Greenhouse effect

B.2 · SL and HL

Why does an atmosphere change the energy balance?

A planet's temperature is set by a balance between power absorbed and power radiated.

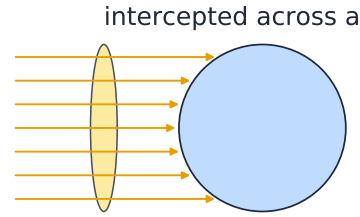
- Orbital distance alone does not determine surface temperature.
- Reflection, heat storage and atmospheric radiation affect the energy balance.
- The layer diagram is an illustrative model, not a measured global budget.

Radiative equilibrium

> In equilibrium, power absorbed $=$ power radiated.

- Absorbing more than it radiates, a planet warms.
- A warmer planet radiates more, $\propto T^4$, and settles at a new temperature.

Why the mean intensity is S/4



mean intensity

$$\frac{S\,\pi R^2}{4\pi R^2} = \frac{S}{4}$$

spread over a sphere of area $4\pi R^2$

- $S \approx 1360$ W m^{-2} at the Earth; 590 W m^{-2} at Mars.
- Intercepted over πR^2, spread over $4\pi R^2$.

Albedo and emissivity

Albedo

Fraction of incoming power reflected or scattered.

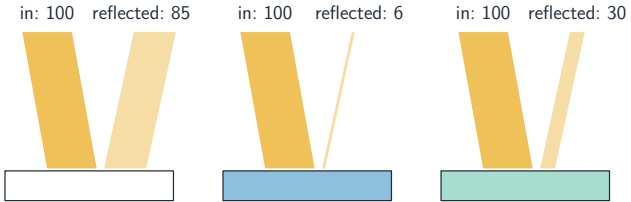
Higher with cloud, ice and snow, and near the poles.

Emissivity

Power radiated per unit area divided by σT^4.

A body radiates $P = e\sigma A T^4$.

Albedo compares surfaces



Albedo is reflected power over incident power

Equilibrium temperature

- Earth: $0.70 \times 340 = 238$ W m^{-2} absorbed.
- $T = (238/\sigma)^{1/4} = 255$ K, but the real surface is 288 K.

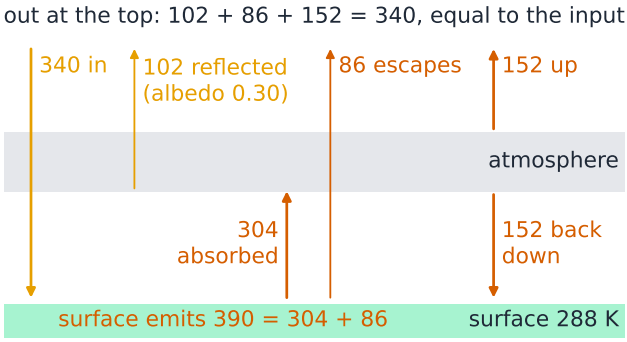
$$(1-\alpha)\frac{S}{4} = e\sigma T^4$$

The conventional 255 K versus 288 K comparison holds **albedo** fixed; it illustrates greenhouse warming.

Prediction against measurement

Body	**Predicted / K**	**Measured / K**
Earth	255	288
Mars	210	about 210
Venus	231	737

The one-layer model



- Surface: $238 + 152 = 390$ in, 390 out.
- Atmosphere: 304 in, $152 + 152$ out.

Check: the atmosphere absorbs more

Your turn

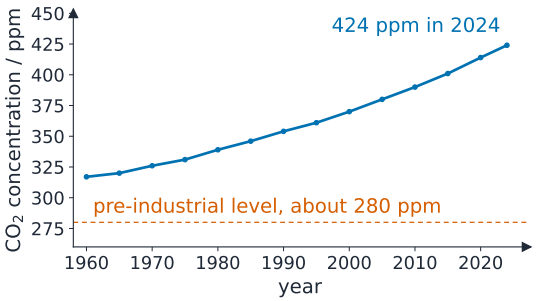
At an initial balance check, hold surface emission at 390 W m^{-2}. The model atmosphere absorbs 80% and emits that absorbed power equally upward and downward. Direct solar absorption at the surface is 238 W m^{-2}. What is the total incoming surface power per area before its temperature responds?

A. 238 W m^{-2}
B. 390 W m^{-2}
C. 394 W m^{-2}
D. 550 W m^{-2}

Greenhouse gases

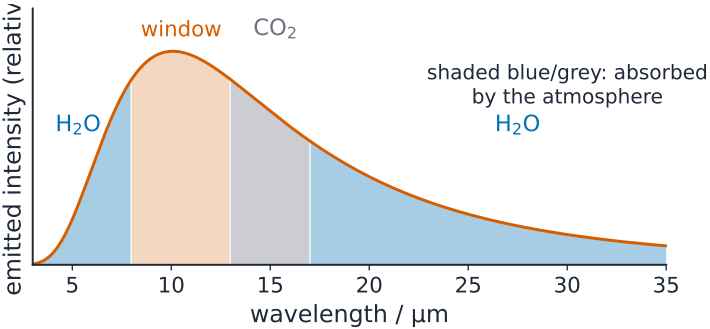
Gas	Main human source
water vapour	more evaporation in a warmer climate
carbon dioxide	burning fossil fuels, deforestation
methane	cattle, rice paddies, landfill
nitrous oxide	nitrogen fertilizers

Carbon dioxide at Mauna Loa



The rise is getting faster

Sunlight in, infrared out



- The atmosphere is largely transparent to the Sun's visible peak.
- The surface peaks near 10 μm, where H_2O and CO_2 absorb.

Two models of absorption

Energy levels

A **photon** is absorbed if hf equals a vibrational energy gap.

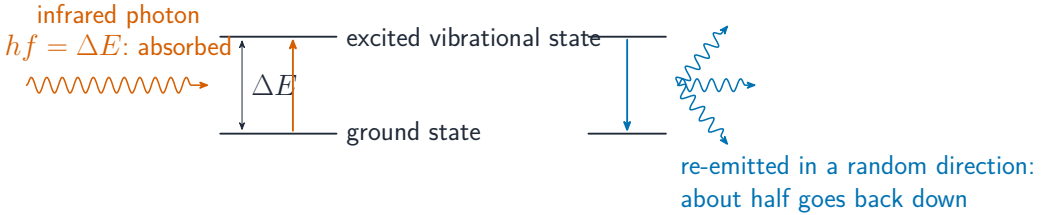
Collisions can redistribute absorbed energy; the warm atmosphere emits upward and downward.

Resonance

Bonds act as springs with a **natural frequency**.

Infrared at that frequency drives the vibration strongly.

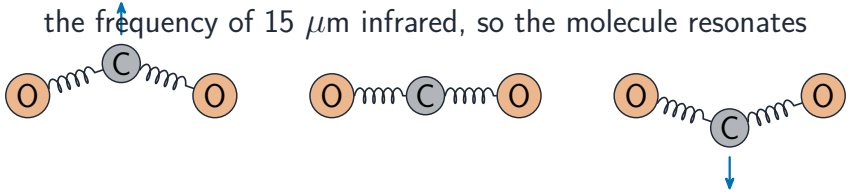
How a molecule absorbs infrared



About half goes back down towards the surface

Why carbon dioxide absorbs 15 µm infrared

bonds act as springs: natural frequency $\approx 2 \times 10^{13}$ Hz,
the frequency of 15 μm infrared, so the molecule resonates



bent one way | straight | bent the other way

Resonance: it matches 15 µm infrared

The enhanced greenhouse effect

- Fossil-fuel combustion adds CO_2; NOAA reports a 2025 remote-marine-boundary-layer global annual mean of 425.62 ppm.
- Less energy leaves than arrives, so the surface warms to a new balance.

Enhanced greenhouse effect extra warming caused by human activities that increase **greenhouse gas** concentrations

Choosing a climate response

1. **Classify.** Invented town: lower-emission buses address causes (mitigation); a flood barrier reduces harm (adaptation).
2. **Evidence.** Compare lifetime bus emissions, including the electricity supply, with local flood-protection evidence.
3. **Assess.** Compare effectiveness and costs. Check permits and protection standards; identify who pays and benefits.

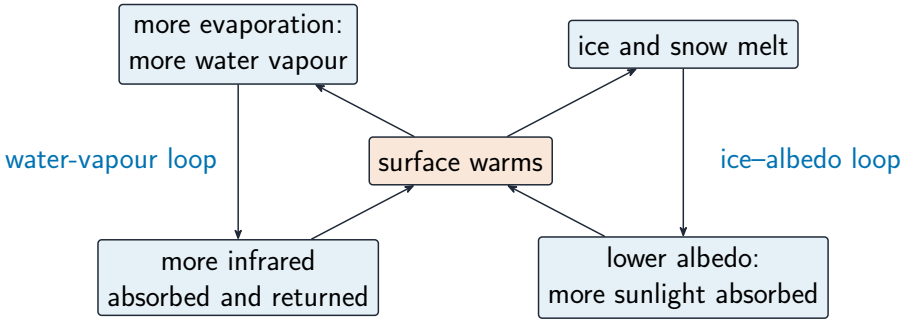
Decision

Connect the decision to law, economics and ethics; low cost alone is insufficient.

Comparing climate evidence

1. **Define.** State the region, years and uncertainty; compare multi-year averages.
2. **Align.** Use the same reference period for temperature anomalies, or convert to a common baseline.
3. **Interpret.** A single local hot year does not establish a global long-term trend.

Two positive feedback loops



Both loops warm the surface further

Exam tips

> Write power in $=$ power out, then solve for T^4.

- Use $S/4$ and multiply by $1-\alpha$.
- Check each layer separately in an energy-flow diagram.
- Greenhouse effect: emit infrared, absorb, re-emit in all directions.

Check yourself

Try these

Find the equilibrium temperature of Mars, with $S = 590$ W m^{-2} and albedo 0.25.

Find the equilibrium temperature of a planet with $S = 1000$ W m^{-2}, albedo 0.20 and emissivity 0.90.

Explain why Venus is 500 K hotter than its predicted equilibrium temperature.