9.2 Thermodynamics (full B.4, HL)

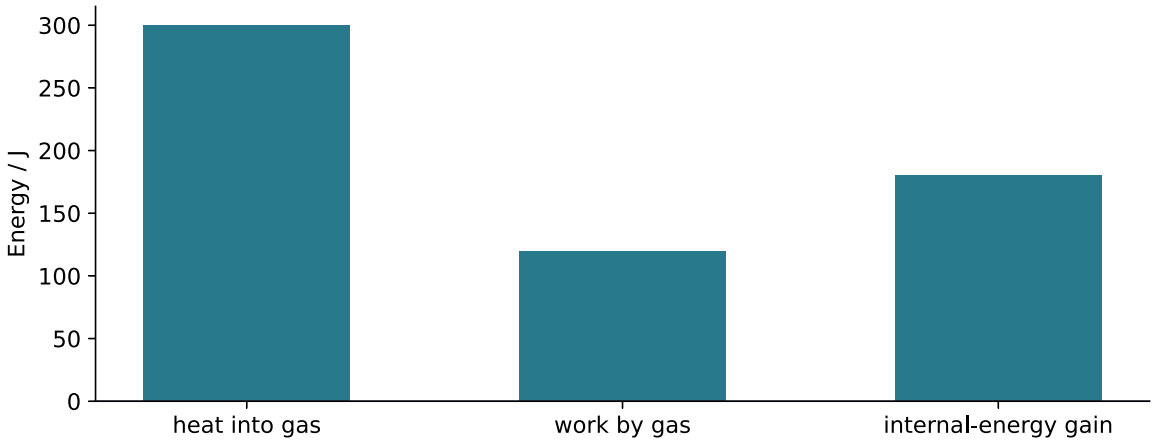
Name: _____ Class: _____ Date: _____ **Total: 23 marks**

KEY WORDS entropy • adiabatic • Carnot cycle

Objective

Practise the full guide B.4 toolkit (HL only): the first law Q = ΔU + W with W = PΔV, ΔU = 3/2 nRΔT, entropy by ΔS = ΔQ/T and $S = k_B \ln \Omega$, the second law for isolated and non-isolated systems, the four named processes with the adiabatic $PV^{5/3}$ = constant, heat-engine efficiency and the Carnot limit. Original practice; not an official IB paper.

1 Key knowledge and worked examples



■ **The B.4 equation set**

$$Q = \Delta U + W \qquad W = P\,\Delta V \qquad \Delta U = \tfrac{3}{2} nR\Delta T$$

$$\Delta S = \frac{\Delta Q}{T} \qquad S = k_B \ln \Omega \qquad \eta_{\text{Carnot}} = 1 - \frac{T_c}{T_h}$$

Clausius convention: Q supplied to the system, W done by the system. Monatomic adiabatic: $PV^{5/3}$ = constant.

Worked check. 3.0 mol of a monatomic gas expands isobarically at 1.0×10^5 Pa by 2.0×10^{-3} m^3 while receiving 1500 J: W = 200 J, so ΔU = 1300 J and ΔT = 1300/(1.5 × 3.0 × 8.31) = 34.8 ≈ 35 K.

2 Practice

2.1 State the first law with the sign convention. [2]

2.2 Calculate the work done by a gas expanding 5.0×10^{-3} m^3 at a constant 2.0×10^5 Pa. [2]

2.3 Calculate the entropy change of a reservoir at 300 K that loses 600 J. [2]

2.4 Name the four processes that keep one variable fixed. [4]

2.5 State the Carnot efficiency for $T_h = 500$ K, $T_c = 300$ K. [2]

3 Exam-style questions

3.1 2.0 mol of a monatomic ideal gas is heated at constant volume from 300 K to 360 K. Calculate ΔU and the heat supplied, and state W. [4]

3.2 A heat engine takes in 800 J per cycle and does 200 J of useful work. Calculate the efficiency, the maximum possible efficiency if the hot reservoir is at 600 K and the cold at 300 K, and comment on the comparison. [4]

3.3 A refrigerator's interior (an open, non-isolated system) has its entropy decrease. Explain why this does not violate the second law. [3]

Solutions

Original-task marking: M1 method, A1 accuracy, B1 reasoning.

2.1 $Q = \Delta U + W$; Q is the heat supplied to the system, W the work done by the system.

2.2 $W = P\Delta V = 2.0\times10^{5} \times 5.0\times10^{-3} = 1.0\times10^{3}$ J.

2.3 $\Delta S = -600/300 = -2.0$ J/K – the reservoir loses entropy.

2.4 Isovolumetric (constant V), isobaric (constant P), isothermal (constant T), adiabatic (no heat exchange).

2.5 $\eta = 1 - 300/500 = 0.40$.

3.1 $\Delta T = 60$ K; $\Delta U = 1.5 \times 2.0 \times 8.31 \times 60 = 1.496\times10^{3} \approx 1.5\times10^{3}$ J; at constant V, $W = 0$, so $Q = \Delta U = 1.5\times10^{3}$ J.

3.2 $\eta = 200/800 = 0.25$; $\eta_{\text{Carnot}} = 1 - 300/600 = 0.50$; the engine runs at half the Carnot limit – allowed, since Carnot is an upper bound, not a requirement.

3.3 The second law applies to isolated systems; the refrigerator plus its power source and surroundings form the relevant isolated system; the heat pumped out and the work consumed raise the surroundings' entropy by at least as much as the interior's decrease.