7.2 Greenhouse effect and energy balance (full B.2)

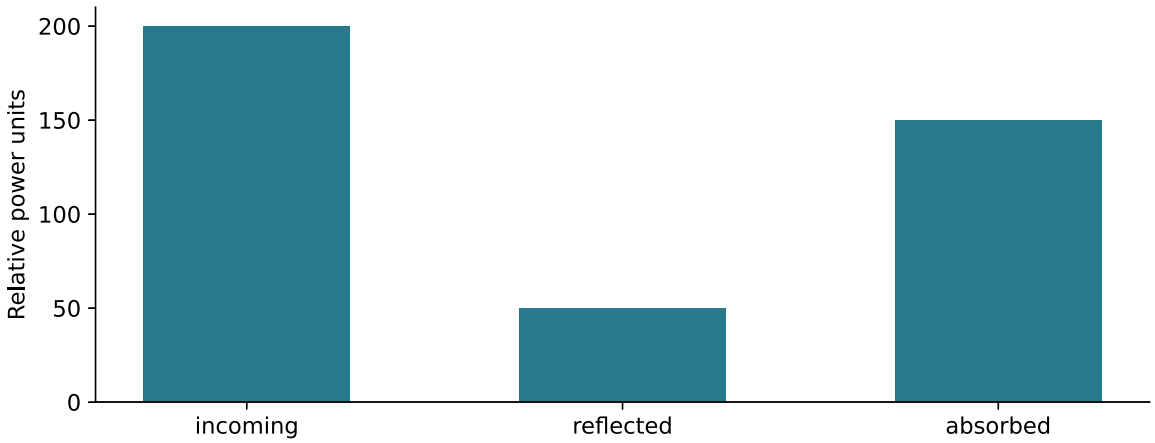
Name: _____ Class: _____ Date: _____ **Total: 23 marks**

KEY WORDS emissivity • albedo • enhanced greenhouse effect

Objective

Practise the full guide B.2 toolkit: emissivity and albedo definitions, the solar constant with the S/4 disc-to-sphere averaging, equilibrium temperature from energy balance, the four named greenhouse gases with their natural and human origins, molecular-energy-level absorption with re-emission in all directions, the resonance model, and the enhanced greenhouse effect. Original practice; not an official IB paper.

1 Key knowledge and worked examples



■ The energy-balance toolkit

$$\text{emissivity} = \frac{\text{power radiated per unit area}}{\sigma T^4} \qquad \text{albedo} = \frac{\text{total scattered power}}{\text{total incident power}} \qquad \langle I \rangle = \frac{S}{4}$$

Equilibrium: absorbed incoming = radiated outgoing, so $(1 - \text{albedo})\frac{S}{4} = e\,\sigma T^4$.

Worked check. A planet with S = 586 W/m^2, albedo 0.25, emissivity 0.90: absorbed $= 0.75 \times 586/4 = 110$ W/m^2; $T = (110/(0.90 \times 5.7 \times 10^{-8}))^{1/4} = 215$ K.

Greenhouse gases absorb infrared via molecular energy-level transitions and re-emit in all directions; human enhancement is the enhanced greenhouse effect.

2 Practice

2.1 Define emissivity. [1]

2.2 Define albedo and name two factors that change Earth's albedo daily. [3]

2.3 Explain why the mean incoming solar intensity is S/4, not S. [2]

2.4 Name the four main greenhouse gases. [4]

2.5 State what the enhanced greenhouse effect is. [1]

3 Exam-style questions

3.1 A planet orbits at a distance where $S = 2200\ W/m^2$, with albedo 0.40 and emissivity 1.0. Calculate its equilibrium temperature, stating the balance equation you used. [4]

3.2 Explain, in terms of molecular energy levels, how CO_2 absorbs outgoing infrared and why this raises the surface temperature above the equilibrium value in 3.1-style balance. [4]

3.3 A surface radiates 300 W/m^2 at 300 K. Calculate its emissivity ($\sigma = 5.7\times10^{-8}$ $W \cdot m^{-2} \cdot K^{-4}$), and the power a black body of the same area and temperature would radiate. [4]

Solutions

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

2.1 The ratio of the power radiated per unit area by a surface to that of an ideal black surface at the same temperature.

2.2 Total scattered power ÷ total incident power; cloud formations and latitude.

2.3 The planet absorbs over its projected disc (πR^2) but the power spreads over the whole sphere ($4\pi R^2$), so the average over the surface is S/4.

2.4 Methane CH_4, water vapour H_2O, carbon dioxide CO_2, nitrous oxide N_2O.

2.5 The augmentation of the greenhouse effect due to human activities.

3.1 Absorbed: $0.60 \times 2200/4 = 330$ W/m^2; balance $\sigma T^4 = 330$; $T = (330/5.7 \times 10^{-8})^{1/4} = 276$ K.

3.2 Infrared photons match gaps between CO_2 molecular energy levels, so the molecules absorb them and gain energy; the excited molecules re-emit radiation in all directions, including back towards the surface; this returned energy adds to the surface energy budget, so the surface settles warmer than the no-atmosphere balance temperature.

3.3 Black body: $\sigma T^4 = 5.7 \times 10^{-8} \times 300^4 = 462$ W/m^2 (461.7); emissivity $= 300/462 = 0.65$. A black body of the same area radiates 462 W per unit area – 1.54× more.