$\theta_2 = 90^o$

Critical angle $= \theta_1 =$ $\theta_c = ?$,

Angle of entry $= \theta_1' = ?$

Solution:

We know that:

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

$$\sin\theta_1 = \frac{n_2 \sin\theta_2}{n_1}$$

Substituting the values we get

$$= \frac{1.4 \times \sin 90^o}{1.6}$$

$$\sin\theta_1 = 0.875$$

$$\theta_1 = \sin^{-1} 0.875$$

$$\theta_1 = 61^\circ$$

as $\theta_1 = \theta_c = 61^\circ$

(b) $n_1 = 1$, (for air)

$n_2 = 1.6$, (for core)

$\theta_1' = ?$,

$\theta_2' = 90 - \theta_1$ from the diagram

$\theta_2' = 90^o - 61^o = 29^o$

Using snell's law

$$n_1 \sin\theta_1' = n_2 \sin\theta_2'$$

$$\sin\theta_1' = \frac{n_2 \sin\theta_2'}{n_1}$$

$$= \frac{1.6 \times \sin 29^o}{1}$$

$$= 1.6 \times 0.484$$

$$\sin\theta_1' = 0.7744$$

$$\theta_1' = \sin^{-1}(0.7744)$$

$$\theta_1' = 50.750^o$$

or $\theta_1' = 51^\circ$

Unit 11

HEAT AND THERMODYNAMICS

troduction:

Heat is a form of energy and can be converted into other forms of energy. The branch of ysics which deals with various phenomena of energy and related properties of matter, especially transformation of heat into other forms of energies, is known as thermodynamics. ermodynamics plays an important role in technology and science. In this chapter we will study ermal behaviour of gases and the principles governing the inter-conversion of heat into mechanical rk.

1 Describe the fundamental postulates of the kinetic theory of gases. 11111001

netic theory of gases:

For explanation of thermal behaviour of the gases kinetic theory was proposed having following umptions.

- A finite volume of gas contains large number of identical, point - like particles called molecules.
- The average distance between any two molecules is very large as compared to their sizes.
- The gas molecules are in random motion and change their direction of the motion after every collision.
- Collisions of the molecules among themselves and with the walls of container are perfectly elastic.
- Molecules do not exert forces of attraction on each other, except during collision.

2 Using kinetic theory of gases, prove the following relations: (Board 2009) 11111002

(i) $P = \frac{1}{3}\rho < v^2 >$ (ii) $p \propto < K.E >$ (iii) $T \propto < \frac{1}{2} mv^2 >$

ssure of gas:

According to kinetic theory, the pressure exerted by the gas is due to transfer of momentum of the lecules to the walls of container per second per unit area due to the collisions.

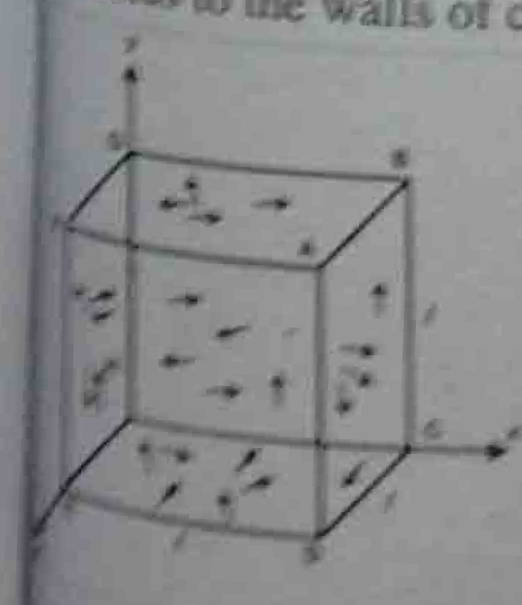


fig. (1)

Consider a cubical box; the length of the each edge of the box is 'l'. It contains "N" number of molecules as shown in fig (1). The molecules in the box are moving in random directions. The molecules are moving with different velocities. The velocities of molecules can be resolved into their components along x-axis, y-axis, and z-axis. Let m be the mass of each molecule of the gas.

Let one of the molecules moving with velocity v_1 is colliding with face ABCD of the container. The components of the velocity $\vec{v_1}$ of the molecule are v_{1x}, v_{1y} and v_{1z} along x, y and z axes respectively. The

molecule will bounce back with same speed from face ABCD. The components of velocity of the molecule after collision are $-v_{1x}$, $-v_{1y}$ and $-v_{1z}$ respectively.

Initial momentum of molecule along x-axis = $m\,v_{1x}$

Final momentum of molecule along x-axis = $-m\,v_{1x}$

Change in momentum = Final momentum – Initial momentum.

Change in momentum = $-m\,v_1x - m\,v_1x$

Change in momentum = $-2mv_1x$ ……………………(1)

Frequency of collision:

After collision the molecule move towards opposite face EFGH and collide with it. The molecule again rebounds and travel back towards the face ABCD. The molecule covers distance "2l" between two successive collisions with face ABCD. Thus the time $\triangle t$ between two successive collisions with face ABCD is written as

$$\Delta t = \frac{2\ell}{v_{1x}} \quad \text{………………(2)}$$

The number of collisions per second also called the frequency of collision, is given by:

$$f = \frac{v_{1x}}{2\ell} \quad \text{-------------------- (3)}$$

Thus rate of change of the momentum of the molecule is given by

$$= -2mv_{1x} \times \frac{v_{1x}}{2\ell}$$

$$= \frac{-mv_{1x}^2}{\ell}$$

The rate of change of momentum of the molecule is equal to the force applied by the wall. According to Newton's third law of motion, force F_{1x} exerted by the molecule on face ABCD is equal but opposite, so

$$F_{1x} = \frac{-\left(-mv_{1x}^2\right)}{\ell} = \frac{mv_{1x}^2}{\ell} \quad \text{………(4)}$$

Similarly the force exerted by the other molecules with face ABCD

$$F_2x = \frac{mv_2^2x}{\ell}$$

$$F_3x = F_2 \times \frac{mv_3^2}{\ell}$$

……………………………

$$F_nx = \frac{mv_{nx}^2}{\ell}$$

Total force on the wall ABCD will be equal to

$$F_x = F_{1x} + F_{2x} + F_{3x} + \text{…………}F_{nx}$$

i.e. $F_x = F_x = \frac{mv_1^2}{\ell} + \frac{mv_2^2}{\ell} + \text{……………………} + \frac{mv^2 nx}{\ell}$

As $\text{Pressure} = \frac{\text{Force}}{\text{Area}}$

So $P_x = \frac{F_x}{\ell^2}$

Or $P_x = \frac{1}{\ell^2}\left(\frac{mv_{1n}^2}{\ell} + \frac{mv_{2n}^2}{\ell} + \text{…………}\frac{mv_n^2}{\ell}\right)$

$$P_x = \frac{m}{l^3}\left(v_{1x}^2 + v_{2x}^2 + \text{……………} + v_{nx}^2\right)$$

Multiply and divide the right hand side by N.

$$P_x = \frac{mN}{l^3}\left(\frac{v_{1x}^2 + v_{2x}^2 + \text{…………} v_{nx}^2}{N}\right)$$

Where $mN = M$ = mass of the gas, and $\ell^3 = V$ = volume of gas

$$P_x = \frac{M}{V}\left(\frac{v_{1x}^2 + v_{2x}^2 + \text{…………} v_{nx}^2}{N}\right)$$

But $\frac{M}{V} = \rho$ = density of gas

$$\boxed{P_x = \rho\left(\frac{v_{1x}^2 + v_{2x}^2 + \text{…………} v_{nx}^2}{N}\right)}$$

and $\left(\frac{v_{1x}^2 + v_{2x}^2 + \text{…………} v_{nx}^2}{N}\right)$ = average of squared velocities of the molecule along X-axis and represented by $\langle v_x^2 \rangle$

$$\therefore \quad P_x = \rho\langle v_x^2\rangle \quad \text{-------------------- (5)}$$

The average of the square of velocity of the gas molecules is given by:

$$\langle v^2\rangle = \langle v_x^2\rangle + \langle v_y^2\rangle + \langle v_z^2\rangle$$

As the components of the velocity of the molecule along x-axis, y-axis, and z-axis are equally probable

$$\therefore \quad \langle v_x^2\rangle = \langle v_y^2\rangle = \langle v_z^2\rangle$$

Hence

$$\langle v^2\rangle = \langle v_x^2\rangle + \langle v_x^2\rangle + \langle v_x^2\rangle$$

$$\langle v^2\rangle = 3\,\langle v_x^2\rangle$$

$$\langle v_x^2\rangle = \frac{1}{3}\langle v^2\rangle \quad \text{-------------------- (6)}$$

Substituting the value in eq. (4)

$$\boxed{P = \frac{1}{3}\rho\langle v^2\rangle} \quad \text{-------------------- (7)}$$

The relation between pressure and average kinetic energy:

The density of gas "ρ" is given by

$$\rho = \frac{M}{V}$$

Putting value of ρ in equation (7)

$$P = \frac{1}{3}\frac{M}{V}\langle v^2\rangle$$

Where $M = mN$ is the mass of gas

$$\text{so } P = \frac{1}{3}\frac{mN}{V}\langle v^2\rangle$$

Dividing and multiplying by 2 on right hand side and rearranging

$$\boxed{P = \frac{2}{3}\frac{N}{V}\langle\frac{1}{2}mv^2\rangle}$$

Where $\frac{N}{V}$ are the number of molecules per unit volume = N_o

$$\boxed{\therefore\ P = \frac{2}{3}N_o\langle\frac{1}{2}mv^2\rangle}$$

as $\frac{2}{3}N_o = \text{Constant}$

$$P = \text{constant} \times \langle\frac{1}{2}mv^2\rangle$$

$$\Rightarrow \boxed{P \propto \langle K.E\rangle}$$

Hence pressure of an ideal gas is proportional to average K.E of the gas molecules.

Interpretation of temperature:

According to kinetic theory of gasses

$$P = \frac{2}{3}\frac{N}{V}\langle\frac{1}{2}mv^2\rangle \quad \text{-----------------} (1)$$

And according to ideal gas law

$$PV = nRT$$

$$\text{or} \quad P = \frac{nRT}{V} \quad \text{-----------------} (2)$$

The gas constant per molecule known as Boltzman constant is written as

$$k = \frac{R}{N_A}$$

$$\therefore\ R = kN_A$$

where N_A = Avogadro number

substituting value of R in equation (2) we get

$$P = \frac{nN_AkT}{V}$$

Where the total number of molecules $N = nN_A$

$$\therefore\ P = \frac{NkT}{V} \quad \text{-----------------} (2)$$

Comparing equation (1) and (2)

$$\frac{NkT}{V} = \frac{2}{3}\frac{N}{V}\langle\frac{1}{2}mv^2\rangle$$

$$\therefore\ T = \frac{2}{3k}\langle\frac{1}{2}mv^2\rangle \quad \text{-----------------} (3)$$

Where $\frac{2}{3k} = \text{constant}$

$$\therefore\ \boxed{T \propto \langle\frac{1}{2}mv^2\rangle}$$

Hence, temperature of the gas is directly proportional to average K.E of the gas molecules.

Q3 Deduce the Boyle's law and Charles' Law from kinetic theory of gases. 11111003

Derivation of gas laws from kinetic theory of gasses:

1. **Boyle's Law:**

From kinetic theory of gases

$$P = \frac{2}{3}\frac{N}{V}\langle\frac{1}{2}mv^2\rangle$$

$$PV = \frac{2}{3}N\langle\frac{1}{2}mv^2\rangle$$

If we keep temperature constant, average K.E energy remains constant so the right hand side of above equation is constant. Hence,

$$PV = \text{Constant}$$

$$\text{or} \quad P = \text{Constant} \times \frac{1}{V}$$

$$\text{or} \quad P \propto \frac{1}{V}$$

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

2. **Charles' Law:** **(Board 2008)**

From kinetic theory of gases.

$$P = \frac{2}{3}\frac{N}{V}\left\langle\frac{1}{2}mv^2\right\rangle$$

$$\text{or} \quad V = \frac{2N}{3P}\left\langle\frac{1}{2}mv^2\right\rangle$$

If pressure is constant, then $\frac{2N}{3P}$ is also constant

$$V = \text{Constant}\left\langle\frac{1}{2}mv^2\right\rangle$$

$$\therefore\ V \propto \left\langle\frac{1}{2}mv^2\right\rangle$$

$$\text{Since } \left\langle\frac{1}{2}mv^2\right\rangle \propto T$$

Hence $\boxed{V \propto T}$

Thus volume of given mass of gas is directly proportional to absolute temperature provided pressure is kept constant. This is known as Charles' law.

Q.4 Define the term "internal energy". Show that internal energy is a function of state and independent of paths.

Internal energy:

The sum of all forms of molecular energies (kinetic and potential) of a substance is known as internal energy.

A diatomic gas molecule has both translational and rotational energy. It also has vibratory energy associated due to spring like bond between its atoms. This is the shown in fig. (2).

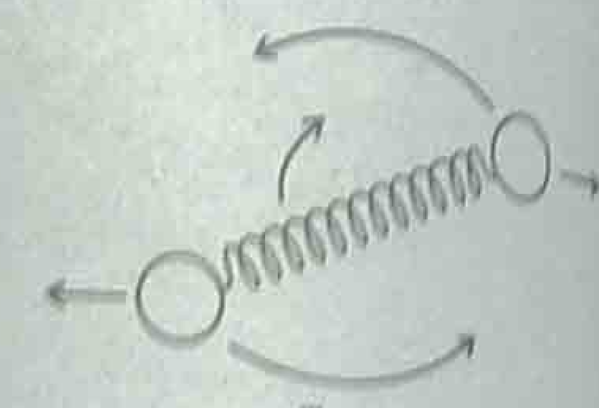


fig. (2)

Explanation:

In the study of thermodynamics we usually consider an ideal gas as a working substance. The molecules in ideal gas are treated as light point masses, which exert no forces on one another. Therefore internal energy of an ideal gas is generally the translational K.E. By kinetic theory of gases the average kinetic energy of molecule is directly proportional to temperature. On supplying heat energy the energy associated with its atoms and molecules is increased i.e. heat is converted into internal energy. It should be noted that some time without adding heat energy into the system the internal energy of the system can be increased.

Examples:

1. When two objects are rubbed together internal energy increases due to conversion of mechanical energy into heat. The temperature of the objects increase which indicates increase in internal energy.
2. When object slides on any surface and comes to rest due to frictional forces, the mechanical work done by the system is partially converted into internal energy.

Internal energy as a state function:

The internal energy is a state function of the system which depends upon initial and final states of the system and does not depend on the path or process. When the system undergoes a process in which its state changes from (P_a, V_a) to (P_b, V_b) as shown in the fig (3), regardless of the processes (paths) by which system changes from initial to final state, the change in internal energy is always same and is independent of the paths C_1 and C_2 as shown in diagram.

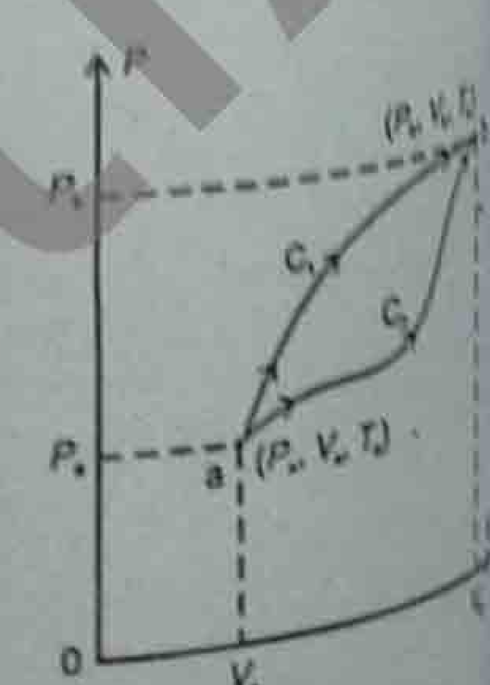


fig. (3)

The internal energy is similar to the gravitational P.E. So, it is the change is internal energy and not its absolute value, which is important. i.e.

$$\Delta U = U_b - U_a$$

Where,

U_b = internal energy at state b.

And U_a = internal energy at state a.

During cyclic process the change in internal energy of the system is zero. The internal energy of an ideal gas is generally the translational K.E of its molecules.

Q.5 Describe transfer of energy into work and heat. Calculate the work done by a thermodynamic system. 11111005

Work and heat:

We know that both heat and work are related with transfer of energy by some means. This idea was applied first to the construction of steam engine which converts heat into the work. Both heat in and work out are taken as positive quantities. Hence work done by the system (gas) on its environment is taken positive while work done on the system by the environment is taken negative.

When an amount of heat "Q" enters the system, it either appears as an increase in internal energy of the system or is used up on doing work by the system on its surroundings.

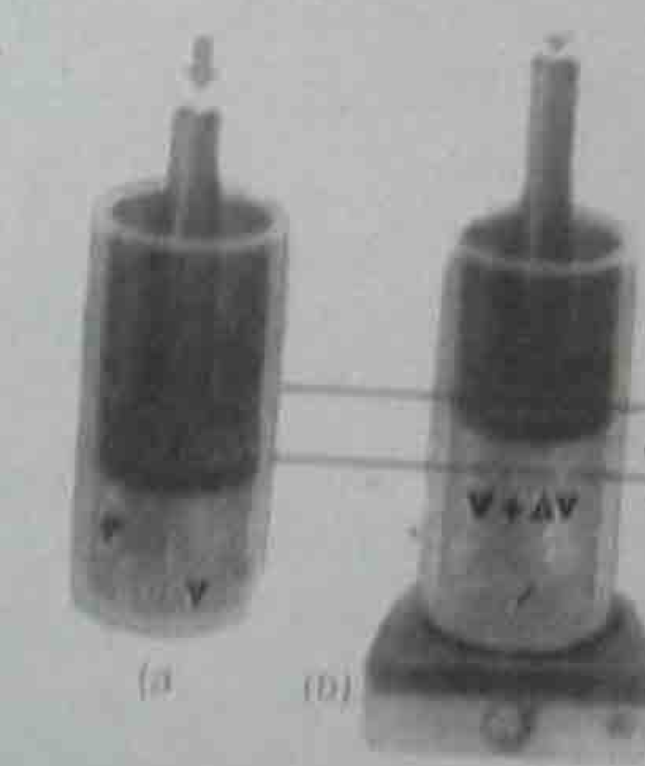


fig (4)

Expression for Work:

Consider a gas enclosed in a cylinder, which is fitted with freely movable piston. Let the cross sectional area of the piston is "A" as shown in figure (4a). The system is in equilibrium and occupies volume "V" and exerts a pressure "P" on walls of cylinder and piston.

From definition of pressure

$$P = \frac{F}{A}$$

or $F = PA$

Let the piston moves upward through small distance "Δy", the work done by the system is

$W = \vec{F}.\vec{d}$

$= Fd \cos\theta$ where $\theta = 0^o$

$= Fd \cos 0^o$

$= Fd\,(1)$

Putting $F = PA$ and $d = \Delta y$

$\therefore \quad W = PA\,\Delta y$

But $A\Delta y = \Delta V$ = Change in volume of gas.

$\therefore \quad W = P\Delta V$

Where $\Delta V = V_2 - V_1$

$\therefore \quad W = P(V_2 - V_1)$ ---------- (1)

When gas expands $V_2 > V_1$ then by equation (1) the work done by the system will be positive. When gas is compressed $V_2 < V_1$ then the work done on the system is negative.

Graphical representation of work:

The work done by gas on piston can also be calculated by the area under the graph on PV-diagram as shown in fig.(5).

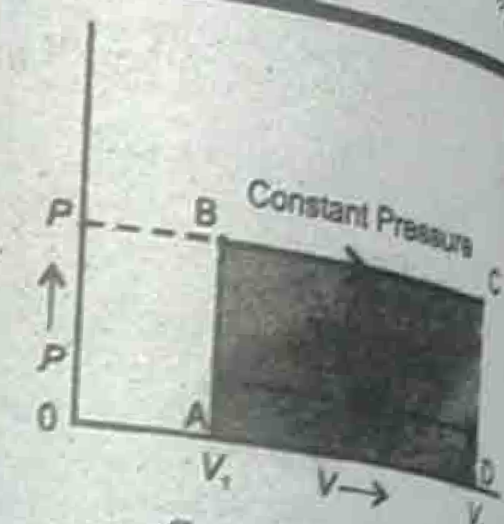


fig (5)

Q.6 State and explain first law of thermodynamics.

1st Law of Thermodynamics:

Statement:

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

Explanation:

When heat is added to system then there is an increase in its internal energy due to rise in temperature and increase in pressure or change in the state of system. If at the same time, system is allowed to do work on its environment by expansion, the heat added to the system will produce change in internal energy from U_1 to U_2 plus the work done by the system on environment.

Mathematically it can be written as:

$$Q = (U_2 - U_1) + W$$

or $$Q = \Delta U + W \quad \text{------------------- (1)}$$

This is mathematical form of first law of thermodynamics which is in fact a form of the law of conservation of energy.

Change in Internal Energy:

Equation (1) can be written as

$$\Delta U = Q - W$$

Where $\Delta U = U_2 - U_1$, is the change in internal energy of the system. From equation (1) the change in internal energy of the system is equal to the energy flowing into the system as heat minus the energy flowing out of the system in the form of work.

Examples of First Law of Thermodynamics

(1) Bicycle Pump

When we pump the handle rapidly it becomes hot due to work done on the gas thus, raising its internal energy. This can be explained by a simple experiment as shown in fig. (6). It consists of a bicycle pump with blocked outlet. A thermocouple is connected with its blocked outlet to monitor the temperature of air.

When piston of the pump is rapidly moved inward, thermometer shows a rise in temperature due to increase in internal energy.

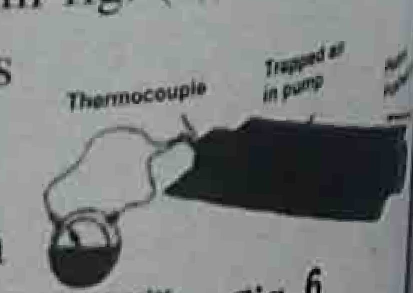


Fig. 6

(2) Human Metabolism

It is also another example of energy conservation. The energy transforming processes that occur within an organism is named as metabolism. Human beings and animals when they run or move heavy objects they do work. The work requires energy which is needed for growth, making of

cells and to replace the old ones. We can apply the first law of thermodynamics i.e. $\Delta U = Q - W$ to an organism of human body. The work "W" done will result in decrease in internal energy of the body. As a result body temperature will fall and is maintained by the food that we eat.

Q.7 Discuss the applications of 1st law of thermodynamics. OR

Discuss the following processes and draw P – V diagram in each case.

(i) Isothermal process (ii) Adiabatic process

Application of 1st law of thermodynamics:

Isothermal Process:

"The process during which the temperature of the system remains constant is known as isothermal process".

For gaseous system during isothermal process product of pressure and volume remain constant i.e. the Boyle's law is fulfilled when a gas expands or compresses isothermally. If P_1, V_1 are initial pressure and volume where as P_2, V_2 are final pressure and volume then

$$P_1 V_1 = P_2 V_2$$

As the internal energy of an ideal gas depends upon the temperature therefore, during isothermal process change in internal energy will be zero i.e. $\Delta U = 0$. By 1st law of thermodynamics

$$Q = 0 + W$$

or $$\boxed{Q = W}$$

Hence all the heat energy supplied during isothermal process is converted into work. Thus when gas expand and do external work 'W' then amount of heat 'Q' has to be supplied to the gas in order to produce an isothermal change. Since transfer of heat from one place to another require time hence to keep temperature of the gas constant, the expansion or compression must take place slowly.

Graphical Representation of isothermal process:

Graphically the process on PV-plane is represented by a curved line known as isotherm, this is shown in fig. (7)

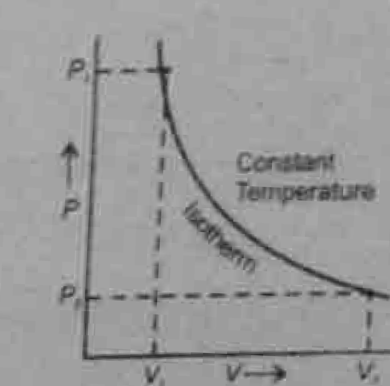


fig. (7)

Adiabatic Process:

"The process, in which the system does not exchange heat energy i.e. no heat enters or leave the system, is known as adiabatic process".

In this case Q = O. By applying 1st law of thermodynamics we can write

$$O = \Delta U + W$$

or $$\Delta U = -W$$

Thus, if the gas expands and does external work, it is done at the cost of internal energy of its molecules. Therefore the temperature of the gas falls. On the other hand if the gas is compressed adiabatically the temperature of the gas will rise. The adiabatic change occur when gas expands or is compressed rapidly so that heat should not get any time to leave or enter into the system

Examples

i. The rapid escape of air from a burst tyre.
ii. The rapid expansion and compression of air through which a sound wave is passing.
iii. Cloud formation in the atmosphere.

During the adiabatic process there is change in internal energy, therefore temperature of the system will not remain same. In this case:

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

Where $\gamma = \frac{C_p}{C_v}$

Graphical representation:

The adiabatic process on the PV plane is represented by the curve which is steeper than the corresponding "isotherm". The curve is known as "adiabat," and is shown in fig (8)

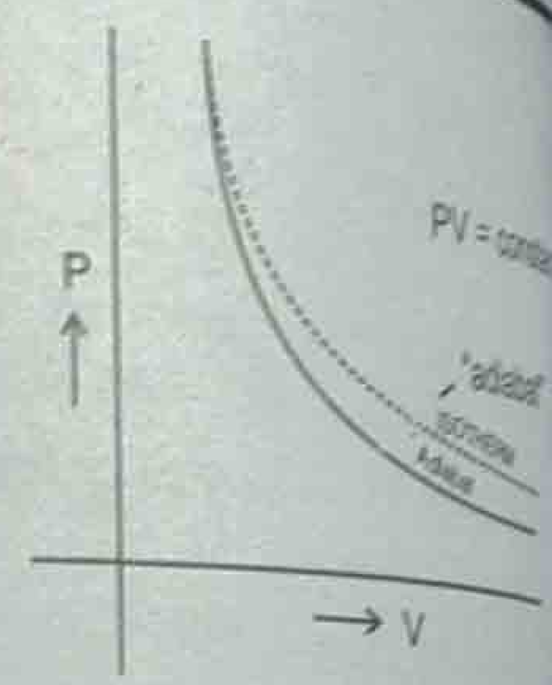


fig (8)

Q.8 Define molar specific heats of a gas. Also prove that $C_p - C_v = R$. OR

Show that difference between two specific heats of a gas is equal to molar gas constant.

Molar specific heats of gas:

The amount of heat supplied to the substances having one kilogram mass is different because they contains different number of molecules. But one mole of different substances contains same number of molecules. Thus molar specific heat of a substance is defined as:

"The heat required to raise the temperature of one mole of the substance through 1 K".

In case of solids and liquids during transfer of heat the change in volume is negligible. Therefore the work done against external pressure during change of temperature is very small.

The same can not be true for the gases which suffer variation of pressure as well as volume with the rise in temperature. Therefore, it is customary to define molar specific heat of a gas in two ways.

Molar Specific Heat Capacity at Constant Volume (C_v):

It is an amount of heat required to raise the temperature of one mole of a gas by one kelvin (K) by keeping the volume constant. Mathematically it is written as:

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

Therefore

For one mole of a gas

$$Q_v = C_V\Delta T \quad \text{----------- (1)}$$

According to 1st law of thermodynamics

$$Qv = \Delta U + W$$

As $W = P\Delta V$

$$\therefore \quad Q_v = \Delta U + P\Delta V$$

As volume of the system is kept constant therefore $\Delta V = 0$, Hence

$$Q_v = \Delta U$$

Therefore 1st law of thermodynamics gives:

$$C_v\Delta T = \Delta U \quad \text{-------- (2)}$$

Molar specific heat capacity at constant pressure: "C_p"

It is the amount of heat required to raise the temperature of one mole of a gas by one kelvin by keeping the pressure constant. Mathematically

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

$$\therefore \quad Q_p = nC_p\Delta T$$

for one mole of a gas

$$Q_P = C_P\Delta T$$

It should be noted that S.I unit of C_P and C_v, are $J\,mole^{-1}K^{-1}$

Derivation of $C_p - C_v = R$:

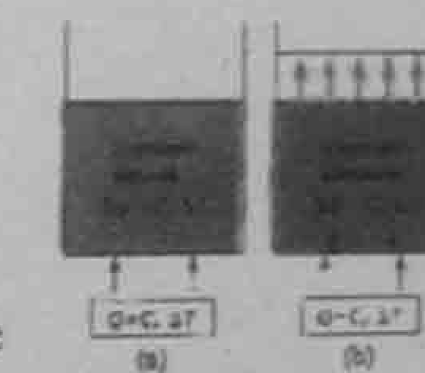


Fig. 9

Consider two cylinders as shown in fig (9) each containing one mole of an ideal gas. Let in one of the cylinder the piston is firmly fixed and in 2nd cylinder it is freely movable. In both the cases the temperature of the gas is increased from T to T + ΔT.

The heat supplied at constant volume is written as:

$$Q_V = nC_V\Delta T$$

as $n = 1$ mole

$$\therefore \quad Q_V = C_V\Delta T \quad \text{--------------- (1)}$$

The work done in this case will be zero, because piston doesn't move.

as $W = P\Delta V$

and $\Delta V = 0$

$\therefore \quad W = 0$

Using 1st Law of thermodynamics that is:

$$Q_v = \Delta U + W$$

$$Q_v = \Delta U + 0 = \Delta U$$

$$\therefore \quad \Delta U = C_V\Delta T \quad \text{-------------- (2)}$$

In 2nd case heat is supplied at constant pressure Q_P which is greater than Qv, it is because piston is freely movable and work is required to push the piston upward. The heat supplied to increase the temperature by ΔT Kelvin is given by

$$Q_P = C_P\Delta T$$

In this case work is done by the system as the piston moves upward through a distance Δy and is given by:

$$W = P\Delta V$$

Using first law of thermodynamics i.e

$$Q_P = \Delta U + W$$

Substituting the value of Q_P and ΔU

$$C_P\Delta T = C_V\Delta T + P\Delta V \quad \text{------------- (3)}$$

Using general gas equation for one mole

$$P\Delta V = R\Delta T$$

Substituting the value of $P\Delta V$ in eq. (3)

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

dividing by ΔT

$$\frac{C_P\Delta T}{\Delta T} = \frac{C_V\Delta T}{\Delta T} + \frac{R\Delta T}{\Delta T}$$

$$C_P = C_V + R$$

$$C_p - C_V = R$$

$$C_P = C_V + R$$

$$\boxed{C_P - C_V = R}$$

This equation shows that $C_P > C_V$ by an amount equal to universal gas constant R.

Q.9 Describe reversible and irreversible processes.

Reversible process:

The process which can be retraced by reversing the controlling factors without producing change in the surrounding is known as reversible process.

Explanation:

In the reverse process, the working substance passes through the same stages as in the direct process but thermal and mechanical effects at each stage are exactly reversed. It means that during reversible process, if heat is absorbed in the direct process, it will be given out in reverse process. Similarly if work is done by the working substance in direct process, an equal amount of work will be done on working substance in reverse process. Hence thermal and mechanical effects are exactly reversed.

Examples:

1. Slow expansion and compression of the gas.
2. Liquefaction and Evaporation.

Irreversible process:

A process which cannot be retraced in the backward direction by reversing the controlling factors is known as irreversible process.

Explanation:

All sudden changes which involve frictional effects or dissipation of energy are irreversible. The energy dissipation may be the result of conduction, convection or radiation.

Example: 1. Work done against friction is an irreversible process.
2. A chemical explosion.
3. All engines in practical life.

Q.10 What is heat engine? What is its principle?

Heat engine:

"The device which converts heat energy into mechanical work is known as heat engine." Usually the heat comes from burning of fuel. The first heat engine was a steam engine. It was developed on the fact that when water is boiled in a vessel covered with a lid a steam inside tries to push the lid showing ability to do work.

Principle: A heat engine consists of hot reservoir which is a source of heat and a cold reservoir which is also known as sink. The working substance is needed which absorbs heat Q_1 from source, converts some of it into mechanical work W and rest of the heat energy Q_2 is rejected to cold reservoir or sink. For a continuous supply of work the heat engine is made cyclic i.e., the working substance is brought back to its initial state repeatedly.

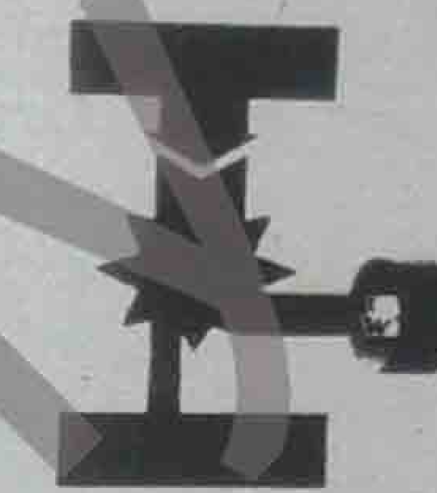


Fig 10

Q.11 State and explain second law of thermodynamics. 11111011

Second law of Thermodynamics:

First Law of thermodynamics tells us that heat energy can be converted into equivalent amount of work, but it tells nothing about the conditions under which this conversion takes place. Second law is concerned with the circumstances in which heat can be converted into work and direction of flow of heat.

Explanation:

The engine or the system is represented by a block diagram as shown in fig. 10. It absorb a quantity of heat Q_1 from the source at temperature T_1 after doing work W expels heat Q_2 to low temperature reservoir at temperature T_2. The working substance under goes a cyclic process which finally bring back the system to its initial state. Therefore, the change in internal energy ΔU is zero. Applying first law of thermodynamics i.e.

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

Where $\Delta Q = Q_1 - Q_2$

$$\therefore \quad Q_1 - Q_2 = W$$

In real heat engine of a motor car convert a part of the energy obtained from burning of fuel into work and rest of the energy is rejected to the atmosphere. The petrol engine converts 25% and diesel engine converts 35 to 40% of total energy into mechanical work.

Lord Kelvin's Statement:

According to Lord Kelvin, it is impossible to devise a process which may convert heat taken from a single reservoir entirely into work without leaving any change in the working system. This is illustrated in fig. (11).

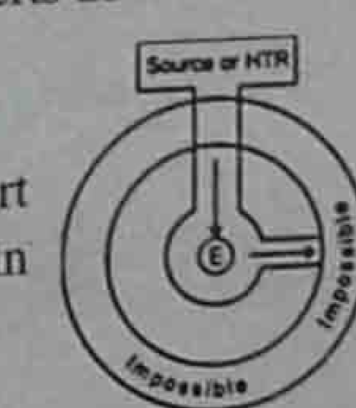


Fig. 11

Explanation:

A single reservoir of heat, no matter how much energy it contains cannot be made to perform any work. If this would have been true then enormous amount of heat energy in our oceans and atmosphere could be made available to be converted into useful work. Thus according to second law of thermodynamics two bodies at different temperature are essential for conversion of heat into work. The body at higher temperature is known as source from which the heat is taken and the body at lower temperature is known as sink to which heat is rejected.

Q.12 What is Carnot engine? Describe the Construction, principle and working of Carnot engine. Derive the expression for the efficiency of Carnot engine. Also state Carnot theorem. 11111012

Carnot Engine and Carnot's Theorem:

In 1840, Sadi Carnot proposed an ideal heat engine which involves isothermal and adiabatic processes. He showed that efficiency of such engine is maximum when it works in reversible cyclic

process between two heat reservoir at different temperature. Such heat engine is free from all ... frictional losses and losses of heat due to conduction.

The Carnot's cycle using an ideal gas as a working substance is shown on PV diagram as shown in fig. (12). The Carnot's engine consists of a cylinder with non conducting walls, piston and conducting base. An ideal gas is enclosed in the cylinder as a working substance.

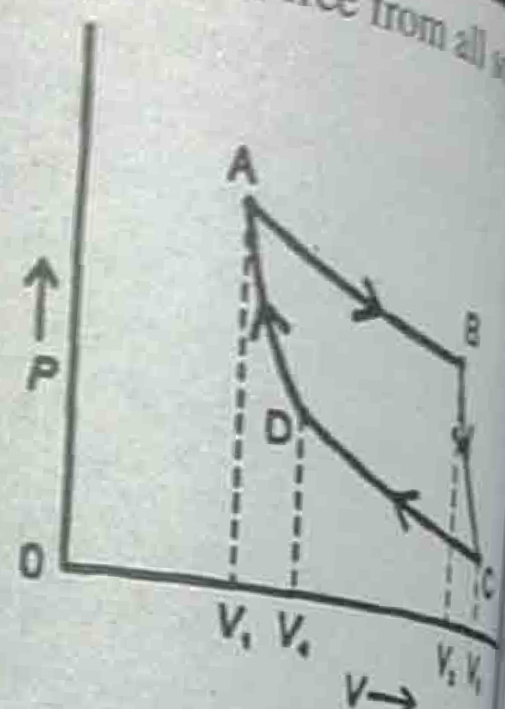


Fig. 12

Principle:

Like other cyclic heat engines Carnot's engine also take heat energy from the hot body and convert into work while the remaining part of energy is rejected to the sink or cold body.

Working:

The cyclic process in which the engine operates is known as Carnot's cycle. It consists of following four processes (1) Isothermal expansion (2) Adiabatic expansion (3) Isothermal compression ... Adiabatic compression. This is shown in fig. (12).

(1) Isothermal expansion:

This process is realized by placing a Carnot's engine on a hot reservoir at temperature T_1 ... gas is allowed to expand. During the expansion temperature of the gas falls and engine absorbs ... amount of heat from the high temperature reservoir. In this way temperature of the gas will remain constant. This process is represented by curve AB in the fig. (12).

(2) Adiabatic expansion:

Carnot's engine is placed on an insulator and gas is allowed to expand further adiabatically. The temperature of the gas falls from T_1 to T_2. This process is represented by the curve BC as shown in fig. (12).

(3) Isothermal compression:

The engine is now placed at cold reservoir. Gas is compressed slowly. During ... compression the temperature of the gas increases. In order to keep the temperature constant, engine rejects heat energy Q_2 to the cold reservoir. This process is represented by the curve CD as shown in fig. (12).

(4) Adiabatic compression:

The engine is finally placed on an insulator and gas is compressed slowly. The temperature of the gas rises from T_2 to T_1 and the system returns to its initial state. This is represented by the curve DA as shown in fig (12).

Expression for efficiency:

In Carnot's cycle the system finally returns to its initial state therefore there is no change in its internal energy i.e., $\Delta U = 0$

The network done 'W' in the cyclic process is equal to the area enclosed by the cycle ABCDA on PV diagram. The net heat absorb Q in one cycle is given by

$$Q = Q_1 - Q_2$$

Using first law of thermodynamics.

$$Q = \Delta U + W$$

$$Q_1 - Q_2 = 0 + W$$

or $$W = Q_1 - Q_2 \quad \text{------ (1)}$$

The efficiency η of the heat engine is defined as

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

$$\eta = \frac{W}{Q_1} \quad \text{------ (2)}$$

Substituting value of W from equation (1), we get

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

$$\eta = \left(1 - \frac{Q_2}{Q_1}\right) \quad \text{------ (3)}$$

The energy transfer in isothermal expansion or compression comes out to be proportional to Kelvin's temperature of source and sink.

i.e., $Q_1 \propto T_1$

$Q_2 \propto T_2$

Where T_1 and T_2 are the Kelvin's temperature of HTR and LTR respectively

$$\therefore \quad \boxed{\frac{Q_2}{Q_1} = \frac{T_2}{T_1}} \quad \text{------ (4)}$$

Using equation (4) and equation (3), we get.

$$\eta = \left(1 - \frac{T_2}{T_1}\right) \quad \text{------ (5)}$$

The efficiency is usually taken in percentage, therefore,

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

Results:

From the above discussion it becomes evident:

- Efficiency of a Carnot engine is always less than 100%.
- The efficiency of Carnot engine depends upon the temperature difference of HTR and LTR.
- The efficiency of the engine is independent of the nature of working substance.

Carnot Theorem:

No heat engine can be more efficient than a Carnot engine operating between the same two temperatures. The Carnot's theorem can be extended to state that:

"All reversible engines operating between the same two temperatures have the same efficiency, irrespective of the nature of the working substance."

In most practical cases the sink is at environment temperature so the efficiency can only be increases by raising the temperature of hot reservoir. All the real heat engines are less efficient than Carnot engine due to friction and other heat losses.

Q.13 Describe thermodynamic scale of temperature.

Thermodynamic scale of temperature:

The temperature scale is established by choosing two fixed points and using phy... property of material, which varies linearly with temperature. The Carnot's engine provides us the basis to define a temperature scale which is independent of the nature of the material used as thermometric substance.

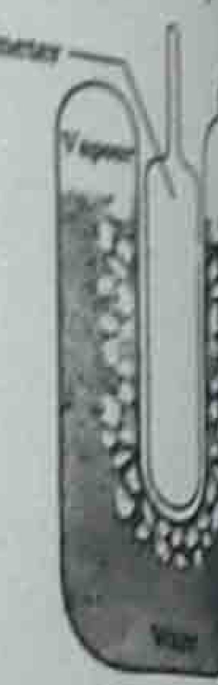


Fig. 13

This relation can be used to define a thermodynamic scale of temperature. In this scale of temperature the absolute temperature 273.16K is used as one of the fixed point and absolute zero as the other. The unit of thermodynamic scale is Kelvin.

Kelvin: One Kelvin is defined as $\frac{1}{273.16}$ of the thermodynamic temperature of the triple point of water.

Q.14 What is meant of triple point?

Triple Point:

It is the state at which ice, water and its vapours co-exists in equilibrium and it oc... uniquely at one particular pressure and temperature. The experimental description of triple poi... water is shown in fig. (13).

Consider a system which is passed through a Carnot's cycle in which it absorb Q amount of heat from the source at temperature T and reject heat Q_3 to the reservoir whose temperature is th... triple point of water T_3. Then the unknown temperature of the source T can be found by using the relation.

$$\frac{Q}{Q_3} = \frac{T}{T_3}$$

$$\therefore \quad T = \frac{Q}{Q_3} \times T_3$$

Where T_3 is the temperature of triple point of water.

$$T = 273.16\,K$$

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

Since the scale is independent of the property of working substance, hence, it can be appl... very low temperature.

...5 Describe the principle, construction and working of petrol engine. (Board 2008) 11111015

...ol Engine:

The Petrol engine as shown in fig. (14), is a practical ... engine consists of a combustion chamber in the form of a ...der fitted with a piston. The connecting rod connects the ...on with the crankshaft. At the top of combustion chamber ... valves namely inlet and exhaust valve are connected. The ...k plug is also fitted at the top of the combustion chamber. ...e cyclic process of petrol engine consist of four strokes ...cesses) named as:

- Intake stroke
- Compression stroke
- Ignition or power stroke
- Exhaust stroke

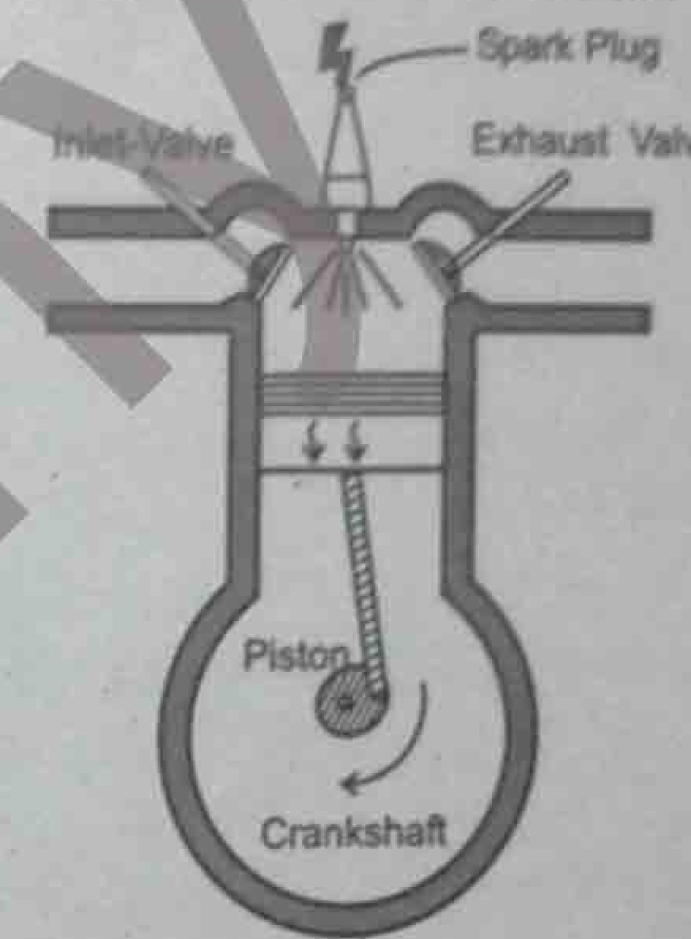


fig. (14)

During intake stroke, the piston moves downward and inlet valves is opened. The carbureted air rushes into the chamber.

In compression stroke inlet valve is closed and the mixture is compressed adiabatically.

In the power stroke spark plug glows and the mixture catch fire causing an increase in temperature and pressure. The hot gases push the piston downward and power is delivered by the connecting rod to the crankshaft.

On the exhaust stroke outlet valve is opened and the hot gases are expelled and piston moves inward.

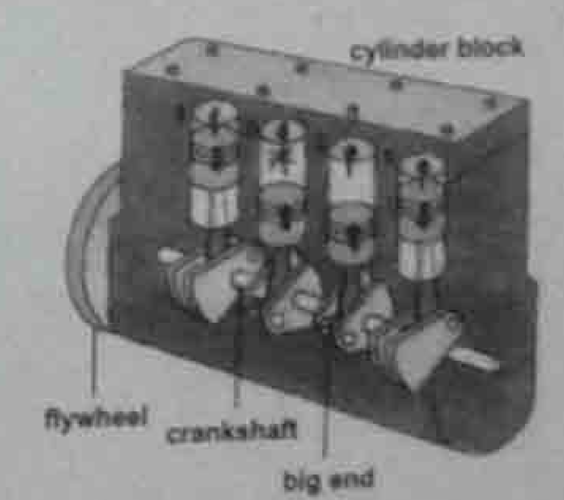


fig. (15)

Most of the motor bikes have one cylinder engine but car usually have four cylinders with ...tons on same crankshaft as shown in fig. (15). The cylinders are fired turn by turn in a sequence ...r its smooth running. The efficiency of petrol engine ranges from 25% to 30% due to frictional and ...her heat losses.

...16 Discuss diesel engine in detail. (Board 2008) 11111016

Diesel engine:

In diesel engine as shown in fig. (16) the diesel is sprayed into the cylinder at maximum compression. The air is at very high temperature immediately after compression the fuel mixture ignites on contact with air. The diesel catches fire and the temperature inside the cylinder increases. As a result, the piston is pushed outward and supplies power to the flywheel of the engine. The efficiency of the diesel engine is about 35% to 40%. It should be noted that no spark plug is needed in the diesel engine.

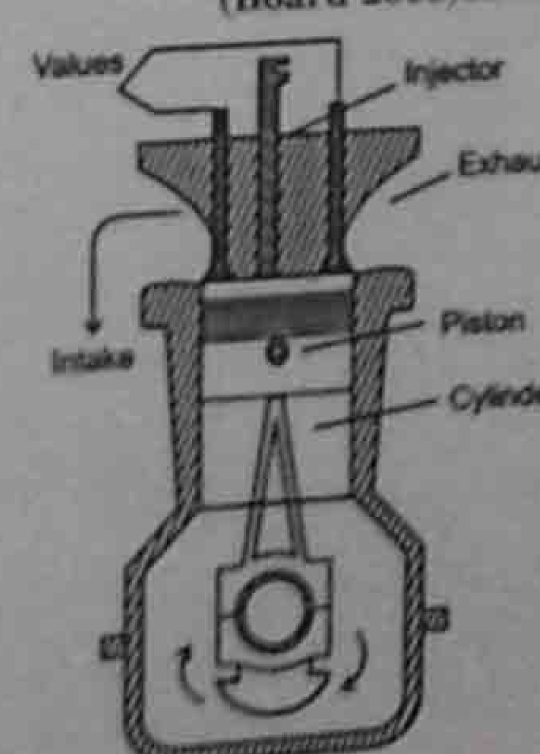


fig. (16)

Q.17 What is entropy? Explain it.

11111017

Entropy:

Entropy is a state function in thermodynamics and it was introduced by Rudolph Claus 1856 to give quantitative meanings to the second law of thermodynamics. It is another variable pressure, volume, temperature and internal energy. Like other state functions it is the change entropy of the system and not its absolute value, which is important, when a system undergoes reversible process.

Expression:

Let a system undergoes a reversible process in which it absorb ΔQ amount of heat at absolute temperature T. The change in entropy "ΔS" is given by

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

Where ΔS is positive when heat is absorbed by the system ΔS is negative when heat removed from the system. SI unit for entropy is JK^{-1}. Like internal energy the change in entropy depends upon the initial and final states of the system.

Change in entropy during irreversible process:

Consider an irreversible process in which heat is transferred from hot to the cold body through a metallic rod. Let the temperature of hot and cold bodies are T_1 and T_2 K respectively. The amount of heat removed from the hot body is totally transferred to the cold body. The change entropy of the hot body ΔS_1 is given by:

$$\Delta S_1 = \frac{-Q}{T_1}$$

Change in entropy of the cold body ΔS_2 is:

$$\Delta S_2 = \frac{Q}{T_2}$$

Net change in entropy ΔS

$$\Delta S = \Delta S_1 + \Delta S_2$$

$$= \frac{-Q}{T_1} + \frac{Q}{T_2}$$

$$\Delta S = \frac{Q}{T_2} - \frac{Q}{T_1}$$

As T_2 is less then T_1 i.e. $T_2 < T_1$

$$\therefore \quad \frac{Q}{T_2} > \frac{Q}{T_1}$$

$$\Rightarrow \quad \Delta S > O$$

Therefore, the entropy increases during all natural processes where heat flows from one system to another.

Q.18 Explain second law of thermodynamics in terms of entropy.

The second law of thermodynamics in terms of entropy can also be defined as:

"When a system undergoes a natural process, it will always proceed in a direction that causes the entropy of system and environment to increase. "

Explanation:

It is observed that natural processes proceed toward the state of greater disorder, thus there is relation between entropy and molecular disorder. For example, in irreversible process heat flows from hot to cold body, results in increase in disorder. It is because molecules are initially sorted out in hot and cold regions. This order is lost when the system comes to thermal equilibrium. Addition of heat to the system increases disorder because of increase in average molecular speed. Similarly, in free expansion of gas increases disorder because the molecules have greater randomness of position after expansion. In both examples the entropy of the system increases.

Q.19 Increase in entropy means degradation of energy. Discuss. 11111019

Whenever, the entropy of the system increases then available heat energy which can be converted into work is lost. For example, there is an increase in entropy when hot and cold water are mixed. The warm water which results cannot be separated into hot layer and cold layer. Although, there is no loss of energy but some of the energy is no longer available for conversion into work. Therefore, as a result of increase in entropy, the energy is degraded from a higher level where more work can be extracted to lower level at which less or no useful work can be done.

Q.20 How environmental crisis are related with entropy crisis. 11111020

The environmental crisis result from our attempt to order nature for our comfort and greed. For example, when we drive a car, the atmosphere acts as cold reservoir, the heat rejected by the car engine goes to the atmosphere. As a result, the temperature difference between the engine and atmosphere decreases. Thus the efficiency of the engine decreases as the entropy increases. Thus the environment is thermally polluted due to conversion of heat energy into Mechanical Energy, which is called environment crisis.

The increase in thermal pollution in the environment means increase in entropy. This increase in entropy creates the crisis of a better environment. We cannot avoid ourselves from the thermal pollution of air caused by the heat engines used for transportation. Thus the ecological balance is disturbed seriously even by the smaller changes in temperature which affect plants and animals.

Whenever we want to do anything, it is very much necessary from the point of view of second law of thermodynamics that upper limit of efficiency must be kept in mind. Only then we can prevent the degradation of life on our beautiful Earth.

Short Questions

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

(Board 2010) 11111021

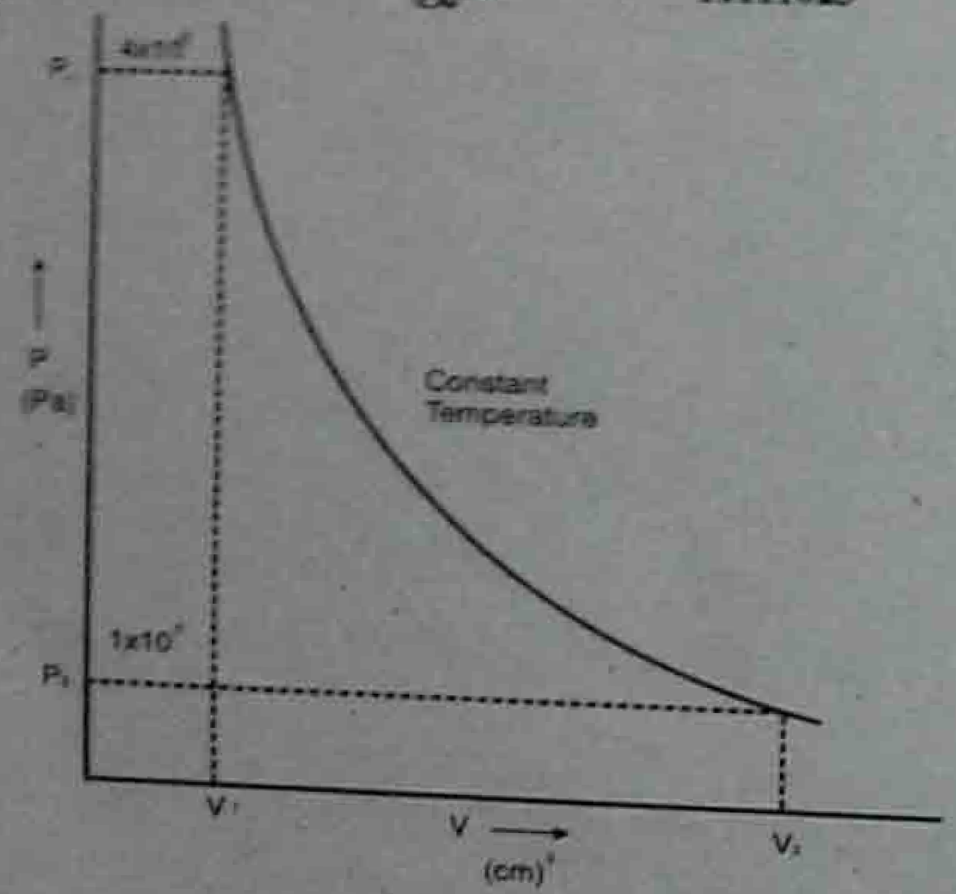
Ans. Average velocity of the molecule is zero because the vector sum of the velocities of the molecule will be zero due to random motion of molecules of gas. Statistically, the number of molecules moving in one direction is equal to the number of molecules moving in opposite direction. Therefore, the average velocity of the molecule will be zero. But the square of the negative velocity is also positive number hence the average of the square of velocity will not be zero.

i.e. $$\langle v^2 \rangle = \frac{v_1^2 + v_2^2 + \ldots\ldots\ldots\ldots + v_n^2}{N} \neq 0$$

11.2 Why does the pressure of a gas in a car tyre increase when it is driven through some distance? (Board 2014) 11111022

Ans. When car is driven through a certain distance then due to friction between road and tyre heat is produced. This heat will increase the average translational K.E. of the gas molecules inside the tyre. As we know that $P \propto \left(\frac{1}{2}mv^2\right)$ hence, the pressure will increase.

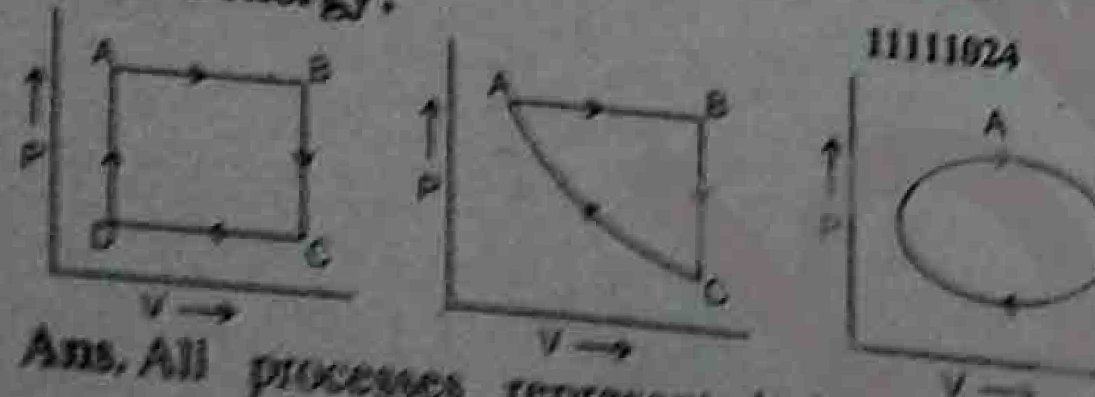
11.3 A system undergoes from state P_1V_1 to state P_2V_2 as shown in fig. What will be the change in internal energy? 11111023



Ans.

There is no change in internal energy because the temperature remains constant. It is an isothermal process and during an isothermal process $\Delta U = 0$

11.4 Variation of volume by pressure is given in fig. A gas is taken along the paths ABCDA, ABCA and A to A what will be the change in internal energy? 11111024



Ans. All processes represented in fig. are cyclic, because in each case system returns to initial state therefore, there is no change in internal energy.

or $\Delta U = 0$

11.5 Specific heat of a gas at constant pressure is greater than specific heat at constant volume. Why? (Board 2010, 14) 11111025

Ans. Heat supplied at constant pressure is greater than the heat supplied at constant volume because heating the gas at constant pressure the work is also done by the system in moving the piston in the upward direction. Therefore the heat supplied to one mole of the gas at constant pressure is greater than the heat supplied at constant volume. i.e.

$$Q_P > Q_V$$

$$C_P\Delta T > C_V\Delta T$$

or $C_P > C_V$

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. (Board 2009) 11111026

Ans. Adiabatic process is the example of a process in which no heat is transferred to or from the system but the temperature of the system changes. In shaking the thermo flask violently the temperature of the milk inside will increase although no heat is supplied or removed from the system. The work done on the system is converted into internal energy.

11.7 Is it possible to convert internal energy into mechanical energy? Explain with an example. (Board 2014) 11111027

Ans. Yes, it is possible to convert internal energy into mechanical energy during expansion of a gas. When gas expands the work is done by the system at the cost of its internal energy. Therefore, internal energy is converted into work.

11.8 Is it possible to construct a heat engine that will not expel heat into the atmosphere? (Board 2010) 11111028

Ans. No, it is not possible to construct a heat engine that will not expel heat into the atmosphere. Since environment act as a cold body or sink of a heat engine to which a part of the heat energy is to be rejected. Therefore we cannot construct heat engine which will not expel heat to the environment. It will be against the second law of Thermodynamics.

11.9 A thermos flask containing milk as a system is shaken rapidly. Does the temperature of milk rise? 11111029

Ans. On shaking the thermos flask vigorously the internal energy of the milk particles will increase, hence, temperature of the milk will rise.

11.10 What happens to the temperature of the room, when air conditioner is left running on a table in the middle of the room? (Board 2009) 11111030

Ans. The temperature of the room increases because air conditioner will remove Q amount of heat from the room and by doing W amount of work rejects Q + W back to the room. Therefore after each cycle the heat energy will be added into the room which will increase its temperature.

11.11 Can the mechanical energy be converted completely into heat energy? If, so give an example? (Board 2008) 11111031

Ans. When brakes are applied to the car. The mechanical energy of the car is used up in doing work against friction which is converted entirely in to heat energy.

11.12 Does entropy of a system increase or decrease due to friction? (Board 2014) 11111032

Ans. When work is done against friction it is converted into heat energy, which is added into the system. Therefore, ΔQ is positive by using relation

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

It is concluded that entropy of system will increase.

11.13 Give an example of a natural process that involves an increase in entropy. (Board 2009) 11111033

Ans. We know that entropy can be measured by following equation

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

The entropy increases when heat is added into the system. When ice melts the heat is absorbed from the surrounding therefore entropy of the melted ice that is water increases.

11.14 An adiabatic change is the one in which? 11111034

(a) No heat is added to or taken out of the system.
(b) No change of temperature takes place.
(c) Boyle's law is applicable.
(d) Pressure and Volume remain constant.

Ans. "a" No heat is added to or taken out of the system.

11.15 Which one of the following process is irreversible? 11111035

(a) Slow compression of an elastic spring.
(b) Slow evaporation for a substance in a isolated vessel.
(c) Slow compression of a gas.
(d) A chemical explosion.

Ans. "d" A chemical explosion.

11.16 An ideal reversible heat engine has 11111036

(a) 100% efficiency.
(b) Highest efficiency.
(c) An efficiency which depends on the nature of working substance.
(d) None of these.

Ans. (b) Highest possible efficiency

Solved Examples

Example 1: What is the average translational Kinetic energy of molecules in a gas at temperature 27C°? 11111037

Solution:

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

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

Where $T = 27 + 273 = 300\ K$

$k = 1.38 \times 10^{-23}\ JK^{-1}$

so $< K.E. > = \frac{3}{2} \times 1.38 \times 10^{-23}\ JK^{-1} \times 300\ K$

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

Example 2: Find the average speed of oxygen molecule in the air at S.T.P. 11111038

Solution: Under standard conditions

Temperature $T = 0°C = 273\ K$

From Eq.

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

or $< v^2 > = \frac{3kT}{m}$

Using Avogadro's number $N_A = 6.022 \times 10^{23}$, the mass m of one molecule of oxygen is

$$m = \frac{\text{molecular mass}}{N_A} = \frac{32\ g}{6.022 \times 10^{23}} = \frac{32\ kg}{6.022 \times 10^{26}}$$

Substituting the values of k, T and m, we get

$$< v^2 > = \frac{3 \times 1.38 \times 10^{-23}\ JK^{-1} \times 273\ K \times 6.022 \times 10^{26}}{32\ kg} = 212693 m^2s^{-2}$$

or $< v > = 461\ ms^{-1}$

Example 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 4.0 cm. If 42 J heat is transferred to the system during the expansion, what is the change in internal energy of the system? 11111039

Solution:

The work done by the gas is

$$W = P\Delta V = PA\Delta y = 8000\ Nm^{-2} \times 0.10\ m^2 \times 4.0 \times 10^{-2}\ m$$

$= 32\ Nm = 32\ J$

The change in internal energy is found from first law of thermodynamics.

$$\Delta U = Q - W = 42\ J - 32\ J = 10\ J$$

Example 4: The turbine in a steam power plant takes steam from a boiler at 427°C and exhausts into a low temperature reservoir at 77°C. What is the maximum possible efficiency? 11111040

Solution:

Maximum efficiency for any engine operating between temperature T_1 and T_2 is

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

Where $T_1 = 427 + 273 = 700\ K$

And $T_2 = 77 + 273 = 350\ K$

so $\eta = \frac{700\ K - 350\ K}{700\ K} = \frac{350\ K}{700\ K} = \frac{1}{2} = 0.5$

or $\eta = 50\%$

Example 5: Calculate the entropy change when 1.0 kg ice at 0°C melts into water at 0°C. Latent heat of fusion of ice $L_f = 3.36 \times 10^5\ J\ kg^{-1}$. 11111041

Solution:

$m = 1\ kg$

$T = 0°C = 273\ K$

$L_f = 3.36 \times 10^5\ J\ kg^{-1}$

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

where $\Delta Q = mL_f$

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

$$\Delta S = \frac{1.00\ kg \times 3.36 \times 10^5\ J\ kg^{-1}}{273\ K}$$

$\Delta S = 1.23 \times 10^3\ J\ K^{-1}$

Thus entropy increases as it changes to water. 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.

Numericals

11.1 Estimate the average speed of nitrogen molecules in air under standard conditions of pressure and temperature. 11111042

Data:

$T = 0°C + 273 = 273K$

$k = 1.38 \times 10^{-23}\ J/K$

Molecular Weight of $N_2 = 28$

Root mean square velocity. $v_{rms} = ?$

Solution:

We know that

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

$$\sqrt{\frac{3kT}{m}} = \langle\sqrt{v^2}\rangle$$

6.02×10^{23} molecules of N_2 have mass = 28g

$m = \frac{28}{6.02 \times 10^{23}}\ g$

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

$$v_{rms} = \sqrt{\frac{3 \times 1.38 \times 10^{-23} \times 273}{4.64 \times 10^{-26}}}$$

$$\boxed{v_{rms} = 493\ ms^{-1}}$$

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. 11111043

Solution:

As the temperature is same, therefore, average translational K.E. of the gas molecule will be equal.

$$\left\langle \frac{1}{2} m_1 v_1^2 \right\rangle = \left\langle \frac{1}{2} m_2 v_2^2 \right\rangle$$

or

$$\frac{\langle v_1^2 \rangle}{\langle v_2^2 \rangle} = \frac{m_2}{m_1}$$

$$\frac{\sqrt{\langle v_1^2 \rangle}}{\sqrt{\langle v_2^2 \rangle}} = \frac{\sqrt{m_2}}{\sqrt{m_1}}$$

Taking square root of both sides we get

$$\boxed{\frac{(v_1)_{rms}}{(v_2)_{rms}} = \frac{\sqrt{m_2}}{\sqrt{m_1}}}$$

Therefore the ratio of the rms speeds of the gas molecules of two different gases is equal to the inverse ratio of the square root of their masses.

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

Data: 11111044

Let the initial volume = V_1

Final Volume $V_2 = \frac{1}{2} V_1$

∴ $V_1 = 2V_2$

$P = 1.25 \times 10^5\ N/m^2$

$W = -100\ J$

∴ $V_2 = ?$

Solution:

We know that

$W = P\Delta V$

$W = P(V_2 - V_1)$

$-100 = 1.25 \times 10^5 (V_2 - 2V_2)$

$-100 = -1.25 \times 10^5 V_2$

$V_2 = \frac{100}{1.25 \times 10^5}$

$\boxed{V_2 = 8 \times 10^{-4}\ m^3}$

11.4 A thermodynamic system undergoes a process in which its internal energy decreases by 300J. If at the same time 120J of work is done on the system, find the heat lost by the system. 111110

Data:

$\Delta U = -300\ J$

$W = -120\ J$

$Q = ?$

Solution:

We know that

$Q = \Delta U + W$

$= -300 - 120$

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

11.5 A Carnot engine utilize 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. (Board 2010) 11111

Data:

$T_1 = 227°C = 227 + 273 = 500\ K$

$T_2 = 127°C = 127 + 273 = 400\ K$

$W = 10000\ J$

$\eta = ?$

$Q_1 = ?$

$Q_2 = ?$

Solution:

We know that

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

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

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

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

$\boxed{\eta = 20\%}$

$\eta = \frac{W}{Q_1} \times 100$

$Q_1 = \frac{W}{\eta} \times 100$

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

$= 50{,}000\ J$

$\boxed{Q_1 = 5 \times 10^4\ J}$

$W = Q_1 - Q_2$

$Q_2 = Q_1 - W$

$= 5 \times 10^4 - 10{,}000$

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

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: 11111047

$Q_1 = 746\ J$

$Q_2 = 547\ J$

$(T_1 - T_2) = \Delta T = 100$

$T_1 = ?$

$T_2 = ?$

Solution:

We know that:

$\frac{Q_1}{Q_2} = \frac{T_1}{T_2}$

$\frac{746}{546} = \frac{T_1}{T_2}$

∴ $T_2 = \frac{746}{546} \times T_1$

Since $T_1 - T_2 = 100$ --------------- (1)

$T_1 - \frac{546}{746} \times T_1 = 100$

$\frac{746T_1 - 546T_1}{746} = 100$

$\frac{200T_1}{746} = 100$

$T_1 = \frac{746}{200} \times 100$

$T_1 = 373\ K$

or $\boxed{T_1 = 100°C}$

Putting T_1 in (1) we get

$373 - T_2 = 100$

∴ $T_2 = 373 - 100$

or $\boxed{T_2 = 273\ K \text{ or } 0°C}$

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. 11111048

Data:

$T_1 = 327°C = 327 + 273 = 600\ K$

$T_2 = 27°C = 27 + 273 = 300\ K$

$\eta = ?$

Solution:

We know that

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

$\eta = \left(1 - \frac{300}{600}\right) \times 100$

$= \left(\frac{600 - 300}{600}\right) \times 100$

$\boxed{\eta = 50\%}$

His claim, that the efficiency is 52% is incorrect.

11.8 A heat engine performs 100 J of work and at the same time rejects 400J of heat energy to the cold reservoir. What is the efficiency of the engine? (Board 2014) 11111049

Data:

$W = 100\ J$

$Q_2 = 400\ J$

$\eta = ?$

Solution:

We know that

$W = Q_1 - Q_2$

$100 = Q_1 - 400$

$400 + 100 = Q_1$

$\boxed{Q_1 = 500J}$

$\eta = \frac{W}{Q_1} \times 100$

By putting values of W and Q_1 we get

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

$\boxed{\eta = 20\%}$

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: 11111050

$\eta_1 = 50\%$

$\eta_2 = 70\%$

$T_2 = 7°C = 7 + 273 = 280\ K$

$\Delta T = ?$

Solution:

when $\eta_1 = 50\%$

$\eta_1 = \left(1 - \frac{T_2}{T_1}\right) \times 100$

$50 = 1 - \frac{280}{T_1} \times 100$

$\frac{50}{100} = \frac{T_1 - 280}{T_1}$

$0.5 = \frac{T_1 - 280}{T_1}$

$0.5\ T_1 = T - 280$

$280 = T_1 - 0.5\ T_1$

$280 = 0.5\ T_1$

$T_1 = \frac{280}{0.5}$

$T_1 = 560\ K$

When $\eta_2 = 70\%$

Suppose in this case the temperature of the source is T_1' therefore

$\eta_2 = \left(1 - \frac{T_2}{T_1'}\right) \times 100$

$70 = \left(1 - \frac{280}{T_1'}\right) \times 100$

$\frac{70}{100} = = \left(\frac{T_1' - 280}{T_1'}\right) \times 100$

$0.7\ T_1' = T_1' - 280$

$280 = T_1' - 0.7 T_1'$

$280 = 0.3\ T_1'$

$\frac{280}{0.3} = T_1'$

$933.3\ K = T_1$

$\Delta T = T_1' - T_1$

$= 933.3 - 560$

$\Delta T = 373\ K$ or $373\ C°$

11.10 A steam engine has a boiler that operates at 450K. The heat changes water into steam, which drives the piston. The exhaust temperature of the outside air is about 300K. What is the maximum efficiency of the steam engine? 11111051

Data:

$T_1 = 450\ K$

$T_2 = 300\ K$

Solution:

We know that

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

$\eta = \left(1 - \frac{300}{450}\right) \times 100$

$= \left(\frac{450 - 300}{450}\right) \times 100$

$= 33\%$

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 is changed to ice at 0°C by a refrigerator? (Board 2009) 11111052

Data:

$m = 30\ g$

$L_f = 336\ J/gm$

$T = 0°C = 0 + 273 = 273\ K$

$\Delta S = ?$

Solution:

we know that

$\Delta Q = -mL_f$

$= 30 \times 336$

$= -10080\ J$

Negative sign shows that for freezing water into ice heat is to be removed.

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

$\therefore \Delta S = \frac{-10080}{273}$

$\boxed{\Delta S = -36.8\ J/K}$