Learning Objectives

After studying this unit, the student will be able to

- Know about the relation between heat and mechanical energies
- Limitations of heat energy produced
- Heating effects on a perfect gas

1.0 Introduction

The Science which deals with conversion of heat energy into mechanical energy and the properties of the system is called “THERMODYNAMICS”. This conversion is based on certain laws, generally known as “Laws of Thermodynamics”.

1.1 Thermodynamic System

The region in the space that contained matter whose behavior is to be investigated is called “Thermodynamic System” or simply referred as “System”.

The System is enclosed by a “boundary”. Every thing which is not in the System i.e. outside the boundary is called “Surrounding”. 
**Working Fluid:** It is a fluid on which the Thermodynamic processes are performed. The gases, vapours (steam) and liquids are employed as working fluids.

**State of System:** The Thermodynamic state of system or a working substance is defined by particular values of independent properties. It can be described by its properties such as temperature, pressure, volume, density etc.

### 1.2 Types of Thermodynamic System

The Thermodynamics Systems may be classified into the following three types. 1. Closed System 2. Open System 3. Isolated System

1. **Closed System:** This is a system of fixed mass and Identity whose boundaries are determined by the space of the matter (working substance) Occupied in it.

   The gas in the cylinder is considered as a system. If heat is supplied to the cylinder from some external source, the temperature of the gas will increase and the piston will rise. In other words, the heat and work cross the boundary of the system during the process. But there is no addition or loss of the original mass of the working substance, which comprises the system is fixed.

![Fig. 1.1](image)

#### 1.2.1 Types of Thermodynamic Systems

Thermodynamics Systems can be classified as

1. Closed System
2. Open System
3. Isolated System
1. Closed System

In closed system there will be only energy transaction with surroundings. Thus a closed system contains a fixed quantity of matter and has no mass transfer across its boundary. Only energy may flow across the boundary. ex: The gas contained in a cylinder.

2. Open System

This system permits the transfer of matter and energy across the boundary. The mass confined within the boundary may change or it may constant.

Ex: i) Flow of air through the compressor.

ii) Flow of steam through the nozzle and Turbine blades.

3. Isolated System

It has no transaction with surroundings. It will not permit transfer of both matter and energy across the boundary Ex: Thermodynamic Universe.

1.3 Thermodynamic Properties

A Thermodynamics Property can be defined as any observable character stick of system.

These are divided into two classes.

1. Extensive properties

2. Intensive properties

An extensive property is one that depends on the mass (Quantity) of the system.

Ex:- Mass, volume, internal energy, enthalpy etc.

An intensive property is independent of the mass of the system.

Ex:- Specific volume, pressure, temperature, density etc.

For clear understanding the concept, consider an amount of matter that is uniform in temperature and imagine that it is divided into two parts. The mass of the whole is the sum of the mass of the two parts; overall volume is the sum of the volumes of the both parts. However the temperature of the whole is not the sum of the temperature of the parts.

Here the Mass and volume are extensive properties and the Temperature is the intensive property.
1.4 Definitions of Some of the Properties

1.4.1 Pressure

The term “Pressure” may be defined as the force per unit area. The Unit of pressure depends upon the Units of force and area.

In M.K.S System, the practical unit of pressure is Kg/cm²

Sometimes pressure is also mentioned in terms of technical Atmosphere and is denoted by ata. 1 ata = 1 kg/cm²

In S.I System, the practical unit of pressure is N/mm², N/m², KN/m² etc

1 pascal = 1 N/m²
1 bar = 10.5 N/m² = 102 KN/m²

1.4.2 Atmospheric Pressure

The Normal force exerted by the atmosphere on a Unit surface area is called Atmosphere Pressure”. It is measured by mercury barometer

1 atm = 760 mm Hg = 1.01325 bar

= 101.325 KN/m²

1.4.3 Gauge Pressure

The Pressure recorded by the instrument above atmospheric pressure is called “Gauge pressure”

1.4.4 Absolute Pressure

The pressure measured above Absolute Zero pressure is called Absolute pressure

Absolute pressure = Atmosphere pressure + gauge pressure

= Atmosphere pressure – vacuum

1.4.5 Volume: Volume of a substance is defined as the space which it occupies and is dependent on the mass of the surface.

It’s basic unit is cubic meters(m³)

It is also expressed in Liters 10³L = 1 m³

1.4.6 Specific Volume: The Volume per unit mass of the substance is called specific volume.
Specific volume, \( v = \frac{V}{m} \text{ m}^3/\text{kg} \)

1.4.7 Temperature: It is defined as the degree of hotness or level of heat intensity of a body. It is measured by thermometer in the following commonly used scales.

(i) Centigrade scale or Celsius scale

(ii) Fahrenheit scale

i) Centigrade Scale or Celsius Scale: This scale is most commonly used by Engineers and scientists. The freezing point of water in this scale is “Zero” degree Celsius.

The boiling point of water is 100\(^{\circ}\)C. (1 each division in this scale is “one” degree centigrade (It is written as \(^{\circ}\)C)

ii) Fahrenheit scale: In this scale, the freezing point of water is marked as 32 and boiling point of water as 212. The space between these two points are divided into 120 equal division and each degree represents 1 degree Fahrenheit (written as \(^{\circ}\)F)

\[
\left(\frac{c}{100}\right) = \left(\frac{F - 32}{180}\right)
\]

1.4.8 Absolute Temperature

At lowest temperature the gas will occupy zero volume. This lowest temperature at which the volume of gas is “zero” is called “Absolute Temperature” It is equal to “-273\(^{\circ}\)C” or “-460\(^{\circ}\)F” The temperature measured from this zero is called Absolute temperature.

\[0^\circ K = 0^\circ C + 273 \quad (K = \text{Kelvin unit})\]

\[0^\circ R = 0^\circ F + 460 \quad (R = \text{Rankine unit})\]

1.4.9 Internal Energy

It is defined as the energy stored or possessed by the thermodynamic system. The molecules of a gas (real or ideal gas) may be imagined to be in motion thereby possess kinetic energy of transition, rotation as well as vibration motion.

For an ideal gas, internal optional energy is ‘zero’ because no inter molecular force exist between the molecular.

The total change of internal energy is \( U_2 - U_1 = m \cdot CV \cdot (T_2 - T_1) \)

where \( m = \text{mass of the gas} \)
\[ C_v = \text{Specific heat at constant volume} \]
\[ T_2 = \text{Final temperature} \]
\[ T_1 = \text{Initial temperature} \]

Units: In S.I. System the change of Internal energy is expressed in Joules or kilojoules (J/kg or KJ/ kg)

**1.4.10 Enthalpy**

It is a derived thermodynamic quantity and is defined as the sum of internal energy and the product of pressure and volume.

\[ H = U + pV \text{ Joules or Kilojoules} \]

It depends on temperature only energy change in internal energy.

\[ H_2 - H_1 = mC_p (T_2 - T_1) \text{ KJ} \]

**1.5 Definitions of Flow of Work and Specific Heat**

**1.51 Flow of Work**

The work done in moving the fluid into or out of the system is called flow of work.

Consider the fluid crossing the boundary. The approaching fluid must displace an equal amount of fluid inside the system in order to cross the boundary and enter the system. The energy required to achieve this is called flow of work.

\[ \text{Flow of work} = \text{Force} \times \text{displacement} \]
\[ = pA \times dx \]

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**Fig. 1.2**

Flow of work = Force x displacement

\[ = P.A \times dx \]
1.5.2 Specific Heat

Specific heat may be defined as the Quantity of heat required to raise the temperature of one kilogram of substance through one degree Celsius.

1.5.2.1. Specific heat at constant volume: The specific heat of a gas at constant volume is defined as the heat required to raise the temperature of 1 kg of gas, by one degree Celsius, heat being supplied at constant volume.

1.5.2.2. Specific heat at constant pressure: The Specific heat of a gas at constant pressure is defined as the heat required to raise the temperature of 1 kg of gas, by one degree Celsius, heat being supplied at constant pressure.

Summary

1. System: The thermodynamic system is a definite Area or space where the thermodynamic process is taking place. A thermodynamic system has its ‘boundaries’ and anything outside the boundaries is called ‘Surroundings’.

2. Types of Thermodynamic Systems
   a) Closed system
   b) Open system
   c) Isolated system

   Closed System: The system of fixed mass and identify whose boundaries are determined by the working substance in it.

   Open System: In this system, the working substance crosses boundary of the system. Heat and work may also cross the boundary.

   Isolated System: System of fixed mass and no heat or work cross the boundary.

3. Properties
   a) Intensive properties: These properties are independent of the mass of the system.
      Ex.: Specific Volume; pressure, temperature, density etc.,
   b) Extensive properties: These properties depends upon the mass of the system.
      Ex.: Mass, Volume, Internal energy, Enthalpy etc.,
4. **Pressure**

Pressure is a force applied per unit area and is measured in units of N/m² or Pascal.

5. **Volume**

Volume of a substance is defined as the space which it occupies and is dependent on the mass of the substance; its basic unit is m³.

6. **Temperature**

It is an indication of degree of hotness or coldness. It is the measure of intensity of heat in the metric system, the temperature is commonly measured in degree Celsius.

7. **Internal Energy**

It is the energy stored or possessed by the system. It is independent of pressure and volume and is only a function of temperature.

\[ DU = m \cdot c_v \cdot dT \]

8. **Enthalpy**

It is the sum of Internal energy and the product of pressure and volume expressed in consistent units. It is designated in ‘H’

\[ H = U + PV \]

9. **Specific Heat**

The amount of heat required to raise the temperature of a unit mass of any substance through 1°C. It is generally denoted by ‘C’

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**Short Answer Type Questions**

1. Define System.
2. Mention the types of thermodynamic systems.
3. Define Intensive properties and give examples.
4. Define Pressure and write its units.
5. What is Internal Energy.
6. Define Enthalpy.
Long Answer Type Questions

1. Mention the types of Thermodynamic system and explain them
2. Define system, Boundary, Surrounding and explain them
3. What is Specific heat? Maintain and explain the types of Specific heats.
Learning Objectives

After studying this unit, the student will be able to

- Understand the gas laws like Charle’s, Boyle’s, Avagadro’s etc.
- Relation between Pressure, volume and temperatures of gas.

2.0 Introduction

A Perfect gas (or an Ideal gas) may be defined as a state of a substance whose evaporation from its liquid state is complete. From this point of view the substances like oxygen, Nitrogen, Hydrogen and air, within certain temperature limits, are also regarded as perfect gases.

2.1 Laws of Perfect Gases

The physical properties of perfect gases are controlled by the following three variables.

1. Pressure exerted by the gas.
2. Volume occupied by the gas.
3. Temperature of the gas.

The behaviour of a perfect gas, undergoing any change in the above mentioned variables, is governed by certain laws of gases.
2.1.1 Boyle’s Law

This law was formulated by Robert Boyle in the year 1662. It states that “The absolute pressure of a given mass of a perfect gas varies inversely as its volume, when the temperature remains constant”.

\[ P \propto \frac{1}{V} \text{ or } PV = \text{constant} \]

The more useful form of the above equation is

\[ P_1 V_1 = P_2 V_2 = P_3 V_3 = \ldots = \text{Constant} \]

Mathematically,

\[ P \propto \frac{1}{V} \text{ or } PV = \text{Constant, if temperature remains constant.} \]

If the gas changes from state (1) to state (2) at constant temperature, the two end states are related by the equation:

\[ P_1 V_1 = P_2 V_2 \]

If the change in pressure and volume is represented on P-V diagram, the path or curve obtained is a rectangular hyperbola, having the equation \( PV = \text{constant} \).

2.1.2 Charle’s Law

This Law was formulated by a French scientist Jacques A.C. Charles in about 1787. It may be stated as

“The volume of a given mass of a perfect gas varies directly as its absolute temperature, when the absolute pressure remains constant.”
Mathematically,

\( V \alpha T \) or \( \frac{V}{T} = \text{Constant} \).

(or) \( \frac{V_1}{T_1} = \frac{V_2}{T_2} = \frac{V_3}{T_3} = \text{Constant} \)

The Charles’s law can also be stated as follows:

“If the volume of a gas is kept constant, then the absolute pressure is directly proportional to the absolute temperature.”

At constant volume, \( P \alpha T \) or \( \frac{P}{T} = \text{Constant} \)

At constant volume \( \frac{P_1}{T_1} = \frac{P_2}{T_2} \)

The change of states at constant pressure and constant volume are represented on P-V diagrams.

![Diagram](image)

(a) Constant pressure  (b) Constant Volume.

**Fig. 2.2**

### 2.1.3 Avogadro’s Law

It states, “Equal volumes of all gases at the same temperature and pressure, contain equal number of molecules.

Thus according to Avogadro’s law.

1 m³ of Oxygen (\( O_2 \)) will contain the same number of molecules as 1 m³ of Hydrogen (\( H_2 \)) when the temperature and pressure remain same.

### 2.1.4 Joule’s Law

It states, “The change of Internal energy of a perfect gas is directly proportional to the change of temperature.”
Mathematically \( dE \propto dT = m \cdot c \cdot dT \)
where \( m \) = mass of the gas and
\( c \) = A constant of proportionality known as specific heat.

### 2.1.5 Regnault’s Law

It states that “The Specific heats of a perfect gas remain constant when pressure and volume are constant”.

Thus two specific heats \( CP \) and \( CV \) of a perfect gas do not change with the change in temperature.

### 2.2.1 General Gas Equation

In gas Laws we will get the relation between the two Variables when the third Variable is constant. But in actual practice, all the three Variables i.e pressure, volume and temperature change simultaneously. In order to deal with all practical cases, the Boyle’s Law and Charles’ Law are combined together, which gives us General Gas equation

According to Boyle’s Law,

\[
P \propto \frac{1}{V} \quad \text{(keeping } T \text{ constant)}
\]

\[V \propto \frac{1}{P}\]

According to Charles’ Law

\[V \propto T \quad \text{(Keeping } P \text{ Constant)}\]

It is thus obvious that

\[V \propto \frac{1}{P} \text{ and } T\]

Or \[V \propto \frac{T}{P}\]

\[\therefore PV \propto T \text{ or } PV = CT \text{ or } \frac{PV}{T} = C\]

Where ‘C’ is a constant whose value depends upon the mass and properties of the gas constant

\[\text{i.e. } \frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2} = \frac{P_3 V_3}{T_3} = \ldots \ldots \ldots \ldots \text{Constant}\]
2.2.2 Characteristic Gas Equation

It is a modified form of general gas equation. If the volume (V) in the gas equation is taken as that of 1 kg of gas (known as specific volume and denoted by VS) then the constant ‘c’ (in the general gas equation) is represented by constant R (in the characteristic gas equation)

Then \( PV_s = RT \)

Where R is known as characteristic gas constant for any mass \( m \) kg of a gas, characteristic gas equation becomes.

\[ mPV_s = mRT \]

or \( PV = mRT \) \( \therefore \ mV_s = V \)

2.2.3 Universal Gas Constant or Molar Constant

The Universal Gas constant or Molar constant (General denoted by \( R_u \)) of a gas is the product of gas constant and molecular weight of the gas.

Mathematically, \( R_u = MR \)

Where \( M = \) Molecular weight of the gas expressed either in gm (gram mole) or in kg m. (kg mole) \( R = \) Gas constant.

In general if \( M_1, M_2, M_3 \) etc are the molecular weight of different gases and \( R_1, R_2, R_3 \) etc are their gas constants respectively.

Then

\[ M_1R_1 = M_2R_2 = M_3R_3 = \ldots \ldots \ldots R_U \]

\[ PV = nR_uT \]

Or \( R_U = PV/nt \) J/k mole K. or K J/k mole K.

2.3 Specific Heats of Gas

The specific heat of a substance may be broadly defined as the amount of heat required to raise the temperature of its unit mass through 1°C. All the liquids and solids have one specific heat only. But a gas can have different specific heats depending upon the conditions under which it is heated. The following two are different specific heats.

i) Specific heat at constant volume

ii) Specific heat at constant pressure.
### 2.3.1 Specific Heat at Constant Volume

It is the amount of heat required to raise the temperature of a unit mass of gas through 1°C when it is heated at a constant volume.

It is generally denoted by $C_v$ or $K_v$.

Consider a gas contained in a Container with a fixed lid.

Now if this gas is heated, it will increase the temperature and pressure of the gas in the container.

Since the lid of the container is fixed, the volume of gas remains unchanged.

![Fixed Lid](image)

**Fig. 2.3**

\[ M = \text{Mass of the gas} \]
\[ T_1 = \text{Initial Temperature of the gas} \]
\[ T_2 = \text{Final Temperature of the gas} \]

\[ \therefore \text{Total heat supplied to the gas at constant volume} \]
\[ H = \text{Mass} \times \text{sp. Heat at constant volume} \times \text{Rise in temperature} \]
\[ = M \times C_v (T_2 - T_1) \]

Whenever a gas is heated at constant volume, work is done by the gas.

The whole heat energy is utilized in increasing temperature and pressure of the gas.

That means - all the amount of heat supplied remains within the body of the gas, and represents the increase in internal energy of the gas.
2.3.2 Specific Heat At Constant Pressure

It is the amount of heat required to raise the temperature of a unit mass of gas through 1°C, when it is heated at constant pressure.

It is generally denoted by \( C_p \) or \( K_p \).

Consider a gas contained in a container with a movable lid. If the gas heated, it will increase the temperature and pressure of the gas in the container.

Since the lid of the container is movable, it will move upwards, in order to counter balance the tendency for pressure to raise.

\[ H = m \times C_p \times (T_2 - T_1) \]

2.3.3 Relation Between Two Specific Heats

Consider a gas enclosed in a container and being heated at constant pressure.

Let \( M = \) Mass of the gas
\( T_1 \) = Initial Absolute temperature or the gas
\( T_2 \) = Final Absolute temperature of the gas
\( V_1 \) = Initial volume of the gas
\( V_2 \) = Final volume of the gas
\( C_p \) = Specific heat at constant pressure
\( C_v \) = Specific heat at constant volume
\( P \) = Constant pressure

As we know that,

The heat supplied to the gas at constant pressure,
\[ H = mC_p (T_2 - T_1) \]

As already discussed, a part of this heat is utilized in doing external work, and the rest remains within the gas, and is used in increasing the internal energy of the gas.

Heat utilized for external work,
\[ W = \frac{P (V_2 - V_1)}{J} \] ...............................(i)

And increase in internal energy,
\[ E = mC_v (T_2 - T_1) \] .................................(ii)

We know that \( H = W + E \) .................................(iii)

\[ \therefore M. C_p (T_2 - T_1) = \frac{P(V_2 - V_1)}{J} + M.C_v (T_2 - T_1) \] .................................(iv)

Using characteristic gas equation, (ie. \( P \_v = mRT \))

We have
\[ PV_1 = mRT_1 \] (for initial conditions)
\[ PV_2 = mRT_2 \] (for final conditions)
\[ P (V_2 - V_1) = mR (T_2 - T_1) \]

Now substituting the value of \( P (V_2 - V_1) \) in equation (v)
\[ M \, C_P \, (T_2 - T_1) = m \, R \, \frac{(T_2 - T_1)}{J} + m \, C_v \, (T_2 - T_1) \]

\[ \therefore \, C_P = \frac{R}{J} + C_v \] ................................. (vi)

(or) \[ C_P - C_v = \frac{R}{J} \] ................................. (vii)

The above equation may be re-written as

\[ C_P - C_v = \frac{R}{J} \]

\[ C_v \, (\gamma - 1) = \frac{R}{J} \] ................................. (Where \( \gamma = \frac{C_p}{C_v} \))

\[ C_v = \frac{R}{J} (\gamma - 1) \]

Where \( R \) is a gas constant and its volume is taken as

\[ 0.287 \, \text{KJ/Kg O}_k \]

The characteristic gas constant of a gas is equal to the difference of its two specific heats.

Now Consider a certain quantity a perfect gas being expanded adiabatically.

Let \( V_1 \) = Initial volume of the gas

\( P_1 \) = Initial pressure of the gas

\( V_2 \) = Final volume of the gas

\( P_2 \) = Final pressure of the gas

Now consider at any Point ‘E’ on the curve AB. Let ‘P’ and ‘V’ be the volume of the gas at this point ‘E’

Let the volume of gas increase by a small amount \( dv \).

This change is so small that the pressure during the change may be assured to remain constant.

: Work done during this change,

\[ Dw = P \, dv \] ................................. (In work Units)

\[ = P \, dv/J \] ................................. (In heat Units)

As the work done is at the expense of Internal energy, the internal energy must decrease by an equal amount

Let the temperature of the gas fall by a small amount ‘dT’
Then decrease internal energy $= dE = mc v dT$

Since $dE + dw = 0$

$mc v dT + pdv/J = 0$

$or mcv dT = -pdv/J \ldots (i)$

We know that $pv = mRT$

Differentiating this expression, we get

$Pdv + vdp = mRdT \ldots (ii)$

We also know that $R = J(Cp - Cv)$

Substituting value of $R$ in equation (ii)

$Pdv + vdp = mJ(cp - cv)dT$\ldots (iii)

Dividing Equation III by Equation (i)

$mJ(cp - cv)dT/mcvdT = pdv + vdp/ -pdv/J$

$cp - cv/cv = -1 - (v/dv x dp/p)$

$V = -(v/dv x dp/p)$

$(cp/cv = r)$

$V x dv/v = -dp/p$

$V dv/v + dp/p = 0$

Integrating both sides.

$V log e v + log e p = constant$

$Or log PV_2 = log e c$

$PV_2 = c$

$Or P_1 V_1 = P_2 V_2 = \ldots \ldots C \ldots \ldots (iv)$

$Or P_1/P_2 = (V_2/V_1) \ldots \ldots (v)$

**Summary**

1. The physical properties of perfect gases are controlled by
(i) Pressure exerted by the gas
(ii) Volume occupied by the gas
(iii) Temperature of the gas

2. Boyle’s Law : The absolute pressure of a given mass of the perfect gas varies inversely as its volume, when the temperature remains constant.

\[ P \alpha \frac{1}{v} \text{ or } PV = \text{Constant} \]

3. Charle’s Law : The volume of a given mass of a perfect gas varies directly as its absolute temperature, when the absolute pressure remains constant.

\[ V \alpha T \text{ or } \frac{V}{T} = \text{constant} \]

4. Avagadro’s Law : Equal volumes of all gases at the same temperature and pressure, contain equal number of molecules.

5. Joule’s Law : The change of Internal energy of a perfect gas is directly proportional to the change of temperature.

\[ dE \alpha dT = m.c.dT \]

6. Regnault’s Law : The specific heats of a perfect gas remain constant when pressure and volume are constant.

7. General Gas Equation :

\[ \frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2} = \frac{P_3 V_3}{T_3} = \ldots \ldots \ldots \text{Constant} \]

8. Characteristic Gas Equation

\[ PV = mRT \]

9. Universal Gas Constant (or) Molar Constant

The universal gas constant or Molar constant of a gas is the product of the gas constant and molecular weight of the gas.

\[ R_u = MR \]

10. Specific heat of a gas at constant volume : It is the amount of heat required to raise the temperature of a unit mass of gas through 1°C, when it is heated at constant volume.

11. Specific heat of a gas at constant pressure : It is the amount of heat required to raise the temperature of a unit mass of gas through 1°C, when it is heated at constant pressure.
Short Answer Type Questions
1. State Boyle’s Law
2. State Charle’s Law
3. Mention Avagadro’s Law
4. State Joule’s Law
5. State Regnault’s law
6. What is universal gas constant
7. Define specific heat of a gas at constant volume
8. Define specific heat of a gas at constant pressure.

Long Answer Type Questions
1. Explain Charle’s law with the help of P-V diagram
2. Explain Boyle’s law with the help of P-V diagram.
3. Derive general gas equation.
Learning Objectives

After studying this unit, the student will be able to

• Understand on which laws of thermodynamics, the thermodynamic process will work

• To know about the operations of IC Engines and other related any kind of heat engines and their performances.

3.1 Laws of Thermodynamic

The amount of useful work and power which can be developed by the engine, and the possible efficiency of the engine are governed by the laws of Thermodynamics.

3.1.1 Zeroth Law of Thermodynamic

It states that ‘when two bodies are in thermal equilibrium with a third body, they are also in thermal equilibrium with each other and hence they are at the same temperature.

If the bodies A and B are in thermal equilibrium with body C, then A and B must be in thermal equilibrium.
3.1.2 First Law of Thermodynamics

It states that ‘the heat and mechanical work are mutually convertible.’ According to this law, a definite amount of mechanical work in needed to produce a definite amount of heat and vice versa.

The First Law of Thermodynamics can also be stated as, “the energy can neither be created nor destroyed, though it can be transformed from one form to another”.

According to this law, the energy due to heat supplied must be balanced by the external work done plus gain in internal energy due to rise in temperature.

Mathematically \( H = E + W \).

Where \( H \) = Heat transferred.

\( E \) = Change in internal energy

\( W \) = Work done in heat units.

\( dH = dE + dW \).

3.1.3 Second Law of Thermodynamics

It states that ‘There is a definite limit to the amount of mechanical energy, which can be obtained from a given quantity of heat energy’.

According to Clausius, ‘It is impossible for a self acting machine working in a cyclic process, to transfer heat from a body at a lower temperature to a body at a higher temperature without the aid of a external agency.'
According to Kelvin - Plank, ‘It is impossible to construct an engine working in a cycle, that will produce no other effect than the extraction of heat from a single heat reservoir and the performance of an equal amount of work.

**Summary**

Zeroth law of thermodynamics : When two bodies are in thermal equilibrium with a third body, they are also in thermal equilibrium with each other and hence they are at the same temperature.

First Law of Thermodynamics : The energy can neither be created nor destroyed though it can be transformed from one form to another.

Second Law of Thermodynamics : There is a definite limit of amount of mechanical energy which can be obtained from a given quantity of heat energy.

**Short Answer Type Questions**

1. State Zeroth law of Thermodynamics.
2. State First law of Thermodynamics

**Long Answer Type Questions**

1. Explain the laws of Thermodynamics.
Learning Objectives

After studying this unit, the student will be to

- Know the different processes applied on gases like constant volume, constant pressure, constant temperature etc.
- The relation between the specific heats of constant volume and constant pressure processes.
- Know about work done during different processes and the heat energy developed through them

4.0 Introduction

The process of heating and expanding of a gas may, broadly, be defined as a thermodynamics process or non flow process.

It has been observed that as a result of flow of energy, change takes place in various properties of the gas such as pressure, volume, temperature, specific energy, specific enthalpy etc.

Some of the important thermodynamics processes are

1. Constant volume process
2. Constant pressure process
3. Hyperbolic process
4. Isothermal process (constant temperature process).
5. Adiabatic process (or) Isentropic process.
6. Polytrophic process.
7. Free expansion process.
8. Throttling process.

4.1.1. Constant Volume Process

As we already know that when a gas is heated at constant volume, its temperature and pressure will increase. Since there is no change in its volume, no external work is done by the gas. All the heat supplied is stored in the body of the gas in the form of internal energy.

Now consider m kg of a certain gas being heated at constant volume from an initial temperature $T_1$ to final temperature $T_2$.

![Fig. 4.1 P-V diagram](image)

We know that $H = E + W$

Or $H = E$ (since $W = 0$)

We also know that

Internal Energy, $E = mCV (T_2 - T_1)$

$\therefore$ Heat supplied, $H = 3 = mCV (T_2 - T_1)$. 
4.1.2 Constant Pressure Process

When a gas is heated at a constant pressure, its temperature and volume will increase. Since there is a change in its volume, the heat supplied is utilised in increasing the internal energy of the gas and also for doing some external work.

Now consider m kg at a certain gas being heated at a constant pressure from an initial temperature $T_1$ to the final temperature $T_2$.

![Fig. 4.2](image)

We know that the heat supplied to the gas at constant pressure, $H = mCV(T_2 - T_1)$ increase in internal energy, $E = mC_v(T_2 - T_1)$ and work done during the process.

$W = \text{Area below the line 1-2}$.

4.1.3 Constant Temperature Process (Isothermal Process)

A process, in which the temperature of working substance remains constant during its expansion or compression, is called an ‘Isothermal process’ or constant temperature process.

This will happen when the working substance remains in a perfect thermal contact with the surroundings.

As there is no change in temperature, there is also no change in internal energy.

$H = E + W$

Therefore $H = O + W$ ....................(∵ $E = 0$)

Or $H = W$ ........................................ (In work units).

or $H = W/J$ ....................... (in heat units).
Hence, during Isothermal expansion of a gas, Heat added = Work done by the gas.

Similarly, during isothermal compression of a gas,

Heat substracted = Work done on the gas.

Isothermal process is governed by Boyle’s law,

\[ \therefore \text{ Perfect gas } pv = \text{ constant work done during isothermal expansion.} \]

Let \( V_1 \) = Initial volume of gas

\( P_1 \) = Initial pressure of gas

\( V_2 \) = Final volume of gas

\( P_2 \) = Final pressure of gas.

Now consider any point E on the curve AB.

Let P and V are pressure and volume of gas at the point E.

Let Volume of the gas increase by a very small amount \( dv \).

This change is so small that the pressure during the change may be assumed to remain constant.

\( dw = \text{area of the shaded portion} = P \cdot dv. \)

Now, the total work done during expansion from A to B is can be obtained by integrating the above equation between the limits \( V1 \) and \( V2 \).
Therefore the work done, \( W = \text{Area under the curve AB} \)

\[
= \int p \, dv \quad \ldots \ldots \ldots \quad (i)
\]

Since the expansion is Isothermal, \( V \frac{p}{v} = c \)

Therefore \( PV = P_1 V_1 \quad V_1 \)

Therefore \( P = P_1 V_1 / V \).

Substituting the value of \( P \) in equation (i)

\[
w = \int_{V_1}^{V_2} P_1 \frac{V_1}{V} \, dv = P_1 V_1 \int_{V_1}^{V_2} \frac{dv}{V}
\]

\[
= P_1 V_1 \left[ \log_e V \right]^{V_2}_{V_1} = P_1 V_1 \log_e \frac{V_2}{V_1}
\]

Using logarithm table

\[
w = 2.3 P_1 V_1 \log \frac{V_2}{V_1}
\]

(Or) \( 2.3 P_1 V_1 \log r \) \( (: \ r = \text{expansion ratio}) \)

we know that \( P_1 V_1 = mRT \)

\( . \) : Work done = \( w = 2.3 mRT \log \frac{V_2}{V_1} \)

\[
= 2.3 mRT \log r
\]

\( \text{Sine} \ P_1 V_1 = P_2 V_2 \), then \( \frac{V_2}{V_1} = \frac{P_1}{P_2} \)

\( . \) : Work done = \( w = 2.3 P_1 V_1 \log \frac{P_1}{P_2} \)

### 4.1.4 Adiabatic Process (or) Isentropic Process

A process in which the working substance neither receives nor gives out heat to its surroundings, during its expansion or compression is called ‘Adiabatic Process’.

This will happen when the working substance remains thermally insulated, so that no heat enters or leaves it during the process.

Thus in an adiabatic process,
1. No heat enters or leaves the gas.

2. As the temperature of gas changes, the work is done at the expense of internal energy.

3. The change in internal energy is equal to the mechanical work done.

We know that
\[ H = E + W \]
\[ O = E + W \] (\( \because \) \( H = 0 \))
\[ \therefore E = - W \] (in work units).

Minus sign indicates that, for increase in internal energy work must be done on the gas.

i.e. Negative work must be done by the gas.

Similarly, for decrease in internal energy, work must be done by the gas.

Now consider a certain quantity a perfect gas being expanded adiabatically.

![Diagram](Fig. 4.4)

Let \( V_1 = \) Initial volume of gas

\( P_1 = \) Initial pressure of gas

\( V_2 = \) Final volume of gas

\( P_2 = \) Final pressure of gas.

Now consider any point E on the curve AB.

Let P and V are pressure and volume of gas at the point E.

Let the volume of the gas increase by a very small amount \( dv \).
This change is so small that the pressure during the change may be assumed to remain constant.

∴ Work done during this change,
\[ dw = p \, dv \] ................................. (in work units)
\[ = \frac{p \, dv}{J} \] ................................. (in work units).

As the work done is at the expense of internal energy, the internal energy must decrease by an equal amount. Let the temperature of the gas fall by a small amount ‘dT’, then decrease in internal energy = \( dE = mC_v \, dT \).

Since \( dE + dw = 0 \).

Therefore \( mC_v \, dT + p \, dv/J = 0 \)

Or \( mC_v \, dT = - p \, dv/J \) ............................(i)

We know that \( pv = mRT \).

Differentiating this expression, we get
\[ pdv + v \, dp = m \, R \, dt \] ..........................(ii)

we also know that \( R = J(\text{CP} – C_V) \)

substituting value of \( R \) in equation (ii)
\[ pdv + v \, dp = mJ ((C_p – C_V)dT. \]
\[ mJ(C_p – C_V)dT = pdv + Vdp \] ...............(iii)

dividing the equation (iii) by equation (i)

\[ \frac{mJ \, (C_p – C_V) \, dT}{m \, C_v \, dT} = \frac{Pdv + vdp}{pdv} - \frac{pdv}{J} \]

\[ \frac{(C_p – C_V)}{C_V} = -1 \left( \frac{v}{dv} \times \frac{dp}{p} \right) \]

\[ \gamma = \frac{1}{\frac{v}{dv} \times \frac{dp}{p}} \]
\[
\gamma \frac{dv}{v} = \frac{-dp}{p}
\]
Integrating both sides:
\[
\gamma \log_e v + \log_e P = \text{constant}
\]
or \(\log_e P v^\gamma = \log_e C\)
or \(P v^\gamma = c\)
or \(P V_1 = P V_2 = C\)
dividing equation III by equation (i)

\[
mJ (C_p - C_v) dT = PdV + vdp
\]

\[
\frac{mJ (C_p - C_v) dT}{C_p - C_v} = \frac{-pdv}{C_v}
\]

\[
\frac{Cv}{C_p} = -1 \left( \frac{dv}{v} \times \frac{P}{dp} \right)
\]
\[
\frac{Cv}{C_p} = -1 = -1 \left( \frac{dv}{v} \times \frac{P}{dp} \right)
\]
\[
\gamma = - \frac{v}{dp} \left( \frac{dv}{v} \times \frac{P}{dp} \right)
\]

\[
\therefore \gamma x dv / V = -dp / p
\]
\[
\gamma x dv / V = -dp / p = 0
\]
Integrating both sides:
\[
\gamma \log_e v + \log_e P = \text{constant}
\]
or \(\log_e P v^\gamma = \log_e C\)
\[
\therefore P v^\gamma = C
\]
or \(P V_1 = P V_2 = C\) ............ (iv)
or \(P_1 / P_2 = (V_2 / V_1)^\gamma = C\) ............ (v)
from general gas equation, we know that

\[
\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}
\]

\[
\frac{P_1}{P_2} = \frac{T_1}{T_2} \times \frac{V_2}{V_1} \quad \text{.......................... (vi)}
\]

Equation (v) and (vi)

\[
\frac{P_1}{P_2} = \left(\frac{V_2}{V_1}\right)^\gamma
\]

\[
\frac{T_1}{T_2} \times \frac{V_2}{V_1} = \left(\frac{V_2}{V_1}\right)^\gamma
\]

\[
\frac{T_1}{T_2} = \left(\frac{V_2}{V_1}\right)^\gamma = \left(\frac{V_2}{V_1}\right)^{\gamma-1}
\]

From general gas equation \( P_1 \frac{V_1}{T_1} = P_2 \frac{V_2}{T_2} \)

\[
\frac{P_1}{P_2} \times \frac{T_2}{T_1} = \frac{V_2}{V_1}
\]

\[
\frac{P_1}{P_2} = \left(\frac{P_1}{P_2} \times \frac{T_2}{T_1}\right)^\gamma = \left(\frac{P_1}{P_2}\right)^\gamma \left(\frac{T_2}{T_1}\right)^\gamma
\]

\[
\left(\frac{T_2}{T_1}\right)^\gamma = \left(\frac{P_1}{P_2}\right)^{1-\gamma}
\]
Work done by the Gas:

For any non flow process

\begin{align*}
\text{Work done, } W_{1\rightarrow 2} &= \int_{V_1}^{V_2} P \, dV \\
 &= \int_{V_1}^{V_2} \frac{C}{V^\gamma} \, dV = C \int_{V_1}^{V_2} V^{-\gamma} \, dV \\
 &= C \left( \frac{V_2^{1+1}}{1+1} \right) = C \left( \frac{V_2^{1+1} - V_1^{1+1}}{1+1} \right) \\
&= \frac{C \cdot V_2^{1+1} - C \cdot V_1^{1+1}}{1+1} \\
&= \frac{P_2 V_2^\gamma \cdot V_2^{1+1} - P_1 V_1^\gamma \cdot V_1^{1+1}}{1+1} \\
&= \frac{P_2 V_2 - P_1 V_1}{1+1}
\end{align*}
Work done, \( W_{1-2} = \frac{P_1 V_1 - P_2 V_2}{\gamma - 1} \)

\[ mR (T_1 - T_2) \]

\[ \gamma - 1 \]

### 4.1.5 Polytropic Process

The polytropic process is also known as the general law for the expansion and compression of gases and is given by the relation

\[ P V^n = \text{Constant} \]

Where ‘\( n \)’ is a polytropic index which may have any value from ‘zero’ to ‘Infinity’ depending upon the manner in which expansion or compression has taken place.

The various equations for polytropic process may be expressed by changing the index \( n \) for \( r \) in adiabatic process.

\[ \frac{T_1}{T_2} = \left( \frac{V_2}{V_1} \right)^{n-1} \]

\[ \frac{T_1}{T_2} = \left( \frac{P_1}{P_2} \right)^{\frac{(n-1)/n}{}} \]

Similarly \( \frac{V_1}{V_2} = (\frac{P_2}{P_1})^{1/n} \)

Work done by the gas for any non flow process

\[ \text{Work done} = W_{1-2} = \int \frac{P}{V} \, dV \]

As per polytropic law \( PV^n = C \) Since \( P = C / V^n \)

\[ W_{1-2} = \int \frac{C}{V_1 V^n} \, dV \]

\[ = C \int V^{-n} \, dv = C \left( \frac{V^{-n+1}}{-n+1} \right)_{V_1}^{V_2} \]
\[ PV^n = C \]

But \( P_1 V_1^n = P_2 V_2^n = C \)

\[
\frac{P_2 V_2^n V_2^{-n+1}}{-n+1} - \frac{P_1 V_1^n V_1^{-n+1}}{-n+1} = \frac{P_2 V_2 - P_1 V_1}{-n+1}
\]

Therefore \( W_{1\rightarrow 2} = \frac{P_1 V_1 - P_2 V_2}{n-1} \) or \( \frac{mR (T_1 - T_2)}{n-1} \)

(Since \( P_v = mRT \))

**Summary**

1. **Constant volume process**: When a gas is heated at constant volume, its temperature and pressure will increase. All the heat supplied is stored in the body of the gas in the form of internal energy.

2. **Constant Pressure Process**: When a gas is heated at constant pressure, its temperature and volume will increase. Since there is a change in its volume, the heat supplied is utilized in increasing the internal energy of the gas.
3. Isothermal Process: A process in which the temperature of the working substance remains constant during its expansion or compression is called Isothermal process.

4. Adiabatic Process: A process in which the working substance neither receives nor gives out heat to its surroundings, during its expansion or compression is called Adiabatic Process.

Short Answer Type Questions

1. Define Constant Volume process
2. Define Constant pressure process.
3. Define Isothermal process.
4. Define Adiabatic process

Long Answer Type Questions

1. Explain constant volume process with P-V diagram and write the formulae for work done.
2. Explain the constant pressure process with P-V diagram and write the formulae for work done.
3. Explain the constant temperature process with P-V diagram and write the formula for work done.
4. Explain the Adiabatic process with P-V diagram.
Learning Objectives

After studying this unit, the student will be able to

• Understand the term fuel

• Different types of fuels with examples, comparison of solid, liquid and gaseous fuels.

• Qualities of good fuel.

• To know about octane number, cetane number.

• To know about alternate fuels.

5.0 Introduction

A fuel may be defined as a substance, which on burning with oxygen in the atmosphere air, produces a large amount of heat. The amount of heat generated is known as Calorific value of the fuel.

As the main constituents of fuel are carbon and hydrogen, these are also known hydrocarbon fuels.

5.1 Types of Fuels

The fuels may be classified into three general forms:

1. Solid fuels
2. Liquid fuels
3. Gaseous fuels
Each of these fuels may be further subdivided into following two types.

(a) Natural fuels and (b) Prepared fuels.

5.2.1 Solid Fuels

The natural solid fuels are ‘wood’, ‘peat’, ‘lignite’ or ‘brown coal’, ‘bituminous coal’ and ‘anthracite coal’.

The prepared solid fuels are wood charcoal, cake, briquetted coal and pulverized coal.

5.2.1 (a) Wood

In rural areas and also in olden days, it was extensively used as a fuel for cooking purpose. It consists of mainly carbon and hydrogen. The wood is converted into coal when burnt in the absence of air. The calorific value of wood varies with its kind and moisture content. The average calorific value of the wood is 4700 k.Cal/kg.

5.2.1 (b) Peat

Peat is the first stage in the formation of coal from wood. It is a spongy humified substance found in boggy land. It has a large amount of water contents upto 30% and therefore has to be dried for a longer period before using it as a fuel. It’s calorific value is 5500 k.Cal/kg.

5.2.1 (c) Lignite (or) Brown Coal

It is the next stage of peat in the formation of coal. It is the between stage of ‘peat’ and ‘bituminous coal’. It contains nearly 40% of moisture and 60% of carbon. It is brown in colour and it is also known as ‘brown coat’. These are used in generation of thermal power, Fertiliser manufacturing. It’s average calorific value is 6000 k.Cal/kg.

5.2.1 (d) Bituminous Coal

It is the next stage of lignite in the coat formation. It contain very little moisture of about 4 to 6% and carbon content is high as much as 75% to 90%. It’s average calorific value is 8000 k.Cal/kg.

It is of two types.

(i) Coking Bituminous coal: It is also known as soft coal. It is soft in condition and swells on heating. It is mainly used in manufacturing of gas.

(ii) Non-coking Bituminous coal: It gives little or no-smoke. It is mostly used as fuel for stream boiler. Hence it is also known as steam coal.
5.2.1 (e) Anthracite Coal

It is the final stage of coal formation. It contains 90% or more carbon with a very little volatile matter. It is comparatively smokeless and has very little flame. It possesses a high calorific value of about 8600 k.Cal/kg and is used for steam raising and general power purposes.

5.2.1 (f) Wood Charcoal

It is made by heating wood with a limited supply of air to a temperature of not less than 280°C. It is a good prepared solid fuel and is used for various metallurgical purposes.

5.2.1 (g) Coke

It is produced when coal is strongly heated continuously for 42 to 48 hours in the absence of air in a closed vessel. This process is known as Carbonisation of coal.

Coke is dull black in colour, porous and smokeless. It has high carbon content of 85% to 90% and has a higher calorific value than coal.

The soft coke or lower temperature coke is carbonized at a temperature of 500° to 700°C and is used as domestic fuel.

The hard coke or high temperature coke is carbonized at a temperature of 900° to 1100°C and is used in blast furnace for extracting 'Pig Iron' from Iron ore and also used in cupola furnace for producing cast Iron.

5.2.1 (h) Briquetted Coal

It is produced from finely ground coal by moulding under pressure with or without a binding material.

5.2.1 (i) Pulverised Coal

It is the low grade coal with high ash content, is powdered to produce pulverized coal. It is widely used in cement industry and also in metallurgical processes.

5.2.1 (j) Solid Fuels

Solid fuels are having the following advantages

- Cheaper than any other fuel.
- Coal is the raw material for producing other fuels such as coke, producer gas, water gas etc.
• Risk of fire is minimum.

Limitations

• These fuels contain in combustible matter.
• They need large amount of storage space.
• Properties of these fuels are not uniform.
• Handling is not easy and therefore may be costly sometimes.

5.2.2 Liquid Fuels

Almost all commercial liquid fuels are derived from natural petroleum (or crude oil). The crude oil is obtained from bored holes in the earth’s crest in certain parts of the world. The liquid fuels consists of hydro carbons.

The natural petroleum may be separated into petrol or gasoline, paraffin oil or kerosene, fuel oils and lubricating oils by boiling the crude oil at different temperatures and subsequent fractional distillation. Some liquid fuels are also obtained from coal (coal tar etc). The following are the some of the important liquid fuels:

Petrol or gasoline: Petrol is the highest and most volatile liquid fuel. It is mostly used as fuel for petrol engines, air craft engines (aviation petrol). It is distillated at temperature from 65°C to 220°C. It’s calorific value is 11,000 k.Cal/kg and above.

Kerosene or paraffin oil: It is obtained by fractional distillation of crude oil between 220°C and 345°C. It is used as fuel for some stationary engines etc.

Diesel: It is obtained by straight distillation of several crude oils. It is used as fuel for diesel engines.

Heavy fuel oil: It is obtained by distillation of crude oil between 200°C to 360°C. These oils are mostly used in steam power plants, heating furnaces and in diesel engines also. It is distillated at a temperature from 345°C to 470°C.

Merits and Demerite of Liquid fuels over solid fuels:

Following are merits and demerits of liquid fuels over solid fuels.

a) Merits:

i) Higher calorific value.
ii) Lower storage capacity
iii) Better economy in handling
iv) Better content of consumption by using valves.
v) Better cleanliness and freedom from dust.
vi) Practically no ashes
vii) Non-corrosion of boiler plates.
viii) Higher efficiency.

(b) Demerits
i) Higher cost
ii) Greater risk of fire
iii) Costly containers are required for storage and transport.

Gaseous Fuels

The natural gas is usually found in or near the petroleum fuels, under the earth’s surface. It consists of marsh gas or methane (CH\(_4\)) together with small amounts of other gases such as ethane (\(C_{2}H_{6}\)), carbon dioxide (CO\(_2\)) and carbon monoxide (CO). The common example of manufactured gases are Coal gas, producer gas, water gas, mond gas, coke over gas and blast furnace gas.

Natural Gas

Natural gas is found in the petroleum fields under the earth’s surface. It consists of methane (CH\(_4\)) and ethane (\(C_{2}H_{6}\)) together with small amounts of hydrogen sulphide, carbon dioxide and nitrogen.

Coal Gas

It is obtained by destructive distillation of bituminous coal in a fire clay retort. It consists of carbon monoxide, carbon dioxide, hydrogen and methane. It is used in boilers, gas engines, and also for lighting and heating applications.

Producer Gas

It is obtained by partial burning of coke in a mixed air stream blast. It consists of hydrogen. It is mainly used in power generation and glass melting furnaces.

Water gas (Blue gas):

It is produced by blowing the steam through red hot coal or coke. It consists of carbon monoxide and hydrogen along with small amounts of carbon dioxide and nitrogen.
Mond Gas:

It is produced by passing air and large amount of steam over water coal at 650°C. It is used in furnaces, gas engines and for heating purposes.

Coke oven Gas:

It is a by-product from coke oven and is obtained by the carbonization of bituminous coal. It is used for industrial heating and power generation.

Blast Furnace Gas:

It is a by-product in the production of pig iron in the blast furnace. It is used as fuel in steel works; for power generation; in gas engines; for stream raising in boilers and for pre-heating the blast furnace.

Merits and Demerits of Gaseous Fuels:

Merits

1. As the supply of fuel gas can be controlled by operating valves; temperature of the furnace can be controlled easily and accurately.
2. These gases are directly used in internal combustion engines.
3. They are free from liquid and solid impurities.
4. They do not produce ash or smoke.
5. Minimum air is needed for their complete combustion.

Demerits:

1. They are readily inflammable.
2. They require large storage capacity.

Calorific Value of Fuels

The calorific value or heat value of a solid or liquid fuel may be defined as the amount of heat given out by the complete combustion of ‘1kg’ of fuel. It is expressed in terms of k.Cal/kg of fuel. However, the calorific value of gaseous fuels is expressed in terms of k.Cal/m³ at a specified temperature and pressure.

These are two types of calorific values of fuels:

(i) Gross or Higher calorific value.
(ii) Net of Lower calorific value.
Gross or Higher Calorific Value:

All fuels usually contain some percentage of hydrogen when a given quantity of fuel is burnt, some heat is produced. Moreover, some hot flue gases are also produced. The water content of the fuel is converted into steam. If the heat is recovered from the flue gases and the steam is condensed from the flue gases and the steam is condensed back to water at room temperature (i.e. 15°C), then the amount of total heat produced per kg is known as Gross or Higher Calorific value.

In other words, ‘the amount of heat obtained by the complete combustion of 1kg of fuel, when the products of the combustion are cooled down to the temperature of supplied air of 15°C is called Gross or Higher Calorific value of fuel’.

It is briefly written as H.C.V.

Net or Lower Calorific Value:

When the heat absorbed or carried away by the products of combustion is not recovered and the steam formed during combustion is not condensed, then the amount of heat obtained per kg of the fuel is known as Net or Lower Calorific value of the fuel. It is briefly written as L.C.V.

If the H.C.V. is known, then the L.C.V. may be obtained by subtracting the amount of heat carried away by the products of combustion from H.C.V.

Therefore L.C.V. = H.C.V. — Heat of steam formed during combustion.

The amount of heat per kg of steam in latent heat of steam is 586 k.cal/kg, and the amount of steam formed in $9H_2$.

Therefore L.C.V. = H.C.V. – ($9H_2$ x 586) k.Cal/kg.

In SI units, the corresponding relation is L.C.V. = H.C.V. – ($9H_2$ x 2442) k.Cal/kg.

Fuels Used in I.C. Engines

The thermally crossed and straight run gasoline and mixed to obtain commercial motor fuel.

There are following three grades of fuels are available.

The following three grades of fuels are available in market for automotive use.

a. Super premium grade of fuel
b. Premium grade fuel

c. Regular grade fuel.

The automotive fuels are marked under state and federal specifications. These specifications cover the major characteristics of gasoline, which are related to the operation of the engine.

Petroleum consists of many hydrocarbon series such as paraffin series, olefin series, aromatic series, etc.

- **Paraffin** $\text{C}_n\text{H}_{2n+2}$: Methane, ethane, hexane, hexadecane.
- **Olefin** $\text{C}_n\text{H}_{2n}$: Ethene, Propene, butane.
- **Naphthene** $\text{C}_n\text{H}_{2n}$: Cyclic compounds, saturated.
- **Aromatic** $\text{C}_n\text{H}_{2n-6}$: Susceptible to oxidation, highly anti knocking.
- **Diolefin** $\text{C}_n\text{H}_{2n-2}$: Extremely active, tends to polymerize.
- **Cyclic** $\text{C}_n\text{H}_{2n-4}$: These series predominate in the higher boiling point oils such as gas oils and lubricating oils.

$\text{C}_n\text{H}_{2n-8}$:

Other constituents — Sulphur, oxygen compounds, nitrogen arphaltenes and resins.

**Characteristics of Gasoline:** Major characteristics of gasoline are as follows:

1. **Volutility**: It is the tendency of gasoline to pass from the liquid into the vapour state at any give temperature.
2. **Anti knock quality**: The pressure increases evenly inside the engine cylinder during the normal combustion of air fuel mixture. But under some condition, the last part of compressed air fuel mixture explodes which suddenly increases the pressure. This causes knocking noise that sounds like hammer blow on the piston heat. Certain chemicals are mixed with gasolines to decrease the knocking quality of gasoline.
3. **Sulphur content** : The crude oil consist of sulphur while refining the crude oil, part of sulphur is carried to the gasoline. Too much sulphur is likely to corrode cylinder bores, bearing surfaces and exhaust systems. Hence the sulphur contents are to be removed.

4. **Gum Content** : A good fuel should have a minimum amount of gum. When gasoline is exposed to air, some of the hydro carbons are oxidized into sticky gum which causes sticking of values, clogged carburetor etc. The gumming tendencies of the gasoline can be controlled by proper chemical treatment by adding suitable gum inhibitor or anti oxidant.

5. **Purity** : The gasoline used as motor fuel must be free from dirt, grease and traces of chemicals and water. These should be removed properly in a refinery.

6. **Calorific Value** : The engine fuels must have calorific values upto 24000 CHU/kg.

7. **Operating Economy** : The nature of the fuel is one of the most important factors which determines the kilometers per litre of the fuel. It also depends on conditions of the engine, roads on which vehicle travels etc.

**Octane Number**

The anti knock value of fuel is measured in octane number rating (ONR). The fuel is iso-octane resistant to knock. It is given an octane rating of 100.

Iso octane and heptane are the reference fuels to test the ONR of the unknown fuels. These fuels are mixed in certain proportion to the given fuel to determine octane rating. There are two basic methods.

1. Laboratory method
2. Road test method.

**Diesel Engine Fuel**

Diesel is light, with low viscosity and high cetane number rating. Diesel must have the following requirements to operate satisfactorily.

1. It must ignite readily and burn evenly.
2. It must have certain lubricating qualities as the diesel is being operated in pumps and nozzles etc.
3. It must have low viscosity so that it can readily be atomized.
4. It should not have large foreign matter deposits which may damage the engine parts.

**Properties of Diesel**

The following are the desirable properties for diesel.

i) Grade  
ii) Gravity  
iii) Pour point  
iv) Volatility  
v) Flash point  
vi) Cetane rating  
vii) Distillation recovery  
viii) Viscosity  
ix) Water and sediment  
x) Reduction of ash  
xi) Less corrosion

**Cetane Rating**

The number is an indication of ignition quality and the rapidity with which the fuel in burned after injection takes place. Usually 45 to 60 cetane is the range of cetane. Between 50 to 55 is the normal cetane rating.

**Alternate Fuels:**

Alternate fuels are known as Non-conventional or advanced fuels. These are the materials which can be used as fuels other than conventional fuels include petroleum fuels, coal, propane, natural gas etc.

Some well known alternative fuels include Biodiesel, Bioalcohol (methanol, ethanol, Intanol), chemically stored electricity (batteries, fuel cells), hydrogen, non-fossil methane non-fossil natural gas, vegetable oils and other biomass sources.

**Biomass**

Biomass in the energy production industry is living and recently dead biological material which can be used as fuel or for industrial production.
Biodiesel

Biodiesel are made from animal fats or vegetable oils, renewable resources that come from plants such as soya bean, sunflower, corn, olive, peanut, palm, coconut, cotton seed etc. Biodiesel is prepared from the chemical reaction while mixing of these fats after filtering their hydro carbons and then combined with alcohol like methanol. These biodiesel produce small quantity of pollutants.

Alcohol Fuels

Butanol fuels, ethanol fuel and methanol fuel are known as Alcohol Fuels. Methanol and ethanol fuel are primary sources of energy. These can be used directly in internal combustion engines as alternative fuels.

Ammonia

Ammonia can be used as fuel. A small machine can be setup to create the fuel and it is used where it is made.

Hydrogen Fuel: Hydrogen is emissionless fuel. The by-product of hydrogen burning is water.

HCNG

HCNG (OR H₂CNG) is a mixture of compressed natural gas and 4 – 9% of hydrogen by energy.

Compressed Air:

Some of the engines are using compressed air as fuels.

Alternative Fossil Fuels:

Compressed natural gas (CNG) is a cleaner burning alternative to conventional petroleum automobile fuels. It’s energy efficiency is generally equal to that of gasoline engines, but lower compared with modern diesel engines.

Natural gas like hydrogen, is another fuel that burns cleanly. Also none of the smog-forming contaminates are emitted.

Requirements of Good Fuel

A good fuel should have a low ignition point
It should have high calorific value
It should freely burn with high efficiency, once it is ignited
It should not produce harmful gases
It should produce least quality of smoke and gases.

It should be economical, easy to store and convenient to transport.

**Summary**

1. Fuel is a substance mostly contains carbon and hydrogen which on burning with oxygen in the atmospheric air, produces a large amount of heat.

2. The amount of heat generated is known as calorific value.

3. Types of fuels (i) Solid fuels (ii) Liquid Fuels (iii) Gaseous fuels.

   Again these are sub divided as (a) Natural fuels (b) Prepared fuels


5. Liquid Fuels: Petrol, Kerosene, Diesel, Heavy fuel oil

6. Gaseous Fuels: Natural gas, coal gas, producer gas, water gas, coke oven gas etc.

7. Calorific value of fuel: It may be defined as the amount of heat given out by the complete combustion of ‘1 kg’ of fuel. It is expressed in terms of K.cal/kg of fuel.

   These are two types

   (a) Gross or higher calorific value (b) Net or Lower calorific value

**Short Answer Type Questions**

1. Define fuel.

2. Mention types of solid fuels

3. Mention types of liquid fuels.

4. Mention types of gaseous fuels

5. Define calorific value.

**Long Answer Type Questions**

1. Explain the types of solid fuels

2. Explain the types of liquid fuels

3. Explain the merits and demerits of Liquid fuels over solid fuels.


Learning Objectives
After studying this unit, the student will be able to

- Understand Thermodynamic cycle like Otto Cycle, Diesel Cycle, and their applications in engines etc.
- Understand the application of Thermodynamic cycle etc.
- Understand about process of heat energy being utilized as mechanical energy in different engines by applying these cycles

6.0 Introduction
Thermodynamics cycle consists of a series of thermodynamics processes, which takes place in a certain order and the initial conditions are restored at the end of processes.

Assumption in Thermodynamics Cycles
The analysis of all thermodynamics cycles is based on the following assumptions:
1. The gas in the engine cylinder is a perfect gas i.e. it obeys the gas laws and constant specific heats.

2. The physical constants of the gas in the engine cylinder are same as those of air at moderate temperature.

3. All the compression and expansion processes are adiabatic and they take place without any internal friction.

4. Heat is supplied by bringing a hot body in contact with the cylinder at appropriate points during the process. Similarly, heat is rejected by bringing a cold body in contact with the cylinder at these points.

5. It is a closed cycle and the same air is being used again and again and no chemical reaction takes place.

### 6.1 Classification of Thermodynamics Cycles

The thermodynamics cycles may be classified mainly as:

1. Reversible cycle
2. Irreversible cycle

**1. Reversible Cycle:** A process, in which some change in the reverse direction, reverses the process completely, is known as reversible cycle.

   In a reversible process, there should not be any loss of heat due to friction, radiation or conduction etc. A cycle will be reversible if all the processes constituting the cycle are reversible. Thus in reversible cycle, the initial conditions are restored at the end of the cycle.

**2. Irreversible Cycle:** If in a thermodynamics cycle, the change does not reverse the process, it is called irreversible cycle. In an irreversible cycle, the initial conditions are not restored at the end of the cycle.

### Types of Thermodynamics Cycles

Some of the important thermodynamics cycles are

1. Carnot cycle
2. Stirling cycle
3. Ericsson cycle
4. Joule Cycle
5. Otto cycle
6. Diesel cycle
7. Dual combination cycle.

**Carnot Cycle:** This cycle was devised by Sir Nicholas Leonard Sadi Carnot, who was the first scientist to analyse the problem of the efficiency of a heat engine.

In a carnot cycle, the working substance is subjected to a cyclic operation consisting of two isothermal and two adiabatic operations.

The engine imagined by carnot has air which is supposed to behave like a perfect gas as its working substance enclosed in a cylinder, in which a frictionless piston ‘A’ moves. The walls of the cylinder and piston are perfect non-conductors of heat. But the bottom ‘B’ of the cylinder is a perfect conductor of heat. The engine is assumed to work between two sources of infinite capacity, one at higher temperature and the other at lower temperature.

Now, let us consider the four stages of the carnot cycle. Let the engine cylinder contain m kg of air at its original condition presented by point 1 on the p-v and T-S diagram.

At this stage, let $P_1$, $T_1$ and $V_1$ be the pressure, temperature and volume of the air respectively.

1. **First stage:** The source (hot body, (HB)) at a higher temperature is brought in contact with the bottom B of the cylinder. The air expands practically at constant temperature $T_1$, from $V_1$ to $V_2$. It means that the temperature $T_2$ (at point 2) is equal to the temperature $T_1$. The isothermal expansion is represented by curve 1-2 on p-v and T-S diagrams. The heat supplied by the hot body is fully absorbed by the air, and is utilized in doing external work.

   \[
   \text{Heat supplied} = \text{Work done isothermal expansion.}
   \]

   \[
   H_1 = P_1 V_1 \log_a \left( \frac{V_2}{V_1} \right) = mRT_1 \left( \frac{V_2}{V_1} \right) \quad (\text{since } P_1 V_1 = mRT_1)
   \]

   \[
   = 2.3 mRT_1 \log r.
   \]

1. **Second stage:** The hot body is removed from the bottom of the cylinder ‘B’ and the insulating cap I.C is brought in contact. The air is now allowed to expand adiabatically.

   Thus adiabatic expansion is represented by the curve 2-3 p-v and T-S diagram. The temperature of the air falls from $T_2$ to $T_3$.

   Since no heat is absorbed or rejected by the air, therefore decrease in internal energy.
= work done by the air.

\[ \frac{(P_2V_2 - P_3V_3)}{\gamma - 1} = \frac{(mRT_2 - mRT_3)}{\gamma - 1} \]

\[ \therefore pv = mRT \]

3. Third stage: Now remove the insulating cap I.C from the bottom of the cylinder and bring the cold body CB in its contact. The air is compressed practically at a constant temperature \( T_3 \) from \( V_3 \) to \( V_4 \). It means the temperature \( T_4 \) (at point 4) is equal to the temperature \( T_3 \). This isothermal compression is represented by the curve 3-4 on p-v and T-S diagram. During the process, the heat is rejected to the cold body and is equal to the work done on the air.

Therefore Heat rejected = work done on the air.

\[ H_2 = P_3V_3 \log_e \left( \frac{V_3}{V_4} \right) \]

\[ = MRT_3 \log_e \left( \frac{V_3}{V_4} \right) \]

\[ = 2.3 \text{Mrt}_3 \log r \text{ (since } r = V_3/V_4 = \text{compression ratio)}. \]

4. Fourth stage: The insulated cap I.C is again brought in contact with the bottom of the cylinder B and the air is allowed to be adiabatically. The adiabatic compression is represented by the curve 4-1 on p-v and T-S diagram. The temperature of the air increases from \( T_4 \) to \( T_1 \), since no heat is absorbed or rejected by the air, therefore

Increase in Internal energy

\[ = \text{work done on the air} \]

\[ = (P_1V_1 - P_4V_4)/\gamma - 1 \]

\[ = (mRT_1 - mRT_4)/\gamma - 1 \text{ (since } pv = mRT) \]

\[ = (mR(T_1 - T_4))/\gamma - 1 \text{ (since } T_3 = T_4) \]

The decrease in internal energy during adiabatic expansion 2-3 is equal to the increase in internal energy during adiabatic compression 4 – 1.

Heat supplied during Isothermal expansion 1 – 2

\[ = H_1 = T_1(S_2 - S_1) \]
and heat during isothermal compression 4 – 1

\[ H_1 = T_4 (S_2 - S_1) = T_3 (S_2 - S_1) \]

Work done = heat supplied – heat rejected.

\[ = T_1 (S_2 - S_1) - T_3 (S_2 - S_1) \]

\[ = (T_1 - T_3) (S_2 - S_1) \]

Therefore efficiency \( n = \frac{\text{work done}}{\text{heat supplied}} \)

\[ = \frac{(T_1 - T_3) (S_2 - S_1)}{T_1 (S_2 - S_1)} \]

\[ = \frac{(T_1 - T_3)/T_1}{1 - T_3/T_1} \]

(p-v and T-S diagram).

### 6.2 Otto Cycle

This cycle was originally devised by a Frenchman Bean-do-Rochas in 1862. The first successful engine working on this cycle was built by a German Engineer, Nicholas A. OTTO in 1876. It is also known as ‘constant volume cycle engine’ as the heat is received and rejected in a constant volume.

An ideal otto cycle consists of two constant volume and two adiabatic processes as shown in the p-v and T-S diagram.

1. **First stage:** The air is expanded adiabatically from initial temperature \( T_1 \) to a temperature \( T_2 \) as per the graph 1.2. In this process, no heat is absorbed or rejected by the air.

2. **Second stage:** The air is cooled at constant volume from temperature \( T_2 \) to temperature \( T_3 \) as per the graph 2 -3. We know that heat rejected by the air during the process,

\[ H_2 = mC_v (T_2 - T_3) \] ............... (i)

3. **Third stage:** The air is compressed adiabatically from \( T_3 \) to temperature \( T_4 \) as per the graph 3 -4. In this process no heat is absorbed or rejected by the air.

4. **Fourth stage:** The air is now heated at constant volume from temperature \( T_4 \) to temperature \( T_1 \) as per the graph 4 – 1. We know that heat absorbed during the process

\[ H_2 = mC_v (T_1 - T_4) \] ............... (ii)
We can see that air has been brought back to its original conditions of pressure, volume and temperature, thus completing the cycle.

\[
\text{Work done} = \text{heat absorbed} - \text{heat rejected} = mC_v(T_1 - T_4) - mC_v(T_2 - T_3)
\]

Therefore efficiency or air standard efficiency,

\[
\eta = \frac{\text{work done}}{\text{heat absorbed}} = \frac{(mC_v(T_1 - T_4) - mC_v(T_2 - T_3))}{mC_v(T_1 - T_4)}
\]

\[
= 1 - \frac{T_2 - T_3}{T_1 - T_4} = 1 - \frac{T_3}{T_4} \left( \frac{T_2}{T_3} - 1 \right) \quad \ldots \ldots \ldots (iii)
\]

We know that from adiabatic expansion process (1-2),

\[
\frac{T_2}{T_1} = \left( \frac{V_1}{V_2} \right)^{\gamma-1} = \left( \frac{1}{r} \right)^{\gamma-1}
\]

Similarly from adiabatic compression process (3-4)

\[
\frac{T_3}{T_4} = \left( \frac{V_4}{V_3} \right)^{\gamma-1} = \left( \frac{1}{r} \right)^{\gamma-1}
\]

From the above two equations, we find that

\[
\frac{T_3}{T_4} = \frac{T_2}{T_1} = \left( \frac{1}{r} \right)^{\gamma-1} = \frac{1}{(r)^{\gamma-1}}
\]

### 6.3 Diesel Cycle

This cycle was devised by Dr. Rudolph Diesel in 1893. This is an important cycle on which all the diesel engines work. It is also known as constant pressure cycle engine a heat is received at constant pressure.

The engine imagined by Diesel has air enclosed in the cylinder, whose walls are perfectly non-conductor of heat, but bottom is a perfect conductor of heat. Again there is a hot body and cold body and an insulating cap, which are alternatively brought in contact with the cylinder.
The ideal diesel cycle consists of two adiabatic, a constant pressure and a constant volume processes.

Let the engine cylinder contain m kg of air at point ‘t’. At this point, let \( P_1, T_1 \) and \( V_1 \) be the pressure, temperature and volume of the air.

1. **First stage:** The air heated at constant pressure from initial temperature \( T_1 \) to a temperature \( T_2 \) as per the graph 1.2.

Therefore Heat supplied to the air = \( mC_p(T_2 - T_1) \) .................. (i)

2. **Second stage:** The air is expanded adiabatically from temperature \( T_2 \) to temperature \( T_3 \) as per the graph 2-3. In this process, no heat is absorbed or rejected by the air.

3. **Third stage:** The air is now cooled at constant volume from temperature \( T_3 \) to temperature \( T_4 \) as per the graph 3-4.

Therefore Heat rejected by the air = \( mC_v(T_3 - T_4) \) .................. (ii)

4. **Fourth stage:** The air is compressed adiabatically from a temperature \( T_4 \) to temperature \( T_1 \) as per the graph 4-1. In this process no heat is absorbed or rejected by the air.

We see that air has been brought back to its original conditions of pressure, volume and temperature.

\[
\text{Work done} = \text{heat absorbed} - \text{heat rejected} = mC_p(T_2 - T_1) - mC_v(T_3 - T_4)
\]

Therefore standard efficiency \( \eta = \) work done / heat absorbed

\[
\eta = \frac{\text{Heat absorbed} - \text{heat rejected}}{\text{Heat Absorbed}} = \frac{mC_p(T_2 - T_1) - mC_v(T_3 - T_4)}{mC_p(T_2 - T_1)}
\]

\[
= 1 - \frac{C_v}{C_p} \left( \frac{T_3 - T_4}{T_2 - T_1} \right) = 1 - \frac{1}{\gamma} \left( \frac{T_3 - T_4}{T_2 - T_1} \right) \text{ .................. (iii)}
\]

Now let compress ratio

\[
r = \frac{V_4}{V_1}
\]
Cut off ratio  \( p = \frac{V_2}{V_1} \)

Expansion ratio, \( r_1 = \frac{V_3}{V_2} = \frac{V_4}{V_2} \) (Since \( V_3 = V_4 \))

\[ = \frac{V_4}{V_1} \times \frac{V_1}{V_2} = r \times \frac{1}{p} = \frac{r}{p} \]

For Constant pressure heating process (1-2)

\( \frac{V_1}{T_1} = \frac{V_2}{T_2} = \frac{V_3}{T_3} \) (Charle’s Law)

Therefore \( T_2 = T_1 \times \frac{V_2}{V_1} = T_1 \times p \) ................. (iv)

Similarly

In adiabatic compression process (2-3)

\[ \frac{T_3}{T_2} = \left( \frac{\frac{V_2}{V_3}}{\gamma} \right)^{\gamma-1} = \left( \frac{\frac{1}{r_1}}{\gamma} \right)^{\gamma-1} = \left( \frac{\frac{p}{r}}{\gamma} \right)^{\gamma-1} \]

Therefore \( T_2 = T_2 \left( \frac{p}{r} \right)^{\gamma-1} = T_1 \times p \left( \frac{p}{r} \right)^{\gamma-1} \)

And in an adiabatic compression process (4-1)

\[ \frac{T_1}{T_4} = \left( \frac{V_4}{V_1} \right)^{\gamma-1} = (r) \] ................. (vi)

Substituting the value of \( T_1 \) in equations (iv) and (iv)

\( T_2 = T_4 \left( \frac{p}{r} \right)^{\gamma} \) .................(vii)

and \( T_3 = T_4 \left( \frac{p}{r} \right)^{\gamma-1} \times p \left( \frac{p}{r} \right)^{\gamma-1} = T_4 \left( \frac{p}{r} \right)^{\gamma} \) ....... (viii)

Now substituting the values of \( T_1, T_2 \) and \( T_3 \) in equation (iii)

\[ n = 1 - \frac{1}{\gamma} \left[ \frac{\left( \frac{p}{r} \right)^{\gamma} - T_4}{\left( \frac{p}{r} \right)^{\gamma-1} - \frac{T_4}{\gamma} \left( \frac{p}{r} \right)^{\gamma-1} - 1} \right] \]

\[ = 1 - \frac{1}{\gamma} \left[ \frac{\left( \frac{p}{r} \right)^{\gamma} - 1}{\gamma (p - 1)} \right] \]
Short Answer Type Questions

1. Define Otto Cycle and draw its P-V diagram
2. Define Diesel cycle and draw its P-V diagram
3. Define Carnot Cycle and draw its PV Diagram

Long Answer Type Questions

1. Explain Otto cycle with P-V diagram
2. Explain Diesel Cycle with P-V diagram
Learning Objectives
After studying this unit, the student will be able to

- Understand how the mechanical power is being transmitted,
- Different methods of transmitting power, chain drive, belt drive, rope drive, their application, how to use them.
- Compound gear drive, and also the uses of Jackey pulley.

7.0 Introduction to Transmission of Power

Power transmission is the movement of energy from its place of generation to a location where it is applied to perform useful work.

Power is defined as units of energy per unit time.

In SI units

Watt = joule / second = Newton x meter / second.

Mechanical power transmission is used for short distances. Mechanical power may be transmitted directly using solid structures such as drive shaft, transmission gears etc. The transmission gears can adjust the amount of torque or force v/s speed.
A shaft is a rotating machine member usually having a circular cross section much smaller in diameter than its length. Power transmitting elements namely, pulleys, belts, ropes, chains, gears etc. are mounted on the shafts.

### 7.1 Types of Power Transmitting drives

1. Belt drive
2. Rope drive
3. Chain drive
4. Gear drive

#### 7.1.1 Belt Drive

Belts are used to transmit power between two parallel shafts. A belt drive consists of two pulleys on which belt is passed. One of the pulleys called the ‘driver’ is mounted on the driving shaft, while the other, which is mounted on the shaft to which power is transmitted is called the ‘driven’.

The diameters of the driving and driven pulleys on the ‘speed ratio’ of the drive. The power is transmitted from the driver pulley to the driven pulley by the frictional grip between the belt and the surfaces of the pulleys.

**Types of Belts**

Based on the cross section of the belts, the belt drives are divided as follows:

- **Flat belt**: It is used in factories, workshops and flour mills for transmitting a moderate amount of power.

- **V-belt**: It is used for transmitting a moderate amount of power, when the centre distance between the driver and driven is very less.

**Types of Belt drive**

**a. Open Belt Drive**: The open belt drive is used when two parallel shafts of the driver and driven rotate at the same direction.

The power transmitting capacity of belt drive depends on the tensions in the tight and slack sides, angle of contact of the smaller pulley (α) and the coefficient of friction (µ) between the belt and the pulley materials.

**Velocity Ratio**: The velocity ratio (i) is defined as the ratio of the speed of the driving pulley (N₁ in rpm) to the speed of the driven pulley (N₂ in rpm). Assuming no slip between the belt and the pulleys, the speed at every point in
the belt is same. Therefore the linear speed of the belt and the circumferential
speeds of the driving and driven pulleys are equal.

\[ \pi \, d_1 \, N_1 = \pi \, d_2 \, N_2 \]

\[ i = N_1 / N_2 = d_1 / d_2 \]

where \( d_1 \) = diameter of driver pulley

\( d_2 \) = diameter of driven pulley.

**Tight side**

Assume clockwise rotation of the driver pulley. The driver pulley pulls the
belt from the lower side and delivers to the upper side. Thus the tension in the
lower side belt will be more than that of the upper side belt. Because of the
higher tension, the lower side belt is known as tight side.

\[ T_1 = \text{Tension in the tight side} \]

**Slack Side**

Because of less tension, the upper side is known as ‘Slack side’.

\[ T_2 = \text{Tension of the slack side.} \]

**b. Crossed Belt Drive**

It is used when two parallel shafts of the driver and the driven rotate in the
opposite directions. At the point when the belt crosses, it runs against itself
causing excessive wear. To avoid this, the shafts should be placed at maximum
distance ‘20w’.

Where \( w \) is the width of the belt and operated at velocities less than 15m/
sec.

**Belt Slip**

In flat belt drive, the difference between tensions in tight and slack sides of
the belt is equal to force of friction between belt and pulley. When the frictional
grip becomes insufficient, the belt begins to slide over the surface of the pulley.
This sliding of the belt which causes relative motion between pulley and belt is
called ‘slip’ of the belt.

**V-Belt drive:** When a belt is trapezoidal in section, designed to run in a
‘V-shaped groove’, it is known as V-belt. The V-belt runs is 30° to 40° vee
grooves in the pulleys. The effect of the groove is to increase the frictional grip
of the V-belt on the pulley and thus reduce the tendency of slipping.
7.1.2 Rope Drive

Rope drive are widely used where the power to be transmitted is more than 150 KW and centre distance is more than 10m. In spinning mills, where number of driving pulleys are more, these drives are used. Steel wired ropes are used in hoisting equipment, craves, elevators, conveyors and other material handling equipment.

7.1.3 Chain Drive

Chains are made up of rigid links hinged together. Chain drives are positive drives with no slipping. Hence velocity ratio remains constant. Power transmitted is as high as 100 KW. Wheels having teeth especially designed for chain are known as ‘Chain Sprockets’. Chain drive is used when the centre distance is less as in bicycles, motor cycles, road rollers, agricultural machinery etc.

Gear Drive

Gears are defined as toothed wheels which transmit power from one shaft to another by means by successive engagement of teeth.

Gear drives are used to transmit moderate or large amount of power positively over a short distance with a ‘constant velocity ratio’.

Gear Trains

Any combination of gear wheels by means of which power is transmitted from one shaft to another shaft is called ‘Gear Train’. Usually the ‘train’ is applied only to combinations, in which there are more than one pair.

Types of gear drive

1. Simple gear drive
2. Compound gear drive
3. Reverted gear drive
4. Epicyclic gear drive

Simple gear drive

A simple gear drive train is one which each shaft carries one gear only. These are employed where a small velocity ratio is required. When distance between two shafts is small, gears 1 and 2 are in mesh with each other to transmit motion from one shaft to the other.

\[ \text{Velocity Ratio} = \frac{N_1}{N_2} = \frac{T_2}{T_1} \]
Where \( N_1 \) and \( N_2 \) are speeds of drive and driven gears in r/min

\( T_1 \) and \( T_2 \) are number of driving and driven gears.

**Compound Gear Drive**

In a gear train, when the intermediate shaft carries two gears, it is known as compound gear drive. The compound gear drive is used when the velocity ratio is so high that one of the gears in the simple gear drive is very small.

**Belt Fastener**

There are different types of belt fasteners. Some of them are:

a. **Plate grip fasteners**: These can be used on belts of any width and varying thickness.

b. **Riv-Nail fasteners**: These can be used as synthetic high strength belt fabrics.

c. **Staple grip fasteners**: These fasteners are very strong. It’s hinged plates are held in compression with ‘high tensile stainless steel staples’.

d. **Steel grip fasteners**: These are having combined toughness and with ease of installation.

e. **Flex grip round belt couplings**: These are smooth in operation with tough grip in multidirectional turns.

**7.2 Jackey Pulley**

Jackey Pulley is used to maintain tension in a chain or belt by using jackey wheel. These wheels are used in causes and other pulley equipments.

**Summary**

**Types of Transmission devices**

(a) Belt drive

(b) Rope drive

(c) Chain drive

(d) Gear drive

**Type of Belt drive**

(a) Flat belt drive

(b) V- belt drive
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Short Answer Type Questions

1. Mention the types of power transmitting drives.
2. Mention the types of belt drives
3. Mention the types of Gear drives

Long Answer Type Questions

1. Explain different types of power transmitting drives.
**Learning Objectives**

After studying this unit, the student will be able to

- Understand Fasteners and different types of fasteners
- Understand about Nuts, Bolts, Rivets, Welding application in engineering usage.

**8.0 Introduction**

Fastener is a hardware device that mechanically joins or affixes two or more objects together. Screws, nuts and bolts, rivets, clamps etc are different types of Fasteners used in mechanical engineering application.

**Screws**

A screw is a type of fastener characterized by a helical ridge, known as an external thread often in the form of a nut or an object that has the internal thread formed into it.

**Nut & Bolt**

A nut is a type of hardware fastener with a threaded hole. Nuts are almost always used opposite a mating bolt to faster stack of parts together. Nuts are graded with strength ratings compatible with their respective tools.
Bolt is a type of joint which is the common element in construction and machine design. They consist of fasteners that capture and join other parts and are secured with mating of screw threads.

**Rivet**

Rivet is a permanent mechanical fastener. A rivet consists of a smooth cylindrical shaft with a head on one end. The end opposite to head is called the buck-tail. On installation, the rivet is placed on a pre-drilled hole, and the tail is upset or bucked so that it expands to about 1.5 times the original shaft diameter. It can support tension loads.

**Clamps**

Clamps are fastening devices to hold or secure objects tightly together to prevent movement or separation through the application of inward pressure.

Some clamps are temporary and they are used to position components temporarily for various tasks.

Some changes are permanent like Hose clamps, Marman clamps, Wire rope clamps etc.

---

**Short Answer Type Questions**

1. Define Fastener
2. Define Screws
3. What is the usage of Nut and Bolt
4. What is the purpose of Rivet.
5. Why clamps are used.

---

**Long Answer Type Questions**

1. Explain different fasteners and their usage.
Learning Objectives

After studying this unit, the student will be able to

- Understand Work, Power, Energy and their units
- Types of Energy and their application in engineering usage.

9.1 Introduction

The mechanical terms of work, power and energy are related to the work done by the force and the energy is this related process are the important terms relating to a similar work.

Work

It is a scalar quantity and is the product of force of magnitude \( F \) acts on a point that move \( d \) distance in the direction of force, then the work \( w \) done by this force is calculated as \( w = Fxd \).

The rate of work done by a force measured in Joules/second or watts. It is a scalar product. The work done by a force of one Newton acting over a distance of ‘1 metre’.

Power

Power is the rate at which the energy is transferred.
Energy transfer can be used to do work, so power is also the rate at which the work is performed.

The S.I Unit of power is ‘Watt’.

1 Watt=1 Joule/second

The mechanical power is combination of force and movement.

It is the product of a force on an object and the velocity of the object or the product of a torque on a shaft and the angular velocity of a shaft.

**Energy**

It is the ability of a physical system which is to do work on other physical systems.

The total energy contained in an object is identified with its mass.

The energy cannot be created or destroyed.

It may be stored in system without being present in the matter.

It is the sum of energy of potential and kinetic energies.

The potential energy is the energy of the position and the kinetic energy is the energy developed by the motion or movement of the object.

\[ K.E = \frac{1}{2} mv^2 \]

---

**Short Answer Type Questions**

1. Define work and mention its units.
2. Define Power and mention its units
3. Define Energy and mention its units.
4. Mention the types of energy

**Long Answer Type Questions**

1. Mention and explain the work, power, energy with their units.
Learning Objectives

After studying this unit, the student will be able to

- Know about the safety precautions while doing different works in electrical field.
- Causes of electrical shocks and their treatment
- Prevention of electrical Shocks

10.1 Introduction

Safety plays an important role in doing electrical jobs where extreme care has to be taken in performing certain works on live wires of electricity. A little carelessness causes electric shock which may cause an injury or death as the severity of electric shock increases. Due to these reasons, utmost care has to be taken while doing electric workers. Even though, after taking some precautions, a little carelessness causes electric shock.

Then certain first aid measures are to be taken.

10.1 Precautions in Handling Tools

The most commonly used tools by an electrician are

i). Screw driver
ii). Pliers

iii). Bradawl

iv). Gimlet

v). Chisels

vi). Saws

vii). Hammers

viii). Electric Knife

ix). Hand drilling machine

x). Files

xi). Vices

xii). Soldering Iron etc

While working with the above tools in an electrical work, the following precautions to be taken.

1. Use proper tools for each job.

2. Don’t use hammer on the head of the screw driver.

3. While removing Nuts and Bolts, only spanners are to be used but not pliers.

4. Protect the tools against must.

5. A tool with properly fixed handle is to be used.

6. Pointed tips and insulated handles should not be damaged.

7. The tools should not be placed in a haphazard way.

8. Proper precautionary instructions should be placed on the job while working on it.

9. Drilling tools should be driven straight.

10. Thoroughly clean the tools before using, so that oil or grease should not be present on them.

11. Don’t cut the wires with plier. Only cutter is to be used for it.

12. Before doing any job on live wire, the tools should be properly insulated.
13. The handles of chisels, hammers, saws etc. are properly fixed.

14. The wire gage and wire handles are to be fully clean while working on them.

15. Always be sure of proper safety while working.

10.2 Causes of Electric Shock

The electric shock may be caused due to the following reasons.

1. The electric wires through which the current passes are not properly insulated.

2. There may be loose contact between any two wires.

3. There may be water or moisture surrounding the live wires.

4. The person who is working with wires is not properly insulated for his safety.

5. The earthy, positive and negative wires are not properly connected accordingly.

6. The connection from transformer to main connection are not in proper manner.

7. If the careless are not according to the recommendaion of the load, they may melt and it causes shock.

8. Always use recommended gaused wires.

10.3.1 Cure of Electric Shock

If a person gets electric shock or gets contact with live wire, first switch off the main switch where the current passes to him. It is not in easily approach to you, then

1. Pull the victimwhile keeping yourself insulated by wrapping a dry and thick paper or cloth on your hands.

2. If the victim’s clothes are dry then you may remove him from electric contact by pulling the edges of his clothes.

3. A dry wooden stick or a light wooden place may be used to remove him from the electric contact.

Always remember that while removing the victim from the electric contact otherwise you may also get an electric shock.
10.3.2 First Aid to Victim of Electric Shock

(i) If the victim of electric shock is senseless, then lay him down immediately on a dry wooden place or on a dry led so that the electricity stored in his body may finish.

(ii) Never lay him down on the ground because it may be possible that he may not regain sense.

(iii) Extinguish any fire or flame that may be present in his clothes.

(iv) Apply coconut oil the burnt parts.

(v) Do not give any food to the victim without the consultation of doctor.

If necessary, fresh water may be given if the patient is conscious.

(vi) Keep the victim covered with blanket, so that he may not catch cold.

(vii) Watch that he is breathing properly or not. If he is not breathing properly, artificial respiration may be given to him as first aid.

10.3.3 Methods of Artificial Respiration

There are two main methods of artificial respiration.

(i) Sylvester’s method

(ii) Schaffer’s method

10.3.3.1 Sylvester’s Method

If there are burns on the chest of victim, then lay down him on his back. Looser the clothes and put a pillow beneath his shoulders, so that his chest may raise upwards. Open the victim’s to allow the fresh air to get into his lungs.

First Position

Sit on your knees near the victim’s head, hold his both hands and spread them wide.

Second Position

Apply some preassure on his hands in the first position. So that the lungs can discharge their inside air release the after 2-3 seconds and bring the victim’ m hands in the previous position. Now fresh air into the lungs of the patient.

By repeating above actions, the victim starts breathing. While the artificial respiration procedures are in continuaion, keep the victim’s mouth also open, so
that the air passage remains clear. The whole position should not be repeated 10-12 times per minutes.

For complete relief, the artificial respirations should be continued for 1-3 hours.

10.3.3.2 Schaffer’s Method

If the burns on the back of victim, them lay him down with his chest downwards. Loose or remove his clothes, rest his face on to one side, spread his pillow beneath his chest so that his back rises upwards slightly.

First Position

Kneel over the patient’s back and place your both hands on his back near the lowest rib is such a way that the fingers are spread outwards while the two thumbs almost touch each other and remain parallel to the spire.

Second Position

Apply some pressure at the victim’s back while keeping your hands straight. Rock yourself forward gently. After 2-3 seconds, release the pressure slowly and return to the first position by sliding your palms sideways. Repeat the process for about 12-15 times a minute. It will expand and contract the lungs of the victim and thus will help the victim in breathing. A victim may require 1-3 hours for reestablishing his nature breathing.

10.4 New Methods of Artificial Respiration

The new methods of artificial respiration are comparatively easier and help the victim to get normal breathing rapidly.

These are as under

(i) Mouth to Mouth Method

In this method, the air is filled into the victim’s mouth by blowing with your own mouth.

Lay down the victim on his back. Loose his clothes. Put a pillow beneath his neck so that his head is tilted backwards. Open the victim’s mouth and clean it with your finger.

Now put your one hand under the victim’s neck and second hand on his mouth such a way that his mouth remains open. Now take a deep breath, keep your lips on the victim’s lips and blow the air with a force into the mouth while keeping his nose shut. The air is filled into his lungs by this procedure. Now
remove your mouth so that the lungs can discharge the inside air. Repeat the above action 10-12 times a minute.

As a precaution, you may be use a clean and fine cloth piece between the two mouths while blowing the air into the mouth.

(ii) Mouth to Nose Method

If it becomes different to given the victim’s mouth then apply mouth to nose method.

Lay down the victim on his back. Loose his shirt put a pillow beneath his neck so that his head his is tilted backwards. Now blow the air into his nose while keeping his mouth closed. Remove your mouth from his nose so that the lungs can discharge the inside air. If the blown in air does not enter the lungs, then shake his shoulders. The whole action is repeated 10-12 times a minute. A piece of time and clean cloth may be used between his nose and your mouth.

Summary

1. Always use properly insulated and greaded wires and cables according to the requirements of connections.
2. Never use loose connections between any two live wires.
3. Use proper insulated tools while working an electric live wires.
4. Always the cautions in connecting wires.
5. Proper safety measures to the followed while connecting terminals.
6. First aid measures are to be followed if any person gets electric shock.

Short Answer Type Questions

1. What are the commonly used tools of an electrician?
2. What will you do, if any person is shocked by electric current?
3. Write briefly about Electric shock?
4. What is artificial respiration?

Long Answer Type Questions

1. What are the safety precaution while working on an electric job?
2. What are the causes of electric shock?
3. Mentain the artificial respiration methods and explain any one method?
Learning Objectives

After studying this unit, the student will be able to

• Understand electric laws like Ohms law, Kirchoff’s law
• Definitions like conductors, semi conductors, insulators, voltage, resistance etc.
• Know about specific resistance and its units.

Introduction

The fact that amber, when rubbed, was capable of attracting light objects was known to the Greeks 2500 years ago. Thales of Miletus become aware of this peculiar property in 600 B.C.

William Gilbert (1544-1603), who was the physician of Queen Elizabeth, made further investigations and learned that many substances besides amber attracted other objects when activated by friction. He called such attraction ‘electric’ after the Greek word ‘electric’ meaning amber.

In 1729 Stephen Gray found that when substance has been electrified by friction and then was allowed to touch another substance the power of attraction was passed to the second substance seven years later, desauliers, pointed out that same substances possessed the ability to transmit the attractive from one
point to another. He called such substances conductors. The other substances which are not having such properly are called insulators.

11.1 Electric Current

The rate at which the electrons move or flow along the wire gives the strength of the current. Current is represented by the letter symbol “I” ans is measured in amperes (A).

Voltage

The force that tends to cause the free electrons to move from the negative to the positive end of the wire is called 'electron moving force' or 'electro motive force'. It is denoted by EMF or ‘Voltage’ or ‘potential Difference’.

11.2 Conductors, Semi Conductors, Insulators

The continuous flow of electrons constitutes an electric current. It is found that those substances whose atoms have their outer most orbits incomplete act as good conductors of electricity. i.e. they permit an easy detachment of their outermost electrons and offer very little hinderance. Such substances are known as good conductors.

But substances whose electrons are rigidly held to their atoms are called ‘Bad conductors’ materials like germanium, silicon, silicon carbide etc. Whose resistances at ordinary temperature lie in between those of typical metals and typical insulators are called semi - conductors.

11.3 Conventional Electric Current Flow

In a simple voltaic cell, there is a copper plate (known as anode) and a zinc rod (i.e cathode) immersed in dilute sulphuric acid (H\textsubscript{2}SO\textsubscript{4})
contained is suitable vessel. The chemical action taking place within the
cell causes the electrons to be removed from Cu plate and is to deposited on
Zinc rod at the same time. This transfer of electrons is accomplished through
the agency of the diluted H₂SO₄.

Which is known as electrolyte. The Zinc rod becomes negatigative due to
the deposition of electrons an it and the Cu plate becomes positive due to the
removal of electons from it. Then the electrons move from -Ve terminal to +Ve
terminal is called conventional electric current.

The rate at which the electrons flow or move along the wire gives the current
strength or simply ‘current’ and is represented by the letter ‘I’ and is measured in
ampered (A).

11.4 Idea of Electric Potential

The force that tends to cause the force electrons to move from the negative
to the positive end of the wire is called electron moving force or potential
difference. It is known as voltage and measured in volts (V).

11.5 Definition of Electrical Resistance Unit

The properly of a substance / material due to which it opposes the flow of
electrons (current) through it is called resistance. The resistance is represented
by the latter ‘R’ and is measured in Ohm.

11.6 Calculation of Resistance of a Conductor

The resistance a material depends upon the following factors.

i). The resistance of a conductor is directly proportional to its length -‘l’.
   i.e. R α l

ii). The resistance of a conductor is inversely proportional to its cross
   sectional area- ‘a’.
   i.e. R α 1/a

iii). The resistance of a conductor depends upon the material with which it
   is made. Various substances havedifferent atomic structure and therefore they
   offer different resistance for the same length and area of cross section.

iv). The resistance of a conductor depends upon the working temperature
   .
   i.e. R α l/a
or \[ R = \rho \frac{l}{a} \]

When \( \rho \) (Greek letter ‘Rho’) is proportionality constant and is called resistivity or specific resistance.

### 11.7 Definition of Specific Resistance - Unit

The specific resistance may be defined as the resistance of a material of unit length and of unit cross sectional area. i.e. the resistance between the opposite faces of a unit cube is

\[ R = \rho \frac{l}{a} \]

\[ \rho = \frac{R a}{l} = \text{dim} \times \text{m}^2/\text{m} = \text{dim} - \text{m}. \]

Hence the specific resistance is measured in \( \text{dim} - \text{material/Ohm-cms/micro Ohm-m} \) etc.

### 11.8 Simple Problems

**Example 1**

Determine the resistance of a 564 m length of aluminium conductor whose regular cross section is 4 cm by 2 cm.

Take \( \rho = 2.826 \times 10^{-8} \Omega \cdot \text{m} \)

Solution:

Given data

\( l = 564 \text{ m} \)

\( b = 2 \text{ cm} = 0.02 \text{ m} \)

\( t = 4 \text{ cm} = 0.04 \text{ m} \)

\( \rho = 2.826 \times 10^{-8} \Omega \cdot \text{m} \)

Cross sectional area, \( a = b \times t \)

\[ = 0.02 \times 0.04 \]

\[ = 0.0008 \text{ m}^2 \]

\[ = 8 \times 10^{-4} \text{ m}^2 \]

\[ R = \rho \frac{l}{a} = 2.828 \times 10^{-8} \times 564/8 \times 10^{-4} \]

\[ = 0.02 \ \Omega \]
Example 2

Calculate the length of copper wire, 1.5 mm in diameter to have a resistance of 0.3 ohm given the resistivity of copper is 0.017 micro-ohm-metre

Solution:

Given data

d = 1.5 x 10^{-3}
R = 0.3 \Omega
\rho = 0.017 \times 10^{-6}
l = ?

Cross sectional area of wire

A = \pi/4 \times d^2
   = \pi/4 \times (1.5 \times 10^{-3})^2
   = 1.767 \times 10^{-6} \text{m}^2

R = \rho l/a

l = 0.3 \times 1.767 \times 10^{-6}/0.017 \times 10^{-6}
l = 31.185 \text{m}

11.9 Effect of Temperature on Resistance

Connect a tungsten filament lamp across a battery. The voltmeter across the lamp given the potential across it. By varying the number of cells in the circuit, the current taken by the lamp.

It can be proved that the resistance of most of the metals increase with temperature.

When a potential is applied to the ends of a conductor, the current flows. The movement of electrons is opposed by ions of the materials. At lower temperature these ions are assumed to be stationary. But as the temperature of the material increases, these ions gain energy and oscillate about their mean position. The amplitude of these oscillation is dependent upon the temperature of the material. Higher the temperature the greater is the amplitude of oscillation. The random movement of ions opposes the electron movement and increases the chances of collision.
Hence due to increase of this opposition to the movement of the electrons, the resistance of the conductor increases.

If the temperature of the conductor decreases, the amplitude of the conductor and the chance of collision of electrons decreases and hence the resistance of the conductor decreases the resistance in temperature.

11.10 Temperature Co-efficient of Resistance

The temperature co-efficient of resistance is not constant at all temperatures. For determining the resistance at initial temperature the temperature co-efficient at initial temperature should be used. In order to develop a relation between temperature co-efficient at different temperature.

Let us consider a conductor having

\[ R_0 = \text{Resistance at } 0^\circ \text{C} \]
\[ R_1 = \text{Resistance at } t_1 ^\circ \text{C} \]
\[ R_2 = \text{Resistance at } t_2 ^\circ \text{C} \]
\[ \alpha_0 = \text{Temperature co-efficient at } 0^\circ \text{C} \]
\[ \alpha_1 = \text{Temperature co-efficient at } t_1 ^\circ \text{C} \]

then \[ R_1 = R_0 (1+\alpha_0 t_1) \] and \[ R_2 = R_0 (1+\alpha_1 t_2) \]

\[ \frac{R_2}{R_1} = 1+\alpha_0 (t_2-t_1) \] (IV)

(Since initial temperature is \(0^\circ \text{C} , \alpha_0 \) is to be taken)

Divide the Equation II with Eq I.

\[ \frac{R_2}{R_1} = 1+\alpha_0 \frac{t_2}{t_1} / 1+\alpha_0 t_1 \] (III)

Using Binomial theorem for expansion and neglecting higher power of \((\alpha_0 t_1)\)

we can write

\[ = 1+\alpha_0(t_2-t_1) \]
\[ R_2 = R_0 \left(1+ \alpha_0 (t_2-t_1) \right) \] (IV)

Now to find the \( R_2 \) at \( t_2^\circ \text{C} \) from the initial temperature \( t_1^\circ \text{C} \), temperature coefficient used must be at \( t_1^\circ \text{C} \).

\[ R_2 = R_1 \left(1+ \alpha_1 (t_2-t_1) \right) \] (V)
or

\[ \frac{R_2}{R_1} = \left(1 + \alpha_1(t_2-t_1) \right) \]  

(VI)

Equating equation III and VI

\[ 1 + \alpha_0 \frac{t_2}{t_1} + \alpha_0 t_1 = 1 + \alpha_1(t_2-t_1) \]

\[ \alpha_1(t_2-t_1) = 1 + \alpha_0 \frac{t_2}{t_1} + \alpha_0 t_1 - 1 = 1 + \alpha_0 \frac{t_2}{t_1} - \alpha_0 t_1 / (1 + \alpha_0 t_1) \]

\[ \alpha_1(t_2-t_1) = \alpha_0 (t_2-t_1) / (1 + \alpha_0 t_1) \]

\[ \alpha_1 = \frac{\alpha_0}{1 + \alpha_0 t_1} \]

It is the relation between temperature coefficient at \(0^0 C\) and \(t_1^0 C\)

\[ \alpha_1 = \frac{\alpha_0}{1 + \alpha_0 t_1} \]

### 11.11 Ohm’s Law

This law applies to electric conduction through good conductors.

It can be stated as

“The ratio of potential difference (V) between any two points on a conductor to the current (I) flowing between them, is constant, provided the temperature of the conductor does not change”.

In other words

“The current flowing in a current is directly proportional to the potential difference, provided the temperature is constant”.

i.e. \( V/I = \text{Constant} \)

or

\( V/I = R \)

Where R is the resistance of the conductor between the two points.

### 11.12 Resistances in series

When some conductors having resistances \(R_1, R_2,\) and \(R_3\) etc are joined end to end, they are said to be connected in series. It can be proved that the equivalent resistance between the points A and D is equal to the sum of the three individual resistances.
Figure

Being a series circuit
i). Current is the same through all the three conductors.

ii). But voltage drop across each is different due to its different resistance and is given by ohm’s law.

iii). Sum of three voltage drops is equal to the voltage applied across the conductors.

\[ V = V_1 + V_2 + V_3 = IR_1 + IR_2 + IR_3 \]

(According to the ohm’s law)

Where R is the equivalent resistance of the series combinations

\[ IR = IR_1 + IR_2 + IR_3 \]

Resistances in Parallel

Three resistances are connected in parallel.

In this case

i). Potential difference across all resistances is the same.

ii). Current in each resistor is different and given by ohm’s law.

iii). Total current is the sum of the three currents.

\[ I = I_1 + I_2 + I_3 \]

\[ I = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3} \]

Now \( I = \frac{V}{R} \) where V is applied voltage.
R = Equivalent resistance of parallel combination.

Therefore \( V/R = V/R_1 + V/R_2 + V/R_3 \)

or

\( 1/R = 1/R_1 + 1/R_2 + 1/R_3 \)

**Resistance in Series and Parallel Combination**

Sometimes the circuits may be neither pure series nor pure parallel, not a combination of series and parallel may come across. For such circuits, first parallel combination of resistance \( R_1 \) and \( R_2 \) should be solved for finding its equivalent resistance \( R_e \).

\[
\frac{1}{R_e} = \frac{1}{R_1} + \frac{1}{R_2}
\]

or

\[
R_e = \frac{R_1 R_2}{R_1 + R_2}
\]

Then the equivalent resistance \( R_e \) and \( R_1 \) from a series circuit.

Thus the result that resistance is the total of resistance of \( R_e \) and \( R_3 \).

**Solved Problems**

1. Calculate the effective resistance of the following combination of the resistance and the voltage drop across each resistance when 60 V is applied.

**Figure**

**Solution**

**Given data**

\( R_1 = 3 \ \Omega \)

\( R_2 = 6 \ \Omega \)
\[ R_3 = 18 \Omega \]
\[ R_4 = 5 \Omega \]
\[ V = 60 \text{ V} \]
\[ R = ? \]
\[ V_1, V_2, V_3 = ? \]

Resistance between the points A and B is
\[ R_{AB} = \frac{R_1 \times R_2}{R_1 + R_2} \]
\[ = \frac{3 \times 6}{3 + 6} \]
\[ = \frac{18}{9} \]
\[ R_{AB} = 2 \Omega \]
\[ R_{AC} = R_{AB} + R_3 \]
\[ = 2 + 18 \]
\[ R_{AC} = 20 \Omega \]

Effective resistance of the combination is
\[ R = R_{PQ} \]
\[ = \frac{20 \times 5}{20 + 5} \]
\[ = \frac{100}{25} \]
\[ R = 4 \Omega \]

Total Current
\[ I = \frac{V}{R} \]
\[ = \frac{60}{4} \]
\[ I = 15 \text{ Amps} \]

Current in 5 \( \Omega \) resistor \( = \frac{V}{R_4} = \frac{60}{5} = 12 \) Amperes

Current through AC (i.e. \( R_{AB} \) and \( R_3 \)) is 15-12 = 3 Amperes.

Therefore drop across \( R_1 \) and \( R_2 \) combination = 3 \times 2 = 6 volts

Voltage drop across \( R_3 = 3 \times 18 = 54 \) Volts.

Voltage drop across \( R_4 = 12 \times 5 = 60 \) volts.
2. In the circuit given below calculate the voltage across 10 Ω resistance.

![Circuit Diagram]

**Solution**

14 Ω and 6 Ω resistors are in parallel.
Their equivalent = $14 \times 6 / (14 + 6)$
= $84 / 20$
= 4.2 Ω

Similarly 2 Ω and 8 Ω are in parallel
Their equivalent = $2 \times 8 / (2 + 8)$
= $16 / 10$
= 1.6 Ω

(4.2+1.6) Ω and 4.2 Ω are in parallel.
= $(4.2+1.6) \times 4.2 / ((4.2+1.6)+4.2)$
= 2.436

Total resistance of the circuit $R_T = 2.436 + 10$
= 12.436 Ω

Total amount $I = V / R$
= $25 / 12.436$
= 2.0103 A

Voltage across 10 Ω resistor

= I x10

= 2.0103 x10

Voltage across 10 Ω resistor = 20.103 volts

Kirchoff’s Laws

These laws are used for solving electrical networks. These laws are particularly useful in determining the equivalent resistance of a complicated network of conductors and for calculating the current flowing in the various conductors.

i) Point Law or Current Law

(Kirchoff’s First Law)

It states as follows

“In any electrical network, the algebraic sum of the current meeting at a point or junction is zero.

In case of a few conductors meeting at a point A. Some conductors have currents leading to point A whereas some current leading away from point A.

Assuming the incoming currents to be positive and the outgoing currents negative.

I₁ + (-I₂) + (-I₃) + I₄ + (-I₅) = 0

I₁ - I₂ - I₃ + I₄ - I₅ = 0

i.e. ε I = 0 at a junction
ii) Mesh Law or Voltage Law

(Kirchoff’s Voltage Law)

It states as follows

“The algebraic sum of the products of currents and resistances in each of the conductors in any closed path (or mesh) in a network plus the algebraic sum of the e.m.f’s is that path is zero”.

\[ \sum \varepsilon \ I R \ + \ \varepsilon \ e.m.f \ = 0 \quad \text{round a mesh} \]

**Energy**

The total amount of work done in an electric circuit is called electrical energy.

i.e. Electrical energy = Total work done in electric circuit.

It is measured by the product of power and time.

Electric energy = Power x time

= VI x t

= VI t watt-second (Since p=VI)

= IR \ t \ watt-second

---

**Key Concepts**

**Electric Current**

The rate at which the electrons flow or move along the wire gives the current.

**Voltage**

The force that tends to cause the free electrons to move the negative to positive end of the wire is called electron moving force or voltage or potential difference.

**Resistance**

The property or a substance / material due to which it opposes the flow of electrons (current) through it is called resistance. It is represented by the letter ‘R’ and measured in Ohm(\(\Omega\)).

**Specific Resistance**

It is the resistance of a material of unit length and unit cross-sectional area
Ohm’s Law

The current flowing in a circuit is directly proportional to the potential difference, provided the temperature is constant.

\[ I \propto V \]

or

\[ I = \frac{V}{R} \]

Kirchoff’s Point Law (or) Current Law

In any electrical network, the algebraic sum of the currents meeting at a point or junction is zero.

Kirchoff’s Mesh Law or Voltage Law

The algebraic sum of products of currents and resistances in each of the conductors in any closed mesh in a network plus the algebraic sum of the e.m.f’s in that path is zero.

Work

Work is said to be done in an electric circuit when, Q ampere second of electricity pass through a circuit against a potential difference of V volt.

Power

Electrical power is the rate at which work is done in an electric circuit.

Energy

The total amount of work done in electric circuit is called electrical energy.

Short Answer Type Questions

1. Define Electric Current?
2. Define Voltage?
3. State Ohm’s Law?
4. Mention Kirchoff’s Point Law?
5. Mention Kirchoff’s Voltage Law?

Long Answer Type Questions

1. Explain Electrical Work, Power, Energy with their units?
2. Explain Kirchoff’s Laws?
Learning Objectives

After studying this unit, the student will be able

- Understand different measuring instruments used in electricity
- Understand the working of volt meter, Ammeter, watt meter, energy meter, megger, continuity tester etc.
- Able to know about their usage and their maintenance

12.0 Introduction

The various electrical measuring instruments are being used in the field of electricity which are to know about the levels of voltage, resistance, capacity of battery, multimeter testing, energy levels of battery, AC containments testing etc. While working an electricity, one should know the actual position of electricity. How it is being passed etc. For this purpose the different meaning instruments are used.

12.1 Classification of Electrical Measuring Instruments

The principle of working of all electrical measuring instruments depends upon various effects of electric current or voltage.
There are two basic types of these instruments i.e. attraction type. The operation of attraction type depends on the attraction of a single piece of soft iron into a magnetic field and that of repulsion type depends on the repulsion if two adjustment pieces of iron magnetized by same magnetic field. For both types of these instruments the necessary magnetic field is produced by the ampere turns of current carrying coil.

In case the instrument is to be used as an ammeter, the coil has comparatively few turns of thick wire so that the ammeter has low resistance because it is connected in series with the circuit.

In case it is used as a voltmeter, the coil has high impedance so as to draw as small a current as passive since it is connected in parallel with the circuit.

The ammeter shows the capacity of battery in ampere’s and voltmeter shows the voltage or potential difference capacity of the battery.

A voltmeter is an instrument used to measure voltage. When the connections are made, the voltmeter shows the voltage of the battery. These are designed as a special sort of ammeters which can calculate the voltage by assessing the electrical current and applying ohm’s law.
12.3 Moving- Coil Meters and Moving- Iron meters

Moving coil meters or instruments are used where high level of accuracy is needed due to sensitive and accuracy, the moving coil instruments are used.

i). In the measurement of direct current and voltages.

ii). In D.C galvanometers to detect small currents.

iii). In conjunction with rectifiers or thermo junction for A.C measurements over a wide range of frequencies.

iv). Due to self shielding magnets mechanism there are particularly used in aircraft and aerospace applications.

Moving Iron Instruments

Basically these instruments are of two types

a). Attraction type moving iron instruments

b). Repulsion type moving iron instruments

a) Attraction type moving iron instruments

It works on the principle of attraction of a single piece of soft iron into a magnetic field. It consists of a fixed coil or solenoid through which the current passes. An oval shaped soft iron is attached to the spindle in such a way that it can move in and out of the coil. A pointer is attached to the spindle. When the instrument is connected to the circuit to measure the current or voltage, the opening circuit flows through the coil. The coil behaves like a magnet when current passes through the coil. It attaches the soft iron piece towards it and provide deflecting torque \( T_d \).

b) Moving Iron Type (Repulsion Type)

It works on the principle of magnetic repulsion. When two adjustments iron pieces are magnetized by the same magnetic field, these will be magnetised with similar polarities and pole strength. Hence because of same polarity, these will experience a force of repulsion.

12.4 Method of Connecting Ammeters and voltmeters

The majority of Ammeters are either connected in series with the circuit carrying the current to be measured or have their shunt resistors connected similarly in series.

The current passes through the meter through its shunt. They must not be
connected to a source of volt. They are designes for minimal burden, which refers to the voltage drop across the Ammeter.

The Voltmeter can be connected with two wires to where the voltage is. One wire to positive one and the other the negative. With same voltmeters, one must make sure that the wires are connected right; the positive connection of voltmeter to the positive part of the voltmeter source; and the negative to is parallel to the electric circuit.

**12.5 Watt Meter**

It is an instrument to show the consumption of electric power or supply state of electrical energy in the circuit. This instrument is used while measuring electrical energy in Watt hours which accumulates or averages readings. It can display may parameters and can be used where a Watt Meter is needed - volts, current in amperes.

**12.6 Energy Meter**

It is an electrical measuring device which is used to record electrical energy consumed over as specified periods of time in terms of units.

**12.7 Power Factor Meter**

The power factor of an A.C electric power system is defined as the ration of real power flowing to the load to the apparent power in the circuit. Real power is the capacity of the circuit for performing work in a particular time. Apparent power is the product of the current and voltage of the circuit.

The power factor meter measures the power factor with the method of Wattmeter - Ammeter - Voltmeter method.

A direct reading power factor meter can be made with a moving coil meter of electrodynamic type, carrying two perpendicular coils on the moving part of the instrument.

**12.8 Megger**

It is a portable instrument used for testing the insulation resistance of a circuit and for measuring resistance of the order of megohms. Which are connected across the outside terminals.

**Working Principle**

In a cross coil type megger, two coils A and B are mounted rigidly at right angles to each other on a common axis and free to rotate in a magnetic field. When currents are passed through them, the two coils area acted upon torque
of coil A is proportional to \( I_1 \cos \theta \) and that of coil B is proportional to \( I_2 \cos(90-\theta) \) or \( I_2 \sin \theta \). The two coils come to a position are opposite of equilibrium where the two torques are opposite and equal.

\[
I_1 \cos \theta = I_2 \sin \theta
\]

or

\[
\tan \theta = \frac{I_1}{I_2}
\]

Whenever a current carrying conductor placed in a magnetic field, a torque is produced on the conductor which tends to rotate it.

\[12.9 \text{ Continuity Tester}\]

It is an item of electrical testing equipment which is used to determine if an electrical path can be established between two points is an electric circuit.

The circuit to be tested completely generalized prior to connecting. The apparatus. The tester consists of an indicator connected in series with the source of electric power.

\[12.10 \text{ Measurement of Insulation Resistance}\]

Insulation resistance test is required by the electrical safety standards. It consists of a gear in resistance of a device while phase and neutral are connected together. The measured resistance has to be higher than the indicated limit from the international standard. It is used to measure the Ohmic value of an insulator.
As per the effect of electricity the electrical measuring instruments are classified.


**Electro dynamic effect**  - Ammeters, Voltmeters, Wattmeters.

**Electro magnetic effect**  - Ammeters, Voltmeters, Wattmeters, Energy meters.

**Thermal effect**  - Ammeters, Voltmeters.

**Chemical effect**  - Ampere ohmmeter.

**Electrostatic effect**  - Voltmeters.

### Ammeter

An ammeter is a measuring instrument used to measure the electric current in a circuit. Electric currents are measured in amperes (A).

### Voltmeter

A voltmeter is an instrument used for measuring electrical potential difference between two points in and electric current.

### Wattmeter

It is an instrument to show the consumption of electric power and measure energy in watt ohms.

### Energy Meter

It is an electrical measuring device which is used to record electrical energy consumed over a specified period of time in terms of units.

### Power Factor Meter

It measures the proper factor with the method of wattmeter- ammeter-voltmeter.

### Megger

It is used for testing the insulation resistance of a circuit and for measuring resistances in mega ohms.
Short Answer Type Questions

1. What are the types of electric measuring instruments?
2. Define Ammeter?
3. Define Voltmeter?
4. Define Energymeter?
5. What is the purpose of megger?

Long Answer Type Questions

1. Briefly explain the connecting of Ammeters and Voltmeters?
2. Explain the Working Principle of Megger?
3. Differentiate moving coil moving Iron instruments?