IB DP PHYSICS · THEME B THE PARTICULATE NATURE OF MATTER · B.2 · ~6 MIN READ

B.2 Greenhouse effect

Emissivity and albedo, the solar constant and the factor of four, a simple energy-balance model of the Earth, greenhouse gases and their sources, why molecules absorb infrared, and the enhanced greenhouse effect.

Emissivity | Albedo | Solar constant & S/4 | Energy balance | Greenhouse gases | Resonance & molecular energy levels | Enhanced greenhouse effect

RS by Riyaz Sir
mentorriyaz.in

No tag = **SL and HL** HL ONLY HL students only DATA BOOKLET given in the exam

M1 A1 how marks are awarded highlight = comes up again and again Test yourself at the end

IN 30 SECONDS

- The Earth receives short-wavelength radiation from the Sun and emits long-wavelength **infrared**. Its temperature settles where **power in = power out**.
- **Albedo** is the fraction of incoming power reflected or scattered (about 0.30 for the Earth). **Emissivity** compares a surface with a perfect black body.
- **Greenhouse gases** (H_2O, CO_2, CH_4, N_2O) absorb infrared from the surface and re-emit it in all directions, some back down. This keeps the surface about 33 K warmer than it would otherwise be.
- Burning fossil fuels and other human activity adds greenhouse gases: the **enhanced greenhouse effect** behind global warming.
- **B.2 is the same at SL and HL.**

BY THE END YOU CAN

- Define emissivity and albedo and explain what changes the Earth's albedo.
- Explain why the mean incoming intensity is S/4 and use an energy-balance model.
- Name the main greenhouse gases and their natural and human sources.
- Explain infrared absorption using resonance and molecular energy levels.
- Distinguish the natural and the enhanced greenhouse effect.

1 Emissivity and albedo

$$\text{emissivity } e = \frac{\text{power radiated per unit area}}{\sigma T^4}$$ DATA BOOKLET

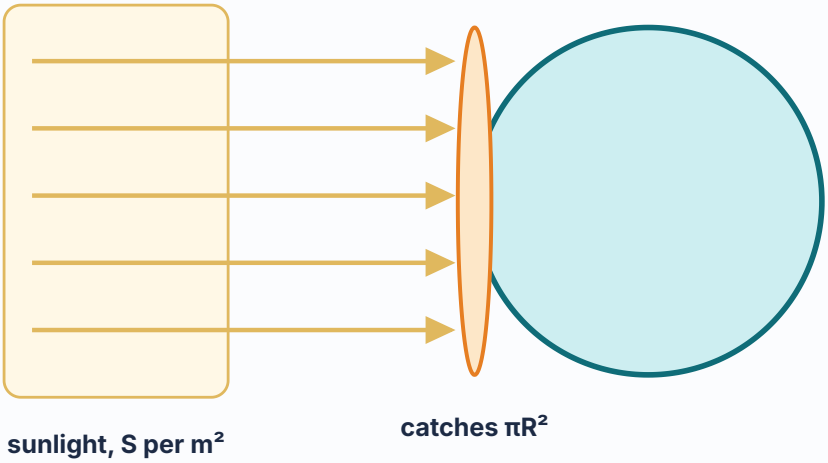
1 for a black body, less than 1 for real surfaces

$$\text{albedo } \alpha = \frac{\text{total scattered power}}{\text{total incident power}}$$ DATA BOOKLET

0 = absorbs everything, 1 = reflects everything

- **Albedo depends on the surface:** fresh snow and ice about 0.8–0.9, clouds 0.4–0.8, ocean about 0.06, forest about 0.1–0.2. Cloud cover and latitude (low Sun angle, ice at the poles) both change it.
- **Positive feedback:** warming melts ice, albedo falls, more power is absorbed, more warming.

2 Solar constant and the factor of four



area hit: πR^2

surface: $4\pi R^2$

mean intensity

$= S \times \pi R^2 / 4\pi R^2$

$= S/4 \approx 340$ W m^{-2}

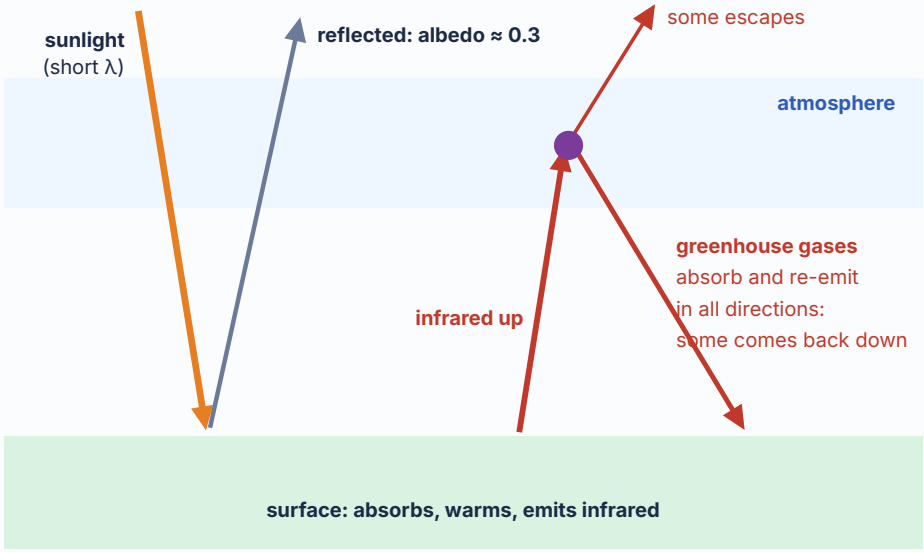
The Earth intercepts sunlight over a disc but radiates from its whole sphere, four times the area.

Solar constant S — the intensity of the Sun's radiation at the top of the Earth's atmosphere, on a surface facing the Sun: about 1.36×10^3 W m^{-2}.

$$\text{mean incoming intensity} = \frac{S}{4}$$

averaged over the whole surface, day and night (about 340 W m^{-2})

3 A simple energy-balance model



Sunlight passes through the atmosphere; much of the outgoing infrared does not.

- **Power in per m^2:** $(1 - \alpha) \times S/4$. **Power out per m^2:** $e\sigma T^4$. In equilibrium the two are equal.

WORKED EXAMPLE

Find the Earth's mean surface temperature with no atmosphere (α = 0.30, e = 1).

1. $(1 - 0.30) \times 1360/4 = 238\ \text{W m}^{-2}$ M1
2. $\sigma T^4 = 238 \Rightarrow T^4 = 4.20 \times 10^9$ M1
3. **T = 255 K (−18 °C), much colder than the real 288 K** A1

WORKED EXAMPLE

What effective emissivity gives the observed 288 K?

1. $e = 238/(\sigma \times 288^4)$ M1
2. $= 238/(5.67 \times 10^{-8} \times 6.88 \times 10^9)$ M1
3. **e ≈ 0.61: the atmosphere stops about 39 % of the surface's emission escaping** A1

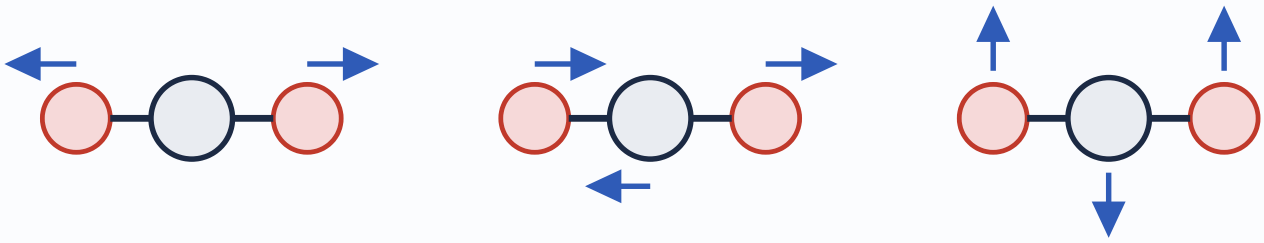
COMMON MISTAKE

Using S instead of S/4, or forgetting (1 − α). Both are needed: S/4 for the geometry, (1 − α) for the reflection.

4 Greenhouse gases

Gas	Natural sources	Human sources
H_2O (water vapour)	evaporation from oceans and lakes	irrigation; mainly a feedback as air warms
CO_2	respiration, volcanoes, decay	burning fossil fuels, deforestation, cement
CH_4 (methane)	wetlands, termites	cattle, rice paddies, landfill, gas leaks
N_2O (nitrous oxide)	soil bacteria, oceans	fertilisers, industry

Why they absorb infrared



symmetric stretch
(not IR-active)

asymmetric stretch
absorbs IR

bending
absorbs IR

IR at the natural frequency of a vibration is absorbed: resonance.

A vibration that changes the molecule's charge distribution can absorb infrared at its natural frequency.

- **Resonance explanation:** the bonds in the molecule have natural frequencies of vibration in the infrared range. Infrared at that frequency drives the vibration: resonance. The molecule absorbs the energy.
- **Energy-level explanation:** molecules have discrete vibrational energy levels. A photon whose energy hf equals the gap between levels is absorbed. Later the molecule re-emits a photon in a **random direction**, so about half goes back towards the ground.
- **N_2 and O_2** (99 % of the air) are not greenhouse gases: their vibrations do not change their charge distribution, so they hardly absorb infrared.

EXAM TIP

Exam answers need the full chain: surface emits IR → greenhouse gases absorb it (resonance) → re-emit in all directions → some returns to the surface → surface warmer than without them.

5 The enhanced greenhouse effect

- **Natural greenhouse effect:** keeps the Earth habitable (288 K instead of 255 K).
- **Enhanced greenhouse effect:** extra greenhouse gases from human activity absorb more of the outgoing IR, so the surface must warm until it radiates enough to balance again. Atmospheric CO_2 has risen from about 280 ppm before industrialisation to over 420 ppm today.
- **Evidence and consequences:** ice-core records, rising average temperatures, melting ice, sea-level rise (thermal expansion of water and melting land ice), more extreme weather.
- **Responses:** renewable and nuclear energy, efficiency, carbon capture, protecting forests.

LINKING QUESTION

The model relies on Stefan–Boltzmann (B.1) and on photon energies E = hf matching molecular energy levels, the same idea as atomic spectra in E.1.

IDEA FOR YOUR IA / EXPLORATION

Model a "planet" with two identical containers under a lamp, one with extra CO_2 (from vinegar and baking soda). Compare their temperature rise, and discuss why the effect in a small box is different from the atmosphere.

Test yourself — cover the answers first

QUICK CHECK

1. Define albedo.
2. Why is the mean incoming intensity S/4?
3. Name four greenhouse gases.
4. Why are N_2 and O_2 not greenhouse gases?
5. What happens to Earth's albedo when sea ice melts?

EXAM-STYLE

6. If the Earth's albedo fell from 0.30 to 0.28, by how much would the no-atmosphere temperature rise?
7. A planet receives 600 W m^{-2} at its distance from its star, has albedo 0.20 and effective emissivity 0.90. Find its equilibrium temperature.

Show answers

1. the ratio of total scattered (reflected) power to total incident power
2. the Earth intercepts sunlight over a disc (πR^2) but its surface area is $4\pi R^2$
3. water vapour, carbon dioxide, methane, nitrous oxide
4. their vibrations do not change their charge distribution, so they do not absorb IR
5. it decreases (water absorbs more)
6. $T \propto (1 - \alpha)^{1/4}$
   $T = 255 \times (0.72/0.70)^{1/4}$
   $= 256.8$ K: a rise of about **1.8 K**
7. power in $= 0.80 \times 600/4 = 120$ W m^{-2}
   $0.90\sigma T^4 = 120$
   $T^4 = 2.35 \times 10^9$
   $T =$ **220 K**

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