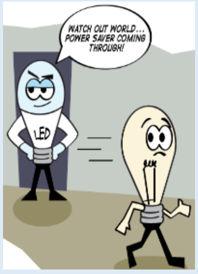



**Fig. 1.30 Symbol of Light Emitting Diode**

| **Know More...** Why are LEDs a good choice? |   |
|---|---|
| 1 Long life | |
| 2 Durable | |
| 3 High efficiency | |
| 4 Low energy use | |
| 5 Compact size | |
| 6 No UV issue | |

## Check Your Progress



**A. Multiple Choice Questions**

1. Which of the following is a semiconductor material? (a) Silicon (b) Germanium (c) Both A and B (d) None of these
2. A LED produces light when it is ________. (a) Forward biased (b) Reverse biased (c) Unbiased (d) None of the above
3. Three terminals semiconductor device is _____. (a) Diode (b) Transistor (c) IC (d) All of the above
4. LED requires _____ supply. (a) AC (b) DC (c) AC or DC (d) None of these
5. Transistor has ____ layers and ______ junctions. (a) Two, Three (b) Three, Two (c) Three, Three (d) Two, Two
6. Diode is forward biased when _____. (a) Cathode is connected to positive and anode is connected to negative terminal of battery (b) Cathode is connected to negative and anode is connected to positive terminal of battery (c) No specific polarity is required (d) None of these
7. Pentavalent impurities in extrinsic semiconductor have ____ electrons in its outermost orbit. (a) 3 (b) 5 (c) 4 (d) 2
8. Trivalent impurities in extrinsic semiconductor have _____ electrons in its outermost orbit. (a) 3 (b) 5 (c) 4 (d) 2
9. Pure form of semiconductor is called as ___. (a) Intrinsic semiconductors (b) Extrinsic semiconductors (c) Both A and B (d) None of these
10. Impure form of semiconductor is called as ____. (a) Intrinsic semiconductors (b) Extrinsic semiconductors (c) Both A and B (d) None of these

**B. Fill in the blanks**

1. Extrinsic semiconductor is ______ form of semiconductor.
2. Intrinsic semiconductor is _______ form of semiconductor.

3. Diode has _____ terminals.
4. Transistor has _____ terminals.
5. When LED is forward biased it will turn ______.
6. Integrated circuit has number of _____________.
7. An integrated circuit is a combination of electronic components on single piece (or "chip") of _____________________ such as silicon.
8. FET has three layers i.e. _____________, ________ and __________Switch is a device.
9. Which performs two operations i.e. ____________ and _____________.
10. Amplification is the process of ______________ the level of voltage and current

**C. State whether the statements given below are True or False.**

1. LED emits light in a particular colour and this colour is dependent on the type of semiconductor material used in it. ( )
2. Transistor is used as an amplifier and switch. ( )
3. The junction where emitter layer and base layer touch each other is named as emitter base junction. ( )
4. Amplification is the process of increasing the level of voltage and current. ( )
5. Semiconductors are materials whose conductivity lie between conductors and insulators. ( )
6. Point where the two layers touch each other is known as junction. ( )
7. Field effect transistor is of single types P-channel FET. ( )
8. Emitter to base is one PN junction (diode) and base to collector another PN junction (diode) in total in a single transistor two diode can be form logically. ( )
9. The junction where emitter and base layer touches each other is called as emitter-base junction (EB junction). ( )
10. The junction where collector and base layer touches each other is called as emitter-base junction. ( )

**D. Short answer questions**

1. Write short notes on: Diode, Transistor, LED
2. What is an extrinsic semiconductor?
3. What is an intrinsic semiconductor?
4. What are the applications of transistor?
5. Why LEDs are good choice?

**Exercise:** Identify and name the P type and N type terminal of diode in the Figure 1.31. Also, specify the anode and cathode terminals of diode.

Fig. 1.31 ......................................

**Exercise:** Identify the parts of Light Emitting Diode (LED) in the Figure 1.32.

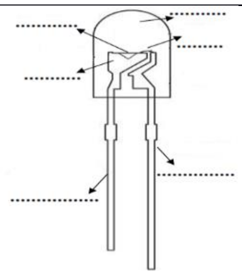


Fig. 1.32 ..............................

**E. Match the column**

| Name of components | Associated terms |
|---|---|
| A. Semiconductor | 1. Unidirectional device |
| B. Field Effect Transistor | 2. Base, emitter, collector |
| C. Diode | 3. Gate, source, drain |
| D. Bipolar Junction Transistor | 7. Trivalent and pentavalent |

# Session 2. Sensors, Transducers, and Signal Generating Equipment

Vikas and his father planned to visit a city mall when they entered the city mall, the doors glided open effortlessly as they approached. This automatic opening of the gate fascinated Vikas, He turned to his father and asked about the magic behind it. His father explained, "It's the work of a sensor. When it detects a person, it sends a signal to a processing unit, which then commands the motor to open the doors." Vikas was amazed by the simple yet ingenious technology at play.

**Fig. 2.1 Vikas and his father in front of the automated door of a mall**

In this chapter, we will understand the basics of sensor transducers and other signal-generating equipment used in the real world for the automation of electrical and electronic devices.

**2.1 Sensors**

Sensors are devices designed to detect and measure physical quantities or environmental conditions. They are commonly used across various fields, including technology, engineering, manufacturing, transportation, and science. Sensors convert the detected physical phenomena into electrical signals or other readable formats, which can then be processed and analysed by electronic systems. Figure 2.2 shows how a sensor first detects signals, converts them into electrical signals, and then transfers these signals to a signal conditioning unit for processing before moving on to the next stage.

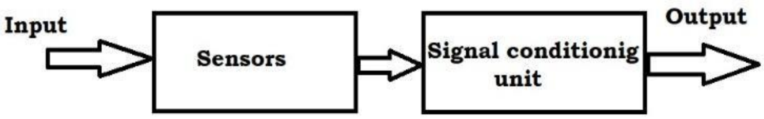



**Fig. 2.2 Basic block diagram of sensors**

### 2.1.1 Classification of Sensors

Sensors can be classified into several categories based on different criteria. Figure 2.3 illustrates the various types of sensors available for analysing the physical parameters.

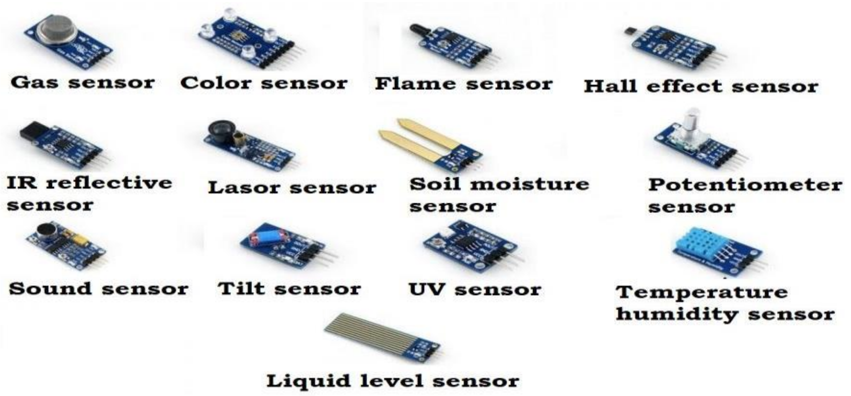



**Fig. 2.3 Sensors**

**A. Classification Based on the Measured Quantity –** The classification of the sensors is based on the method of how they convert the physical quantity. These are various types such as – Temperature sensors, pressure sensors, humidity sensors, Light sensors, Motion sensors, proximity sensors, and many more.

**B. Classification Based on the Technology Used –** This type of classification is based on the conversion phenomenon such as Resistive sensors – These types of sensors use changes in electrical resistance to measure physical quantities (e.g., thermistors). Such as capacitive, inductive, optical, piezoelectric, and hall effect sensors.

**Capacitive sensors –** These types of sensors are used to measure changes in capacitance due to the applied physical quantity (e.g., touch sensors).

**Inductive sensors –** These types of sensors use Detect changes in inductance caused by the presence or absence of objects.

**Optical sensors –** These types of sensors use light to measure various parameters (e.g., light intensity, color, or distance).

**Piezoelectric sensors –** These types of sensors are used to generate electrical charges when subjected to mechanical stress or pressure.

**Hall effect sensors –** These types of sensors are used to measure changes in the magnetic field using the Hall effect.

**C. Classification Based on the Application Domain –** This type of classification is based on application phenomena such as environmental, biomedical, pressure, aerospace, automotive, industrial, and structural health monitoring sensors.

**Environmental sensors –** These types of sensor monitor and measure environmental parameters like temperature, humidity, air quality, etc.

**Biomedical sensors** – These types of sensors are used in healthcare for measuring vital signs, monitoring glucose levels, ECG, etc.

**Automotive sensors –** These types of sensors include sensors for engine monitoring, tire pressure, proximity detection, etc.

**Industrial sensors –** These types of sensors are used in manufacturing processes for monitoring pressure, flow, level, etc.

**Aerospace sensors –** These types of sensors are designed for aircraft and space applications, including altitude, attitude, and navigation sensors.

**Structural health monitoring sensors –** These types of sensors monitor the condition of structures and detect any potential damage or stress.

**D. Classification Based on Output Signals –** This type of classification is based on the output signals such as analog sensors and digital sensors.

**Analog sensors** are used to provide continuous output signals proportional to the measured quantity. Whereas, the **Digital sensors** are used to provide discrete output signals in the form of binary code (0s and 1s) or specific data protocols.

**E. Classification Based on the Sensing Method –** This type of classification is based on the sensing method such as contact and noncontact type of sensors.

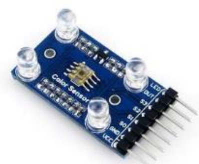
**Contact sensors:** These types of sensors require physical contact with the object or medium being measured.

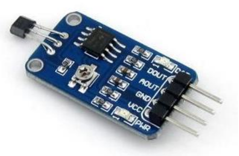
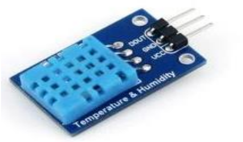
**Non-contact sensors:** These types of sensors are used to measure the physical quantity without direct contact with the object (e.g., optical or proximity sensors).

### 2.1.2 Types of Sensors

There are various types of sensors available in the real world for the conversion of physical parameters into electrical signals. Some of the sensors are illustrated in Table 2.1

**Table 2.1 Various Sensors and Their application**

| | | |
|---|---|---|
| 1 | **Gas Sensor-** Gas sensors, also known as gas detectors are electronic devices that detect and identify different types of gasses. For example, MQ135, MQ02, MQ06, etc. A typical gas sensor is shown in Figure 2.4. |  Fig. 2.4 Gas Sensor |
| 2 | **Color sensor-** it is a sensor that detects the light, those that detect the three primary colors of red, green, and blue are called color sensors. Color sensors detect RGB values by receiving ambient light using a photodiode. A typical color sensor is shown in Figure 2.5. |  Fig. 2.5 Colour sensor |
| 3 | **Flame sensor-** A flame sensor is one kind of detector that is mainly designed for detecting as well as responding to the occurrence of a fire or flame. A typical Flame sensor is shown in Figure 2.6. |  Fig. 2.6 Flame sensor |

| | | |
|---|---|---|
| 4 | **Hall effect sensor-** The hall effect is seen when a conductor is passed through a uniform magnetic field. A Hall effect sensor is a device that is used to measure the magnitude of a magnetic field. Its output voltage is directly proportional to the magnetic field strength through it. This sensor is used for proximity sensing, positioning, speed detection, and current sensing applications. A typical Hall effect sensor is shown in Figure 2.7. |  Fig. 2.7 Hall effect sensor |
| 5 | **Infrared reflective sensor-** IR Infrared transmitters and receiver tubes are used in the sensor module, which has great adaptability to ambient light. The infrared emitting tube emits a particular frequency, detects an obstacle (reflecting surface), reflects to the receiver tube receiving, the LED lights up after a comparator circuit processing, and the output signal will be digital. A typical infrared reflective sensor is shown in Figure 2.2. |  Fig. 2.8 Infrared reflective sensor |
| 6 | **Water flow sensor-** A water flow sensor measures the flow rate of water. It is installed at the water source or pipes to measure the rate of flow of water and calculate the amount of water flowing through the pipe. A typical water flow sensor is shown in Figure 2.9. |  Fig. 2.9 Water flow sensor |
| 7 | **Sound sensor-** Sound sensors are used to detect sounds. Generally, this module detects the intensity of sound. This module is mostly used for security, monitoring, and switch applications. A typical Sound sensor is shown in Figure 2.10. |  Fig. 2.10 Sound sensor |
| 8 | **Temperature and humidity sensor-** A temperature and humidity sensor (or RH temp sensor) converts temperature and humidity into electrical signals that can be measured easily. A typical Temperature and humidity sensor example DHT11, DHT 22 etc. is shown in Figure 2.11. |  Fig. 2.11 Temperature and humidity sensor |
| 9 | **Tilt Sensor-** A tilt sensor detects orientation or inclination. Their small size, low power consumption, and ease of use make them a great choice. They are also called mercury switches, tilt switches, or rolling ball sensors.<br>A typical tilt sensor is shown in Figure 2.12. |  Fig. 2.12 Tilt sensor |

| | | |
|---|---|---|
| 10 | **NTC Thermistor Sensor-** It is used to detect the temperature of the surrounding environment. The temperature detection range of the module is between 20 and 80 degrees Celsius. A typical NTC thermistor sensor is shown in Figure 2.13. |  Fig. 2.13 NTC thermistor sensor |
| 11 | **Liquid level sensor-** Liquid level sensors, also called liquid level switches, are designed to change state when immersed in a liquid. It is a resistive type sensor. A typical liquid level sensor is shown in Figure 2.14. |  Fi.g 2.14 Liquid level sensor |
| 12 | **TDS Sensor-** TDS Sensor/Meter for Arduino is a kit that allows you to measure the total dissolved solids (TDS) in water using an Arduino board. TDS is a measure of the dissolved minerals, salts, and other substances in water, and can be used to reflect the cleanliness and quality of the water. The TDS sensor is shown in Figure 2.15. |  Fig. 2.15 TDS sensor |

**2.2 Transducer**

A transducer is a device that transforms one form of energy into another. Transducers are capable of converting various types of energy-such as electrical, mechanical, thermal, optical, or chemical-into a measurable or usable form. They can be categorized based on the type of energy conversion they perform. For instance, an electric generator converts mechanical energy into electrical energy, a solar cell in solar panels transforms light energy into electrical energy, and a battery converts chemical energy into electrical energy. Figure 2.16 depicts several transducers that are used to convert one form of energy into another.

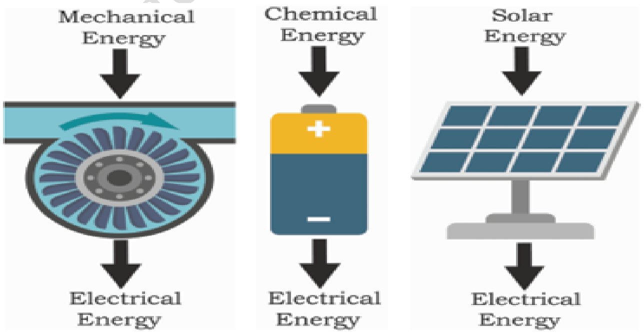



**Fig. 2.16 Examples of the transducer**

**2.2.1 Classification of Transducers**

Transducers can be classified based on several criteria, including their principle of operation, the type of input and output signals, and their application.

**Classification of transducers based on active or passive transducers –** This type of classification is based on active or passive in nature.

a) **Active transducer –** These transducers require an external power source to operate and provide an amplified output signal. For example, solar cells, and piezoelectric crystals. Figure 2.17 illustrates a solar cell that is used to convert solar energy into electrical energy and

Figure 2.18 illustrates a typical piezoelectric crystal that is used to convert mechanical energy to electrical energy and vice versa.

**Fig. 2.17 Solar panel in street light** **Fig.2.18 Piezoelectric Crystal**

**Know More…**

The piezoelectric crystal is one of the small-scale energy resources. When these crystals are automatically deformed then they produce a tiny voltage, which is known as piezoelectricity.

b) **Passive Transducer –** These transducers do not require an external power source and produce a weak output signal. They often need external signal conditioning. For example, light-dependent resistors, and thermistors. The light-dependent resistor, shown in Figure 2.19, illustrates a typical Light-dependent resistor (LDR) that is used to detect light.

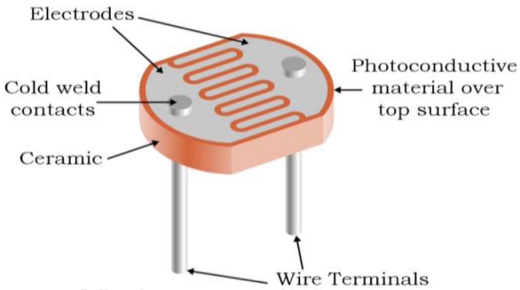



**Fig. 2.19 Light Dependent Resistor**

**Classification of transducers based on the Principle of Operation –** This type of classification is based on how they can operate. They can be classified as resistive, capacitive, inductive, piezoelectric, and optical transducers.

**a) Resistive Transducers –** These transducers change their resistance based on the input parameter. Examples include strain gauges and thermistors. Figure 2.20 illustrates a strain gauge transducer which is a resistive type and is used to measure the force.

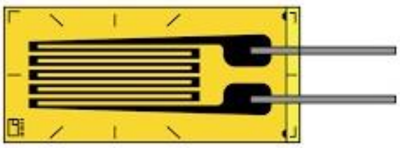


**Fig. 2.20 Light Dependent Resistor**

**b) Capacitive Transducers –** These transducers utilize changes in capacitance to measure the input parameter. Examples include capacitive pressure sensors and humidity sensors.

**c) Inductive Transducers –** These transducers use changes in inductance to measure the input parameter. Examples include inductive position sensors and inductive proximity sensors.

**d) Piezoelectric Transducers –** These transducers generate an electrical signal in response to mechanical stress or vibration. Examples include piezoelectric sensors and actuators.

e) **Optical Transducers –** These transducers utilize the properties of light to measure or transmit signals. Examples include photodiodes, fiber optic sensors, and laser rangefinders.

**Classification of transducers based on the application –** This type of classification is based on how they are applicable and can be classified as primary and secondary transducers.

a) **Primary Transducer –** A primary transducer, also referred to as a sensing element or sensor, is the component that directly interacts with the physical parameter being measured. It converts the physical quantity into an electrical or mechanical signal that can be further processed or transmitted. Examples of primary transducers include thermocouples, pressure sensors, strain gauges, accelerometers, and photodiodes. These devices directly sense parameters such as temperature, pressure, strain, acceleration, or light intensity and produce an electrical output signal proportional to the input parameter.

b) **Secondary Transducer** – A secondary transducer, also known as a signal conditioner or transducer amplifier, receives the electrical or mechanical signal from the primary transducer and modifies and amplifies it for further processing or transmission. Its role is to improve signal quality, adjust signal levels, and eliminate noise or interference. Examples of secondary transducers include operational amplifiers (op-amps) and analog-to-digital converters, which enhance and convert the signals for accurate and reliable data processing.

**Classification of transducers based on the form of output signal –** This type of classification is based on how they produce their output signal such as analog and digital. They can be classified as analog and digital transducers.

a) **Analog Transducers –** Analog transducers provide an output signal that continuously represents the input physical quantity. Their output signal varies smoothly and proportionally with changes in the input parameter, producing a range of values within a continuous spectrum. Examples of analog transducers include potentiometers, thermocouples, strain gauges, and analog pressure sensors. These devices generate an analog electrical signal, such as voltage or current, that directly corresponds to the magnitude of the input being measured. The output signal can be further processed, amplified, or converted for display or recording. Analog transducers are widely used in applications that require continuous and precise measurement or control, such as in analog data acquisition systems, control systems, and analog signal processing.

b) **Digital Transducers –** Digital transducers provide an output signal that represents the input physical quantity in discrete, binary form. Their output consists of a sequence of digital values, usually in binary digits (bits), that indicate specific levels or states. Examples of digital transducers include digital temperature sensors, digital pressure sensors, and digital encoders. These transducers produce digital outputs that can be readily processed, stored, and transmitted using digital systems, such as microcontrollers, digital data acquisition systems, and digital communication protocols.

### 2.2.2 Types of Transducers

There are various types of transducers available. These transducers can be selected according to the application. Some of the transducers are discussed below such as thermocouples, thermistors, RTD, and strain gauge.

**Thermocouple –** A thermocouple is a transducer used to measure temperature by converting it into an electric current or electromotive force (EMF). It operates based on the Seebeck effect, where a voltage is generated at the junction of two dissimilar metals in response to temperature changes.

In a thermocouple, two different metal wires are joined at one end to form a junction, known as the "hot" or measuring junction. The other ends of the wires, which are not joined, are called the "cold" or reference junction. Figure 2.21 illustrates the working principle of thermocouples based on the Seebeck effect. The voltage generated at the hot junction is proportional to the temperature difference between the hot junction and the cold junction, allowing for temperature measurement.

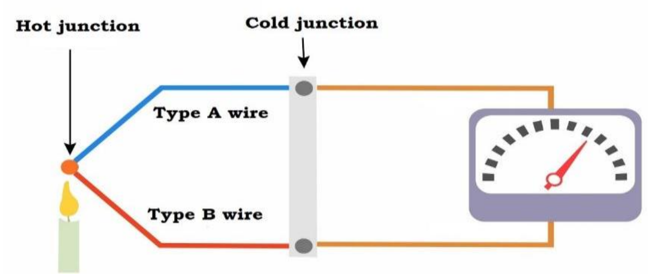



**Fig. 2.21 Thermocouple based on the principle of the See beck effect**

When there is a temperature difference between the hot junction and the cold junction of a thermocouple, an electromotive force (EMF) is generated due to the Seebeck effect. The magnitude of this EMF is directly proportional to the temperature difference between the two junctions.

The metals used in thermocouples are chosen for their specific thermoelectric properties and temperature range. Different thermocouple types are identified by letter codes, such as Type K, Type J, and Type T, each representing different metal combinations. For instance:

- Type K: Made from Chromel (Nickel-Chromium) and Alumel (Nickel-Aluminum).
- Type J: Made from Iron and Constantan.

Thermocouples are valued for their durability, simplicity, wide temperature range, and fast response time. They are capable of measuring temperatures ranging from -200°C to over 2300°C, depending on the specific type of thermocouple. Their versatility makes them widely used in various industries and applications for accurate temperature measurement.

Practical activity 2.1 demonstrates the measurement of thermoelectric emf produced by the thermocouple.

**Practical Activity 2.1 –** To measure the temperature difference using the thermocouple.

**Material Required –** Aluminum and copper wire, candle, voltmeter, notepad, pen.

**Procedure**

**Step 1.** Take two metal wires of aluminum and copper of length 60 cm each.

**Step 2.** Join the ends of wires that will form the two junctions.

**Step 3.** Connect the voltmeter in between the junctions as shown in Figure 2.22.

**Step 4.** Observe the deflection and note down the reading of the voltmeter.

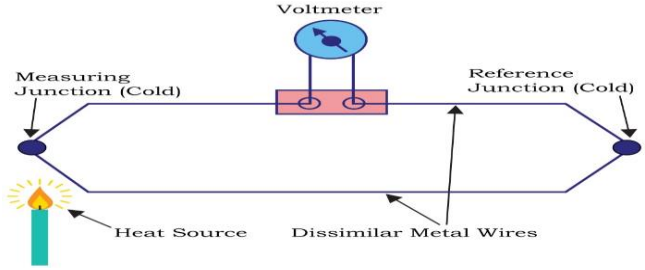



**Fig. 2.22 Thermocouple Transducer**

**Thermistor –** A thermistor is a type of temperature sensor that relies on the change in its electrical resistance with temperature. The name "thermistor" is a combination of "thermal" and "resistor". Thermistors are typically made from semiconductor materials with a high-temperature coefficient of resistance. The thermistor can be classified into two types: Negative temperature coefficient (NTC) and a positive temperature coefficient (PTC).

a) **NTC –** NTC stands for "Negative Temperature Coefficient". In this thermistor, resistance decreases with increase in temperature. They are primarily used as temperature sensors. A typical NTC thermistor is shown in Figure 2.23.


**Fig. 2.23 Negative temperature coefficient thermistor**

b) **PTC –** PTC stands for "Positive Temperature Coefficient". In this thermistor, resistance decreases with increase in temperature. A typical PTC thermistor is shown in Figure 2.24.


**Fig. 2.24 Positive temperature coefficient**

**Resistance Temperature Detector (RTD) –** It is a type of temperature sensor that measures temperature by detecting changes in the electrical resistance of a metal wire or element as a function of temperature. RTDs are known for their high accuracy, stability, and repeatability, making them widely used in various industrial and scientific applications. Figure 2.25 illustrates the typical RTD.

**Fig. 2.25 Resistance Temperature Detector**

The resistance of an RTD increases with an increase in temperature according to a predictable and repeatable relationship.

RTDs offer several advantages over other temperature sensors, such as thermocouples or thermistors. Some of the key advantages of RTDs are –

a) **High Accuracy –** RTDs provide high accuracy and precision in temperature measurement, with typical accuracies within a few tenths of a degree Celsius.

b) **Wide Temperature Range –** RTDs can measure temperatures over a wide range, typically from -200°C to 850°C depending on the specific RTD and calibration.

c) **Stability and Repeatability –** RTDs exhibit excellent long-term stability and repeatability, ensuring consistent and reliable temperature measurements over time.

d) **Linearity –** The resistance-temperature relationship of an RTD is highly linear, simplifying calibration and conversion of resistance values to temperature readings.

**Strain gauge –** A strain gauge is a type of sensor used to measure strain or deformation in materials. It is based on the principle that when a material undergoes mechanical stress or strain, its electrical resistance changes proportionally.

The most common type of strain gauge is a foil strain gauge, which consists of a thin wire or foil grid pattern bonded to a flexible backing material. The grid pattern is typically made of resistive material, such as metal or semiconductor, with a known resistance. When the strain gauge is bonded to a surface, any deformation or strain in the material causes the grid pattern to stretch or compress, resulting in a change in its electrical resistance.

To measure the change in resistance of a strain gauge, it is connected to a Wheatstone bridge circuit. The Wheatstone bridge balances the resistance values and produces an output voltage proportional to the strain-induced resistance change. The output voltage can be measured using instrumentation amplifiers or data acquisition systems to obtain the strain measurement. Figure 2.25 illustrates the strain gauge is connected to the Wein Bridge circuit.

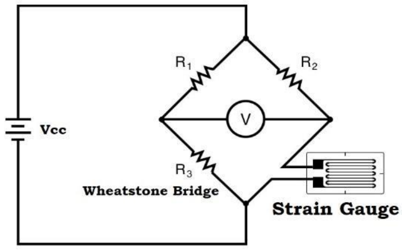



**Fig. 2.25 Strain gauge is connected to the Wheatstone bridge circuit**

Strain gauges are widely used in various applications, including structural engineering, mechanical testing, load and force measurement, stress analysis, and industrial process monitoring.

**2.3 Actuator**

An actuator is a device that converts energy, which may be electric, hydraulic, pneumatic, etc., to mechanical in such a way that it can be controlled. The quantity and the nature of input depend on the kind of energy to be converted and the function of the actuator. Electric and piezoelectric actuators, for instance, work on the input of electric current or voltage, for hydraulic actuators, it's incompressible liquid, and for pneumatic actuators, the input is air. The output is always mechanical energy.

Various types of the actuator are explained below

| | | |
|---|---|---|
| **1** | **Solenoid water/Air valve:** Solenoid Water Air Valve Switch (Normally Closed) 1/2 controls the flow of fluid (liquid or air) and acts as a valve between high-pressure fluid. There are two (Nominal NPT) outlets. Normally, the valve is closed. When a 12V DC supply is applied to the two terminals, the valve opens and water can push through. A typical solenoid water/air valve is shown in Figure 2.26 |  Fig. 2.26 Solenoid water/air valve |
| 2 | **DC Motor:** DC motor converts the electrical signal into mechanical rotation dc motor operates only on DC voltage. A typical DC motor is shown in Figure 2.27 |  Fig. 2.27 DC motor |
| 3 | **AC Motor:** AC motor converts the electrical signal into mechanical rotation; it works on AC voltage. A typical DC motor is shown in Figure 2.28 |  Fig. 2.28 AC motor |

| | | |
|---|---|---|
| 4 | **Relay module** A relay is an electromechanical switching device which is electrically operated. It works on the principle of electromagnetism. It consists of a set of input terminals for single or multiple control signals, and a set of operating contact terminals. A typical relay is shown in Figure 2.29 |  Fig. 2.29 Relay module |

## 2.4 Signal generator

A signal generator is a device used to generate electronic signals of various types and frequencies. It produces electrical waveforms that can be used for testing, calibration, troubleshooting, and design verification in a wide range of electronic and communication systems.

Signal generators can generate different types of signals, including:

a) **Continuous Wave Signal –** A simple sinusoidal waveform with a constant frequency and amplitude. It is often used for basic testing and calibration purposes.

b) **Function Generator –** A versatile signal generator that can produce a variety of waveforms, such as sine, square, triangle, sawtooth, pulse, and arbitrary waveforms. Function generators are commonly used in circuit design, education, and general-purpose testing.

c) **Pulse Generator –** Generates square wave or pulse signals with adjustable frequency, duty cycle, and amplitude. Pulse generators are essential for testing digital circuits, timing analysis, and communication systems.

d) **Arbitrary Waveform Generator –** An advanced signal generator capable of producing complex waveforms with precise control over frequency, amplitude, phase, and shape. AWGs are commonly used in the research, development, and design of communication systems, radar systems, and electronic instrumentation.

e) **Sweep Generator –** Generates a continuously changing frequency or amplitude signal over a specific range. Sweep generators are used for frequency response analysis, filter characterization, and tuning.

Some signal-generating instruments are oscillators and multi vibrators.

### 2.4.1 Oscillator

Oscillator is an electric circuit, which produces a continuous and repeated alternating waveform. It requires only one-time input, using this input it generates waveforms. It converts DC voltage into AC voltage. This alternating voltage has some frequency. This way it generates the sinewave, which will be used in the analysis of electric circuits as shown in Figure 2.30.

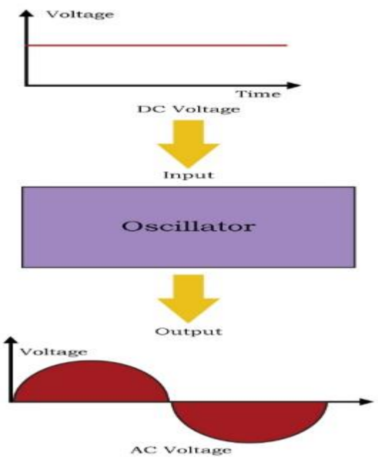



**Fig. 2.30 Logical diagram of the oscillator**

### 2.4.2 Multi vibrator

A multi vibrator is an electronic circuit that generates continuous square wave or pulse waveforms. It consists of active electronic components, such as transistors or operational amplifiers, along with passive components like resistors, capacitors, and sometimes inductors. The term "multi vibrator" is derived from the ability of the circuit to generate multiple pulses or oscillations. There are three types of multi vibrators: a stable, monostable, and bi-stable multi vibrators.

a) **A stable Multi vibrator –** It is also known as a free-running multi vibrator, an a stable multi vibrator continuously generates a square wave or pulse waveform without the need for external triggering. It alternates between two stable states, typically high and low, at a predetermined frequency determined by the values of the circuit components.

b) **Monostable Multi vibrator –** A monostable multi vibrator, also called a one-shot or delay circuit, generates a single pulse or a fixed duration pulse in response to an external trigger signal. After the trigger is applied, the circuit returns to its stable state until the next trigger is received.

c) **Bi-stable Multi vibrator –** A bi-stable multi vibrator, also known as a flip-flop, has two stable states and remains in one of these states until it receives a triggering signal. It can be set to either of the two states and will retain that state until the next trigger causes it to switch to the other state.

There are various applications of multi vibrators in various electronic circuits and electronic systems some of the applications are discussed below –

a) Timing and clock generation in digital circuits and microprocessors.

b) Frequency division and counting in frequency counters and timers.

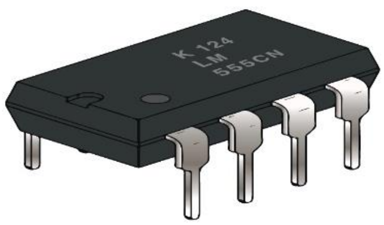
c) Pulse generation for digital logic circuits and waveform shaping.

d) Triggering and synchronization in electronic systems.

e) Oscillation and signal generation in audio and radio frequency circuits.

Multi vibrators can be implemented using discrete components or integrated circuits (ICs) such as 555 timers, flip-flops, or operational amplifiers. Integrated circuits offer more compact and convenient solutions with built-in functionalities, making them popular choices for many multi vibrator applications.

The integrated circuit (IC) 555-timer is a multi vibrator IC. As shown in figure 2.2 the round mark on the IC 555-timer shows pin1 and followed by pin 2, pin 3, and so on. Multi vibrator works in three modes namely a stable, monostable, and bi-stable.



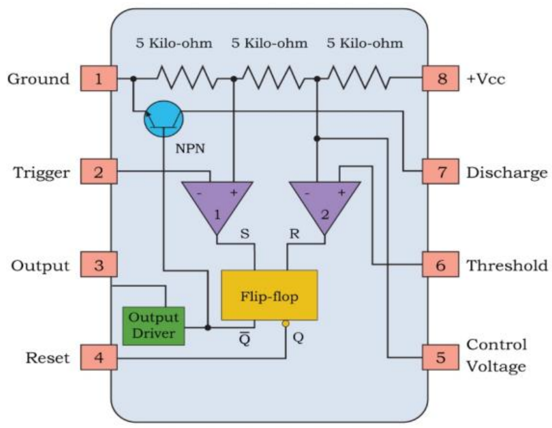




**Fig. 2.31 555-timer integrated circuit (IC)** **Fig. 2.32 Internal architecture of 555-timer IC**

**2.5 Cathode Ray Oscilloscope (CRO)**

It is a common laboratory instrument. It is used to provide accurate time and amplitude measurements of voltage and current signals. It is a reliable, stable, and easy-to-operate instrument. Typical, CRO parts are shown in Figure 2.33

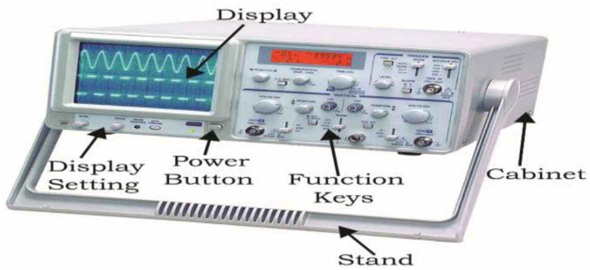



**Fig. 2.33 Cathode ray oscilloscope**

Major parts of CRO are the cathode ray tube (CRT), electron gun, deflection plates, display, and operating knobs.

**Cathode Ray Tube –** It is the heart of CRO. It is cylindrical in shape. It includes various sections such as electron guns, deflection plates, and accelerating plates.

**Electron Gun –** It produces a beam of electrons.

**Deflection Plate –** They provide a vertical and horizontal deflection to the beam.

**Display:** It provides the vision to the beam.



## Check Your Progress

**A. Multiple Choice Questions**

1. Which of the following is not the part of cathode ray oscilloscope? (a) Electron gun (b) Deflection plate (c) Display (d) Acceleration tube
2. Which of the following transducer is use to convert the motion into electrical signal? (a) Capacitive transducer (b) Resistive transducer (c) Inductive transducer (d) Reactive transducer
3. Which of the following transducer resistance decreases with increase in temperature? (a) Negative temperature coefficient thermistor (b) Positive temperature coefficient thermistor (c) Thermocouple (d) Photoresistor
4. Which of the following is the passive transducer? (a) Piezoelectric (b) LVDT (c) Dish TV antenna (d) Thermocouple
5. Which of the following transducer resistance increases with increase in temperature? (a) Negative temperature coefficient thermistor (b) Positive temperature coefficient thermistor (c) Thermocouple (d) Photoresistor
6. Which of the following is the active transducer? (a) Solar cell (b) Piezoelectric crystal (c) Dish TV antenna (d) All of the above
7. Which of the following is not the mode of multi-vibrator? (a) Monostable multi-vibrator (b) Astable multi-vibrator (c) Bi-stable multi-vibrator (d) Tri-state multi-vibrator
8. Which of the following is called as free running multi-vibrator? (a) Monostable multi-vibrator (b) Astable multi-vibrator (c) Bi-stable multi-vibrator (d) Tri-state multi-vibrator

9. Which of the following device is used to generator an alternating waveform? (a) Oscillator (b) Cathode ray tube (c) Monostable multi vibrator (d) None of the above
10. Which of the following integrated circuit is used as multi-vibrator? (a) 555 timer (b) 551 timer (c) 556 timer (d) 552 timer

**B. Fill in the blanks**

1. Thermocouples are made up of _____ wires.
2. The____ crystal is one of a small-scale energy resource.
3. Bi-stable multi-vibrator has two states i.e. ___ and ___.
4. Monostable multi-vibrator has only _____ stable state.
5. Oscillator converts ___ current into ____ current.
6. Inductive Transducer is type of transducer is use to convert the motion into _________.
7. The capacitive transducer is used for measuring the ___________, ______________and other physical quantities.
8. Electron Gun produces a beam of ______________.
9. Deflection Plate provide a vertical and horizontal_________________ to the beam.
10. Display provides the vision to the______________.

**C. State whether the following statements are True or False.**

1. Multi-vibrator converts solar energy into electrical energy. ( )
2. NTC and PTC are the types of thermistor. ( )
3. Oscillators are used to produce DC signal. ( )
4. Piezoelectric crystal is an oscillator. ( )
5. In thermocouple wires of two different metals are used. ( )
6. Major parts of CRO are cathode ray tube (CRT), electron gun only. ( )
7. PTC stands for "Positive Temperature Coefficient". ( )
8. NTC stands for "Negative Temperature". ( )
9. A thermistor is a type of resistor whose resistance is dependent on temperature. ( )
10. Thermocouple Transducer is a sensor use to measure the temperature. It measures the temperature in the form of an electric current or the EMF. ( )

**D. Short question answer**

1. List down the parts of cathode ray tube.
2. Define oscillator.
3. What are the applications of bi-stable multi-vibrator?
4. Write the working principle of thermocouple.
5. What do mean by the word thermistor?
6. What is Light Dependent Resistor?
7. Write the classification of thermistor?
8. What are inductive transducers?
9. What are the applications of monostable multi-vibrator?
10. What are the applications of astable multi-vibrator?

# Session 3. Digital Electronics

One day, Vikas watched his father diligently working on the laptop. He couldn't resist asking his father "Dad, how does a computer store a huge movie in such a small space?" His father explained the concept of binary files and how they are used to store data on a hard disk. After listening to that Vikas's curiosity grew further. Then he asked about the binary system. His father explained that the Binary system is a numerical system that uses only two digits: 0 and 1. It is the foundation of digital electronics and computing, allowing information to be represented and processed in electronic devices.

**Fig. 3.1. Vikas's father explaining the binary numbers**

In this chapter, we will understand the introduction to digital electronics and various number systems and also understand how logic gates are implemented in various digital circuits.

**3.1 Digital and Analog Quantities**

Analog and digital circuits are two broad categories of electronic circuits. Digital involves quantities with discrete values which means 0's and 1's. And analog electronics involve quantities with continuous values.

A digital quantity is one having a discrete set of values. Most things that we measure are analog. For example, the air temperature changes over a continuous range of values. During the day, the temperature does not go from, say, 30° Celsius to 31° Celsius instantaneously. It takes on all the infinite values between 30 ° to 31° Celsius. Figure 3.2 illustrates a graph of temperature on a summer day. it would have a smooth, continuous curve.  Similarly, the other examples of analog quantities are time, pressure, distance, and sound.

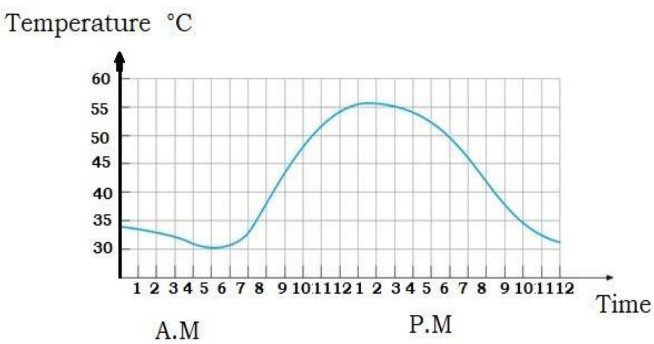



**Fig. 3.2 Graph of an analog quantity (temperature vs time)**

Rather than graphing the temperature continuously, suppose it just takes a temperature reading every hour. Now, it has sampled values representing the temperature at discrete points in time i.e. every hour over 24 hours, as indicated in Figure 3.3.

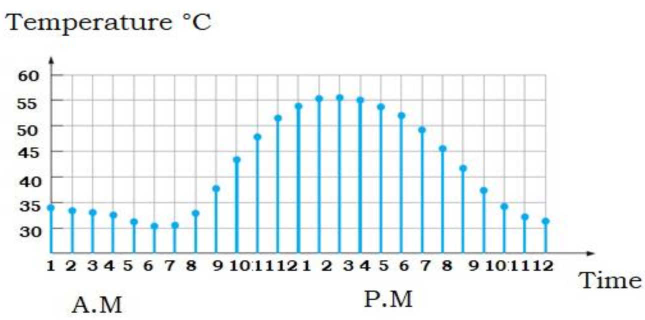



**Fig. 3.3 Sampled-value representation of the analog quantity in discrete value**

## 3.2 Binary Number System

The binary number system forms the foundation of digital electronics. Unlike the decimal system, which consists of ten digits (0-9) and is commonly used in daily life, the binary system relies on just two digits: 0 and 1. This system is particularly well-suited for electronic devices because binary numbers can be easily represented by voltage levels, such as 0 volts and 5 volts.

Each of the two digits in the binary system i.e. 0 and 1 is called a bit, which is a contraction of the word binary digit. In digital circuits, two different voltage levels are used to represent the two bits. Generally, 1 is represented by the higher voltage, which will refer to as a HIGH, and 0 is represented by the lower voltage level, which will refer to as a LOW. This is called **positive logic.**

In another system known as **negative logic**, a 1 is represented by a LOW signal, while a 0 is represented by a HIGH signal. Collections of bits, which are combinations of 1s and 0s, are referred to as codes and are used to represent numbers, letters, symbols, and instructions.

**Logic Levels –** The voltages used to signify a 0 and a 1 are referred to as logic levels. Ideally, one voltage level corresponds to a LOW signal, while another represents a HIGH signal. In a practical digital circuit, a HIGH can be any voltage within a specified range, while a LOW can also span a defined range of voltages. Figure 3.4 demonstrates the relationship between different logic states and their corresponding analog voltage levels. For instance, 0 volts is represented as 0 or VL (Min), and 5 volts is represented as 1 or VH (Max). The graph is divided into three sections, with the voltage range from VL (Min) to VL (Max) being classified as logic 0.

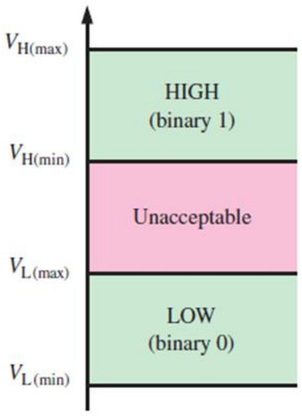



**Fig. 3.4 Logic level ranges of voltage for a digital circuit**

Digital logic involves voltage levels that fluctuate between HIGH and LOW states. Figure 3.5 (a) shows a single positive-going pulse, which occurs when the voltage transitions from its default LOW level to a HIGH level and then returns to its LOW level. Conversely, Figure 3.5 (b) illustrates a negative-going pulse, where the voltage drops from its default HIGH level to a LOW level and then returns to the HIGH level. A digital waveform is composed of a sequence of such pulses.

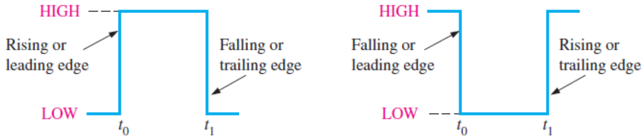



**Fig. 3.5 Ideal pulses (a) Positive-going pulse (b) Negative-going pulse**

### 3.2.1 Boolean gates

Boolean gates are essential components in digital logic circuits. They perform mathematical operations on one or more binary inputs (0 or 1) and generate a binary output according to specific logic rules. There are various types of Boolean gates, each with distinct functionality. The three fundamental Boolean gates are the NOT gate, AND gate, and OR gate. Figure 3.6 shows the symbolic representation of these gates.

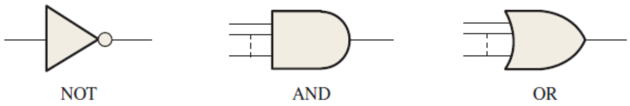



**Fig. 3.6 The basic logic functions and symbols**

**NOT Gate –** A NOT gate, also referred to as an inverter, is a basic Boolean gate with a single input that produces an output that is the opposite of the input. This means that if the input is 1, the output will be 0, and if the input is 0, the output will be 1. Figure 3.7 demonstrates that when the input is HIGH (1), the output becomes LOW (0), and when the input is LOW (0), the output switches to HIGH (1). In both scenarios, the output is always the inverse of the input. The NOT function is realized through a logic circuit known as an inverter.


**Fig. 3.7 The NOT gate**

Table 3.1 illustrates the truth table of the NOT gate. When the input is low then the output is high and when the output is high then the input is low.

Table 3.1 The truth table of NOT gate

| X | Output |
|---|---|
| 0 | 1 |
| 1 | 0 |

**AND Gate –** An AND gate is a fundamental Boolean gate that processes two or more inputs and generates an output according to the logical AND operation. The output of an AND gate is 1 only when all of its input signals are 1; if any input is 0, the output will be 0. The truth table for the AND gate is presented in Table 3.2.

Table 3.2 The truth table of AND gate

| X | Y | Output |
|---|---|---|
| 0 | 0 | 0 |
| 0 | 1 | 0 |
| 1 | 0 | 0 |
| 1 | 1 | 1 |

Figure 3.8 illustrates the AND gate and whenever both inputs are HIGH the output become HIGH

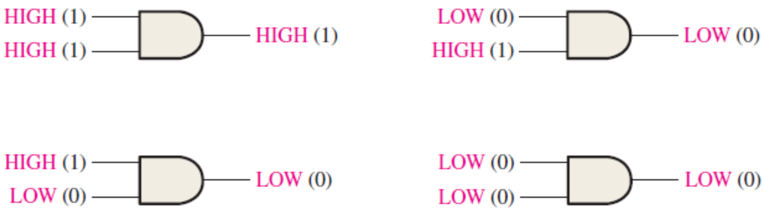



**Fig. 3.8 The AND function**

The Boolean expression for an AND gate is represented by the symbol "∧" or by the multiplication operator (*).

**OR Gate –** An OR gate is another fundamental Boolean gate that takes two or more inputs and produces an output based on the logical OR operation. The output of an OR gate is 1 if at least one of its input signals is 1; otherwise, the output is 0. The truth table of the OR gate is shown in Table 3.3.

Table 3.3 The truth table of OR gate

| X | Y | Output |
|---|---|---|
| 0 | 0 | 0 |
| 0 | 1 | 1 |
| 1 | 0 | 1 |
| 1 | 1 | 1 |

Figure 3.9 illustrates the OR gate and whenever both inputs are LOW the output becomes LOW

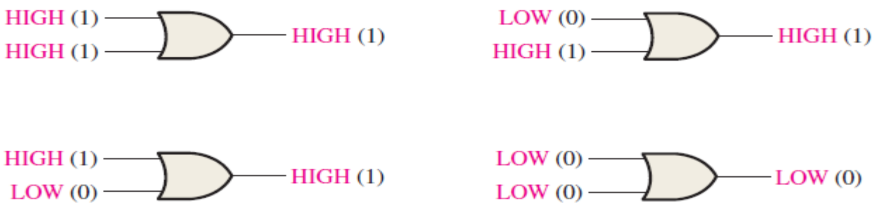



**Fig. 3.9 The OR function**

The OR gate is represented by the symbol "V" or by the addition operator (+).

**XOR Gate –** The XOR gate, or exclusive OR gate, is a digital logic gate with two inputs that outputs a high signal (logic 1) when the number of high inputs is odd. If both inputs are the same (either both high or both low), the output is low (logic 0). The Boolean expression for an XOR gate is Y = A XOR B. The truth table for the XOR gate is displayed in Table 3.4.

Table 3.4 The truth table of XOR gate

| X | Y | Output |
|---|---|---|
| 0 | 0 | 0 |
| 0 | 1 | 1 |
| 1 | 0 | 1 |
| 1 | 1 | 0 |

Figure 3.10 illustrates the XOR gate and whenever both inputs are different the output becomes HIGH

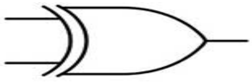


**Fig. 3.10 The XOR function**

**XNOR Gate –** The XNOR gate, or exclusive NOR gate, is the inverse of the XOR gate. It produces a high output (logic 1) when the number of high inputs is even. When both inputs are identical (either both high or both low), the output is high (logic 1). The Boolean expression for an XNOR gate is Y = A XNOR B. The truth table for the XNOR gate is presented in Table 3.5.

Table 3.5 The truth table of XOR gate

| X | Y | Output |
|---|---|---|
| 0 | 0 | 1 |
| 0 | 1 | 0 |
| 1 | 0 | 0 |
| 1 | 1 | 1 |

Figure 3.11 illustrates the XOR gate and whenever both inputs are different the output becomes LOW

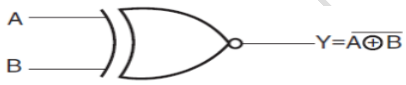



**Fig. 3.11 The XNOR function**

**NAND Gate –** The NAND gate is formed by combining an AND gate with a NOT gate. It produces a low output (logic 0) only when all its inputs are high (logic 1); otherwise, the output is high (logic 1). The Boolean expression for a NAND gate is Y = NOT (A AND B). This gate is considered a universal gate because any other gate can be constructed using a combination of NAND gates. The truth table for the NAND gate is shown in Table 3.6.

Table 3.6 The truth table of NAND gate

| X | Y | Output |
|---|---|---|
| 0 | 0 | 1 |
| 0 | 1 | 1 |
| 1 | 0 | 1 |
| 1 | 1 | 0 |

Figure 3.12 illustrates the NAND gate and the output of this gate is an inverted AND gate.

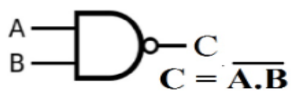



**Fig. 3.12 The NAND function**

**NOR Gate –** The NOR gate is created by combining an OR gate with a NOT gate. It produces a high output (logic 1) only when all its inputs are low (logic 0); otherwise, the output is low (logic 0). The Boolean expression for a NOR gate is Y = NOT (A OR B). As a universal gate, any other gate can be implemented using a combination of NOR gates. The truth table for the NOR gate is shown in Table 3.7.

Table 3.7 The truth table of NOR gate

| X | Y | Output |
|---|---|---|
| 0 | 0 | 1 |
| 0 | 1 | 0 |
| 1 | 0 | 0 |
| 1 | 1 | 0 |

Figure 3.13 illustrates the NOR gate and the output of this gate is an inverted OR gate.


**Fig. 3.13 The NOR function**

### 3.3 Number system

The binary number system and digital codes are essential concepts in computers and digital electronics. This chapter explores both the binary and decimal number systems to establish a foundational understanding of how computers and various digital systems operate. It covers binary numbers to illustrate their role in digital technology. Additionally, digital codes such as Binary Coded Decimal (BCD), Gray code, and ASCII (American Standard Code for Information Interchange) are discussed, highlighting their applications in digital systems.

**3.3.1 Decimal Number** The decimal number system is familiar because it is used daily. In this system, the ten digits (0 through 9) each represent a specific quantity. Although there are only ten symbols, the use of different digits in various positions within a number allows us to represent a wide range of quantities. For example, to express a quantity greater than nine, multiple digits are used, with each digit's position indicating its value. For instance, to represent the number twenty-three, the digit 2 signifies twenty, and the digit 3 represents three, with their positions in the number indicating their respective magnitudes.

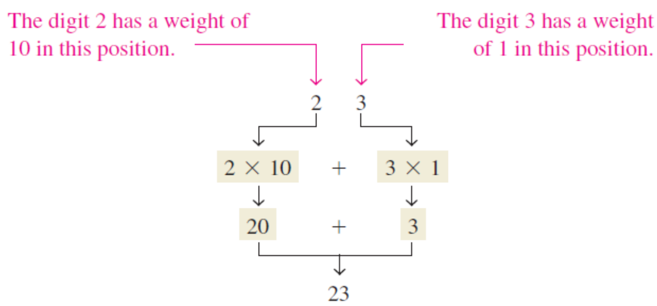



**Fig. 3.14 Addition of decimal number system**

The position of each digit in a decimal number indicates the magnitude of the quantity represented and can be assigned a weight. The weights for whole numbers are positive powers of ten that increase from right to left, beginning with $10^0 = 1$.

$\ldots 10^5\ 10^4\ 10^3\ 10^2\ 10^1\ 10^0$

For fractional numbers, the weights are negative powers of ten that decrease from left to right beginning with $10^{-1}$. The value of a decimal number is the sum of the digits after each digit has been multiplied by its weight.

$$10^2\ 10^1\ 10^0.10^{-1}\ 10^{-2}\ 10^{-3}\ ...$$

Decimal point

**Fig. 3.15 Decimal number system**

**3.3.2 Binary Number:** The binary number system is another method of representing quantities and is simpler than the decimal system because it only uses two digits: 0 and 1. While the decimal system is a base-ten system with ten digits, the binary system is a base-two system. Each digit in a binary number, known as a bit, can be either 0 or 1. The position of each bit in a binary number determines its weight or value, similar to how the position of each digit in the decimal system indicates its value. In binary numbers, the weights are based on powers of two.

A binary count of zero through fifteen is shown in Table 3.8. Notice the patterns with which the 1s and 0s alternate in each column.

Table 3.8 Binary count of decimal digits

| Decimal Number | Binary Number | | | |
|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 |
| 1 | 0 | 0 | 0 | 1 |
| 2 | 0 | 0 | 1 | 0 |
| 3 | 0 | 0 | 1 | 1 |
| 4 | 0 | 1 | 0 | 0 |
| 5 | 0 | 1 | 0 | 1 |
| 6 | 0 | 1 | 1 | 0 |
| 7 | 0 | 1 | 1 | 1 |
| 8 | 1 | 0 | 0 | 0 |
| 9 | 1 | 0 | 0 | 1 |
| 10 | 1 | 0 | 1 | 0 |
| 11 | 1 | 0 | 1 | 1 |
| 12 | 1 | 1 | 0 | 0 |
| 13 | 1 | 1 | 0 | 1 |
| 14 | 1 | 1 | 1 | 0 |
| 15 | 1 | 1 | 1 | 1 |

four bits are required to count from zero to 15. In general, with n bits, one can count up to a number equal to ($2^n$ – 1).

Largest decimal number = $2^n$ - 1

For example, with five bits (n = 5) you can count from zero to thirty-one.

$2^5$ - 1 = 32 - 1 = 31

With six bits (n = 6) you can count from zero to sixty-three.

$2^6$ - 1 = 64 - 1 = 63

**Application of binary number system –** The binary number system is crucial for understanding how digital circuits count events. For instance, consider a scenario where a counter tracks the number of tennis balls entering a box from a conveyor belt. Suppose nine balls are to be collected in each box.

In this setup, the counter, as shown in Figure 3.11, counts pulses from a sensor that detects each ball and generates a sequence of logic levels (digital waveforms) on its four parallel outputs. Each set of these logic levels represents a 4-bit binary number (with HIGH = 1 and LOW = 0). The decoder receives these waveforms, decodes the 4-bit binary number, and displays the corresponding decimal number on a 7-segment display.

When the counter reaches the binary number 1001 (which is 9 in decimal), it indicates that nine balls have been counted. The display then shows the decimal number 9, and a new box is moved into position under the conveyor belt. After this, the counter resets to its zero state (0000) and begins the counting process anew. Note that the use of the number 9 is for simplicity in displaying a single-digit count. Figure 3.16 illustrates this counting process using Boolean logic.

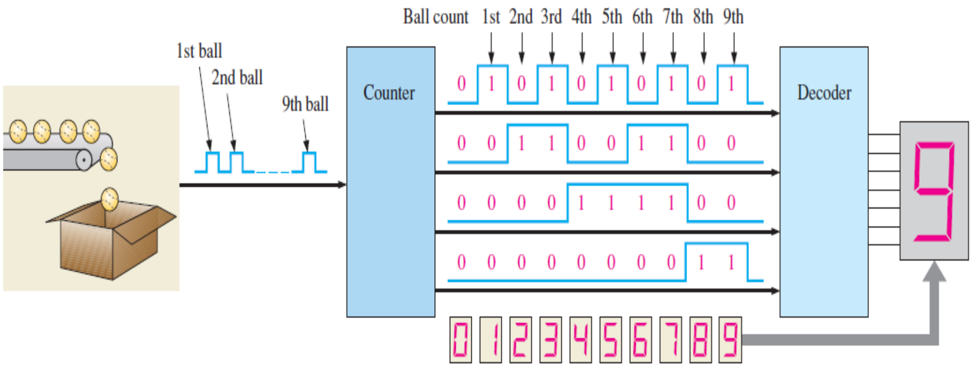



**Fig. 3.16 Illustration of a simple binary counting application**

### 3.3.3 Hexadecimal Number System

The hexadecimal number system, or base-16 system, is frequently utilized in computer science and programming. It includes sixteen digits: 0-9 for the first ten digits and A-F (or a-f) for the remaining six digits. Each hexadecimal digit corresponds to a four-bit binary number, making it a compact and readable way to represent binary values. Hexadecimal is commonly used to simplify binary notation. The conversion from decimal to hexadecimal is illustrated in Table 3.3.

Table 3.9 Hexadecimal of decimal digits

| **Decimal (Base 10)** | **Hexadecimal (Base 16)** |
|---|---|
| **1** | **1** |
| **2** | **2** |
| **3** | **3** |
| **4** | **4** |
| **5** | **5** |
| **6** | **6** |
| **7** | **7** |
| **8** | **8** |
| **9** | **9** |

| | |
|---|---|
| **10** | **A** |
| **11** | **B** |
| **12** | **C** |
| **13** | **D** |
| **14** | **E** |
| **15** | **F** |

For example, the hexadecimal number 2F is equivalent to the binary number 0010 1111, which is equal to the decimal number 43.

### 3.3.4 Octal number system

The octal number system, or base-8 system, uses eight digits: 0 through 7. Although it is less commonly used today, it was prevalent in early computer systems. Each octal digit represents a three-bit binary number. Conversion between octal and binary is straightforward by grouping binary digits into sets of three. For example, the octal number 27 converts to the binary number 010 111, which is equivalent to the decimal number 23.

## Check Your Progress

**A. Multiple Choice Questions**

1. The term bit means (a) A small amount of data (b) 1 or 0 (c) Binary digit (d) Both answers (b) and (c)
2. An inverter (a) Performs the NOT operation (b) Changes a HIGH to a LOW (c) Changes a LOW to a HIGH (d) Does all of the above
3. The output of an OR gate is LOW when (a) Any input is HIGH (b) All inputs are HIGH (c) No inputs are HIGH (d) Both (a) and (b)
4. The output of an AND gate is LOW when (a) Any input is LOW (b) All inputs are HIGH (c) No inputs are HIGH (d) Both (a) and (c)
5. BCD stands for_______. (a) Binary Circuit Design (b) Bit Circuit Decimal (c) Binary Coded Decimal (d) Bit Circuit Design
6. Which of the following logical operation is performed by AND gate? (a) Addition (b) Subtraction (c) Multiplication (d) All of the above
7. Which of the following logical operation is performed by OR gate? (a) Addition (b) Subtraction (c) Multiplication (d) All of the above
8. Which of the following is not an invalid BCD Code? (a) 1011 (b) 1010 (c) 1001 (d) 1100
9. Which of the following logical operation is performed by NOT gate? (a) Addition (b) Subtraction (c) Multiplication (d) Inversion
10. ASCII stands for_______. (a) American Standard Code for Information Interchange (b) American Signal Code for Information Interchange (c) American Standard Code to interchange Information (d) American Standard Code for Inform Interchange

**B. Fill in the blanks**

1. Two broad categories of electronic circuits are _____ and _____.
2. In the decimal number system each of the ten digits, ____ through ____.

3. Digital codes such as binary coded decimal (BCD), ___ and ___ are used in the system.
4. Groups of bits i.e. combinations of 1s and 0s, called ______.
5. A circuit that performs a specified logic function is called a _________.
6. The binary number system and ___________ codes are fundamental to computers and digital electronics in general
7. The OR function produces a ______ output when one or more inputs are _______
8. The AND function produces a ________ output only when all the inputs are ______
9. The NOT function changes one logic level to the _________ logic level
10. The term logic is applied to digital circuits used to implement ____________

**C. State whether the following statements are True or False**

1. Digital signals are continuous in nature. ( )
2. Analog signals are discrete in nature. ( )
3. Binary number system has two state i.e. high and low. ( )
4. Decimal number system is used in our day-to-day life. ( )
5. A logic gate performs logical operations. ( )
6. Digital waveforms consist of voltage levels that are changing back and forth between the HIGH and LOW levels or states. ( )
7. The voltages used to represent a 0 and a 1 are called analog levels. ( )
8. Digital involves quantities with discrete. ( )
9. In digital systems such as computers, combinations of the high and low states are used, which is commonly called as codes. ( )
10. A binary digit is called a bit. ( )

**D. Short answer questions**

1. When does the NOT function produce a HIGH output?
2. When does the AND function produce a HIGH output?
3. When does the OR function produce a HIGH output?
4. What is an inverter?
5. What is a logic gate?
6. Can a digital system exist over a complete interval of time? Why or why not?
7. Define the sequence of bits (1s and 0s) represented by each of the following sequences of levels: HIGH, HIGH, LOW, LOW, LOW, LOW, HIGH, HIGH

   HIGH, LOW, HIGH, LOW, HIGH, LOW, HIGH, LOW
8. Define the term analog.
9. Define the term digital.
10. Explain the difference between a digital quantity and an analog quantity.

# Session 4. Zener Diode, SCR/UJT & Full wave Bridge Rectifier

## 4.1 Basics of Diodes

A diode is made up of two words i.e., "Di "means Two, and "Ode "means Electrodes which means that a device or component has two electrodes. (i.e., cathode and anode). A diode is an electronic device having a two-terminal unidirectional power supply i.e it has two terminals and allows the current to flow only in one direction. Diodes are widely used in modern-day circuits to secure circuits from over-voltage and they are also used to change AC current to DC current.

**Symbol of a Diode**

Diodes are represented using special symbols and the symbol for a standard diode symbol is given below as shown in Figure 4.1. In the given diagram it is clear that a diode has two terminals which are called the cathode and anode. The arrowhead symbol represents the anode and the other end represents the cathode. The current flow from anode to cathode in the forward bias condition.

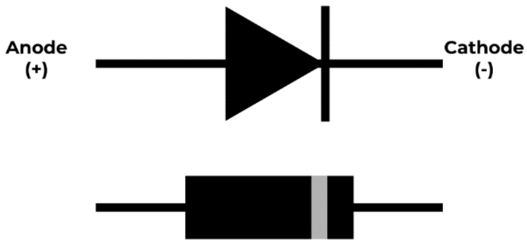



**Fig. 4.1 Symbol of a Diode**

**PN Junction Diode**

The electrical conductivity of a semiconductor material is between that of a conductor, such as metallic copper, and that of an insulator, such as glass. Its resistivity decreases as the temperature rises, whereas metals have the reverse effect. By adding impurities (doping) into the crystal structure, its conducting characteristics can be changed in beneficial ways. Diodes, transistors, and most contemporary electronics are built on the behaviour of charge carriers such as electrons, ions, and electron holes at these junctions.

Silicon, germanium, gallium arsenide, and elements along the periodic table's so-called metalloid staircase are examples of semiconductors. Gallium arsenide is the second most common semiconductor after silicon, and it is used in laser diodes, solar cells, microwave-frequency integrated circuits, and other applications. Silicon is a crucial component in the production of most electrical circuits. It is shown in Figure 4.2.


**Fig. 4.2 PN Diode**

**Bipolar junction**

A bipolar junction transistor is a single silicon component where electrons and holes are used as charge carriers. A bipolar junction transistor lets a small current be injected at one of its terminals to control large amounts of current flowing between the other two terminals. This makes the device capable of performing switching or amplification.

**Bipolar junction transistor is of two types:**

PNP transistor

NPN transistor

This bipolar PNP junction transistor is formed with three layers of semiconductor material, with two P-type regions sandwiched between one N-type region.

**PNP transistor**

The PNP transistor is a type of transistor in which one n-type material is doped with two p-type materials. It is a device that is controlled by the current. Both the emitter and collector currents were controlled by the small amount of base current. Two crystal diodes are connected back-to-back in the PNP transistor. The emitter-base diode is located on the left side of the diode, while the collector-base diode is located on the right side. The current in the hole is made up of the majority of carriers of the PNP transistors.

**Symbol of PNP Transistor:**

The PNP Transistor is denoted by the letters PNP. In the diagram below, the symbol for a PNP transistor is depicted. In a PNP transistor, the current flows from the emitter to the collector, as shown in Figure 4.3 by the inward arrow.

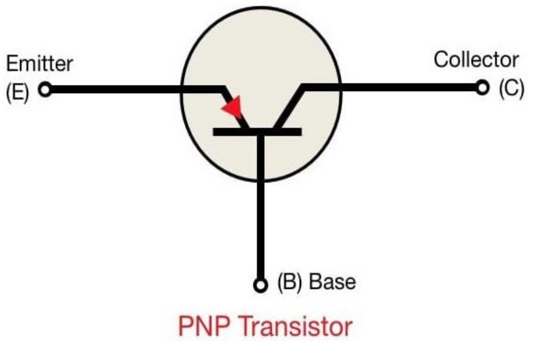



**Fig. 4.3 Symbol of PNP Transistor**

**Construction of PNP Transistor:**

The structure of a PNP transistor is depicted in the diagram below. The emitter and base junctions are forward biased, while the collector and base junctions are reverse biased. The forward biased emitter attracts electrons to the battery, causing current to flow from the emitter to the collector as shown in Figure 4.4.

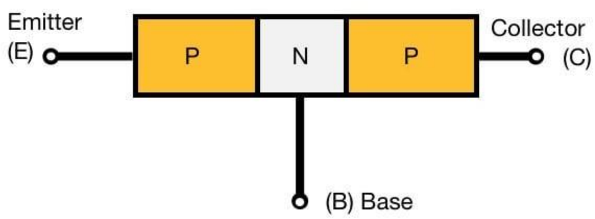



**Fig. 4.4 Construction of PNP Transistor**

Doped semiconductors are found in three sections of a transistor. On one side, there is an emitter, and on the other, there is a collector. The base refers to the area in the middle. The transistor's three components are described in detail below.

**Emitter:** The emitter's job is to provide charge carriers to the receiver. When compared to the base, the emitter is always forward biased in order to supply a large number of charge carriers.

**Base:** The base of a transistor is the section in the middle that forms the two PN-junctions between the emitter and the collector. The base-emitter junction is forward biased, allowing the emitter circuit to have low resistance. Due to the reverse bias of the base-collector junction, the collector circuit has a high resistance.

**Collector:** The collector is the section on the opposite side of the emitter that collects the charges. When it comes to collecting, the collector is always biased in the opposite direction.

**NPN Transistor**

The NPN transistor consists of two n-type semiconductors that sandwich a p-type semiconductor. Here, electrons are the majority charge carriers, while holes are the minority charge carriers. The NPN transistor is represented, as shown in Figure 4.5.

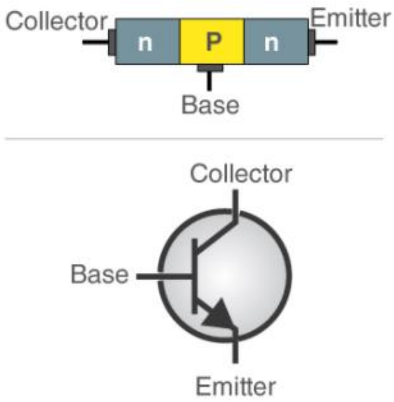



**Fig. 4.5 NPN Transistor**

**Construction of NPN Transistor**

The NPN transistor is made of semiconductor materials like silicon or germanium. When a p-type semiconductor material is fused between two n-type semiconductor materials, an NPN transistor is formed.

The NPN transistor features three terminals: emitter, base and collector. This transistor features two diodes that are connected back to back. The diode seen between the emitter-base terminal is referred to as the emitter-base diode. The diode between collector and base terminal is known as collector-base diodes. It is shown in Figure 4.6.

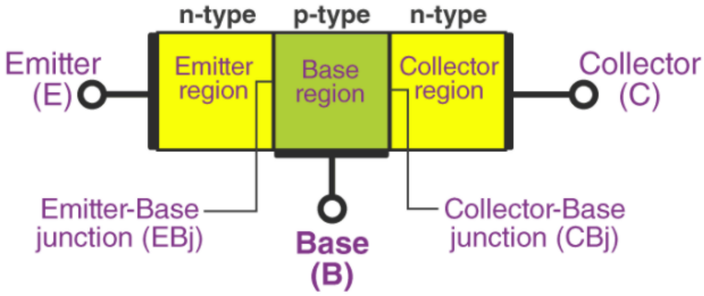



**Fig. 4.6 Construction of NPN Transistor**

**4.2 Zener Diodes**

When a PN-junction diode is reverse biased, the majority carriers (holes in the P-type material and electrons in the N-type material) move away from the junction, causing the depletion region to widen. This expansion increases the resistance of the depletion region, making it difficult for majority carrier current to flow. However, a small leakage current due to minority carriers persists, remaining almost constant until a specific reverse voltage is reached. Beyond this point, known as the **breakdown voltage**, the reverse current rises sharply with even a slight increase in reverse voltage. While any diode can reach this breakdown point, not all are designed to safely handle the associated power. **Zener diodes,** however, are specifically engineered to operate in the reverse-bias breakdown region.

Two distinct mechanisms explain the behavior of PN junctions during breakdown: the **Zener effect** and the **avalanche effect**. In Zener diodes, both effects can occur. The Zener effect is the primary mechanism at lower breakdown voltages, while at higher voltages, the avalanche effect becomes the dominant cause of breakdown.

The **Zener effect** was first proposed by Dr. Carl Zener in 1934. According to Dr. Zener's theory, electrical breakdown in solid dielectrics occurs by a process called quantum-mechanical tunneling. The true Zener effect in semiconductors can be described in terms of energy bands; however, only the two upper energy bands are of interest. The two upper bands, illustrated in the figure below, view A, are called the conduction band and the valence band as shown in Figure 4.7

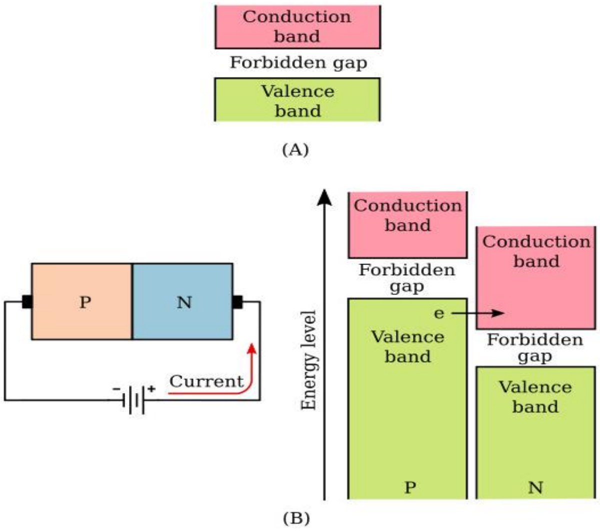



**Figure 4.7 diagram for Zener diode**

The **conduction band** is the energy range where electrons have sufficient energy to move freely under the influence of an external electric field. Since current flow is essentially the movement of electrons, the electrons in the conduction band can easily contribute to this flow when a voltage is applied. As a result, materials with a high number of electrons in the conduction band are known as conductors, as they can efficiently conduct electricity.

The **valence band** is the energy range where electrons have energy levels corresponding to the valence electrons of atoms. These electrons are bound to their respective atoms and, unlike conduction band electrons, are not free to move. However, if enough energy is supplied, electrons in the valence band can be elevated to the conduction band, enabling them to move freely. To make this transition, electrons must cross the gap between the valence band and the conduction band, known as the **forbidden energy band or forbidden gap**. The size of this energy gap determines whether a material behaves as a conductor, semiconductor, or insulator.

In conductors, the forbidden energy gap is so narrow that it is essentially negligible, allowing electrons to move freely and conduct electricity. Semiconductors, on the other hand, have a noticeable forbidden gap, as shown in the diagram. Under normal conditions, a semiconductor does not have electrons at the conduction band level, but the thermal energy at room temperature can provide enough energy to lift a few valence electrons into the conduction band. The introduction of impurities, known as doping, increases the number of free electrons in the conduction band and the number of valence electrons that can transition to the conduction band. In contrast, insulators have a large forbidden gap, preventing electrons from crossing it, which means these materials do not conduct electricity unless subjected to extremely high temperatures.

In a reverse-biased Zener diode, the energy bands of the P-type and N-type materials are naturally at different levels, but the reverse bias causes the valence band of the P-type material to overlap with the conduction band of the N-type material. This overlap allows valence electrons from the P-type material to cross the thin junction region without needing additional energy, a process known as tunneling. When the breakdown voltage of the PN junction is reached, large numbers of minority carriers tunnel across the junction, creating the current observed during breakdown. Tunneling primarily occurs in heavily doped diodes, such as Zener diodes.

The second theory of reverse breakdown in diodes is known as avalanche breakdown, which operates differently from the Zener effect. In the depletion region of a PN junction, thermal energy generates electron-hole pairs. The movement of minority electrons in the electric field across the barrier region causes leakage current. As the reverse voltage increases and reaches a critical point, these thermally released minority electrons gain enough energy to break covalent bonds upon colliding with lattice atoms. This collision releases additional electrons, creating a chain reaction known as the avalanche effect.

When the reverse voltage slightly exceeds the breakdown voltage, the avalanche effect releases a vast number of carriers, making the diode behave like a short circuit. The current in this region is only limited by an external series resistor. Operating a diode in the breakdown region is safe as long as the maximum power dissipation rating of the diode is not exceeded. Once the reverse voltage is removed, all carriers return to their normal energy levels and velocities.

The symbols representing Zener diodes, as shown in the diagram, indicate that electron flow follows the direction of the arrow symbol, unlike in a standard PN-junction diode. This is because breakdown diodes are operated in reverse bias, meaning current flow is primarily due to minority carriers (Figu4.8)

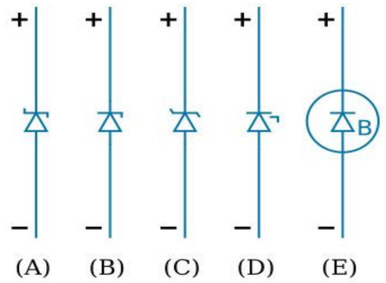



**Fig. 4.8 Schematic symbols for Zener diodes**

Zener diodes come in various types and serve multiple purposes, but their most common application is as voltage regulators. When a Zener diode reaches its breakdown voltage, the voltage across it remains nearly constant, regardless of changes in the supply voltage. This stability allows Zener diodes to maintain a consistent voltage across the load, ensuring a steady output.

**The similarities of a Zener diode with those of general-purpose rectifier diodes are given below:**

1. Zener diodes are also PN junction diodes, which are also generally made of silicon.
2. Zener diodes also have two terminals (anode and cathode).
3. In physical appearance the Zener diodes and ordinary diodes look alike.
4. Like rectifier diodes, Zener diodes are also available with glass plastic and metal casing.
5. The anode and cathode marking technique on the body is same for both Zener and rectifier diodes.

6. The Zener can be tested with an ohm meter in the same way as in rectifier diodes.
7. Zener requires approximately the same voltage for it to be forward biased into conduction as that of an ordinary diode.

**The difference between a rectifier diode and a Zener diode are given below:**

1. Compared to normal rectifier diodes, Zener diodes are heavily doped.
2. Unlike ordinary diodes which do not work in the breakdown region, Zener diodes work only in the breakdown region.
3. General rectifier diodes are used in forward biased condition, whereas Zener are always in reverse biased condition.
4. The reverse breakdown voltage of Zener diodes is very much less (3 to 18V) compared to rectifier diodes (minimum 50V).

**4.3 Silicon Controlled Rectifier (SCR)**

A Silicon Controlled Rectifier (SCR) is a four-layer semiconductor device that functions as an electrically controlled switch. It belongs to the thyristor family and is extensively used in electronic and power control applications. Like a diode, an SCR permits current flow in only one direction, but it can be triggered into conduction by applying a signal to its gate terminal. Constructed from silicon, the SCR is capable of handling high power levels and provides fast switching capabilities, making it ideal for efficiently controlling large amounts of electrical power (Figure 4.9).

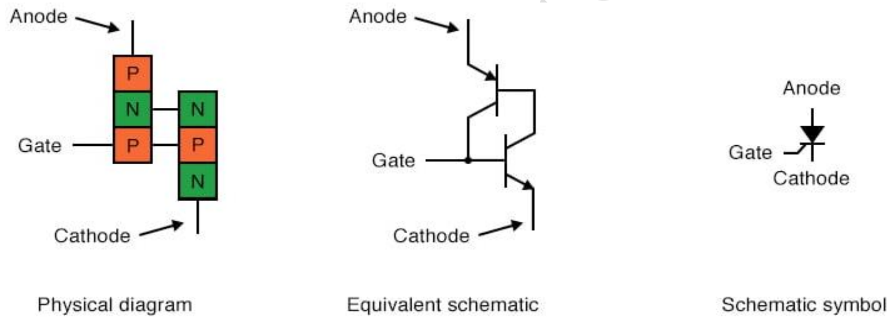



**Fig. 4.9 Silicon Controlled Rectifier**

**The basic structure of an SCR consists of three terminals:**

- Anode (A) is the positive terminal.
- Cathode (K) is the negative terminal.
- Gate (G) is used to control the device.

When a positive voltage is applied to the anode relative to the cathode without any gate current, the SCR remains in the "off" state and does not conduct. However, if a positive gate current is applied while the anode-cathode voltage is positive, the SCR switches to the "on" state and begins conducting. Once triggered, the SCR continues to conduct even if the gate current is removed, until the anode-cathode voltage falls below a certain level, known as the "holding current."

SCRs are ideal for power control applications, including motor speed regulation, lighting control, voltage regulation, and power supplies. They are capable of handling high currents and voltages, often reaching several kilovolts and hundreds or thousands of amperes.

For finding SCRs that meet specific requirements, such as break-over voltage and gate trigger current, you can use the filters on Everything PE's website to narrow down the options based on your needs.

**Testing SCR Functionality with an Ohmmeter**

A rudimentary test of SCR function, or at least terminal identification, may be performed with an ohmmeter. Because the internal connection between gate and cathode is a single PN junction, a meter should indicate continuity between these terminals with the red test lead on the gate and the black test lead on the cathode like this as shown in Figure 4.4.

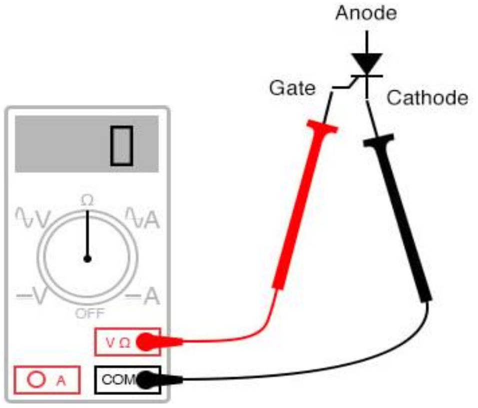



**Fig. 4.10 Rudimentary test of SCR**

When performing continuity measurements on an SCR, the readings often show "open" or "OL" on digital Multimeters, which indicates no conduction. However, this test is quite basic and does not provide a comprehensive evaluation of the SCR's functionality. An SCR may appear to be functional in a continuity test but still be defective. The most reliable way to test an SCR is to apply it to a load current.

If using a multimeter with a "diode check" function, the gate-to-cathode junction voltage you measure may differ from the typical silicon PN junction voltage (approximately 0.7 volts). In some cases, the reading may be significantly lower, often just a few hundredths of a volt. This lower voltage can be attributed to an internal resistor between the gate and cathode in some SCRs. This resistor is designed to prevent false triggering from circuit noise or static discharge, requiring a stronger triggering signal to activate the SCR. This feature is usually present in larger SCRs and less common in smaller ones. It's important to note that an SCR with an internal resistor will show continuity in both directions between the gate and cathode terminals (Figure 4.11).

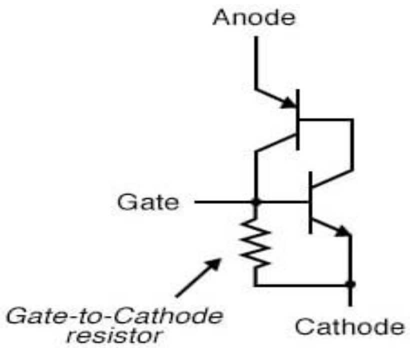



**Fig. 4.11 Larger SCRs have gate to cathode resistor**

**4.4 UNI JUNCTION TRANSISTOR (UJT)**

A Unijunction Transistor (UJT) is a three-terminal semiconductor device known for its unique behaviour when triggered. When a UJT is activated, the emitter current increases in a regenerative manner until it is limited by the emitter power supply. This characteristic makes the UJT particularly useful in applications such as switching pulse generators and saw-tooth wave generators (Figure 4.12).

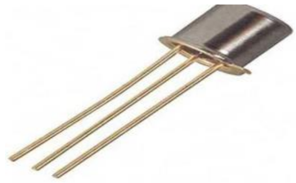
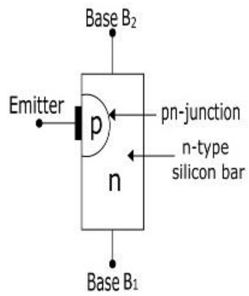


**Fig. 4.12 UNI Junction Transistor (UJT)**

**Construction of UJT**

The UJT is constructed from an n-type silicon semiconductor bar with electrical connections at each end, referred to as the Base terminals (B1 and B2). A pn-junction is formed between a p-type emitter and the n-type silicon bar, located near the Base B2 terminal. This junction is known as the emitter terminal (E). Since the device has three terminals and one pn-junction, for this region this is called as a Unijunction Transistor (UJT)as shown in Figure 4.13 and 4.14.



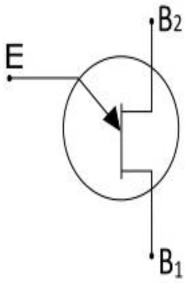




**Fig. 4.13 PN-Junction** **Fig. 4.14 Double based Diode**

The UJT has a single pn-junction, which makes it function as a diode. Since the two base leads are connected to the same section of this diode, the device is also referred to as a Double-Based Diode. The emitter is heavily doped, while the n-type region is lightly doped. As a result, when the emitter terminal is open, the resistance between the base terminals is very high.

**Operation of UJT With Emitter Open**

When the voltage $V_{BB}$ is applied with emitter open. A potential gradient is established along the n-type silicon bar. As the emitter is located close to the base $B_2$, thus a major part of $V_{BB}$ appears between the emitter and base $B_1$. The voltage $V_1$ between emitter and $B_1$, establishes a reverse bias on the pn-junction and the emitter current is cut off, but a small leakage current flows from $B_2$ to emitter due to minority charge carriers. Thus, the device is said to be in OFF state (Figure 4.15).

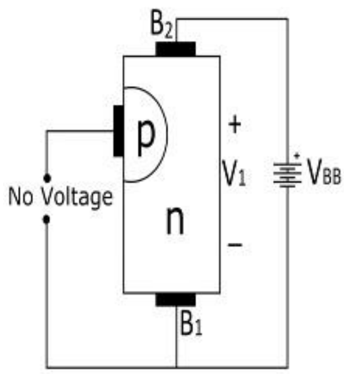



**Fig. 4.15 Operation of UJT**

**With Emitter at Positive Potential**

When a positive voltage is applied at the emitter terminal, the pn-junction will remain reverse biased till the input voltage is less than $V_1$. A soon as the input voltage at emitter exceeds $V_1$, the pn-junction becomes forward biased. Under this condition, holes are supplied from p-type region into the n-type bar. These holes are repelled by positive $B_2$ terminal and attracted towards the $B_1$ terminal. This increase in the number of holes in the emitter to $B_1$ region results in the decrease of resistance of this section of the bar. Because of this, the internal voltage drop from emitter to $B_1$ region is reduced, thus the emitter current ($I_E$) increases. As more holes are supplied, a condition of saturation is reached. At the point of saturation, the emitter current is limited by the emitter power supply. Now, the device is conducting, hence said to be in ON state (Figure 4.16).

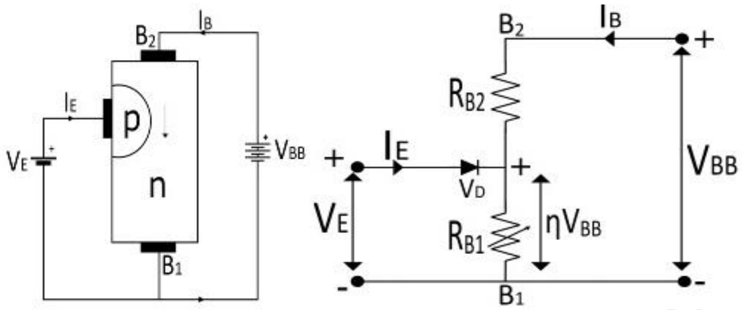



**Fig. 4.16 Positive voltage at emitter terminal**

**Equivalent Circuit of UJT**

- The resistance of silicon bar is called as the **inter-base resistance** (has a value from 4 kΩ to 10 kΩ).
- The resistance $R_{B1}$ is the resistance of the bar between emitter and $B_1$ region. The value of this is variable and depends upon the bias voltage across the pn-junction.
- The resistance $R_{B2}$ is the resistance of the bar between emitter and $B_2$ region.
- The emitter pn-junction is represented by a diode.
- With no voltage applied to the UJT, the value of inter-base resistance is given by

RBB = RB1 + RB2 RBB = RB1+ RB2

- The intrinsic **stand-off ration (η)** of UJT is given by

η = V1VBB = RB1 RB1 + RB2 *η*= V1VBB = RB1 RB1 + RB2

The voltage across RB1 is

V1 = RB1 RB1 + RB2 VBB = η VBB

- The value of η generally lies between 0.51 and 0.82.
- The **Peak Point Voltage (VP)** of the UJT

  Vp = ηVBB + VDVp = *η*VBB + VD

**Characteristics of UJT**

The curve between emitter voltage ($V_E$) and emitter current ($I_E$) of UJT, at a given value of $V_{BB}$ is known as emitter characteristics of UJT as shown in Figure 4.17.

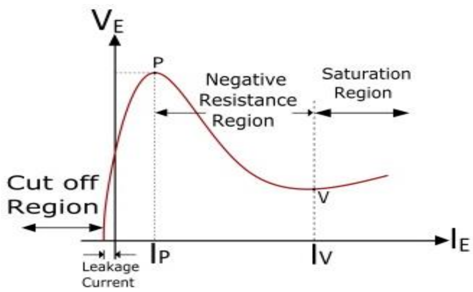



**Fig. 4.17 Curve emitter of UJT**

**Characteristics are Important points**

- At first, in the cut off region, when the emitter voltage increases from zero, due to the minority charge carriers, a small current flow from terminal $B_2$ to emitter. This is called as leakage current.
- Above the definite value of $V_E$, the emitter current ($I_E$) starts to flow and increases until the peak ($V_P$ and $I_P$) is reached at point P.
- After point P, an increase in $V_E$ causes a sudden increase in $I_E$ with a corresponding decrease in $V_E$. This is the **Negative Resistance Region** of the curve as with the increase in $I_E$, $V_E$ decreases.
- The negative resistance region of the curve ends at the **valley-point (V)**, having valley-point voltage $V_V$ and current $I_V$. After the valley-point the device is driven to saturation.

**Advantages of UJT**

- Low cost
- Excellent characteristics
- Low power absorbing device under normal operating conditions

**Applications of UJT**

- Oscillators
- Trigger Circuits
- Saw tooth generator
- Bi-stable networks
- Pulse and voltage sensing circuits
- UJT relaxation oscillators
- Over voltage detectors

## 4.5 Full Wave Rectifier

Electric circuits that convert AC to DC are known as rectifiers. Rectifiers are classified into two types as Half Wave Rectifiers and Full Wave Rectifiers. Significant power is lost while using a half-wave rectifier and is not feasible for applications that need a smooth and steady supply. For a more smooth and steady supply, we use the full wave rectifiers.

### 4.5.1 Defining Full Wave Rectifiers

A full wave rectifier is defined as a rectifier that converts the complete cycle of alternating current into pulsating DC.

Unlike halfwave rectifiers that utilize only the halfwave of the input AC cycle, full wave rectifiers utilize the full cycle. The lower efficiency of the half wave rectifier can be overcome by the full wave rectifier.

### 4.5.2 Full Wave Rectifier Circuit

The circuit of the full wave rectifier can be constructed in two ways. The first method uses a centre tapped transformer and two diodes. This arrangement is known as a centre tapped full wave rectifier. The second method uses a standard transformer with four diodes arranged as a bridge. This is known as a bridge rectifier as shown in Figure 4.18.

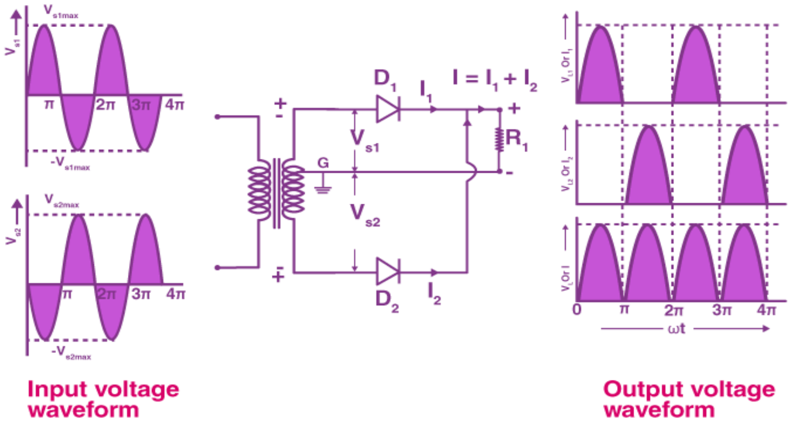



**Fig. 4.18 Full Wave Rectifier**

The circuit of the full wave rectifier consists of a step-down transformer and two diodes that are connected and centre tapped. The output voltage is obtained across the connected load resistor.

**Working of Full Wave Rectifier**

The input AC supplied to the full wave rectifier is very high. The step-down transformer in the rectifier circuit converts the high voltage AC into low voltage AC. The anode of the centre tapped diodes is connected to the transformer's secondary winding and connected to the load resistor. During the positive half cycle of the alternating current, the top half of the secondary winding becomes positive while the second half of the secondary winding becomes negative.

During the positive half cycle, diode D1 is forward biased as it is connected to the top of the secondary winding while diode D2 is reverse biased as it is connected to the bottom of the secondary winding. Due to this, diode D1 will conduct acting as a short circuit and D2 will not conduct acting as an open circuit

During the negative half cycle, the diode D1 is reverse biased and the diode D2 is forward biased because the top half of the secondary circuit becomes negative and the bottom half of the circuit becomes positive. Thus, in a full wave rectifier, DC voltage is obtained for both positive and negative half cycle.

**Full Wave Rectifier Formula**

**Peak Inverse Voltage**

Peak inverse voltage is the maximum voltage a diode can withstand in the reverse-biased direction before breakdown. The peak inverse voltage of the full-wave rectifier is double that of a half-wave rectifier. The PIV across D1 and D2 is 2Vmax.

**DC Output Voltage**

The following formula gives the average value of the DC output voltage:

$Vdc = IavRL = 2/\pi ImaxRL$

**RMS Value of Current**

The RMS value of the current can be calculated using the following formula:

$Irms = Imax/\sqrt{2}$

**Form Factor**

The form factor of the full wave rectifier is calculated using the formula:

$K_f = \frac{\text{RMSvalueofcurrent}}{\text{Averagevalueofcurrent}} = I_{rms}/\mathrm{I}_{dc} = I_{max}/\sqrt{2}/2I_{max}/\pi = \pi/2\sqrt{2} = 1.11$

**Peak Factor**

The following formula gives the peak factor of the full wave rectifier:

$K_p = \frac{\text{Peakvalueofcurrent}}{\text{RMSvalueofcurrent}} = I_{max}/I_{max}\ \sqrt{2} = \sqrt{2}$

**Rectification Efficiency**

The rectification efficiency of the full-wave rectifier can be obtained using the following formula:

$\eta = \frac{\text{DCOutputPower}}{\text{ACOutputPower}}$

The efficiency of the full wave rectifiers is 81.2%.

Advantages of Full Wave Rectifier

- The rectification efficiency of full wave rectifiers is double that of half wave rectifiers. The efficiency of half wave rectifiers is 40.6% while the rectification efficiency of full wave rectifiers is 81.2%.
- The ripple factor in full wave rectifiers is low hence a simple filter is required. The value of ripple factor in full wave rectifier is 0.482 while in half wave rectifier it is about 1.21.
- The output voltage and the output power obtained in full wave rectifiers are higher than that obtained using half wave rectifiers.

**4.6 Bridge Rectifier**

Electronic circuits require a rectified DC power supply to power various electronic basic components from the available AC mains supply. Rectifiers are used to convert an AC power to a DC power. Among the rectifiers, the bridge rectifier is the most efficient rectifier circuit.

We can define bridge rectifiers as a type of full-wave rectifier that uses four or more diodes in a bridge circuit configuration to efficiently convert alternating (AC) current to a direct (DC) current.

**4.6.1 Construction of Bridge Rectifier**

The construction of a bridge rectifier is shown in the Figure 4.19. The bridge rectifier circuit is made of four diodes D1, D2, D3, D4, and a load resistor RL. The four diodes are connected in a closed-loop configuration to efficiently convert the alternating current (AC) into Direct Current (DC). The main advantage of this configuration is the absence of the expensive centre-tapped transformer. Therefore, the size and cost are reduced.

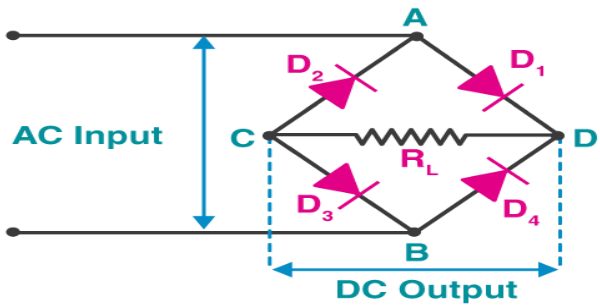



**Fig. 4.19 Bridge Rectifier**

The input signal is applied across terminals A and B, and the output DC signal is obtained across the load resistor RL connected between terminals C and D. The four diodes are arranged in such a way that only two diodes conduct electricity during each half cycle. D1 and D3 are pairs that conduct electric current during the positive half cycle. Likewise, diodes D2 and D4 conduct electric current during a negative half cycle.

**4.6.2 Working**

When an AC signal is applied across the bridge rectifier, terminal A becomes positive during the positive half cycle while terminal B becomes negative. This results in diodes D1 and

D3 becoming forward biased while D2 and D4 becoming reverse biased. The current flow during the positive half-cycle as shown in Figure 4.20.

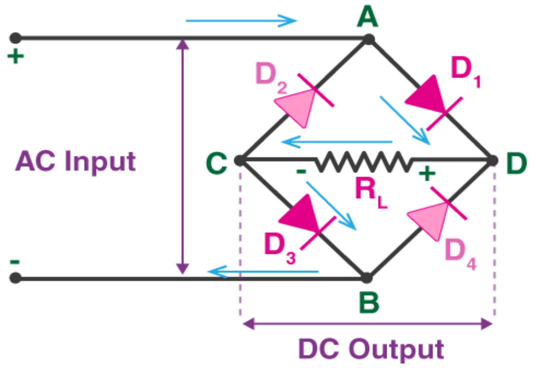



**Fig. 4.20 Current flow the Positive half cycle Bridge Rectifier**

During the negative half-cycle, terminal B becomes positive while terminal A becomes negative. This causes diodes D2 and D4 to become forward biased and diode D1 and D3 to be reverse biased. The current flow during the negative half cycle as shown in the Figure 4.21.

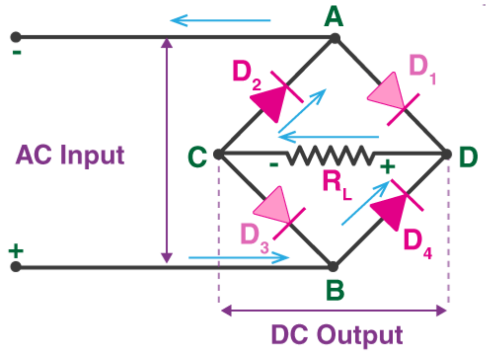



**Fig. 4.21 Current flow the negative half cycle Bridge Rectifier**

From the figures discussed in the successive paragraphs, we notice that the current flow across load resistor RL is the same during the positive and negative half-cycles. The output DC signal polarity may be either completely positive or negative. In our case, it is completely positive. If the diodes' direction is reversed, we get a complete negative DC voltage.

A bridge rectifier allows electric current during both positive and negative half cycles of the input AC signal. The output waveforms of the bridge rectifier as shown in the Figure 4.22.

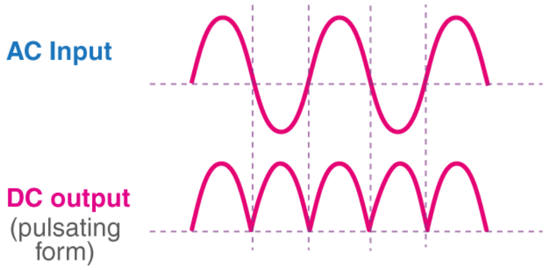



**Fig. 4.22 The output waveforms of the bridge rectifier**

### 4.6.3 Characteristics of Bridge Rectifier

**Ripple Factor**

The smoothness of the output DC signal is measured by a factor known as the ripple factor. The output DC signal with fewer ripples is considered a smooth DC signal while the output with high ripples is considered a high pulsating DC signal.

Mathematically, the ripple factor is defined as the ratio of ripple voltage to pure DC voltage.

The ripple factor for a bridge rectifier is given by $\gamma = (Vrms2VDC) - 1$ For bridge rectifiers, the ripple factor is 0.48.

**Peak Inverse Voltage**

The maximum voltage that a diode can withstand in the reverse bias condition is known as a peak inverse voltage. During the positive half cycle, the diodes D1 and D3 are in the conducting state while D2 and D4 are in the non-conducting state. Similarly, during the negative half cycle, diodes D2 and D4 are in the conducting state, and diodes D1 and D3 are in the non-conducting state.

**Efficiency**

The rectifier efficiency determines how efficiently the rectifier converts Alternating Current (AC) into Direct Current (DC). Rectifier efficiency is defined as the ratio of the DC output power to the AC input power. The maximum efficiency of a bridge rectifier is 81.2%.

$\eta = DC\ Output\ Power\ AC\ Output\ Power$

**Advantages**

- The efficiency of the bridge rectifier is higher than the efficiency of a half-wave rectifier. However, the rectifier efficiency of the bridge rectifier and the centre-tapped full-wave rectifier is the same.
- The DC output signal of the bridge rectifier is smoother than the output DC signal of a half-wave rectifier.
- In a half-wave rectifier, only half of the input AC signal is used, and the other half is blocked. Half of the input signal is wasted in a half-wave rectifier. However, in a bridge rectifier, the electric current is allowed during both positive and negative half cycles of the input AC signal. Hence, the output DC signal is almost equal to the input AC signal.

**Disadvantages**

- The circuit of a bridge rectifier is complex when compared to a half-wave rectifier and centre-tapped full-wave rectifier. Bridge rectifiers use 4 diodes while half-wave rectifiers and centre-tapped full wave rectifiers use only two diodes.
- When more diodes are used more power, loss occurs. In a centre-tapped full-wave rectifier, only one diode conducts during each half cycle. But in a bridge rectifier, two diodes connected in series conduct during each half cycle. Hence, the voltage drop is higher in a bridge rectifier.

## Check Your Progress

**A. Multiple Choice Question**

1. When a PN-junction diode is reverse biased, what happens to the depletion region? (a) It narrows (b) It remains the same (c) It widens (d) It disappears
2. Which effect is dominant in Zener diodes at higher breakdown voltages? (a) Avalanche Effect (b) Zener Effect (c) Tunneling Effect (d) Quantum Effect
3. What is the primary application of Zener diodes? (a) Voltage regulation (b) Signal amplification (c) Oscillation (d) Power switching
4. In which region do Zener diodes operate when they are used as voltage regulators? (a) Forward-biased region (b) Breakdown region (c) Active region (d) Cut-off region

5. What is the main difference between Zener diodes and rectifier diodes? (a) Zener diodes are used in forward bias (b) Rectifier diodes operate in the breakdown region (c) Zener diodes are heavily doped and operate in reverse bias (d) Rectifier diodes have lower breakdown voltage than Zener diodes
6. What does the UJT consist of? (a) A n-type semiconductor with two p-type junctions (b) A p-type semiconductor with two n-type junctions (c) An n-type silicon bar with a single p-type emitter (d) A p-type silicon bar with a single n-type emitter
7. What is the intrinsic stand-off ratio (η) of a UJT given by? (a) η = V1 / VBB (b) η = RB1 / (RB1 + RB2) (c) η = (RB1 + RB2) / RB1 (d) η = VBB / V1
8. In which condition does the UJT enter the ON state? (a) When emitter voltage is less than V1 (b) When the emitter terminal is open (c) When emitter voltage exceeds V1 (d) When emitter current is zero
9. Which of the following is NOT a typical application of a UJT? (a) Oscillators (b) Full wave rectifiers (c) Saw tooth generators (d) Bi-stable networks
10. What is the advantage of using a full wave rectifier over a half wave rectifier? (a) Higher peak inverse voltage (b) Lower rectification efficiency (c) Utilizes the full cycle of input AC (d) Higher ripple factor

**B. Fill in the blanks**

1. When a PN-junction diode is reverse biased, the ............ carriers move away from the junction, causing the depletion region to ............
2. The Zener effect is predominant at ............ breakdown voltages, while the .................... effect is dominant at higher breakdown voltages.
3. In a reverse-biased Zener diode, the ............... band of the P-type material overlaps with the ................. band of the N-type material.
4. The peak inverse voltage (PIV) across the diodes in a full-wave rectifier is ........... times that of a half-wave rectifier.
5. The rectification efficiency of a full-wave rectifier is ........... compared to ........... for a half-wave rectifier.
6. The UJT is also known as a ............... due to its single pn-junction and two base leads.
7. The intrinsic stand-off ratio (η) is given by the formula η = ........./ (RB1 + RB2).
8. In a full wave rectifier, the peak inverse voltage (PIV) across each diode is .......... the maximum voltage of the AC signal.
9. The ripple factor of a bridge rectifier is given by $\gamma = (Vrms\text{^}2\ /\ VDC) - 1$, and for bridge rectifiers, it is .................
10. The UJT's emitter current (IE) increases as more holes are supplied, leading to a condition of .................

**C. State whether the following statements are True or False**

1. Zener diodes operate in the breakdown region when used for voltage regulation.
2. The avalanche effect occurs in Zener diodes at lower breakdown voltages.
3. A Silicon Controlled Rectifier (SCR) can conduct in only one direction.
4. Zener diodes have a wider forbidden gap compared to insulators.
5. The peak factor of a full-wave rectifier is equal to √2.

6. The emitter of a UJT is lightly doped while the n-type region is heavily doped.
7. In a bridge rectifier, only two diodes conduct during each half cycle of the input AC signal.
8. The rectification efficiency of a full wave rectifier is higher than that of a half wave rectifier.
9. The full wave rectifier uses a centre-tapped transformer and two diodes in its basic configuration.
10. The bridge rectifier is less efficient than the centre-tapped full wave rectifier.

**D. Short/Long Questions**

1. Explain the difference between the Zener effect and the avalanche effect in Zener diodes.
2. Describe the construction and function of a Silicon Controlled Rectifier (SCR).
3. Describe the basic construction of a UJT.
4. Explain the difference in operation of a UJT when the emitter terminal is open versus when it is at a positive potential.
5. How does the efficiency of a bridge rectifier compare to that of a half wave rectifier?

# Module 4 Fundamentals of Refrigeration and Air Conditioning

## Module Overview

Mechanical measurement involves the use of sensors and instruments to quantify various physical parameters such as force, pressure, temperature, flow rate, and position. In many systems, including refrigeration and air conditioning, mechanical measurement and control are intricately linked. Accurate measurements are essential for monitoring system performance and ensuring that it operates efficiently within desired parameters.

In a refrigeration system, mechanical measurements are crucial for assessing the system's performance. Parameters such as pressure and temperature need to be continuously monitored to ensure that the refrigeration cycle operates correctly. For example, pressure gauges measure the pressure of refrigerants in the system, while temperature sensors monitor the temperature of the refrigerant at various points. These measurements help in adjusting the system's operation to maintain optimal performance and prevent potential issues such as overheating or inefficient cooling.

Mechanical measurements are similarly vital in air conditioning systems, where they play a key role in maintaining comfortable indoor environments. Temperature sensors measure the temperature of the air entering and exiting the air conditioning unit. Pressure sensors monitor the pressure within the system to ensure it operates within safe and efficient limits. Flow rate meters measure the amount of air or refrigerant circulating through the system, helping to ensure proper distribution and cooling.

To maintain optimal conditions, understanding the principles behind refrigeration is essential. Refrigeration relies on the principles of thermodynamics and heat transfer. By understanding how refrigerants absorb and release heat during phase changes, engineers can design systems that efficiently transfer heat from indoor spaces to the outdoors, thus providing cooling.

Mechanical tools and equipment used in air conditioning systems include various types of sensors, gauges, and controllers. For instance, pressure gauges are used to monitor refrigerant pressures, while thermometers measure temperatures at different points in the system. Controllers adjust system settings based on the readings from these measurements to ensure that the system maintains the desired temperature and pressure levels.

Overall, mechanical measurement is fundamental to the effective operation of refrigeration and air conditioning systems. By continuously monitoring and controlling various parameters, these systems can provide reliable and efficient cooling, ensuring optimal conditions in indoor environments. Understanding and utilizing the correct mechanical tools and principles are crucial for achieving these goals.

## Learning Outcomes

After completing this module, you will be able to:

- The principles and techniques for accurate measurement in electrical and mechanical systems.
- The basic concepts of thermodynamics, including heat transfer, energy, and the laws governing thermodynamic processes.
- Identify and explain the function of key components in refrigeration and air conditioning systems.
- The properties, types, and environmental impact of refrigerants used in cooling systems.

## Module Structure

| |
|---|
| Session 1. Basics of measurement |
| Session 2. Thermodynamics |
| Session 3. Basic Components of Refrigeration and Air Conditioning |
| Session 4. Refrigerants |

# Session 1. Basics of measurement

Kanak wants to measure the height and weight of her daughter Aarvi. She took Aarvi to the stand where the weight and height were measured. But every time she measured she found a wrong reading. Then she decided to take the help of an expert. The expert tells her about the accurate and precise method of measurement. She also tells her about the types of errors and how they affect the measurement. Figure 1.1 illustrates that Kanak is trying to measure the weight and height of her daughter Aarvi but every time she finds a different measurement.

**Fig. 1.1 Kanak trying to measure the height and weight of her daughter**

In this chapter, we will explore the principles of measurement, including the use of SI units and the identification of errors. Measurement is the process of quantifying the extent, amount, or size of an object or phenomenon.

We will examine how measurements are taken using a variety of tools and instruments, such as rulers, thermometers, scales, and spirit levels. These measurements can be expressed in different units, including meters, grams, and degrees Celsius.

For effective air conditioning installation, precise and accurate measurements are essential. Without proper calculations and measurements, technicians would be unable to successfully install and calibrate air conditioning systems.

## 1.1 UNITS OF MEASUREMENT

Units of measurement are standardized quantities used to express the value or amount of physical properties such as length, mass, time, temperature, electric current, and luminosity. There are various systems of measurement in use around the world. They are as follows –

a) The FPS (foot, pound, second) system

b) The CGS (centimeter, gram, second) system

c) MKS (meter, kilogram, second) system

d) SI system or the International System of Standards

But the most widely used system is the International System of Units (SI), which is based on the metric system.

### 1.1.1 International System of Units (SI)

The International System of Units has the abbreviation SI from the French 'Le Système International d'Unités'. The SI is at the center of all modern science and technology and is used worldwide to ensure measurements can be standardized everywhere. There are tremendous benefits to using SI units and countries routinely compare their SI measurement standards. This keeps measurements made in different countries compatible with one another.

**Base SI units -** There are seven base units of the SI, in terms of which all physical quantities can be expressed in Table 1.1

Table 1.1 Basic SI units

| Quantities | SI unit | Symbol |
|---|---|---|
| Length | meter | M |
| Mass | kilogram | kg |
| Time | second | S |
| Electric current | ampere | A |

| | | |
|---|---|---|
| Temperature | kelvin | K |
| Amount of substance | mole | mol |
| Luminous intensity | candela | Cd |

**Derived SI unit-** All measurements can be expressed using combinations of the seven base units. These combinations are called derived units. Several derived units can be formed by these seven basic units; some of the derived units are expressed in Table 1.2.

Table 1.2 Derived SI units

| Quantities | SI unit | Symbol |
|---|---|---|
| Area | square meter | $m^2$ |
| Volume | cubic meter | $m^3$ |
| Velocity | meters per second | m/s or $ms^{-1}$ |
| Acceleration | meters per second squared | $m/s^2$ or $ms^{-2}$ |
| Force | Newton | N |
| Energy | Joule | J |
| Power | Watt | W |
| Pressure | Pascal | Pa |

**Know more...**

The SI unit has other two equivalent units for temperature, which are degree Celsius (°C) and degree Fahrenheit (°F). 0 °C is equal to 273.15 K and similarly 0°F is equal to 255.372 K.

The formula used for the conversion of **Kelvin in Celsius** is, Kelvin = (Celsius + 273.15)

The formula used for the conversion of **Kelvin to Fahrenheit** is, °F = (K − 273.15) × 9/5 + 32,

The formula to convert **Celsius to Fahrenheit** is given by: °F = °C × (9/5) + 32.

**Internationally accepted SI exceptions -** The International System of Units (SI) provides a standardized system for measuring physical quantities. While the system is widely accepted and used around the world, there are some exceptions or variations to its use in certain countries or regions.

**a) United States customary units -** The United States continues to use a non-SI system of measurement alongside the SI system. This system, known as the United States customary units, includes units such as inches, feet, pounds, and gallons.

**b) Imperial units -** In some countries, such as the United Kingdom, imperial units are still used alongside the SI system. Imperial units include units such as inches, feet, ounces, and pounds.

**c) Astronomical units -** Astronomical units, which are used to measure distances in space, are not part of the SI system but are recognized by the International Astronomical Union.

**d) Nautical miles -** Nautical miles, which are used to measure distances at sea, are not part of the SI system but are recognized by the International Hydrographic Organization.

e) **Non-metric units for time -** In some cases, non-metric units are used to measure time, such as the hour, minute, and second, which are not based on the decimal system.

Some of the Internationally accepted SI units are expressed in Table 1.3

Table 1.3 Internationally accepted SI units

| Name | Symbol | Quantity | Equivalent SI unit |
|---|---|---|---|
| minuet | min | time | 1 min = 60 sec |
| hour | hrs | time | 1 hrs = 3600 sec |
| Day | day | time | I day = 86400 sec |
| degree of arc | ° | angle | 1° = (π/180) rad |
| minute of arc | ' | angle | 1' = (π/10800) rad |
| second of arc | '' | angle | 1'' = (π/648000) rad |
| hectare | ha | area | 1 ha = 10000 $m^2$ |
| litter | L or l | volume | 1 L = 0.001 $m^3$ |
| tonne | t | mass | 1 t = 1000 kg |

**1.1.2 Prefixes used for multiple units**

SI prefixes are a system of prefixes used to denote multiples or fractions of the base units of the International System of Units (SI). These prefixes are used to form the names of metric units by combining them with the names of the base units. Some of the prefixes are expressed in Table 1.4.

Table 1.4 Prefix for unit

| Prefix | Symbol | Power of 10 |
|---|---|---|
| Yotta | Y | $10^{24}$ |
| Zetta | Z | $10^{21}$ |
| Exa | E | $10^{18}$ |
| Peta | P | $10^{15}$ |
| Tera | T | $10^{12}$ |
| Giga | G | $10^{9}$ |
| Mega | M | $10^{6}$ |
| Kilo | k | $10^{3}$ |
| Hecto | h | $10^{2}$ |
| Deca | da | $10^{1}$ |
| Deci | d | $10^{-1}$ |
| Centi | c | $10^{-2}$ |
| Milli | m | $10^{-3}$ |
| Micro | µ | $10^{-6}$ |
| Nano | n | $10^{-9}$ |

| | | |
|---|---|---|
| Pico | p | $10^{-12}$ |
| Femto | f | $10^{-15}$ |
| Atto | a | $10^{-18}$ |
| Zepto | z | $10^{-21}$ |
| Zepto | y | $10^{-24}$ |

## 1.2 MEASUREMENT IN PRACTICE

Measurement is an essential component of many practices, including scientific research, engineering, manufacturing, and quality control. It allows practitioners to gather objective data, identify patterns and trends, and make informed decisions based on that information. To measure effectively, it is important to establish clear and specific criteria for what is being measured. This may involve defining the units of measurement, determining the appropriate instruments or tools to use, and establishing a consistent method for collecting and analysing data.

### 1.2.1 Elements of measurement system

The measurement system can be understood with the help of a block diagram. It consists of six major elements namely Primary Sensing Element, Variable Conversion Element, Variable manipulation element, Data-Transmission Element, Data presentation element, and Data Storage/Playback Element. Figure 1.2 illustrates the various elements of the measurement system and its use in the measurement.

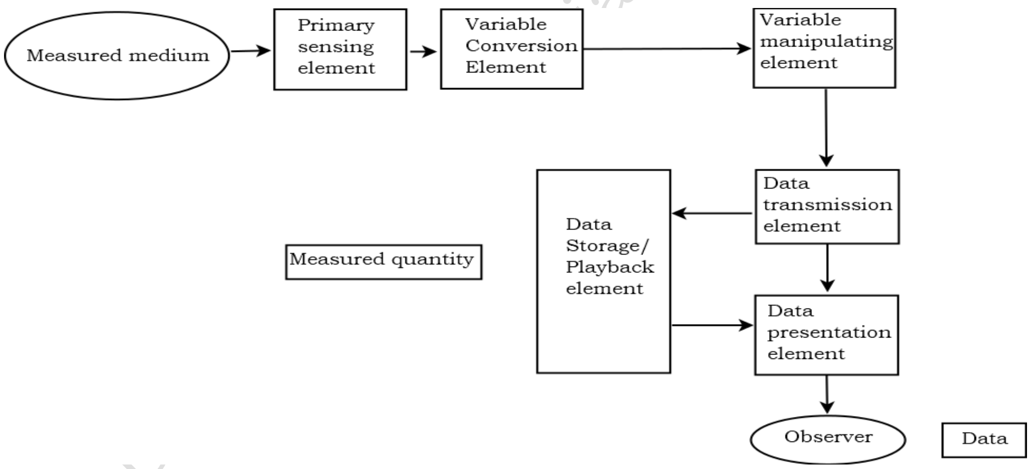



**Fig. 1.2 Block diagram of the measurement process**

**Primary Sensing Element –** It is the first element near the measured medium. It receives the energy from the measured medium and provides output depending upon the measured quantity.

This can be understood with a simple example, suppose a technician wants to measure the displacement of some quantity. Then the instrument he/she uses, first extracts some energy from the displacement with the help of a transducer.

**Variable Conversion Element –** It converts one form of energy into another form. In other words, the output of the primary sensing element is converted into another more suitable variable but in this process, original information remains preserved.

**Variable manipulation element –** This element is utilized for data representation, such as in a "dial gauge." The displacement signal received from the transducer is shown on the meter's dial.

This signal acts as a controlling parameter, and it remains stable at a given point, allowing for precise measurement and monitoring.

**Data-Transmission Element –** This element is used for transmitting data to another system. For instance, if an analog dial signal needs to be converted into readable digital digits, this element performs that conversion. It enables the transition from analog to digital formats, facilitating accurate data interpretation and integration with digital systems.

**Data presentation element –** This element is used when digital signals are required for monitoring, analysis, and control of parameters. It converts various inputs into digital formats, enabling precise tracking, evaluation, and regulation of different parameters in a system.

**Data Storage/Playback Element –** This element is used for storing and retrieving data for future use. It ensures that information is saved securely and can be accessed or analyzed as needed, facilitating long-term data management and retrieval.

### 1.2.2 Method of measurement

The method of measurement can be classified into two broad categories: Direct method and Indirect method.

**Direct method–** In this method, the unknown quantity is directly compared to a standard quantity, with the final result expressed as a numerical value along with a unit of measurement. The direct method is widely used for measuring physical quantities such as length, mass, and time, and is one of the most common techniques for obtaining accurate measurements.

**Indirect method –** Direct measurement methods are not always practical or feasible, often facing inaccuracies due to human error and limited sensitivity. Consequently, these methods are generally less preferred and used infrequently.

On the other hand, the indirect method utilizes a transducing element to convert the quantity being measured into an analogous form. This analogous signal is subsequently processed and converted into the final measurement.

### 1.2.3 Instruments

An instrument can be defined as a device used to determine the value or magnitude of a quantity or variable being measured. Instruments are primarily categorized into three types: mechanical, electronic, and electrical. However, they can broadly be classified into two main categories: Absolute instruments and Secondary instruments.

**Absolute instruments –** An absolute instrument is a measuring device that provides a direct and independent measurement of a physical quantity, without requiring calibration or comparison to a reference standard. This type of instrument delivers accurate measurements of a quantity unaffected by external factors. Examples of absolute instruments include thermocouples, optical pyrometers, and certain pressure gauges.

**Secondary instruments –** Secondary instruments, also known as comparative instruments, determine the value of a physical quantity by comparing it to a reference standard. These instruments require calibration or verification against a known standard to ensure accuracy. Examples of secondary instruments include rulers, callipers, and voltmeters.

### 1.2.4 Accuracy, Precision, and Uncertainty

Accuracy, precision, and uncertainty are the three major factors that are to be considered during measurements. Let us understand one by one accuracy, precision and uncertainty.

**Accuracy –** Accuracy refers to how close a measurement is to the true value of the quantity being measured. It indicates how well the measurement represents the actual value. To enhance accuracy, it is essential to properly calibrate measurement tools and use them correctly, while also minimizing sources of error such as temperature or pressure variations.

For instance, if the true weight of an object is 100 grams, an accurate measurement would be very close to 100 grams, whereas an inaccurate measurement might be 90 grams or 110 grams.

**Precision –** Precision refers to the degree to which repeated measurements of the same quantity under identical conditions yield the same result. In other words, precision measures the consistency of measurements when taken multiple times.

Achieving high precision is crucial in many fields, especially where small differences in measurements can have significant effects. However, it's important to note that high precision does not necessarily imply high accuracy. Precision is about the consistency of results, while accuracy measures how close a measurement is to the true value.

For example, in archery, shooting arrows at a target can illustrate the concepts of accuracy and precision. Accuracy is reflected by how close the arrows land to the centre of the target (the 'true answer'), while precision is shown by the cluster of arrows closely grouped together, regardless of whether they are near the centre or not.

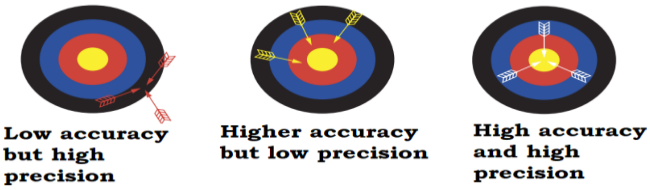



**Fig. 1.3 Accuracy and precision**

**Uncertainty –** Uncertainty refers to the lack of certainty or precision in a measurement or prediction. It quantifies the doubt surrounding the measurement result and provides insight into the quality of the measurement.

Uncertainty can stem from various sources, such as measurement errors, limitations of the measurement instruments or techniques, variations in environmental conditions, and incomplete or inaccurate models. Understanding and addressing uncertainty is essential for evaluating the reliability and accuracy of measurements and predictions.

### 1.2.5 Repeatability, Reproducibility, and Replicability

Repeatability and Reproducibility are the keys to the measurement of the quality of the experiment. In this section, we will discuss the difference between repeatability and reproducibility.

**Repeatability –** Repeatability refers to the ability to achieve consistent or similar results when an experiment or test is repeated under the same conditions. By performing the same measurement multiple times, one can calculate a mean value. High repeatability indicates that the statistical uncertainty in this mean value is low.

In essence, repeatability measures the closeness of agreement between repeated measurements of the same quantity conducted in the same laboratory, using the same approach, by the same person, with the same equipment, and under similar conditions. It reflects the consistency of results obtained when all variables remain constant.

**Reproducibility –** Reproducibility refers to the ability of an experiment or study to be repeated by different teams, using the same experimental setups, and produce similar results. This characteristic allows other researchers to independently verify and build upon previous work, ensuring the reliability and validity of scientific findings.

In other words, reproducibility measures the closeness of agreement between measurements of the same quantity conducted under different circumstances, such as by different individuals, using different methods, or at different times, but within the same experimental framework.

**Replicability –** Replicability refers to the ability to achieve similar results using different experimental setups and methods. This involves conducting the same observation or experiment with a different team, using different measuring systems and datasets, and in a different location. Replicability requires collecting new data to confirm the findings, thereby demonstrating that the results are not unique to a particular setup or method.

Figure 1.4 illustrates the concepts of repeatability, reproducibility, and replicability, highlighting how these terms differ in terms of consistency and verification across various conditions and setups.

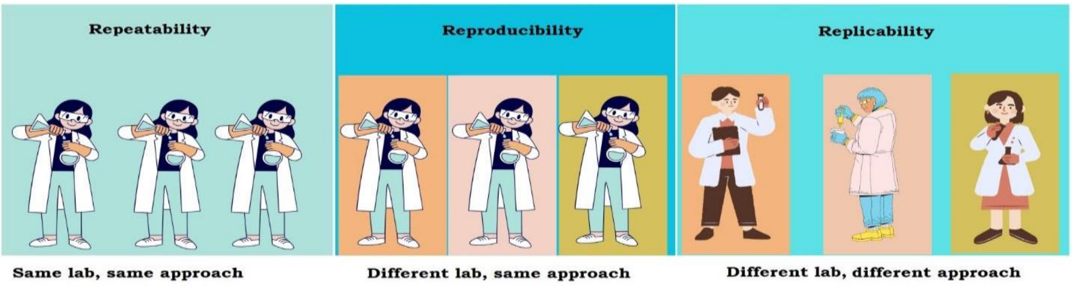



**Fig. 1.4 Repeatability, Reproducibility, and Replicability**

## Check Your Progress

**A. Multiple Choice Questions**

1. FPS stands for (a) Food Pound and sleep (b) Foot Pound and second (c) Feed provider system (d) None of the above
2. CGS stands for (a) Cinema Motion system (b) Centimetre green sound (c) centimetre, gram, second (d) None of the above
3. MKS stands for (a) meter, kilogram, second (b) meter kilogram second (c) Measurement kilo second (d) None of the above
4. SI stands for (a) System International (b) system input (c) second input (d) None of the above
5. There are ______ base SI units (a) 4 (b) 7 (c) 6 (d) 3
6. Measurements can be expressed using combinations of the base units are called ______ (a) base unit (b) Derived unit (c) Measured unit (d) All of the above
7. The ______ is widely accepted and used around the world (a) SI (b) MKS(c) CGS (d) All of the above
8. In United Kingdom, ________are still used alongside the SI system. (a) ASCII unit (b) imperial units (c) None of the above (d) Both
9. 9 Units used to measure distances in space (a) SI unit (b) Astronomical unit (c) MKS unit (d) All of the above
10. Distance measured at sea (a) Kilometre (b) Mile (c) Nautical mile (d) None of the above

**B. Fill in the blanks**

1. International System of Units (SI) provides a standardized system for measuring___________.
2. The _________units are used to measure time, such as the hour, minute, and second.
3. SI prefixes are a system of prefixes used to denote multiples or fractions of the ________.
4. Measurement is an essential ________of scientific research.

5. First element near the measured medium is called _________.
6. The _________ method, the unknown quantity is directly compared against a standard quantity.
7. An ______ instrument is a measuring device that provides an independent and direct measurement of a physical quantity.
8. Secondary instruments, also known as _______instruments.
9. The ______ is measurement of how close are to the 'true answer' of the quantity being measured.
10. It _______ refers to the degree to which repeated measurements of the same quantity.

**C. State whether the following statements are True or False**

1. an absolute instrument is accurate measurement of a quantity without any external factors affecting the measurement. ( )
2. uncertainty can arise from a variety of sources, including measurement errors. ( )
3. Tolerance refers to the Non-allowable range of variation for a physical dimension or property of an object or component. ( )
4. There are Four types of tolerances used in measurements. ( )
5. Random error is also known as human error. ( )
6. Significant figures are also called significant digits. ( )
7. The difference between the true value and the value obtained during measurement is called error. ( )
8. Absolute error defined as the difference between the expected value and the measured value. ( )
9. Random errors that arise due to an individual's bias, lack of proper setting of the apparatus. ( )
10. Environmental error is caused by changes in the experimental environment that affect the measurements.

**D. Short answer questions**

1. Explain Accuracy?
2. Explain precision?
3. What is direct measurement?
4. What do you understand by Indirect measurement?
5. What is Secondary instrument?
6. What is Repeatability?
7. What is Reproducibility?
8. What is Random error?
9. What is Instrumental error?
10. Explain the Significant figures?

# Session 2. Thermodynamics

Raman and his mother were traveling from Bhopal to Delhi by car when Raman began to feel uncomfortably hot. To alleviate the discomfort, his mother suggested closing all the windows. After doing so, the temperature inside the car began to drop. Curious about the change, Raman asked his mother how this worked. She took the opportunity to explain the car's air conditioning system and its connection to thermodynamics. She described how the air conditioning system uses a refrigeration unit to expel heat from inside the car, effectively cooling the interior. Raman appreciated the explanation and felt more comfortable as they continued their journey. Figure 2.1 illustrates Raman's mother explaining the workings of the car's air conditioning system.

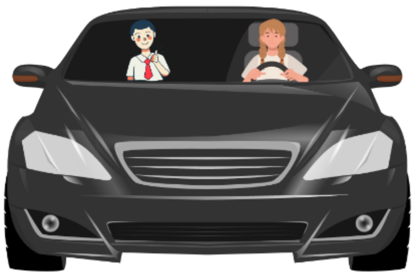


**Fig. 2.1 Raman's mother telling about the air conditioning system**

## 2.1 REFRIGERATION AND AIR CONDITIONING

**Refrigeration** can be defined as the process of extracting heat from a substance or space to lower its temperature under controlled conditions. It involves reducing and maintaining the temperature of an object or space to be below the ambient temperature of its surroundings. Essentially, refrigeration is about continually removing heat from a body or space, resulting in a temperature lower than what would naturally occur due to external conditions.

Refrigeration is characterized by creating a cool environment artificially by withdrawing heat. This involves using a low-boiling substance, known as a refrigerant, to transfer heat from one location to another. By employing this method, the temperature of the substance or space can be lowered below the atmospheric temperature.

**Air conditioning**, on the other hand, refers to the comprehensive control of various environmental factors, including temperature, humidity, cleanliness, and air movement. It can be tailored for different seasons, categorized into summer air conditioning and winter air conditioning, to meet specific comfort and operational needs.

### 2.1.1 Brief history of refrigeration

In ancient times, people in India and Egypt grappled with the challenge of keeping food and drinks cool during the hot summer months without modern refrigeration. Their solution was ingenious: they utilized porous clay pots to store water. By placing these pots outside at night, they took advantage of the cool, dry air and the process of evaporation. As the water evaporated from the pots, they would radiate heat into the chilly night sky, leading to a reduction in temperature inside the pots. Remarkably, despite the surrounding air being warmer than freezing, this method allowed ice to form in the pots, which could then be used to keep food and drinks cold.

Given that natural ice was scarce and high-quality insulation systems were not available at the time, people sought alternative methods for ice production. By the 4th century, East Indians had developed a method to produce ice artificially by dissolving salt in water, leveraging the endothermic nature of the saltwater mixture.

The evolution of refrigeration technology continued through the centuries. In 1790, Thomas Hariss and John Long obtained the first British patent for refrigeration. Then, in 1834, Jacob Perkins innovated by developing a hand-operated refrigeration system that used ether as the working fluid. Figure 2.2 depicts this early hand-operated refrigerator, marking a significant milestone in the history of refrigeration technology.

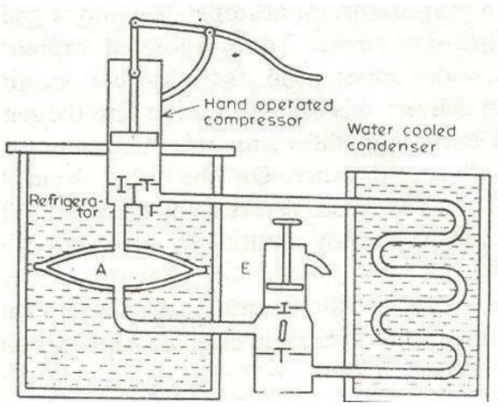



**Fig. 2.2 First-hand operated refrigerator**

In the 19th century, significant advancements were made in refrigeration technology, leading to the development of artificial ice-producing machines to replace the reliance on natural ice. One notable innovation was driven by the need to meet the increased demand for ice during the Civil War.

Ferdinand Carré, an American inventor, responded to this demand by developing a vapor absorption refrigeration system. His system used ammonia and water as the working fluids, marking a key advancement in refrigeration technology. This vapor absorption refrigeration system was a significant step forward in the ability to produce ice and maintain cooling on a larger scale.

Figure 2.3 illustrates the Vapor-Absorption Machine created by Ferdinand Carré, showcasing the early technology that laid the foundation for modern refrigeration systems. This invention was pivotal in advancing the field of refrigeration, allowing for more reliable and widespread production of artificial ice.

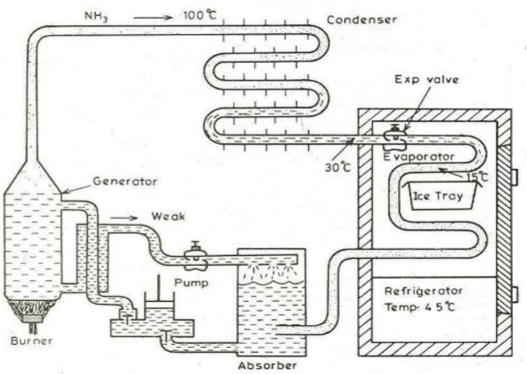



**Fig. 2.3 Vapor-Absorption Machine of Ferdinand Carre**

In the early 19th century, Germany pioneered the use of air conditioning in theatres to enhance comfort for audiences. This marked the beginning of a broader application of air conditioning technology beyond simple refrigeration.

Around 1911, significant advancements were made with the development of compressors capable of operating at speeds between 100 to 300 revolutions per minute (rpm). These early compressors played a crucial role in improving the efficiency and effectiveness of air conditioning systems.

By 1915, the field saw the introduction of the first two-stage modern compressor, a key development that further refined air conditioning technology. This innovation provided greater control and efficiency in cooling systems, setting the stage for the advanced air conditioning technologies we use today.

### 2.1.2 Units of Refrigeration

The practical unit of refrigeration is expressed in terms of "tonne of refrigeration" briefly written as TR. A tonne of refrigeration is defined as the amount of refrigeration effect produced by the uniform melting of one tonne (1000 kg) of ice from and at 0°C in 24 hours.

The latent heat of ice is 335 kJ/kg, therefore one tonne of refrigeration,

1 TR = 1000 × 335 kJ in 24 hours

$$= \frac{1000 \times 335}{24 \times 60} = 232.6 \text{ kJ/min}$$

In actual practice, one tonne of refrigeration is taken as equivalent to 210 kJ/min or 3.5 kW.

## 2.2 THERMODYNAMICS

The Term "Thermodynamics" was invented around 1840. Thermodynamics is a combination of two Greek words "Therme" which means heat and "Dynamic" which means power or motion. In short, the term thermodynamics stands for "heat power" or "heat in motion". It explains how thermal energy is converted to and from other forms of energy and how it affects the matter. Thermodynamics is the branch of science that is associated with heat and temperature. Also, it deals with the interconversion of heat and other forms of energy.

A thermodynamic system is defined as a space or region where thermodynamic processes occur. This system is separated by a boundary, which can be either real or imaginary. The boundary can be fixed or movable, and it controls the exchange of matter and energy with the surroundings. Anything outside this boundary is considered as the surrounding environment. Figure 2.3 illustrates the concept of a thermodynamic system and its boundaries.

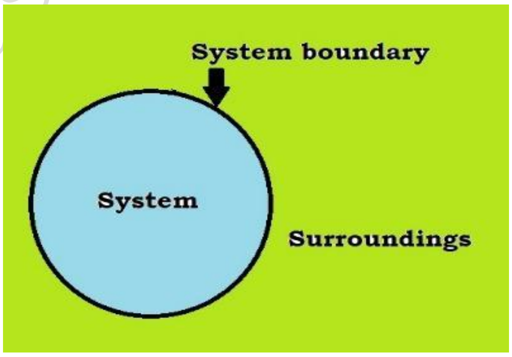



**Fig. 2.4 Thermodynamics system**

A thermodynamic system can be classified into three types – Closed system, Open system, and Isolated system.

**Closed System –** In a closed system, energy can be exchanged between the system and its surroundings, but matter cannot. A sealed container of gas is an example of a closed system because the gas cannot escape, but heat can be transferred to or from the system. Figure 2.5 illustrates that the gas present in the piston is considered a system. And if heat is applied from an external source then the temperature of the gas is increased and the piston rises.

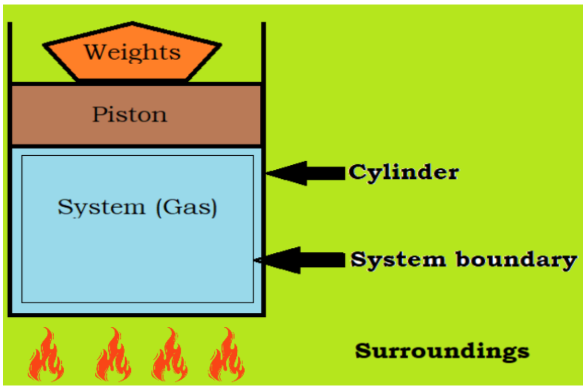



**Fig. 2.5 Closed system**

**Open System –** In an open system, both matter and energy can be exchanged between the system and its surroundings. For example, a pot of boiling water is an open system because heat and steam can escape from the pot. Figure 2.6 illustrates the working of an air compressor. In this compressor, the working substance is air. When the low-pressure air enters the compressor and the high-pressure air comes out. The work crosses the boundary of the system through the driving sharp and the heat is transferred across the boundary from the cylinder walls. Thus, an open system permits both mass and energy (heat and work) transfer across the boundaries, and the mass within the system may not be constant.

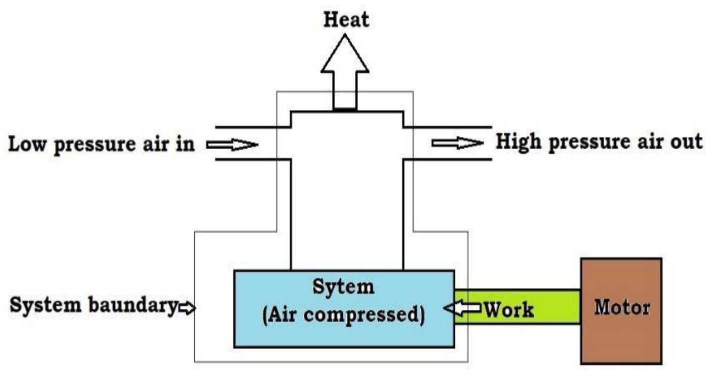



**Fig. 2.6 Closed system**

**Isolated System –** In an isolated system, neither matter nor energy can be exchanged between the system and its surroundings. The universe is an example of an isolated system because it contains all matter and energy, and nothing can enter or leave it.

### 2.2.1 Temperature

Temperature is an intensive thermodynamic property that reflects a system's thermal state without depending on its size or mass. It indicates the level of heat or coldness in a body. A body with a high temperature exhibits greater heat intensity and is perceived as hot, while a body with a low temperature shows lesser heat intensity and is considered cold.

A thermometer, the device used to measure temperature, typically features a tube made of glass or plastic filled with a liquid like mercury or alcohol. This liquid expands or contracts in response to temperature changes, and the tube is marked with a scale (such as Celsius or Fahrenheit) to display the temperature reading.

There are various types of thermometers, including –

**Mercury Thermometers –** These thermometers use mercury as a liquid, which expands when heated and contracts when cooled. Figure 2.7 shows a typical mercury thermometer.

**Fig. 2.7 Mercury thermometer**

**Digital Thermometers –** These thermometers use electronic sensors to measure temperature and display the readings on a digital screen. Figure 2.8 shows a typical digital thermometer.

**Fig. 2.8 Digital thermometer**

**Infrared Thermometers –** These thermometers measure temperature by detecting infrared radiation emitted by the object being measured. Figure 2.9 shows a typical infrared thermometer.


**Fig. 2.9 Infrared thermometer**

**Thermocouple thermometer –** These thermometers use two different metals that generate a voltage proportional to the temperature difference between the two ends. Figure 2.10 shows a typical thermocouple thermometer.


**Fig. 2.10 Thermocouple thermometer**

There are several temperature scales used to measure temperature, the most common ones being Celsius, Fahrenheit, and Kelvin.

**Celsius (°C) –** The Celsius scale, also known as the centigrade scale, is a commonly used temperature scale. On this scale, the freezing point of water is defined as 0°C, and the boiling point of water is defined as 100°C at standard atmospheric pressure. The Celsius scale is widely used in most countries for everyday temperature measurements.

**Fahrenheit (°F) –** The Fahrenheit scale is primarily used in the United States and a few other countries. On this scale, the freezing point of water is defined as 32°F, and the boiling point of water is defined as 212°F at standard atmospheric pressure. The Fahrenheit scale is known for its use in weather forecasts and is still commonly used in the United States for everyday temperature measurements.

The relation between the Celsius scale and the Fahrenheit scale is given by –

$\frac{C}{100} = \frac{F-32}{180}$ or $\frac{C}{5} = \frac{F-32}{9}$

**Kelvin (K) –** The Kelvin scale is an absolute temperature scale widely used in scientific and technical fields. It is anchored at absolute zero, the point at which all thermal motion ceases, making it the lowest possible temperature. This scale is particularly useful in scientific research, especially in physics and chemistry. On the Kelvin scale, water freezes at around 273.15 K and boils at about 373.15 K under standard atmospheric pressure.

**Assignment 1**

1. Go to the medical shop and ask for the thermometer and list out the difference between the various available thermometers.

2.Go to the shopkeeper and ask for the clinical thermometer and room thermometer and list out the difference between both thermometers.

### 2.2.2 Absolute temperature

For simplicity in the measurement of temperature in centigrade or Fahrenheit, zero reading is used. It helps in the calculation of known temperature changes. but whenever the value of temperature is used in an equation relating to the fundamental law, then the value of temperature, whose reference point is true zero or absolute zero is used. The temperature below which the temperature of any substance cannot fall is called an absolute zero temperature.

The absolute zero in all calculations is taken as -273°C or -460°F. The temperature measured from this zero is called the absolute temperature.

The absolute temperature in the Celsius scale is called Kelvin denoted as K and it is expressed as:

K = °C + 273

Similarly, the absolute temperature in the Fahrenheit scale is called the degree Rankine denoted as °R and it is expressed as:

°R = °F + 460

Figure 2.11 illustrates the comparative study between the various temperature scales.

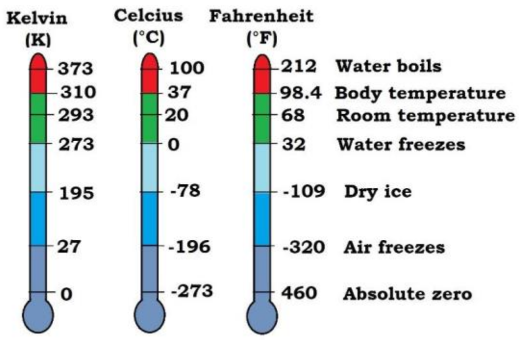



**Fig. 2.11 Relation between various temperature**

**Assignment 2**

1. Convert the Celsius to Fahrenheit from 0°C to 35°C.
2. Convert the Kelvin to Celsius from 0K to 35K.

### 2.2.3 Thermodynamic equilibrium

Thermodynamic equilibrium is a fundamental concept in thermodynamics that helps explain the behavior of systems and predict their future states. A system is in thermodynamic equilibrium when its thermodynamic properties—such as temperature, pressure, and chemical potential—remain stable over time. In this balanced state, there is no net transfer of energy or matter between the system's components.

**Mechanical equilibrium –** A system is in mechanical equilibrium when there is no net force acting on it, meaning the forces within the system are balanced. As a result, there is no motion or deformation occurring. In other words, no unbalanced force is acting on any part of the system or on the system as a whole. In this state, the pressure remains consistent throughout the system and does not change over time. Figure 2.12 visually demonstrates this concept, showing that the net force is zero, indicating the system is in mechanical equilibrium.

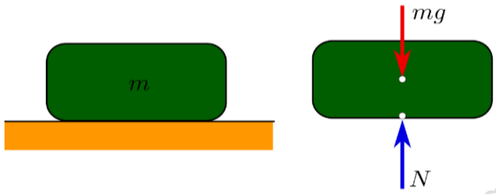



**Fig. 2.12 Mechanical equilibrium**

**Thermal equilibrium –** When two or more objects in contact share the same temperature, they are in thermal equilibrium. In other words, a system is in thermal equilibrium when there is no temperature difference within the system or between the system and its surroundings. Figure 2.13(a) shows a scenario where the system is not in equilibrium, resulting in heat transfer from the hotter object to the cooler one. In contrast, Figure 2.13(b) illustrates a system in thermal equilibrium, where no heat transfer occurs between the bodies.

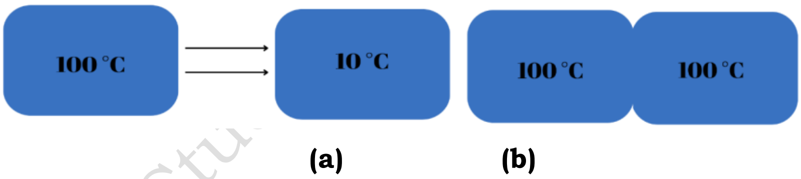



**Fig. 2.13 (a) Heat transfer when no equilibrium is present (b) No heat transfer when the system is in thermal equilibrium**

**Chemical equilibrium –** A system reaches chemical equilibrium when the rates of the forward and reverse reactions are equal, causing the concentrations of reactants and products to remain constant over time. In other words, at chemical equilibrium, no net chemical reactions occur, and the chemical composition is uniform throughout the system, remaining unchanged over time. Figure 2.14 demonstrates a system in chemical equilibrium, where the concentrations of reactants and products are stable and equal.

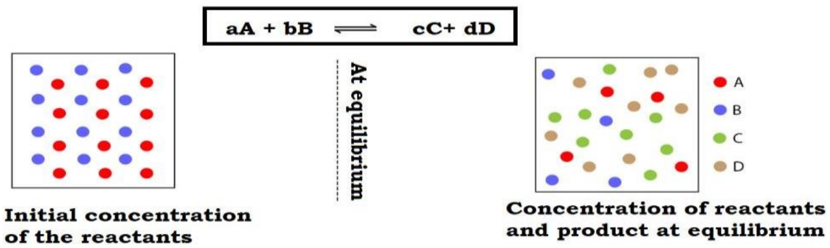



**Fig. 2.14 Chemical equilibrium**

Practical activity 2.1 will demonstrate the principles of mechanical equilibrium. It involves finding the right balance and distribution of weight among the stones to counteract the gravitational forces acting on them. This demonstrates how the forces and torques acting on each stone are balanced, creating a stable structure.

**Practical activity 2.1 –** Demonstrate the mechanical equilibrium by balancing the stone tower

**Material required –**

Several stones or rocks of varying sizes and shapes and a flat surface of the ground.

**Procedure –**

**Step 1 –** Gather a selection of stones with different sizes and shapes. As shown in Figure 2.15

**Fig. 2.15 Collect various stones**

**Step 2 –** Start by placing a larger, stable stone as the base on the flat surface. As shown in Figure 2.16.

**Fig. 2.16 Placing of stones**

**Step 3 –** Take another stone and try to balance it on top of the base stone. try with different orientations and positions until you find a stable position where the stone remains balanced without falling.

**Step 4 –** After successfully balancing the second stone, continue adding more stones on top, one by one, attempting to achieve equilibrium with each addition.

**Step 5 –** Keep trying and adding stones until you have created a tall and stable stone tower. Figure 2.17 illustrates the stable stone tower.

**Fig. 2.17 Stable stone tower**

### 2.2.4 Laws of Thermodynamics

The laws of thermodynamics are a set of fundamental principles that describe how energy behaves in physical systems. They are as follows:

**Zeroth law of thermodynamics –** When two systems are each in thermal equilibrium with a third system, they are also in thermal equilibrium with each other. This principle is known as the zeroth law of thermodynamics. It establishes that if two systems are individually in equilibrium with a common third system, then they must share the same temperature and, therefore, be in thermal equilibrium with one another. This law provides the basis for temperature measurement.

Figure 2.18 (a) illustrates that two systems A and B, are separated by an adiabatic wall, while each is in contact with a third system C, via a conducting wall. The states of the systems will change until both A and B come to thermal equilibrium with C. Figure 2.18 (b) illustrates that the adiabatic wall between A and B is replaced by a conducting wall, and C is insulated from A and B by an adiabatic wall. It is found that the states of A and B change no further i.e. they are found to be in thermal equilibrium with each other.

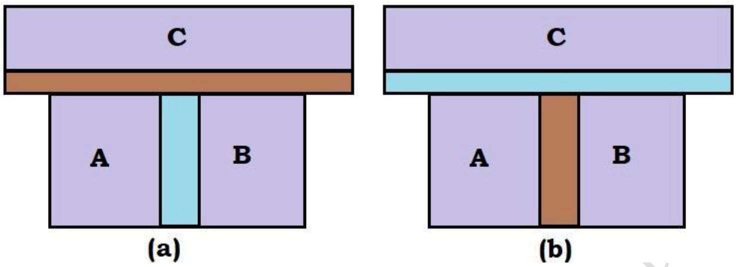



**Fig. 2.18 (a) Systems A and B are separated by an adiabatic wall, while each is in contact with a third system C via a conducting wall. (b) The adiabatic wall between A and B is replaced by a conducting wall, while C is insulated from A and B by an adiabatic** wall.

**First Law of Thermodynamics –** This law, also known as the law of conservation of energy, states that energy cannot be created or destroyed, only transformed from one form to another. In other words, the total energy of a closed system remains constant but can be converted from one form to another.

Figure 2.19 illustrates that heat transfer is converted into work done. The equation for the first law of thermodynamics is given as:

$\Delta U = q + W$

Where,

$\Delta U$ = Change in internal energy of the system

$\Delta U = E_2 - E_1$

q = Algebraic sum of heat transfer between system and surroundings

W = Work interaction of the system with its surroundings

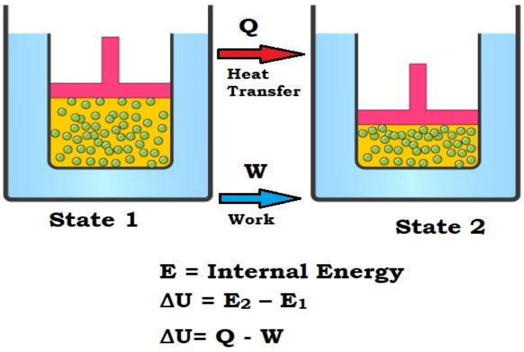



**Fig. 2.19 First law of thermodynamics**

**Second Law of Thermodynamics –** The Second Law of Thermodynamics gives a fundamental limitation to the efficiency of a heat engine and the coefficient of performance of a refrigerator. In simple terms, it says that the efficiency of a heat engine can never be unity. For a refrigerator, the Second Law says that the coefficient of performance can never be infinite. The following two statements, one due to Kelvin and Planck denying the possibility of a perfect heat engine, and another due to Clausius denying the possibility of a perfect refrigerator or heat pump, are a concise summary of these observations.

a) **Kelvin–Plank statement –** No process is possible whose sole result is the absorption of heat from a reservoir and the complete conversion of the heat into work.

b) **Clausius's statement –** No process is possible whose sole result is the transfer of heat from a colder object to a hotter object.

**Third Law of Thermodynamics –** This law states that it is impossible to reach absolute zero temperature, which is the temperature at which all molecular motion stops. This law also implies that the entropy of a perfectly ordered crystal at absolute zero is zero.

Entropy, denoted by 'S', is a measure of the disorder/randomness in a closed system.

**2.2.3 Gas Laws**

Gas laws are a set of fundamental principles that describe the behaviour of gases under different conditions, including pressure, volume, temperature, and the number of particles.

**Boyle's Law –** Boyle's law gives the relationship between the pressure of a gas and the volume of the gas at a constant temperature. This law states that the volume of a gas is inversely proportional to its pressure at a constant temperature. Mathematically, it can be expressed as –

$PV = k$,

Where,

P = Pressure

V = Volume

k = Constant

Figure 2.20 illustrates in the first beaker the volume of gas is more when less pressure is applied and when the pressure is doubled the volume of gases is less. Hence, the volume of gas in the beaker is inversely proportional to the pressure.

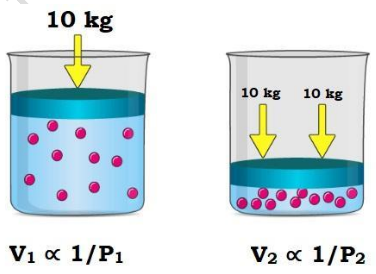



**Fig. 2.20 Boyle's law**

**Charles's Law –** Charle's law states that at constant pressure, the volume of a gas is directly proportional to the temperature in a closed system. This law states that the volume of a gas is directly proportional to its absolute temperature at a constant pressure. Mathematically, it can be expressed as:

$V/T = k$,

Where,

T = Absolute temperature (in Kelvin)

V = Volume

k = Constant

Figure 2.21 illustrates that at constant pressure the volume of gas is directly proportional to temperature in a piston.

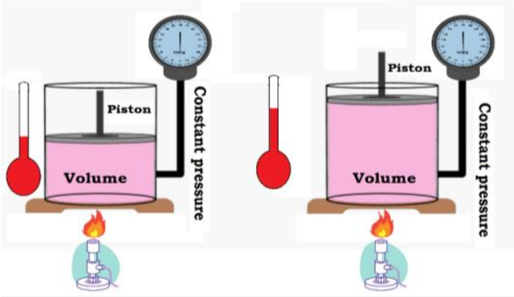



**Fig. 2.21 Charles's Law**

**Gay-Lussac's Law –** Gay-Lussac law gives the relationship between temperature and pressure at constant volume. This law states that the pressure of a gas is directly proportional to its absolute temperature at a constant volume. Mathematically, it can be expressed as –

$P/T = k$.

Where,

P = Pressure

T = Absolute temperature (in Kelvin)

k = Constant.

Figure 2.22 illustrates that at constant volume and a constant number of gas molecules pressure of a gas is directly proportional to its absolute temperature in a piston.

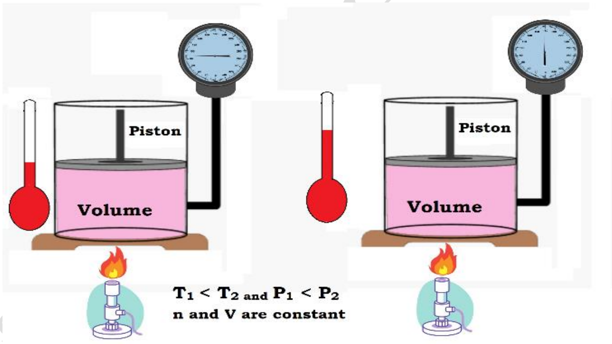



**Fig. 2.22 Gay-Lussac's Law**

**Avogadro's Law –** Avogadro's law states that if the gas is ideal, the same number of molecules exists in the system. The law also states that equal volumes of gases at the same temperature and pressure contain equal numbers of molecules. This statement can be mathematically expressed as:

$V/n = k$,

Where,

V = Volume

n = Number of gas molecules

k = Constant.

Figure 2.23 illustrates that for an ideal gas, the same number of molecules exists in the system at the same temperature and same pressure.

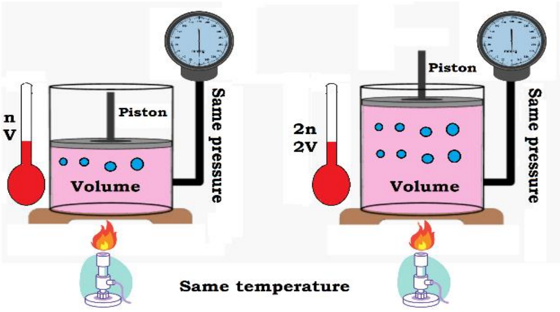



**Fig. 2.23 Avogadro's Law**

**Combined Gas Law –** The combined gas law, also known as a general gas equation, is obtained by combining three gas laws which include Charles's law, Boyle's Law, and Gay-Lussac law. The law shows the relationship between temperature, volume, and pressure for a fixed quantity of gas. The general equation of combined gas law is given as:

$PV / T = k$

Where,

P = Pressure

V = Volume

T = Absolute temperature (in Kelvin)

k = Constant

Practical activity 2.2 demonstrates the first law of thermodynamics that heat energy transfers from the hot water to the surroundings and from the ice cubes to the surrounding air. This practical activity also demonstrates the Second law of thermodynamics that heat naturally flows from hotter objects to colder objects and tends to equalize the temperatures of the objects involved. This law can be observed as the hot water cools down and the ice cubes melt, eventually reaching a thermal equilibrium with their surroundings.

**Practical activity 2.2–** Demonstrate the law of thermodynamics by heat transfer experiment.

**Material required –**

Two containers, Hot water, Ice cubes, a thermometer, Stopwatch or timer.

**Procedure –**

**Step 1 –** Fill one container with hot water and the other with ice cubes as shown in Figure 2.24.

**Fig. 2.24 Container having hot water and ice cubes**

**Step 2 –** Measure and record the initial temperature of both containers using a thermometer as shown in Figure 2.25.

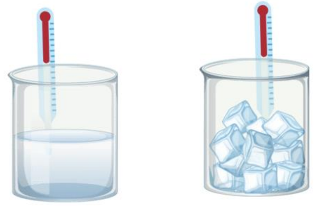


**Fig. 2.25 Place the thermometer in both container**

**Step 3 –** Start the timer or stopwatch. Place the thermometer in the hot water container and record the temperature at regular intervals as shown in Figure 2.26.

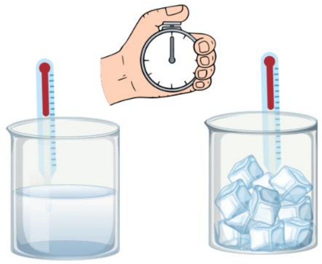


**Fig. 2.26 Measure the time of changing the state of ice and hot water to cool**

**Step 4 –** Repeat the temperature measurements for the container with ice cubes using the same time intervals and duration.

**Step 6 –** Observe and record how the temperatures of both containers change over time.

## 2.3 THERMODYNAMICS INVOLVED IN REFRIGERATION AND AIR CONDITIONER

Refrigeration and air conditioning systems operate based on thermodynamic principles. In an air conditioner, the refrigerant continuously circulates in a cycle, removing heat from the room. Directly exhausting heat into the surrounding environment is not feasible, as the outside temperature is typically higher than the room's temperature. The solution lies in using a heat pump, which adheres to both the first and second laws of thermodynamics to effectively transfer heat from the cooler interior to the warmer exterior.

### 2.3.1 Heat pump

A heat pump operates similarly to a heat engine but in reverse. Its primary function is to transfer heat rather than convert it. It absorbs heat from a colder area and releases it into a warmer area, using mechanical energy supplied by an external source. As a result, the colder area is further cooled. A heat pump typically includes four key components: a **condenser**, a **compressor**, an **expansion valve**, and an **evaporator**. The working fluid in these components is known as the refrigerant.

**Cooling Cycle of heat pump –** The heat pump of the Air conditioner is used to cool the room. It removes the heat from the room and expels it into the environment. Generally, outdoor units of air conditioners are used to expel heat into the environment. Figure 2.27 illustrates the cooling cycle of the air conditioner.

The cooling cycle is divided into four parts they are –

a) The refrigerant absorbs the heat of the room through the evaporator and this makes the room to cool down.

b) The refrigerant then passes through the compressor to increase its temperature.

c) Then the refrigerant is passed through the condenser coils, and transfers the heat to the outside air.

d) Then the refrigerant expands and decreases its pressure and cools down to below the room temperature and then the cycle repeats itself.

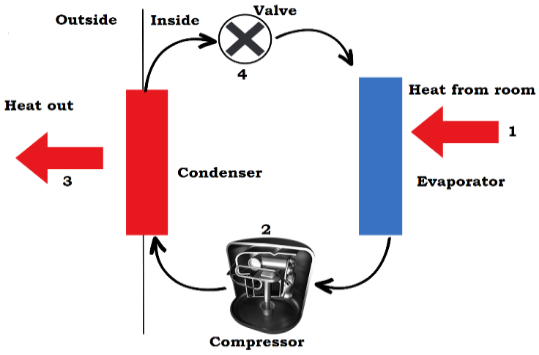



**Fig. 2.27 Cooling cycle**

**Working of Heat pump –** The heat pump is used to circulate the heat and transfer the heat from a cold body to another body. The refrigerant present in the air conditioner absorbs the heat $Q_c$ from the room and heat $Q_h$ is exhausted in the hotter environment.

During this cycle, there is no change in internal energy $Q_c + W = Q_h$ i.e. energy in = energy out. also, the entropy of the refrigerant does not change. Figure 2.28 illustrates the working of the heat pump.

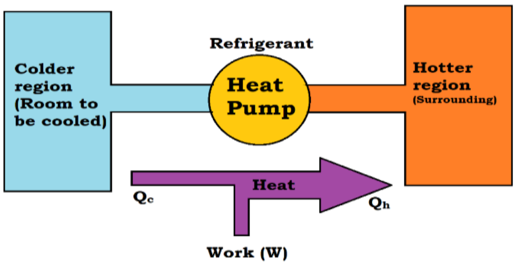



**Fig. 2.28 Working of heat pump**

$Q_c$ = Heat to be removed inside the room

W = Work done on the refrigerant

$Q_h$ = Heat comes out at the outdoor unit of the air conditioner

Figure 2.29 illustrates the schematic of a practical air conditioner. In that, the refrigerant evaporates into a gaseous state, and absorbs the heat from the colder body. The work done is accomplished in the compressor. After that, the refrigerant condenses into a liquid form and exhaust its heat when it comes in contact with an outside warmer environment.

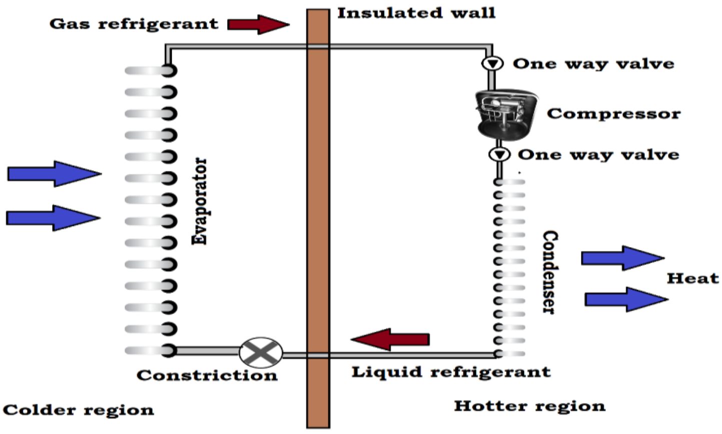



**Fig. 2.29 Working practical air conditioner**

### 2.3.2 Refrigerant

Refrigerants are substances used in refrigeration and air conditioning systems to transfer heat and provide cooling. They undergo a cycle of evaporation and condensation to absorb heat from the surroundings and release it outside.

Various types of refrigerants have been used over the years, with different properties and environmental impacts.

**Chlorofluorocarbons (CFCs) –** CFCs, such as CFC-12 (also known as Freon-12), were widely used as refrigerants in the past. However, they have been phased out due to their harmful impact on the ozone layer.

**Hydrochlorofluorocarbons (HCFCs) –** HCFCs, like HCFC-22 (also known as R-22), were introduced as transitional alternatives to CFCs. They have lower ozone-depleting potential but still contribute to ozone depletion. HCFCs are being phased out as well.

**Hydrofluorocarbons (HFCs) –** HFCs, such as HFC-134a and HFC-410A, became widely used as replacements for CFCs and HCFCs. They do not deplete the ozone layer, but they have high global warming potential (GWP), contributing to climate change.

**Hydrocarbons (HCs) –** Hydrocarbons like propane (R-290) and isobutane (R-600a) are natural refrigerants that have a low environmental impact. They have gained popularity due to their excellent thermodynamic properties and low GWP. However, their flammability requires special safety precautions.

**Ammonia (NH3) –** Ammonia is a highly efficient and widely used refrigerant in industrial applications. It has excellent thermodynamic properties and zero ozone depletion potential (ODP) and GWP. However, it is toxic and requires careful handling.

**Carbon Dioxide ($CO_2$) –** Carbon dioxide is a natural refrigerant that is gaining popularity due to its environmentally friendly properties. It has zero ODP and a very low GWP, making it an attractive option for certain applications. $CO_2$ refrigeration systems are used in some commercial and industrial settings.

## 2.4 TYPES OF REFRIGERATION SYSTEMS

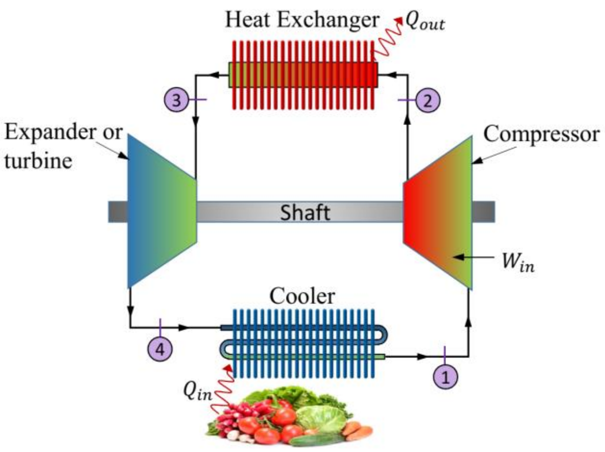
A refrigeration system is a mechanical system designed to transfer heat from a lower temperature area to a higher temperature area, thereby cooling the lower temperature area. It is commonly used for various applications, such as food preservation, air conditioning, and industrial processes.

There are several types of refrigeration systems commonly used in various applications. Such as Air Refrigeration Systems, Vapour Compression Refrigeration Systems (VCRS), Vapour Absorption Refrigeration Systems (VARS), and Thermoelectric Refrigerators.

### 2.4.1 Air Refrigeration System

The air refrigeration cycle works on the Bell-Coleman cycle. The cycle is also known as the reverse Brayton or Joule cycle. Generally, atmospheric air is used as the working fluid (refrigerant) but any other gas may also be used. The compressor discharge and suction pressures are quite above the critical pressure of the refrigerant. Absorbing the heat from a low-temperature system and discharging the same to a high-temperature system is done by air in the form of sensible heat. Earlier, air refrigeration systems were used in ships carrying frozen meat. Nowadays, the systems find their applications in aircraft cabin cooling and liquefaction of various gases. Ordinary passenger aircraft require a cooling capacity of 8 TR whereas jet fighters flying at very high speeds require a cooling capacity of 10 to 20 TR.

The basic components of air refrigeration systems are (i) compressor (ii) heat exchanger (iii) expander and (iv) cooler. Figure 2.30 shows the schematic arrangement of the components.




- Process 1-2: Compression from low to high pressure in a compressor
- Process 2-3: Heat rejection at constant pressure in a heat exchanger
- Process 3-4: Expansion from high to low pressure in an expander or a turbine
- Process 4-1: Heat absorption at constant pressure in a heat exchanger or a cooler

**Fig. 2.30 Schematic arrangement of components in air refrigeration system**

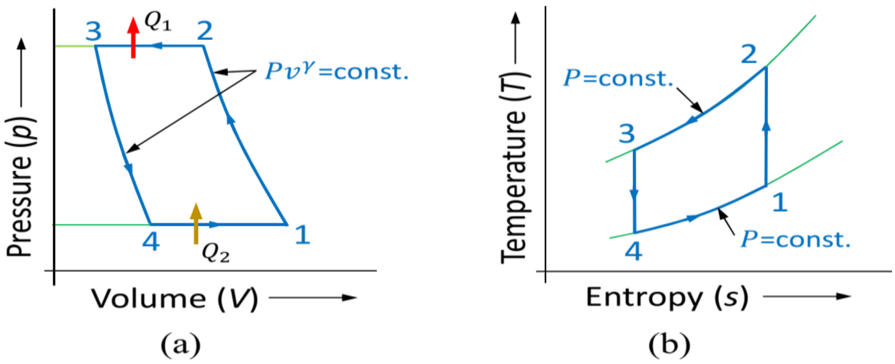



**Fig. 2.31 Plots for air refrigeration system (a) p-V (b) T-s**

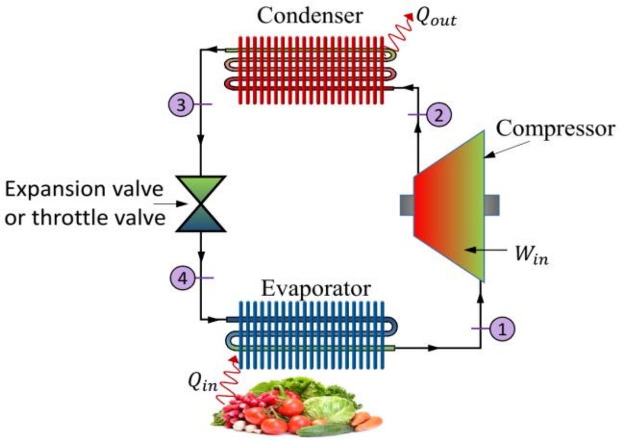
**Working –** Refrigerant air at low pressure is sucked by the compressor and delivered at high pressure, resulting in a high temperature as well (process 1-2). The refrigerant air then flows through the heat exchanger. It is cooled ideally at constant pressure, dissipating its sensible heat to the surroundings, which is either cooling water or cooling air flowing across the coil or tubes (process 2-3). The refrigerant air then flows through the expander or turbine where pressure drops from high to low (process 3-4). This results in a drop in refrigerant air temperature much below the atmospheric temperature. The low-pressure and low-temperature refrigerant is then passed through the cooler where it gains the sensible heat from the refrigerated space (process 4-1).

In the closed cycle, the refrigerant is recycled to the compressor. In the open cycle, used in passenger aircraft cabin cooling, the air after entering the passenger cabin gets contaminated and hence released to the atmosphere, and the fresh atmospheric air is sucked for the repetitive cycle. Figure 2.31 (a) and (b) shows the variation of pressure and temperature on Pressure-Volume (P-v) and Temperature-entropy (T-s) plots. The COP of the air refrigeration systems is very low.

### 2.4.2 Vapour Compression Refrigeration System (VCRS)

In a vapor-compression refrigeration system (VCRS), the compressor discharge and suction pressures are below the critical pressure of the refrigerant. The refrigerant undergoes a phase transformation from vapor to liquid and from liquid to vapor during the completion of the cycle. The latent heat of vaporization is used for carrying the heat from the refrigerator. The required mass flow rates for a given refrigeration capacity will be much smaller compared to an air refrigeration system, which depends upon the sensible heat.

A majority of present-day refrigerators (300 K to 120 K range) are based on the vapor compression refrigeration cycles. Their capacities may range from a few watts to a few megawatts. The most common applications of VCRS include domestic and commercial refrigerators, large-scale warehouses for chilled or frozen storage of foods and meats, refrigerated trucks and railroad cars, automobiles, and air-conditioners. A window-type room air conditioner may consume 2.5 kW of power whereas a domestic refrigerator may consume 100 to 250 W.




- Process 1-2: Compression from low to high pressure in a compressor
- Process 2-3: Latent heat rejection at constant pressure in a heat exchanger
- Process 3-4: Expansion from high to low pressure in an expansion or a throttle valve
- Process 4-1: Latent heat absorption at constant pressure in an evaporator

**Fig. 2.32 Schematic arrangement of components in VCRS**

The basic components of vapor compression refrigeration systems are (i) compressor (ii) condenser (iii) expansion valve or throttle valve and (iv) evaporator. Figure 2.32 shows the schematic arrangement of the components. In earlier days, refrigerants such as R-11, R-12, and R-22 were used in the VCRS. Nowadays, refrigerants with reduced ozone depletion effects such as R-134a are used.

**Working –** Mechanical work from the electric motor run by the electricity is utilized to run the compressor. The compressor sucks the circulating refrigerant coming out of the evaporator, which is in a saturated vapor state corresponding to low pressure $p_e$, It delivers the refrigerant at high pressure ($p_c$), resulting in a high temperature ($T_2$) as well (process 1-2). The compressed vapor is in the superheated vapor state at $p_c$. It flows through the condenser where it dissipates latent heat to the surroundings which are either cooling water or cooling air flowing across the coil or tubes (process 2-3). The cooled vapor is in the saturated liquid state at 3.

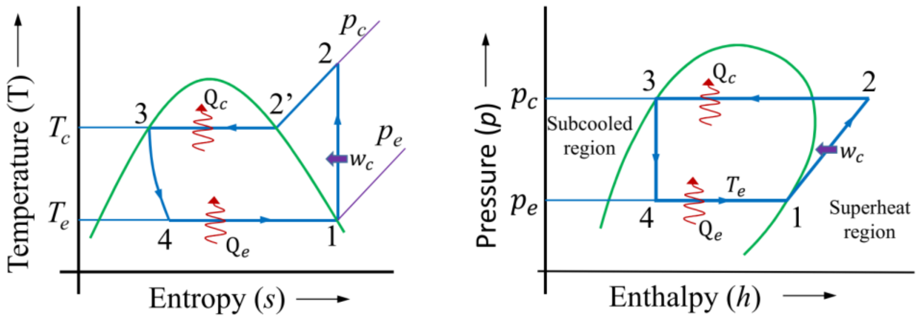



**Fig. 2.33 Plots for vapor compression refrigeration system (a) T-s (b) P-h**

The liquid refrigerant is now routed through an expansion valve where it undergoes an abrupt reduction in pressure from $p_c$ to $p_e$ (process 3-4). As a result, the temperature of the refrigerant goes much below the freezing temperature of the water (around -20°C in the case of the domestic refrigerator). The cooler refrigerant is then routed through the coil or tubes in the evaporator. The liquid refrigerant absorbs the heat from the refrigerated space and evaporates (process 4-1). The dry saturated refrigerant coming out of the evaporator is routed back to the compressor. This completes the vapor compression cycle. Figure 2.5 (a-b) shows the variation of pressure and temperature on T-s and pressure-enthalpy (p-h) plots.

**2.4.3 Vapour Absorption Refrigeration System (VARS)** The major difference between the vapor compression and vapor absorption refrigeration systems is the source of energy input. A vapor compression refrigeration system utilizes mechanical work from the electric motor run by the electricity to drive the cooling process whereas a vapor absorption refrigerator system utilizes thermal energy available at 100°C to 200°C (from heat sources such as solar energy, fossil fuel, geothermal energy, waste heat from industrial process or district heating systems) to drive the cooling process.

The most common fluids used in the VARS are water as absorbent and ammonia as refrigerant. Such systems are called aqua-ammonia refrigeration systems. Other systems include water–lithium bromide and water–lithium chloride systems, where water serves as the refrigerant. Air-conditioning systems based on absorption refrigeration are commonly called absorption chillers.

These are used predominantly in large sizes in systems having a cooling capacity of 100 kW or above, such as large tonnage air-conditioning, industrial process cooling, and cogeneration plants for waste heat utilization and waste-to-energy utilization. They are also used in hotels and offices, where the compressor noise is objectionable. The COP of actual systems is usually less than 1.

A vapor absorption refrigeration system consists of a condenser, an expansion valve, and an evaporator. The compressor is replaced by an absorber, a solution pump, a generator, and a pressure-reducing valve. Figure 2.34 shows the schematic arrangement of all the major components. The basic components (condenser, expansion valve, and evaporator) forms the refrigerant circuit. The part in which the refrigerant-absorbent solution circulates is named the solution circuit.

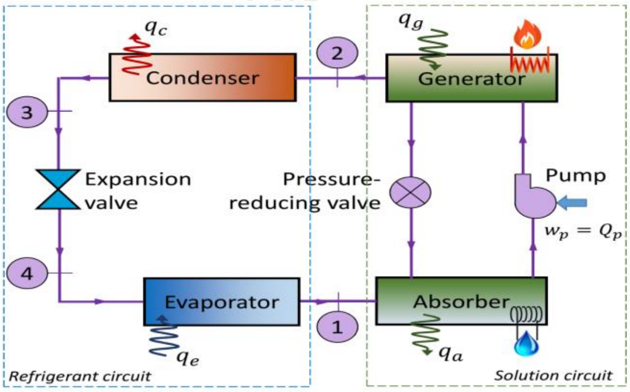



**Fig. 2.34 Schematic arrangement of components in VARS**

**Working –** In this system, the low-pressure ammonia (refrigerant) vapor leaving the evaporator enters the absorber. In the absorber, the weak aqua-ammonia (absorbent) solution has a very strong affinity to absorb ammonia vapor. Therefore, the ammonia vapor is absorbed by its weak/lean aqua-ammonia solution, forming a strong/rich aqua-ammonia solution. The absorption of ammonia vapor in water lowers the pressure in the absorber which in turn draws more ammonia vapor from the evaporator and thereby raises the temperature of the solution. Some form of cooling arrangement (usually water cooling) is employed in the absorber to remove the heat of the solution evolved there.

This is necessary to increase the absorption capacity of water because at higher temperatures water absorbs less ammonia vapor. The strong solution thus formed in the absorber is pumped to the generator by the liquid pump. The pump increases the pressure of the solution up to 10 bar. Because the specific volume of liquid is extremely small to that of the vapor ($v_f \ll v_g$), the work required by the pump is much less than the work required by a vapor compressor for the same pressure difference.

The strong aqua-ammonia solution in the generator is heated at high pressure by some external source such as gas or steam. During the heating process, the ammonia vapor is driven off the solution leaving behind the hot weak ammonia solution in the generator. This weak ammonia solution flows back to the absorber at low pressure after passing through the pressure-reducing valve.

The high-pressure ammonia vapor from the generator is condensed in the condenser to high-pressure liquid ammonia. This liquid ammonia is passed to the expansion valve through the receiver and then to the evaporator. This completes the simple vapor absorption cycle.

### 2.4.4 Thermoelectric Refrigerators

The principle of the thermoelectric (See beck) effect that drives thermocouples is also the basis for thermoelectric refrigeration. Figure 2.35 shows a schematic view of a thermoelectric refrigerator. When current flows in a circuit made of dissimilar metals, it causes a difference in temperatures between two junctions (Peltier effect), normally limited to 30-40 K. The coefficient of performance (COP) is normally less than unity. Refrigerators that are based on the thermoelectric effect are lightweight, compact, and have no moving parts. They are most useful for small cooling applications, typically from a few watts to a few tens of watts. For example, the medical community uses thermoelectric applications in tissue preparation and storage.

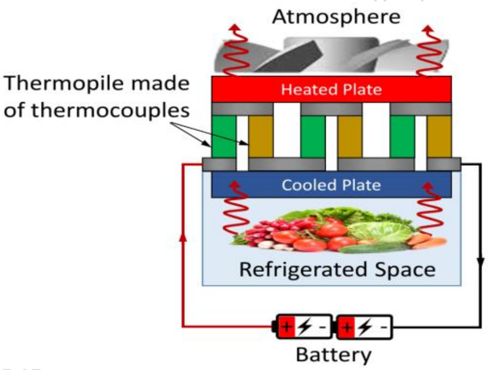



**Fig. 2.35 Schematic diagram of thermoelectric refrigerator**

## Check Your Progress

**A. Multiple Choice Questions**

1. Refrigeration is defined as the process of removing ______from a substance under controlled conditions (a) pressure (b) Heat (c) light (d) None of the above
2. Refrigeration means a continued extraction of (a) Pressure from a body (b) Light from a body (c) heat from a body (d) None of the above
3. It stands to produce cool confinement concerning the surroundings (a) Refrigeration (b) Condensation (c) Evaporations (d) None of the above
4. artificial withdrawal of heat (a) Refrigeration (b) Condensation (c) Evaporations (d) None of the above
5. Air conditioning is defined as the simultaneous control of (a) temperature (b) humidity (c) Air motion (d) All of the above
6. Air conditioning is divided into (a)4 types (b) 2 types (c) 6 types (d) All of the above

7. Vapor absorption refrigeration system using (a) ammonia and water (b) Carbon and water (c) hydrogen and water (d)sodium and water
8. The people of ______used air conditioning in the theatre in early 19th century (a) USA (b) Germany (c) India (d) China
9. The first two-stage modern compressor was developed in year (a) 1865 (b) 1915 (c) 1920 (d) 1870
10. The practical unit of refrigeration is expressed in terms of (a) Kilo of refrigeration (b) Mile of refrigeration (c) tonne of refrigeration (d) None of the above

**B. Fill in the blanks**

1. A low boiling substance is used to remove the heat from one place to another called _______.
2. First British Patent was obtained by __________and John Long for refrigeration.
3. In 1834 _______developed a hand-operated refrigeration system using ether as the working fluid.
4. In the 4th century east Indians produced ice by dissolving ____ in water.
5. The latent heat of ice is________.
6. Thermodynamics is the branch of science that is associated with_________.
7. The thermometers use electronic sensors to measure temperature is called ____________.
8. The thermometers use two different metals that generate a voltage proportional to the temperature difference between the two ends is called __________.
9. The temperature below which the temperature of any substance cannot fall is called an ________.
10. The system which provides a basis for understanding the behaviour of systems and predicting their future states are known as ________.

**C. State whether the following statements are True or False**

1. When there is no net force acting on a system, it is said to be in mechanical equilibrium. ( )
2. When the rates of forward and backward reactions are equal, the system is said to be in chemical equilibrium. ( )
3. Second Law of Thermodynamics also known as the law of conservation of energy. ( )
4. Second law states that it is impossible to reach absolute zero temperature. ( )
5. Charles's law gives the relationship between the pressure of a gas and the volume of the gas at a constant temperature. ( )
6. Laws of thermodynamics are a set of fundamental principles that describe how energy behaves in physical systems. ( )
7. Gas laws are a set of fundamental principles that describe the behaviour of gases under different conditions, including pressure, volume, temperature, and the number of particles. ( )
8. Gay-Lussac law gives the relationship between temperature and pressure at constant volume. ( )
9. A heat pump works same as a heat engine. ( )
10. The combined gas law, also known as a general gas equation, is obtained by combining three gas laws which include Charles's law, Boyle's Law, and Gay-Lussac law. ( )

**D. Short answer questions**

1. Explain Heat pump?

2. Explain combined gas law?
3. What is Refrigerant?
4. What do you understand by Air Refrigeration System?
5. What is Vapour Compression Refrigeration System?
6. What is Vapour Absorption Refrigeration System?
7. What is Thermodynamic equilibrium?
8. What is thermoelectric refrigerator?
9. What is Instrumental error?
10. Explain the working of heat pump?

# Session 3. Basic Components of Refrigeration and Air Conditioning

One Day During the cleaning of the air conditioner, Rohan noticed a mysterious black box situated inside the outdoor unit of an air conditioner. His curiosity peaked up about that mysterious black box. He asked about that black box. His father explained this is a compressor, the heart of the air conditioner. It plays a crucial role in cooling the room air by compressing the refrigerant gas, allowing it to absorb heat and transform into a chilled state. Without it, the air conditioner wouldn't function as effectively. Figure 3.1 illustrates that Rohan's father explains the working of the compressor.

**Fig. 3.1 Rohan's father explains the importance of compressors in air conditioner**

In this chapter, you will understand the compressor, condenser, expanders and evaporators and their types along with their functional aspects.

### 3.1 BASIC PROCESSES AND COMPONENTS OF REFRIGERATION AND AIR CONDITIONING SYSTEMS

In the previous chapter, we learnt that the refrigeration systems have four stages namely Evaporation, Compression, Condensation, and Expansion.

**Evaporation –** It is a process to convert the liquid into gaseous form. In other words, Evaporation is the process by which a liquid, such as water, changes its state from a liquid to a gas or vapor. It occurs when the molecules of the liquid gain enough energy to break free from the liquid's surface and escape into the surrounding environment. Figure 3.2 illustrates that water is evaporating from the ocean and becoming clouds in the atmosphere.

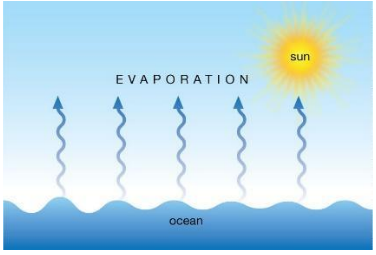



**Fig. 3.2 Evaporation taking place in the ocean**

**Compression –** In refrigeration, it specifies the decrease in the volume of gas or liquid. In other words, Compression refers to the process of reducing the volume or size of a gas or liquid by applying pressure. Figure 3.3 illustrates pressure is applied to the rubber ball to compress it.

**Fig. 3.3 Compressing the hollow rubber ball**

**Condensation –** In refrigeration, Condensation is the process by which a substance changes its state from a gas or vapor to a liquid. It occurs when the temperature of the gas or vapor decreases, causing the particles to lose energy and come together to form liquid droplets. Condensation is the opposite of evaporation. Figure 3.4 illustrates that water vapor is converted into water droplets and accumulates on the glass.

**Fig. 3.4 Condensed water on the glass**

**Expansion –** Expansion refers to the process of increasing in size, volume, or extent. Figure 3.5 illustrates the expansion of air by heating it to blow up the rubber balloon.

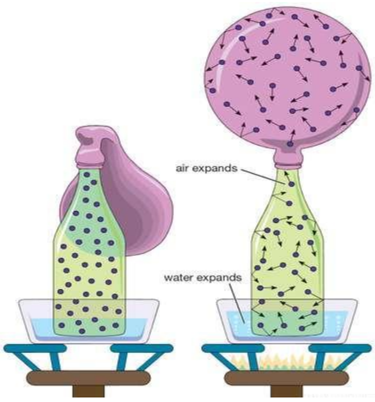



**Fig. 3.5 Expansion of air taking place in the balloon**

### 3.1.1 Refrigeration Cycle

Let us understand the refrigeration cycle in detail. It starts with the absorption of heat using refrigerant. This refrigerant is initially in a liquid state. Once it absorbs the heat, it is converted into a gaseous state. This process is called evaporation. To again cool down the temperature of the refrigerant, it is transferred to the compressor, which converts low-pressure gas to high-pressure. These high-pressure gasses cool down. This process is called condensation. In the condensation process, the refrigerant is again returned to a liquid state. Therefore, to reduce the pressure of liquid refrigerant expansion valve is used. After these stages, refrigerant again comes back to its initial temperature.

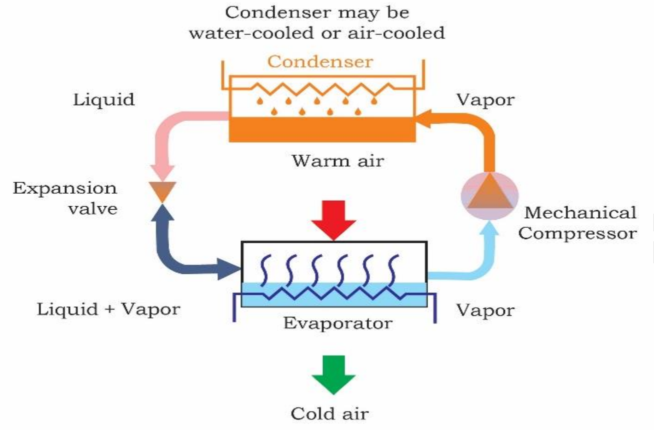



**Fig. 3.6: Refrigeration cycle**

## 3.2 Parts of Refrigeration and Air Conditioner

### 3.2.1 COMPRESSOR

It is a mechanical device. It acts as the heart of the refrigeration system. It helps to maintain the refrigerant flow around the system. It provides the energy needed to circulate and compress the refrigerant throughout the system. It is a crucial component of an air conditioner that plays a vital role in the cooling process. Its primary function is to compress the refrigerant gas, increasing its pressure and temperature before it enters the condenser.

**Functioning of Compressor –** Its function is to take refrigerant vapors from the evaporator coils, compress them from low pressure and temperature to high pressure and temperature, and push it around the refrigeration loop for heat rejection. This compressed gas plays an important role in the cooling of air-conditioners. Figure 3.7 illustrates the functioning of a compressor. The condenser condenses the hot vapor into the liquid. This liquid is passed through the copper pipe to the evaporator unit. This unit converts liquid into gas by heating it. This continuous cycle will provide cooling to the air conditioner.

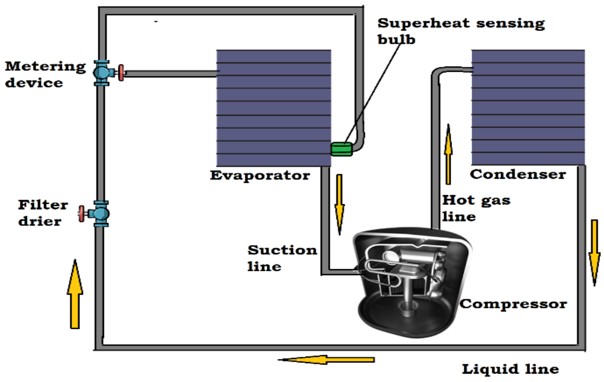



**Fig. 3.7: Functioning of compressor**

The main function of the compressor is described below –

**Refrigerant Flow –** The compressor is part of a closed-loop refrigerant system in an air conditioner. The refrigerant starts as a low-pressure gas in the evaporator coil, where it absorbs heat from the indoor air and evaporates into a low-pressure vapor.

**Suction –** The low-pressure vapor refrigerant is drawn into the compressor through the suction line. Inside the compressor, the vapor is compressed by a piston or a rotating scroll, depending on the type of compressor used in the air conditioner.

**Compression –** The compressor's primary role is to compress the refrigerant vapor, raising its pressure and temperature significantly. As the vapor is compressed, its molecules are packed closer together, increasing the energy and temperature of the refrigerant.

**Discharge –** After compression, the high-pressure and high-temperature refrigerant vapor is discharged from the compressor into the condenser coil. The condenser coil is located outside the building and helps dissipate the heat absorbed from the indoor air.

**Heat Release –** In the condenser coil, the high-pressure refrigerant vapor releases heat to the surrounding outdoor air. As the refrigerant cools and loses heat, it condenses into a high-pressure liquid.

**Expansion –** The high-pressure liquid refrigerant then flows through an expansion valve or metering device, where it undergoes a pressure drop. This drop-in pressure causes the refrigerant to expand rapidly, resulting in a decrease in temperature.

**Evaporation –** The low-pressure and low-temperature refrigerant enters the evaporator coil, located inside the building. Here, the refrigerant absorbs heat from the indoor air, causing it to evaporate into a low-pressure vapor once again.

**Repeat Cycle –** The low-pressure vapor returns to the compressor through the suction line, and the entire process continues in a cycle as long as the air conditioner is operating.

**3.2.1.1** Internal Parts of Compressor

Some of the commonly used parts in a compressor are stator winding, cylinder, piston, valve plate, suction rid, and discharge rid.

Stator Winding – It is part of an electric motor placed inside the compressor. Stator is the static part of the motor. Stator consists of winding which is used to generate a rotating torque in the motor. Figure 3.8 illustrates the stator winding of a compressor.

**Fig. 3.8: Stator winding**

Armature Winding – It is part of an electric motor placed inside the compressor. Armature is the moving part of the motor. Armature has slots on which winding is made to generate the rotating torque. Figure 3.9 illustrates the armature winding of a compressor.

**Fig. 3.9: Armature winding**

Cylinder – It is the main part of the compressor inside which the piston reciprocates back and forth. It can withstand high pressure above 50 bar and can also withstand a temperature of about 20000C. It is made up of cast iron, alloys of steel, and alloys of aluminium. Figure 3.10 illustrates the cylinder of a compressor.

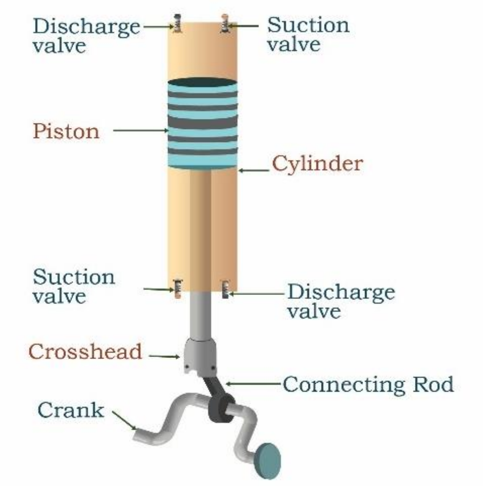



**Fig. 3.10: Cylinder**

Piston – It is the heart of the reciprocating compressor. The piston translates the energy from the crankcase to the gas in the cylinder. It is usually made of aluminium alloy, which has good heat-conducting properties and greater strength at high temperatures. Figure 3.11 illustrates the piston of a compressor.

**Fig. 3.11: Piston**

Crankshaft – It converts the reciprocating motion of the piston into rotary motion with the help of a connecting rod. It is made up of steel alloy. Figure 3.12 illustrates the crankshaft of a compressor.

**Fig. 3.12: Crankshaft**

Crankcase – It is the outer body of the cylinder and crankshaft. It houses the cylinder and crankshaft of the compressor. Figure 3.13 illustrates the crankcase of a compressor.

**Fig. 3.13: Crankcase**

Connecting Rod – It converts the reciprocating motion of the piston into circular motion of the crankshaft, in the working stroke. It is made of steel alloy or aluminium alloy. Figure 3.14 illustrates the connecting rod of a piston in a compressor.

**Fig. 3.14: Connecting rod**

3.2.1.2 Types of Compressors in Air Conditioners

Various types of compressor are used in the air conditioner but commonly two types of compressor are used in the air conditioner they are Hermetic compressor and Rotary compressor. Figure 3.15 (a) shows a typical hermetic compressor and Figure 3.15 (b) shows a typical rotary compressor.

**Fig. 3.15 Commonly used compressor (a) Hermetic compressor (b) Rotary compressor**

1. Hermetic Compressor – It is widely used for refrigeration and air-conditioning applications such as in all household refrigerators, window air conditioners, and split air conditioners. It is very easy to handle and requires low maintenance.

A hermetic compressor is a sealed unit used in refrigeration and air conditioning systems. It combines a motor and compressor within a single housing, ensuring protection against contaminants. The integration eliminates the need for mechanical linkages, simplifying installation and maintenance. Hermetic compressors handle specific refrigerants, preventing leaks and maintaining system efficiency. Their compact size and portability make them ideal for small-scale applications like residential and commercial air conditioners, refrigerators, and freezers. These compressors prioritize energy efficiency through their integrated design, reducing energy losses. Although not easily repairable, they offer reliable performance and are often replaced as a unit rather than repaired. Figure 3.16 illustrates the schematic of hermetic compressor.

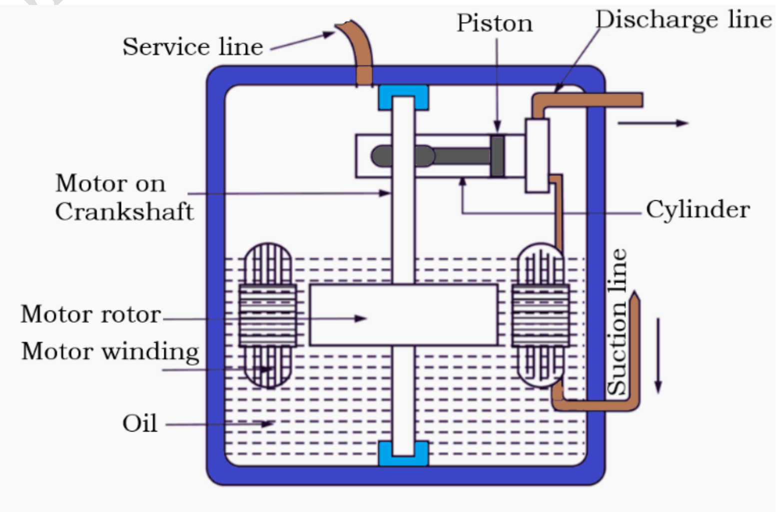



**Fig. 3.16 Hermetic compressor**

**Advantages –**

1. The leakage of refrigerant is completely avoided.
2. It is less noisy in operation.
3. The lubrication is simple as the motor and compressor operate in a sealed space with the lubricating oil.
4. It requires less space.
5. It has a long life.
6. It is portable and can be easily moved during maintenance or repairing.
7. Easy installation.

**Disadvantages –**

1. The maintenance is difficult because the moving part is not accessible.
2. For charging refrigerant separate vacuum pump is required.
3. The lubricant may mix with refrigerant and may deteriorate the quality of the refrigerant.

Various parts of the compressor are the cylinder, piston, connecting rod, and crankshaft. On the other side of the casing, there is a motor, which is used to rotate the crankshafts that will further move the piston. The compressor and motor are enclosed in the welded steel casing and the two are connected by a common shaft. This makes the whole compressor and the motor a single compact and portable unit that can be handled easily. Figure 3.17 illustrates the various dismantled components of the hermetic compressor.


**Fig. 3.17: Disassembled hermetic compressor**

A practical activity 3.1 demonstrates dismantling and observing the parts in the hermetic compressor.

Practical Activity 3.1 – Dismantle and observe various parts of the hermetic compressor.

Material Required

Hermetic compressor, screwdriver, spanner, hammer, notepad, pen.

Procedure

Step 1. Take a hermetic compressor and place it on a flat surface. Figure 3.18 shows that the hermetic compressor is placed on a flat surface.

**Fig. 3.18 Hermetic compressor**

Step 2. Remove the head or dome of the compressor using a hammer or screwdriver as shown in Figure 3.19

**Fig. 3.19 Head of the compressor**

Step 3. After opening the dome observe the internal parts of the compressor as shown in Figure 3.20.

**Fig. 3.20 Parts of the compressor**

Step 4. Observe the body of the compressor as shown in Figure 3.21.

**Fig. 3.21 Compressor body**

Step 5. Observe the tubing used for the flow of the refrigerant. Apart from this, observe the spring used to mount the stator of the motor as shown in Figure 3.22.

**Fig. 3.22 Tube for refrigerant flow**

Step 6. Observe the pressure tube used to check the pressure of the refrigerant as shown in Figure 3.23.

**Fig. 3.23 Pressure tube**

Step 6. Observe the input power supply terminals for the motor namely running, common, and starting. Figure 3.24 illustrates the power supply point of the compressor.

**Fig. 3.24 Slot for power supply**

Step 3. Observe the discharge tube through, which high-pressure refrigerant is passed to the condenser unit of the refrigeration system. The discharge tube is illustrated in Figure 3.25.

**Fig. 3.25 Discharge tube**

Step 3. Observe the suction tube, which will suck the refrigerant into the compressor. The diameter of the suction tube is larger than the discharge tub. The suction tube is illustrated in Figure 3.26.

**Fig. 3.26 Suction tube**

Step 3. Observe the stator part of the two-pole induction motor as shown in Figure 3.26.

**Fig. 3.27 Stator of induction motor**

Step 3. Check the stator winding is placed at the respective slots as shown in Figure 3.28.

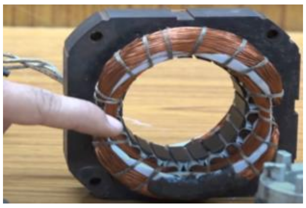


**Fig. 3.28 Slots in the stator**

Step 12. Observe the phase start and run winding of a stator as shown in Figure 3.23.

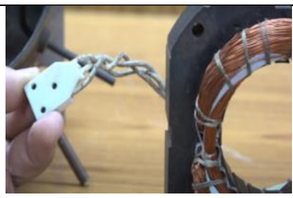


**Fig. 3.29 Winding in the stator**

Step 3. Observe the rotor of the motor, which is placed inside the stator. Figure 3.30(a) illustrates the rotor of the compressor and Figure 3.30(b) illustrates how the rotor is placed inside the stator.

**Fig. 3.30 (a) Rotor (b) Rotor placed in the stator**

Step 14. Observe the engine part of the compressor as shown in Figure 3.31.

**Fig. 3.31 Compressor Engine**

Step 15. Observe the connecting rod as shown in Figure 3.32.

**Fig. 3.32 Connecting rod**

Step 16. Observe the crankshaft as shown in Figure 3.33.

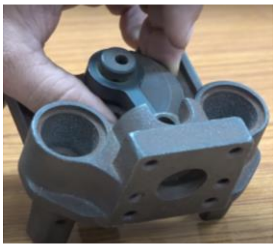


**Fig. 3.33 Crankshaft**

Step 16. Observe the cylinder of the compressor as shown in Figure 3.34.

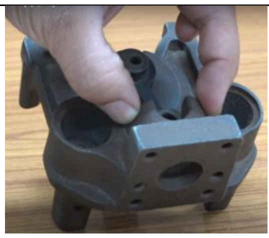


**Fig. 3.34 Compressor cylinder**

Step 13. Observe the suction valve as shown in Figure 3.35.

**Fig. 3.35 Suction valve**

Step 13. Observe the discharge valve as shown in Figure 3.36.

**Fig. 3.36 Discharge valve**

Step 20. Observe the head of the compressor as shown in Figure 3.36.

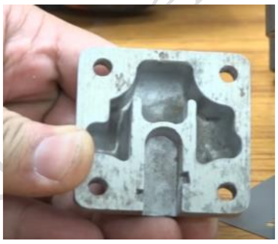


**Fig. 3.37 Compressor head**

Step 21. Observe the relay, which is used to power supply to the compressor as shown in Figure 3.38.

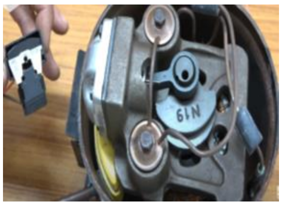


**Fig. 3.38 Relay for power supply**

2. Rotary Compressor – It can be available in many forms namely rotary-vane compressor, rotary-screw compressor, and rotary-scroll compressor.

a) Rotary-Vane Compressor – The rotary piston compressor, also known for its vane mechanism similar to that of a piston, features a fixed casing called a cylinder. Inside, the vane divides the space between the cylinder and the rotating piston into two sections: suction and discharge. As the piston rotates, these sections alternately expand and contract to facilitate the processes of gas suction, compression, and discharge. This type of compressor can be further categorized based on drive speed—either constant or variable—and the number of vanes used. Each operational cycle of the compressor involves five key actions: start, suction, compression, discharge, and end. The compressor's capacity can be adjusted by varying the cylinder volume. The typical cut section of the rotary-vane compressor is shown in Figure 3.39 (a). Parts of the reciprocating compressor are shown in Figure 3.39 (b).

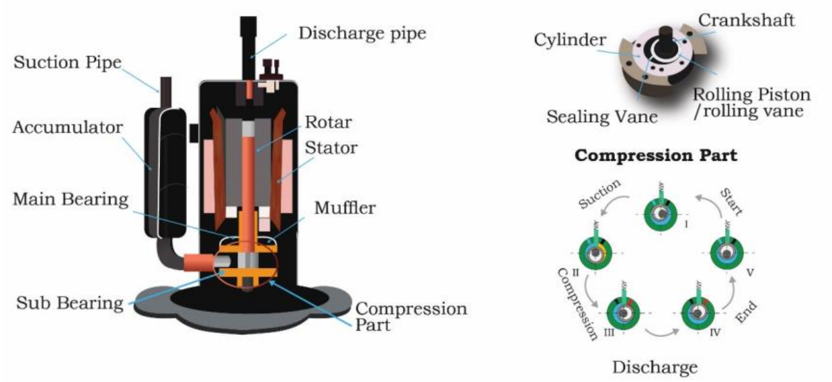



**Fig. 3.39: Rotary-vane compressor (a) Cut-away view (b) Theory of operation benefits**

b) Rotary-Scroll Compressor – In contrast to a rotary-vane compressor, the rotary-scroll compressor is designed to handle larger volumes of gaseous refrigerant and compress it to higher pressures and temperatures using a fixed orbital scroll. The process begins with the intake of cool vapor refrigerant from outside the fixed scroll. This refrigerant is then compressed between the fixed and the orbital scrolls. Finally, the compressed refrigerant is expelled from the centre of the fixed scroll through continuous displacement. The rotary-scroll compressor can also be categorized based on drive speed, which can be either constant or variable. Each operation cycle includes three actions: suction, compression, and discharge. A common industry term used to describe this type of compressor is digital scroll compressor. The typical cut section of the rotary-scroll compressor is shown in Figure 3.40 (a). the theory of operation for the compressor is shown in Figure 3.39 (b).

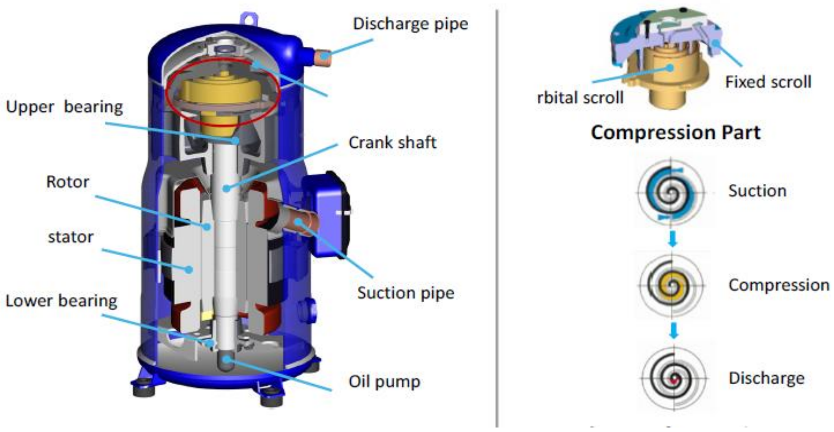



**Fig. 3.40: Rotary-scroll compressor (a) Cut-section (b) Theory of operation**

c) Rotary-Screw Compressor – A rotary-screw compressor uses rotating rotors to compress larger volumes of gaseous refrigerant to high pressures and temperatures. The compression process involves male and female rotors that decrease the volume of the refrigerant gas as they rotate. The cool vapor refrigerant enters through the suction port and is driven through the meshing rotors via the screw threads. The refrigerant is then expelled at the discharge port with increased pressure and temperature. Rotary-screw compressors can be classified based on the number of screws: single, twin, or multi. Figure 3.41(a) shows a cut-away section of a rotary-screw compressor, while Figure 3.41(b) illustrates the operational theory.

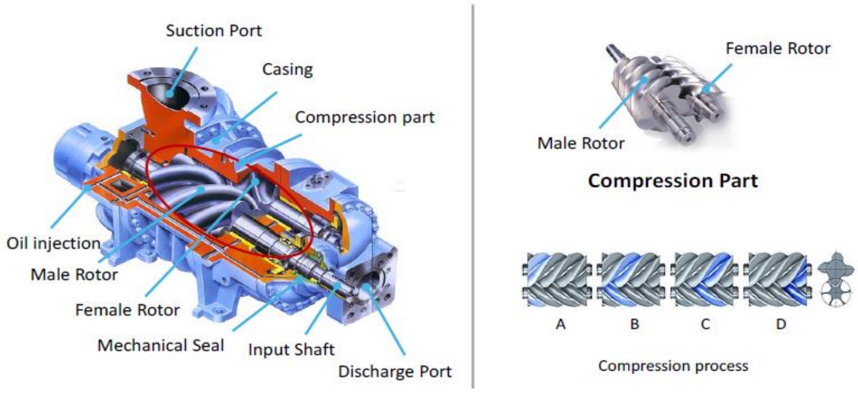



**Fig. 3.41 Rotary-screw (twin-screw) compressor (a) Cut-away view (b) theory of operation**

3.2.1.3 COMPRESSOR LUBRICATION

Lubrication is vital for the performance and longevity of compressors, particularly in refrigeration and air conditioning systems. It minimizes friction and wear between moving parts, which is crucial for maintaining efficiency and preventing damage. Proper lubrication not only ensures optimal performance but also extends the compressor's lifespan. Selecting the appropriate lubricant and following recommended maintenance schedules are essential practices for ensuring reliable operation and minimizing the risk of premature failure. Lubrication involves introducing a viscous fluid into machinery to facilitate smooth operation. It is essential for the efficient functioning of compressors. In compressors, oil is injected into the compression chamber to lubricate moving parts. This lubrication extends to the cylinder walls, rings, and other components such as rods, cranks, and bearings. There are two primary methods of lubrication: splash lubrication and pressure lubrication. Figure 3.47 depicts one example of compressor oil used in these systems.


**Fig. 3.47 Compressor oil**

Polyol ester oil (POE oil) is a type of synthetic oil used in refrigeration compressors that is compatible with refrigerants R-134a, R-410A, and R-12.

Need for Lubrication – Compressors are very sensitive components that must be properly lubricated for them to achieve a long service life. The lubricant not only must be able to lubricate all the parts inside the compressor but also handle the refrigerant with which it is in contact (in the case of refrigeration and air-conditioning compressors).

Some lubricants work better with certain refrigerants, and this must be balanced with the needs of the compressor to select the proper base oil and additive properties.

a) Friction Reduction – Lubrication helps to minimize friction between moving parts within a compressor. By creating a thin film of lubricant between surfaces, it reduces direct metal-to-metal contact, preventing excessive wear and heat generation. This friction reduction improves energy efficiency and extends the lifespan of the compressor.

b) Wear Prevention – Lubrication forms a protective layer on surfaces, preventing wear and damage caused by rubbing, sliding, or rolling motions. It acts as a barrier, reducing the impact of contaminants and debris that may be present in the system, thereby preserving the integrity and performance of the compressor components.

c) Heat Dissipation – Compressors generate heat during operation, and lubrication plays a vital role in dissipating this heat. The lubricant absorbs and carries away heat from friction points, helping to maintain optimal operating temperatures and preventing overheating that can lead to component failure.

d) Seal Enhancement – In some compressors, lubricants also assist in enhancing the sealing between rotating and stationary components. They help to fill small gaps or imperfections, promoting better sealing efficiency and reducing the potential for leaks.

e) Corrosion Protection – Compressors can be exposed to moisture and corrosive elements, especially in certain environments. Lubrication provides a protective barrier, preventing direct contact between metal surfaces and moisture, and helps inhibit corrosion and rust formation, thus preserving the integrity of the compressor.

f) Noise Reduction – Proper lubrication can help reduce the noise generated by a compressor. It acts as a damping agent, absorbing vibrations and reducing the overall noise level during operation.

### 3.2.2 CONDENSER

The condenser in an air conditioner is the outdoor component responsible for releasing heat through the condensation process. Its function can vary depending on the selected mode. When the heat is expelled outside, the unit operates as an air conditioner. However, if the heat exchange direction is reversed to release heat indoors, the unit functions as a heat pump. The primary role of the condenser is to facilitate heat transfer by condensing the gaseous refrigerant until it becomes super-heated. This refrigerant then flows through a series of coils where cool air is blown over them, allowing the latent heat to be expelled and released into the surrounding environment.

Parts of a Condenser

All types of AC units and heat pumps operate using the same elements:

Condenser cabinet: Contains the different elements of the condenser.

Condenser coil: A coil made from copper tubing with aluminium fins the help transfers and disperse heat.

Compressor: Consolidates the heated refrigerant into the condenser coil.

Condenser fan: Helps circulate air around the condenser coil to ensure efficient heat transfer.

#### 3.2.2.1 Working of a Condenser

Understanding how an air conditioning (AC) unit operates is crucial. As discussed earlier, an AC unit relies on refrigerant, which circulates through a series of coils-the evaporator and the condenser. The process starts with the compressor, which pressurizes the refrigerant until it becomes super-heated gas. This hot gas then moves through the condenser coils, located outside, where efficient heat transfer occurs, releasing the heat to the external environment.

As the refrigerant, now a hot gas, passes through the condenser coils, it condenses back into a liquid. This phase change is facilitated by the condenser fan, which blows cool outside air over the coils, rapidly reducing the refrigerant's temperature. The cooled, low-pressure liquid refrigerant then returns inside to the evaporator coils.

In the evaporator coils, the refrigerant evaporates back into a gas as it absorbs heat from inside the building, starting the cycle anew. When operating as an air conditioner, the refrigerant is cooled and condensed outside. In heat pump mode, the cycle reverses, with the refrigerant absorbing heat inside and releasing it outside.

The condenser is a vital component in this process, as it facilitates the heat exchange necessary for cooling or heating. Its efficient operation ensures the proper functioning of both air conditioning and heating modes.

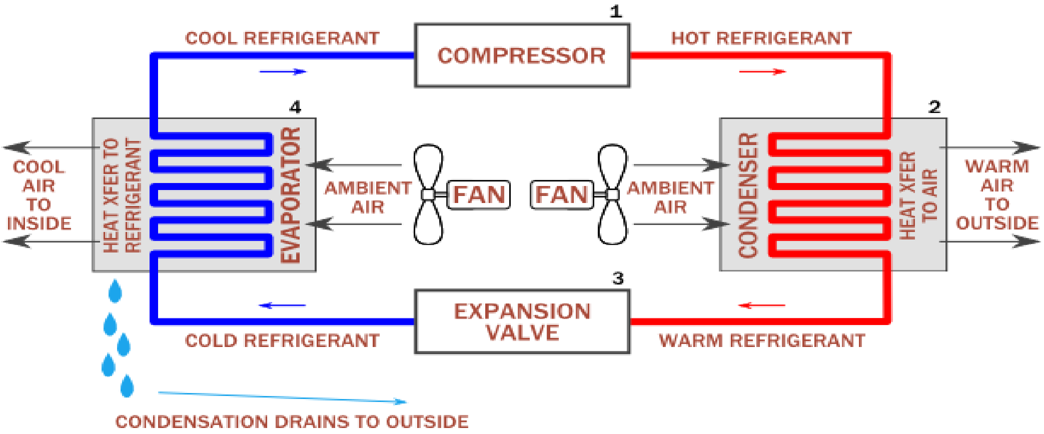
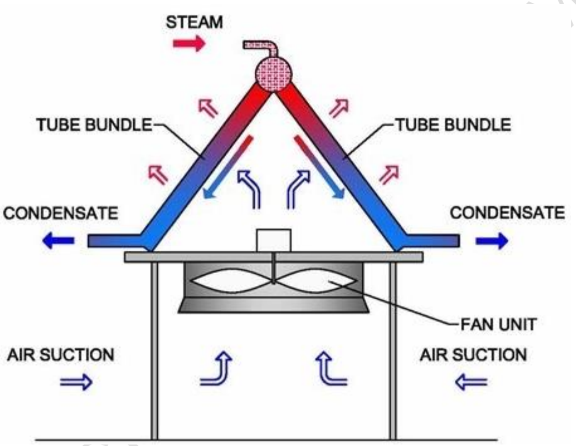



**Fig. 3.48 Working of Condenser in Air Conditioner**

### 3.2.2 Types of Condenser

There are two main types of condensers, an air-cooled condenser (Fig. 3.49), and a water-cooled condenser.

1. Air-cooled Condensers (Fig. 3.50)
    a. Condenser with natural convection
    b. Condenser with forced convection



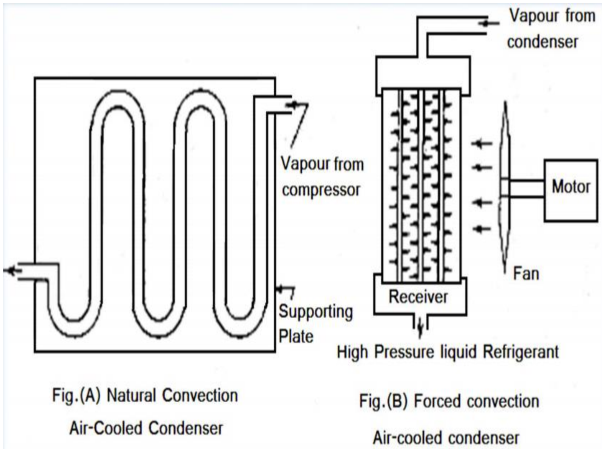




**Fig 3.49: schematic diagram for air-cooled condenser Fig 3.50: Types of air-cooled condenser**

Condenser with Natural Convection: This type relies on the natural flow of air to remove heat. As the air around the condenser warms up, it becomes less dense and rises, allowing cooler air to flow in from below. This natural movement helps in cooling the refrigerant without the need for additional mechanical assistance.

Condenser with Forced Convection: This type uses mechanical means, typically fans, to enhance the airflow over the condenser coils. The forced airflow helps in more efficient heat removal by actively moving air across the coils, improving the cooling process compared to natural convection.

General steps to consider while designing an Air-Cooled Condenser:

i. Dry Bulb temperature: The design of an air-cooled condenser is primarily based on dry bulb temperature at the plant location. Since the cooling medium for steam is air, a higher ambient temperature may lead to a lower heat transfer coefficient, thus a larger sized condenser required. A smaller condenser is essential at lower temperatures. An air-cooled condenser is designed for a temperature range of 2 to 5 % higher than that of the highest ambient temperature at that location.

ii. Air Velocity: A higher air velocity may give a larger heat transfer coefficient; thus, the condenser size will be smaller. While it might need a supply of more power of fan which also leads to increase in pressure drop. Thus, it is necessary to balance the range of power requirement and overall heat transfer coefficient.

iii. Tube Arrangement: The tubes can be arranged in an inline and staggered manner. The inline tube arrangement gives lower pressure drop and poor heat transfer as the flow tends to be channelled into a high-velocity region in the centre of the lanes between the tube rows. While staggered tubes produce good mixing of the flow over the tube banks but give a higher pressure drop.

iv. Pitch: As the distance between the successive tube size increases, the pressure drop inside the fin side decreases and also due to less obstruction. On the other hand, a higher pitch occupies more space. Thus, it is necessary to maintain the balance between space restriction and pressure drop.

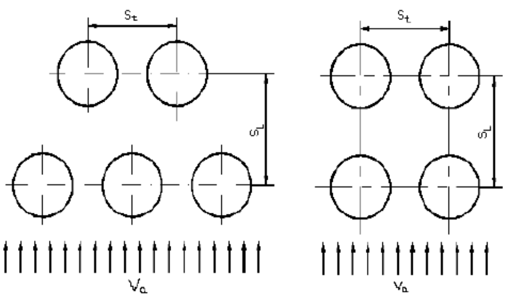


**Fig 3.51: Staggered and Inline Tubes arrangement in** the air-cooled condenser

**Fig 3.52: Air-cooled condenser**

2. Water Cooled Condensers
   a. Double Tube Condenser
   b. Shell and Coil Condenser
   c. Shell and Tube Condenser

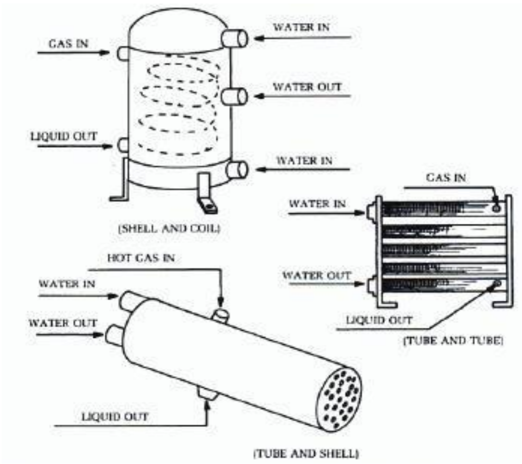



**Fig 3.53: Three different types of the water-cooled condenser**

**General steps to consider while designing a Water-Cooled Condenser:**

The design of the water-cooled condenser depends on the circumstances required in the plant (power plant) where it is to be installed. The temperature and availability of cooling water, pressure drop restrictions, purity of cooling water, and a host of other parameters will affect the choice of design parameters. The following are the most important parameters which need to be considered while designing.

i. Cooling water velocity: It depends on the type of material used for condenser, erosion, and fouling parameters. The cooling water velocity can be increased as the principal barrier to heat transfer is the heat transfer coefficient on the waterside. A high velocity can cause erosion, wear, and high-pressure drop while low water velocity will lead to accumulation and corrosion. To balance the heat transfer rate and power requirement, it is recommended to keep the velocity range between 5 to 8 fps.

ii. Overall Heat Transfer Coefficient: It depends on the cooling water velocity, purity of water, and temperature of cooling water. If there is an increase in the overall heat transfer coefficient, it will decrease the size of the condenser required.

iii. Tube Parameters: The tube material used is depending on the type of water and environment. A tube with a small diameter and thickness gives lower surface area requirements and lower pressure drop as compared to the large-sized tube, keeping the velocity same in both cases. This is because, for a fully developed flow, the Nusselt number is constant. While to maintain the Nusselt number constant, the heat transfer coefficient decreases when the tube diameter increases. Thus, the surface area required for heat transfer increases. However, the higher velocities can't be used in the smaller tubes.

iv. Temperature of Cooling Water: At a lower temperature of cooling water, the turbine will be operated at lower pressure. It helps to obtain the higher turbine output and the surface area required for the condenser is decreased. On the other hand, a low temperature may lead to subcooling where temperature rise in the condenser can be restricted.

v. Pressure Drop: The pressure drop inside the tube must be kept low to reduce the pumping power required. Usually, the accepted pressure drop range is between 2 to 7 psi.

**Fig. 3.54: Shell and Tube type condenser**



| |
|---|
| Practical Activity: The design calculation of Shell and Tube Condenser |
| Initially consider |
| i. Condenser Type: Shell and Tube Condenser |
| ii. No of Tube Passes |
| iii. Velocity of Cooling water |
| iv. Condenser Purity Factor for water with chemical treatment = β |
| v. Tube Size |
| Procedure steps in design Calculation: |
| Step 1: Find the heat duty of the condenser. |
| Step 2: Find the mass flow rate of cooling water. |
| Step 3: Find the overall heat transfer coefficient. |

Step 4: Calculate the cooling surface area.

Step 5: Find the number of tubes with the help of the continuity equation.

Step 6: Find the approximate length of the tube.

Step 7: Find the accurate length of the tube depending on the heat transfer area required.

Step 8: Determine the diameter of the shell.

Step 9: Determine the pumping power.

Step 10: Determine the power of the cooling tower fan.

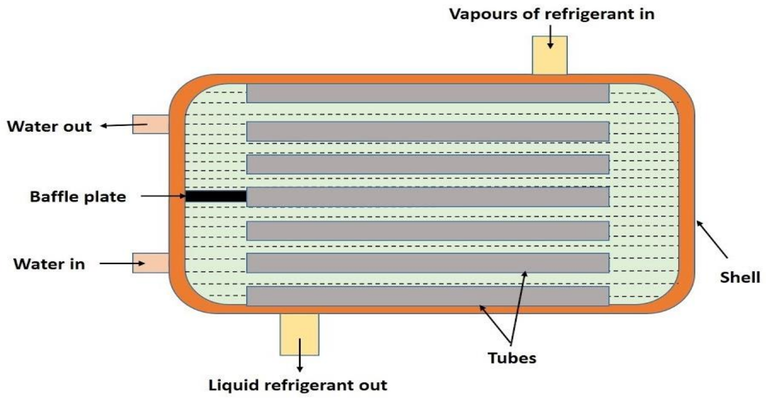



**Fig 3.55: water-cooled condenser - shell and tube type**

3. Evaporative Condenser: The third type of condenser, which is the water-cooled condenser, has design requirements that may vary based on its specific application and operational needs. These design considerations ensure optimal performance and efficiency tailored to the particular requirements of the system. The factors influencing its design include:

Operation Type: The operational characteristics of the system (e.g., power plant, industrial process) can affect the condenser design, such as the required heat transfer capacity and pressure levels.

Cooling Water Temperature: Variations in the temperature of the cooling water impact the condenser's design, including the choice of materials and the size of heat exchange surfaces.

Water Quality: The purity of the cooling water affects the design to prevent scaling and fouling, which can influence the type of materials and treatments used.

Pressure Drop Considerations: The design must address pressure drop restrictions to maintain system efficiency and reduce energy consumption.

Space and Layout: The available space for installation and layout constraints dictate the physical dimensions and configuration of the condenser.

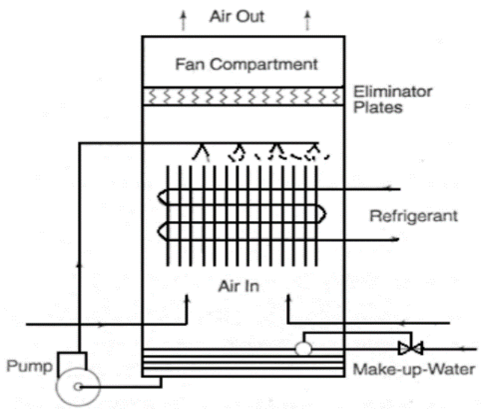
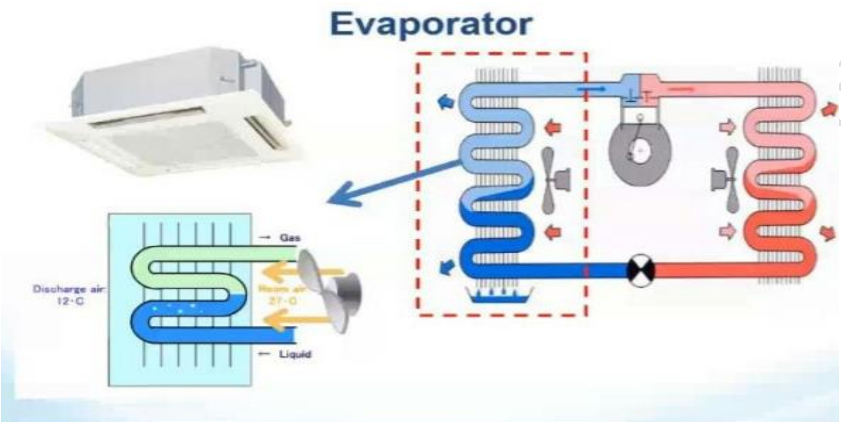



**Fig 3.56: Evaporative Condenser**

### 3.2.3 Evaporators

The evaporator is a crucial component in the low-pressure side of a refrigeration system. It plays a key role by allowing the liquid refrigerant, after passing through the expansion valve, to absorb heat from the surrounding space and convert into vapor. The primary function of the evaporator is to extract heat from its environment, thereby cooling the area.

In a split air conditioner, the evaporator is situated in the indoor unit. It contains the chilled refrigerant that absorbs heat from the indoor air, thus facilitating the delivery of cool, refreshing air into the room. The evaporator coil, which is typically made of materials like copper, steel, or aluminum, enhances heat transfer efficiency. It acts like the heart of the air conditioning system, circulating cool air to maintain a comfortable indoor environment.




| Component | State of refrigerant | Pressure | Temperature | Role (function) |
|---|---|---|---|---|
| Evaporator | Liquid To Gas | Low pressure | Low temp. | Absorbs heat from the room |

**Fig. 3.57 Evaporators in Air conditioning system**

#### 3.2.3.1 Working Principle of Evaporator and its Types

The primary function of an evaporator is to absorb heat from surrounding location or medium which is to be cooled by means of refrigerant. The refrigerant either boils as it flows through a pipe, tube or other type of space so that liquid is continuously wetting all the inside surface or it boils in a shell around submerged tubes through which the fluid to be cooling is flowing. Different methods are used for evaporators, depending upon the refrigerant to be used and evaporator application, but iron, steel and copper predominate. Refrigerant evaporators should be of extended surface or finned tube type whatever practical. In order to keep the average surface temperature down, a good bond between the fin and tube is essential. Integral fins formed out of the tube itself are best in this respect and give the best heat transfer rate.

**A. Type of evaporators based on operating condition:**

1. Flooded type evaporator
2. Dry or direct expansion type evaporator

The flooded type of evaporators is designed to maintain a pool of liquid refrigerant at the bottom of the evaporator shell. This ensures that there is always a sufficient amount of liquid refrigerant available to absorb heat. Because the evaporator is flooded with refrigerant, it can provide efficient heat transfer and cooling. The liquid refrigerant in contact with the heat exchange surface maximizes the heat absorption process. These may be Shell-and-Tube type and Shell-and-Coil type.

Dry or direct expansion type evaporators is a common design used in refrigeration and air conditioning systems. The term "direct expansion" refers to the fact that the refrigerant evaporates directly in the evaporator coil, and there is no separate refrigerant-to-water heat exchanger. The evaporator coils are designed to maximize heat exchange between the refrigerant and the medium being cooled. These coils are usually made from materials with good thermal conductivity, such as copper or aluminum. In a direct expansion evaporator, the refrigerant enters the evaporator as a liquid, which then evaporates into a gas as it absorbs heat from the surrounding medium. As the refrigerant passes through the evaporator coils or tubes, it absorbs heat from the medium (such as air or water) being cooled. This heat absorption causes the refrigerant to evaporate into a gas. The evaporator typically consists of a series of coils or tubes through which the refrigerant flows. The medium to be cooled (e.g., air in an air conditioning system) is blown across these coils, transferring heat to the refrigerant. The gaseous refrigerant is then collected and sent to the compressor, where it is compressed and subsequently cycled through the condenser.

**B. Type of evaporator based on construction:**

1. Bare tube evaporator
2. Plate evaporator
3. Finned tube evaporator
4. Shell tube evaporator
5. Tube in tube evaporator

1. Bare tube evaporator: The bare tube evaporators are made up of copper tubing or steel pipes. The copper tubing is used for small evaporators where the refrigerant other than ammonia is used while the steel pipes are used with the large evaporators that uses ammonia as refrigerants. The evaporator comprises of several turns of tubing and are usually used for liquid chilling. In blast cooling and freezing operations, atmospheric air flows over bare tube evaporator and the chilled air leaving it used for cooling purposes.

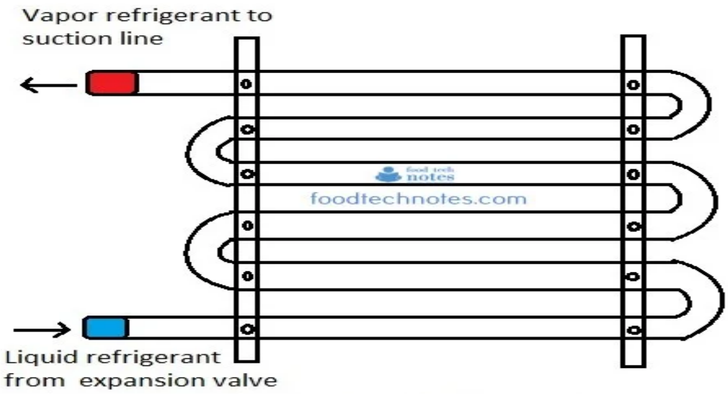



**Fig. 3.58 Bare tube evaporator**

2. Plate evaporators: In plate type evaporators, the coil usually made of copper of aluminium is embedded in the plate so as to form a flat looking surface. Externally the plate type evaporator looks like single plate but inside it, there are several turns of the metal tubing through which the refrigerant flows. The advantage of plate type evaporator is that they are more rigid as the external plate provides lots of safety. The external plate also helps increasing heat transfer from metal tubing to the substance to be chilled. These types of evaporators are easy to clean and can be manufactured cheaply. They can be converted into box shape, partitions or shelves as required for different purposes. Due to various advantage and flexibility offered by plate type evaporator, they are used extensively.

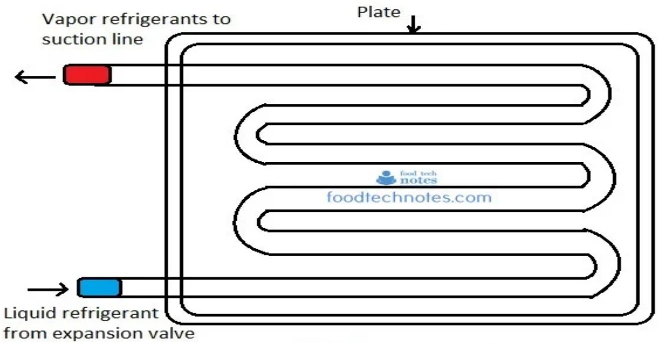



**Fig. 3.59 Plate evaporator**

3. Finned tube evaporator: The finned evaporators are tube type evaporators covered with the fins. When the fluid (air or water) to be chilled flows over the bare tube evaporator, lots of cooling effect from the refrigerant goes wasted since there is less surface for transfer of heat from fluid to refrigerant. The fins on the finned tube evaporator increases contact surface area and increases heat transfer rate. Thus, finned evaporators are more effective than bare tube evaporators.

For fins to be effective, it is very important that there is good contact between coil and the fins. In some cases, fins are soldered directly to surface of the coil and in other cases, the fins are just slipped over the surface of tubes or coils. The finned evaporators are most commonly used in the air conditioners of almost all type like window, split, packaged and central air conditioning. In this system, finned evaporator is known as cooling coil. The hot air flows over finned evaporator for cooling. To increase effectiveness of heat transfer from evaporator, the tubing is also given internal fins. These fins are made by forming different internal cross section shapes at the time of manufacturing of tubing.

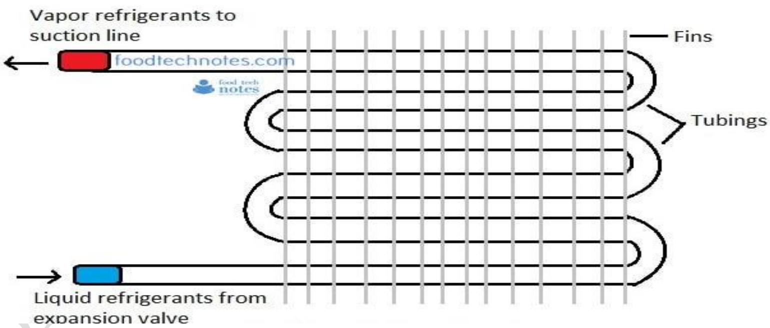



**Fig. 3.60 Finned tube evaporator**

### 3.2.4 Expansion Devices

An expansion device, sometimes called an expansion valve, is a small but significant component found in refrigeration and cooling systems. Its primary purpose is to regulate the flow of a refrigerant or a working fluid through the system, allowing it to undergo a phase change from a high-pressure liquid to a low-pressure gas.

Important of Expansion Devices in air conditioning

Expansion devices are vital for the proper functioning of refrigeration and cooling systems. When a refrigerant undergoes expansion, it changes from a liquid to a gas and absorbs heat from its surroundings. This cooling effect is what makes refrigerators keep our food fresh and air conditioners keep our homes comfortable during hot weather.

Think of expansion devices as the gateway between the high-pressure and low-pressure sides of a cooling system. Without them, the refrigerant would not expand properly, leading to inefficiency and potentially damaging the system.

Working of Expansion Devices

Expansion devices work based on a simple principle: they create a pressure drop in the refrigerant, causing it to change its state from a high-pressure liquid to a low-pressure gas. This process enables the refrigerant to absorb heat effectively.

Types of Expansion Devices:

1. Thermal Expansion Valve (TXV): The thermal expansion valve (TXV) is a widely used component in refrigeration and air conditioning systems. It comprises three main parts: a sensing bulb, a diaphragm, and a valve. The sensing bulb, typically mounted on the evaporator, monitors the temperature of the refrigerant. Based on this temperature data, the sensing bulb communicates with the diaphragm to regulate the valve's opening. This adjustment controls the refrigerant flow into the evaporator, ensuring efficient system operation.

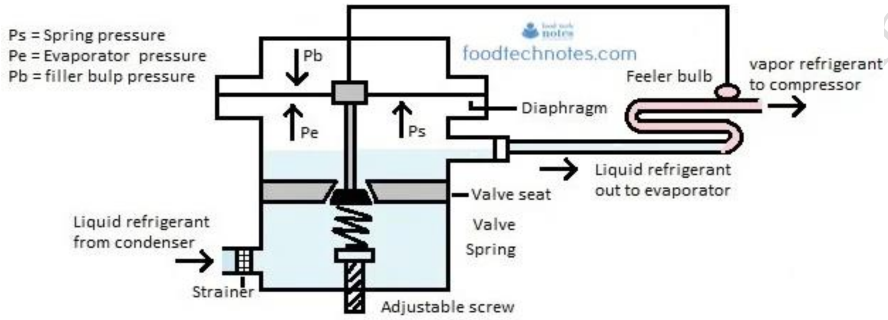



**Fig. 3.61 Thermostatic Expansion valve**

2. Capillary Tube: A capillary tube is a basic and economical expansion device used in refrigeration and air conditioning systems. It is essentially a long, thin tube with a small diameter. As the refrigerant flows through this narrow passage, it experiences a pressure drop due to the tube's restricted size. Although capillary tubes offer less precision compared to thermal expansion valves, they are commonly employed in smaller cooling systems and refrigeration units due to their simplicity and low cost.

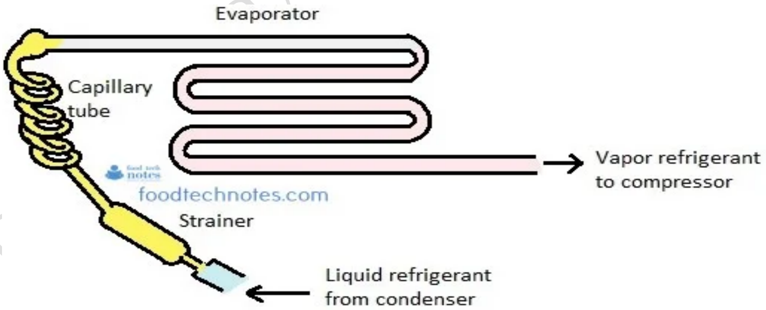



**Fig. 3.62 Capillary tube**

**Summary**

- **Cylinder**: It is the Main part where the piston reciprocates.
  **Material:** Cast iron, steel alloys, aluminium alloys.
  **Specifications:** Withstands high pressure (above 50 bar) and high temperature (up to 200°C).
- **Piston** translates energy from the crankcase to the gas in the cylinder.
  .
- **Crankshaft** Converts reciprocating motion of the piston into rotary motion using a connecting rod.
- **Crankcase** acts as Outer body housing the cylinder and crankshaft.

- **Connecting Rod** Converts piston's reciprocating motion into circular motion of the crankshaft.
- **Types of Compressors**: Hermetic Compressor, Rotary Compressor

  **Applications**: Common in household refrigerators, window air conditioners, and split air conditioners.

  **Advantages:** Prevents refrigerant leakage, quieter operation, easy lubrication, space-efficient, portable.

  **Disadvantages**: Difficult maintenance, requires separate vacuum pump for refrigerant charging, potential lubricant-refrigerant mix.

  Applications: It is Used in various air conditioning systems.
- **Lubrication**: It minimizes friction and wear, improving efficiency and lifespan. It protects against wear and damage. It absorbs and carries away heat. It improves sealing efficiency. It Protects against moisture and corrosion.it also reduces operational noise.
- **Condenser** releases heat through condensation, facilitating heat transfer by condensing the gaseous refrigerant into a liquid. It acts as an air conditioner by expelling heat outside, or as a heat pump by releasing heat indoors when the direction of heat exchange is reversed.
- **Parts of a Condenser**:

  **Condenser Cabinet**: It houses all condenser elements.

  **Condenser Coil:** it is Copper tubing with aluminium fins for heat transfer.

  **Compressor**: Consolidates heated refrigerant into the condenser coil.

  **Condenser Fan**: Circulates air around the coils for efficient heat transfer.

  Working of a Condenser:
- **Types of Condensers**: Air-Cooled Condensers, Natural Convection, Forced Convection, Water-Cooled Condensers, Double Tube Condenser, Shell and Coil Condenser, Shell and Tube Condenser, Evaporative Condenser
- **Evaporators:** The primary function of the evaporator is to extract heat from its environment, thereby cooling the area.
- The evaporator is essential in the low-pressure side of a refrigeration system.
- It allows liquid refrigerant, after passing through the expansion valve, to absorb heat from the surrounding area.
- The refrigerant converts into vapor, extracting heat and cooling the environment.

  **Types of Evaporators:**- Bare tube evaporator ,Plate evaporator ,Finned tube evaporator , Shell tube evaporator, Tube in tube evaporator
- **Expansion Devices**: Expansion devices regulate the flow of refrigerant, allowing it to change from a high-pressure liquid to a low-pressure gas. This process is crucial for the refrigerant to absorb heat and create a cooling effect.
- **Types of Expansion Devices:**

  **Thermal Expansion Valve (TXV):** It utilizes a sensing bulb, diaphragm, and valve to regulate refrigerant flow based on temperature data, ensuring precise system control.

  **Capillary Tube :** A simple, cost-effective device used in smaller systems, creating a pressure drop through its long, narrow passage, though less precise than TXVs.

# Check Your Progress

**A. Multiple Choice Question**

1. Which of the following oil is used in the compressor? (a) Grease (b) Polyolester Oil (PoE) (c) Mineral Oil (d) Engine Oil
2. Which of the following is not used to manufacture the cylinder of the compressor? (a) Cast iron (b) Steel alloy (c) Nickel (d) Aluminum alloy
3. Which of the following is the position after which piston reverses its direction? (a) Dead center (b) Compression stroke (c) Suction stroke (d) Discharge stroke
4. Which of the following parameter is increased by the compressor? (a) Force (b) Pressure (c) Velocity (d) Acceleration
5. It is defined as the ratio of the volume of air before compression to the volume of air after compression. (a) Compression Ratio (b) Rotary-screw compressor (c) Scroll Compressor (d) Screw Compressor
6. Which of the following term is not associated with the refrigeration system? (a) Condensation (b) Evaporation (c) Engine (d) Compressor
7. In compressor position is the nearest to the crankshaft is called (a) Bottom Dead Centre (BDC) (b) Suction Stroke (c) Intake Stroke (b) Out Stroke
8. Which of the following is not the part of a compressor? (a) Cylinder (b) Piston (c) Connecting rod (d) Connecting Belt
9. Which of the following is not mentioned on the plate of compressor? (a) Type of compressor (b) Refrigerant (c) Operating frequency (d) Lubrication used
10. Which of the following material is used to manufacture crankshaft of the compressor? (a) Steel Alloy (b) Cast Iron (c) Nickel (d) Aluminum Alloy

**B. Fill in the blanks**

1. Crankshaft coverts the reciprocating motion of the piston into the rotary motion with the help of ____________________.
2. Rotary-Vane Compressor is also known as a ________ compressor.
3. Evaporation is a process to convert them ______________ into gaseous form.
4. Compression in the refrigeration specify the____________ in the volume of gas or liquid.
5. Condensation is a process to convert them ___________ into liquid.
6. Expansion in the refrigeration specify the ________ in the volume of gas or liquid.
7. The refrigeration cycle starts by the _______________ of heat using refrigerant.
8. Compressor helps to maintain the __________ flow around the system.
9. The _____stage compressors in which compression of air takes place in one cylinder only.
10. Armature is the_____________ of the motor.

**C. Match the following**

| Name of component | Material used |
|---|---|
| 1. Cylinder | a. Aluminum alloy |
| 2. Piston | b. Cast iron, steel alloy, aluminum alloy |

| | |
|---|---|
| 3. Connecting rod | c. Special steel alloy |
| 4. Crankshaft | d. Aluminum alloy |
| 5. Outer body | e. Steel alloy and aluminum alloy |

**D. Short Answer Questions**

1. What is the compressor?
2. Name the internal parts of the compressor?
3. What is hermetic compressor?
4. Define the refrigeration system?
5. Explain evaporation, condensation, expansion and compression?
6. Draw Refrigeration cycle?
7. What is compressor?
8. Name the internal parts of the compressor?
9. What is hermetic compressor and where it is used.?
10. Why lubrication is necessary in the compressor?

# Session 4. Refrigerants

One day, Rahul's father called a technician to fix their malfunctioning air conditioner. Rahul observed with great curiosity as the technician began filling the air conditioner with a mysterious gas. He is so curious about this unfamiliar process. Rahul asked his father and inquired about this process and the nature of the gas. Patiently, his father explained that it was a “refrigerant”, a specialized gas used in air conditioners for cooling purposes. The refrigerant circulated through the coils of the air conditioner, absorbing heat from the indoor air and releasing it outside, resulting in a comfortable and cool environment. Figure 4.1 illustrates that Rahul and his father are discussing the filling of refrigerant in the air conditioner.

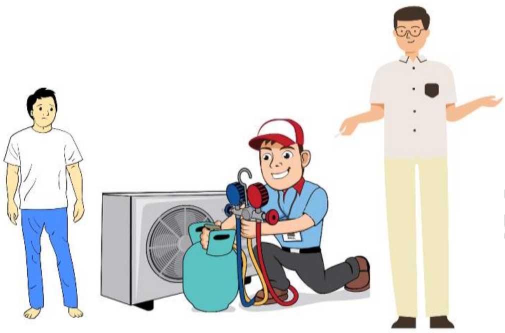


**Fig. 4.1 Rahul and his father discussing the filling of refrigerant in the air conditioner**

## 4.1 REFRIGERANT

A refrigerant is a substance or mixture, in the form of fluid, used in a heat pump and refrigeration system. The basic principle behind that is, any fluid that is capable of absorbing heat from another substance can be used as a refrigerant.

The refrigerants, which absorb and dissipate heat in the form of latent heat, are more efficient than those that carry heat in the form of sensible heat. Refrigerant is a working fluid used within a heat pump and refrigeration system.

The selection of appropriate refrigerant has been an important issue for air-conditioning. The most commonly known refrigerant in the past was chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs), but due to their harmful effects on the ozone layer, they have been phased out globally.

Figure 4.2 highlights the desired qualities of refrigerants. With the phasing out of fluorocarbons because of their ozone depletion effects, nowadays, the common refrigerants used in various applications are ammonia, R134a, and non-halogenated hydrocarbons such as propane. This chapter reviews the selection of refrigerants for vapor compression refrigeration systems.


**Fig. 4.2: Qualities of an Ideal Refrigerant**

### 4.1.1 History of Refrigerant

Refrigerants have specific properties that make them suitable for cooling applications. They have a low boiling point, allowing them to evaporate quickly and absorb heat from the surrounding environment. Figure 4.3 depicts the history of refrigerants.

In the period between 1830 and 1930, when the refrigeration system was evolving, natural refrigerants such as ammonia, carbon dioxide, sulfur dioxide, water, air, and ethyl ethers were used as refrigerants. They are classified as first-generation refrigerants. These refrigerants had high flammability, toxicity, and reactivity.

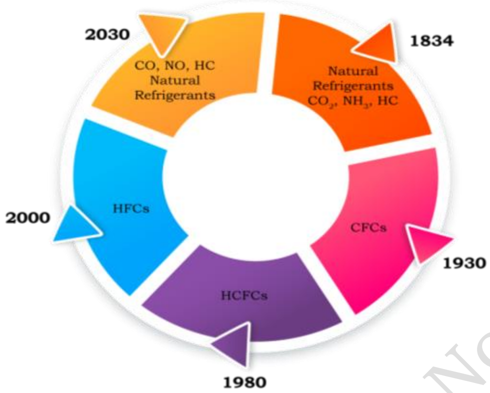



**Fig. 4.3: History of refrigerants**

In 1930, chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs) were produced and consumed on a large scale, particularly in developed countries. They are classified as second-generation refrigerants. The refrigerants were considered safe and durable due to their special characteristics such as stability, in flammability, non-toxicity, and good material compatibility. In 1987, the Montreal Protocol was designed as a framework to protect the ozone layer by phasing out the refrigerants, which are responsible for ozone depletion.

The initial step of the Montreal Protocol was to switch over from CFCs to HCFCs due to the ozone depletion potential (ODP) of HCFCs. Subsequently, a range of HFCs and their derivatives or blends was developed to meet the specifications of refrigeration applications. This class of refrigerants was considered third-generation.

In 1994, under the United Nations Framework Convention on Climate Change (UNFCCC), the Kyoto Protocol was designed as a concrete implementing tool to control Greenhouse gas (GHG) emissions. Both developed and developing countries are making efforts to reduce the use of ozone-depleting agents as well as strengthen controls outlined in the Protocol. Presently, HCFCs and HFCs contribute only about 2% of the total global warming, therefore, these are on schedule to be phased out by 2030.

The fourth-generation refrigerants include fluorinated propene (propylene) isomers with low Global Warming Potential GWP. At present, the most likely replacement is another new class of fluorocarbon refrigerant, viz. HFOs. They have very low GWP and are expected to replace HFCs in many applications. HFO-1234yf is an example of a fourth-generation refrigerant.

### 4.1.2 Primary and Secondary Refrigerants

Refrigerants are classified as Primary and Secondary refrigerants depending upon their direct or indirectly used within the refrigeration system.

**Primary Refrigerants –** These are fluids, which are used directly as working fluids in the vapor compression and vapor absorption refrigeration systems. These fluids provide refrigeration by undergoing a phase change process in the condenser and evaporator. In other words, primary refrigerants are the main working fluids within a refrigeration system. They directly participate in the heat transfer process and undergo phase changes to absorb and release heat. Figure 4.4 shows the detailed classification of primary refrigerants.

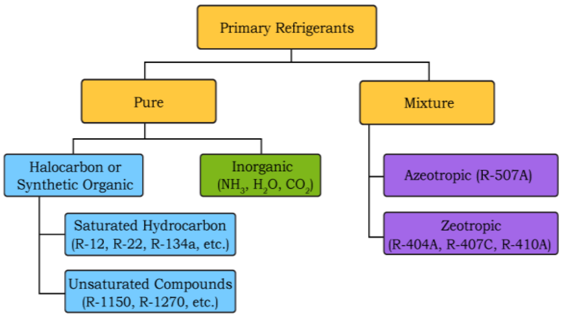



**Fig. 4.4 Classification of primary refrigerants**

All the refrigerants are designated by the capital letter R followed by a unique number. The unique number has been formalized as "ASHRAE" (American Society of Heating, Refrigerating, and Air-Conditioning Engineers).

1. **Saturated Hydrocarbons –** These refrigerants are derivatives of alkanes ($C_nH_{2n+2}$) such as methane ($CH_4$), ethane ($C_2H_6$), and propane ($C_3H_8$). They are denoted by the chemical formula $C_mH_nF_pCl_q$ in which (n + p + q) = 2m + 2. These refrigerants are designated by R – (m – 1) (n + 1) (p), as described in Figure 4.5, where, m indicates the number of Carbon (C) atoms, n indicates the number of Hydrogen (H) atoms and p indicates the number of Fluorine (F) atoms. The balance indicates (q) the number of Chlorine (Cl) atoms.

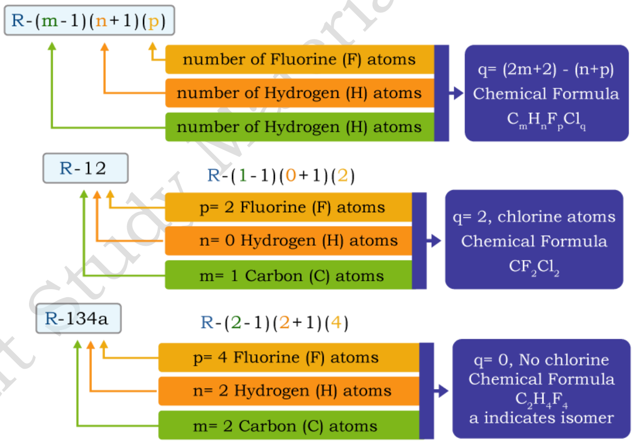



**Fig. 4.5 Saturated Hydrocarbons**

Hence, in dichloro-difluoro-methane, $CCl_2F_2$, in which there are carbon atoms (m = 1) and a hydrogen atom (n = 0), and a fluorine atom (p = 2), the designation is R – (1 – 1) (0 + 1) (p), or R–12.

In the case of isomers, i.e., compounds with the same chemical formula but different molecular structures, subscripts, a, b, etc., are used after the designations. Hence, tetrafluoroethene ($C_2H_2F_4$) has two isotopes, $CHF_2$–$CHF_2$ called 1,1,2,2-tetrafluoroethane and $CH_2F$–$CF_3$ called 1,1,1,2-tetrafluoroethane. They have a carbon atom (m = 2) and hydrogen atom (n = 4) and fluorine atom (p = 4), the designation is R – (2 – 1) (2 + 1) (p), or R–134. The isotope 1,1,1,2-Tetrafluoroethane is designated as R–134a.

In this manner, there are 15 derivatives of methane, 55 derivatives of ethane, and 332 of propane.

The prescribed method of designation cannot be used for $C_4H_{10}$ and higher hydrocarbons. Higher hydrocarbon refrigerants are denoted by an arbitrary number in the R600 series. Oxygen, Nitrogen, and Sulphur compounds are also included in the R600 series. Accordingly, n-butane and isobutane are assigned the designations arbitrarily as R-600 and R-600a respectively.

2. **Inorganic Refrigerants –** Inorganic refrigerants are denoted by the R700 series. The numerical designations are given according to their molecular weight. Ammonia ($NH_3$) having a molecular weight of 17 is designated as R-717, carbon dioxide ($CO_2$) having a molecular weight of 44 is designated as R-744, and sulfur dioxide ($SO_2$) having a molecular weight of 64 is designated as R-764.
3. **Mixed Refrigerants –** Pure refrigerants, which have low Ozone Depletion Potential (ODP) and Global Warming Potential (GWP), are very limited and the number of diverse applications of refrigeration is ever-increasing. Hence, new working substances are required for specific applications. If a pure refrigerant cannot meet the requirements, then the obvious choice is to try a mixture of two refrigerants, which may meet the requirements. Refrigerants that are mixed must be compatible and must not have any chemical effect on each other, neither immediately nor over a long time.

**Secondary Refrigerants –** Secondary refrigerants do not directly participate in the heat transfer process but act as intermediate fluids to transport thermal energy from the primary refrigerant to the desired cooling area. They circulate in a closed-loop system, absorbing heat from the primary refrigerant in an evaporator and releasing it in a separate heat exchanger or cooling device. Secondary refrigerants often have properties that make them safer or more suitable for specific applications. In other words, Secondary refrigerants are those fluids, which are used for carrying refrigeration from the plant room to the space where it is usefully applied, instead of directly obtaining it by the evaporating refrigerant at the place of application. Figure 4.6 illustrate that for the cooling of a plant room by air conditioner both primary and secondary refrigerant are used. Here, the chilled water is used as a secondary refrigerant in air conditioning applications. But for low-temperature applications (below 0°C) brines or antifreeze, glycols, and hydrocarbons are used.

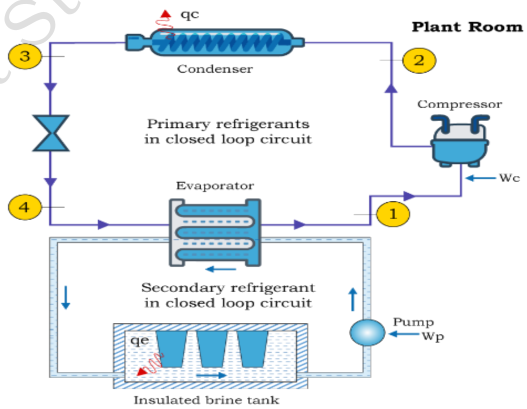



**Fig. 4.6 Primary and secondary refrigerants**

### 4.1.3 Colour Codes

The refrigerant containers which are used to store the refrigerant are having different color codes. The color coding of refrigerants varies depending on the region and the specific standards followed. For labelling these containers, a special ink is used called PMS (Pantone Matching System) ink color. Figure 4.7 (a) illustrates that before 2016 different color codes were used for the identification of refrigerants. But as the number of approved refrigerants is increased there is a chance for misidentifying the color code of these containers. And due to this, various safety-related issues arose. Because refrigerants have different operating pressures and flammable properties.


**Fig. 4.7 Colour codes (a) before 2016 (b) after 2020**

Therefore, after 2016, Air Conditioning, Heating, and Refrigeration Institute (AHRI) updated the guidelines. They decided that after 2020, all the refrigerant containers shall have uniform light-green-grey paint color only. Labelling the refrigerant containers with PMS ink colors shall continue. Figure 4.7(b) illustrates that all refrigerant containers are colored with uniform light-green-grey and flammable refrigerant containers have a red band.

## 4.2 CHARACTERISTICS OF REFRIGERANTS

A refrigerant is a substance used in cooling systems that has certain important qualities. No single refrigerant can have all the desired properties, so we choose a refrigerant that meets most of the required qualities.

### 4.2.1 Thermodynamic properties

The thermodynamic properties of refrigerants are a property that describes how it behaves during the heat transfer and cooling process in a refrigeration system. This property includes Condensing and Evaporating Pressures, Critical Temperature and Pressure, Freezing Point, Volume of Suction Vapour, Pressure ratio or Compression ratio, Latent heat of vaporization, and Specific heat.

a) **Condensing and Evaporating Pressures –** The evaporating pressure should be positive and as near atmospheric as possible. If it is too low, it would result in a large volume of suction vapor. If it is too high, the condenser pressure would result in heavier construction.

   A positive pressure is required to eliminate the possibility of the entry of air and moisture into the system. R-502, R-22, and $NH_3$ are high-pressure refrigerants as compared to R-12 whereas R-114, R-113, and R-11 are low-pressure refrigerants. R-134a, R-152, and to an extent isobutene have pressures close to those of R-12.

b) **Critical Temperature and Pressure –** The critical temperature of a substance is the temperature at and above which vapors cannot be liquified (condensed), no matter how much pressure is applied. For high COP, in general, the critical temperature should be very high. Also, the critical pressure should be low to result in low condensing pressure.

c) **Freezing Point –** As the refrigerant must operate in the cycle above its freezing point, it is evident that the freezing point for the refrigerant must be lower than system temperatures. It will be seen that except in the case of water for which the freezing point is 0°C, other refrigerants have reasonably low values. Water can, therefore, be used only in air-conditioning applications, viz., above 0°C.

d) **The volume of Suction Vapour –** The volume of the suction vapor required per TR, is an indication of the size of the compressor. Reciprocating compressors are used with refrigerants with high pressures and small volumes of suction vapor. Centrifugal compressors are used with refrigerants with low pressures and large volumes of suction vapor. R123 and R11 are suited for use with centrifugal compressors whereas R-152a, R-134a, and R-12 are mostly used with reciprocating compressors.

**e) The pressure ratio or Compression ratio –** Should be as small as possible for high volumetric efficiency and low power consumption.

**f) Latent heat of vaporization –** It should be as large as possible so that the required mass flow rate per unit cooling capacity will be small. It can be seen that for given condenser and evaporator temperatures, as the latent heat of vaporization increases, the pressure ratio also increases. Hence, a trade-off is required between the latent heat of vaporization and the pressure ratio.

**g) Specific heat –** Refrigerants should have low liquid specific heat so that the saturated line in the T-S plot becomes almost vertical. This will reduce irreversibility during throttling. Similarly, a small value of the specific heat of vapor will make the saturated vapor line almost vertical. If both the liquid and vapor-saturated lines are vertical then the efficiency of the refrigeration cycle approaches that of the reversed Carnot cycle.

### 4.2.2 Chemical Properties

Chemical properties of refrigerants refer to the characteristics and behaviors of the substances at a molecular level. There are various chemical properties of refrigerants, some of the chemical properties are Flammability and Toxicity, Action of Refrigerant with Water, Chemical Stability, Action with Oil, and Action with Materials of Construction.

**Flammability and Toxicity –** Refrigerant has to be non-toxic and non-flammable. There is no refrigerant, which can be called ideal.

a) **Flammability –** A flammable material catches fire immediately upon exposure to flame. The refrigerants are classified into three groups according to their flammability, as shown in Table 4.1.

i. **Class 1 – No Flame Propagation:** Indicates refrigerants that do not show flame propagation when tested in air at 21°C and 1 bar. Examples R-134a, R-410A, and R-22.

ii. **Class 2 – Lower Flammability:** Indicates refrigerants having a lower flammability limit of more than 0.10 kg/m$^3$ at 21°C and 1 bar or heat of combustion of less than 19 kJ/kg. Example R-717, R-141b, R-143a.

iii. **Class 2L – Lower Burning Velocity:** Refrigerants in this sub-classification have a burning velocity of less than or equal to 10 cm/s. Example HFO-1234yf.

iv. **Class 3 – Higher Flammability:** Indicate that they are the highly flammable limit of less than or equal to 0.10 kg/m$^3$ at 21°C and 1 bar or heat of combustion greater than or equal to 19 kJ/kg. Example R-170, R-290 and R-600a.

b) **Toxicity –** It is defined as the degree to which a chemical substance can damage an organism. The effects of a toxicant are dose and time-dependent. Refrigerants that pose a high risk to the human body in small quantities, even with short exposures, are regarded as highly toxic. It increases suffocation and poisons the air used for breathing. When choosing refrigerants for hospitals or cold storage, this is a major consideration. The refrigerants are divided into two groups according to their toxicity, as shown in Table 4.1.

i. **Class A Toxicity –** It signifies refrigerants for which toxicity has not been identified at concentrations of less than or equal to four-hundred parts per million (ppm). Some example refrigerants that are rated as non-toxic are R-22, R-134a, and R-410A.

ii. **Class B Toxicity –** It signifies refrigerants for which there is evidence of toxicity at concentrations below four hundred parts per million. Some example refrigerants are Ammonia (R-717) and XP30 (R-514A). R-514A is a new refrigerant designed to be a replacement for R-123 for centrifugal chillers.

**Table 4.1 Classification based on Flammability and Toxicity**

| | Lower Toxicity | Higher Toxicity |
|---|---|---|
| **No Flame Propagation** | A1<br>R-22, R-124a, R- 410, R-404A, R-407C, R- 507A, R-744 | B1<br>R-123, R- 514A |
| **Lower flammability** | A2<br>R- 152a | B2 |
| | A2L<br>R-32, R-1234yf, R-1234ze(E) | B2L<br>R-717(Ammonia) |
| **Higher flammability** | A3<br>R-290 (Propane), R-600a (Isobutane) | B3 |

**The action of Refrigerant with Water –** Moisture should not be allowed to enter refrigeration systems operating below 0°C. If more water is present then there is danger of ice formation and consequent choking in the expansion valve or capillary tube used for throttling in the system. This is called moisture choking. This is avoided by proper dehydration of the unit before charging and by the use of a silica gel drier in the liquid line.

**Chemical Stability –** An ideal refrigerant should be chemically stable in use within the system but would decompose easily in the atmosphere without the formation of any harmful substances. The Freon refrigerants are not used with rubber gaskets as it acts as a solvent with rubber.

**Action with Oil –** Refrigerants that are not miscible with mineral oil, such as ammonia or carbon dioxide, do not present any problems. Refrigerants that are completely miscible with mineral oil, such as R-12, R-152a, R-290, R-600a, etc., also do not present problems. The miscibility of the refrigerant with lubricating oil ensures an oil return to the compressor.

In refrigerants that are partially miscible with mineral oil, such as R-22, and R-134a, the return of the oil to the compressor creates problems. The oil is carried to the evaporator where it separates from the refrigerant. This results in a reduced heat transfer coefficient and oil choking in the evaporator. The use of synthetic oils which are miscible to refrigerants is recommended.

**Action with Materials of Construction –** Ammonia attacks copper and copper-bearing materials. Iron and steel are found suitable for use with ammonia. The recommended material for use for piping with halocarbons is copper. Because of its cheapness and availability, aluminium is used in place of copper in fluorocarbon refrigeration equipment. A vigorous reaction is expected between aluminium and R-134a. Therefore, aluminium protected by a tenacious oxide film which makes it non-reactive, can be used.

### 4.2.3 Physical Properties

The physical properties of refrigerants are the characteristics that can be observed or measured without altering the chemical composition of the substance. These properties play a significant role in determining the suitability of a refrigerant for a particular application.

**Thermal Conductivity –** Thermal conductivity should be high in both liquid and vapor phases for higher heat transfer coefficients.

**Viscosity –** Viscosity should be small in both liquid and vapor phases for smaller frictional pressure drops.

**Dielectric Strength –** Dielectric strength refers to the resistance a refrigerant offers to the flow of electric current through it. Specifically, it is the voltage required to cause an electric arc to form across two electrodes placed 1 inch apart within the refrigerant. This property is crucial for maintaining electrical insulation and preventing electrical discharge within the refrigerant system.

Moisture and contaminants present in the refrigerant can significantly reduce its dielectric strength. This reduction in dielectric strength can lead to electrical arcing, which can damage the compressor and other electrical components within the refrigeration system.

In hermetic compressors, where the refrigerant comes into direct contact with the motor and electrical components, maintaining high dielectric strength is essential. This ensures effective electrical insulation, preventing potential electrical failures and enhancing the reliability and longevity of the compressor. Proper management of refrigerant purity and moisture levels is vital to ensure the dielectric strength remains high and the system operates safely and efficiently.

**Leak Tendency and Odour –** The refrigerants should not have a leak tendency. If there is a leakage then it should be easily detectable. Odour helps to detect the leakage of ammonia and sulfur dioxide refrigerants. Sometimes a strong-smelling chemical like acrolein is added to the refrigerant for detection purposes.

**Ozone Depletion Potential (ODP) –** According to the Montreal Protocol, the ODP of refrigerants should be zero. Since ODP depends mainly on the presence of chlorine or bromine in the molecules, refrigerants having either chlorine or bromine cannot be used under the new regulations.

**Global Warming Potential (GWP) –** Refrigerants should have as low a GWP value as possible to minimize global warming.

**Cost of Refrigerant –** The consideration of the cost of a refrigerant has for many years commended the use of ammonia as a refrigerant in large industrial plants, such as cold storages and ice plants. The cost of losses due to leakage is also important. In small-capacity units requiring only a small charge of the refrigerant, the cost of refrigerant is immaterial. Ammonia is the cheapest refrigerant. In addition, it is environmentally-friendly. The future may see the return of ammonia in a big way.

### 4.3 Environmental Management

Ozone depletion and global warming are two major environmental concerns with serious implications for the future development of refrigeration-based industries.

**4.3.1 Ozone Layer Depletion –** Ozone ($O_3$) is an allotrope of oxygen ($O_2$), having three atoms of oxygen. Ozone in the earth's stratosphere, which is about 15-30 km above the earth's surface, is referred to as the ozone layer. It is formed naturally by the action of ultraviolet (UV) radiations with molecular oxygen ($O_2$) and electrical discharges within the Earth's atmosphere. Life on the earth has been safeguarded for thousands of years because ozone acts as a shield against the harmful ultraviolet B (UV-B) radiation from the sun. Exposure to increased UV-B radiation can lead to incidents of eye damage, such as cataracts, deformation of eye lenses, and presbyopia, cause skin cancer, reduce rates of plant growth, upset the balance of ecosystems, and accelerate the risk of disease. Figure 4.8 illustrates that the ozone layer is depleted due to pollution.

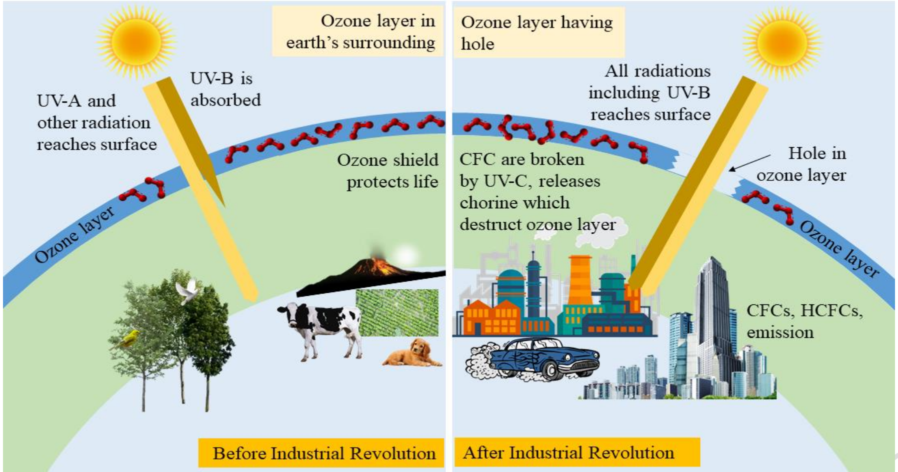



**Fig. 4.8 Ozone layer before and after the industrial revolution**

CFCs and HCFCs have been used for years as refrigerants, solvents, and blowing agents. The stable structure of these chemicals enables them to attack the ozone layer. If these chemicals escape into the atmosphere, they drift up to the stratosphere and intense UV-C radiation breaks their chemical bonds, releasing chlorine, which strips an atom of the ozone molecule, reducing it to an oxygen molecule.

$Cl + O_3 \rightarrow O_2 + ClO$

Chlorine acts as a catalyst, which accomplishes this destruction without itself undergoing any permanent changes; therefore, it can go on repeating the process. It has been discovered that one chlorine atom can destroy 100,000 ozone molecules. The higher the chlorine content of a compound, the longer will be its impact on the ozone layer.

CFCs have more chlorine content than HCFC, therefore CFCs have a higher potential for ozone depletion. The efficacy of ozone destruction is often measured by a comparative unit termed Ozone depletion potential (ODP), which is based upon the ODP of trichloro-fluoro-methane (CFC-11) being assigned a value of unity. The ODP is defined as the ratio of the global loss of ozone due to a given substance and the global loss of ozone due to CFC-11 of the same mass. Hydrofluorocarbons (HFC) have no chlorine content, so their ODP is essentially zero.

The concerns over ozone depletion led to the adoption of the Montreal Protocol in 1987, which bans the production of CFCs, halons, and other ozone-depleting chemicals. The ban came into effect in 1989. Ozone levels stabilized by the mid-1990s and began to recover in the 2000s. Recovery is projected to continue over the next century, and the ozone hole is expected to reach pre-1980 levels by around 2075.

**4.3.2 Global Warming Potential (GWP) –** Global warming or climate change is a second major environmental concern. Figure 4.9 shows greenhouse gases and global warming before and after the industrial revolution. When solar radiation reaches the earth's atmosphere, some of it is reflected to space and the rest is absorbed and re-radiated by greenhouse gases. The greenhouse effect is a process of trapping the solar radiation within the atmosphere. With the help of the natural greenhouse effect (carbon emission through volcanoes and hotspots), the average temperature at the earth's surface is maintained at an average temperature of 15°C, making life possible. Without greenhouse gases, the average temperature of the earth's surface would be about −18°C. Human activities emit about 35 billion tons of greenhouse gases per year (100–300 times more than volcanoes). Global warming arises because of the greenhouse effect. Some of these greenhouse gases include CFCs, HCFCs, $CO_2$, methane ($CH_4$), and nitrous oxide ($N_2O$).

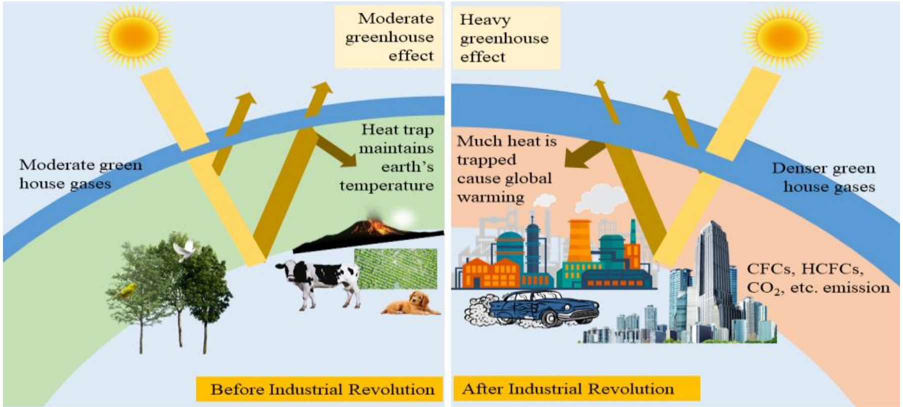



**Fig. 4.9 Greenhouse gases and global warming before and after the industrial revolution**

Global Warming Potential (GWP) is the amount of infrared radiation that the gas can absorb, relative to carbon dioxide with an assigned GWP of 1, integrated over 100 years. There are two types of global warming effects. The first is the direct global-warming potential that is due to the emission of refrigerants and other pollutants. The second type is an indirect global-warming potential, which results from the emission of carbon dioxide due to the consumption of energy obtained from the combustion of fossil fuels (oil, natural gas, and coal). The combined effects of the two global warming potentials are known as Total Equivalent Warming Impact (TEWI).

**4.3.3 International Treaties to Phase out Halogenated Fluids –** The discovery of the two major environmental problems, discussed above, has resulted in a series of international treaties demanding a gradual phase-out of halogenated fluids. The CFCs were phased out in 204. Initial alternatives to CFCs included some hydro-chlorofluorocarbons (HCFCs) will be used but they will also be phased out internationally by the year 2030 because their ozone depletion potentials (ODPs) and global warming potentials (GWPs) are in relatively high levels though less than those of CFCs.

It has already been suggested that R-134a may be decomposed by sunlight in the troposphere and form acid and poisonous substances. If this should turn out to be true, the world may have to face yet another catastrophe, even worse than the CFC experience. HFCs are equally like CFCs and HCFCs foreign to nature, consequently, it is obvious and much preferable to use natural compounds, which are already circulating in quantity in the biosphere and are known to be harmless. Table 4.2 provides the environmental effects of some common refrigerants.

Table 4.2 ODP and GWP of some common refrigerants

| Compositional group | Refrigerants | Ozone depletion potential (ODP) | Global warming potential (GWP) (100 years horizon) |
|---|---|---|---|
| CFCs | R11 | 1 | 3800 |
| | R12 | 1 | 8100 |
| | R113 | 0.8 | 4800 |
| | R114 | 1 | 9000 |
| | R115 | 0.6 | 9000 |
| HCFCs | R22 | 0.055 | 1500 |
| | R123 | 0.02 | 90 |
| | R124 | 0.022 | 470 |

| | | | |
|---|---|---|---|
| | R141b | 0.11 | 630 |
| | R142b | 0.065 | 2000 |
| HFCs | R23 | 0 | 11700 |
| | R32 | 0 | 650 |
| | R125 | 0 | 2800 |
| | R134a | 0 | 1300 |
| | R143a | 0 | 3800 |
| | R152a | 0 | 140 |
| Natural | R290 | 0 | 3 |
| Refrigerants | R600a | 0 | 3 |
| | R717 | 0 | 0 |
| | R718 | 0 | 0 |
| | R744 | 0 | 1 |

## Check Your Progress

**A. Multiple Choice Questions**

1. Any fluid that is capable of absorbing heat from another substance can be used as a (a) pressure (b) refrigerant (c) light (d) None of the above
2. The selection of appropriate refrigerant has been an important issue for (a) air-conditioning (b) Cooling system (c) refrigeration system (d) all of the above
3. These are fluids, which are used directly as working fluids in the vapor compression and vapor absorption refrigeration systems (a)Primary refrigerants (b) Condensation (c) Evaporations (d) None of the above
4. Refrigerants are denoted by the R700 series (a) Inorganic Refrigerants (b) Condensation (c) Evaporations (d) None of the above
5. Refrigerants do not directly participate in the heat transfer process (a) Inorganic Refrigerants (b) Secondary Refrigerants (c) Primary Refrigerants (d) None of the above
6. properties of refrigerants refer to the characteristics and behaviours of the substances at a molecular level (a)Physical (b) Chemical (c) Organic (d) All of the above
7. A material catches fire immediately upon exposure to flame (a) flammable material(b) Carbon and water (c) hydrogen and water (d) water
8. It attacks copper and copper-bearing materials (a) Petrol (b) Ammonia (c) hydrogen (d) carbon
9. Refrigerants that are completely miscible with mineral oil (a) R-3 (b) R-23 (c) R-12 (d) R-17
10. Odour helps to detect the leakage of refrigerants. (a) ammonia (b) sulphur dioxide (c) Both (d) None of the above

**B. Fill in the blanks**

1. The ________ used in a heat pump and refrigeration system.
2. Refrigerant must be non-toxic and _________.
3. The ________ conductivity should be high in both liquid and vapor phases for higher heat transfer coefficients.
4. Thermal conductivity should be high in both liquid and vapor phases for higher ________ coefficients.
5. The ______ should be small in both liquid and vapor phases for smaller frictional pressure drops.
6. According to the Montreal Protocol, the ODP of refrigerants should be______.
7. ODP depends mainly on the presence of ________ in the molecules.
8. Refrigerants should have as ______ a GWP value as possible to minimize global warming.
9. Ozone ($O_3$) is an allotrope of ______.
10. Chlorine acts as a ________ in ozone layer depletion.

**C. State whether the following statements are True or False**

1. The refrigerants should not have a leak tendency.
2. CFCs and HCFCs have been used for years as refrigerants.
3. The unstable structure of CFCs and HCFCs enables them to attack the ozone layer.
4. The lower the chlorine content of a compound, the longer will be its impact on the ozone layer.
5. The greenhouse effect is a process of releasing the solar radiation.
6. The ODP is defined as the ratio of the global loss of ozone due to a given substance and the global loss of ozone due to CFC-11 of the same mass.
7. Global Warming Potential (GWP) is the amount of infrared radiation that the gas can absorb.
8. R-134a may be decomposed by sunlight in the troposphere and form acid and poisonous substances.
9. Hydrofluorocarbons (HFC) have chlorine content.
10. When solar radiation reaches the earth's atmosphere, some of it is reflected to space and the rest is absorbed and re-radiated by greenhouse gases.

**D. Short answer questions**

1. Explain Greenhouse effect?
2. Explain hydrofluorocarbon?
3. What is Global Warming Potential?
4. What do you understand by Cost of Refrigerant?
5. What is Environmental Management?
6. What is Ozone Depletion Potential?
7. Explain characteristics of refrigerant
8. What are Thermodynamic properties of refrigerants?
9. What do you understand by colour codes of refrigerants?
10. Explain chemical properties of refrigerants?

# Module 5 Installation of Air conditioner

## Module Overview

Installing an air conditioner involves a series of critical steps to ensure that the unit operates efficiently, reliably, and has a long service life. Proper installation is key to achieving optimal cooling performance and preventing potential issues. Here is a detailed breakdown of the installation process:

**Choosing the Right Location:**

**Indoor Unit:** The indoor unit should be placed in a central location within the room to ensure even air distribution. Avoid locations near heat sources, direct sunlight, or areas that obstruct airflow.

**Outdoor Unit:** The outdoor unit should be installed on a level surface, such as a concrete pad or a mounting bracket. It should be placed away from obstructions like walls or vegetation that could hinder airflow and heat dissipation.

**Installing the Indoor and Outdoor Units:**

Securely mount the indoor unit on the wall or ceiling according to the manufacturer's guidelines. Ensure it is level and that there is sufficient clearance around it for proper airflow. Position the outdoor unit on its base or bracket. Ensure it is adequately supported and that it has ample space around it for ventilation.

**Connecting Electrical Wires:**

Properly connect the electrical wires from the power source to the air conditioner. Follow the manufacturer's wiring diagram and ensure all connections are secure and insulated. This step is crucial for safe and efficient operation.

**Setting Up Pipes for the Refrigerant:**

Install the refrigerant lines between the indoor and outdoor units. These lines must be properly insulated to prevent energy loss and potential freezing. Ensure all connections are tight and leak-free.

**Ensuring Proper Water Drainage:**

Install a drain line to allow the condensation produced by the air conditioner to flow out of the system. The drain line should be properly sloped to prevent clogs and ensure efficient drainage.

**Testing the System:**

Once installation is complete, perform a thorough test of the air conditioner. Check for any leaks in the refrigerant lines, ensure that the electrical connections are secure, and verify that the system operates correctly. Test the cooling performance and check for any unusual noises or issues.

Importance of Proper Installation:

**Effective Cooling:** Proper installation ensures the air conditioner cools the space effectively and efficiently.

**Reliability:** Correct setup reduces the likelihood of operational issues and breakdowns.

**Longevity:** A well-installed unit is less prone to wear and tear, extending its lifespan.

**Adherence to Manufacturer Instructions and Local Regulations:**

Always follow the manufacturer's installation instructions to ensure compliance with warranty requirements and to achieve optimal performance. Consider local codes and regulations, which may have specific requirements for installation practices and safety measures.

**Role of Trained Experts:**

Enlisting the help of certified HVAC professionals ensures that the installation is performed correctly and safely. Experts can also provide valuable advice on system maintenance and troubleshooting.

**Types of Air Conditioners and Tools Required:**

**Types:** Understanding the different types of air conditioners (e.g., window units, split systems, central systems) and their specific installation requirements is essential.

**Tools:** Essential tools for installation, repair, and maintenance include a level, drill, wrench set, refrigerant gauges, vacuum pump, and multimeter.

By following these steps and considerations, you can ensure that your air conditioner is installed properly, providing you with effective cooling, reliability, and long-term performance.

In this unit, you will understand the various types of air conditioners and their installation in different places in the home and also what important tools are required for installation, repair, and maintenance of air conditioners.

## Learning Outcomes

After completing this module, you will be able to:

- The working principles and key components of an air conditioner.
- We learn the step-by-step process of installing an air conditioner, including electrical and mechanical connections.
- Operate an air conditioner using a remote control and perform tests to ensure proper installation and functionality.

## Module Structure

| |
|---|
| Session 1. Air Conditioner |
| Session 2. Installation of Air Conditioner |
| Session 3. Use of remote control and Installation test of Air Conditioner |

# Session 1. Air Conditioner

One day Sunita went to buy an air conditioner for her house. She entered a store with little knowledge about air conditioners. She directly approached a sales executive, seeking help. She explained her needs, and she asked about the differences between window AC and split AC. Patiently, the sales executive explained the features of each type. Such as the window ACs were smaller and easier to install, while split ACs offer better cooling with separate indoor and outdoor units. Sunita listened the information carefully, and was grateful for the information. Feeling more confident, she decided on a split AC that suited her requirements.

In this chapter, you will understand the types of air conditioners and their uses, advantages, and disadvantages. Figure 1.1 illustrates that Sunita is discussing her requirement for an air conditioner with the sales executive.

**Fig. 1.1 Sunita in discussion with sales executive about the features of Air conditioner**

## 1.1 NEED FOR AIR CONDITIONER

In modern society, a typical person spends most of their time (typically 90%) of each day indoors. Therefore, providing a healthy and comfortable indoor environment has become an important factor in our economy. Air conditioning typically means conditioning of indoor (room, cabin, or space) air to improve the comfort of occupants.

To an average person air conditioning simply means the cooling of air. However, this definition is neither sufficiently useful nor accurate. Technically, air conditioning is the process of treating air in an internal environment to establish and maintain required standards of temperature, humidity, cleanliness, and motion. It should also attenuate any objectionable noise produced by the air conditioning equipment.

### 1.1.1 Requirements of Air Conditioning

The requirements of air conditioning depend on various factors, including the size of the space, the desired level of cooling, energy efficiency, and the specific needs of the occupants. Here are some common requirements to consider when installing or using air conditioning. There are various requirements for air conditioners. Some of the requirements of air conditioners are described below.

**Power supply –** Air conditioning systems require a reliable and adequate power supply to operate. The specific power requirements vary depending on the size and capacity of the system. It is essential to ensure the electrical system can handle the power demands of the air conditioner.

Figure 1.2 illustrates that for an air conditioner proper connection of the power supply is required.

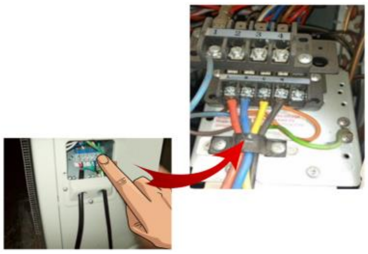


**Fig. 1.2 Power connection for an air conditioner**

**Proper insulation –** Adequate insulation in the building helps retain the cooled air and prevent heat transfer from the outside. Insulation reduces the workload on the air conditioning system, making it more energy-efficient and effective in cooling the space. Figure 1.3 illustrates that proper insulation is required for the electrical wires to avoid overheating, shock and electrical hazards.

**Fig. 1.3 Insulation required for the electrical wires used in air conditioners**

**Sizing and capacity –** It is crucial to select an air conditioning system with the appropriate size and cooling capacity for the intended space. An undersized system may struggle to cool the area effectively, while an oversized system may cycle on and off frequently, leading to inefficiency and temperature fluctuations. Table 1.1 illustrate the load capacity of room for a domestic air conditioner.

Table 1.1 Load calculation for a room in a domestic air conditioner

| **Room size** | **Capacity** |
|---|---|
| Upto 100 $ft^2$ | 0.8 ton |
| Upto 150 $ft^2$ | 1 ton |
| Upto 250 $ft^2$ | 1.5 ton |
| Upto 400 $ft^2$ | 2 ton |

**Airflow management –** Proper airflow is necessary for optimal cooling and distribution of conditioned air throughout the space. Design considerations should include the positioning of supply and return vents, ensuring unobstructed airflow, and avoiding the direct exposure of occupants to the air stream. Figure 1.4 illustrates the airflow directions of an air conditioner.

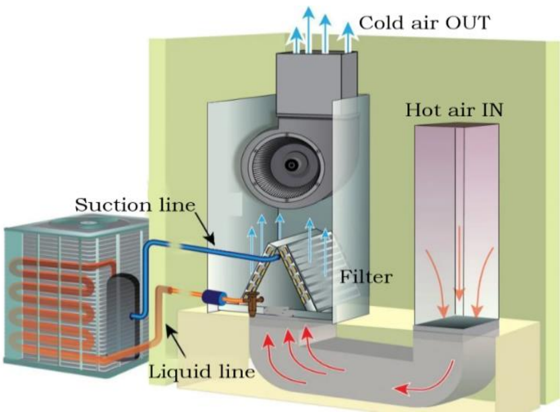



**Fig. 1.4 Airflow management for air conditioner**

**Maintenance and servicing –** Air conditioning systems require regular maintenance and servicing to ensure that they continue to operate effectively. This includes tasks like cleaning filters, inspecting and cleaning coils, checking refrigerant levels, and ensuring all components are in good working condition. Scheduled maintenance helps extend the lifespan of the system and ensures optimal performance. Figure 1.5 illustrates that the technician is servicing the outdoor unit of an air conditioner.

**Fig. 1.5 Proper maintenance and servicing of an air conditioner**

### 1.1.2 Rating of Air Conditioning Equipment

Air conditioning equipment must have a capacity rating system so that equipment made by different manufacturers and different models can be compared. Ton of refrigeration (TR) is a unit used to describe the heat-extraction capacity of refrigeration and air conditioning equipment.

The ton of refrigeration (TR) is defined as "the rate of heat transfer that results in the freezing or melting of 1 ton of pure ice from and at 0°C in 24 hours. Figure 1.6 illustrates that one ton of ice melts in 24 hours.


**Fig. 1.6 One ton of pure ice at 0°C melts in 24 hours**

One ton is equivalent to 2,000 lb or 906.185 kg and one metric ton is equivalent to 1000 kg. The latent heat of fusion of ice or water is 334.944 kJ/kg.

The heat needed to melt one short ton of ice in 24 hours = 334.944 × 906.185 kJ

The heat needed to melt a ton of ice in 1 minute $\frac{334.944 \times 906.185}{24 \times 60}$ = **210 kJ/min**

The heat needed to melt a ton of ice in 1 second $\frac{334.944 \times 906.185}{24 \times 60 \times 60} = 3.517\,\text{kJ/s} \approx 3.5\text{kW}$

A refrigeration ton is approximately equivalent to 3.5 kW (12000 BTU/h or 50 kcal/min).

**Calculation of Heat Load –** Before purchasing air conditioners, it is necessary to calculate the amount of heat that must be displaced from the space to maintain the temperature in an acceptable range. The amount of heat generated is known as heat gain or heat load. Heat is measured in either British Thermal Units (BTU) or Kilowatts (kW).

Heat gains are either in the form of sensible heat, which causes an increase in air temperature; or latent heat, which causes an increase in moisture content. The sensible heat gains originate from the solar radiation through windows, walls, and roofs; transmission through the building envelope and by the natural infiltration of warmer air from outside; people or occupants; and electric appliances such as lighting, pressing iron, etc. Latent heat gains are due to the presence of the occupants and the natural infiltration of more humid air from outside. In the case of industrial air conditioning, there may be additional sensible and latent heat gains from the processes carried out.

All the above sources of heat gain are well researched but a measure of uncertainty is introduced by the random nature of some, such as the varying presence of people and the way electric lights are switched. The design engineer must be able to calculate the heat gains with some assurance and this can be done when generally accepted methods of calculation are followed.

### 1.1.3 Classification of Air-Conditioning

Air conditioning systems can be classified into several categories based on various factors such as the method of operation, system configuration, and application. Here are some common classifications of air conditioning –

**Based on the system configuration**

**Window Air Conditioners –** These units are self-contained and installed in a window or a slot in an exterior wall. They consist of a single unit containing all the components, including the compressor, condenser, expansion valve, and evaporator.

a) **Split Air Conditioners –** Split systems have two separate units: an indoor unit and an outdoor unit. The indoor unit contains the evaporator and fan, while the outdoor unit houses the compressor and condenser. The two units are connected by refrigerant lines and electrical cables.

b) **Packaged Air Conditioners –** Packaged units are self-contained systems where all the components, including the compressor, condenser, evaporator, and fans, are housed in a single unit. They are typically installed on rooftops or in utility rooms, offering a space-saving solution for commercial buildings.

c) **Central Air Conditioning –** Central air conditioning systems are designed to cool large spaces or entire buildings. They consist of a centralized unit, often located outside the building, that cools the air and distributes it through a network of ducts and vents.

**Based on application**

a) **Residential Air Conditioning –** These systems are specifically designed for cooling individual homes or apartments. They can include window units, split systems, or central air conditioning systems.

b) **Commercial Air Conditioning –** Commercial air conditioning systems are designed to cool large commercial spaces such as offices, retail stores, restaurants, and hotels. They often utilize centralized systems or a combination of packaged units and split systems.

c) **Industrial Air Conditioning –** Industrial air conditioning systems are employed in industrial facilities, manufacturing plants, data centers, and other large-scale industrial applications. They are designed to handle high cooling loads and provide precise temperature control for industrial processes and equipment.

**Assignment 1**

1. list out the devices that are used for heating and enlist how many of them are used for cooling.
2. Calculate the heat needed to melt a 3 ton of ice in 1 minute.

## 1.2 TYPES OF AIR CONDITIONERS

As described earlier there are so many types of air conditioners available in markets for different applications and various places, but in this section, we only discuss the domestic air conditioner. The choice of which air conditioner system to use depends upon several factors such as the space or area or dimensions to be cooled, and the total heat generated inside the enclosed area. Hence, the designer considers all the related parameters. Based on it suggests the suitable type of AC for the space. For domestic applications, there are two types of air conditioners are generally used they are

1. Window Air Conditioner
2. Split Air Conditioner

**1.2.1 Window Air Conditioner –**A window air conditioner, also known as a window AC or a room air conditioner, is a compact cooling unit. It is designed to be installed on a window or a hole in an exterior wall of a room. It is a self-contained system that provides localized cooling for a specific area. It_is the commonly used air conditioner for single rooms.

Window air conditioners are relatively easy to install. They are typically placed in a window opening or a specially designed hole in the wall. The unit is secured and sealed in place, and the exhaust system is directed outside. It requires proper support and sealing to ensure efficient operation and prevent air leakage. Figure 10.8 illustrates that in the front of the window air conditioner on the room side, there is a front panel on which the supply and return air grills are fitted. There is also an opening in the grill that allows access to the control panel or operating panel in front of the window air conditioner

There is a major drawback associated with window air conditioners that they may produce some noise during operation. Also, regular maintenance is essential to ensure its optimal performance.

**Fig. 1.7 Window air conditioner**

**Parts of windows air conditioner –** The air conditioner components namely the compressor, condenser, expansion valve or coil, evaporator, and cooling coil are enclosed in a single box. This unit is fitted in a window of the room. The whole assembly of the window air conditioner can be divided into two compartments namely the room side portion, which is also the cooling side, and the outdoor side from where the heat absorbed by the room air is liberated to the atmosphere. The room side and outdoor side are separated from each other by an insulated partition enclosed inside the window air conditioner assembly. Figure 1.8 illustrates the various parts of the window air conditioner. The parts of the window air conditioner are discussed in preceding paragraph.

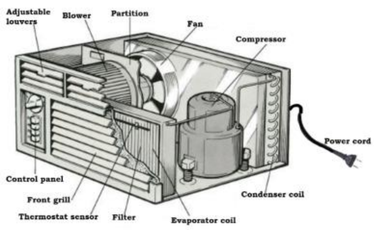



**Fig. 1.8 Cut section view of window air conditioner**

**Cabinet of window air conditioner –** It is an external body of the window air conditioner. A cabinet is used to hold all the parts of the window air conditioner. It also provides an external covering to save the internal parts from any foreign body. Figure 1.9 illustrates the cabinet for the window air conditioner.

**Fig. 1.9 Cabinet of window air conditioner**

**Control panel –** The control panel is used to interact with the user. It is situated in the front inside the room portion. In the case of older AC units, they contain mechanical knobs to control the fan speed and temperature of the air conditioner. The modern windows air conditioner units have electronic controls such as push buttons for temperature and speed control. It also has an LED to display the temperature and humidity. The most advanced feature is that it comes with the remote control to control and monitor the parameters of an air conditioner. Figure 1.10 illustrates the control panel of a window air conditioner.

**Fig. 1.10 Control panel of window air conditioner**

**Front Grill –** The front grill of a window AC helps to control the direction of airflow. It acts as a protective barrier for the internal components of the air conditioner. It helps to prevent the objects from accidentally entering the unit and causing damage to the delicate parts. The grill also helps to prevent the entry of dust and debris inside the AC unit. Figure 1.11 illustrates the front grill of a window air conditioner.

**Fig. 1.11Front grill of windows air conditioner**

**Adjustable louvers –** Adjustable louvers or vents can be opened or closed to direct the cooled air in a specific direction. This allows to adjust the airflow according to the preference and distribute the cool air evenly inside the room. Figure 1.12 illustrates the adjustable louvers of a window air conditioner.

**Fig. 1.12 Adjustable louvers**

**Air Filter –** The front grill houses the air filter. The filter helps to trap the dust, pollen, and other airborne particles by preventing them from entering the room. This improves the indoor air quality. The grill typically has a filter access panel or a removable section that allows to easily remove and clean or replace the filter. Figure 1.13 illustrates the air filter of a window air conditioner.

**Fig. 1.13 Air filter**

**Cooling Coil –** The cooling coil is used for the heat exchange between the refrigerant in the AC system and the air in the room. Figure 1.14 illustrates the cooling coil of a window air conditioner.

**Fig. 1.14 Cooling coil**

**Temperature sensor –** The temperature sensor of a windows air conditioner is used to detect the temperature of the cooling coil and the outdoor temperature of the room. Figure 1.15 illustrates the cooling coil of a window air conditioner.

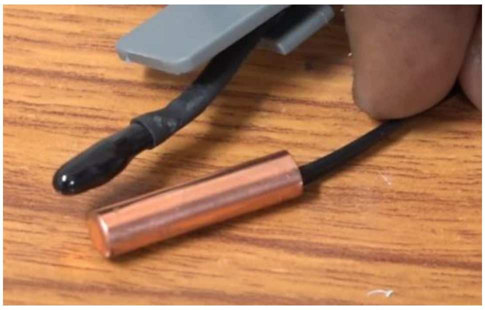


**Fig. 1.15 Temperature sensor**

**Blower –** It is a centrifugal evaporator type blower to discharge the cool air into the room. Figure 1.16 illustrates the blower of a window air conditioner.

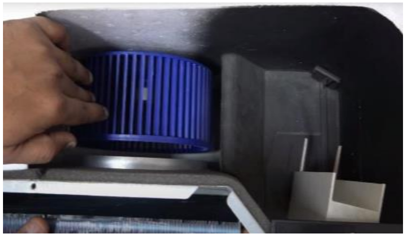


**Fig. 1.16 Blower**

**Propeller Fan –** Propeller Fan is used in the air-cooled condenser to help move the air molecules over the surface of the condensing coil. Figure 1.16 illustrates the propeller fan of a window air conditioner.

**Fig. 1.17 Propeller fan**

**Condenser Coil –** Condenser Coil is used to reject heat from refrigeration system to the outside air. Figure 1.18 illustrates the condenser coil of a window air conditioner.

**Fig. 1.18 Condenser coil**

**Fan motor –** Fan Motor is used to rotate the blower and propeller fan. It has a double shaft where the indoor blower and outdoor propeller fan are connected. Figure 1.19 illustrates the Fan motor of a window air conditioner.

**Air Conditioner Compressor –** The compressor is used to compress the refrigerant. Figure 1.20 illustrates the compressor of a window air conditioner.

**Fig. 1.20 Compressor**

**Capillary Tube –** Capillary tube is used as an expansion device. Figure 1.21 illustrates the capillary tube of a window air conditioner.

**Fig.1.21 Capillary tube**

**PCB Box –** PCB box is a place where all electronic components are mounted for the electrical connection and automated operation of the window air conditioner. Figure 1.22 illustrates the PCB box of a window air conditioner.

**Fig. 1.22 PCB box**

### 1.2.2 Split Air Conditioner

A split air conditioner is a type of cooling system that consists of two main components: an indoor unit and an outdoor unit. The indoor unit is typically mounted on a wall inside the room to be cooled, while the outdoor unit is placed outside the building. The indoor unit contains the evaporator coil, which cools and dehumidifies the air, and a fan that circulates the cooled air within the room. It also houses the air filters to remove dust and other particles from the air.

Figure 1.22 illustrates the indoor unit of the split air conditioner mounted on a wall.

**Fig. 1.23 Indoor unit of split air conditioner**

The outdoor unit houses the compressor, condenser coil, expansion valve, and fan. The compressor circulates refrigerant between the indoor and outdoor units, absorbing the heat from the indoor air and releasing it outside. Figure 1.22 illustrates the outdoor unit of the split air conditioner mounted on the other side of a wall open in the air.

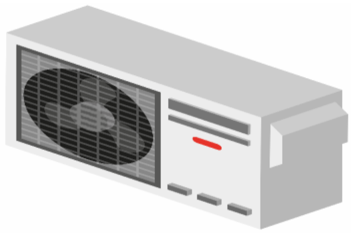


**Fig. 1.24 Outdoor unit of split air conditioner**

The two units are connected by refrigerant lines, electrical wiring, and a drainage pipe. The split design allows for quieter operation inside the room, as the noisy compressor and condenser fan are located outside. Additionally, split air conditioners offer greater flexibility in terms of installation and can cool individual rooms or zones independently.

Split air conditioner units do not take up as much space as a window unit. A split air conditioner can be used to cool one or two rooms.

**Parts of split air conditioner –** As described earlier in this chapter the split air conditioner has two units: an indoor unit and an outdoor unit. In this section, each part of the indoor unit and external unit are described separately.

**A. Indoor unit**

The indoor unit in an air conditioning system is responsible for cooling and circulating the conditioned air within a specific space, such as a room or an area of a building. It is typically installed inside the room where cooling is desired. There are various components installed inside and outside of the indoor unit. Some of the components are described here such as the Display unit of the split air conditioner, the Swing louver of the indoor unit, the Air Filter, the Swing motor, the Indoor unit Printed Circuit Board (PCB), the Evaporator Coil, the Anticorrosive net, Blower Fan, Control panel, and Temperature sensor.

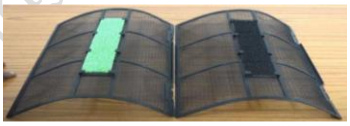
1. **The display unit of the split air conditioner –** The display unit is an external part of an indoor unit. It is situated in the front of the indoor unit. It displays the temperature of the room continuously. Figure 1.25 illustrates the display unit of the indoor unit.

**Fig. 1.25: Display unit of the Indoor unit on the split air conditioner**

2. **Swing louver of the indoor unit –** The swing louver is also known as the horizontal or vertical louver. It is responsible for controlling the direction of airflow from the indoor unit. The swing louver can move horizontally or vertically, depending on the design of the air conditioner. Figure 1.26 illustrates the swing louver of the indoor unit.

**Fig. 1.26 Swing louver**

3. **Air Filter –** It is located in the indoor unit and serves to filter the air that is drawn into the system for cooling. The primary function of the air filter is to remove dust, pollen, pet dander, and other airborne particles from the indoor air. Figure 1.27 illustrates the two types used in indoor units: Catechin filter and carbon filter.



**(a) (b)**

**Fig. 1.27 Air Filter (a) Catechin filter (b) Carbon Filter**

4. **Swing motor –** It is used to swing the louver. It provides motion to the swing louver. Figure 1.28 illustrates that the swing motor is connected to the flaps of the indoor unit.

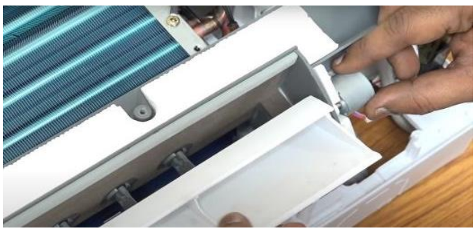


**Fig. 1.28 Swing motor**

5. **Indoor unit Printed Circuit Board (PCB) –** The PCB consists of all electronic components such as transistors, IC, capacitors, diodes, voltage regulators, buzzers, Cmos battery, and microcontrollers. This unit is responsible for the remote operation using remote control. Figure 1.29 illustrates that the PCB unit is connected via electrical connectors to the indoor unit.

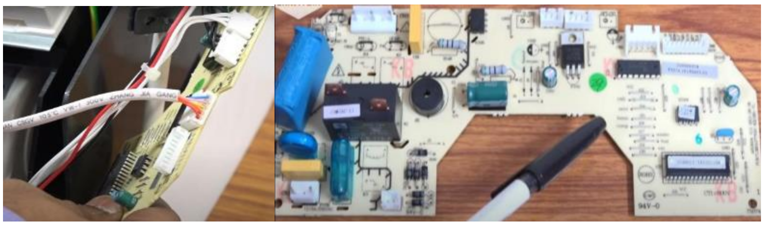


**Fig. 1.29 Indoor unit Printed Circuit Board (PCB)**

6. **Evaporator Coil –** This coil is responsible for cooling and dehumidifying the indoor air as it passes through the evaporator or cooling coils. It contains a refrigerant that absorbs heat from the air, cooling it down. Figure 1.30 illustrates the evaporator coil or cooling coil of the indoor unit.

**Fig. 1.30 Evaporator coil or Cooling coil of the indoor unit**

7. **Anticorrosive net –** This is a net made up of anticorrosive material for the protection of cooling coils and evenly spreading of temperature in the room. Figure 1.31 illustrates the Anticorrosive net installed in front of the evaporator coils.

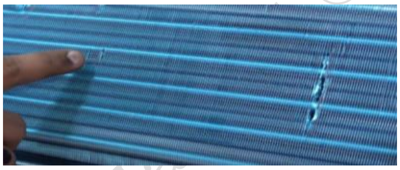


**Fig. 1.31 Anticorrosive net**

8. **Blower Fan –** The fan blows the cooled air into the room, creating airflow and distributing the conditioned air. Figure 1.32 illustrates the blower fan is connected to the blower motor.

**Fig. 1.32 Indoor Unit Blower or Cross Flow Fan**

9. Blower motor – it is used to rotate the blower fan at a particular speed. Figure 1.33 shows the blower motor.

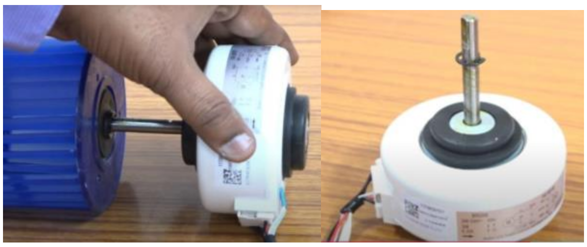


**Fig. 1.33 Blower motor**

10. **Control panel –** The control panel on the indoor unit allows you to adjust settings such as temperature, fan speed, and mode. It is also attached to the LED display unit to display the current temperature of the air conditioner. Figure 1.34 shows the control panel of the indoor unit.

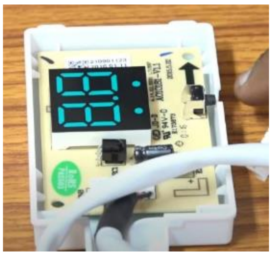


**Fig. 1.34 Control panel of indoor unit**

11. **Temperature sensor –** It is used to measure the coil temperature and the outside temperature. Figure 1.35 shows the temperature sensor. This sensor is generally a negative temperature coefficient type thermistor.

**Fig. 1.35 Temperature sensor**

**B. Outdoor Unit**

The outdoor unit in an air conditioning system plays a crucial role in the cooling process. It is typically installed outside the building or in an open space and is connected to the indoor unit through refrigerant lines. There are various components installed inside and outside of the outdoor unit. Some of the components are described here such as the Outdoor unit fan guard, Outdoor Valves, Compressor, Accumulator, Condenser Fan, Condenser Coil, and Expansion Valve.

1. **Outdoor unit fan guard –** It is used to cover the outdoor unit fan. It will protect entering any foreign body inside the outdoor unit. It also prevents major accidents. Figure 1.36 illustrates the outdoor unit fan guard.

**Fig. 1.36 Outdoor unit fan guard**

2. **Outdoor Valves –** these valves are used to connect the indoor unit through copper pipes. Figure 1.37 illustrates that the upper valve is called the suction valve and the lower valve is called the liquid valve.

**Fig. 1.37 Outdoor valves**

3. **Compressor –** It is typically located in the outdoor unit and plays a crucial role in the refrigeration cycle that cools the indoor air. It is used to circulate refrigerant through the air conditioning system. It increases the pressure and temperature of the refrigerant, transforming it

from a low-pressure gas to a high-pressure gas. Figure 1.37 illustrates that a compressor is mounted inside the outdoor unit.

**Fig. 1.38 Compressor**

4. **Accumulator –** The accumulator is used to store and collect liquid refrigerant from the evaporator coil and prevent it from reaching the compressor. It acts as a temporary storage tank for liquid refrigerant and separates it from any remaining vapor or gas. Figure 1.39 illustrates that an accumulator is mounted near the compressor in the outdoor unit.

**Fig. 1.39 Accumulator**

5. **Condenser Fan –** The fan helps dissipate heat from the condenser coil by blowing air over it, assisting in the cooling process. Figure 1.40 illustrates that a condenser fan is used to dissipate heat from a condenser coil.

**Fig. 1.40 Outdoor unit condenser fan blade**

6. **Condenser Coil –** This coil is responsible for releasing heat from the refrigerant to the outside air. It helps convert the high-pressure, high-temperature refrigerant gas into a liquid state. Figure 1.41 illustrates a condenser coil.

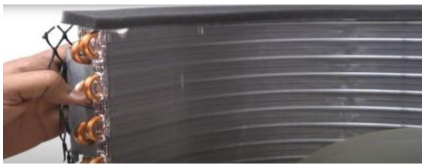


**Fig. 1.41 Copper pipe of condenser**

7. **Expansion Valve –** This valve regulates the flow of the refrigerant from the high-pressure side to the low-pressure side, causing it to expand and cool down. Figure 1.41 illustrates an expansion valve.

**Fig. 1.42 Expansion valve**

Practical activity 1.1 Demonstrate to start or turn on the split-type air conditioner for cooling

**Practical activity 1.1.** Demonstrate to start or turn on the split-type air conditioner for cooling

**Material required**

Split air conditioner and remote control

**Procedure**

**Step 1.** Connect the power cord of the indoor unit to the power supply. Figure 1.43 illustrate how to connect the power cord to the AC indoor unit.

**Fig. 1.43 Connection of AC indoor unit with power supply**

**Step 2.** Locate the power switch on the indoor unit and turn it on. Look for a light or display to confirm that the unit is powered on. Figure 1.44 illustrates pressing the power switch to turn on the AC.

**Fig. 1.44 Power switch on the indoor unit**

**Step 2.** On the remote control or control panel, choose the cooling mode and adjust the temperature using the "+" or "-" buttons. Figure 1.45 illustrates the use of remote for adjusting various parameters.

**Fig. 1.45 Adjust the temperature, fan speed, and other parameters**

**Step 3.** Select the fan speed such as low, medium, or high that suits your comfort preferences on the control panel or remote control as shown in Figure 1.45.

**Step 4.** Activate the swing mode on the remote control or control panel to enable the oscillating airflow direction for even distribution of cooled air throughout the room as shown in Figure 1.45.

**Step 5.** Wait for the compressor to start. The indoor unit's display will indicate the operating status. Soon, you will feel cool air flowing from the air vents.

## 1.3 ENERGY EFFICIENCY RATING (EER) OF AIR CONDITIONER

A room air conditioner's efficiency is measured by the energy efficiency ratio (EER). The EER is the ratio of the cooling capacity in British Thermal Units (BTU) per hour to the power input in (watts). The higher the EER rating, the more efficient the air conditioner.

The EER rating is typically displayed on the product specifications or Energy Guide label of the air conditioner. The Department of Energy requires manufacturers to provide the EER rating for air conditioners. Figure 1.46 illustrates the 3-star EER for a particular air conditioner.

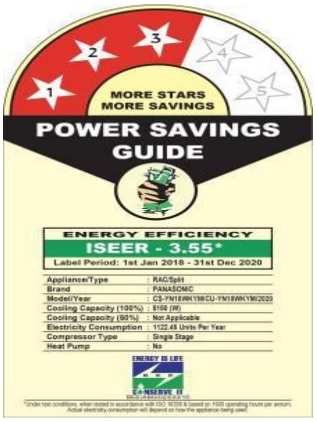



**Fig. 1.46 Energy Efficiency Rating**

### 1.3.1 How to Calculate EER Rating of an Air Conditioner

It is calculated by dividing the cooling capacity of the air conditioner (in British Thermal Units or BTUs) by its power consumption (in watts). The EER indicates how efficiently an air conditioner converts electrical energy into cooling output.

Calculating the EER rating requires the capacity of an air conditioner. And the power of an air conditioner.

$\text{EERrating} = \frac{\text{Capacity(BTU)}}{\text{Power(W)}}$

Let us say one has a 12,000 BTU mini split air conditioner that is powered by 1000 W. We can calculate the EER rating like this –

$$\text{EERrating} = \frac{12{,}000\text{BTU}}{1000\text{W}} = 12$$

EER rating of 12 tells us that for every 1W of energy we provide to the air conditioner, the air conditioner will give us 12 BTU of cooling effect.

Figure 1.47 illustrates the importance of the Energy Efficiency Rating in efficiency

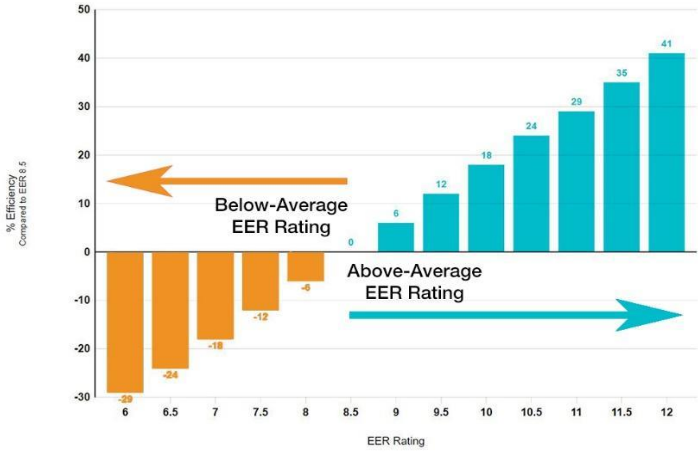



**Fig. 1.47 Importance of the Energy Efficiency Rating in efficiency**

# Check Your Progress

**A. Multiple Choice Question**

1. The requirements of air conditioning depend on (a) Space (b) level of cooling(c) Energy efficiency (d) All of the above
2. For a room of 150 ft$^2$ minimum capacity of AC is (a) 0.5 ton (b) 2 ton (c) 1 ton (d) 5 ton
3. Air conditioners are installed in a window or a slot in an exterior wall are called (a) Split AC (b) Centralized AC (c) Window AC (d) Industrial AC
4. Window air conditioner consist of a single unit containing (a) Compressor (b) Evaporator (c) Condenser (d) All above
5. A room air conditioner's efficiency is measured by the? (a) EER (b) EPR (c) ESR (d) EEE
6. This valve regulates the flow of the refrigerant from the high-pressure side to the low-pressure side (a) Expansion valve (b) Reduction valve(c) holder valve (d) compression valve
7. It increases the pressure and temperature of the refrigerant, transforming it from a low-pressure gas to a high-pressure gas. (a) Compressor (b) Evaporator (c) condenser (d) none of the above
8. This coil is responsible for releasing heat from the refrigerant to the outside air. (a) Condenser coil (b) Evaporator coil (c) Temperature coil (d) Power cord
9. The fan helps dissipate heat from the condenser coil by blowing air is called (a) vapour fan (b) Evaporator fan (c) compressor (d) Condenser fan
10. It used to store and collect liquid refrigerant from the evaporator coil and prevent it from reaching the compressor (a) Accumulator (b) Evaporator (c) compressor (d) Reduction valve.

**B. Fill in the blanks**

1. Split AC systems have ______ separate units.
2. The indoor unit of Split AC contains the ______________ and_______.
3. The outdoor unit of Split AC contains the ______________ and_______.
4. Blower is a centrifugal ____________to discharge cool air into the room.
5. The indoor unit of split AC contains the ________coil
6. The compressor _________refrigerant between the indoor and outdoor units.
7. Swing motor is used to _______the louver.
8. Evaporator coil contains a refrigerant that ______heat from the air, cooling it down.
9. The _____________indicates how efficiently an air conditioner converts electrical energy into cooling output.
10. BTU stands for_____________.

**C. State whether the following statements are True or False**

1. For the proper cooling Airflow management is necessary.
2. Air conditioning systems require regular maintenance and servicing to ensure they continue to operate effectively.
3. Central air conditioning systems are designed to cool large spaces or entire buildings.
4. Commercial air conditioning systems are designed to cool small places.
5. Central air conditioner distributes cool air through the network of ducts and vents.
6. For a domestic application two types of AC are used.

7. The control panel of Ac is not used to interact with the user.
8. The front grill of a window AC helps control the direction of airflow.
9. Adjustable louvers are used be opened or closed to direct the cooled air in a specific direction.
10. Compressor is a centrifugal evaporator to discharge cool air into the room.

**D. Short Answer Questions**

1. Explain types of domestic Air conditioner.
2. Explain Energy efficiency ratio?
3. Explain working of window AC?
4. Explain Accumulator?
5. What is the role of outdoor unit in split AC?

# Session 2. Installation of Air Conditioner

One day Sameer and his father came home with a newly purchased Air Conditioner (AC). The next day a technician arrived to install the AC. Sameer watched the work of technician who came with tools and equipment to install the AC. The technician carefully assessed the ideal location for the AC unit, measured and marked the spots for mounting brackets, and securely installed them using a power drill. The technician then lifted the AC and placed it on the brackets, ensuring it was levelled and aligned perfectly. The technician then connected the electrical wires and switched on the AC. After switching ON the AC, the room was filled with cold air that brought relief to Sameer and his family. Figure 2.1 illustrates that the technician is installing the outdoor unit after installing the indoor unit.

**Fig. 2.1 Installation of the air conditioner by a skilled technician**

As discussed in previous sessions, an air conditioner is a system, used to cool a closed room by extracting the heat from the room and throws it out to the outer surrounding. The domestic air conditioners are of two types, windows air conditioners, and split air conditioners. For proper cooling of the room, it is very much essential to install the air conditioner correctly.

**2.1 INSTALLATION OF SPLIT AIR CONDITIONER**

The word "split" in the case of split air conditioner specifies that the indoor and outdoor units are a distance apart. It is a ductless type of air conditioner which does not require a duct. As described in an earlier chapter, the indoor unit is a cooling unit which is installed inside the room, and the outdoor unit contains the compressor and condenser which is installed outside the room. Both units are connected with refrigeration lines or insulated copper pipes and power cables.

### 2.1.1 Precautions and Safety during the Installation of Split air conditioner

During the installation procedure of a split air conditioner, the technician can face many difficulties that are summarised as follows:

**Power Supply –** Before starting any installation work, ensure that the power supply to the area is turned off. This helps prevent the risk of electric shock. Figure 2.2 illustrates switching off the electrical supply before the installation of the air conditioner.

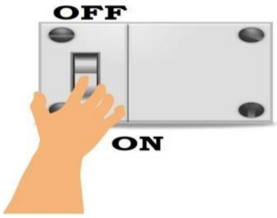



**Fig. 2.2 Switch off the power supply**

**Proper Wiring –** Ensure that the electrical wiring is done according to the manufacturer's instructions. Improper wiring can lead to electrical hazards or damage to the AC unit. Figure 2.3 illustrates the proper connection of the split air conditioner.

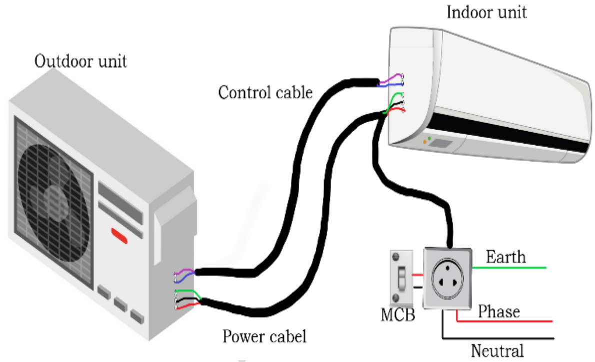



**Fig. 2.3 Proper electrical connection of both AC units**

**Weight and Support –** Air conditioners can be heavy, so make sure the mounting surface, such as walls or windows, is strong enough to support the weight of the unit. Always use a mounting bracket for large weights as shown in Figure 2.4.

**Mounting Brackets –** If using mounting brackets, ensure they are securely attached to the wall or window frame to prevent the AC unit from falling or becoming unstable. Figure 2.4 illustrates that brackets are mounted on the wall.

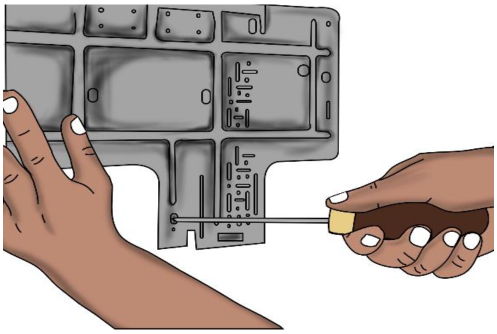


**Fig.2.4 Mounting of Bracket**

**Refrigerant Handling –** Refrigerant lines contain potentially harmful substances. It is important to follow safety guidelines and regulations when handling refrigerants. Avoid puncturing or damaging the refrigerant lines during installation. Figure 2.5 illustrate that a technician is taking all precautions while filling the refrigerant in the AC

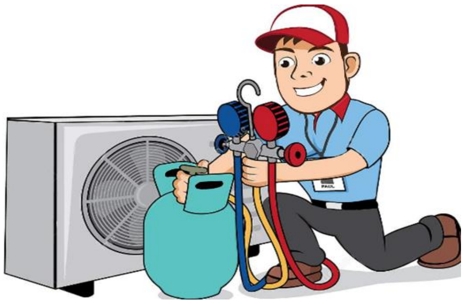


**Fig.2.5 Technician is filling refrigerant in the AC**

**Personal Protective Equipment or PPE** – If you are involved in the installation process, use appropriate safety equipment such as gloves, safety glasses, and protective clothing to protect yourself from potential hazards. Figure 2.6 illustrates the complete PPE kit for an AC technician.

**Fig.2.6 PPE kit for AC technician**

**Drainage of water for the outdoor unit –** Choose a location that is close to an existing drain. This will make it easier to drain the water coming from the outdoor unit. Figure 2.7 illustrates the proper drainage of AC outdoor units.

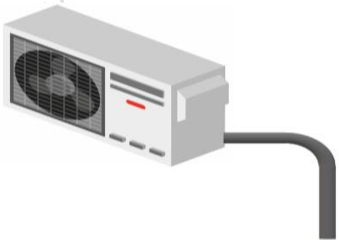


**Fig.2.7 Proper drainage for outdoor unit**

### 2.1.2 Procedure of Installation

The installation procedure may vary depending on the specific model and manufacturer's instructions. There are various steps involved in the installation of the split air conditioner. In this section, we will discuss in brief to install split air conditioners in both units.

**Opening of the package –** When the user purchases the new split air conditioner, it comes in two different boxes one box is for the indoor unit and another one is for the outdoor unit. Figure 2.8. illustrates the split air conditioner consists of two boxes.

**Fig.2.8 Split air conditioner package**

Both the boxes are sealed with plastic tape. So safely, open the packages of indoor and outdoor units of a split air-conditioner. Figure 2.9 illustrates the safely opened boxes of both indoor and outdoor units of an air conditioner.

**Fig.2.9 Package of the outdoor and indoor unit**

The outdoor unit box contains an extra package having a refrigerant pipe, small parts such as a feedthrough tube, insulation tape, sealant, and rubber mounts. Figure 2.10 illustrates the extra parts which are stored in the outdoor unit box.

**Fig.2.10 Parts in the package of split air conditioner**

**Measurement –** When installing a split air conditioner, it is very important to measure the width, height, and depth of the wall where the AC unit will be placed. Additionally, measure the spacing for mounting brackets, clearance requirements for proper airflow, and the length of refrigerant lines needed to connect the indoor and outdoor units. Figure 2.11 illustrate the way to measure the distance between the holes of the wall bracket from the outer edge of the unit

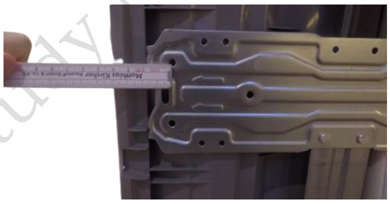


**Fig.2.11 Measuring the distance of mounting holes on the bracket**

For proper air circulation, it is required to measure the roof distance from the upper edge of the indoor unit. Keep at least 15 cm from the roof, this will provide sufficient space for air circulation in the room. Figure 2.12 illustrates a minimum distance is 15 cm from the roof and a minimum of 215 cm from the ground is required for proper air circulation.

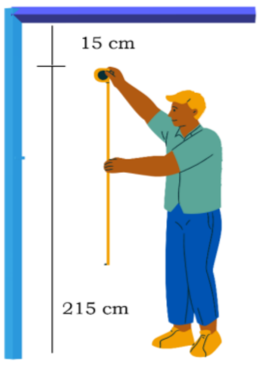



**Fig.2.12 Measuring the space for air circulation**

After measuring the distance between the roof and the ground Make a horizontal straight line using a level and pencil as shown in Figure 2.2.

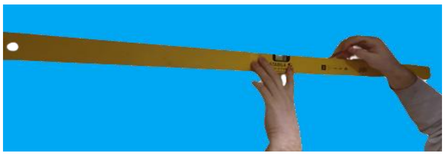


**Fig.2.13 Marking the straight line using the level**

Mounting brackets are used during the installation of air conditioners to provide a stable and secure platform for the unit. They distribute the weight evenly, ensuring the AC remains in place and reducing the risk of instability or falling. Mounting brackets also make it easier to align the unit properly and maintain proper clearance from the wall. They are essential for safe and secure installation, allowing the air conditioner to function effectively and efficiently. Figure 2.14 illustrates that the mounting bracket is used for marking holes at exact positions for the purpose of mounting the AC indoor unit.

**Fig.2.14 Mark the points to be drill**

**Drilling –** Drilling is commonly used during the installation of an indoor unit in an air conditioner. For mounting the mounting brackets on the wall, drilling is necessary. The mounting plate provides a secure base for attaching the indoor unit. After marking, perform the drill operation on the marked point. Figure 2.15 illustrates the drilling action performed by the drill machine to make a hole for anchoring.

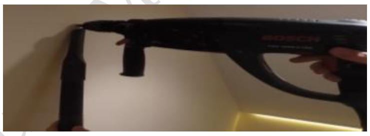


**Fig.2.15 Marked points to be drilled**

After drilling, a drill anchor is used for all the drilled holes. It allows holes for the secure attachment of the mounting plate. These holes are used to insert anchors or screws that hold the plate firmly in place. Figure 2.16 illustrates the Placement and fixing of the drilling anchor into the drill holes using a hammer.

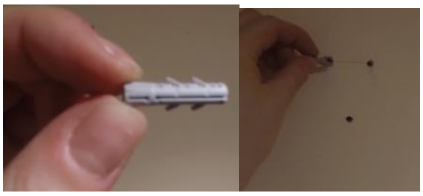


**Fig.2.16 Placing the drilling anchor in the drilled holes**

Now place the mounting plate onto the drilled holes and fix the screw onto the mounting plate. Figure 2.17(a) illustrates the placement of mounting plates on the drilled hole and Figure 2.17(b) illustrates the placing of the screws using a screwdriver.

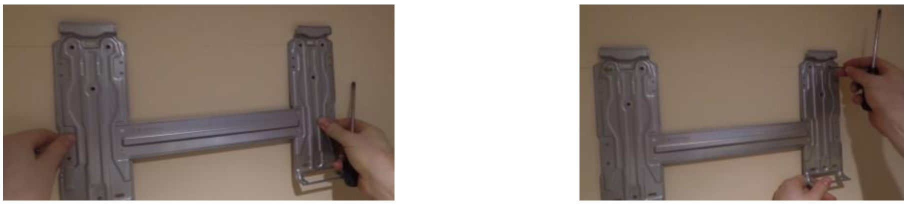


**Fig.2.16(a) Place the mounting plates (b) Placing the screw**

After the placement of the mounting plate, it is important to make another hole for the passing of the copper pipes of the air conditioner. Generally, a 65 mm hole is created in the wall for the passing of the copper tubes. For that special drill bit is used called the concrete shank drill bit. Figure 2.18 illustrates a typical shank drill bit.

**Fig. 2.18 Shank drill bit**

Practical activity 2.1 demonstrates preparing the hole for the passing of copper tubes of the air conditioner.

**Practical activity 2.1** Demonstrate to prepare the hole for the passing of copper tubes of the air conditioner.

**Material required –**

Power drill, Shank drill bit, spirit level, and measuring tape

**Procedure**

**Step 1 –** Check the level of mounting brackets. Figure 2.19 illustrates the measurement of the level using the spirit level.

**Fig.2.19 Measurement of the level using a spirit level**

**Step 2 –** Measure the distance of the hole from the air conditioner mounting brackets both vertically and horizontally. Figure 2.20 illustrates the measurement of the hole for copper tubes horizontally and vertically both.

**Fig.2.20 Measurement of the hole using a measurement tape**

**Step 3 –** Use the long masonry drill to pre-drill the shank hole. The hole must be angled on a downward slope. Figure 2.21 illustrates that a long masonry drill bit is used for a downward slope hole.

**Fig.2.21 Angle downward while drilling**

**Step 4 –** Take the drill bit and tighten it with the chuck of the power drill bit as shown in Figure 2.22

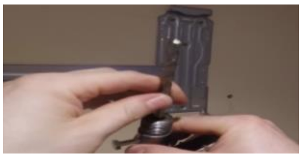


**Fig.2.22 Fixing of the drill bit in the power drill**

**Step 5 –** Insert the shank drill bit into the chuck and ensure it is seated securely. Figure 2.23 illustrates the insertion of the shank bit in the chuck of the power drill.

**Fig.2.23 Fixing of the drill bit in the power drill**

**Step 6 –** Tighten the chuck by turning the chuck key clockwise until the drill bit is firmly held in place. Figure 2.24 illustrate the tightening of the chuck

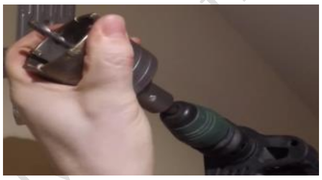


**Fig.2.24 Tightening of the drill bit**

**Step 7 –** Align the tip of the drill bit with the desired drilling location on the material. Figure 2.25 illustrates the alignment of the drill bit.

**Fig.2.25 Alignment of drill bit with the desired drilling location**

**Step 8 –** Slowly start making drill Figure 2.26 illustrate drilling of holes.

**Fig.2.26 drilling of the holes**

**Step 9 –** Every few inches empty out the drill. Figure 2.27 illustrate empty the removal coming out from the wall.

**Fig.2.27 Empty the removal coming from the wall**

**Step 10 –** Continue the drill from the inside out to complete the hole. As shown in Figure 2.28.

**Fig.2.28 Making a final hole in the wall**

**The electrical connection of the air conditioner –** The electrical connection of an air conditioner typically involves connecting it to a dedicated electrical circuit to ensure safe and efficient operation. For that bring the indoor unit of split air-conditioner and open the maintenance cover of the indoor unit. Figure 2.29 illustrates the opening of the maintenance cover of the indoor unit of the air conditioner.

**Fig.2.29 Opening of the maintenance cover of the indoor unit**

After opening the maintenance cover there will be a cover for the power terminal using the Philips screwdriver for unscrewing the power cover. Figure 2.30 illustrates the unscrewing of the cover of the power terminal.

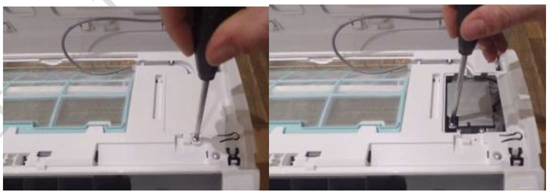


**Fig.2.30 Unscrewing of the cover of the power terminal.**

Practical activity 2.2 demonstrates connecting the wires to the indoor unit power connection terminals. This connection is demonstrated for the single-phase AC supply.

**Practical activity 2.2** Demonstrate to connect the wires for the single-phase power connection terminals of the indoor unit.

**Material required –**

Screwdriver

**Procedure**

**Step 1 –** open the cover by unscrewing the power terminal cover using the screwdriver. Figure 2.31 illustrates the power terminal of the indoor unit.

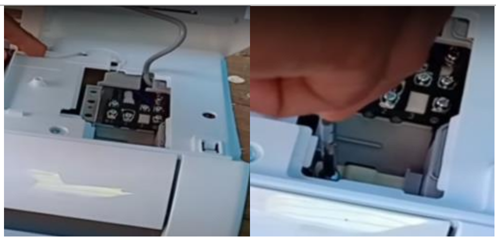


**Fig.2.31 Power terminal.**

**Step 2 –** The point for the connection of wires is already mentioned in the power terminal for the ease of understanding of the technician. Figure 2.32 illustrates the connection points

**Fig.2.32 Connection points**

**Step 3 –** Insert the power cable into the indoor unit. Figure 2.33 illustrates the insertion of the power cable

**Fig.2.33 Insertion of the power cable**

**Step 4 –** Connect the phase wire in red color with terminal number 1 neutral wire in black color with terminal number 2 and earth wire in green color with terminal number 4. Figure 2.34 illustrates the proper connection of the electrical wire of the indoor unit

**Fig.2.34 Connect the respective wire**

**Step 5 –** Close the power terminal cover using the Phillips screwdriver as shown in Figure 2.35

**Fig.2.35 Close the cover**

**Step 6 –** After confirming that the power connections are correctly made and insulated, securely close the maintenance cover as shown in Figure 2.36.

**Fig.2.36 Closing the maintenance cover**

**Connection of outdoor unit to indoor unit with power cables and copper pipe –** The connection between the outdoor unit and indoor unit in an air conditioner requires two main components: power cables and copper pipes. These connections are essential for the transfer of electrical power and refrigerant between the two units.

The copper pipes are used to connect the refrigerant lines between the outdoor and indoor units. These lines carry the refrigerant, which is responsible for the cooling or heating process. It comes in two variants: a smaller-diameter liquid line and a larger-diameter suction line.

The liquid line carries the liquid refrigerant from the outdoor unit to the indoor unit. It is typically insulated to prevent heat gain and maintain the refrigerant's temperature. And the suction line carries the gaseous refrigerant from the indoor unit back to the outdoor unit for the refrigeration cycle to continue.

The copper pipes are usually pre-charged with refrigerant at the factory, but additional refrigerant may be added during installation, in case required, depending on the pipe lengths and system design. Proper insulation of the copper pipes is essential to prevent condensation and ensure efficient operation. Insulation materials specifically designed for refrigerant lines are used for this purpose.

**Practical activity 2.3 demonstrate to connect the indoor unit to the outdoor unit using copper cables**

**Practical activity 2.3** Demonstrate to connect the indoor unit to the outdoor unit using copper cables.

**Material required –**

Plier, screwdriver, wire stripper, measurement tape, hammer and wrench

**Procedure**

**Step 1 –** Check the back side of the indoor unit. Figure 2.37 illustrates the back panel of the indoor unit of air conditioner.

**Fig.2.37 Back side of the indoor unit**

**Step 2 –** Find out the suction and discharge pipe of the indoor unit. They can be identified from their smaller-diameter (liquid line) and a larger-diameter (suction line). Try to get them as straight as possible to minimise the losses. Figure 2.38 illustrates the suction and discharge pipe of the indoor unit of the air conditioner.

**Fig.2.38 Suction and discharge pipe of the indoor unit**

**Step 3 –** Take the copper pipes for the connection of the suction and discharge pipes. Lie on the ground and try to make it as straight as possible. Figure 2.39 illustrates the straightening of copper pipes.

**Fig.2.39 Straightening of copper pipes**

**Step 4 –** Place the rubber or plastic gasket in the nut of the pipe. Figure 2.40 illustrates the placement of the rubber or plastic gasket.

**Fig.2.40 Placing of rubber or plastic gasket**

**Step 5 –** Now connect the copper pipes and suction line with the help of a hand and wrench. Similarly, connect the other copper pipe with the discharge line. Figure 2.41 illustrates the connection between both nut and bolt.

**Fig.2.41 Connection of copper pipes**

**Practical activity 2.4 demonstrates the flaring of the copper tube.**

**Practical activity 2.4** Demonstrate the flaring of the copper tube.

**Material required –**

Copper tube, flaring Clamp

**Procedure**

**Step 1 –** Take a copper tube for flaring. As shown in Figure 2.42.

**Fig.2.42 Copper tube for flaring**

**Step 2 –** Take our flare nut and slide it over the copper tube with the threats facing the end of the tubing. Figure 2.43 illustrates the placement of the flare nut on the copper tubes.

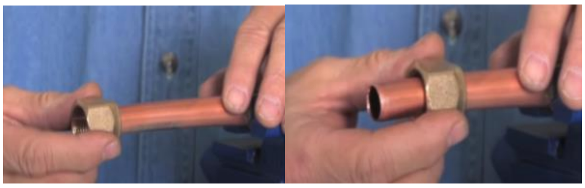


**Fig.2.43 Placement of flare nut**

**Step 3 –** Take a flaring clamp, it has different sizes for tubes of different sizes. Figure 2.44 illustrates the use of flaring clam

**Fig.2.44 Use of flaring clamp**

**Step 4 –** Take the clamp and attach it over the top of the tube. Leave some portion of the tube for flaring. Figure 2.45 illustrates the use of a flaring clamp with a copper tube.

**Fig.2.45 Connection of flaring clamp with copper tunes**

**Step 5 –** Tighten the nuts of the clamp. As shown in Figure 2.46

**Fig.2.46 Tightening of copper nut**

**Step 6 –** Take a flaring cone and slide it over the tubing clamp. Tighten the flaring cone over the tube as shown in Figure 2.47

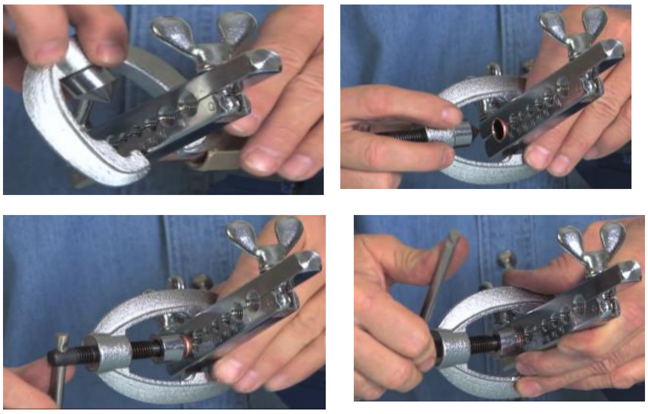


**Fig.2.47 Tighten the flaring cone over the tube**

**Step 7 –** Now after using, loosen the flaring cone. As shown in Figure 2.48

**Fig.2.48 Loosening of the flaring cone over the tube**

**Step 8 –** Loosen the nuts of the tube clamp. As shown in Figure 2.49

**Fig. 2.49 Loosing of the nuts of the flaring clamp**

**Step 9 –** Inspect for any leaks in the flaring.

**Caution!**

1. While bending the pipe, one must be careful that it should not be crushed.
2. To prevent the breaking of the pipe, avoid sharp bends.
3. If the copper pipe is bent or pulled too often, it will become stiff.
4. Do not bend the pipe more than three times from the same section.

After the connection of both the copper tubes with the drain and suction tubes. Cover the copper pipes using the heat-insulated tube. Figure 2.50 illustrate the proper insulation of copper pipes

**Fig. 2.50 Proper insulation of the both the copper pipes**

Now after insulation, extend the drainpipe of the split air conditioner. Figure 2.51 illustrate the Extension of the drain pipe.

**Fig. 2.51 Extension of drain pipe**

Secure the insulation using duct tape. Figure 2.52 illustrates Securing the insulation using duct tape. Using duct tape place all the pipes and cables together i.e. drain pipe, copper pipes, and electric cable together in one bundle.

**Fig. 2.52 Securing the insulation using duct tape**

After ducting the tubes, tightly wrap the insulation material around the bundle as shown in Figure 2.53.

**Fig. 2.53 Wrapping the insulation material**

Now, the bundle is set to be pushed through the hole in the wall. One person pushes the bundle through the hole and the other holds up the indoor unit. Figure 2.54 illustrates the placing of the bundle through the hole.

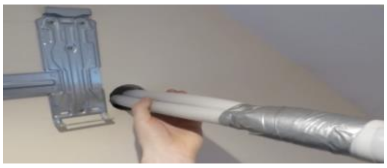


**Fig. 2.54 Placing the bundle through the hole**

Then, carefully pull the bundle from outside. Figure 2.55 illustrates the pulling of the bundle from the other side until the indoor unit has reached the wall.

**Fig. 2.55 Pulling the bundle from outside**

Now, hang the unit on the wall bracket plate, and the indoor unit fits smoothly against the wall on the mounting bracket. Figure 2.56 illustrates the hanging of the indoor unit onto the wall.

**Fig. 2.56 Hanging the indoor unit onto the wall**

Practical activity 2.5 demonstrate the installation of the outdoor unit

**Practical activity 2.5** Demonstrate the installation of the outdoor unit

**Material required –**

Copper tube, flaring Clamp

**Procedure**

**Step 1 –** Identify the location where the bundle of power cables and copper pipes terminates, usually near the indoor unit. Figure 2.57 illustrates the identification of the place to install the outdoor unit.

**Fig. 2.57 Identification of the location where the tubes end**

**Step 2 –** Mark the holes for the bracket rails. Figure 2.58 illustrates the marking points.

**Fig. 2.58 Mark the points to be drilled**

**Step 3 –** Drill at the marked places. Figure 2.59 illustrates the drilling of the hole at marked points.

**Fig. 2.59 Drilling on marked points**

**Step 4 –** Fix the bracket rails using the screws. Figure 2.60 illustrates the mounting of bracket rails.

**Fig. 2.60 Fixing of the bracket rails**

**Step 5 –** Fix the lower part of the mount onto the rails. Figure 2.61 illustrates the fixing of bracket rails.

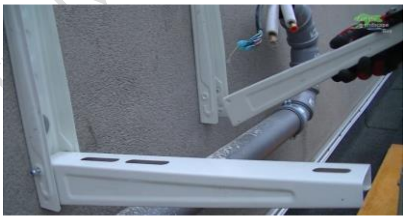


**Fig. 2.61 Fixing of the lower parts of the bracket rail**

**Step 6 –** Place the outdoor unit on the bracket rails. Figure 2.62 illustrates the mounting of the outdoor unit on the bracket rails.

**Fig. 2.62 Outdoor unit on the bracket rails**



After the placement of the outdoor unit, the first step is to fill the refringent and connect copper tubes to the outdoor unit. These copper tubes serve as refrigerant lines, allowing the transfer of refrigerant between the two units. As we already understand, flare the copper tube with flaring tools in practical activity 2.4. Therefore, by using a flaring tool, create flared ends on the cut tubes. The flaring process ensures a secure connection with the fittings and prevents any leakage.

After the flaring of the copper tubes, attach the flared ends of the copper tubes to the corresponding fittings on both the outdoor and indoor units. Tighten the fittings securely, but be careful not to overtighten and damage the tubes or fittings. Figure 2.63 illustrates the connection of both copper tubes with the suction and discharge ends of the outdoor unit.

**Fig. 2.63 Connection of copper tubes with the outdoor unit**

After connecting the copper tubes, perform a thorough inspection to ensure there are no leaks. Use a suitable leak detection method, such as a leak detection solution or a pressure test, to verify the integrity of the connections.

Practical activity 2.6 demonstrate checking the leak of the refrigerant by pressure test.

**Practical activity 2.6** Demonstrate checking the leakage of the refrigerant by pressure test

**Material required –**

Pressure gauge, Allen key, Wrench

**Procedure**

**Step 1 –** Prepare the pressure gauge by connecting the pipe. Figure 2.64 illustrates the measurement of pressure using a pressure gauge.

**Fig. 2.64 Fix the pipe in the pressure gauge**

**Step 2 –** Open the nut of the suction pipe. Figure 2.65 illustrates the way to open the nut of the suction pipe

**Fig. 2.65 Open the nut of the suction pipe**

**Step 3 –** Connect the pressure gauge to the suction valve. Figure 2.66 illustrates the connection of the pressure gauge.

**Fig. 2.66 Connecting the pressure gauge on the suction valve**

**Step 4 –** Open the nut of the discharge pipe. Figure 2.67 illustrates the removal of the nut from the discharge line.

**Fig. 2.67 Remove the nut of the discharge pipe**

**Step 5 –** Use the correct size of the allen key tool to lose the valve of the discharge pipe for 4-5 seconds. After 4-5 seconds, again tighten the valve of the discharge pipe. Figure 2.68 illustrates the opening of the valve using the allen key.

**Fig. 2.68 Operating the discharge value using the allen key**

**Step 6 –** Observe the pressure value in the pressure gauge fitted at the suction pipe. After 20-25 minutes again observe the pressure value in the pressure gauge, if it is not changed then it can be said that there is no leakage of gas in the system. Figure 2.69 illustrates the checking of pressure on the pressure gauge.

**Fig. 2.69 Pressure value in the pressure gauge**

After the placement of the outdoor unit, connection and leakage check of the copper tubes, the most essential thing is to connect the outdoor unit with the power supply. We have already discussed the way of connecting the indoor unit with the power cord in practical activity 2.2. Now for the connection of the power cable to the outdoor unit, open the box cover above the power terminal on the outdoor unit. Figure 2.70 illustrate the opening of the power box terminal using the screwdriver


**Fig. 2.70 Opening of the power box**

After opening the box cover, check the connection for the power terminal and make the connections.

Connect the phase wire in red color with terminal number 1 neutral wire in black color with terminal number 2 and earth wire in green color with terminal number 3. Figure 2.71 illustrates the proper connection of the electrical wire of the outdoor unit.

**Fig. 2.71 Connection of electrical wire**

During the electrical installation of the indoor and outdoor unit of air conditioner, it consists of three main components i.e., MCB, Flex outlet, and isolator switch along with the indoor and outdoor unit.

1. **MCB –** MCB stands for Miniature Circuit Breaker. It is an electrical switch that automatically protects an electrical circuit from excessive current flow, preventing damage to the circuit and reducing the risk of electrical fires.
2. **Flex outlet –** It is an electrical extender it works as a connector between all the units.
3. **Isolator switch –** It is an electrical switch used to disconnect the power supply to a specific circuit or equipment. It is commonly used as a safety measure during maintenance or repairs to ensure that the circuit or equipment is completely de-energized and isolated from the power source.

Figure 2.72 illustrates the electrical connections between both units are made according to the wiring diagram.

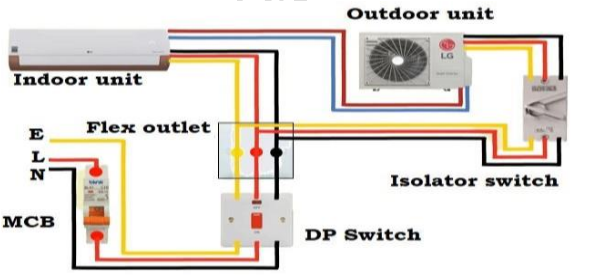



**Fig. 2.72 Connection of single-phase AC supply**

**Note –** The above electrical connection is for the single-phase alternating current power supply

The three-phase alternating current electrical connection for air conditioners is commonly used for larger air conditioning systems that require higher power loads.

The first step is to ensure that the electrical panel or distribution board where the air conditioner will be connected has three-phase power available. It should have three-phase circuit breakers or fuses capable of handling the required current.

Always use appropriately sized and rated electrical cables to connect the air conditioner to the electrical panel.

Now Locate the electrical terminal block or connection points on the outdoor unit of the air conditioner. There will be eight terminals labelled R, S, T, N, 1, 2, 3, and G. For the Indoor unit, there are four terminals 1,2,3 and G.

Connect the corresponding phase wires from the MCB to the R, S, and T, and the neutral wire is connected to the N terminals of the outdoor unit of the air conditioner.

Now connect the corresponding phase wire from the outdoor unit to the indoor unit 1, 2, and 3 also Connect the grounding wire which is usually green or green/yellow denoted by "G" from the outdoor unit of the air conditioner to the grounding point "G".

Figure 2.73 illustrates the proper electrical connection between the Indoor unit and the outdoor unit for a three-phase alternating current air conditioner.

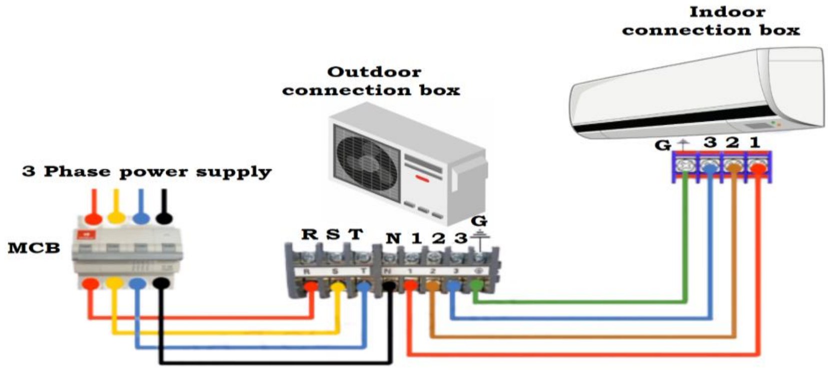



Fig. 2.73 Connection of single-phase AC supply

## 2.2 INSTALLATION OF WINDOW AIR CONDITIONER

Window air conditioners are compact and convenient cooling solutions for homes and small spaces. They are easily installed in a window opening, saving valuable floor space. These units efficiently cool a single room or small area by drawing in warm air, cooling it through a refrigeration system, and expelling the cooled air back into the room. With energy-saving features and various sizes available, window air conditioners offer affordability and versatility to suit different cooling needs.

For the window air conditioner, the indoor unit and outdoor unit are packed in a single box. For the installation of window air conditioners, always keep the cooling unit inside the room and the compressor and condenser unit outside

Practical activity 2.7 demonstrate installing the window air conditioner

**Practical activity 2.7** Demonstration to install a window air conditioner.

**Material required –**

Copper tube, Flaring clamp

**Procedure**

**Step 1 –** Unpack the box of window air conditioners and unpack all the accessories from the box to confirm all the parts are delivered safely. Figure 2.74 illustrates the opening of a cardboard box.


**Fig. 2.74 Unpacking of windows air conditioner**

**Step 2 –** Choose a window, which is near to the power socket.

**Step 3 –** Measure the width of the window, and mark its center using a measuring tape. Ensure the side panels evenly reach both sides of a window. Figure 2.75 illustrates the way of conducting dimensional measurement of the window.

**Fig. 2.75 Measuring of the width of the window**

**Step 3 –** Seal the window with a weather strip. These strips help to block any air that may pass through tiny cracks and protects the window from possible damage. Figure 2.76 illustrates the sealing of the window with a weather strip.

**Fig. 2.76 Seal of the window**

**Step 4 –** Attach the side panels. The side panel is to cover the extra space. Figure 2.77 illustrates the attachment of the side panel.

**Fig. 2.77 Attachment of side panel**

**Step 5 –** Place the AC unit in the window. Figure 2.78 illustrates the placement of AC in the windows.

**Fig. 2.78 Placement of AC**

**Step 6 –** The AC unit must be in the center of a window and close the window. As shown in Figure 2.79.

**Fig. 2.79 Closing of windows**

**Step 7 –** Screw the L bracket or brackets to the top of the opened window. This prevents the window from being pushed up. Figure 2.80 illustrate the placing of the L bracket.

**Fig. 2.80 Placement of L bracket**

**Step 8 –** Add the window padding to the sides of your open window as shown in Figure 2.81.

**Fig. 2.81 Add the padding to the window AC**

**Step 9 –** Extend the side panels to reach your window as shown in Figure 2.82.

**Fig. 2.82 Add padding to window AC**

**Step 10 –** Plug in and turn on your AC. One should immediately feel it cooling their room. Figure 2.83 illustrates that the AC is plugged into the power socket.

**Fig. 2.83 AC plugged to the power mains**



## Check Your Progress

**A. Multiple Choice Questions**

1. The air conditioning is that branch of engineering science, which deals with the study of (a) conditioning of air (b) conditioning of water (c) conditioning of oil (d) conditioning of refrigerant
2. Split Air conditioner units are easier to install, and more energy efficient than (a) Packed Air conditioner (b) central air conditioner (c) window air conditioner (d) centralized air conditioner

3. Indoor Unit is a box type housing of an air conditioner. It is mounted (a) outside the room (b) inside the balcony (c) on the wall (d) inside the room
4. Window Air Conditioners are (a) ductless (b) have duct (c) pipe less (d) have only indoor unit
5. Control __________which connects the outdoor and indoor unit, must be covered by the wall cover. (a) wire (b) electrical line(c) cable (d) pipe
6. As excessive torque in torque wrench can damage the _______while bending (a) copper pipe (b) plastic pipe (c) aluminium pipe (d) PVC pipe
7. Vacuum cleaner is used to catch the __________generate at the time of drilling (a) wooden waste particles (b) dust particles (c) water drops (d) oil drops
8. Airflow of outdoor unit should be (a) blocked (b) not blocked (c) windows to be opened (d) vacuumed
9. Ensure they are securely attached to the wall or window frame to prevent the AC unit from falling or becoming unstable (a) bolt (b) mounting bracket (c) nut (d) wiring
10. Appropriate safety equipment is used protect yourself from potential hazards (a) gloves (b) safety glasses (c) protective clothing (d) all of the above

**B. Fill in the blanks**

1. Correct installation of window air conditioner is a task for a ........................
2. Mount and install the indoor unit on a strong ............., which is not subjected to vibration.
3. Positioning the air-conditioner is a critical task. ................................. must suggest the correct location for the installation of indoor and outdoor units.
4. Outdoor unit is usually located in the rear or side of house and it is the unit from where the ........................ It contains the compressor, condenser coil and a fan.
5. In installation procedure of split air conditioner, the cooling unit is placed inside and the ......................................... unit is placed outside the premises.
6. Use vacuum cleaner to catch the dust generate at the time of ...........................
7. While bending the pipe, one must be careful that it should not be ........................
8. A torque .............................. has a socket on which crowfoot set is used to tighten the connections.
9. Window air conditioners are ....................
11. Climate change refers to a rise in average .............................

**C. State whether the following statements are True or False.**

1. An air conditioner is a system, used to cool a closed room by extracting the heat from the room to outer area.
2. In installation procedure of split air conditioner, the cooling unit is not placed inside and the compressor and condenser units are placed outside the premises.
3. The word split air conditioner specifies that the indoor and outdoor units are distance apart.
4. Indoor unit is a box type housing of air conditioner. It is mounted inside a room.
5. Outdoor unit is usually located in the rear or side of house and it is the unit from where the heat is not dispersed.
6. While, bending the pipe, one must be careful that it should be crushed.
7. Torque does not depend on the diameter of the copper pipes.
8. Torque wrench has a socket on which crowfoot set is used to tighten the connections.

9. Leakage of the gas can be checked using the suction and discharge pipe.
10. In window air conditioner, one needs to install the cooling unit inside and the compressor and condenser unit outside.

**D. Short answer questions**

1. How the air conditioner can be classified?
2. What is the difference between the ductless and duct AC?
3. How air conditioner indoor and outdoor units are mounted?
4. How the flaring of the copper tubes is performed while AC fitting?
5. How do you install the window Air Conditioner?

# Session 3. Use of remote control and Installation test of Air Conditioner

After the installation of the air conditioner in Vijay's house, he eagerly tried to power it on. But, he couldn't figure out how to operate it. Then he called the technician who had installed it. The technician arrived and taught Vijay how to use the remote control. He also explained all the functions of the air conditioner.

With the technician's guidance, Vijay quickly grasped the functions of the remote control. He discovered the power button, temperature controls, and various modes of the air conditioner. Figure 3.1 illustrates the AC technician teaching Vijay to operate AC using remote control.

**Fig. 3.1 Vijay is learning about the functions of the remote control of the AC**

In this chapter, we will discuss the use of remote control of the air conditioner and post installation of the air conditioner for its proper operation and functioning.

**3.1 Test of an air conditioner just after installation**

Testing an air conditioner just after installation is an important step to ensure that it is functioning properly and providing the desired cooling effect. To conduct a basic test of the newly installed air conditioner, the following steps should be performed.

**Power supply –** Ensure that the air conditioner is properly connected to a power source and that the power supply is turned on.

**Thermostat settings –** Set the thermostat to the desired temperature and mode (cooling mode).

**Airflow check –** Stand in front of the air conditioner and check if the airflow feels strong and consistent. Make sure that the air is blowing in the right direction, typically towards the room.

**Temperature check –** Measure the ambient temperature of the room using a thermometer. Compare it to the temperature set on the thermostat. The air conditioner should start cooling the room and bring the temperature down gradually.

**Cooling performance –** Allow the air conditioner to run for some time, usually 10-15 minutes, and monitor the temperature drop. You can use a separate thermometer to check the air temperature coming out of the air conditioners vents. It should be noticeably colder than the room temperature.

**Noise level –** Pay attention to any unusual noises or vibrations coming from the air conditioner. While some noise is expected during operation, excessive noise or unusual sounds may indicate a problem.

**Air quality –** Check if the air conditioner is effectively filtering and dehumidifying the air. Look for a decrease in humidity levels and improved air quality.

**Remote control and settings –** Test the functionality of the remote control by adjusting the temperature, mode, and fan speed. Ensure that all the buttons and settings are working properly.

**Safety features –** Verify that the air conditioner's safety features, such as automatic shut-off in case of malfunctions or overheating, are functioning as intended.

### 3.2 Remote control of AC

The remote control of an air conditioner (AC) is a handheld device that allows the users to conveniently operate and control the functions of their AC unit from a distance. It serves as a wireless interface between the user and the AC system, providing a range of options to adjust settings, modes, and temperature preferences.

Remote control can vary between different AC brands and models. Therefore, it is advisable to refer to the user manual provided by the manufacturer for detailed instructions on how to operate the AC unit using the remote control.

#### 3.2.1 Inserting of batteries in remote control of AC

Batteries play a crucial role in powering the remote control of an air conditioner. The remote control requires a portable and reliable power source to transmit signals to the AC unit.

Practical activity 3.1 demonstrates the procedure to insert new batteries or replace old batteries in the remote control of the AC.

**Practical activity 3.1** Demonstrate to insert the new batteries in the remote control of the AC.

**Material required –**

AC remote, AA 1.5 Volt batteries.

**Procedure**

**Step 1 –** Open the battery cover as illustrated in Figure 3.2.

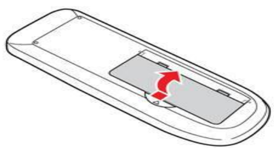


**Fig. 3.2 Opening the cover of remote**

**Step 2 –** Insert the batteries with the + and – ends facing as shown in Figure 3.3.

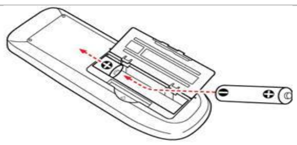


**Fig. 3.3 Insert new batteries in the slots provided**

**Step 3 –** Close the battery cover and press it down until it clicks into place as illustrated in Figure 3.4.

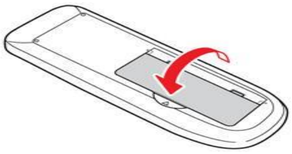


**Fig. 3.4 Closing of remote control**

**Note…**

Use 2 LR03 AAA (1.5 volt) batteries. Do not use rechargeable batteries.

Replace batteries with new ones of the same type when the display becomes dim.

If the replacement is done within 1 minute, the remote control will keep the original pre-setting.

However, if you replace batteries taking more than 3 minutes, all pre-setting will be cancelled and the timer will display zero.

### 3.2.2 Replacing of batteries in remote control of AC

Replacing old batteries in the remote control of an AC is necessary for several reasons:

**Maintaining functionality –** Over a period of time, the batteries in a remote control gradually lose their power capacity. As the battery voltage decreases, it can lead to reduced signal strength or intermittent transmission. Replacing old batteries ensures that the remote control has a reliable power source to function properly.

**Consistent performance –** When the batteries in the remote control are fresh, they provide consistent power, allowing for reliable transmission of signals to the AC unit. This helps ensure that the remote-control commands are received and executed accurately.

**Preventing signal disruptions –** Weak or depleted batteries can cause signal disruptions between the remote control and the AC unit. This can result in delays, inconsistencies, or failures in adjusting the settings or activating functions. By replacing the old batteries, you minimize the chances of signal disruptions and maintain smooth communication between the remote control and the AC unit.

**Avoiding control issues –** In some cases, low battery levels can cause buttons on the remote control to become unresponsive or function incorrectly. This can lead to frustration and difficulties in controlling the AC unit effectively. Replacing the old batteries helps prevent control issues and ensures that all buttons respond as intended.

**Longer battery life –** When old batteries are replaced with fresh ones, you can expect a longer lifespan for the new batteries. This means you won't have to replace them as frequently, reducing the inconvenience and cost of purchasing batteries frequently.

**Overall convenience –** A remote control with new batteries provides convenience in controlling the AC unit from a distance. It allows you to adjust settings, change modes, and control the temperature with ease, enhancing the overall user experience.

Practical activity 3.2 demonstrates replacing batteries from the remote control of an air conditioner.

**Practical activity 3.1** Demonstrate to replace old batteries in the remote control of the AC.

**Material required –**

AC remote, AA 1.5 Volt batteries

**Procedure**

**Step 1 –** Open the battery cover as illustrated in Figure 3.2.

**Step 2 –** Remove the old batteries as shown in Figure 3.5.

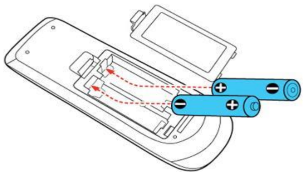


**Fig. 3.5 Replace used batteries**

**Step 3 –** Insert the batteries with the + and – ends facing as shown in Figure 3.3.

**Step 4 –** Close the battery cover and press it down until it clicks into place as illustrated in Figure 3.4.

### 3.2.3 Functions of remote control of AC

The remote control of an AC serves as a convenient interface between the user and the AC unit, providing various functions and features for controlling and adjusting the settings. Figure 3.6 shows a typical AC remote control.

**Fig. 3.6 AC remote control**

To operate the air conditioner with the remote control, aim the remote control at the signal receptor from no more than 23 ft. (7 m) away. There are various functions and operational modes available in remote control according to the product manufacturer some of the functions described below.

**Power ON or OFF –** Press the power button to ON the air conditioner. Figure 3.7 illustrates the Power button.

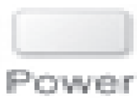



**Fig.3.7 Power button**

**Selecting Mode –** Using this button various modes of operation can be operated. Press and release MODE until you see the symbol glow for the desired setting. There are three modes available: Cooling, Dry, or Fan Only mode. Figure 3.8 illustrates the Mode button.


**Fig. 3.8 Mode button**

**a) Cooling-** Selecting this mode cools the room. Press the Fan button to select Auto, High, Mid, or Low. Press the button up or down. Adjust the button to adjust the temperature.

**b) Dry –** Dries the room. The air conditioner automatically selects the temperature. The fan runs at low speed only.

**c) Fan Only –** Only the fan runs. Press FAN to select High, Mid, or Low.

**3.2.4 Function descriptions**

**Sixth sense mode –** The air conditioner automatically selects cooling or dry mode, depending on room temperature, and sets the target temperature.

Operation mode and temperature are determined by indoor temperature. Table 3.1 illustrates the various modes in the sixth sense mode.

For activation of sixth sense mode, press the sixth sense button. Figure 3.9 shows the button to activate the sixth sense mode.


**Fig.3.9 Sixth sense**

But if it is to be operated in fan-only mode, press the Fan to select high, mid, or low.

Table 3.1 Sixth sense mode

| Indoor Temperature | Operation Mode | Target Temperature |
|---|---|---|
| 26°C or below | DRY | Room temperature decreased by 1.5°C after operating for 3 minutes |
| Over 26°C | COOLING | 26°C |

**Note...**Temperature, airflow and direction are controlled automatically in sixth sense mode. However, a decrease or rise of up to 2°C can be set with the remote control if you still feel uncomfortable.

**Rapid Cool –** Used for fast cooling. The air conditioner automatically sets the fan speed to high and the temperature to 18°C.

For activation of rapid cool press the Rapid Cool button. The air conditioner automatically sets the fan speed to High and the temperature to 18°C. Figure 3.10 shows the button to activate the Rapid Cool mode.


**Fig.3.10 Rapid Cool mode**

2. To exit Rapid Cool mode, press any button except Timer On/Off and Swing button.

**Fan Speed –** It is used to adjust the various speeds of the fan. Figure 3.11 shows the button to activate the Fan speed. To activate, choose the desired fan speed. Figure 3.11 shows the button to activate the Fan speed. Table 3.2 illustrates the various modes of cooling.

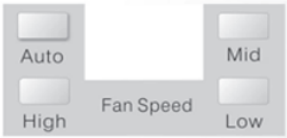
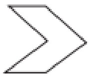
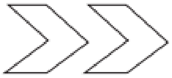
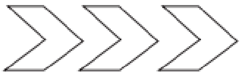
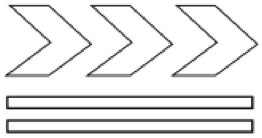



**Fig.3.11 Fan speed mode**

Table 3.2 Fan cool mode mode

| **Mode** | **Button** | **Function** |
|---|---|---|
| LOW |  Fig.3.12 Low mode | Low – for the selection of minimum cooling. Figure 3.12 shows the button to activate the Low Fan mode. |
| MID |  Fig.3.13 Mid mode | Mid –for the selection of normal cooling. Figure 3.13 shows the button to activate the Mid Fan mode. |
| HIGH |  Fig.3.14 High mode | High – – for the selection of maximum cooling. Figure 3.14 shows the button to activate the High Fan mode. |
| AUTO |  Fig.3.15 Auto mode | Auto – for the selection of Automatic fan speed according to the surrounding temperature. Figure 3.15 shows the button to activate the Fan Auto mode. |

**Note...**Auto fan speed cannot be selected in Fan Only mode.

**Temperature –** Press the plus button to raise the temperature. Press the plus button once to increase the set temperature by 1°C, or press twice to increase the set temperature by 2°C. Figure 3.16 shows the button for increasing the temperature.


**Fig. 3.16 Temperature button**

Press the minus button to lower the temperature. Press the minus button to decrease the set temperature by 1°C, or press twice to decrease the set temperature by 2°C. Figure 3.17 shows the button for decreasing the temperature.


**Fig. 3.17 Temperature button**

**Note...**
- In the cooling mode, the temperature can be set between 18°C and 32°C.
- In fan-only mode, the temperature cannot be set.

**Sleep mode –** Press the Sleep button on the remote control, the appliance operates in sleep mode and the fan speed is automatically set to low speed.

**Note...**

In Cooling mode, if the current room temperature is 26°C or higher the set temperature will not change when sleep mode is activated, otherwise, the temperature will automatically increase 1°C during the first hour.

The set temperature will not increase during the last 7 hours in sleep mode.

1. Press MODE to select Cooling or Dry.

Sleep mode cannot be selected when Fan only is selected.

2. Press the Fan button.
3. Press the  or  button to set the temperature.
4. Press SLEEP. After 5 seconds, the lights on the control panel display will dim.

**Note...**

The temperature and airflow direction can be adjusted during Sleep Mode.

To turn off Sleep mode, press MODE, ON/OFF, 6th SENSE, JET or SLEEP again or wait 8 hours for the air conditioner to turn off automatically.

**Changing air direction –** On the remote-control press SWING once to change the vertical airflow direction. Press again to stop the airflow louver at desired airflow direction.

**Normal sounds –** When the air conditioner is operating normally, one may hear sounds such as:

- Air movement from the fan.
- Clicks from the thermostat cycle.
- Vibrations or noise due to poor wall or window construction.
- A high-pitched hum or pulsating noise is caused by the modern high-efficiency compressor cycling ON and OFF.



## Check Your Progress

**A. Multiple choice questions**

1. Which of the following indicator given by the indoor unit for air filtering cleaning (a) VF (b) CF (c) DF (d) EF
2. Which of the following indicator given by the indoor unit for auto cleaning. (a) Cl (b) Dl (c) Fl (d) Jl
3. Which of the following is not included in the basic setting of the smart thing's application? (a) App setting (b) Energy monitoring (c) Self-diagnosis (d) Set temperature
4. Which of the following is not the operation mode of an air conditioner? (a) Cool (b) Dry (c) Auto (d) Humidity
5. Motion detection in an air conditioner helps to reduce the __. (a) Heat (b) Power (c) Motion (d) Humidity
6. When the air conditioner is operating normally, one may hear sounds (a) Air movement from the fan. (b) Clicks from the thermostat cycle. (C) Vibrations or noise due to poor wall or window construction. (d) All of the above

7. On the remote-control press SWING to change the vertical airflow direction. (a) Once (b) Twice (c) Thrice (d) None
8. On the remote-control press again to the airflow louver at desired airflow direction. (a) Start (b) Stop (c) Timer (d) None
9. In _______ mode and the fan speed is automatically set to low speed. (a) Sleep (b) Auto (c) fast (d) None
10. For the selection of Automatic fan speed according to the surrounding temperature (a) Sleep (b) Auto (c) fast (d) None

**B. Fill in the blanks**

1. To turn ON or OFF the air conditioner ______ button is used.
2. To automatically change the temperature the cooling at night _____ function is used.
3. Users can choose the ______ directions of the operation mode.
4. Self-diagnosis is used to check the ___ instructions on your smartphone directly.
5. When user turn on the Wi-Fi function, your smartphone pairs with the air conditioner, ____ appears on the remote-control display.
6. When the batteries in the remote control are fresh, they provide consistent _________.
7. Low battery levels can cause buttons on the remote control to become ___________.
8. Using __________ various modes of operation can be operated.
9. The ___________ mode dries the room.
10. In the _________ mode, the air conditioner automatically selects Cooling or Dry mode, depending on room temperature, and sets the target temperature

**C. State whether the following statements are True or False**

1. dF indication is used for automatic defrost function.
2. User cannot be able to set the schedule for an air conditioner.
3. Smart things app is used to control the IoT based refrigerator.
4. Devices and hubs are the physical products that connects to smart things platform.
5. Android OS version of 5.0 is required to operate the smart things app in the mobile phone.
6. Weak or depleted batteries can cause signal disruptions between the remote control and the AC unit.
7. HIGH Mode for the selection of maximum cooling.
8. MID Mode for the selection of normal cooling
9. LOW Mode for the selection of minimum cooling
10. Fan Speed is used to adjust the various speed of the fan.

**D. Short answer questions**

1. Briefly describe the architecture of the IoT-based air conditioner application.
2. Discuss the steps to connect the smart things app to an air conditioner.
3. Tabulate the common error codes in the AC.
4. Tabulate the function of various buttons in the AC remote.
5. What are the features of smart things applications?

# Glossary

**Torque**: A force that causes rotation.

**Bearing**: A machine element that reduces friction between moving parts.

**Gear**: A rotating machine part with cut teeth or cogs that engage with another toothed part to transmit torque.

**Pulley**: A wheel with a grooved rim around which a cord passes to change the direction of the force applied.

**Belt**: A continuous loop of material used to transmit motion between two or more pulleys.

**Lever**: A rigid bar used to exert pressure or sustain a weight at one point by applying force at another.

**Current**: The flow of electric charge, typically measured in amperes (A).

**Voltage**: The electrical potential difference between two points, measured in volts (V).

**Resistance**: The opposition to the flow of electric current, measured in ohms (Ω).

**Conductor**: A material that allows the flow of electric charge, such as copper.

**Insulator**: A material that resists the flow of electric current, such as rubber.

**Transformer**: A device used to increase or decrease the voltage of an alternating current.

**Diode**: A semiconductor device that allows current to flow in one direction only.

**Transistor**: A semiconductor device used to amplify or switch electronic signals.

**Capacitor**: A device used to store electric charge.

**Resistor**: A component used to resist the flow of current in a circuit.

**IC (Integrated Circuit)**: A miniaturized electronic circuit consisting of multiple components.

**LED (Light Emitting Diode)**: A semiconductor light source that emits light when current flows through it.

**Refrigerant**: A substance used in refrigeration cycles to absorb and release heat.

**Evaporation**: The process in which a liquid turns into vapor.

**Condensation**: The process in which a vapor turns into a liquid.

**Compressor**: A device used to increase the pressure of the refrigerant in the system.

**Condenser**: A heat exchanger that condenses refrigerant vapor into a liquid.

**Thermostat**: A device used to regulate temperature by controlling the operation of heating and cooling systems.

**Mounting Bracket**: A support used to mount the air conditioning unit on a wall or ceiling.

**Refrigerant Line**: A pipeline that carries refrigerant between components of the air conditioning system.

**Drain Pipe**: A pipe used to remove condensed water from the air conditioner.

**Flare Nut**: A type of nut used to connect pipes and tubing in refrigeration systems.

**Vacuum Pump**: A device used to remove air and moisture from the refrigeration system during installation.

**Remote Control**: A handheld device used to operate the air conditioner from a distance.

# Answer Key

**Module 1. Basic Mechanical Systems**

**Session 1. Fitting, Tools and Equipment**

**A. Multiple Choice Questions**

1. (c) 2. (c) 3. (d) 4. (c) 5. (a) 6. (a) 7. (c) 8. (a) 9. (d) 10. (a)

**B. Fill in the blanks**

1. Cutting and gripping 2. Clamp meter 3. Neon bulb 4. Current 5. Current 6. Expanding 7. Holes 8. Flat end, metal 9. Detect live 10. Solid, flat mouthpiece

**C. True or False**

1. (T) 2. (T) 3. (F) 4. (F) 5. (T) 6. (T) 7. (F) 8. (T) 9. (F) 10. (T)

**Session 2. Sheet Metal**

**A. Multiple Choice Questions**

1. (b) 2. (c) 3. (b) 4. () 5. (a) 6. (d) 7. (c) 8. (b) 9. (a) 10. (c)

**B. Fill in the blanks**

1. 10 2. Seam 3. Bolt cutters 4. Mallets 5. Hacksaw 6. Snips 7. Cold chisel 8. Shaping and Smoothing 9. Metal shears 10. Rubber

**C. True or False**

(1) F (2) T (3) F (4) T (5) F (6) T (7) F (8) F (9) T (10) T

**Session 3. Welding, Brazing and Soldering**

**A. Multiple Choice Questions**

1. (a) 2. (c) 3. (b) 4. (b) 5. (c) 6. (c) 7. (b) 8. (a) 9. (a) 10. (b)

**B. Fill in the blanks**

1. Filler 2. Metal wire 3. Electron Beam 4. Friction stir 5. Submerged 6. Strong 7. Cost effective 8. Electron 9. Forge 10. Shielding gas

**C. True or False**

1. (F) 2. (T) 3. (F) 4. (T) 5. (F) 6. (T) 7. (F) 8. (T) 9. (F) 10. (F)

**Module 2. Basic Electricity**

**Session 1. Electricity**

**A. Multiple Choice Questions**

1. (c) 2. (b) 3. (d) 4. (d) 5. (d) 6. (c) 7. (c) 8. (b) 9. (c) 10. (a) 11. (b) 12 (b) 13. (a) 14. (c) 15. (a)

**B. Fill in the blanks**

1. Work, 2. North and South 3. Positive 4. Energy 5. 1000, 3600 6. Negative 7. Sinusoidal 8. Unidirectional 9. Frequency 10. DC

**C. State whether the following statements are True or False**

1. (F) 2. (F) 3. (T) 4. (F) 5. (T) 6. (F) 7. (F) 8. (T) 9. (F) 10. (T)

**Session 2. Electric Circuit Analysis**

**A. Multiple Choice Questions**

1. (b) 2. (d) 3. (a) 4. (b) 5. (a) 6. (c) 7. (b) 8. (d) 9. (a) 10. (b)

**B. Fill in the blanks**

1. Series 2. Parallel 3. Switch 4. Ohm's 5. Open and close 6. Electrical and Electronic 7. free electrons

**C. State whether the following statements are True or False**

1. (F) 2. (F) 3. (T) 4. (T) 5. (T) 6. (T) 7. (T) (8). T (9). T (10). T

**Session 3. Electrical Components**

**A. Multiple Choice Questions**

1. (a) 2. (a) 3. (c) 4. (a) 5. (a) 6. (d) 7. (b) 8. (d) 9. (b) 10. (a)

**B. Fill in the blanks**

1. Induction 2. Electric 3. Magnetic 4. 53.00k 5. 71.00k 6. Tolerance 7. Series 8. Parallel 9. Electric filed 10. Farad

**C. State whether the following statements are True or False.**

1. (T) 2. (F) 3. (T) 4. (F) 5. (T) 6. (T) 7. (T) 8. (F) 9. (T) 10. (F)

**E. Match the column**

A. (b) B. (c) C. (d) D. (a)

**Module 3. Basic Electronics**

**Session 1. Electronic Components**

**A. Multiple Choice Questions**

1. (c) 2. (a) 3. (b) 4. (b) 5. (b) 6. (b) 7. (b) 8. (a) 9. (a) 10. (b)

**B. Fill in the blanks**

1. Impure 2. Pure 3. Two 4. Three 5. ON 6. Integrated circuit 7. Semiconductor Material 8. Source, Gate, and Drain 9. ON and OFF 10. Increasing

**C. State whether the statements given below are True or False.**

1. (T) 2. (T) 3. (T) 4. (T) 5. (T) 6. (T) 7. (F) 8. (T) 9. (T) 10. (F)

**E. Match the column**

A. (c) B. (d) C. (b) D. (a)

**Session 2. Sensors, Transducers, and Signal Generating Equipment**

**A. Multiple Choice Questions**

1. (d) 2. (d) 3. (a) 4. (b) 5. (b) 6. (b) 7. (d) 8. (b) 9. (a) 10. (a)

**B. Fill in the blanks**

1. Two 2. Piezoelectric 3. Two 4. One 5. DC, AC 6. Eelectrical signal 7. Displacement, pressure 8. Electron 9. Deflection 10. Beam.

**C. State whether the following statements are True or False.**

1. (F) 2. (T) 3. (F) 4. (T) 5. (T) 6. (F) 7. (T) 8. (F) 9. (T) 10. (T)

**Session 3. Digital Electronics**

**A. Multiple Choice Questions**

1. (d) 2. (d) 3. (a) 4. (a) 5. (c) 6. (c) 7. (a) 8. (c) 9. (d) 10. (a)

**B. Fill in the blanks**

1. Analog and Digital 2. 0, 9 3. 0 and 9 4. Binary digits 5. Gate 6. Digital 7. High, High 8. High, High 9. Opposite 10. Logic functions.

**C. State whether the following statements are True or False**

1. (F) 2. (F) 3. (T) 4. (F) 5. (T) 6. (T) 7. (F) 8. (T) 9. (T) 10. (T)

**Session 4. Zener Diode, SCR/UJT & Full wave Bridge Rectifier**

**A. Multiple Choice Questions**

1. (c) 2. (a) 3. (a) 4. (b) 5. (c) 6. (c) 7. (b) 8. (c) 9. (b) 10. (c)

**B. Fill in the blanks**

1. Majority, Widen 2. Lower, Avalanche 3. Valence, Conduction 4. Two 5. 81.2%, 40.6% 6. Double-Based Diode 7. RB1 8. Twice 9. 0.48 10. Saturation

**C. State whether the following statements are True or False**

1. (T) 2. (F) 3. (T) 4. (F) 5. (T) 6. (F) 7. (T) 8. (T) 9. (T) 10. (F)

**Module 4. Fundamentals of Refrigeration and Air Conditioning**

**Session 1. Basics of measurement**

**A. Multiple Choice Questions**

1. (b) 2. (c) 3. (a) 4. (a) 5. (b) 6. (b) 7. (a) 8. (b) 9. (b) 10. (c)

**B. Fill in the blanks**

1. Physical Quantities 2. Non-Metric 3. Base Units 4. Component 5. Primary Sensing Element 6. Direct 7. Absolute 8. Comparative 9. Accuracy 10. Precision

**C. State whether the following statements are True or False**

1. (T) 2. (T) 3. (F) 4. (F) 5. (F) 6. (T) 7. (T) 8. (T) 9. (F) 10. (T)

**Session 2. Thermodynamics**

**A. Multiple Choice Questions**

1. (b) 2. (c) 3. (a) 4. (a) 5. (d) 6. (b) 7. (a) 8. (b) 9. (b) 10. (c)

**B. Fill in the blanks**

1. Refrigerant 2. Thomas Hariss 3. Jacob Perkins 4. Salt 5. 335kJ/kg 6. Heat and Temperature 7. Digital Thermometer 8. Thermocouple Thermometer 9. Absolute Zero Temperature 10. Thermodynamic Equilibrium

**C. State whether the following statements are True or False**

1. (T) 2. (T) 3. (F) 4. (F) 5. (F) 6. (T) 7. (T) 8. (T) 9. (F) 10. (T)

**Session 3. Basic Components of Refrigeration and Air Conditioning**

**A. Multiple Choice Question**

1. (c) 2. (a) 3. (b) 4. (b) 5. (a) 6. (c) 7. (a) 8. (d) 9. (c) 10. (b)

**B. Fill in the blanks**

1. Connecting rod 2. Rotary Piston 3. Liquid 4. Decrease 5. Gases 6. Increase 7. Absorption 8. Refrigerant 9. Single 10. Moving part

**C. Match the following**

1. (b) 2. (a) 3. (d) 4. (e) 5. (c)

**Session 4. Refrigerants**

**CHECK YOUR PROGRESS**

**A. Multiple Choice Questions**

1. (b) 2. (d) 3. (a) 4. (a) 5. (b) 6. (b) 7. (a) 8. (b) 9. (b) 10. (c)

**B. Fill in the blanks**

1. Refrigerant 2. Non-Flammable 3. Thermal 4. Heat Transfer 5. Viscosity 6. Zero 7. Chlorine/Bromine 8. Low 9. Oxygen 10. Catalyst

**C. State whether the following statements are True or False**

1. (T) 2. (T) 3. (F) 4. (F) 5. (F) 6. (T) 7. (T) 8. (T) 9. (F) 10. (T)

**Module 5. Installation of Air conditioner**

**Session 1. Air Conditioner**

**A. Multiple Choice Questions**

1. (d) 2. (c) 3. (c) 4. (d) 5. (a) 6. (a) 7. (a) 8. (a) 9. (d) 10. (a)

**B. Fill in the blanks**

1. Two 2. Evaporator, fan 3. Compressor, Condenser 4. Evaporator 5. Evaporator 6. Circulates 7. Swing 8. Absorbs 9. EER 10. British Thermal Units

**C. State whether the following statements are True or False**

1. (T) 2. (T) 3. (T) 4. (F) 5. (T) 6. (T) 7. (F) 8. (T) 9. (T) 10. (F)

**Session 2. Installation of Air Conditioner**

**A. Multiple Choice Questions**

1. (a) 2. (b) 3. (d) 4. (a) 5. (d) 6. (a) 7. (b) 8. (b) 9. (b) 10. (d)

**B. Fill in the blanks**

1. Technician 2. Wall 3. Customer and technician 4. Heat dispersed 5. Compressor and condenser 6. Drilling 7. Crushed 8. Wrench 9. Ductless 10. Global temperature

**C. State whether the following statements are True or False**

1. (T) 2. (F) 3. (T) 4. (T) 5. (F) 6. (F) 7. (F) 8. (T) 9. (T) 10. (T)

**Session 3. Use of remote control and Installation test of Air Conditioner**

**A. Multiple Choice Questions**

1. (b) 2. (a) 3. (d) 4. (d) 5. (b) 6. (d) 7. (a) 8. (b) 9. (a) 10. (b)

**B. Fill in the blanks**

1. Power 2. Good Sleep 3. Wind directions 4. Troubleshooting 5. AP 6 Power 7 Unresponsive 8 MODE 9 Dry 10 Sixth sense

**C. State whether the following statements are True or False**

1. (T) 2. (F) 3. (T) 4. (T) 5. (F) 6. (T) 7. (T) 8. (T) 9. (T) 10. (T)