

## 9.2 Thermodynamics (full B.4, HL)

Name: \_\_\_\_\_ Class: \_\_\_\_\_ Date: \_\_\_\_\_

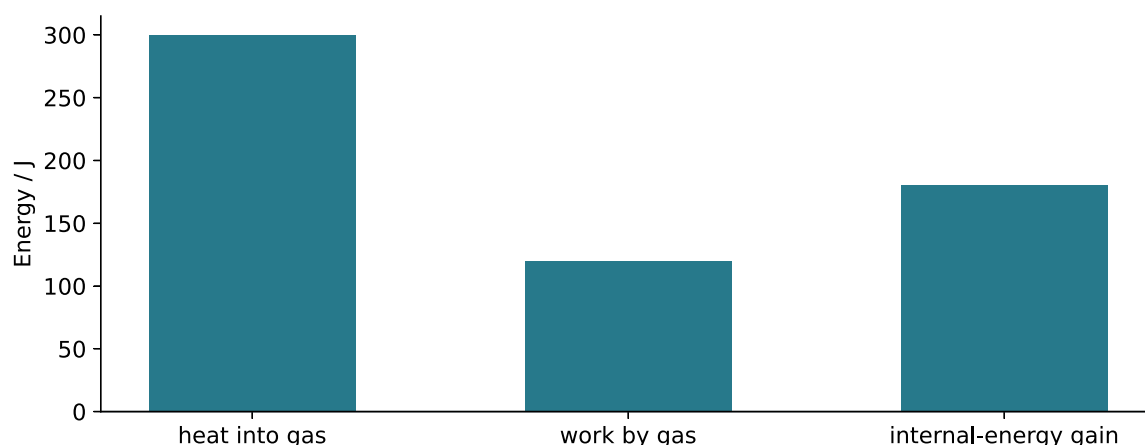
Total: 23 marks

**KEY WORDS** entropy • adiabatic • Carnot cycle

### Objective

Practise the full guide B.4 toolkit (HL only): the first law  $Q = \Delta U + W$  with  $W = P\Delta V$ ,  $\Delta U = \frac{3}{2} nR\Delta T$ , entropy by  $\Delta S = \Delta Q/T$  and  $S = k_B \ln \Omega$ , the second law for isolated and non-isolated systems, the four named processes with the adiabatic  $PV^{5/3} = \text{constant}$ , 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

$$Q = \Delta U + W \quad W = P \Delta V \quad \Delta U = \frac{3}{2} nR\Delta T$$

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

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

**Worked check.** 3.0 mol of a monatomic gas expands isobarically at  $1.0 \times 10^5$  Pa by  $2.0 \times 10^{-3} \text{ m}^3$  while receiving 1500 J:  $W = 200 \text{ J}$ , so  $\Delta U = 1300 \text{ J}$  and  $\Delta T = 1300 / (1.5 \times 3.0 \times 8.31) = 34.8 \approx 35 \text{ K}$ .

## 2 Practice

---

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

---

---

**2.2** Calculate the work done by a gas expanding  $5.0 \times 10^{-3} \text{ m}^3$  at a constant  $2.0 \times 10^5 \text{ Pa}$ . [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  $T_h = 500 \text{ K}$ ,  $T_c = 300 \text{ K}$ . [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  $\Delta U$  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**  $W = P\Delta V = 2.0 \times 10^5 \times 5.0 \times 10^{-3} = 1.0 \times 10^3 \text{ J}$ .

**2.3**  $\Delta S = -600/300 = -2.0 \text{ J/K}$  – 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**  $\Delta T = 60 \text{ K}$ ;  $\Delta U = 1.5 \times 2.0 \times 8.31 \times 60 = 1.496 \times 10^3 \approx 1.5 \times 10^3 \text{ J}$ ; at constant  $V$ ,  $W = 0$ , so  $Q = \Delta U = 1.5 \times 10^3 \text{ J}$ .

**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.