Chapter – 12 Thermodynamics

Exercises

12.1 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 $4.0 \times 10^4\ J/g$?

Solution:

Flowing rate of water $= 3.0$ litre/min

Temperature of water rising from $27\ °C$ to $77\ °C$

Primary temperature $T_1 = 27\ °C$

Final temperature $T_2 = 77\ °C$

$\therefore \Delta T = T_2 - T_1 = 77 - 27 = 50\ ^oC$

Combustion Heat $= 4.0 \times 10^4\ J/g$

Specific heat of water, c $= 4.2$ J g^{-1} $^oC^{-1}$

Mass of flowing water, $m = 3.0\ litre/\min = 3000\ g/\min$

Now,

$\Delta Q = mc\Delta T$

$= 3000 \times 4.2 \times 50$

$= 6.3 \times 10^5\ J/\min$

$\therefore$ Rate of consumption $= \dfrac{6.3 \times 10^5}{4 \times 10^4} = 15.75\ g/\min$

12.2 What amount of heat must be supplied to $2.0 \times 10^{-2}\ kg$ 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:

Mass of nitrogen, $m = 2.0 \times 10^{-2}\ kg = 20g$

Temperature rise $\Delta T = 45\ ^oC$

Nitrogen's molecular mass, M $= 28\ g$

Universal gas constant R $= 8.3\ J\ mol^{-1}\ K^{-1}$

Number of moles, $n = \frac{m}{M}$

$$= \frac{2.0 \times 10^{-2} \times 10^{3}}{28} = 0.714$$

For nitrogen, molar specific heat at constant pressure $C_p = \frac{7}{2} R$

$$= \frac{7}{2} \times 8.3$$

$$= 29.05\ J\ mol^{-1}\ K^{-1}$$

The relationship gives the total amount of heat to be supplied:

$$\Delta Q = nC_p \Delta T$$
$$= 0.714 \times 29.05 \times 45$$
$$= 933.38\ J$$

As a result, the total quantity of heat required is $933.38\ J$.

12.3 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 $\frac{(T_1 + T_2)}{2}$.

Solution: When two bodies with different temperatures T_1 and T_2 come into thermal contact, heat flows from the body with the higher temperature to the body with the lower temperature until equilibrium is reached, at which point the temperatures of both bodies are equal. When the thermal capacity of both bodies is identical, the equilibrium temperature equals the mean temperature $\frac{(T1 + T2)}{2}$.

(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.

Solution: A chemical or nuclear plant's coolant should have high specific heat. This is because the coolant's heat-absorbing capacity is proportional to its specific heat, and vice versa. As a result, the best coolant to be used in a nuclear or chemical plant is a liquid having high specific heat. This would keep the plant from overheating in different areas.

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

Solution: The air temperature inside an automobile rises as it is in motion due to the velocity of the air molecules. Temperature and pressure are directly related, according to Charles' law. When a result, as the temperature within a tyre rises, so does the air pressure.

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

Solution: A port town has a more temperate environment (i.e., no extremes of heat or cold) than a town at the same latitude located in a desert. Because the relative humidity in a port town is higher than in a desert town, this is the case.

12.4 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:

The cylinder is fully sealed off from the rest of the world. As a result, there is no heat transfer between the system (cylinder) and the environment. As a result, the procedure is adiabatic.

Initial pressure inside the cylinder $= P_1$

Final pressure inside the cylinder $= P_2$

Initial volume inside the cylinder $= V_1$

Final volume inside the cylinder $= V_2$

Ratio of specific heats, $\gamma = 1.4$

For adiabatic process,

$$P_1V_1^{\gamma} = P_1V_1^{\gamma}$$

The final volume is reduced to half its original size. $\therefore V_2 = \dfrac{V_1}{2}$

$$P_1(V_1)^{\gamma} = P_2\left(\frac{V_1}{2}\right)^{\gamma}$$

$$\frac{P_2}{P_1} = \frac{(V_1)^{\gamma}}{\left(\frac{V_1}{2}\right)^{\gamma}} = (2)^{\gamma} = (2)^{1.4} = 2.639$$

As a result, the pressure rises by 2.639 times.

12.5 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 1 cal = 4.19 J)

Solution:

While the gas transitions from state A to state B, $22.3\ J$ of work is done on the system. An adiabatic process is what this is called. As a result, there is no change in heat.

$\therefore \Delta Q = 0$

$\Delta W = -22.3\ J$ (Work is done on the system)

From first law of thermodynamics,

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

$\therefore\ \Delta U = \Delta Q - \Delta W = -(-22.3\,J)$

$\therefore\ \Delta U = +22.3\ J$

The net heat absorbed by the system as the gas moves from state A to state B via a process is

$\Delta Q = 9.35\ cal = 9.35 \times 4.19 = 39.1765\ J$

Heat absorbed, $\Delta Q = \Delta U + \Delta W$

$$\begin{aligned}\therefore\ \Delta W &= \Delta Q - \Delta U \\ &= 39.1765 - 22.3 \\ &= 16.8765\ J\end{aligned}$$

As a result, the system performs $16.88\ J$ of work.

12.6 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?

Solution: 0.5 atm

When the stopcock between cylinders A and B is opened, the volume of gas available doubles. Because volume and pressure are inversely related, the pressure will fall to one-half of its original value. Because the gas's initial pressure is 1 atm, each cylinder's pressure will be 0.5 atm.

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

Solution: Zero

Only when work is done by or on the gas can the internal energy of the gas change. The internal energy of the gas will not change because no work is done by or on the gas in this situation.

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

Solution: Zero

The temperature of the gas will not change at all during expansion since the gas is not doing any work.

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

Solution: No

The technique described here is an example of free expansion. It is uncontrollable and uncontrollable. The intermediate states do not satisfy the gas equation, and they do not lie on the system's P-V-T surface since they are in non-equilibrium states.

12.7 A steam engine delivers 5.4×10^8 J of work per minute and services 3.6×10^9 J of heat per minute from its boiler. What is the efficiency of the engine? How much heat is wasted per minute?

Solution:

Work done by the steam engine, $W = 5.4 \times 10^8\ J$

Heat supplied from the boiler, $H = 3.6 \times 10^9\ J$

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

$$\therefore \eta = \frac{W}{H} = \frac{5.4 \times 10^8}{3.6 \times 10^9} = 0.15$$

As a result, the engine's efficiency percentage is 15%.

$$Wasted\ heat = 3.6 \times 10^9 - 5.4 \times 10^8$$

$$= 30.6 \times 10^8 = 3.06 \times 10^9\ J$$

As a result, the total amount of heat lost every minute is $3.06\times10^9\ J$.

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

Solution:

The heat is delivered at a rate of 100 watts.

$\therefore$ Heat supplied, Q = 100 J/s

system performs at a rate of $75\ J/s$

$\therefore$ Work done, W = 75 J/s

From, first law of thermodynamics:

$Q = U + W$

$\therefore U = Q - W$

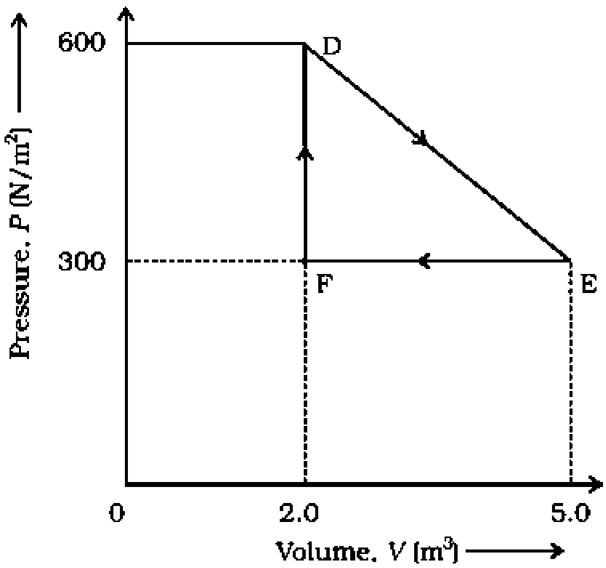
$= 100 - 75$

$= 25\ J/s$

$= 25\ W$

As a result, the specified electric heater's internal energy increases at a rate of 25 W.

12.9 **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.

Solution:

Total work done from D to E to F $=$ Area of ΔDEF

Area of $\Delta DEF = \frac{1}{2} DE \times EF$

Where, DF $=$ change in pressure

$$= 600\,\frac{N}{m^2} - 300\,\frac{N}{m^2}$$

$$= 300\,\frac{N}{m^2}$$

FE $=$ Change in volume

$$= 5.0\ m^3 - 2.0\ m^3 = 3.0\ m^3$$

Area of $\Delta DEF = \frac{1}{2} \times 300 \times 3 = 450\ J$

As a result, the gas' total work from D to E to F is 450 J.

12.10 A refrigerator is to maintain eatables kept inside at $9\ ^oC$. If room temperature is 36^0C, calculate the coefficient of performance.

Solution:

Temperature inside refrigerator, $T_1 = 36^oC = 309\,K$

Coefficient of performance = $\dfrac{T_1}{T_2 - T_1}$

$$= \frac{282}{309 - 282}$$

$$= 10.44$$

As a result, the supplied refrigerator's performance coefficient is 10.44.