

Thermodynamics

Answers

Module 1 Scope of Thermodynamics

A 12.1.1 (D)

As per the zeroth law of thermodynamics, if two objects are individually in thermal equilibrium with a third object C, they are also in thermal equilibrium with each other. This implies that their temperatures acquire identical values (and there is no flow of heat between them when they are kept in contact with each other).

A.12.1.2 (A)

The zeroth law of thermodynamics was developed after the development of the first and second laws (in that order). It was for this reason that it was named as the zeroth law (as it was regarded as something needed before the first and second laws) and not the third or fourth law of thermodynamics.

A.12.1.3 (C)

The heat exchanged/work done, in going from a state 1 to another state 2, depends on the way/path followed in bringing about this change. The internal energy change, however, is independent of the path followed. Therefore, out of the given three thermodynamic variables, only internal energy is a state variable.

A.12.1.4 (B)

Definition (a), based on the zeroth law of thermodynamics, is the thermodynamic definition of temperature.

Definition (b), is based on the kinetic theory of gasses.

A.12.1.5 (D)

Since the bodies are in thermal equilibrium, they are at the same temperature. Hence there would be no heat transfer between them when they are put in contact with each other.

A.12.1.6 (D)

Let the energy spent in going up be q joule; the energy spent in going down is then $(q/2)$ joule.

Now $q = Mgh$

$\therefore$ Total energy spent in one cycle is $\frac{3}{2} Mgh$.

The energy that he needs to spend (in achieving his aim) is

$$m(Q \times 10^3 \times 4.2)$$

Hence the number of cycles that he needs to undertake is $\frac{m(Q \times 10^3 \times 4.2)}{(\frac{3}{2} Mgh)} = \frac{2800mQ}{MgH}$

A.12.1.7 (C)

For ideal gasses (potential energy of the system taken as zero), we regard the internal energy as the kinetic energy of the molecules. It, therefore, changes only when the temperature of the system changes.

For practical systems, we can also associate a potential energy with a system which changes with a change in the state of the system. The internal energy of such practical systems can, therefore, change even when there is no change in their temperature. The changes, associated with a change of state of a solid into a liquid, a liquid into a gas, are examples of such situations.

A.12.1.8 (D)

The thermodynamic state is expressed in terms of the three variables (P, V, T). It is clear, therefore, that the thermodynamic state of a system would change if any one of its three state variables has a value different from its initial value.

A.12.1.9 (D)

The direction of heat flow is determined not by the heat content but by the temperature. The temperature of system A being more than that of either system B or system C, heat would flow from A to B as well as from A to C.

In case of system B and C, the direction of heat flow would be from B to C as B is at a higher temperature than C.

A.12.1.10 (D)

internal energy is directly related to temperature of the system.

Module 2 Thermodynamic Processes

A.12.2.1 (D)

A close look at the initial and final values of (P , V and T) reveals that the expansion

- (i) in case (i), is an isothermal expansion
- (ii) in case (ii), is an isobaric expansion

The P – V diagrams, corresponding to these two types of expansion, are the ones shown in option (D).

A.12.2.2 (A)

The temperature, and therefore, the internal energy of a system remains constant in an isothermal change. The heat supplied is all used up in doing work against the surroundings.

A.12.2.3 (B)

For the process

$$P = aV^3 + bV^2 + cV + d$$

$$\frac{dP}{dV} = 3aV^2 + 2bV + c$$

For an adiabatic process

$$PV^\gamma = k \therefore \frac{dP}{dV} V^\gamma + \gamma P V^{\gamma-1} = 0$$

$$\text{Or } \frac{dP}{dV} = - \frac{\gamma P V^{\gamma-1}}{V^\gamma} = - \gamma P V^{-1} = - \frac{\gamma P}{V}$$

$\therefore$ Ratio of the two slopes, at the point (P_0 , V_0), is

$$\frac{(3aV_0^2 + 2bV_0 + c)V_0}{-\gamma P_0} = -\frac{1}{\gamma P_0} [3aV_0^3 + 2bV_0^2 + cV_0]$$

A.12.2.4 (B)

The gas is undergoing an adiabatic change.

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

$$\therefore P_2 V_2^\gamma = P_1 V_1^\gamma$$

$$\text{or } P_2 = P_1 \left(\frac{V_1}{V_2} \right)^\gamma$$

$$P_1 (2)^\gamma (\because V_2 = \frac{1}{2} V_1)$$

$$\therefore \frac{P_2}{P_1} = 2^\gamma$$

Hence,

For hydrogen, a diatomic gas, $\gamma = 5/3$

$$\therefore \frac{P_2}{P_1} = 2^{5/3}$$

12.2.5 (A)

For container A,

$$P_{2A} \frac{V}{4} = PV \tag{A.12.2.1}$$

For container B

$$PV^\gamma = P_{2B}(V/8)^\gamma$$

(A.12.2.2)

Dividing Eq(A.12.2.2) by Eq(A.12.2.1) we will have

$$\frac{P_{2B}}{P_{2A}} = 2^{11/5}$$

A.12.2.6 (A)

We know that

$$W = \int_{P_1}^{P_2} P dV$$

The process being adiabatic, we can write

$$P(V + \Delta V)^\gamma = (P + \Delta P)V^\gamma$$

$$\therefore PV^\gamma \left(1 + \frac{\Delta V}{V}\right)^\gamma = PV^\gamma \left(1 + \frac{\Delta P}{P}\right)$$

$$\therefore \left(1 + \frac{\Delta P}{P}\right) \simeq \left(1 + \gamma \frac{\Delta V}{V} + \dots\right)$$

$$\text{or, } \frac{\Delta P}{P} \simeq \gamma \frac{\Delta V}{V}$$

$$\text{or, } \Delta V = \frac{V}{\gamma P} \Delta P$$

$$\therefore W = \int_{P_1}^{P_2} P dV = \int_{P_1}^{P_2} P \frac{V}{\gamma P} dP = \frac{V}{\gamma} \int_{P_1}^{P_2} dP = \frac{V}{\gamma} (P_2 - P_1) = \frac{3}{5} V (P_2 - P_1) (\because \gamma = 7/5 \text{ s for a diatomic gas.})$$

A.12.2.7 (C)

Option (A.) is incorrect because an 'isotherm' can intersect an 'adiabat'.

Option (B.) is incorrect because the complete conversion of mechanical energy into heat is permissible.

Option (C.) is correct. In the cycle shown xy is an isotherm for which (as per the first law) $dQ = dW$ ($dU = 0$ for an isotherm). Also $dQ = 0$ for the parts yz and zx as they are both labeled as 'adiabatic'. Hence as per this cycle, we have $dQ = dW$, i.e., heat is getting completely converted into work. This, as we know, is NOT in accordance with the second law of thermodynamics.

Option(D.) is incorrect because here $U_x = U_y (\neq U_z)$. There is no change in internal energy during an isothermal change. Internal energy', however, changes during an adiabatic change).

A.12.2.8 (C)

for an adiabatic change

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

$$\therefore \frac{nRT}{V} \cdot V^\gamma = \text{constant} \quad \text{Also, for a perfect gas, } PV = nRT = \text{constant}$$

$$\text{or } TV^{\gamma-1} = \text{constant}$$

$$\therefore T' (32V)^{\frac{7}{5}-1} = T (V)^{\left(\frac{7}{5}-1\right)} \left(\gamma = \frac{7}{5}\right) \text{ for a diatomic gas}$$

$$\text{Or } \frac{T'}{T} = \frac{V^{\frac{2}{5}}}{(32V)^{\frac{2}{5}}} = \frac{1}{(32)^{\frac{2}{5}}} = \frac{1}{4} = 2^{-2}$$

A.12.2.9 (A)

$$\text{Net work done} = W_{AB} + W_{BC} + W_{CD} + W_{DA}$$

Work done, during the adiabatic expansion from A to B, is (Here $PV^\gamma = K$)

$$W_{AB} = \int_{v_A}^{v_B} P dv = \int_{v_A}^{v_B} \frac{K}{v^\gamma} dv = \frac{K}{(1-\gamma)} \left[V_B^{1-\gamma} - V_A^{1-\gamma} \right] = \frac{1}{(1-\gamma)} \left[P_B V_B - P_A V_A \right] \quad \left[\because K = P_B V_B^\gamma = P_A V_A^\gamma \right]$$

$$\text{Similarly } W_{CD} = \frac{1}{(1-\gamma)} \left[P_D V_A - P_C V_B \right]$$

Also $W_{BC} = W_{DA} = 0$ (these are isochoric changes)

$$\text{Net work done} = W_{AB} = W_{CD} = \frac{1}{(1-\gamma)} \left[(P_B - P_C) V_B + (P_D - P_A) V_A \right]$$

A.12.2.10 (C)

The given (P - V) diagram (and its mathematical expression) show that the gas is undergoing an isothermal expansion.

Hence the T - P diagram must be a straight line parallel to the P -axis. Further, as per the given diagram, the pressure, at point (1), is more than that at point (2). Hence the correct line corresponds to option (C). (The line, in option (D), shows the pressure values in the reverse (incorrect) order) .

A.12.2.11 (D)

The given (P - V) diagram, and (its mathematical form) show that the gas is undergoing an isothermal compression.

Hence the (T - V) diagram must be a straight line parallel to the V -axis. In this diagram, the value of V , at point (1), must be more than that at point (2). The diagram, given in option(4), is in accord with both these requirements.



Module 3 First Law of Thermodynamics

A.12.3.1 (C)

By the first law of thermodynamics

$$dQ = dU + dW$$

$$\text{Or } dU = dQ - dW$$

$$\therefore (U_Y - U_X)(\text{for path 1}) = 1000 \text{ J} - W_1 \quad \text{and} \quad (U_Y - U_X)(\text{for path 2}) = Q - W_2$$

$$\therefore 1000 \text{ J} - W = Q - W_2$$

$$\text{or } Q = (1000 - W_1 + W_2) = [1000 - (W_1 - W_2)] \text{ J} = (1000 - 100) \text{ J} = 900 \text{ J}$$

A.12.3.2 (C)

In the usual statement of the first law of thermodynamics, it is assumed that the heat supplied to the system is used

- (i) partly in increasing the internal energy and, therefore, the temperature of the system, and
- (ii) partly in doing external work, i.e. work done by the system (on the surroundings).

Thus dU is (+ve) when the temperature of the system increases and dW is (+ve) when work is done by the system.

A.12.3.3 (B)

- (i) During an isothermal change, the temperature and therefore, the internal energy of the gas remains unchanged. Hence $dU = 0$
- (ii) During an isochoric change, the volume of the gas remains unchanged. Hence there is no work done by/on the gas. Hence $dW = 0$.

A.12.3.4 (B)

We have by the first law of thermodynamics,

$$dQ = dU + dW$$

$$dU = dQ - dW$$

In **case (i)**, $dW = 75$ joule per sec and $dU = (100 - 75)$ joule/sec = 25 joule per sec

and in **case (ii)**, $dW = -75$ joule per second

and $dU = (100 - (-75))$ joule per second = 175 joule per second.

A.12.3.5(A)

We have $dQ = dU + dW$

In the first case, $dQ = 0$. Hence

$$dU = -dW = -(-22.3 \text{ J}) = 22.3 \text{ J}$$

In the second case,

$$dQ = 39.2 \text{ J}$$

$$dW = dQ - dU = (39.2 - 22.3) \text{ J} = 16.9 \text{ J}$$

(dU is same as the initial and the final states are the same in this case also)

A.12.3.6 (C)

The given value of C_p , for the gas, indicates that it is a monatomic gas. Hence (from the given names) the permissible name, for this gas, could only be helium or neon.

$$\text{Also } C_v = C_p - R = \frac{3}{2}R$$

As per the first law of thermodynamics. We have $dQ = dU + dW$

During a constant volume (isochoric) process,

$dW \left(= \int P dV \right)$ is zero as there is no change in the volume of the gas,. Also

$$dU = \eta C_V dT = \frac{3}{2} \eta R dT$$

$$\therefore dQ = \frac{3}{2} \eta R dT$$

Hence the rise in temperature of the gas is

$$dT = \frac{Q}{\left(\frac{3}{2} \eta R \right)} = \frac{2}{3} \frac{Q}{\eta R}.$$

A.12.3.7 (C)

It is only the internal energy (of a system) that depends only on the state of the system and not on the way that state has arrived. Thus ΔU remains the same irrespective of the way the transition (between two given states) is brought about. This is not true for ΔH and ΔW ; they depend on the 'path followed' in going from the initial to the final state.

A.12.3.8 (C)

Using the gas equation, we find that the temperature at L should be given by

$$(3P_o) (3V_o) = 1.R.T_L \text{ or } T_L = \frac{9P_o V_o}{R}$$

For the point K, we have

$$P_o V_o = 1.R.T_K$$

$$\text{Or } T_K = \frac{P_o V_o}{R}$$

$$\therefore T_L = 9T_K = 9 T_o$$

$$\text{Now } dQ = dU + dW$$

$$\text{Here } dU = c_v(9T_o - T_o) = 8 C_v T_o = 8\left(\frac{3}{2}R\right)T_o$$

$$= 12RT_o (\because C_v = \frac{3}{2}R) \text{ for monoatomic gas}$$

A.12.3.9 (D)

The internal energy of a gas, in a given state, is a characteristic of that state and does not depend on the way that state has been arrived at. The value of U_B (and U_A) would, therefore, be the same for all the four cases and hence

$$\Delta U = U_B - U_A$$

Would have the same value for all the four cases.

A.12.3.10 (C)

The work done by gas $\left(= \int_A^B P dV\right)$ depends on the path, followed by it, in going from its initial state to its final state. It therefore, equals the area under the corresponding P - V diagram.

We see, from the given diagram, that the area, under the curve, for path y is greater than that under 'path' x , which in turn, is greater than that under 'path' z . hence $W_y > W_x > W_z$

A.12.3.11 (C)

When a gas undergoes an adiabatic change, the heat added to (or taken out of) it is zero. By first law,

$$dQ = dU + dW = 0$$

$$\therefore dU = -dW$$

Here dU is positive as the temperature, and, therefore, the internal energy of the gas have increased. This means that dW must be taken with a negative sign. Hence work has been done ON the gas. The gas must have, therefore, been (adiabatically) compressed.

Module 4 Second Law of Thermodynamics

A.12.4.1 (D)

We have

$$9 = \frac{Q_2}{W} = \frac{Q_2}{Q_1 - Q_2} = \frac{T_2}{T_1 - T_2}$$

$$\therefore 9 = \frac{T_2}{300 - T_2}$$

$$\therefore 2700 = 10 T_2$$

$$\text{Or } T_2 = 270 \text{ Kelvin}$$

$$\therefore \text{Temperature Inside the refrigerator} = - 3^\circ\text{C}$$

A.12.4.2 (B)

The coefficient of performance, of the ideal refrigerator, working between a 'sink' temperature of T_2 kelvin and a

'source' temperature of T_1 kelvin, is $\frac{Q_2}{W} = \frac{Q_2}{Q_1 - Q_2} = \frac{T_2}{T_1 - T_2} = \frac{270}{300 - 270} = 9$

Hence, in this case, the coefficient of performance being 50%, the effective coefficient of performance, is

$$0.5 \times 9 = 4.5$$

Hence $\frac{Q_2}{W} = 4.5$

Or $Q_2 = 1 \times 4.5 \text{ kw} = 4.5 \text{ kw}$

$\therefore$ Heat taken out of the refrigerator per second is (4.5 kJ/sec)

A.12.4.3 (A)

For section AB, $dQ = dU = \frac{3}{2}R(T_B - T_A) = \frac{3}{2}V_A(P_B - P_A)$

For section BC $dQ = dU + dW$

$$= \frac{3}{2}P_B(V_C - V_B) + P_B(V_C - V_B) = \frac{5}{2}P_B(V_C - V_B)$$

For section CD, $dQ = 0$

For section DA, $dQ = dU + dW$

$$= \frac{3}{2}P_A(V_A - V_D) + P_A(V_A - V_D) = \frac{5}{2}P_A(V_A - V_D)$$

A.12.4.4 (B)

Coefficient of performance

$$= \frac{T_2}{T_1 - T_2} = \frac{273+9}{(273+36)-(273+9)} = \frac{282}{27} = 10.4$$

A.12.4.5 (B)

$$\text{Coefficient of performance} = \frac{Q_2}{W} = \frac{Q_2}{Q_1 - Q_2} = \frac{T_2}{T_1 - T_2}$$

$$\therefore 5 = \frac{(273+\theta)}{(273+27)-(273+\theta)} = \frac{273+\theta}{27-\theta}$$

$$\therefore 135 - 5\theta = 273 + \theta \quad \text{or} \quad 6\theta = -138^\circ\text{C} \quad \therefore \theta = -23^\circ\text{C}$$

A.12.4.6 (C)

For the Carnot cycle

$$\frac{H_1}{H_2} = \frac{T_1}{T_2}$$

$$\text{and } H_1 - H_2 = W$$

$$\therefore \frac{H_1}{H_2} = \frac{500}{300} = \frac{5}{3}$$

$$\text{and } H_1 - H_2 = 1 \text{ kJ}$$

$$\therefore H_1 - \frac{3}{5}H_1 = 1 \text{ kJ}$$

$$\text{or } H_1 = \frac{1 \times 5}{2} \text{ kJ} = 2.5 \text{ kJ}$$

$$\therefore H_2 = \frac{3}{5}H_1 = 1.5 \text{ kJ}$$

A.12.4.7 (B)

efficiency of the heat engine = $\frac{\text{Work done}}{\text{Heat absorbed}}$

$$n_1 = \frac{1.4 \times 10^3}{1 \times 4.2 \times 10^3} = \frac{1}{3}$$

For the ideal heat engine,

$$\text{Efficiency} = \eta = \frac{T_1 - T_2}{T_1} = \frac{600 - 300}{600} = \frac{1}{2}$$

$$\therefore \frac{\eta_1}{\eta_2} = \frac{1}{3} \times \frac{2}{1} = \frac{2}{3}$$

A.12.4.8 (A)

This setup corresponds to a refrigerator in which the system is taking heat from the sink, having work done on it, and transforming heat is the source. For this case, both Q_1 and Q_2 are positive with $Q_1 > Q_2$.

A.12.4.9 (B)

$$\text{coefficient of performance} = \frac{Q_2}{W} = \frac{Q_2}{Q_1 - Q_2} = \frac{T_2}{T_1 - T_2}$$

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

$$\text{or } T_1 = 2T_2$$

$$\text{or } (t_1 + 273) = 2(t_2 + 273)$$

$$\therefore t_1 = (2t_2 + 273)$$

A.12.4.10 (C)

$$\text{efficiency of an ideal heat engine} = \frac{Q_1 - Q_2}{Q_1} = \frac{T_1 - T_2}{T_1}$$

$$\therefore 25\% = \frac{1}{4} = \frac{T_1 - T_2}{T_1}$$

$$\text{Or } 4T_1 - 4T_2 = T_1$$

$$\therefore T_1 = \frac{4}{3} T_2$$

$$\text{Or } (t_1 + 273) = \frac{4}{3} (t_2 + 273) = \frac{4}{3} t_2 + 364$$

$$t_1 = \frac{4}{3} t_2 + 91$$

Development Team

N.K.Sehgal, Former Associate Professor, Hans Raj College, Delhi University

Review Team

C.K .Ghosh, Former Director, NCIDE, IGNOU, New Delhi

Surendar Kumar, Vice Principal, KVS, Keltron Nagar, Kannaur, Kerala

Nidhi Kalucha, PGT Sanskriti School, New Delhi

Vikrant Bhardwaj, PGT, Kendriya Vidyalaya, Gole Market, New Delhi

Anuradha Rajesh, Physics Teacher, Shaheed Rajpal DAV Public School, Delhi

Member- Coordinator

Shashi Prabha, Professor, CIET, NCERT, New Delhi

Technical support

Riya Rani, JPF, CIET, NCERT, New Delhi

Bhawana Bhatt, Technical Content Developer, CIET, NCERT, New Delhi

Rajat Kumar, Graphic Designer, CIET, NCERT, New Delhi

