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.

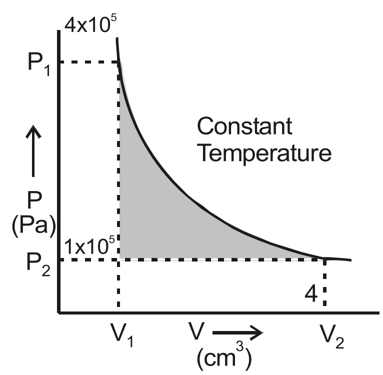
11.2 Why does the pressure of a gas in a car tyre increase when it is driven through some distance?

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.,

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

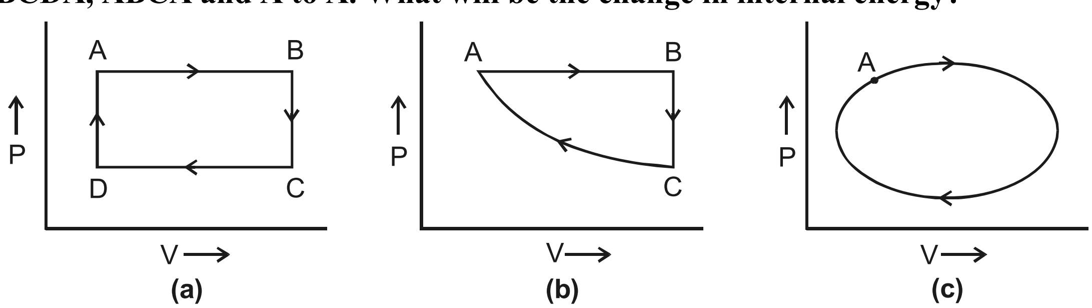
Hence pressure of a gas in a car tyre increases.

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

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

For 2nd gas

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

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

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

$$\Delta W = PV_2$$

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

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

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

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

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 $= T_1 - T_2 = 100°C = 100\text{ K}$

Heat absorbed $= Q_1 = 746\text{ J}$

Heat rejected $= Q_2 = 546\text{ J}$

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 $T_1 - T_2 = 100°C = 100\text{ K}$

$$T_1 - T_2 = 100$$

Therefore;

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

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

$$\frac{26.8}{100} = \frac{100}{T_1}$$

$$26.8\, T_1 = 100 \times 100$$

$$T_1 = \frac{100 \times 100}{26.8}$$

$$T_1 = 373\text{ K} - 273$$

$$= 100°C$$

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 $= T_1 = 327°C + 273$

$= 600\text{ K}$

Temperature of sink $= T_2 = 27°C + 273$

$= 300\text{ K}$

Given efficiency $= \eta = 52\%$

To Find

Is his claim correct = ?

SOLUTION

By formula

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

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

$$= \frac{300}{600} \times 100$$

$$= 50\%$$

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 $= W = 100\text{ J}$

Heat rejected $= Q_2 = 400\text{ J}$

To Find

Efficiency of the engine $= \eta = ?$

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 $Q_1 - Q_2 = W$

$$Q_1 = W + Q_2$$

$$= 100 + 400$$

$$= 500\ J$$

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

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

$$= 20\%$$

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 $= T_2 = 7°C + 273$

$= 280\ K$

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 $\Delta Q = mH_f$

$= 30 \times 336$ J

So $$\Delta S = -\frac{30 \times 336}{273}$$

$= -36.9$ J/K

Result

Change in entropy = ΔS = -36.9 J/K