PHYSICS – CLASS XI

Chapter 11 : Thermodynamics

SOLUTIONS AND MARKING SCHEME (Step-by-Step)

Marks for each step are shown in brackets. Alternative correct methods carry full marks.

Quick answer key – Section A

Q	1	2	3	4	5	6	7	8
Ans	(c)	(c)	(d)	(a)	600 J	300 J	800 J	70%

SECTION A

1. **Ans: (c).** **(1)**

By the Zeroth law, two systems each in thermal equilibrium with a third are in thermal equilibrium with each other. So when the wall is made conducting, **no heat flows** between A and B.

2. **Ans: (c) the same along all three paths.** **(1)**

Internal energy is a state variable: ΔU depends only on the initial and final states, not on the path. (Work and heat do depend on the path.)

3. **Ans: (d) Work done.** **(1)**

Internal energy, pressure and temperature depend only on the state of the system; work (like heat) depends on the path, so it is not a state variable.

4. **Ans: (a).** **(1)**

$\eta = 1 - T_2/T_1$ is 1 only if $T_2 = 0$ K, which is unattainable; so R explains A.

5. **Ans: 600 J.** **(1)**

$W = P\Delta V = 2 \times 10^5 \times (4 - 1) \times 10^{-3} =$ **600 J** (area under the graph).

6. **Ans: 300 J.** **(1)**

$\Delta U = \Delta Q - \Delta W = 500 - 200 =$ **300 J** (increase).

7. **Ans: 800 J.** **(1)**

Net work = area of the loop $= (3 - 1) \times 10^5 \times (6 - 2) \times 10^{-3} = 2 \times 10^5 \times 4 \times 10^{-3} =$ **800 J** (clockwise, so positive).

8. **Ans: 70%.** **(1)**

$T_1 = 1000$ K, $T_2 = 300$ K. $\eta = 1 - T_2/T_1 = 1 - 0.3 =$ **0.7 = 70%**.

SECTION B

9. **(i)** $W = P\Delta V = 1 \times 10^5 \times (4 - 2) \times 10^{-3} =$ **200 J**. (1) **(2)**

(ii) First law: $\Delta U = \Delta Q - \Delta W = 600 - 200 =$ **400 J**. (1)

10. **(i)** The gas expands into a vacuum, so it does no work ($W = 0$), and the system is insulated ($Q = 0$). Hence $\Delta U =$ **0**. For an ideal gas U depends only on temperature, so $\Delta T =$ **0**. (1) **(2)**

(ii) The temperature is unchanged and the volume doubles, so by PV = constant the final pressure is $\boldsymbol{P/2}$. (1)

11. $\Delta Q = \Delta U + P\Delta V$. At constant volume ($\Delta V = 0$): $C_v = \Delta U/\Delta T$. (1) **(2)**
At constant pressure: $C_p = \Delta U/\Delta T + P(\Delta V/\Delta T)_p = C_v + R$, since for one mole $PV = RT$ gives $P(\Delta V/\Delta T)_p = R$ (ΔU of an ideal gas depends only on T). Hence $C_p - C_v = R$. (1)

OR

Kelvin–Planck: No process is possible whose sole result is the absorption of heat from a reservoir and the complete conversion of this heat into work. (1)
Clausius: No process is possible whose sole result is the transfer of heat from a colder object to a hotter object. (1)

12. **(i)** Curve **2** (the one ending at the higher pressure C) is the adiabatic compression. (1) **(2)**
(ii) In the adiabatic compression no heat escapes, so the work done on the gas increases its internal energy and its temperature rises; with the same final volume the pressure is then higher than in the isothermal case. (Equivalently, the adiabatic curve PV^{γ} = constant is steeper than the isotherm PV = constant.) (1)

SECTION C

13. **(i)** Net work = area of triangle ABC = ½ × (6 − 2) × 10^{-3} × (3 − 1) × 10^5 = ½ × 4 × 10^{-3} × 2 × 10^5 = **400 J**. (1) **(3)**
(ii) Efficiency $\eta = W/Q_1 = 400/1600 =$ **0.25 = 25%**. (1)
(iii) $Q_2 = Q_1 - W = 1600 - 400 =$ **1200 J**. (1)

14. **(i)** At constant volume no work is done: $Q = \Delta U = \mu C_v \Delta T = 2 \times (3/2) \times 8.3 \times 10 =$ **249 J**. (1) **(3)**
(ii) $Q_p = \mu C_p \Delta T = 2 \times (5/2) \times 8.3 \times 10 =$ **415 J**. (1)
(iii) $W = P\Delta V = \mu R \Delta T = 2 \times 8.3 \times 10 =$ **166 J**. (Check: 415 − 249 = 166 J.) (1)

OR

(i) $Q = mL = 1 \times 2.25 \times 10^6 =$ **2.25×10^6 J**. (1)
(ii) $W = P(V_g - V_l) = 1 \times 10^5 \times (1.67 - 0.001) \approx$ **1.67×10^5 J**. (1)
(iii) $\Delta U = Q - W = 2.25 \times 10^6 - 1.67 \times 10^5 \approx$ **2.08×10^6 J** (most of the heat increases the internal energy). (1)

15. **(i)** $P_1V_1^{\gamma} = P_2V_2^{\gamma} \rightarrow P_2 = P_1(V_1/V_2)^{\gamma} = 1 \times 10^5 \times 8^{5/3} =$ **3.2×10^6 Pa**. (1) **(3)**
(ii) $TV^{\gamma-1}$ = constant $\rightarrow T_2 = T_1(V_1/V_2)^{2/3} = 300 \times 4 =$ **1200 K**. (1)
(iii) Work done by the gas $W = (P_2V_2 - P_1V_1)/(1 - \gamma) = (3200 - 800)/(-2/3) = -3600$ J. So the work done **on** the gas = **3600 J**. (1)

SECTION D

16. **(5)**

(a) 1 → 2: isothermal expansion (at T_1); 2 → 3: adiabatic expansion; 3 → 4: isothermal compression (at T_2); 4 → 1: adiabatic compression. (1)

(b) $\eta = 1 - T_2/T_1 = 1 - 300/600 =$ **0.5 = 50%**. (1)

(c) $W = \eta Q_1 = 0.5 \times 1200 =$ **600 J**. (1)

(d) $Q_2 = Q_1 - W = 1200 - 600 =$ **600 J**. (1)

(e) $\eta' = 1 - 150/600 =$ **0.75 = 75%**. It can never be 100%, because that needs $T_2 =$ 0 K (or a perfect engine, forbidden by the second law). (1)

OR

(a) Clausius statement: no process is possible whose sole result is the transfer of heat from a colder object to a hotter object. (1)

(b) For a reversible (Carnot) cycle $Q_1/Q_2 = T_1/T_2 = 300/250 =$ **6/5**. (1)

(c) $Q_1 - Q_2 = W = 200$ and $Q_1 = 1.2Q_2 \rightarrow 0.2Q_2 = 200 \rightarrow Q_2 =$ **1000 J**. (1)

(d) $Q_1 = 1000 + 200 =$ **1200 J**. (1)

(e) Coefficient of performance $= Q_2/W = 1000/200 =$ **5**. (1)

17. **(5)**

(a) Internal energy is a state variable: it depends only on the initial and final states of the gas, not on the path followed. (1)

(b) Path 1: A → C is at constant volume ($W = 0$); C → B is at constant pressure 3×10^5 Pa: $W_1 = 3 \times 10^5 \times (6 - 2) \times 10^{-3} =$ **1200 J**. (1)

(c) Path 2: A → D is at constant pressure 1×10^5 Pa: $W_2 = 1 \times 10^5 \times 4 \times 10^{-3} =$ **400 J**; D → B is at constant volume ($W = 0$). (1)

(d) $Q_1 = \Delta U + W_1 = 1000 + 1200 =$ **2200 J**. (1)

(e) $Q_2 = \Delta U + W_2 = 1000 + 400 =$ **1400 J**. (Work and heat are path dependent.) (1)

OR

(a) $\Delta Q = \Delta U + \Delta W$, where ΔQ is the heat supplied to the system, ΔU the change in its internal energy and ΔW the work done by the system. (1)

(b) $\Delta U = 500 - 300 =$ **200 J**. (1)

(c) $\Delta Q = -100$ J (heat given out) and $\Delta W = -300$ J (work done on the gas): $\Delta U = -100 - (-300) =$ **+200 J**. (1)

(d) $\Delta U = 0$ for an ideal gas at constant temperature, so $\Delta Q = \Delta W$: all the heat absorbed is converted into work. (1)

(e) Heat and work are modes of energy transfer whose amounts depend on the path between two states, not on the state itself; a system does not “contain” heat or work. (1)

— END OF SOLUTIONS —