11.1 A geyser heats water flowing at the rate of 3.0 litres per minute from 27°C to 77°C. If the geyser operates on a gas burner, what is the rate of consumption of the fuel if its heat of combustion is 4.0×10^4 J/g?

SOLUTION:

Given – flowing rate = 3L/min, T_1 = 27°C, T_2 = 77°C, heat of combustion (Q) = 4.0×10^4 J/g

Need to find – rate of consumption of the fuel

Mass of water heated, m = 3000 g per minute

Increase in temperature, ΔT = 77°C-27°C = 50°C

Specific heat of water, c = 4.2 $Jg^{-1}°C^{-1}$

amount of heat used,

Q = mcΔT

$$Q = 3000\text{gmin}^{-1}\times 4.2\text{Jg}^{-1}°\text{C}^{-1}\times 50°\text{C}$$

$$Q = 63\times10^4\,\text{Jmin}^{-1}$$

$$\text{Rate of combustion of fuel} = \frac{63\times10^4\,\text{J min}^{-1}}{4.0\times10^4\,\text{J g}^{-1}} = 15.75\,\text{g min}^{-1}$$

Therefore, rate of consumption of fuel is 15.75 g min^{-1}

11.2 What amount of heat must be supplied to 2.0×10^{-2} kg of nitrogen (at room temperature) to raise its temperature by 45°C at constant pressure? (Molecular mass of N_2= 28; R = 8.3 J mol^{-1} K^{-1}.

SOLUTION:

Given – mass of gas, m = 2×10^{-2} kg = 20g, rise in temperature, ΔT = 45°C, Molecular mass, M = 28

Need to find – Heat required, ΔQ

$$\text{Number of moles, } n = \frac{m}{M} = \frac{20}{28} = 0.714$$

As nitrogen is a diatomic gas, molar specific heat at constant pressure is

$$C_P = \frac{7}{2}R = \frac{7}{2}\times 8.3\text{Jmol}^{-1}\text{K}^{-1}$$

$$\Delta Q = nC_P\Delta T$$

$$\therefore \Delta Q = 0.714\times\frac{7}{2}\times 8.3\times 45\text{J} = 933.4\text{J}$$

Therefore, amount of the heat supplied is 933.4J

11.3 Explain why

(a) Two bodies at different temperatures T_1 and T_2 if brought in thermal contact do not necessarily settle to the mean temperature $(T^1+T^2)/2$.

(b) The coolant in a chemical or a nuclear plant (i.e., the liquid used to prevent the different parts of a plant from getting too hot) should have high specific heat.

(c) Air pressure in a car tyre increases during driving.

(d) The climate of a harbour town is more temperate than that of a town in a desert at the same latitude.

SOLUTION:

(a) In thermal contact, heat flows from the body at higher temperature to the body at lower temperature till temperatures become equal. The final temperature can be the mean temperature $(T^1+T^2)/2$ only when thermal capacities of the two bodies are equal.

(b) This is because heat absorbed by a substance is directly proportional to the specific heat of the substance.

(c) When car is driven, some work is being done on types in order to overcome dissipative forces of friction and air resistance etc. This work done is transformed into heat, due to which temperature of the car types increases.

(d) The climate of a harbour town is more temperate (neither too hot nor too cool) due to formation of sea breeze at daytime and land breeze at nighttime as already explained in Chapter 11.

11.4 A cylinder with a movable piston contains 3 moles of hydrogen at standard temperature and pressure. The walls of the cylinder are made of a heat insulator, and the piston is insulated by having a pile of sand on it. By what factor does the pressure of the gas increase if the gas is compressed to half its original volume?

SOLUTION:

Given- $V_2 = \frac{V_1}{2}, P_2 = 1\,\text{atm}$

Need to find- factor by which pressure of the gas increases

Here the process is adiabatic compression and for hydrogen (a diatomic gas) $\gamma = 1.4$.

$$\because P_1V_1^{\gamma} = P_2V_2^{\gamma}, \text{ Hence } P_2 = P_1\left(\frac{V_1}{V_2}\right)^{\gamma} = 1\text{atm}\left(\frac{V_1}{\frac{V_1}{2}}\right)^{1.4}$$

$$\Rightarrow \begin{aligned} P_2 &= (2)^{1.4}\text{atm} \\ P_2 &= 2.64\text{atm.} \end{aligned}$$

factor by which pressure of the gas increases is 2.64.

11.5 In changing the state of a gas adiabatically from an equilibrium state A to another equilibrium state B, an amount of work equal to 22.3 J is done on the system. If the gas is taken from state A to B via a process in which the net heat absorbed by the system is 9.35 cal, how much is the net work done by the system in the latter case? (Take 1cal = 4.19 J)

SOLUTION:

Given – Amount of work done on the system (ΔW = -22.3 J), 1 cal= 4.19J, net heat absorbed by the system = 9.35 calorie

Need to find – net work done by the system

Here, when the change is adiabatic, ΔQ=0,

If ΔU is change in internal energy of the system, then

as

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

$$0 = \Delta U - 22.3 \text{ or } \Delta U = 22.3\text{J}$$

In the second case, ΔQ = 9.35 cal = 9.35×4.2 J = 39.3 J

Heat absorbed can be given by the equation,

39.3 J – 23.3 J = 16.7 J

Clearly, 16.88 J work is done by the system.

11.6 Two cylinders A and B of equal capacity are connected to each other via a stopcock. A contains a gas at standard temperature and pressure. B is completely evacuated. The entire system is thermally insulated. The stopcock is suddenly opened. Answer the following :

(a) What is the final pressure of the gas in A and B?

(b) What is the change in internal energy of the gas?

(c) What is the change in the temperature of the gas?

(d) Do the intermediate states of the system (before settling to the final equilibrium state) lie on its P - V - T surface?

SOLUTION:

(a) Since the final temperature and initial temperature remain the same,

$$\therefore P_2V_2 = P_1V_1$$

$$\text{But } P_1 = 1\text{atm}, V_1 = V, V_2 = 2V$$

$$\therefore P_2 = \frac{P_1V_1}{V_2} = \frac{1\times V}{2V} = 0.5\text{atm}$$

(b) Since the temperature of the system remains unchanged, change in internal energy is zero.

(c) The system being thermally insulated, there is no change in temperature (because of free expansion)

(d) The expansion is a free expansion. Therefore, the intermediate states are non-equilibrium states and the gas equation is not satisfied in these states. As a result, the gas cannot return to an equilibrium state which lie on the P-V-T surface.

11.7 An electric heater supplies heat to a system at a rate of 100 W. If system performs work at a rate of 75 joules per second. At what rate is the internal energy increasing?

SOLUTION:

Given – Rate of heat ΔQ = 100J/s, work rate ΔW = 75J/s
Need to find – rate at which internal energy is increasing
Using law of thermodynamics-
ΔQ = ΔU+ΔW
Change in internal energy,
(ΔU& =ΔQ-ΔW
ΔU& =100-75=25 J/s)
Rate at which internal energy is increasing is 25 J/s

11.8 A thermodynamic system is taken from an original state to an intermediate state by the linear process shown in Fig. Its volume is then reduced to the original value from E to F by an isobaric process. Calculate the total work done by the gas from D to E to F.

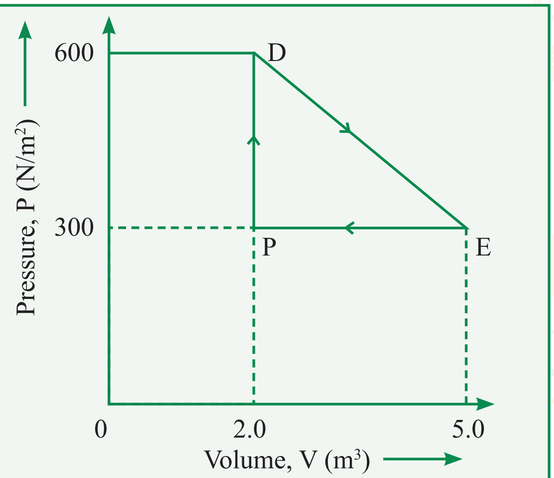

Fig.

SOLUTION:

As it is clear from Fig.
Change in pressure, ΔP = EF = 5.0-2.0 = 3.0atm = 3.0×10^5 Nm^{-2}
Change in volume, ΔV = DF = 600-300 = 300cc = $300\times10^{-6}m^3$
Work done by the gas from D to E to F = area of ΔDEF

$$W = \frac{1}{2}\times DF\times EF$$

$$W = \frac{1}{2}\times\left(300\times10^{-6}\right)\times\left(3.0\times10^{5}\right)$$

W = 45 J
Total work done by the gas is 45 J.