IB DP PHYSICS

Theme B · The Particulate Nature of Matter

MARK SCHEME

B.1 Thermal Energy Transfers · B.2 The Greenhouse Effect · B.3 Gas Laws
B.4 Thermodynamics (HL) · B.5 Current and Circuits

Standard and Higher Level · Syllabus 2025

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Original exam-style questions written for the IB Diploma Programme Physics course (first assessment 2025)

Section A — Multiple Choice: Answer Key (15 marks)

1. Answer: **C** — $Q = mc\Delta\theta = 2.0\cdot4200\cdot60 = 5.04\times10^5$ J.

2. Answer: **C** — Thermal radiation is transferred by electromagnetic waves, which can travel through a vacuum; conduction and convection both require particles of a medium.

3. Answer: **C** — $L = Q/m = 1.67\times10^5/0.50 = 3.34\times10^5$ J kg^{-1}.

4. Answer: **C** — $P = S\cdot A = 1361\cdot2.0 = 2722$ W.

5. Answer: **B** — Greenhouse gases are largely transparent to incoming (mostly visible/short-wave) solar radiation but absorb outgoing long-wave infrared radiation, re-emitting part of it back toward the surface and warming it.

6. Answer: **C** — Absorbed fraction = 1 − albedo = 1 − 0.30 = 0.70.

7. Answer: **D** — Boyle's law: $P_1V_1 = P_2V_2 \Rightarrow P_2 = 2.0\times10^5\cdot3.0\times10^{-3}/1.0\times10^{-3} = 6.0\times10^5$ Pa.

8. Answer: **B** — Kinetic theory: average translational KE per molecule = (3/2)kT, so absolute temperature is a direct measure of the average molecular translational kinetic energy.

9. Answer: **D** — At constant volume, $P \in T$, so $T_2 = 300\cdot2 = 600$ K.

10. Answer: **C** — First law: $\Delta U = Q - W = 500 - 200 = 300$ J.

11. Answer: **B** — The second law states that the total entropy of an isolated system can never decrease; it stays the same for a reversible process and increases for any irreversible (real) process.

12. Answer: **C** — $W = P\Delta V = 1.5\times10^5\cdot3.0\times10^{-3} = 450$ J.

13. Answer: **B** — $V = IR = 15\cdot0.40 = 6.0$ V.

14. Answer: **B** — Parallel combination of equal resistors gives a lower total resistance than series, so (for the same emf) more total current is drawn from the battery.

15. Answer: **C** — $I = P/V = 2000/230 = 8.7$ A.

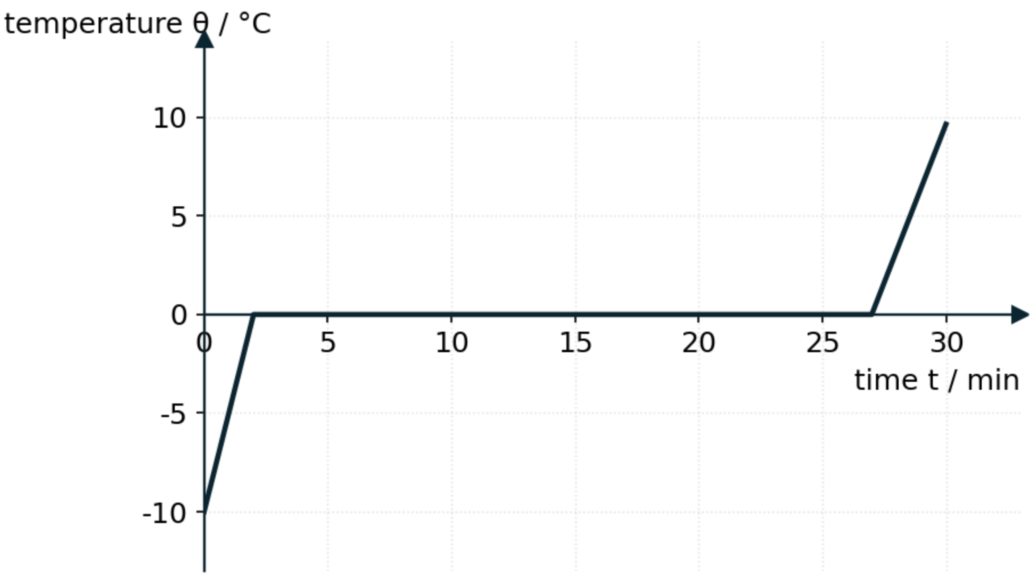
Section B — Structured Questions: Worked Solutions (68 marks)

Mark-scheme notation: M = method mark, A = accuracy mark (dependent on the preceding M mark), R = reasoning mark.

B.1 Thermal Energy Transfers

Question 1 [7 marks]

A 0.20 kg block of ice, initially at −10°C, is heated at a constant rate by a 45 W heater. The graph shows how its temperature changes with time as it warms, melts, and the resulting water warms further.



Temperature−time graph for the heated ice/water sample (values on the axes are the given data for this question).

(a) Use the first 2.0 minutes of data (solid ice warming from −10°C to 0°C) to calculate the specific heat capacity of ice. **[2]**

$Q = Pt_1 = 45 \cdot 120 = 5400$ J. **M1 A1**
$c_{ice} = Q/(m\Delta\theta) = 5400/(0.20 \cdot 10) =$ **$2700\ \mathrm{J\ kg^{-1}\ K^{-1}}$**.

(b) Use the 25-minute plateau (from t = 2.0 min to t = 27.0 min, during which the ice melts at constant temperature) to calculate the specific latent heat of fusion of the ice. **[3]**

$Q = Pt_2 = 45 \cdot 1500 = 67500$ J. **M1 M1 A1**
$L_{fus} = Q/m = 67500/0.20 =$ **$337500\ \mathrm{J\ kg^{-1}}$** ($\approx 337.5\times10^3\ \mathrm{J\ kg^{-1}}$).

(c) Given that the specific heat capacity of liquid water is $4200\ \mathrm{J\ kg^{-1}\ K^{-1}}$, use the final 3.0 minutes of data to calculate the temperature reached at t = 30.0 min. **[2]**

$\Delta\theta = Pt_3/(mc_{water}) = (45 \cdot 180)/(0.20 \cdot 4200) = 8100/840 = 9.64$ K. **M1 A1**
Final temperature = 0 + 9.64 = **9.6 °C**.

Question 2 [6 marks]

A tungsten filament in an incandescent light bulb behaves approximately as a black body. It has a surface area of $8.0\times10^{-5}\ \mathrm{m^2}$ and operates at a temperature of 2500 K. (Stefan−Boltzmann constant $\sigma = 5.67\times10^{-8}\ \mathrm{W\ m^{-2}\ K^{-4}}$; Wien's law constant $b = 2.898\times10^{-3}$ m K.)

(a) Calculate the total power radiated by the filament, assuming it radiates as an ideal black body. **[2]**

$P = \sigma AT^4 = 5.67\times10^{-8}\cdot8.0\times10^{-5}\cdot2500^4 =$ **177 W**. **M1 A1**

(b) Use Wien's displacement law to calculate the peak wavelength emitted by the filament. **[2]**

$\lambda_{max} = b/T = 2.898\times10^{-3}/2500 =$ **1159 nm** (= 1.159×10^{-6} m). **M1 A1**

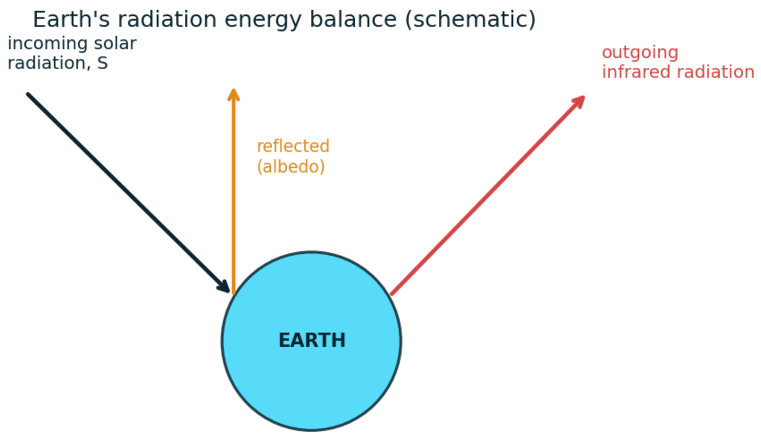
(c) State the region of the electromagnetic spectrum in which this peak wavelength lies, and hence explain why an incandescent bulb is an inefficient source of visible light. **[2]**

The peak wavelength (≈ 1159 nm) lies in the **infrared** region, well beyond the visible range (400−700 nm). Since most of the radiated power is emitted as infrared rather than visible light, only a small fraction of the electrical energy supplied is converted into useful visible light − the rest is wasted as heat. **A1 R1**

B.2 The Greenhouse Effect

Question 3 [7 marks]

The Sun delivers a solar constant of $S = 1361$ W m^{-2} at Earth's orbit. Earth has a mean radius of 6.37×10^6 m and an average albedo of 0.30, as shown in the schematic.



Earth's radiation energy balance: incoming solar radiation is partly reflected (albedo) and partly absorbed; the planet also emits outgoing infrared radiation.

(a) Show that Earth presents a cross-sectional area of about 1.27×10^{14} m^2 to the incoming solar radiation, and hence calculate the total power intercepted, P_{in}. **[3]**

Cross-sectional area = $\pi r^2 = \pi\cdot(6.37\times10^6)^2 \approx 1.27\times10^{14}$ m^2. **M1 M1 A1**
$P_{in} = S\cdot\text{area} = 1361\cdot1.27\times10^{14} =$ **1.735×10^{17} W**.

(b) Calculate the total power absorbed by the Earth system, P_{abs}, given the albedo of 0.30. **[2]**

$P_{abs} = P_{in}(1 - \text{albedo}) = 1.735\times10^{17}\cdot0.70 =$ **1.214×10^{17} W**. **M1 A1**

(c) Explain, in terms of radiative equilibrium, the condition required for Earth's average surface temperature to remain stable over long timescales. **[2]**

For a stable long-term average temperature, the total power absorbed by the Earth system must equal the total power it radiates back to space as infrared (outgoing) radiation, so that there is no net gain or loss of energy over time (radiative equilibrium). **R1 R1**

Question 4 [6 marks]

Treating the Earth as a black body radiating uniformly from its entire surface (total surface area $4\pi r^2$), and using the absorbed power P_{abs} found in Question 3(b).

(a) Calculate the equilibrium black-body temperature of the Earth's surface, assuming all absorbed power is re-radiated as a black body over the full surface area $4\pi r^2 = 5.099\times10^{14}$ m^2. **[3]**

At equilibrium, $P_{abs} = \sigma(4\pi r^2)T^4$. **M1 M1 A1**
$T = [P_{abs}/(\sigma\cdot4\pi r^2)]^{1/4}$ = **254.6 K** (≈ -18.4 °C).

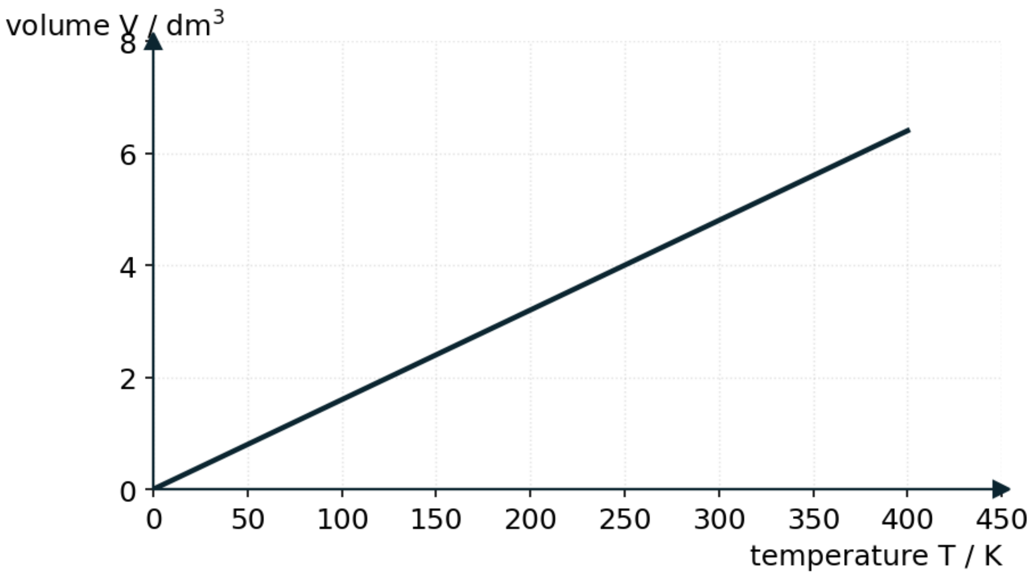
(b) Earth's actual average surface temperature is about 15°C. Explain, in terms of the greenhouse effect, the difference between this calculated equilibrium temperature and the actual surface temperature. **[3]**

The calculated value (≈ -18.4 °C) is much colder than the actual average surface temperature (15°C) because the simple black-body model ignores the atmosphere. Greenhouse gases absorb some of the outgoing infrared radiation and re-emit part of it back toward the surface, trapping additional energy near the surface and raising the equilibrium surface temperature above the simple black-body prediction. **R1 R1 A1**

B.3 Gas Laws

Question 5 [7 marks]

A fixed mass of an ideal gas is held at a constant pressure of 1.0×10^5 Pa in a cylinder with a frictionless piston. The graph shows how its volume varies with absolute temperature.



Volume–temperature graph for the gas at constant pressure (given data).

(a) Use the two labelled points on the graph to show that the gas obeys V/T = constant (Charles's law). **[2]**

At (250 K, 4.0 dm^3): $V/T = 4.0\times10^{-3}/250 = 1.60\times10^{-5}\ m^3\ K^{-1}$. **M1 A1**
At (400 K, 6.4 dm^3): $V/T = 6.4\times10^{-3}/400 = 1.60\times10^{-5}\ m^3\ K^{-1}$ — the same value, confirming V/T is constant.

(b) Using one of the graph points and the ideal gas equation pV = nRT ($R = 8.31\ J\ mol^{-1}\ K^{-1}$), calculate the amount of gas present, in moles. **[3]**

$n = pV/(RT) = (1.0\times10^5\cdot4.0\times10^{-3})/(8.31\cdot250) =$ **0.193 mol**. **M1 M1 A1**

(c) Calculate the number of gas molecules present (Avogadro constant $N_A = 6.02\times10^{23}\ mol^{-1}$). **[2]**

$N = nN_A = 0.193\cdot6.02\times10^{23} =$ **1.159×10^{23}** molecules. **M1 A1**

Question 6 [7 marks]

A sample of oxygen gas (molar mass $M = 0.032\ kg\ mol^{-1}$) is at a temperature of 300 K. (Boltzmann constant $k = 1.38\times10^{-23}\ J\ K^{-1}$; $N_A = 6.02\times10^{23}\ mol^{-1}$.)

(a) Calculate the average translational kinetic energy of a single oxygen molecule. **[2]**

$E_k = (3/2)kT = 1.5\cdot1.38\times10^{-23}\cdot300 =$ **6.21×10^{-21} J**. **M1 A1**

(b) Hence calculate the root-mean-square (rms) speed of the oxygen molecules. **[3]**

Molecular mass $m = M/N_A = 0.032/6.02\times10^{23} = 5.316\times10^{-26}$ kg. **M1 M1 A1**
$(3/2)kT = ½mv_{rms}^2 \Rightarrow v_{rms} = \sqrt{(2E_k/m)} =$ **483.4 m s^{-1}**.

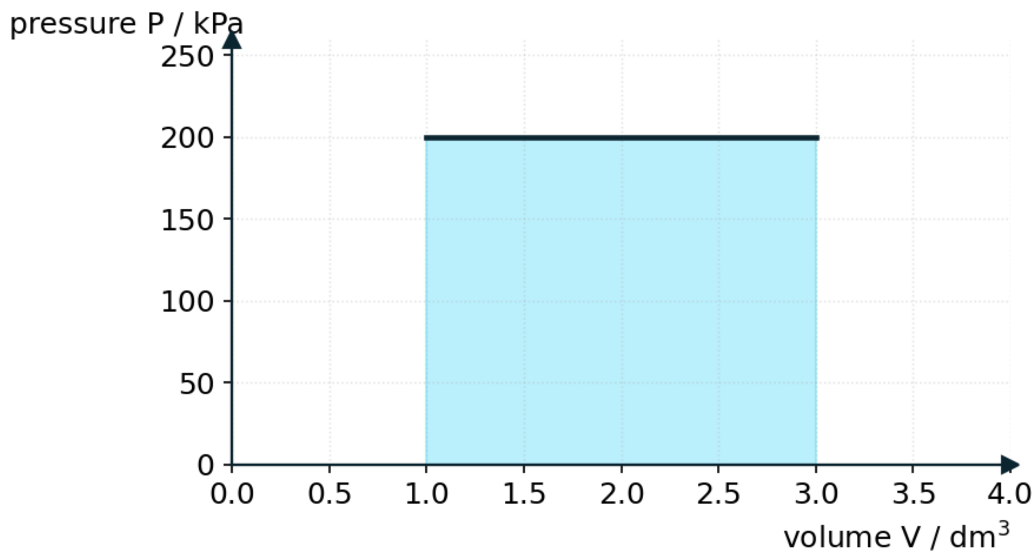
(c) State and explain, in terms of kinetic theory, what happens to the rms speed of the molecules if the absolute temperature is doubled. **[2]**

Since $E_k \in T$ and $E_k \in v_{rms}^2$, it follows that $v_{rms} \in\sqrt{T}$. Doubling T increases v_{rms} by a factor of $\sqrt{2} \approx 1.41$, giving $v_{rms} \approx$ **683.6 m s^{-1}**, NOT simply double. **R1 A1**

B.4 Thermodynamics (HL)

Question 7 [6 marks]

A fixed mass of ideal gas undergoes an isobaric (constant-pressure) expansion at $P = 2.0\times10^5$ Pa, from $V_1 = 1.0\ dm^3$ to $V_2 = 3.0\ dm^3$, while absorbing 800 J of thermal energy, as shown on the p–V graph.



Pressure–volume graph for the isobaric expansion; the shaded area equals the work done by the gas.

(a) Calculate the work done BY the gas during the expansion (the shaded area on the graph). **[2]**

$W = P\Delta V = 2.0\times10^{5}\cdot2.0\times10^{-3} =$ **400 J**. **M1 A1**

(b) Using the first law of thermodynamics, calculate the change in internal energy of the gas. **[2]**

$\Delta U = Q - W = 800 - 400 =$ **400 J**. **M1 A1**

(c) State whether the temperature of the gas increases, decreases, or stays the same during this process, and justify your answer. **[2]**

Since $\Delta U > 0$ and, for an ideal gas, internal energy depends only on temperature, an increase in internal energy means the **temperature increases** during the expansion. **A1 R1**

Question 8 [8 marks]

A 25 g ice cube at 0°C (273 K) is left in a room held at a constant 20°C and completely melts, absorbing thermal energy from the room. (Specific latent heat of fusion of ice = 3.34×10^{5} J kg^{-1}.)

(a) Calculate the thermal energy absorbed by the ice as it melts. **[2]**

$Q = mL = 0.025\cdot3.34\times10^{5} =$ **8350 J**. **M1 A1**

(b) Calculate the entropy change of the ice as it melts at a constant temperature of 273 K. **[3]**

$\Delta S_{ice} = Q/T = 8350/273 =$ **30.6 J K^{-1}**. **M1 A1**

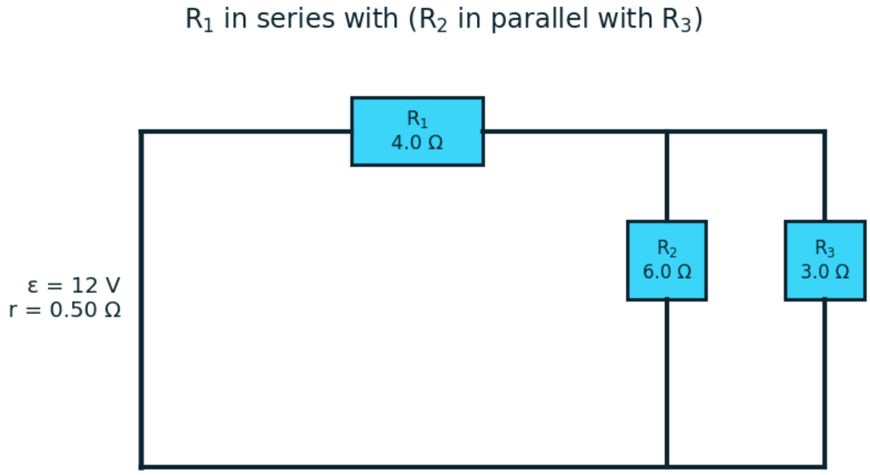
(c) As it supplies this heat, the entropy of the room decreases by 28.5 J K^{-1}. Calculate the total entropy change of the (ice + room) system, and state what this shows about whether the process obeys the second law of thermodynamics. **[3]**

$\Delta S_{total} = \Delta S_{ice} + \Delta S_{room} = 30.6 - 28.5 =$ **+2.09 J K^{-1}**. **M1 A1 R1**
Since ΔS_{total} is positive, the total entropy of the (ice + room) system increases, which is **consistent with** the second law of thermodynamics.

B.5 Current and Circuits

Question 9 [8 marks]

In the circuit shown, a cell of emf ε = 12 V and internal resistance r = 0.50 Ω drives current through a 4.0 Ω resistor R_1 connected in series with a parallel combination of R_2 = 6.0 Ω and R_3 = 3.0 Ω.



R_1 in series with the parallel combination of R_2 and R_3.

(a) Calculate the combined resistance of the parallel section (R_2 and R_3). **[2]**

$1/R_{23} = 1/R_2 + 1/R_3 \Rightarrow R_{23} = (R_2R_3)/(R_2+R_3) = (6.0·3.0)/9.0 = \mathbf{2.0}$ Ω. **M1 A1**

(b) Calculate the current drawn from the cell. **[3]**

Total external resistance $R_{ext} = R_1 + R_{23} = 4.0 + 2.0 = 6.0$ Ω. **M1 M1 A1**
$I = ε/(R_{ext} + r) = 12/(6.0 + 0.50) = 12/6.5 = \mathbf{1.85}$ **A**.

(c) Calculate the terminal potential difference of the cell (the p.d. across the external circuit). **[3]**

$V_{terminal} = ε − Ir = 12 − 1.85·0.50$, or equivalently $V_{terminal} = IR_{ext} = 1.85·6.0 = \mathbf{11.1}$ **V**. **M1 A1**

Question 10 [6 marks]

A nichrome wire (resistivity ρ = $1.10×10^{-6}$ Ω m) has length 2.5 m and cross-sectional area $2.0×10^{-7}$ m^2. It is connected across a 12 V supply.

(a) Calculate the resistance of the wire. **[2]**

$R = ρL/A = (1.10×10^{-6}·2.5)/2.0×10^{-7} = \mathbf{13.75}$ Ω. **M1 A1**

(b) Calculate the current in the wire. **[2]**

$I = V/R = 12/13.75 = \mathbf{0.873}$ **A**. **M1 A1**

(c) Calculate the power dissipated as heat in the wire. **[2]**

$P = VI = 12·0.873 = \mathbf{10.5}$ **W**. **M1 A1**