

HEAT AND THERMODYNAMICS

LEARNING OBJECTIVES

At the end of this chapter the students will be able to:

State the basic postulates of kinetic theory of gases.

Derive gas laws on the basis of kinetic theory.

Describe that the internal energy of an ideal gas is due to kinetic energy of its molecules.

Understand and use the terms work and heat in thermodynamics.

Differentiate between isothermal and adiabatic processes.

Explain the molar specific heats of a gas.

Apply first law of thermodynamics to derive $C_p - C_v = R$.

Explain the second law of thermodynamics and its meaning in terms of entropy.

Understand the concept of reversible and irreversible processes.

Define the term heat engine.

Understand and describe Carnot theorem.

Describe the thermodynamic scale of temperature.

Explain the term entropy.

INTRODUCTION

Thermodynamics deals with various phenomena of energy and related properties of matter, especially the transformation of heat into other forms of energy. An example of such transformation is the process converting heat into mechanical work. Thermodynamics thus plays central role in

Q.1 Define thermodynamics.

Ans. **THERMODYNAMICS**

"Thermodynamics is the branch of physics, which deals with transformation of heat energy into mechanical energy (work)."

Q.2 What are the basic assumption of kinetic molecular theory of gases?

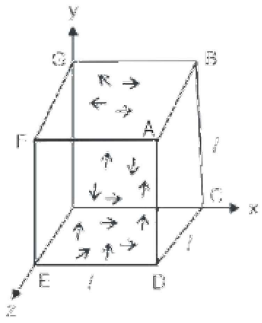
Ans. **KINETIC THEORY OF GASES**

Matter is composed of tiny molecules which are not in the state of rest. These molecules move in different direction and make collision with each other as well as with the walls of the container. The molecular kinetic theory of gases based on the following postulates.

1. A finite volume of gas consists of a very large number of molecules.
2. The size of the molecule is much smaller than the separation between molecules.
3. The gas molecules are in random motion and may change their direction of motion after every collision.
4. Collision between gas molecules themselves and with walls of container are assumed to be perfectly elastic.
5. Molecules do not exert force on each other except during a collision.

Q.3 Define pressure. Also derive the expression for the pressure of a gas.

Ans. **PRESSURE OF GAS**



According to kinetic theory of gas,

Molecules collide with the walls of container and exert pressure on the walls. An expression for this can be obtained as follow

Consider a cubical container of side of length 'l', which has 'N' number of molecules moving in random motion as shown in figure.

Area of each face = A = $l \times l = l^2$

Volume of container = V = A x l

= $l^2 \times l = l^3$

Consider a signal molecule of mass 'm' moving with velocity '$\vec{V}_1$', which has three components $\vec{V}_{1x}$, $\vec{V}_{1y}$, $\vec{V}_{1z}$ along x, y and z axes.

Momentum of molecule before striking the face

ABCDA = $P_i = m V_{1x}$

If collision is assumed to be perfectly elastic, the molecule will rebound from this face with same velocity

$$\Delta P = -m V_{1x} - m V_{1x}$$

$$\Delta P = -2m V_{1x} \quad \ldots\ldots\ldots (1)$$

After recoil the molecule travels to the opposite face EFGHE and collides with it, rebounds and travels back to the face 'ABCDA' after covering a distance $2l$. The time 'Δt', between two successive collision with face 'ABCDA' is

As, $S = V t$

$$2l = V_{1x} \Delta t$$

$$\Delta t = \frac{2l}{V_{1x}} \quad \ldots\ldots\ldots (2)$$

So, the number of collisions per–second that the molecule will make with this face is;

$$\Delta t = \frac{\Delta V_{1x}}{2l} \qquad \left(\because f = \frac{1}{\Delta t}\right)$$

$$\left(f = \frac{1}{\frac{2l}{V_{1x}}}\right)$$

$$\left(f = \frac{V_{1x}}{2l}\right)$$

Now according to Newton's 2nd law, in term of momentum, the force 'F_m' exerted on the molecule by the wall, is equal to rate of change of momentum i.e.,

$$F_m = \frac{\Delta P}{\Delta t}$$

Putting value of ΔP.

$$\therefore \quad F_m = -\frac{2m V_{1x}}{\Delta t} \quad \ldots\ldots\ldots (3)$$

According to Newton's 3rd law of motion force F_{1x} exerted by the molecule on the face ABCDA is equal but opposite so,

$$F_{1x} = -F_m$$

Putting value of F_m from equation (3)

$$\therefore \quad F_{1x} = -\left(\frac{-2m V_{1x}}{\Delta t}\right)$$

$$F_{1x} = \frac{2m V_{1x}}{\Delta t}$$

Putting value of Δt.

$$\therefore \quad F_{1x} = \frac{2m V_{1x}}{2l/V_{1x}}$$

$$= \frac{m}{2}$$

Similarly the forces due to all other molecule can be determined. Thus the total x–directed force F_x due to 'N' number of molecules moving with velocities $V_1, V_2, \ldots\ldots, V_N$ is

$$F_x = F_{1x} + F_{2x} + \ldots\ldots + F_{Nx}$$

$$\therefore \quad F_x = \frac{m}{l} V_{1x}^2 + \frac{m}{l} V_{2x}^2 + \ldots\ldots + \frac{m}{l} V_{Nx}^2$$

$$F_x = \frac{m}{l} \left(V_{1x}^2 + V_{2x}^2 + \ldots\ldots + V_{Nx}^2 \right)$$

As pressure is normal force per unit area, hence pressure P_x, on the face perpendicular to x-axis is

$$P_x = \frac{F_x}{A} = \frac{F_x}{l^2}$$

$$P_x = \frac{1}{l^2} \left(\frac{m\, V_{1x}^2}{l} + \frac{m\, V_{2x}^2}{l} + \frac{m\, V_{3x}^2}{l} + \ldots\ldots + \frac{m\, V_{Nx}^2}{l} \right)$$

$$P_x = \frac{m}{l^3} \left(V_{1x}^2 + V_{2x}^2 + V_{3x}^2 + \ldots\ldots + V_{Nx}^2 \right) \quad \ldots\ldots\ldots (4)$$

As the mass of single molecule is m, the mass of N molecule will be m N

Since density;

$$\rho = \frac{\text{Mass}}{\text{Volume}} = \frac{m\, N}{l^3}$$

Hence, $$\frac{m}{l^3} = \frac{\rho}{N}$$

Substituting the value of $\frac{m}{l^3}$ in equation (4).

$$\therefore \quad P_x = \frac{\rho}{N} \left(V_{1x}^2 + V_{2x}^2 + V_{3x}^2 + \ldots\ldots + V_{Nx}^2 \right)$$

or $$P_x = \rho \left(\frac{V_{1x}^2 + V_{2x}^2 + V_{3x}^2 + \ldots\ldots + V_{Nx}^2}{N} \right) \quad \ldots\ldots\ldots (5)$$

where $$= \left(\frac{V_{1x}^2 + V_{2x}^2 + V_{3x}^2 + \ldots\ldots + V_{Nx}^2}{N} \right)$$

is called the mean of squared velocities of the molecules moving along 'x' direction, known as mean square velocity, represented by $< V_x^2 >$.

$\therefore$ equation (5) becomes

$$P_x = \rho < V_x^2 > \quad \ldots\ldots\ldots (6)$$

Similarly pressure on the faces perpendicular to 'y' and 'z' axes will be

$$P_y = \rho < V_y^2 > \quad \text{and} \quad P_z = \rho < V_z^2 >$$

The mean square of all the component velocities will be equal. Hence,

$$< V_x^2 > = < V_y^2 > = < V_z^2 >$$

$$< V^2 > = < V_x^2 > + < V_x^2 > + < V_x^2 >$$

thus, $$< V^2 > = 3 < V_x^2 >$$

or $$< V_x^2 > = \frac{1}{3} < V^2 >$$

Putting this value of $< V_x^2 >$ in equation (6).

$$\therefore \quad P_x = \frac{\rho}{3} < V^2 >$$

By Pascal's law the pressure on the other sides and everywhere inside the vessel will be the same provided the gas is of uniform density. So,

$$P_x = P_y = P_z = \frac{\rho}{3} < V^2 >$$

Thus in general,

$$P = \frac{1}{3} \rho < V^2 >$$

Since Density $= \rho = \frac{m N}{V}$

Hence, $$P = \frac{m N}{V} < V^2 >$$

Multiply and divide by (2)

$$P = \frac{2}{3} \frac{N}{V} < \frac{1}{2} m V^2 >$$

$$P = \frac{2}{3} N_0 < \frac{1}{2} m V^2 >$$

Where 'N_0' is the number of molecules per unit volume.

Thus, $$P = \text{Constant} < \text{K.E.} >$$

$$\therefore \quad P \propto < \text{K.E.} >$$

Hence pressure exerted by the gas is directly proportional to the average translational K.E. of the gas molecules.

INTERPRETATION OF TEMPERATURE

Q.4 Show that absolute temperature is directly proportional to average translational K.E.

Ans. From ideal gas law;

$$PV = n RT \quad \ldots\ldots\ldots (1)$$

$$n = \frac{N}{N_A}$$

$\therefore$ equation (1) becomes

$$PV = \frac{N}{N_A} RT$$

$$PV = N \frac{R}{N_A} T$$

$$PV = N\,k\,T \qquad \ldots\ldots\ldots (2)$$

Where $k = \frac{R}{N_A}$ is the Boltzman constant and has the value $= 1.38 \times 10^{-23}\ J\ K^{-1}$

As, $$P = \frac{2}{3}\frac{N}{V} < \frac{1}{2} m\ V^2 >$$

$$PV = \frac{2}{3} N < \frac{1}{2} m\ V^2 > \qquad \ldots\ldots\ldots (3)$$

Comparing (2) and (3)

$$NkT = \frac{2}{3} N < \frac{1}{2} m\ V^2 >$$

$$kT = \frac{2}{3} < \frac{1}{2} m\ V^2 >$$

$$T = \frac{2}{3\,k} < \frac{1}{2} m\ V^2 >$$

$$T = \text{Constant } < \frac{1}{2} m\ V^2 >$$

or $$T \propto < \text{K.E.} >$$

DERIVATION OF GAS LAWS

Q.5 Derive Boyle's law from the kinetic molecules theory of gases.

Ans. **BOYLE'S LAW**

As, $$P = \frac{2}{3}\frac{N}{V} < \frac{1}{2} m\ V^2 >$$

$$PV = \frac{2}{3} N < \frac{1}{2} m\ V^2 >$$

If we keep the temperature constant.

$\therefore$ $< \frac{1}{2} m\ V^2 >$ is constant $(\because\ T \propto \text{K.E.})$

Thus pressure 'P' is inversely proportional to volume V at constant temperature of gas, which is Boyle's law.

Q.6 Derive Charles's from the kinetic molecular theory of gases.

Ans. **CHARLES'S LAW**

As, $$P = \frac{2}{3}\frac{N}{V}<\frac{1}{2}mV^2>$$

$$V = \frac{2}{3}\frac{N}{P}<\frac{1}{2}mV^2>$$

If pressure is kept constant.

$$\therefore \quad V = \text{Constant} <\frac{1}{2}mV^2>$$

$$\therefore \quad V \propto <\frac{1}{2}mV^2>$$

or $$V \propto T \quad \left(\because T \propto <\frac{1}{2}mV^2>\right)$$

Thus volume is directly proportional to absolute temperature of gas, provided pressure is kept constant.

Q.7 What is internal energy?

Ans. **INTERNAL ENERGY**

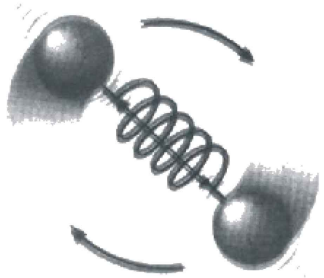
"The sum of all forms of molecular energies (K.E. and P.E.) of a substance is termed as its internal energy."

In the study of thermodynamics, usually ideal gas is considered as a working substances. The molecules of an ideal gas are mere mass points, which exert forces on one another. So the internal energy of an ideal gas system is generally the translational K.E. of its molecules. Since the temperature of a system is defined as the average K.E. of its molecules, thus for an ideal gas system, the internal energy is directly proportional to its temperature.

When we heat a substance, energy associated with its atoms or molecules is increased i.e., heat is converted to internal energy.

It is important to note that energy can be added to a system even though no heat transfer takes place. For example, when two objects are

Do You Know?



A diatomic gas molecule has both transnational and rotational energy. It also has vibrational energy associated with the spring like

increase in the internal energy. Similarly, when an object slides over any surface and comes to rest because of frictional forces, the mechanical work done on or by the system is partially converted into internal energy.

In thermodynamics, internal energy is a function of state. Consequently, it does not depend on path but depends on initial and final states of the system. consider a system, which undergoes a pressure and volume change from P_a and V_a to P_b and V_b respectively, regardless of the process by which

System

It is the collection of matter, which has distinct boundaries.

For example a gas enclosed in a cylinder.

Q.8 What is the relation between work and heat?

Ans. **WORK AND HEAT**

Heat is the form of energy, which can travel from one body to another.

Its unit is joule (J).

Consider the gas enclosed in a cylinder with a movable frictionless piston of cross-sectional area A. In equilibrium the system occupies volume 'V', and exerts a pressure 'P' on the walls of the cylinder and its piston. The force 'F' exerted by the gas on the piston is PA.

We assume that the gas expands through ΔV very slowly, so that it remains in equilibrium. As the piston moves up through a small distance ΔY, the work (W) done by the gas is;

$$W = F\,\Delta Y = PA\,\Delta Y$$

Since $A\,\Delta Y = \Delta V$ (Change in volume)

Hence $W = P\,\Delta V$

The work done can also be calculated by area of the curve under P – V graph, as shown in figure.

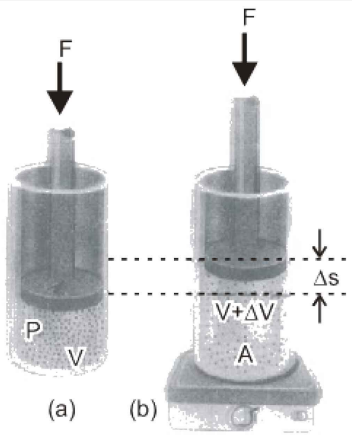
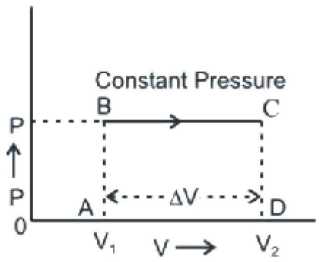


Fig. A gas sealed in a cylinder by a weightless, frictionaless piston. The constant downward applied force F equals PA, and when the poiston is displaced, downward work is done on the gas.



Q.9 State and explain first law of thermodynamics.

Ans. **FIRST LAW OF THERMODYNAMIC**

"In any thermodynamic process, when heat 'Q' is added to the system, this energy appears as an increase in the internal energy 'ΔU' stored in the system plus the work 'W' done by the system on its surroundings."

Let 'Q' be the heat supplied to the system, so that the change in internal energy is ΔU and total work done by the system is 'W', so

$$Q = \Delta U + W \quad \ldots\ldots\ldots (1)$$

$$(\Delta U = U_2 - U_1)$$

When heat supplied to the system then K.E. of molecules increases, so internal energy increase. Also molecules push the piston upward and work is done by the system.

From equation (1).

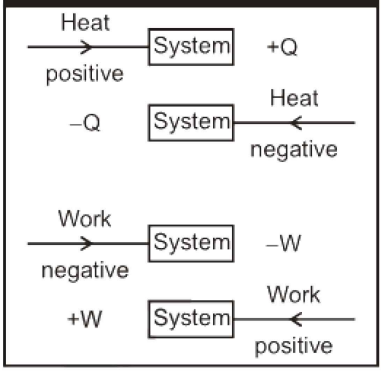
$$\Delta U = Q - W \quad \ldots\ldots\ldots (2)$$

So, change in internal energy is defined as;

"The heat supplied to the system–work done by the system."

This law is the extended form of the law of conservation of energy.

For Your Information





Examples

(1) Heat engine (2) A bicycle pump (3) Human metabolism

Q.10 Describe the isothermal process and also draw P-V diagram.

Ans. **ISOTHERMAL PROCESS**

"The process, in which temperature of the system remains constant is called an isothermal process."

Consider a system consisting of an ideal gas, in a cylinder having conducting base and non-conducting walls and piston. The piston is frictionless and moveable.

The cylinder is placed on heat reservoir. In order to keep the temperature of the gas constant, the expansion or compression must take place slowly because transfer of heat requires time. In case of an ideal gas potential energy associated with its molecules is zero. Hence the internal energy of an ideal gas depends only on its temperature, which is constant

$$\therefore \quad \Delta U = 0$$

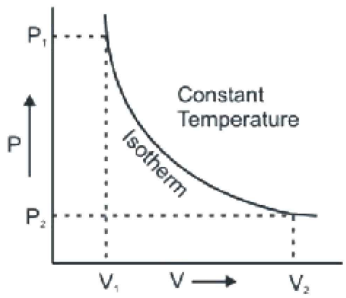
Hence 1st law of thermodynamics becomes;

$$Q = \Delta U + W$$

$$Q = 0 + W$$

$$Q = W$$

This shows that if the gas expands and does an external work 'W', then an amount of heat 'Q', has to be supplied to keep the temperature constant. Conversely, if the gas is compressed i.e., work is done on the system, then heat 'Q' should leave the system to keep the temperature constant.



"The curve representing an isothermal process is called an isotherm."

The relation for isothermal process is;

$$PV = \text{Constant}$$

Q.11 Describe adiabatic process and also draw P-V diagram.

Ans. **ADIABATIC PROCESS**

"An adiabatic process is the one, in which no heat enters or leaves, the system."

i.e., $Q = 0$

This prevention of heat may be achieved either by surrounding the system with a layer of insulting material or by performing expansion or compression process quickly, because heat flow require finite time and any process performed quickly is practically adiabatic.

e.g., 1. The rapid escape of air from a burst tyre.

2. The rapid expansion and compression of air through, which a sound wave is passing.

3. Cloud formation in the atmosphere.

Consider a system consisting of a gas enclosed in a heat insulator. For adiabatic process;

$$Q = 0$$

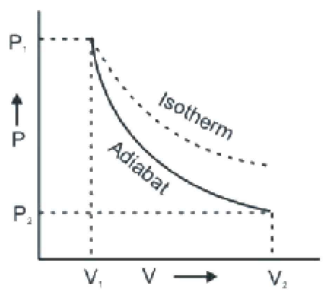
$\therefore$ 1st law of thermodynamics becomes;

$$Q = \Delta U + W$$

$$O = \Delta U + W$$

$$W = -\Delta U$$

In this case work is done by the system and is equal to decrease in internal energy i.e., work is done at the cost of internal energy.



or $\Delta U = -W$

In this case work is done on the system and is equal to increase in internal energy.

The curve is called adiabatic and is obtained by

$$PV^{\gamma} = \text{Constant}$$

Isochoric Process

Such a process in which volume is constant.

Isobaric Process

Such a process in which pressure is constant.

Q.12 Define molar specific heat of a gas.

Ans. **MOLAR SPECIFIC HEAT OF A GAS**

"The amount of heat required to raise the temperature of one mole of the substance through 1K, is called molar specific heat of a gas."

Consider 'n' number of moles of a substance. The amount of heat 'Q', absorbed by it depends on;

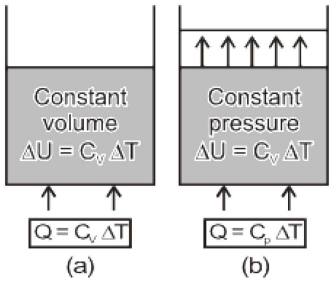
1. Number of moles i.e. $Q \propto n$ ..... (1)
2. Temperature difference i.e., $Q \propto \Delta T$ ..... (2)

Combining (1) and (2).

$$Q \propto n \Delta T$$

$$Q = C_m n \Delta T$$

$$\therefore \quad C_m = \frac{Q}{n \Delta T}$$



where C_m is the molar specific heat.

Unit

J/mole k or $J\ mole^{-1}\ k^{-1}$

Q.13 Define molar specific heat at constant volume.

Ans. **MOLAR SPECIFIC HEAT AT CONSTANT VOLUME**

"The amount of heat required to raise the temperature of one mole of the gas through 1K, at constant volume, is called molar specific heat at constant volume."

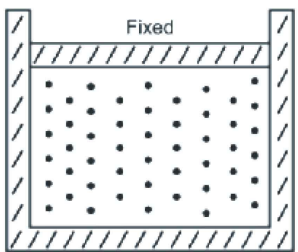
It is represented by C_V.

For 'n' moles

$$C_V = \frac{Q_V}{n \Delta T}$$

For 1 mole

$$C_V = \frac{Q_V}{\Delta T}$$



As, $W = P\,\Delta V$

Since piston is fixed

$\therefore \quad \Delta V = 0$

$\therefore \quad W = P\,(0)$

$W = 0$

Now applying 1st law of thermodynamics, at constant volume;

$\therefore \quad Q_V = \Delta U + W$

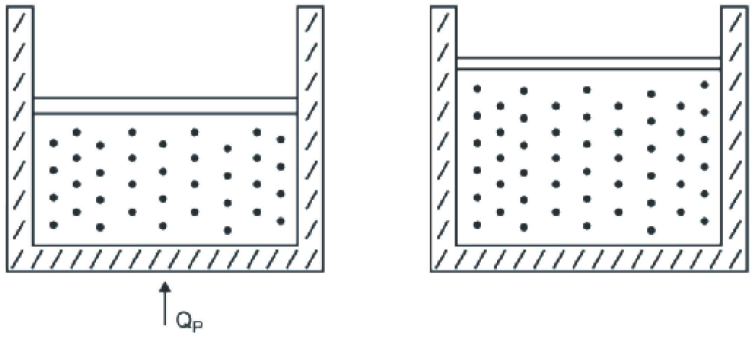
$C_V\,\Delta T = \Delta U + 0$

$\therefore \quad \Delta U = C_V\,\Delta T$

Q.14 Define molar specific heat at constant pressure.

Ans. **MOLAR SPECIFIC HEAT AT CONSTANT PRESSURE**

"The amount of heat required to raise the temperature of one mole of a gas, through 1K at constant pressure, is called molar specific heat at constant pressure."



For 'n' moles;

$$C_P = \frac{Q_P}{n\,\Delta T}$$

For 1 mole

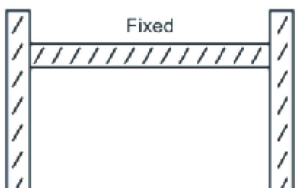
$$C_P = \frac{Q_P}{\Delta T}$$

$Q_P = C_P\,\Delta T$

Q.15 Prove that molar heat capacity at constant pressure is greater than molar heat capacity at constant volume. Show that $C_P - C_V = R$.

Ans. Consider one mole of an ideal gas, contained in a cylinder, fitted with a fixed piston. As the piston is fixed and the gas is heated, its volume remains constant and all heat supplied goes to increase K.E. of gas molecules due to which temperature of gas increase. If 'Q_V' is heat supplied and 'Δt' is rise in temperature, then by the definition of 'C_V' we have,

$Q_V = C_V\,\Delta T$ ..... (1)



As piston is fixed

$\therefore \quad \Delta V = 0$

Now applying 1st law of thermodynamics at constant volume;

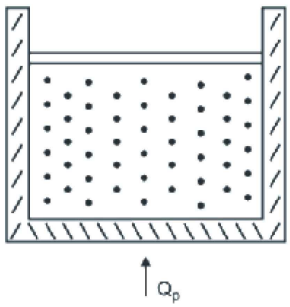
$$Q_V = \Delta U + W$$

$$C_V \Delta T = \Delta U + 0$$

$$\Delta U = C_V \Delta T \quad \ldots\ldots (2)$$

Now if the piston is free to move through small distance, when 'Q_P' is supplied, from definition of 'C_P'.

$$Q_P = C_P \Delta T \quad \ldots\ldots (3)$$



When gas is heated, its temperature rises and doing some work in pushing the piston upward at constant external pressure.

As $W = P \Delta V \quad \ldots\ldots (4)$

Using ideal gas equation for one mole.

$$\therefore \quad PV = RT \quad \begin{pmatrix} PV = n RT \\ n = 1 \end{pmatrix} \ldots\ldots (5)$$

At constant pressure 'P', amount of work done by one mole of a gas due to expansion 'ΔV' caused by the rise in temperature ΔT so equation (5) becomes.

$$P\Delta V = R \Delta T \quad \ldots\ldots\ldots (6)$$

Comparing (4) and (6).

$$W = R \Delta T \quad \ldots\ldots\ldots (7)$$

Now using 1st law of thermodynamics at constant pressure.

$$Q_P = \Delta U + W \quad \ldots\ldots\ldots (8)$$

When one mole of a gas is heated at constant pressure, the internal energy increases, by the same amount, as at constant volume for the same rise in temperature 'ΔT'.

i.e., $(\Delta U = \Delta U_P = \Delta U_V = C_V \Delta T)$

Putting values of Q, ΔU, W from equation (3), (2) and equation (7) in equation (8).

$$\therefore \quad C_P \Delta T = C_V \Delta T + R \Delta T$$

$$C_P \Delta T = \Delta T (C_V + R)$$

$$C_P = C_V + R$$

$$C_P - C_V = R$$

As R is positive

$$\therefore \quad C_P > C_V$$

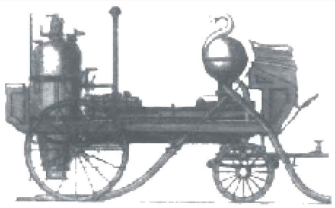
REVERSIBLE AND IRREVERSIBLE PROCESSES

heat is absorbed in the direct process, it will be given out in the reverse process and if work is done by the substance in the direct process, work will be done on the substance in the reverse process. Hence, the working substance is restored to its original conditions.

A succession of events which bring the system back to its initial condition is called a cycle. A reversible cycle is the one in which all the changes are reversible.

Although no actual change is completely reversible but the processes of liquefaction and evaporation of a substance, performed slowly, are practically reversible. Similarly the slow compression of a gas in a cylinder is reversible process as the compression can be changed to expansion by slowly decreasing the pressure on the piston to reverse the operation.

Do You Know?



The steam engine is a thermodynamics system.

If a process cannot be retraced in the backward direction by reversing the controlling factors, it is an irreversible process.

All changes which occur suddenly or which involve friction or dissipation of energy through condition, convection or radiation are irreversible. An example of highly irreversible process is an explosion.

Q.16 What is heat engine?

Ans. **HEAT ENGINE**

A heat engine converts some thermal energy to mechanical work. Usually the heat comes from the burning of a fuel. The earliest heat engine was the steam engine. It was developed on the fact that when water is boiled in a vessel covered with a lid, the steam inside tries to push the lid off showing the ability to do work. This observation helped to develop a steam engine.

Basically a heat engine (figure) consists of hot reservoir or source which can supply heat at high temperature and a cold reservoir or sink into which heat is rejected at a lower temperature. A working substance is needed which can absorb heat Q_1 from source, converts some of it into work W by its expansion and rejects the rest heat Q_2 to the cold reservoir or sink. A heat engine is made cyclic to provide a continuous supply of work.

Q.17 State second law of thermodynamics.

Ans. SECOND LAW OF THERMODYNAMICS

First law of thermodynamics tells us that heat energy can be converted into equivalent amount of work, but it is silent about the conditions under which this conversion takes place. The second law is concerned with the circumstances in which heat can be converted into work and direction of flow of heat.

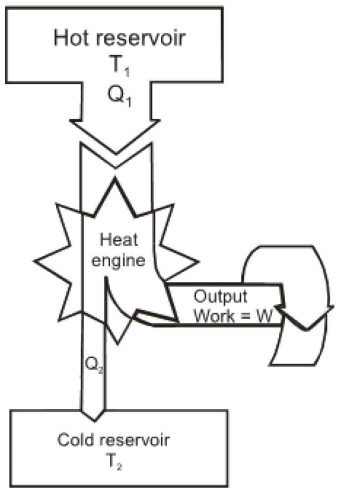


Fig. Schematic representation of a heat engine. The engine absorbs heat Q_1 from the hot reservoir, expels heat Q_2 to the cold reservoir and does work W.

Before initiating the discussion on formal statement of the second law of thermodynamics, let us analyze briefly the factual operation of an engine. The engine or the system represented by the block diagram absorbs a quantity of heat Q_1 from the heat source at temperature T_1. It does work W and expels heat Q_2 to low temperature reservoir at temperature T_2. As the working substance goes through a cyclic process, in which the substance eventually returns to its initial state, the change in internal energy is zero. Hence from the first law of thermodynamics, net work done should be equal to the net heat absorbed.

$$W = Q_1 - Q_2$$

In practice, the petrol engine of a motor car extracts heat from the burning fuel and converts a fraction of this energy to mechanical energy or work and expels the rest to atmosphere. It has been observed that petrol engines convert roughly 25% and diesel engines 35 to 40% available heat energy into work.

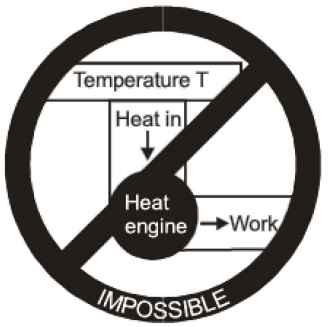
The second law of thermodynamics is a format statement based on these observations. It can be stated in a number of different ways.

According to Lord Kelvin's statement based on the work of a heat engine.

It is impossible to devise a process which may convert heat, extracted from a single reservoir, entirely into work without leaving any change in the working system.

This means that a single heat reservoir, no matter how much energy it contains, cannot be made to perform any work. This is true for oceans and our atmosphere which contain a large amount of heat energy but cannot be converted into useful mechanical work. As a consequence of second law of thermodynamics, two bodies at different temperatures are essential for the conversion of heat into work. Hence for the working of heat engine there must be a source of heat at a high temperature and a sink at low temperature to which heat may be expelled. The reason for our inability to utilize the heat contents of

Tidbits



According to the Kelvin statement of the second law of thermodynamics, the process pictured here is impossible. Heat from a source at a single temperature cannot be converted entirely into work.

Q.18 What is Carnot engine? Describe the four processes (steps) of the operating cycle of the Carnot engine.

Ans. **CARNOT ENGINE**

It is an ideal heat engine, whose efficiency is nearly 100%.

In 1840 CARNOT described an ideal engine using isothermal and adiabatic processes, he showed that a heat engine operating in an ideal reversible cycle, between to heat reservoirs, of different temperatures, would be the most efficiency engine.

Working Principle

It absorbs some heat from H.T.R., convert a part of it into work and reject the remaining part to L.T.R.

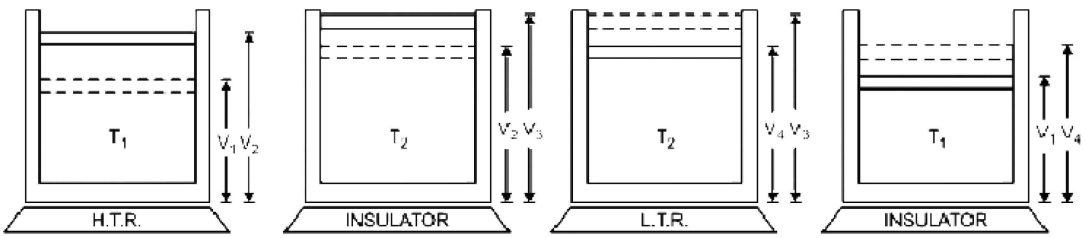
Construction

It consists of an ideal gas, enclosed in a cylinder, provided by a frictionless, movable and non-conducting piston. The walls of the cylinder are non-conducting, while the base is conducting to heat.

The operating cycle of CARNOT engine is called CARNOT cycle.

Carnot Cycle

It consist of 4 processes, which are shown on PV diagram, as shown in Fig.



Process 1

The cylinder is placed on H.T.R. and the gas is allowed to expand isothermally of temperature T_1.

Heat Q_1 flows into the cylinder due to conduction through base and the gas does some work on piston. The process is represented by curve AB.

Process 2

The cylinder is placed on an insulator and the gas is allowed to expand.

As no heat can enter or leave the system, the expansion is adiabatic and the temperature of gas fall from T_1 to T_2, the gas does work on the piston. The process is represented by curve BC.

Process 3

The cylinder is placed on a L.T.R. and the gas is compressed slowly.

During this compression temperature of gas rises, but heat Q_2 is rejected to L.T.R. making temperature constant, some work is done on the gas. The process is represented by curve CD.

Process 4

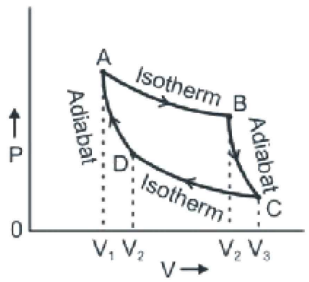
During this compression, temperature of the gas increases from T_2 to T_1. The process is represented by curve DA.

Q.19 What is Carnot's theorem? Also calculate the efficiency of such a engine in terms of temperature of source and sink.

Ans. **CARNOT'S THEOREM**

"No heat engine can be more efficient than a CARNOT engine operating between the same two temperature."

The Carnot's theorem can be extended to state that all Carnot's engines operating between the same two temperatures have the same efficiency, irrespective of the nature of working substance.



All real heat engines are less efficient than Carnot engine due to friction and other heat losses.

As the working substance returns to the initial state, there is no change in its internal energy i.e., $\Delta U = 0$.

The net work done during one cycle equals to the area enclosed by the path ABCDA of the PV diagram. It can also be estimated from net heat 'ΔQ', absorbed in one cycle.

$$\Delta Q = Q_1 - Q_2$$

From 1st law of thermodynamics;

$$Q = \Delta U + \Delta W$$

$$\Delta W = Q_1 - Q_2 \qquad (\because \Delta U = 0)$$

The efficiency η of the heat engine is defined as;

$$\eta = \frac{(\text{Output})}{(\text{Input})}$$

thus, $$\eta = \frac{Q_1 - Q_2}{Q_1}$$

or, $$\eta = 1 - \frac{Q_2}{Q_1}$$

The energy transfer in an isothermal expansion or compression turns out to be proportional to Kelvin temperature. So Q_1 and Q_2 are proportional to Kelvin temperature, T_1 and T_2 respectively and hence

$$\eta = 1 - \frac{T_2}{T_1}$$

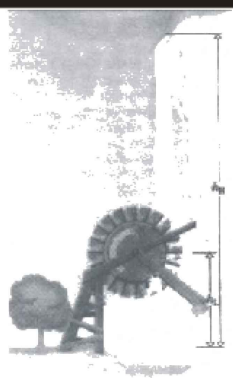
The efficiency in % age.

$$\%\text{ age efficiency} = \left(1 - \frac{T_2}{T_1}\right) 100\ \%$$

Thus the efficiency of CARNOT engine depends on the temperature of hot and cold reservoirs. It is independent of the nature of working substance. The larger the temperature difference of two reservoirs, the greater is the efficiency. But it can never be one or 100% unless cold reservoir is at absolute zero temperature.

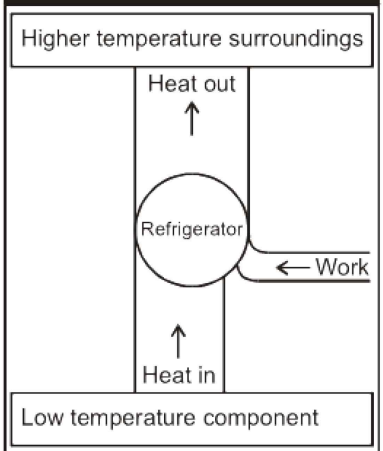
i.e., $T_2 = 0K$

Interesting Information



A waterfall analogy for the heat engine.

Do You Know?



A refrigerator transfers heat from a low-temperature compartment to higher-temperature surroundings with the help of external work. It is a heat engine operating in reverse order.

Q.20 What is thermodynamic scale of temperature?

Ans. **THERMODYNAMIC SCALE OF TEMPERATURE**

The CARNOT cycle provides us the basis to define a temperature scale which is independent of material properties of the working substance.

The thermodynamic scale of temperature is defined by choosing 273.16 K as absolute temperature of the triple point of water as one fixed point and absolute zero as the other.

Unit

The unit of thermodynamic scale is Kelvin.

Kelvin

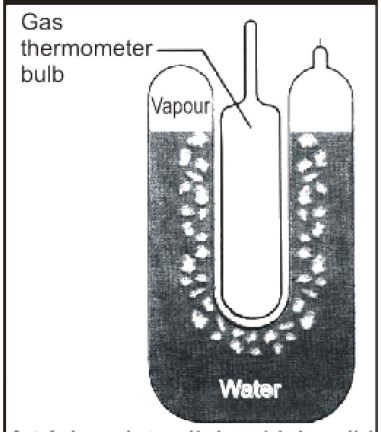
As, 273.16 K = Thermodynamic temperature of the triple point of water.

$\therefore \quad 1K = \frac{1}{273.16} \times$ Thermodynamic temperature of the triple point of water.

Triple Point of Water

"It is a state in which ice, water and vapour co–exists in equilibrium and it occurs uniquely, at one particular pressure (0.61 K pa) and temperature (273.16 K)."

For Your Information



A triple-point cell, in which solid ice, liquid water, and water vapour coexist in thermal equilibrium. By international agreement, the temperature of the mixture has been defined to be 273.16 K. The bulb of a constant-volume gas thermometer is shown inserted into the well of the cell.

If heat Q is absorbed or rejected by system at T and Q_s is heat absorbed or rejected by system when it is at temperature of triple point of water then unknown temperature T is given by

$$\frac{Q}{Q_3} = \frac{T}{273.16}$$

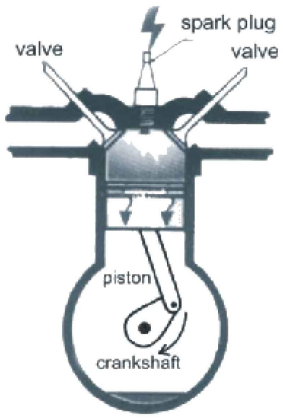
$$\therefore \quad T = \frac{Q}{Q_3}(273.16)$$

Since this scale is independent of working substance hence can be applied at very low temperature.

Q.21 What is the principle, construction and working of a petrol engine?

Ans. **PETROL ENGINE**

Although different engines may differ in their construction technology but they are based on principle of a Carnot cycle. A typical four stroke petrol engine also under goes four successive processes in each cycle.



Construction

It consists of pistons, crankshaft, sparking plug and valves, as shown in figure.

(1) Intake Stroke

The cycle starts on intake stroke in which piston moves outward and petrol air mixture is drawn through an inlet valve into the cylinder

On the compression stroke, the inlet valve is closed and the mixture is compressed adiabatically by inward movement of the piston.

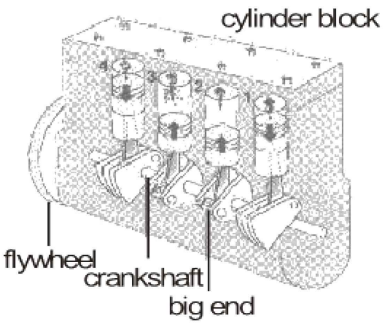
(3) Power Stroke

An electric spark is produced by the sparking plug. On the power stroke a spark fires the mixture causing a rapid increase in pressure and temperature. The burning mixture expands adiabatically and forces the piston to move outward. This is the only working stroke in the cycle which delivers power to crank shaft to derive the fly wheel.

(4) Exhaust Stroke

On the exhaust stroke, the outlet valve opens. The residual gases are expelled and piston moves inward.

The cycle then begins again. Most motor bikes have one cylinder engine but cars usually have four cylinders on the same crankshaft. The cylinders are timed to fire turn by turn in succession for smooth running of the car. The actual efficiency of properly tuned engine is not more than 25% to 30% due to friction and other heat losses.



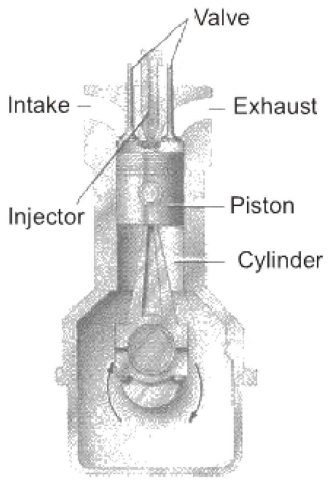
Q.22 What is diesel engine?

Ans. **DIESEL ENGINE**

No spark plug is needed in diesel engine. Diesel is sprayed into the cylinder but maximum compression by a strong compression pump.

Because air is at very high temperature immediately after compression, the fuel mixture ignites on contact with the air in the cylinder and pushed the piston upward.

The operation of diesel engine is very easy and its efficiency is greater than that of petrol engine which is about 35% to 40%.



Q.23 What is entropy? Explain it with examples.

Ans. **ENTROPY**

The concept of entropy was introduced into the study of thermodynamics by **Rudolph Clausius** in 1856 to give a quantitative basis for the second law. It provides another variable to describe the state of a system to go along with pressure, volume, temperature and internal energy. If a system undergoes a reversible process during which it absorbs a quantity of heat ΔQ at absolute temperature T, then the increase in the state variable called entropy ΔS of the system is given by

Like potential energy or internal energy, it is the change in entropy of the system which is important. Change in entropy is positive when heat is added and negative when heat is removed from the system. Suppose, an amount of heat Q flows from a reservoir at temperature T_1 through a conducting rod to a reservoir at temperature T_2 when $T_1 > T_2$. The change in entropy of the reservoir, at temperature T_1, which loses heat, decreases by Q/T_1 and of the reservoir at temperature T_2, which gains heat, increases by Q/T_2. As $T_1 > T_2$ so Q/T_2 will be greater than Q/T_1 i.e., $Q/T_2 > Q/T_1$.

Hence, net change in entropy $= \frac{Q}{T_2} - \frac{Q}{T_1}$ is positive.

It follows that in all natural processes where heat flows from one system to another, there is always a net increase in entropy. This is another statement of 2nd law of thermodynamics. According to this law

If a system undergoes a natural process, it will go in the direction that causes the entropy of the system plus the environment to increase.

It is observed that a natural process tends to proceed towards a state of greater disorder. Thus, there is a relation between entropy and molecular disorder. For example an irreversible heat flow from a hot to a cold substance of a system increases disorder because the molecules are initially sorted out in hotter and cooler regions. This order is lost when the system comes to thermal equilibrium. Addition of heat to a system increases its disorder because of increase in average molecular speeds and therefore, the randomness of molecular motion. Similarly, free expansion of gas increases its disorder because the molecules have greater randomness of position after expansion than before. Thus in both examples, entropy is said to be increased.

We can conclude that only those processes are probable for which entropy of the system increases or remains constant. The process for which entropy remains constant is a reversible process; whereas for all irreversible processes, entropy of the system increases.

Every time entropy increases, the opportunity to convert some heat into work is lost. For example there is an increase in entropy when hot and cold waters are mixed. Then warm water which results cannot be separated into a hot layer and a cold layer. There has been no loss of energy but some of the energy is no longer available for conversion into work. Therefore, increase in entropy means degradation of energy from a higher level where more work can be extracted to a lower level at which less or no useful work can be done. The energy in a sense is degraded, going from more orderly form to less orderly form, eventually ending up as thermal energy.

In all real processes where heat transfer occurs, the energy available for doing useful work decreases. In other words the

Do You Know?

Approximate efficiencies of various devices

Device	Efficiency (%)
Electric generator	70-99
Electric motor	50-93
Dry cell battery	90
Domestic gas furnace	70-85
Storage battery	72
Hydrogen-oxygen fuel cell	60
Liquid fuel rocket	47
Steam turbine	35-46
Fossil-fuel power plant	30-40
Nuclear reactor	39
Aircraft gas turbine engine	36
Solid-state laser	30
Internal combustion gasoline engine	20-30
Gallium arsenide solar cells	>20
Fluorescent lamp	20
Silicon solar cell	12-15
Steam locomotive	8

ENVIRONMENTAL CRISIS AS ENTROPY CRISIS

The second law of thermodynamics provides us the key for both understanding our environmental crisis, and for understanding how we must deal with this crisis.

From a human standpoint the environmental crisis results from our attempts to order nature for our comforts and greed. From a physical standpoint, however, the environmental crisis is an entropy or disorder crisis resulting from our futile efforts to ignore the second law of thermodynamics. According to which, any increase in the order in a system will produce an even greater increase in entropy or disorder in the environment. An individual impact may not have a major consequence but an impact of large number of all individuals disorder producing activities can affect the overall life support system.

The energy processes we use are not very efficient. As a result most of the energy is lost as heat to the environment. Although we can improve the efficiency but 2^{nd} law eventually imposes an upper limit on efficiency improvement. Thermal pollution is an inevitable consequence of 2^{nd} law of thermodynamics and the heat is the ultimate death of any form of energy. The increase in thermal pollution of the environment means increase in the entropy and that causes great concern. Even small temperature changes in the environment can have significant effects on metabolic rates in plants and animals. This can cause serious disruption of the overall ecological balance.

For Your Information



The jet engines on this aircraft convert thermal energy to work, but the visible exhaust clearly shows that a considerable amount of thermal energy is lost as waste heat.

In addition to thermal pollution, the most energy transformation processes such as heat engines used for transportation and for power generation cause air pollution. In effect, all forms of energy production have some undesirable effects and in some cases all problems can not be anticipated in advance.

The imperative from thermodynamics is that whenever you do anything, be sure to take into account its present and possible future impact on your environment. This is an ecological imperative that we must consider now if we are to prevent a drastic degradation of life on our beautiful but fragile Earth.

SOLVED EXAMPLES

EXAMPLE 11.1

What is the average transnational kinetic energy of molecules in a gas at temperature 27 ^{o}C?

Data

Temperature = T = 27 ^{o}C

= 27 + 273

= 300 K

To Find

Average translational kinetic energy = <K.E.> = ?

SOLUTION

Using

$$T = \frac{2}{3K} <K.E.>$$

$$\therefore \quad <K.E.> = \frac{3\,K\,T}{2}$$

Putting values

$$<K.E.> = \frac{3 \times 1.38 \times 10^{-23} \times 300}{2}$$

$$= \frac{1242 \times 10^{-23}}{2}$$

$$= 621 \times 10^{-23}\ J$$

$$= 6.21 \times 10^{-21}\ J$$

Result

Average translation kinetic energy = <K.E.> = 6.21×10^{-21} J

EXAMPLE 11.2

Find the average speed of oxygen molecule in the air at S.T.P.

To Find

Average speed of oxygen molecule = < V > = ?

SOLUTION

At S.T.P.

$$T = 273\ K$$

Using

$$T = \frac{2}{3K}\left\langle \frac{1}{2} m V^2 \right\rangle$$

$$T = \frac{m}{3K}\langle V^2 \rangle$$

or $$\langle V^2 \rangle = \frac{3KT}{m} \quad \ldots\ldots\ldots (1)$$

As mass of one molecule of O_2 is

$$m = \frac{\text{Molecular mass of } O_2}{N_A}$$

$$= \frac{32\ g}{6.02 \times 10^{23}}$$

$$= \frac{32}{6.02 \times 10^{26}}$$

$$= 5.31 \times 10^{-26}\ kg$$

Putting values in equation (1)

$$\therefore \quad \langle V^2 \rangle = \frac{3 \times 1.38 \times 10^{-23} \times 273}{5.31 \times 10^{-26}}$$

$$= \frac{1130.22}{5.31} \times 10^{-23+26}$$

$$= 212.85 \times 10^3$$

$$\langle V^2 \rangle = 21.29 \times 10^4$$

Taking square root

$$\langle V \rangle = 4.61 \times 10^2\ m/s$$

$$= 461\ m/s$$

Result

Average speed of oxygen molecule = $\langle V \rangle$ = 461 m/s

EXAMPLE 11.3

A gas is enclosed in a container fitted with a piston of cross–sectional area $0.10 m^2$. The pressure of the gas is maintained at $8000\ Nm^{-2}$. When heat is slowly transferred, the piston is pushed up through a distance of 4.0cm. If 42J heat is transferred to the system during the expansion, what is the change in internal energy of the system?

Data

Area of piston = A = $0.10\ m^2$

Pressure of gas = P = $8000\ Nm^{-2}$

Distance moved by piston = ΔY = 4 cm

$= 0.04$ m

Heat transferred $= Q = 42$J

To Find

Change in internal energy $= \Delta U = ?$

SOLUTION

Using

$$W = P \Delta V$$

or $$W = PA \Delta Y$$

$$= 8000 \times 0.10 \times 0.04 \quad (\because \Delta V = A\Delta y)$$

$$= 32 \text{ J} \quad (\text{Volume} = \text{Area} \times \text{Height})$$

Using 1st law of thermodynamics

$$Q = \Delta U + W$$

$$\therefore \quad \Delta U = Q - W$$

$$= 42 - 32$$

$$= 10 \text{ J}$$

Result

Change in internal energy $= \Delta U = 10$ J

EXAMPLE 11.4

The turbine in a steam power plant takes steam from a boiler at 427 ^{o}C and exhausts into a low temperature reservoir at 77 ^{o}C. What is the maximum possible efficiency.

Data

Temperature of source $= T_1 = 427\ ^{o}C$

$$= 427 + 273$$

$$= 700 \text{ K}$$

Temperature of sink $= T_2 = 77\ ^{o}C$

$$= 77 + 273$$

$$= 350 \text{ K}$$

To Find

Efficiency $= \eta = ?$

SOLUTION

Using

$$= 1 - \frac{350}{700}$$

$$= \frac{700 - 350}{700} = \frac{350}{700}$$

$$\eta = \frac{1}{2}$$

$$\eta\% = \frac{1}{2} \times 100$$

$$= 50\%$$

Result

Efficiency $= \eta = 50\%$

EXAMPLE 11.5

Calculate the entropy change when 1.0kg ice at 0^oC melts into water at 0^oC. Latent heat of fusion of ice $L_f = 3.36 \times 10^5$ J kg^{-1}.

Data

Temperature $= T = 0^oC$

$= 0 + 273$

$= 273$ K

Mass of ice $= m = 1$ kg

Latent heat of fusion $= L_f = 3.36 \times 10^5$ J/kg

To Find

Entropy change $= \Delta S = ?$

SOLUTION

Using

$$\Delta Q = m L_f$$

$$= 1 \times 3.36 \times 10^5$$

$$= 3.36 \times 10^5 \text{ J}$$

Now using

$$\Delta S = \frac{\Delta Q}{T}$$

Putting values

$$\Delta S = \frac{3.36 \times 10^5}{273}$$

Positive sign shows entropy increases because ice changes into water. Because the increase in entropy in this case is a measure of increase in the disorder of water molecules that change from solid to liquid state.

Result

Entropy change = ΔS = 1.2×10^3 Jk^{-1}



HEAT AND THERMODYNAMICS

Each question has four possible answers, encircled the correct answer:

1. The degree of hotness or coldness of an object is called:

(a) Temperature **(b)** Chemical energy

(c) Mechanical energy **(d)** Heat

2. Temperature is a property that determines:

(a) The ability of a body to transfer heat **(b)** A body with lower thermal conductivity

(c) A body with higher thermal conductivity **(d)** How much energy is present in the body

3. Something which flows from a hot body to a cold body is known as:

(a) Heat **(b)** Internal energy

(c) Temperature **(d)** None of these

4. The direction of the flow of heat between two bodies depends upon:

(a) Thermal conductivity **(b)** Internal energies

(c) Temperature **(d)** Specific heat

5. The branch of physics which deals with the transfer of heat into other form of energy is called:

(a) Heat and temperature **(b)** Thermodynamics

(c) Mechanics **(d)** All of above

6. Sum of all forms of molecular energies of a substance is called its:

(a) External energy **(b)** Kinetic energy

(c) Potential energy **(d)** Internal energy

7. A relationship between the mechanical work and heat energy has derived by:

(a) Joule **(b)** Newton

(c) Kelvin **(d)** Einstien

8. The pressure of a gas is defined as:

(a) Force per unit area **(b)** Mass per unit volume

(c) Energy per unit volume **(d)** Energy per unit area

9. Pressure of a gas depends upon:

(a) The mass of molecules **(b)** Molecular speed

(c) Number of molecules **(d)** All of above

10. When a gas is compressed:

(a) Its temperature decreases **(b)** Its internal energy decreases

(c) Its temperature increases **(d)** None of these

11. The pressure exerted by the gas molecules on the walls of the vessel is due to:

(a) Continuous collision of its molecules **(b)** Free motion of its molecules

(c) Momentum of its molecules **(d)** All of above

12. Select the statement that agrees the kinetic molecular theory of gases:

(a) Molecules of a gas suffer elastic collisions

(b) There are large number of molecules in a finite volume

(c) Molecules do not exert force except during collision

(d) All of the above

13. The expression for pressure exerted by an ideal gas is given by:

(a) $P = \frac{1}{3} N_0 < \frac{1}{2} mv^2 >$ **(b)** $P = \frac{1}{2} N_0 < \frac{1}{2} mv^2 >$

(c) $P = \frac{2}{3} N_0 < \frac{1}{2} mv^2 >$ **(d)** $P = \frac{2}{3} N_A < \frac{1}{2} mv^2 >$

14. Mean square velocity of gas molecules moving along x-direction is represented by:

(a) $< V_y^2 >$ **(b)** $< V_x^2 >$

(c) $< V_z^2 >$ **(d)** None of these

15. The Boltzman constant K in terms of universal gas constant R and Avogadro's number N_A is:

(a) $K = \frac{R}{N_A}$ **(b)** $K = \frac{N_A}{R}$

(c) $K = \frac{NR}{N_A}$ **(d)** None of these

16. The value of Boltzman gas constant K is:

(a) $1.38 \times 10^{-34}\ J.K^{-1}$ **(b)** $1.38 \times 10^{-23}\ JK^{-1}$

(c) $1.38 \times 10^{-32}\ J\text{-}K^{-1}$ **(d)** $1.38 \times 10^{-27}\ J\ .\ K^{-1}$

17. The average translational kinetic energy per molecule of an ideal gas is given by:

(a) $\frac{3RT}{2N_A}$ **(b)** $\frac{2RT}{3N_A}$

(c) $\frac{2N_AT}{3R}$ **(d)** $\frac{3N_AT}{2R}$

18. Pressure of an ideal gas in terms of its density can be written as:

(a) $P = \rho v^2$ **(b)** $P = \frac{1}{3} \rho v^2$

(c) $P = \frac{2}{3} \rho v^2$ **(d)** $P = \frac{1}{2} \rho v^2$

19. According to the kinetic molecular theory which of the following relation is correct:

(a) $T = \frac{2N_A}{R} < \frac{1}{2} mv^2 >$ **(b)** $T = \frac{3N_A}{2R} < \frac{1}{2} mv^2 >$

(c) $T = \frac{N_A}{3R} < mv^2 >$ **(d)** $T = \frac{2N_A}{3R} < \frac{1}{2} mv^2 >$

20. The average translational kinetic energy of the molecules show itself in the form of:

(a) Viscosity **(b)** Density

(c) Velocity **(d)** Temperature

21. At constant temperature, the volume of a gas is inversely proportional to the pressure is called:

(a) Charle's law **(b)** Boyle's law

(c) Heat law **(d)** None of these

22. At constant pressure, the volume of a gas is directly proportional to the absolute temperature is called:

(a) Charle's law **(b)** Boyle's law

(c) Heat law **(d)** None of these

23. Under the same conditions of temperature and pressure, equal volume of all gases contains the same number of kilo moles is called:

(a) Charle's law **(b)** Boyle's law

(c) Avogadro's law **(d)** Law of pressure

24. The mathematical form of an ideal gas laws is:

(a) $PV = nRT$ **(b)** $PT = nRv$

(c) $PV = \frac{nR}{T}$ **(d)** $TV = nRP$

25. The value of universal gas constant R is:

(a) 8314 J / mole-K **(b)** 83.10 J/mole-K

(c) 8314 J / K-mole K **(d)** 8.314 J/K mole-K

26. The unit of pressure of gas is:

(a) N/m^2 **(b)** Pascal

(c) Atmosphere **(d)** All of these

27. Avogadro's number is known as the number of molecules in:

(a) One mole of a substance **(b)** Total volume of a substance

(c) Unit volume of substance **(d)** One kg of a substance

28. At constant pressure, the graph between volume and absolute temperature is:

(a) Parabola **(b)** Straight line

(c) Hyperbola **(d)** None of these

29. At constant temperature, the graph between volume and pressure is:

(a) Parabola **(b)** Straight line

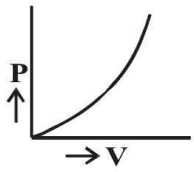
(c) Hyperbola **(d)** None of these

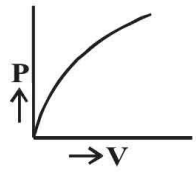
30. For a gas obeying Boyle's law if pressure is doubled, the volume of a gas becomes:

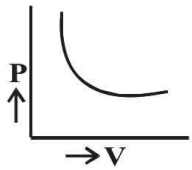
(a) One half **(b)** No change

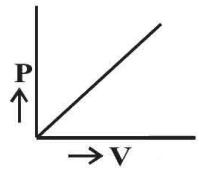
(c) Double **(d)** None of these

31. Which of the following curves represents Boyle's law:

(a) 

(b) 

(c) 

(d) 

32. Mathematically Boyle's law can be written as:

(a) $PV = \text{Constant}$ **(b)** $\frac{P}{V} = \text{Constant}$

(c) $\frac{V}{P} = \text{Constant}$ **(d)** None of these

33. Mathematically, Charle's law can be written as:

(a) $T.V = \text{Constant}$ **(b)** $\frac{V}{T} = \text{Constant}$

(c) $\frac{T}{V} = \text{Constant}$ **(d)** None of these

34. A diatomic gas contains only:

(a) Translational K.E **(b)** Rotational K.E

(c) Vibrational K.E **(d)** All of these

35. Boyle's law is an example of:

(a) Isothermal process **(b)** Adiabatic process

(c) Mechanical process **(d)** None of these

36. The pressure of a gas is directly proportional to:

(a) Root mean square velocity of the molecules

(b) Mean square velocity of the molecules

(c) Mean velocity of the molecules

(d) None of these

37. Gas law $PV^{\gamma} = \text{Constant}$ is for:

(a) Isothermal process **(b)** Adiabotic process

(c) Isobaric process **(d)** Iso choric process

38. The ratio of universal gas constant and Avogadro's number is called:

(a) Universal constant **(b)** Boltzmann constant

(c) Equilibrium constant **(d)** None of these

39. Which one of the following gases is the nearest approach to an ideal gas:

(a) Oxygen **(b)** Nitrogen

(c) Hydrogen **(d)** Carbon dioxide

40. Real gases strictly obey gas laws:

(a) At high pressure and low temperature **(b)** At low pressure and high temperature

(c) At high pressure and high temperature **(d)** At low pressure and low temperature

41. Gas constant per molecule of the gas is called:

(a) Rydberg's constant **(b)** Boltzmann's constant

(c) Stefan's constant **(d)** Molar gas constant

42. If some quantity of water put in a shallow vessel allowed to evaporate, its temperature:

(a) Decreases **(b)** Increases

(c) Remains constant **(d)** None of these

43. When we heat a substance the energy associated with its atoms / molecules is:

(a) Increased **(b)** Decreased

(c) Remains constant **(d)** Becomes zero

44. When a substance is heated, then heat is converted into:

(a) Internal energy **(b)** Initial energy

(c) External energy **(d)** Chemical energy

45. The internal energy of an ideal gas depends upon only on its:

(a) Pressure **(b)** Volume

(c) Temperature **(d)** All of above

46. Work done by the system on its environment is considered as:

(a) Zero **(b)** Positive

(c) Negative **(d)** None of these

47. Work done on the system by its environment is taken as:

(a) Zero **(b)** Positive

(c) Negative **(d)** None of these

48. Which statement about internal energy is correct:

(a) The internal energy of a system can be increased without transfer of energy by heating

(b) The internal energy of a system depends only on its temperature

(c) When the internal energy of a system is increased, its temperature always increased

(d) When two systems have the same internal energy, they must be at the same temperature

49. The sum of total energy of all the molecules of a substance is called:

(a) Heat energy **(b)** Efficiency

(c) Internal energy **(d)** Power

50. The first law of thermodynamics is a special case of the:

(a) Charle's law **(b)** Law of conservation of momentum

(c) Boyle's law **(d)** Law of conservation of energy

51. The principles which deals with the heat energy and its transformation into mechanical energy is called:

(a) Laws of thermodynamics **(b)** Law of conservation of mass

(c) Law of conservation of energy **(d)** First law of thermodynamics

52. First law of thermodynamics is the restatement of:

(a) Law of conservation of mass **(b)** Law of conservation of energy

(c) Both (a) and (b) **(d)** None of these

53. Mathematically the first law of thermodynamics can be expressed as:

(a) $Q = \Delta U + W$ **(b)** $Q = W - \Delta U$

(c) $Q = \Delta U - W$ **(d)** $W = Q + \Delta U$

54. In thermodynamics, the change in the internal energy depends upon:

(a) The initial state of temperature only

(b) The final state of temperature only

(c) The initial and final states of the temperature

(d) None of these

55. The process under which the system undergoes a change of state at constant volume is called:

(a) Adiabatic process **(b)** Isothermal process

(c) Isochoric process **(d)** Isobaric process

56. The process in which the pressure of a system remains constant is called:

(a) Isochoric process **(b)** Isobaric process

(c) Adiabatic process **(d)** Isothermal process

57. The temperature of the system remains constant is called:

(a) Isochoric process **(b)** Isothermal process

(c) Adiabatic process **(d)** Isobaric process

58. That process in which no heat enters or leaves the system is called:

(a) Isochoric process **(b)** Isothermal process

(c) Isoboric process **(d)** Adiabatic process

59. Any thing which have distinct boundaries is called:

(a) Environment **(b)** System

(c) Both (a) and (b) **(d)** None of these

60. Any thing which have no distinct boundaries is called:

(a) Environment **(b)** System

(c) Both (a) and (b) **(d)** None of these

61. A system in which there is no transfer of mass and energy across the boundary is called:

(a) An isolated system **(b)** An open system

(c) A closed system **(d)** None of these

62. A system in which there is no transfer of mass across the boundary is called:

(a) An isolated system **(b)** An open system

(c) A closed system **(d)** None of these

63. In isothermal process:

(a) $\Delta U = W$ **(b)** $\Delta U = -W$

(c) $Q = \Delta U$ **(d)** $Q = W$

64. In an adiabatic process:

(a) $\Delta Q = 0$ **(b)** $Q = W$

(c) $\Delta U = Q$ **(d)** None of these

65. An isothermal process is represented by the mathematical equation:

(a) $\frac{P}{T} = \text{Constant}$ **(b)** $\frac{V}{T} = \text{Constant}$

(c) $PV = \text{Constant}$ **(d)** $PV^{\gamma} = \text{Constant}$

66. The expression $PV^{\gamma} = \text{Constant}$ holds good in:

(a) Adiabatic process **(b)** Isothermal process

(c) Isobaric process **(d)** None of these

67. In an isothermal process, internal energy of the system:

(a) Decreases **(b)** Increases

(c) Remains constant **(d)** None of these

68. The amount of heat required to raise the temperature of one kg of a substance through 1°C is called:

(a) Specific heat **(b)** Molar heat capacity

(c) Heat of fusion **(d)** All of above

69. The amount of heat required to raise the temperature of 1 mole of a substance through 1 K is called:

(a) Heat capacity **(b)** Molar heat capacity

(c) Specific heat **(d)** None of these

70. The difference between C_P and C_V is equal to:

(a) Molar gas constant **(b)** Boltzmann constant

(c) Universal gas constant **(d)** None of these

71. The ratio $\frac{C_P}{C_V} = \gamma$ for diatomic gas like air is:

(a) 1.40 **(b)** 1.30

(c) 1.29 **(d)** 1.67

72. 1 kilo calorie is equal to:

(a) 1.17 watt-hour **(b)** 117.0 watt-hour

(c) 11.7 watt-hour **(d)** None of these

73. Mark the correct statement:

(a) Specific heat of mono-atomic gases is greater than those of poly-atomic gases

(b) Specific heat of mono-atomic gases is less than those of poly-atomic gases

(c) Specific heat of mono-atomic gases is equal to those of poly-atomic gases

(d) None of these

74. The amount of heat energy required to evaporise one kg of a liquid at its boiling without change of temperature is called:

(a) Heat of fusion **(b)** Heat capacity

(c) Heat of vaporization **(d)** Latent heat of vaporization

75. Specific heat of different substances varies because of:

(a) Different K.E of molecules of unit mass **(b)** Different number of molecules in unit mass

(c) Same number of molecules in unit mass **(d)** Same K.E of molecules of unit mass

76. A process which can be retraced in reverse order without produces any change in the environment is called:

(a) Irreversible process **(b)** Reversible process

(c) Isothermal process **(d)** Adiabatic process

77. A process which cannot be retraced in the reverse order is called:

(a) Irreversible process **(b)** Reversible process

(c) Isothermal process **(d)** Isochoric process

78. Which one is the example of irreversible process:

(a) Compton effect **(b)** Melting ice

(c) Heat engine **(d)** Work done against friction

79. Which one is the example of reversible process:

(a) Compton **(b)** Melting ice

(c) Heat engine **(d)** Workdone against friction

80. For diatomic gas $C_V = \frac{5R}{2}$ therefore γ for this gas is:

(a) $\frac{35}{4}$ **(b)** $\frac{5}{7}$

(c) $\frac{4}{35}$ **(d)** $\frac{7}{5}$

81. For mono-atomic gas $C_V = \frac{3R}{2}$ therefore γ for this gas is:

(a) $\frac{15}{4}$ **(b)** $\frac{4}{15}$

(c) $\frac{5}{3}$ **(d)** $\frac{3}{5}$

82. A device which convert heat energy into mechanical energy is called:

(a) Heat engine **(b)** Pettier engine

(c) Carnot engine **(d)** All of above

83. An ideal heat engine has 100% efficiency only if its exhaust temperature is:

(a) Less than input temperature **(b)** Greater than input temperature

(c) Equal to input temperature **(d)** OK

84. It is impossible for heat engine to convert all heat into useful work, the law called:

(a) Second law of thermodynamics **(b)** First law of thermodynamics

(c) Law of conservation of energy **(d)** None of these

85. The statement, it is impossible for a self-acting machine, to transfer heat from a lower to higher temperature refers to:

(a) First law of thermodynamics **(b)** Law of conservation of mass

(c) Second law of thermodynamics **(d)** None of these

86. When the temperatures of source and sink of a heat engine become equal, the entropy change will be:

(a) Maximum **(b)** Minimum

(c) Zero **(d)** None of these

87. The efficiency of heat engine whose lower temperature is 17°C and the high temperature of 200°C is:

(a) 35% **(b)** 80%

(c) 90% **(d)** 25%

88. The formula for the efficiency of heat engine is:

(a) $\eta = \left(1 - \frac{Q_1}{Q_2}\right) \times 100\%$ **(b)** $\eta = \left(\frac{1 - Q_1}{Q_2}\right) \times 100\%$

(c) $h = \left(\frac{Q_2}{Q_1} - 1\right) \times 100\%$ **(d)** $\eta = \left(1 - \frac{Q_2}{Q_1}\right) \times 100\%$

89. An engine which convert heat energy into useful work upto 35% to 40% is:

(a) Petrol engine **(b)** Heat engine

(c) Deisel engine **(d)** Carnot engine

90. An engine which gives maximum efficiency is called:

(a) Carnot engine **(b)** Heat engine

(c) Petrol engine **(d)** All of above

91. The efficiency of carnot engine working between lower temperature T_L and higher temperature T_H is:

(a) $\eta = \left(1 - \frac{T_H}{T_L}\right) \times 100\%$ **(b)** $\eta = \left(1 - \frac{T_L}{T_H}\right) \times 100\%$

(c) $\eta = \left(\frac{T_H}{T_L} - 1\right) \times 100\%$ **(d)** $\eta = \left(\frac{T_L}{T_H} - 1\right) \times 100\%$

92. In carnot engine at the end of the cyclic path, the temperature of working substance is:

(a) Zero **(b)** Less than intital temperature

(c) Greater than initial temperature **(d)** Equal to initial temperature

93. If the temperature of the source increases, then the efficiency of carnot engine is:

(a) Remains constant **(b)** Increases

(c) Decrease **(d)** None of these

94. The efficiency of carnot engine depend upon:

(a) Sink temperature **(b)** Source temperature

(c) Both source and sink **(d)** The working substance

95. Carnot's cycle is an example of:

(a) Irreversible process **(b)** Reversible process

(c) Both (a) and (b) **(d)** None of these

96. Entropy is the measure of:

(a) Disorder of the system **(b)** Order of the system

(c) Internal energy **(d)** Potential energy of the system

97. The change in entropy of the system is given mathematical form:

(a) $\Delta S = -\frac{\Delta Q}{T}$ **(b)** $\Delta S = \frac{T}{\Delta Q}$

(c) $\Delta S = \Delta Q \times T$ **(d)** $\Delta Q = \frac{\Delta S}{T}$

98. Entropy of the universe is increasing due to:

(a) Use of energy into work **(b)** Depletion of ozone

(c) Power generation process **(d)** All of above

99. The concept of entropy was introduced by the scientist:

(a) R Clausius **(b)** Newton

(c) Kelvin **(d)** Carnot Sadi

100. No entropy change is associated with:

(a) Isobaric process **(b)** Isochoric process

(c) Isothermal process **(d)** Adiabatic process

101. The petrol engine is based on the principle of:

(a) Kelvin cycle **(b)** Carnot cycle

(c) Clausius cycle **(d)** Cyclic process

102. Four stroke petrol engine has the following process:

(a) 1 **(b)** 4

(c) 2 **(d)** 3

103. The number of spark plugs needed in the diesel engine is:

(a) 2 **(b)** 3

(c) 0 **(d)** 4

104. The temperature scale which is independent of the nature of the substance used in the thermometer is called:

(a) Absolute or Kelvin scale **(b)** Fahrenheit scale

(c) Centigrade scale **(d)** Thermodynamics scale

105. The relation between centigrade scale and Fahrenheit scale of temperature is:

(a) $\frac{C}{5}=\frac{F-32}{9}$ **(b)** $\frac{C}{9}=\frac{F-32}{5}$

(c) $\frac{C}{5}=\frac{F+32}{9}$ **(d)** $\frac{C}{9}=\frac{F+32}{5}$

106. The centigrade and Fahrenheit scales will have the same reading when the temperature is:

(a) 70° **(b)** –80°

(c) –40° **(d)** 120°

107. The Fahrenheit and Kelvin scale will have the same reading when temperature is:

(a) 370° **(b)** 574.25°

(c) 414.5° **(d)** 388°

108 Mercury thermometer was constructed by:

(a) Rutherford **(b)** Ampere

(c) Lord Kelvin **(d)** Einstien

109. Fahrenheit scale was originally used in:

(a) Meteorology **(b)** Clinical thermometer

(c) Clinical thermometer and meteorology **(d)** None of these

110. Mercury is used as a thermometric substance because:

(a) It does not stick to glass **(b)** Its specific heat is low

(c) Its expansion is uniform **(d)** All of above

111. A gas which strictly obeys the gas laws under all conditions of temperature and pressure is called:

(a) Real gas **(b)** Ideal gas

(c) Inert gas **(d)** None of these

112. Real gases strictly obey gas laws at:

(a) Low pressure and high temperature **(b)** High pressure and low temperature

(c) High pressure and high temperature **(d)** None of these

113. If the volume of a given mass of a gas is doubled at constant temperature then the density of gas becomes:

(a) Remains constant **(b)** Half

(c) Double **(d)** None of these

114. The temperature scale approved in SI units:

(a) Celsius scale **(b)** Fahrenheit scale

(c) Kelvin scale **(d)** None of these

115. Which of the following does not have the same units:

(a) Work **(b)** Heat

(c) Kinetic energy **(d)** Power

116. The motion of molecules in gases:

(a) Random **(b)** Orderly

(c) Circular **(d)** All of these

117. For an ideal gas, the molecules have:

(a) K.E only **(b)** P.E only

(c) Both K.E and P.E **(d)** None of these

118. At constant temperature, if the density of the gas is increased, its pressure will:

(a) Increase **(b)** Decrease

(c) Remains constant **(d)** None of these

119. Truth of kinetic theory is confirmed by:

(a) Brownian motion **(b)** Diffusion of gases

(c) Both (a) and (b) **(d)** None of these

120. When a gas is compressed:

(a) Its temperature decreases **(b)** Its internal energy decreases

(c) Its temperature increases **(d)** None of these

121. If an amount of heat Q enters, the system:

(a) Work is done **(b)** Increase in internal energy

(c) Both (a) and (b) **(d)** None of these

122. The equation $W = -\Delta U$ represents:

(a) Isothermal process **(b)** Adiabatic process

(c) Isobaric process **(d)** Isochoric process

123. Consider volume in a cylinder is 4 c.c. If the piston is kept fixed and gas is heated from 10°C to 15°C then the work done is:

(a) 4.3 J **(b)** 20 J

(c) 15 J **(d)** Zero

124. If C_v is the molar heat capacity at constant volume and ΔT is the change in temperature then $C_v \Delta T$ gives:

(a) Area **(b)** Energy

(c) Volume **(d)** Density

125. When a gas is compressed isothermally, the product of its pressure and volume during the process is:

(a) Remains constant **(b)** Zero

(c) Proportional to energy **(d)** None of these

126. If the temperature difference between hot and cold body is greater than the heat engine is:

(a) Not efficient **(b)** Less efficient

(c) More efficient **(d)** None of these

127. As the working substances of a heat engine completes a cycle, there is no change in:

(a) Internal energy **(b)** Volume

(c) Pressure **(d)** All of these

128. What will be the efficiency of a carnot engine if it is operated between the temperatures 47°C and 127°C:

(a) 25% **(b)** 20%

(c) 50% **(d)** 10%

129. One degree of thermodynamic scale is equal to ———— of the temperature of triple point of water:

(a) $\frac{1}{273.16}$ th **(b)** $\frac{1}{273}$ th

(c) $\frac{1}{100}$ th **(d)** $\frac{1}{32}$ th

130. The unknown temperature T on thermodynamic scale in Kalvin is given by formula:

(a) $T = 273.16 \frac{Q}{Q_3}$ **(b)** $T = 32 \frac{Q}{Q_3}$

(c) $T = 100 \frac{Q}{Q_3}$ **(d)** $T = 273 \frac{Q}{Q_3}$

131. One degree of thermodynamics scale of temperature is called:

(a) Celsius **(b)** Fahrenheit

(c) Kelvin **(d)** Meter

132. At constant pressure, the graph between V and T is:

(a) Hyperbola **(b)** Parabola

(c) Straight line **(d)** Ellipse

133. In reversible process, the entropy:

(a) Remains constant **(b)** Increases

(c) Decreases **(d)** Both (a) and (b)

134. Temperature of –273°C on Kelvin scale is:

(a) +273 K **(b)** +373 K

(c) –273 K **(d)** 0 K

135. In the isothermal process, one of the following is constant:

(a) Pressure **(b)** Volume

(c) Temperature **(d)** Heat energy

136. If a given mass of gas occupies a volume of 100 cc at one atmospheric pressure and temperature of 100°C (373.15 K), what will be its volume at 4 atmospheric pressure, the temperature being the same?

(a) 25 cc **(b)** 100 cc

(c) 104 cc **(d)** 400 cc

137. 'P' is the pressure and 'd' is the density of gas at constant temperature, then:

(a) $P \propto \frac{1}{d}$ **(b)** $P \propto \frac{1}{d^2}$

(c) $P \propto d$ **(d)** $P \propto d^2$

138. Some gas at 300 K is enclosed in a container. Now the container is placed on a fast moving train. While the train is in motion, the temperature of the gas?

(a) Rises above 300°K **(b)** Falls below 300°K

(c) Remains unchanged **(d)** Becomes unsteady

139. Triple point of water is:

(a) 273.16°C **(b)** 273.16 K

(c) 273.16°F **(d)** 373.16 K

140. A diesel locomotive has an efficiency of nearly:

(a) 28% **(b)** 38%

(c) 48% **(d)** 58%

141. A steel tape gives correct measurement at 20°C. The length of a piece of wood is being measured with steel tape at 0°C. The reading is 25 cm on this tape. The real length must be:

(a) 25 cm **(b)** Less than 25 cm

(c) More than 25 cm **(d)** 5 cm

142. A gas performs the most work when it expands:

(a) Isothermally **(b)** Adiabatically

(c) Isoberically **(d)** At a non-uniform rate

143. The following expression represent:

$$\Delta U = -W$$

(a) Isothermal expansion **(b)** Adiabatic compression

(c) Isobaric process **(d)** None

144. In which stroke of petrol engine fuel is ignited?

(a) First **(b)** Second

(c) Third **(d)** Fourth

145. Which of the following process is irreversible?

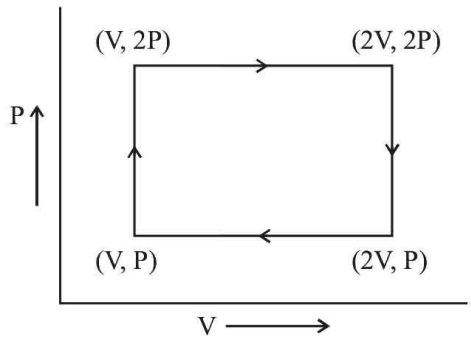
(a) Rapid liquefactions **(b)** Rapid compression of a gas

(c) Explosion **(d)** All

146. The work done during the cycle is:

(a) 1 PV **(b)** 2 PV

(c) 1/2 PV **(d)** Zero



147. The value of Boltzmann's constant is:

(a) 1.38×10^{-23} J/K **(b)** $1.38 \times 10^{+23}$ J/K

(c) 1.38×10^{-23} J/mole-K **(d)** 1.38×10^{-23} J/K mole-K

148. Fahrenheit and centigrade (Celsius) thermometers have the same reading at:

(a) −100°C **(b)** 60°

(c) 40°C **(d)** −40°C

149. If co-efficient of linear expansion of a solid body is α, its co-efficient of cubical expansion will be approximately:

(a) 2α **(b)** 3α

(c) 2.5α **(d)** 4α

150. A system does 600 J of work and at the same time has its internal energy increased by 320 J. How much heat has been supplied?

(a) 280 J **(b)** 920 J

(c) 600 J **(d)** 20 J

151. No entropy change takes place in:

(a) Isothermal process **(b)** Adiabatic process

(c) Isobaric process **(d)** Isochoric process

ANSWERS

1.	(a)	**2.**	(a)	**3.**	(a)	**4.**	(c)
5.	(b)	**6.**	(d)	**7.**	(c)	**8.**	(a)
9.	(d)	**10.**	(c)	**11.**	(a)	**12.**	(d)
13.	(c)	**14.**	(b)	**15.**	(a)	**16.**	(b)
17.	(a)	**18.**	(b)	**19.**	(d)	**20.**	(d)
21.	(b)	**22.**	(a)	**23.**	(c)	**24.**	(a)
25.	(d)	**26.**	(d)	**27.**	(a)	**28.**	(b)
29.	(c)	**30.**	(a)	**31.**	(c)	**32.**	(a)
33.	(b)	**34.**	(c)	**35.**	(a)	**36.**	(b)
37.	(b)	**38.**	(b)	**39.**	(c)	**40.**	(b)
41.	(b)	**42.**	(a)	**43.**	(a)	**44.**	(a)
45.	(c)	**46.**	(b)	**47.**	(c)	**48.**	(a)
49.	(c)	**50.**	(d)	**51.**	(a)	**52.**	(b)
53.	(a)	**54.**	(c)	**55.**	(c)	**56.**	(b)
57.	(b)	**58.**	(d)	**59.**	(b)	**60.**	(a)
61.	(a)	**62.**	(c)	**63.**	(d)	**64.**	(a)
65.	(c)	**66.**	(a)	**67.**	(c)	**68.**	(a)
69.	(b)	**70.**	(c)	**71.**	(a)	**72.**	(a)
73.	(b)	**74.**	(d)	**75.**	(b)	**76.**	(b)
77.	(a)	**78.**	(d)	**79.**	(b)	**80.**	(d)
81.	(c)	**82.**	(a)	**83.**	(d)	**84.**	(a)
85.	(c)	**86.**	(a)	**87.**	(a)	**88.**	(d)
89.	(c)	**90.**	(a)	**91.**	(b)	**92.**	(a)
93.	(a)	**94.**	(c)	**95.**	(a)	**96.**	(b)
97.	(a)	**98.**	(a)	**99.**	(d)	**100.**	(d)
101.	(b)	**102.**	(b)	**103.**	(c)	**104.**	(d)
105.	(a)	**106.**	(c)	**107.**	(b)	**108.**	(c)
109.	(c)	**110.**	(d)	**111.**	(b)	**112.**	(a)
113.	(b)	**114.**	(c)	**115.**	(d)	**116.**	(a)
117.	(a)	**118.**	(a)	**119.**	(c)	**120.**	(c)
121.	(c)	**122.**	(b)	**123.**	(d)	**124.**	(b)
125.	(a)	**126.**	(c)	**127.**	(d)	**128.**	(b)
129.	(a)	**130.**	(a)	**131.**	(c)	**132.**	(c)
133.	(b)	**134.**	(d)	**135.**	(c)	**136.**	(a)
137.	(c)	**138.**	(c)	**139.**	(b)	**140.**	(b)
141.	(b)	**142.**	(c)	**143.**	(b)	**144.**	(c)
145.	(d)	**146.**	(a)	**147.**	(a)	**148.**	(d)
149.	(b)	**150.**	(b)	**151.**	(b)		

SHORT QUESTIONS

11.1 Why is average velocity of the molecules in a gas zero but the average of the square of velocities is not zero?

Ans. According to kinetic molecular theory of gasses, there are a large number of molecules which are in random motion. Due to random motion of molecules, the number of molecules on the average moving in any direction with certain velocity is equal to number of molecules moving on opposite direction with the same velocity. So their average velocity will be zero because their vector sum will be zero i.e.,

$$v + (-v) = 0$$

but we know that square of negative quantity is positive therefore when we take average of the square of velocities it will not be zero, i.e., $V^2 + (-V)^2$ is not zero.

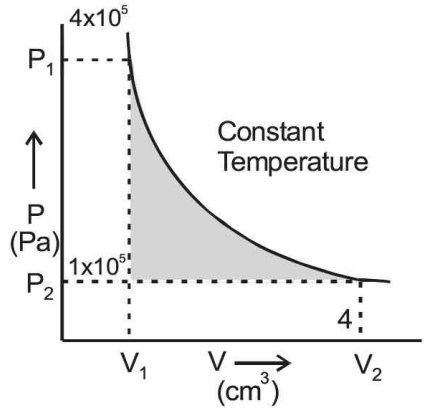
11.2 Why does the pressure of a gas in a car tyre increase when it is driven through some distance?

Ans. When a car is driven on the road through some distance. There is force of friction between the tyre and road. Due to this force of friction, the tyre heats up and the gas inside the tyre. Work done by the car is converted into heat which raises the temperature of the gas in a tyre. This increases the kinetic energy of the molecules. Since pressure is directly proportional to the average kinetic energy. i.e.,

$$P \propto \langle K.E \rangle$$

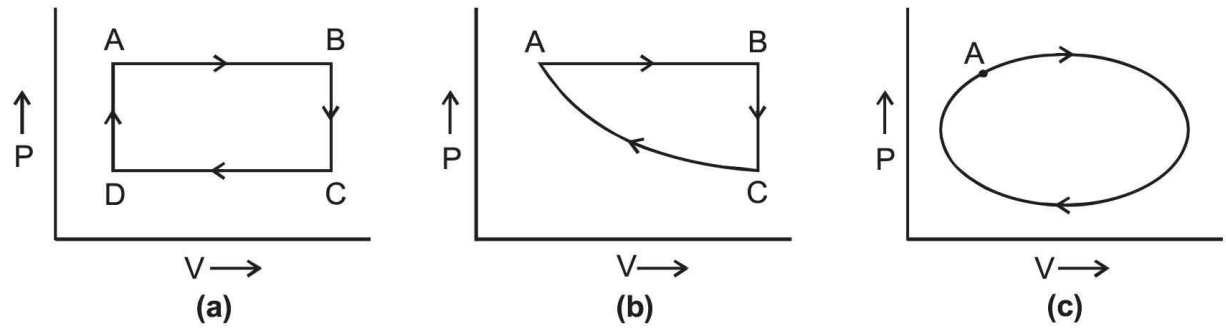
Hence pressure of a gas in a car tyre increases.

11.3 A system undergoes from state P_1V_1 to state P_2V_2 as shown in figure 11.12. What will be the change in internal energy?



Ans. As internal energy depends on temperature. In this case temperature is constant. So internal energy is also constant. Hence there will be no change in internal energy.

11.4 Variation in volume by pressure is given in Fig. 11.13. A gas is taken along the paths ABCDA, ABCA and A to A. What will be the change in internal energy?



Ans. There will be no change in the internal energy in all three cases because the system returns to its initial state.

11.5 Specific heat of a gas at constant pressure is greater than specific heat at constant volume. Why?

Ans. When a gas is heated at constant volume, heat supplied only increase the internal energy i.e., temperature because the piston is fixed so no external work is done to expand the gas i.e., $W = 0$, the total heat supplied is used to increase the internal energy and temperature of the gas. But when a gas is heated at constant pressure, the heat supplied is used in two ways i.e., some heat is used to do external work to expand the gas and the remaining heat is used to increase the internal energy.

Thus more heat is required at constant pressure than at constant volume. So the specific heat at constant pressure is greater than specific heat at constant volume. i.e.,

$$C_p > C_v$$

11.6 Give an example of a process in which no heat is transferred to or from the system but the temperature of the system changes.

Ans. In adiabatic expansion or compression, no heat is transferred to or from the system but the temperature of the system changes. During adiabatic expansion temperature of the system falls while during adiabatic compression temperature of the system rises.

11.7 Is it possible to convert internal energy into mechanical energy? Explain with an example.

Ans. Yes, in adiabatic expansion, internal energy is changed into mechanical energy.

According to 1^{st} law of thermodynamics

$$Q = \Delta U + W$$

In adiabatic process $Q = 0$

Then $$0 = \Delta U + W$$

$$W = -\Delta U$$

Thus the internal energy decreases because some internal energy is converted into mechanical energy.

Example: In petrol engine, hot gasses expand and the piston moves so internal energy is converted into work.

11.8 Is it possible to construct a heat engine that will not expel heat into the atmosphere?

Ans. No it is impossible to construct a heat engine that will not expect heat into the atmosphere. According to second law of thermodynamics (Kelvin's statement).

"No heat engine operating continuously in a cycle can convert all the heat supplied into work".

11.9 A thermos flask containing milk as a system is shaken rapidly. Does the temperature of milk rise?

Ans. When the milk is shaken rapidly, kinetic energy of the milk molecules increases which causes the increase in temperature and internal energy of the molecules of milk. When we are shaking, some work is done on it which converts into K.E of the molecules of milk so the temperature of milk increases.

11.10 What happens to the temperature of the room, when a air conditioner is left running on a table in the middle of the room?

Ans. Temperature of the room increases, as heat absorbed from the room is expelled in the same room. Also work done by the compressor is changed into heat which is expelled in the same room.

11.11 Can the mechanical energy be converted completely into heat energy? If so give an example.

Ans. Yes, mechanical energy can be converted into heat energy. When work is done in compressing the gas by adiabatic process, the increase in internal energy of the gas is equal to the work done according to 1^{st} law of thermodynamics.

$$Q = \Delta U + W$$

In adiabatic process $Q = 0$.

$$0 = \Delta U + W$$

As work is done on gas show work will be negative:

$$0 = \Delta U - W$$

$$\Rightarrow \quad \Delta U = W$$

This shows that in adiabatic process mechanical work is converted into increase in internal energy.

Example: If we rub our hands, the whole mechanical energy is converted into heat energy.

11.12 Does entropy of a system increases or decreases due to friction?

Ans. Entropy of a system increases, as work done due to friction is changed into heat and this heat goes into surrounding and becomes useless. According to law of increase of entropy, entropy increases for irreversible process.

11.13 Give an example of a natural process that involves an increases in entropy.

Ans. When ice is melted due to high temperature of surroundings. The heat transferred to ice from surroundings is positive. Since $\Delta S = \frac{\Delta Q}{T}$. As ΔS is positive thus the entropy of this natural process increases.

11.14 An adiabatic change is the one in which.

(a) No heat is added to or taken out of system.

(b) No change of temperature takes place.

(c) Boyle's law is applicable.

(d) Pressure and volume remains constant.

Ans. (a) is correct because in an adiabatic process, no heat enters or leaves the system.

11.15 Which one of the following process is irreversible?

(a) Slow compressions of an elastic spring.

(b) Slow evaporation of a substance in an isolated vessel.

(c) Slow compression of a gas.

(d) A chemical explosion.

Ans. (d) is correct because a chemical explosion cannot be reversed. It is a irreversible process.

11.16 An ideal reversible heat engine has.

(a) 100% efficiency.

(b) Highest efficiency.

(d) An efficiency which depends on the nature of working substance.

(d) None of these.

Ans. (b) is correct because according to 2^{nd} law of thermodynamics, the efficiency of an ideal heat engine cannot be 100%. It has highest efficiency.

PROBLEMS WITH SOLUTIONS

PROBLEM 11.1

Estimate the average speed of nitrogen molecules in air under standard conditions of pressure and temperature.

Data

At S.T.P

Temperature = T = 0°C = 0 + 273 = 273 K

Pressure = P = 1 atm.

To Find

Average speed of nitrogen molecules = $< v >$ = ?

SOLUTION

As we know that

$$\boxed{T = \frac{2}{3K} < \frac{1}{2} mv^2 >}$$

$$3KT = <mv^2>$$

$$< v^2 > = \frac{3KT}{m} \qquad \ldots\ldots \text{(i)}$$

where K = Boltzman's constant = 1.38×10^{-23} J/K

m = Mass of nitrogen molecules

Since Molecular mass of nitrogen = m = 28 g

= 0.028 kg

$$m = \frac{\text{Molecular mass of nitrogen}}{\text{Avogadro number } (N_A)}$$

$$m = \frac{0.028}{6.022 \times 10^{23}}$$

$$= 4.64 \times 10^{-3-23} \text{ kg}$$

$$= 4.64 \times 10^{-26} \text{ kg}$$

Putting in eq. (i)

$$< v^2 > = \frac{3 \times 1.38 \times 10^{-23} \times 273}{4.64 \times 10^{-26}}$$

$$= 243.58 \times 10^{-23+26}$$

$$= 243.58 \times 10^{3}$$

$$\sqrt{< v^2 >} = \sqrt{243580}$$

$$< v > = 493 \text{ m/s}$$

Result

Average speed of nitrogen molecule = $< v >$ = 493 m/s

PROBLEM 11.2

Show that ratio of the root mean square speeds of molecules of two different gases at a certain temperature is equal to the square root of the inverse ratio of their masses.

Data

Mass of 1st gas = m_1

Mass of 2nd gas = m_2

Velocity of molecules of 1st gas = v_1

Velocity of molecules of 2nd gas = v_2

To Find

Ratio = ?

SOLUTION

As we know that

$$T = \frac{2}{3K} < \frac{1}{2} mv^2 >$$

For 1st gas

$$T = \frac{1}{3K} < m_1 v_1^2 > \quad \ldots\ldots \text{(i)}$$

For 2nd gas

$$T = \frac{1}{3K} < m_2 v_2^2 > \quad \ldots\ldots \text{(ii)}$$

Divide equation (i) by (ii)

$$\frac{T}{T} = \frac{\frac{1}{3K} < m_1 v_1^2 >}{\frac{1}{3K} < m_2 v_2^2 >}$$

$$1 = \frac{< m_1 v_1^2 >}{< m_2 v_2^2 >}$$

$$\frac{m_2}{m_1} = \frac{< v_1^2 >}{< v_2^2 >}$$

$$\sqrt{<\frac{v_1^2}{v_2^2}>} = \sqrt{\frac{m_2}{m_1}}$$

$$<\frac{v_1}{v_2}> = \sqrt{\frac{m_2}{m_1}}$$

Result

Thus the ratio of the root mean square speeds of molecules of two different gases at certain temperature is equal to the square root of the inverse ratio of their mass.

PROBLEM 11.3

A sample of gas is compressed to one half of its initial volume at constant pressure of 1.25×10^5 Nm^{-2}. During the compression, 100 J of work is done on the gas. Determine the final volume of the gas.

Data

Pressure = P = 1.25×10^5 N/m^2

Work done = ΔW = 100 J

To Find

Final volume of the gas = V_2 = ?

SOLUTION

According to relation

$$\Delta W = P\Delta V$$

where ΔV = Change in volume

$$= V_1 - V_2 = V - \frac{V}{2}$$

$$\Delta V = \frac{V}{2} = V_2$$

So $$\Delta W = P\left(\frac{V}{2}\right)$$

$$\Delta W = PV_2$$

$$\boxed{V_2 = \frac{\Delta W}{P}}$$

$$= \frac{100}{1.25 \times 10^5}$$

$$= 80 \times 10^{-5}$$

$$= 8 \times 10^{-4}\ m^3$$

Result

Final volume of the gas = V_2 = 8×10^{-4} m^3

PROBLEM 11.4

A thermodynamic system undergoes a process in which its internal energy decreases by 300 J. If at the same time 120J of work is done on the system, find the heat lost by the system.

Data

Decrease in internal energy = ΔU = -300 J

Work done on the system = ΔW = -120 J

To Find

Heat lost by the system = ΔQ = ?

SOLUTION

By using 1st law of thermodynamic

$$\Delta Q = \Delta U + \Delta W$$

$$= -300 + (-120)$$

$$= -300 - 120$$

$$\Delta Q = -420 \text{ J}$$

Result

Heat lost by the system = ΔQ = -420 J

PROBLEM 11.5

A carnot engine utilises an ideal gas. The source temperature is 227°C and the sink temperature is 127°C. Find the efficiency of the engine. Also find the heat input from the source and heat rejected to the sink when 10000J of work is done.

Data

Source temperature = T_1 = 227°C + 273

= 500 K

Sink temperature = T_2 = 127°C + 273

= 400 K

Work done = W = 10,000 J

To Find

Efficiency of the engine = η = ?

Heat absorbed = Q_1 = ?

Heat rejected = Q_2 = ?

SOLUTION

For the efficiency of the engine

$$\eta = \left(1 - \frac{T_2}{T_1}\right) \times 100$$

$$= \left(1 - \frac{400}{500}\right) \times 100$$

$$= \left(\frac{500 - 400}{500}\right) \times 100$$

$$= \frac{100}{500} \times 100$$

$$\eta = 20\%$$

For heat, as we know that

$$\text{Efficiency} = \frac{\text{Output}}{\text{Input}}$$

$$\boxed{\eta = \frac{W}{Q_1}}$$

$$\frac{20}{100} = \frac{10000}{Q_1}$$

$$\frac{1}{5} = \frac{10000}{Q_1}$$

$$Q_1 = 50000 \text{ J}$$

$$= 5 \times 10^4 \text{ J}$$

For heat rejected

$$W = Q_1 - Q_2$$

$$\boxed{W = Q_1 - W}$$

$$= 50000 - 10000$$

$$= 40000 \text{ J}$$

$$Q_2 = 4 \times 10^4 \text{ J}$$

Result

Efficiency of engine $= \eta = 20\%$

Heat absorbed $= Q_1 = 5 \times 10^5$ J

Heat rejected $= Q_2 = 4 \times 10^4$ J

PROBLEM 11.6

A reversible engine works between two temperatures whose difference is 100°C. If it absorbs 746J of heat from the source and rejects 546J to the sink, calculate the temperature of the source and the sink.

Data

Temperature difference $= T_1 - T_2 = 100°C = 100\ K$

Heat absorbed $= Q_1 = 746\ J$

Heat rejected $= Q_2 = 546\ J$

To Find

Temperature of source $= T_1 = ?$

Temperature of sink $= T_2 = ?$

SOLUTION

By formula

$$\text{Efficiency} = \left(1 - \frac{Q_2}{Q_1}\right) \times 100$$

$$= \left(1 - \frac{546}{746}\right) \times 100$$

$$= \frac{746 - 546}{746} \times 100$$

$$= \frac{200}{746} \times 100$$

$$\eta = 26.8\%$$

As $T_1 - T_2 = 100°C = 100\ K$

$$T_1 - T_2 = 100$$

Therefore;

$$\eta = \left(1 - \frac{T_2}{T_1}\right) \times 100$$

$$\eta = \frac{T_1 - T_2}{T_1}$$

$$\frac{26.8}{100} = \frac{100}{T_1}$$

$$26.8\ T_1 = 100 \times 100$$

$$T_1 = \frac{100 \times 100}{26.8}$$

$$T_1 = 373\ K - 273$$

$$= 100°C$$

So $T_2 = 0°C$

Result

Temperature of source = T_1 = 100°C

Temperature of sink = T_2 = 0°C

PROBLEM 11.7

A mechanical engineer develops an engine, working between 327°C and 27°C and claim to have an efficiency of 52%. Does he claim correctly? Explain.

Data

Temperature of source = T_1 = 327°C + 273

= 600 K

Temperature of sink = T_2 = 27°C + 273

= 300 K

Given efficiency = η = 52%

To Find

Is his claim correct = ?

SOLUTION

By formula

$$\eta = \left(1 - \frac{T_2}{T_1}\right) \times 100$$

$$= \left(1 - \frac{300}{600}\right) \times 100$$

$$= \frac{300}{600} \times 100$$

$$= 50\%$$

Result

As the efficiency of engine is 52% but calculated efficiency of the engine is 50%. So Mechanical Engineer's claim is not correct.

PROBLEM 11.8

A heat engine performs 100J of work and at the same time rejects 400J of heat energy to the cold reservoirs. What is the efficiency of the engine?

Data

Work done = W = 100 J

Heat rejected = Q_2 = 400 J

To Find

Efficiency of the engine = η = ?

SOLUTION

By formula

$$\eta = \left(1 - \frac{Q_2}{Q_1}\right) \times 100$$

$$\eta = \frac{Q_1 - Q_2}{Q_1} \times 100$$

Since $Q_1 - Q_2 = W$

$$Q_1 = W + Q_2$$

$$= 100 + 400$$

$$= 500 \text{ J}$$

$$\boxed{\eta = \frac{W}{Q_1} \times 100}$$

$$\eta = \frac{100}{500} \times 100$$

$$= 20\%$$

Result

Efficiency of the engine $= \eta = 20\%$

PROBLEM 11.9

A Carnot engine whose low temperature reservoir is at 7°C has an efficiency of 50%. It is desired to increase the efficiency to 70%. By how many degrees the temperature of the source be increased?

Data

Temperature of sink $= T_2 = 7°C + 273$

$= 280 \text{ K}$

Efficiency $= \eta = 50\% = \frac{50}{100} = \frac{1}{2}$

Efficiency $= \eta' = 70\% = \frac{70}{100} = \frac{7}{10}$

To Find

Increase in temperature of source $= \Delta T = ?$

SOLUTION

By formula

$$\eta = 1 - \frac{T_2}{T_1}$$

when $\eta = \frac{1}{2}$

$$\frac{1}{2} = 1 - \frac{280}{T_1}$$

$$\frac{1}{2} = \frac{T_1 - 280}{T_1}$$

$$2(T_1 - 280) = T_1$$

$$2T_1 - 560 = T_1$$

$$2T_1 - T_1 = 560$$

$$\boxed{T_1 = 560 \text{ K}}$$

when $\eta' = \frac{7}{10}$

$$\eta' = 1 - \frac{T_2}{T_1'}$$

$$\frac{7}{10} = \frac{T_1' - 280}{T_1'}$$

$$10(T_1' - 280) = 7T_1'$$

$$10T_1' - 2800 = 7T_1'$$

$$10T_1' - 7T_1' = 2800$$

$$3T_1' = 2800$$

$$T_1' = \frac{2800}{3}$$

$$T_1' = 933.3 \text{ K}$$

Increase in temperature of source

$$\Delta T = T_1' - T_1$$

$$= 933 - 560$$

$$= 373 \text{ K}$$

Result

Increase in temperature of source = 373 K or 373°C

PROBLEM 11.10

A steam engine has boiler that operates at 450K. The heat changes water to steam, which derives the piston. The exhaust temperature of the outside air is about 300K. What is maximum efficiency of this steam engine?

Data

Temperature of source = T_1 = 450 K

Temperature of sink = T_2 = 300 K

To Find

Maximum efficiency of steam engine = η = ?

SOLUTION

By formula

$$\eta = \left(1 - \frac{T_2}{T_1}\right) \times 100$$

$$= \left(1 - \frac{300}{450}\right) \times 100$$

$$= \frac{450 - 300}{450} \times 100$$

$$= \frac{150}{450} \times 100$$

$$\eta = 33.3\%$$

Result

Efficiency of steam engine = η = 33.3%

PROBLEM 11.11

336J of energy is required to melt 1g of ice at 0°C what is the change in entropy of 30g of water at 0°C as it changed to ice at 0°C by a refrigerator?

Data

Heat of fusion of ice = H_f = 336 J/g

Mass of water = m = 30 g

Temperature = T = 0°C + 273 = 273 K

To Find

Change in entropy = ΔS = ?

SOLUTION

By formula

$$\boxed{\Delta S = -\frac{\Delta Q}{T}}$$

But $\Delta Q = mH_f$

$$= 30 \times 336 \text{ J}$$

So $$\Delta S = -\frac{30 \times 336}{273}$$

$$= -36.9 \text{ J/K}$$

Result

Change in entropy = ΔS = –36.9 J/K