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B. The particulate nature of matter / B.2 Greenhouse effect

# The big picture

## ? Guiding question(s)

- How does the greenhouse effect help to maintain life on Earth and how does human activity enhance this effect?
- How is the atmosphere as a system modelled to quantify the Earth—atmosphere energy balance?

Keep the guiding questions in mind as you learn the science in this subtopic. You will be ready to answer them at the end of this subtopic. The guiding questions require you to pull together your knowledge and skills from different sections, to see the bigger picture and to build your conceptual understanding.

Think of global warming and many people think of Greta Thunberg, the Swedish youth activist fighting against climate change. In 2018, Thunberg began to stand outside the Swedish parliament with a hand-painted sign saying ‘School Strike for Climate Change’. Since then, she has inspired millions of people in almost two hundred countries to take action to defend our planet and founded the global strike movement Fridays for Future. **Figure 1** shows youth activists demonstrating against climate change.


**Figure 1.** Protesting against climate change.

Credit: FilippoBacci, Getty Images (https://www.gettyimages.co.uk/license/1345174199)

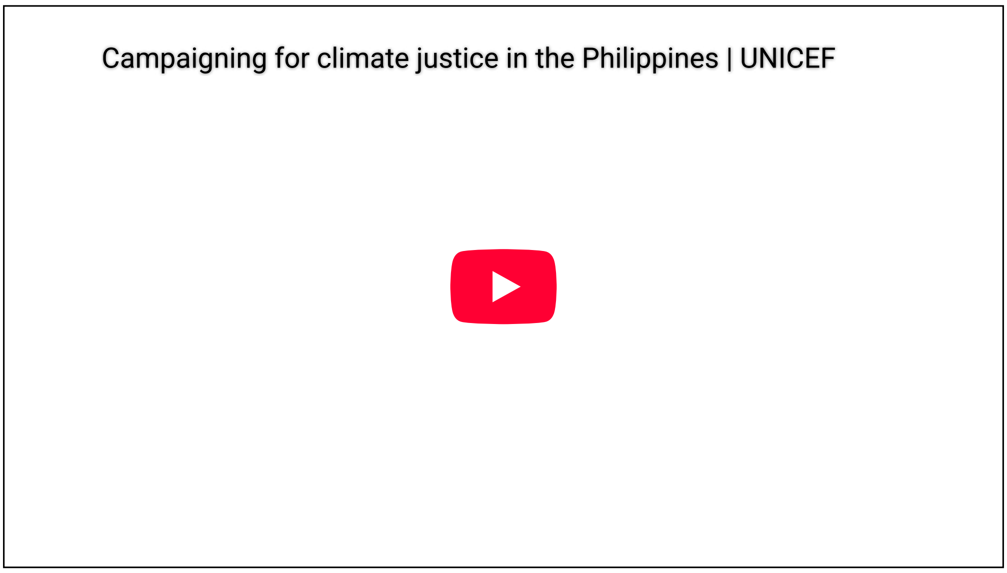
### Theory of Knowledge

In 2018, Greta was 15 years old. She was not an expert in the physical processes of climate change or the sociocultural factors related to energy production and its implications. However, she was able to capture the attention of people around the world and play a pivotal role in the global discussion about humankind's contribution to global warming.

To what extent does the acquisition of knowledge depend on experts?

Mitzi Jonelle Tan from Manila in the Philippines was inspired to take action against climate change. Watch **Video 1** in which Mitzi explains how climate change is affecting her country and what she is doing to help, then ask yourself:

How is climate change affecting your community and what actions can you take today to help build a better future?




Student
view

**Video 1.** Campaigning for climate justice in the Philippines.

More information for video 1

1

00:00:00,083 --> 00:00:01,835

[soft music plays]

Mitzi Jonelle Tan: Hello there!

2

00:00:03,045 --> 00:00:06,673

I am Mitzi Jonelle Tan

from Manila, Philippines.

3

00:00:06,798 --> 00:00:08,717

I am a climate justice activist,

4

00:00:08,884 --> 00:00:10,427

and I am active in the Fridays

5

00:00:10,511 --> 00:00:12,346

For Future international community.

6

00:00:12,429 --> 00:00:14,598

[soft music continues]

7

00:00:18,727 --> 00:00:20,562

Mitzi Jonelle Tan:

A lot of what we do is campaigning

8

00:00:20,646 --> 00:00:23,857

and amplifying the voices

of our environmental defenders,

9

00:00:23,941 --> 00:00:25,776

joining their fight for justice

10

00:00:26,068 --> 00:00:29,196

and demanding accountability

from our national government

11

00:00:29,530 --> 00:00:32,991

to act urgently

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because this is a climate crisis.

12

00:00:34,368 --> 00:00:36,745

Last month, we were hit by

the strongest typhoon

13

00:00:36,828 --> 00:00:39,957

in the planet this year,

and then barely a week

14

00:00:40,040 --> 00:00:42,543

after that, a typhoon

brought a month's worth

15

00:00:42,626 --> 00:00:45,128

of rain in under 24 hours.

16

00:00:46,296 --> 00:00:49,174

When we heard that the typhoons

were coming, my organization,

17

00:00:49,258 --> 00:00:51,677

Youth Advocates

For Climate Action Philippines,

18

00:00:51,760 --> 00:00:54,555

immediately started

to prepare for relief operations.

19

00:00:54,972 --> 00:00:58,100

We talked to the communities

and asked them what they needed the most.

20

00:00:58,267 --> 00:01:01,144

And there was an overwhelming

response that they were hungry

21

00:01:01,270 --> 00:01:02,813

and that they were angry.

22

00:01:02,938 --> 00:01:05,899

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They needed food,

so we went to the small markets,

23

00:01:05,983 --> 00:01:07,776

cooked and prepared everything ourselves,

24

00:01:07,860 --> 00:01:10,112

and then went to the communities

most impacted.

25

00:01:10,237 --> 00:01:12,406

We made sure not to just give them relief,

26

00:01:12,489 --> 00:01:15,659

but also to talk to them and asked them

about what they experienced,

27

00:01:15,742 --> 00:01:18,453

what they saw,

how they felt, and we talked to them.

28

00:01:19,246 --> 00:01:21,206

Some of the saddest

stories were about

29

00:01:21,290 --> 00:01:25,002

how some of the people,

they just didn't see them again.

30

00:01:25,294 --> 00:01:27,212

They didn't see their neighbors anymore.

31

00:01:27,296 --> 00:01:29,423

They don't know where their family is.

32

00:01:31,466 --> 00:01:35,929

I have such vivid memories

of doing my homework

33

00:01:36,054 --> 00:01:39,558

with a flashlight

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because the electricity would be out

34

00:01:39,641 --> 00:01:42,019

because of the raging typhoon outside.

35

00:01:42,102 --> 00:01:44,146

I would wake up in the middle

of the night

36

00:01:44,229 --> 00:01:48,358

with the winds howling outside

and my room would be flooded.

37

00:01:48,525 --> 00:01:49,985

I'd have to scoop flood water out

38

00:01:50,068 --> 00:01:52,821

before it consumed my room.

39

00:01:55,115 --> 00:01:57,451

We know that we have to keep fighting.

40

00:01:57,743 --> 00:02:02,206

We know that this isn't just about

the weather and the environment.

41

00:02:02,331 --> 00:02:03,665

It's about justice.

42

00:02:03,749 --> 00:02:06,835

It's about knowing that we deserve

43

00:02:07,127 --> 00:02:09,963

a safe present,

a just present,

44

00:02:10,047 --> 00:02:12,508

and a green and sustainable future.

45

00:02:15,886 --> 00:02:17,679

[music fades out]

Student view

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In this subtopic, you will learn about the factors that cause the greenhouse effect and why humans could not survive on the Earth without it. You will also learn how human activities enhance the greenhouse effect, which could fundamentally alter the way of life for our species.

### Concept

The effect of the Sun's energy on the Earth provides evidence that **objects can affect each other at a distance.** This **energy is conserved** — some of it is absorbed and some of it is reflected, but the total energy in the system remains constant.

**Matter in the Universe is made up of atoms and molecules.** The greenhouse gas molecules in the Earth's atmosphere absorb radiation emitted from the Earth then re-emit the radiation, some of which goes back towards the Earth's surface.

**The composition of the Earth and its atmosphere, and the processes occurring within them, shape the Earth's surface and its climate.** Human-led processes, such as the combustion of fossil fuels, have changed the composition of the Earth's atmosphere by increasing the concentration of greenhouse gases, leading to the enhanced greenhouse effect.

### Prior learning

Before you study this subtopic, make sure that you understand the following:

- Thermal radiation and black bodies (see subtopic B.1 (/study/app/math-aa-hl/sid-423-cid-762593/book/the-big-picture-id-43777/)).
- Simple harmonic motion (see subtopic C.1 (/study/app/math-aa-hl/sid-423-cid-762593/book/the-big-picture-id-43161/)).
- Electromagnetic spectrum (see subtopic C.2 (/study/app/math-aa-hl/sid-423-cid-762593/book/the-big-picture-id-43778/)).

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# Energy from the Sun



Student view

### Learning outcomes

By the end of this section you should be able to:

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- Outline what emissivity is.
- Outline what albedo is and explain why the Earth's albedo varies.
- Define and calculate the solar constant, *S*.

Every year, vast regions of ice in the Arctic melt away, completely changing the landscape. Watch **Video 1**, which shows the seasonal changes that the Arctic undergoes over the course of a year.


**Video 1.** The changing landscape of the Arctic.

How do these seasonal changes affect the delicate thermal equilibrium between the energy absorbed and emitted by the Earth, and its temperature?

### Making connections

The different forms of energy and how energy can be transferred from one form to another is covered in subtopic A.3 (/study/app/math-aa-hl/sid-423-cid-762593/book/the-big-picture-id-43083/). The idea of conservation of energy is also covered:

Energy cannot be created or destroyed, only transferred from one form to another.

For example, the amount of energy from the Sun incident on the surface of the Earth is equal to the amount of energy reflected by the Earth's surface plus the amount of energy absorbed.

## Emissivity

No object is a true black body (section B.1.5 (/study/app/math-aa-hl/sid-423-cid-762593/book/black-body-emission-id-43785/)). The amount of energy emitted per second by a real object is less than that emitted by a perfect black body of the same size and temperature.

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The ratio of the power emitted per unit area by a real object to the power emitted by a perfect black body of the same size and temperature is known as emissivity. It can be calculated using the equation:

**Table 1.** How to calculate emissivity.

| Equation | Symbols | Units |
|---|---|---|
| $\text{emissivity} = \frac{\text{power radiated per unit area}}{\sigma T^4}$ | emissivity of the object | unitless |
| | power radiated per unit area | watts per metre squared ($W\ m^{-2}$) |
| | $\sigma$ = Stefan—Boltzmann constant, $5.67 \times 10^{-8}\ W\ m^{-2}\ K^{-4}$ | (provided in section 1.6.3 (/study/app/math-aa-hl/sid-423-cid-762593/book/fundamental-constants-id-45155/) of the DP physics data booklet) |
| | $T$ = absolute temperature | kelvin (K) |

The maximum possible value of emissivity is 1. This means that the closer the emissivity of an object is to 1, the closer it approximates a perfect black body. It is worth pointing out that good emitters are also good absorbers.

## Making connections

As emissivity is a **ratio**, it does not have a unit. Where else in DP physics have you come across unitless quantities?

You might also notice that whilst learnng about emissivity you see it expressed elsewhere as an epsilon (ε) or simply the letter e. Normally we would use epsilon ($\varepsilon$) as the symbol for emissivity, but as $\varepsilon$ is used for the electromotive force (emf), and $e$ is used for the coulomb force, it is referred to in the IB course simply as the word 'emissivity' to avoid confusion.

The map in **Figure 1** was produced by NASA's ASTER instrument on the Terra spacecraft and shows the emissivity on different parts of the Earth's surface. Red areas indicate higher emissivity and blue areas indicate lower emissivity. Look at the map and discuss the following questions.

- What do you see?
- What can you infer?
- What questions does it raise?

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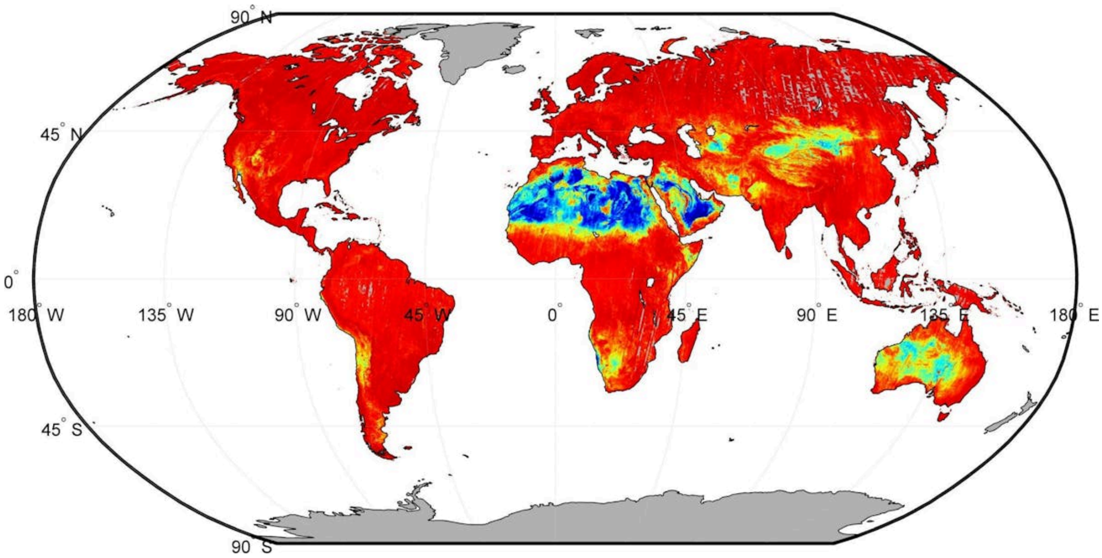


**Figure 1.** The emissivity at different locations on the Earth.

Source: "NASA Spacecraft Maps Earth's Global Emissivity (https://www.jpl.nasa.gov/images/pia18833-nasa-spacecraft-maps-earths-global-emissivity)" by NASA/GSFC/METI/ERSDAC/JAROS, and U.S./Japan ASTER Science Team

More information for figure 1

This is a global map depicting Earth's emissivity at different locations. The map features continents and oceans, with various colors representing emissivity levels. Red areas, primarily covering North America, northern Asia, and parts of South America and Africa, indicate high emissivity. The central part of Africa and some regions in Asia show blue tones, representing lower emissivity levels. Yellow and green regions are seen in Australia and parts of the Sahara, indicating medium emissivity. Longitude and latitude lines are marked at regular intervals, providing geographical context.

[Generated by AI]

### Study skills

Power is the rate of work done or the rate of energy transfer, measured in watts (section A.3.3 (/study/app/math-aa-hl/sid-423-cid-762593/book/power-and-efficiency-id-43086/)). If you substitute the units for work done and time into the equation for power, $P = \frac{\Delta W}{\Delta t}$, you can see that $P = \frac{\text{joules}}{\text{seconds}}$ or $\text{J s}^{-1}$, which is the same as the amount of energy emitted per second. For this reason, the energy emitted per second by a black body can also be described as the power emitted by a black body.

## Worked example 1

Student view

The temperature of Mars is approximately −63 °C, and each square metre of its surface emits 83 J of energy per second. Calculate its emissivity.

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| Solution steps | Calculations |
|---|---|
| **Step 1:** write out the values given in the question and convert the values to the units required for the equation | $T = -63\ ^\circ\text{C}$<br>$P = 83\ \text{J s}^{-1}$ or $83\ \text{W}$<br>$T = -63 + 273$<br>$= 210\ \text{K}$ |
| **Step 2:** write out the equation | $\text{emissivity} = \dfrac{\text{power radiated per unit area}}{\sigma T^4}$ |
| **Step 3:** substitute the values given | $= \dfrac{83}{(5.67 \times 10^{-8})(210^4)}$ |
| **Step 4:** state the answer with appropriate units and the number of significant figures used in rounding | $= 0.753$<br>$= 0.75\ (2\ \text{s.f.})$ |

### Making connections

The luminosity of a black body is the amount of energy it emits per second, and it is calculated using the equation $L = \sigma A T^4$ (section B.1.5 (/study/app/math-aa-hl/sid-423-cid-762593/book/black-body-emission-id-43785/)).

As emissivity is associated with power per unit area, you can remove $A$ from the equation for luminosity. This shows you that the emissivity of an object is the ratio of its luminosity to the luminosity of a black body of the same size and temperature.

# Albedo

You have looked at the energy **emitted** by an object. Now, you will look at the energy **reflected** by an object.

The average energy reflected off a macroscopic system compared to the energy incident on the system is known as albedo. It is calculated using the equation:

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

### Study skills

Student view

'Scattered' power can be taken to mean 'reflected' power.

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## Worked example 2

Use the information in **Figure 2** to calculate the albedo of an urban area, such as Manhattan in New York, USA.

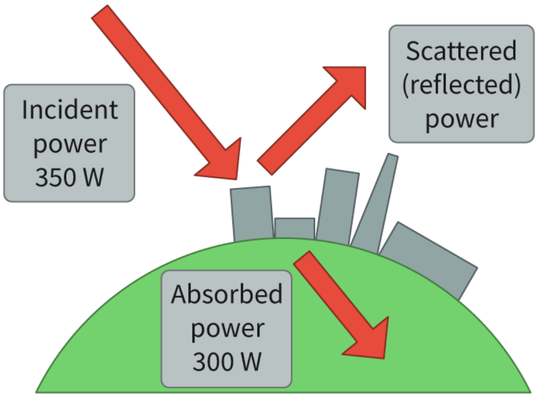


**Figure 2.** Incident, scattered and absorbed power in an urban area.

More information for figure 2

The diagram illustrates three different types of power in an urban area. On the left, an arrow labeled "Incident power 350 W" points downwards towards a green semicircular ground, representing incoming power. An arrow from the semicircle points upward, labeled "Scattered (reflected) power," indicating power reflected from the surface. Another arrow labeled "Absorbed power 300 W" points towards the ground, representing the power absorbed by the surface. The diagram uses arrows and text boxes to provide a visual summary of power distribution in an urban setting.

[Generated by AI]

| Solution steps | Calculations |
|---|---|
| **Step 1:** write out the values given in the question | $\text{incident power} = 350\text{ W}$ <br> $\text{absorbed power} = 300\text{ W}$ |
| **Step 2:** calculate the scattered power | $\begin{aligned}\text{scattered power} &= \text{incident power} - \text{absorbed power}\\ &= 350 - 300\\ &= 50\text{ W}\end{aligned}$ |

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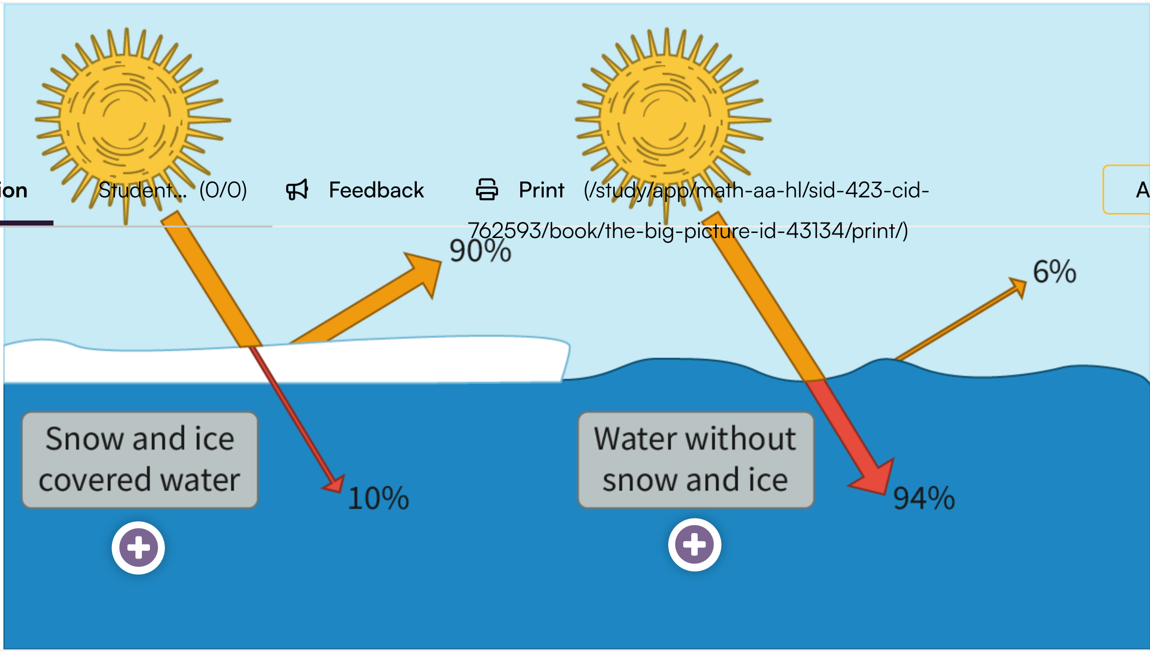
| Solution steps | Calculations |
|---|---|
| **Step 3:** write out the equation | $\text{albedo} = \frac{\text{total scattered power}}{\text{total incident power}}$ |
| **Step 4:** substitute the values given | $= \frac{50}{350}$ |
| **Step 5:** state the answer with appropriate units and the number of significant figures used in rounding | $= 0.143 = 0.14\ (2\ \text{s.f.})$<br><br>Note that urban areas are often grey and black, which are dark colours and poor reflectors, so it makes sense that their albedo is low. |

Look at the diagram in **Interactive 1** showing two situations. Use the equation for albedo to determine the albedo of each situation. Click on the hotspot '+' buttons to check your answers.

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**Interactive 1.** What is the albedo of each situation?

More information for interactive 1

This interactivity illustrates the difference in solar energy absorption and reflection between snow and ice-covered water and open water. It features two sections, each depicting a sun shining down on a water surface. On the left side, the water is covered with snow and ice, while on the right side, the water is exposed. The two plus signs in the image represent interactive hotspots. When clicked, they provide additional information about the processes at play.

In the snow and ice-covered water section, an incoming solar ray is shown striking the surface. A large portion of the energy, 90%, is reflected back into the atmosphere, while only 10% is absorbed. The albedo is defined as the ratio of total scattered power to the total incident power. For the snow and ice-covered water, the albedo is calculated as:

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$$\text{albedo} = \frac{90}{100} = 0.9$$

Clicking the hotspot reads: $\text{albedo} = 0.9$. Snow and ice are white in colour and very reflective. Water is not white and not as reflective. The proportion of incident energy reflected is much higher for ice than for water, so the albedo of ice is higher.

In the water without snow and ice section, the incoming solar ray interacts differently. Here, only $6\%$ of the energy is reflected, while $94\%$ is absorbed by the water. For the water without snow and ice

$$\text{albedo} = \frac{6}{100} = 0.06$$

Clicking the hotspot reads: $\text{albedo} = 0.06$. Snow and ice are white in colour and very reflective. Water is not white and not as reflective. The proportion of incident energy reflected is much lower for water than for ice, so the albedo of water is lower.

This interactivity visualizes the impact of surface type on energy absorption and reflection. It helps users understand why polar ice plays a crucial role in climate regulation and how its loss contributes to a feedback loop of increasing temperatures.

### Study skills

Like emissivity, albedo is a ratio and does not have a unit. The maximum possible value of albedo is 1. The closer the albedo of an object is to 1, the closer the object is to being the opposite of a black body — a body that completely reflects all radiation.

The Earth's average albedo is about 0.30, but its albedo varies daily due to a number of factors including the following:

- The thickness of the clouds above the Earth. If a thick white cloud is above a deep ocean, the albedo will be higher because the light surface of the cloud is more reflective than the dark surface of the ocean.
- The type of cloud cover. Thick, fluffy clouds, like cumulonimbus, have a high albedo, while thin, wispy clouds, like cirrus, have a low albedo (**Figure 3**).

Credit: orleijunior.com, Getty Images

Student view

Credit: Jason Hosking, Getty Images

**Figure 3.** A cumulonimbus cloud and a cirrus cloud.

- Latitude: the further away from the Equator, the higher the albedo. This is geographical (not a mathematical relationship) because there are more light-coloured surfaces further away from the Equator, such as the snow and ice found at the North and South Poles, which reflect more radiation, thus increasing the albedo.
- The type of terrain on the Earth's surface. The material that covers the surface, such as snow and ice, desert, ocean or forest, affect the albedo.

Which types of terrain have a higher albedo? Use **Interactive 2** to find out.

Rights of use

**Interactive 2.** Which Types of Terrains Have Higher Albedos?

More information for interactive 2

An interactive world map presents different geographical features such as landmasses, bodies of water, deserts, forests, and polar regions. The map includes five plus signs, which function as interactive hotspots placed in distinct locations across the globe. These hotspots, when clicked, provide additional information about the specific region they are located in.

Hotspot 1 is in the Arctic, close to Greenland. The text reads, Snowy and icy parts of the Earth's surface have albedos of 0.60 to 0.90 because they are highly reflective.

Hotspot 2 is placed in the Sahara Desert in Africa. The text reads, Deserts have albedos of about 0.40 because their light-

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coloured sands reflect a lot of the incident radiation.

Hotspot 3 appears in the middle of the Pacific ocean. The text reads, Oceans have very low albedos of about 0.06 because their very dark colour absorbs most of the incident radiation.

Hotspot 4 is positioned in the Amazon rainforest in South America. The text reads, Forests have albedos of 0.15 to 0.25 because the dark colours of the vegetation absorb a lot of the incident radiation.

**Aspect:** Theories

As global temperatures continue to rise, and reducing the impact of global warming becomes more important than ever, intelligent urban planning is vital.

In what ways do you think that urban planners and architects can apply theories of emissivity and albedo to the design of cities and buildings in order to play their part in the fight against climate change?

# The solar constant

The solar constant represents the average intensity of electromagnetic radiation incident on the Earth's outer atmosphere, and its value is equal to the average apparent brightness (section B.1.5 (/study/app/math-aa-hl/sid-423-cid-762593/book/black-body-emission-id-43785/)) of the Sun from Earth. This value changes throughout the year which is why we state an average value (**Figure 4**).

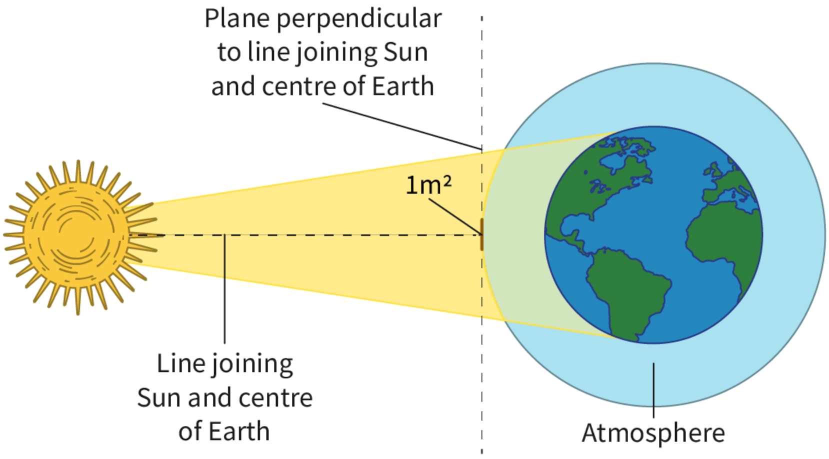


**Figure 4.** The solar constant.

More information for figure 4

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The diagram illustrates solar radiation reaching the Earth's atmosphere. It shows the Sun on the left, emitting light towards Earth, which is on the right, with the blue circle representing Earth's atmosphere. A dotted line connects the Sun and the center of the Earth, indicating the axis. The light from the Sun is depicted as a yellow cone, narrowing to a smaller cross-section marked as 1 square meter, at the edge of the atmosphere. Text labels indicate "Plane perpendicular to line joining Sun and centre of Earth," "1m²," "Line joining Sun and centre of Earth," and "Atmosphere." This diagram visually explains the concept of the solar constant by representing the distribution of solar energy across a specific area of the Earth's atmosphere.

[Generated by AI]

**Figure 4** shows only a small proportion of the energy emitted by the Sun. In reality, the Sun emits energy in all directions. This means that the energy is spread across the inside of an imaginary sphere, with a radius, $r$, equal to the distance between the surface of the Sun and the surface of the atmosphere of the Earth (**Figure 5**).

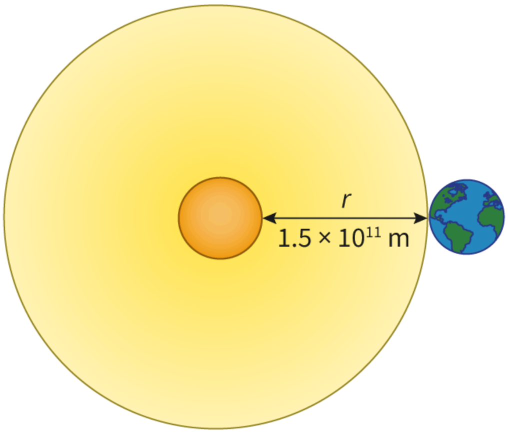


**Figure 5.** The Sun's energy is spread over a sphere.

More information for figure 5

The diagram illustrates how the Sun's energy is distributed over an imaginary sphere. At the center of the diagram is a small, orange circle representing the Sun. Around it is a larger, yellow, translucent circle indicating an imaginary sphere. To the right of the Sun, a line labeled 'r' and '1.5 x 10^11 m' extends from the Sun to the right edge of the sphere, ending at a depiction of Earth. This line represents the distance from the Sun to Earth, illustrating the radius of the sphere over which energy is spread.

[Generated by AI]

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You can calculate the surface area of a sphere using the following equation:

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**Table 1.** Calculating the surface area of a sphere.

| Equation | Symbols | Units |
| --- | --- | --- |
| $A = 4\pi r^2$ | $A$ = surface area of a sphere | metres squared ($m^2$) |
| | $r$ = distance from surface of Sun to surface of atmosphere of Earth | metres (m) |

We can use this equation and the information in **Figure 5** to calculate the amount of energy incident on $1\,m^2$ of the surface of the Earth's atmosphere in 1 second.

First, calculate the surface area of the sphere:

$$\begin{aligned} A &= 4\pi r^2 \\ &= 4\pi \times (1.5\times 10^{11})^2 \\ &= 2.827\times 10^{23}\ \text{m}^2 \end{aligned}$$

The Sun emits $3.9 \times 10^{26}$ J of energy every second. To determine the amount of energy incident on 1 $m^2$ of the surface of the Earth's atmosphere in 1 second, divide this energy by the surface area of the sphere over which the Sun's energy is distributed:

$$\begin{aligned} \frac{3.9\times 10^{26}}{2.827\times 10^{23}} &= 1379\ \text{W m}^{-2} \\ &= 1400\ \text{W m}^{-2}\ (2\ \text{s.f.}) \end{aligned}$$

The power incident on the upper surface of the Earth's atmosphere per square metre from the Sun is known as the solar constant and has the symbol $S$. The solar constant varies slightly depending on the Sun cycle and the Earth's orbit. The value of the solar constant given in section 1.6.3 (/study/app/math-aa-hl/sid-423-cid-762593/book/fundamental-constants-id-45155/) of your DP physics data booklet is $1.36 \times 10^3$ W $m^{-2}$.

### Study skills

In an assessment question, you may be given the energy per second emitted by the Sun and the distance from the surface of the Sun to the surface of the atmosphere of a planet and asked to calculate its 'solar constant'.

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## Worked example 3

The distance from the surface of the Sun to the surface of the atmosphere of Mercury at a particular point in its orbit is $4.6 \times 10^{10}$ m. Calculate the solar constant on Mercury. The Sun emits $3.9 \times 10^{26}$ J of energy every second.

$$\begin{aligned} A &= 4\pi r^2 \\ &= 4\pi \times (4.6 \times 10^{10})^2 \\ &= 2.659 \times 10^{22} \text{ m}^2 \end{aligned}$$

$$S_m = \frac{3.9 \times 10^{26}}{2.659 \times 10^{22}} = 14\,667 \text{ W m}^{-2} \text{ or } 15\,000 \text{ W m}^{-2} \text{ (2 s.f.)}$$

The solar constant gives the amount of solar energy per second per squared metre that is incident upon a circle lying perpendicular to the path of the solar rays at the upper atmosphere of the planet. If you want to know what is the average amount of energy incident per second per metre squared on the **surface** of the Earth, you need to take into account that only one side of the Earth is exposed to the Sun's radiation at any one time and that the Earth is a sphere. The Earth effectively presents a 2D surface to the Sun. This 2D surface is a circle with a radius equal to the Earth's radius (**Figure 6**).


**Figure 6.** The circle that receives the Sun's energy.

More information for figure 6

The diagram illustrates the concept of solar energy being received by the Earth in relation to its position to the Sun. On the left side of the image, the Sun is depicted as a large yellow circle with rays extending outward. Directly opposite, on the right side, is Earth, shown as a smaller blue and green circle.

A yellow rectangular band representing solar energy extends from the Sun to Earth, showing the pathway of solar rays. The Earth's radius is labeled as "r_Earth" with an arrow pointing outward from Earth, indicating the radius's direction. The diagram visualizes how the Earth intercepts solar energy over a circular area equivalent to a cross-sectional slice through the Earth's

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sphere. This illustration supports understanding the solar constant and energy distribution on Earth's surface, discussing how only one side of the planet receives sunlight at any given time.

[Generated by AI]

The area of this circle is $\pi r^2$, so the total energy received on the surface of the Earth is given by $S\pi r^2$.

This total energy is effectively spread across the surface of the Earth, which is a sphere $(A = 4\pi r^2)$.

The average energy incident per second per metre squared on the Earth's surface is then:

$$\begin{aligned}\frac{S\pi r^2}{4\pi r^2} &= \frac{S}{4}\\ &= \frac{1.36\times 10^3}{4}\\ &= 340\ \mathrm{W\ m^{-2}}\end{aligned}$$

As $S = 1.36\times 10^3\ \mathrm{W\ m^{-2}}$ (section 1.6.3 (/study/app/math-aa-hl/sid-423-cid-762593/book/fundamental-constants-id-45155/) of the DP physics data booklet) for the Earth, **Figure 7** shows that averaged over the entire planet, the amount of the Sun's energy arriving at the Earth's upper atmosphere is only one quarter of the solar constant.

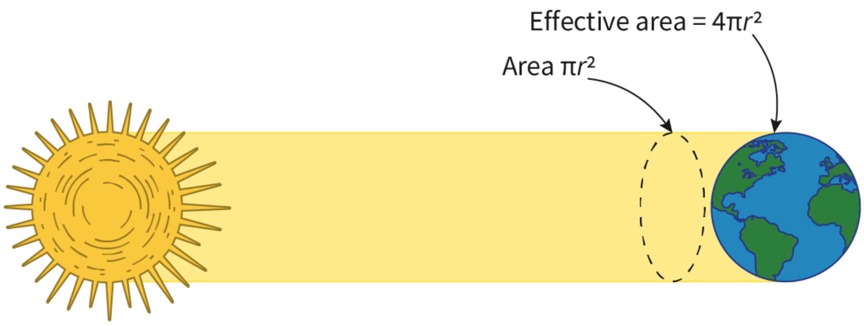


**Figure 7.** Averaged over the entire planet, the energy incident per second per metre squared is one quarter of the solar constant.

More information for figure 7

The diagram illustrates the concept of solar energy distribution over the Earth's surface. On the left, there is a stylized depiction of the Sun emitting light or energy as yellow rays extending outward. This energy encompasses the Earth's atmosphere, represented as a blue sphere on the right side. Two labels are present: "Area πr²" shows the cross-sectional area of the Earth, and "Effective area = 4πr²" indicates the total surface area that receives sunlight. These labels are connected by arrows pointing at their

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corresponding areas. The diagram highlights how the energy from the Sun is averaged over the surface area of the Earth, emphasizing the distinction between the direct cross-sectional area and the broader effective area that accounts for the entire sphere.

[Generated by AI]

Try the following activity to check your understanding of energy from the Sun.

## Activity

- **IB learner profile attribute:** Knowledgeable
- **Approaches to learning:** Thinking skills — Reflecting at all stages of the assessment and learning cycle
- **Time required to complete activity**: 20 minutes
- **Activity type:** Individual activity

Download the worksheet and complete the practice questions.

Worksheet (https://d3vrb2m3yrmyfi.cloudfront.net/media/edusys_2/content_uploads/Physics B.2.1 ACTIVITY Greenhouse effect.2d97a17eab81abe4e76d.pdf)

Remember to show all your working. You can check your answers on the last page.

## 5 section questions

**Question 1**

SL HL Difficulty:

Calculate the power radiated per unit area by an object with an emissivity of 0.8 and a surface temperature of 4500 K.

1 19 MW ✓

2 0.20 mW

3 29 MW

4 0.32 mW

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**Explanation**

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emissivity = 0.8

$T$ = 4500 K

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

$$\begin{aligned}\text{power} &= \text{emissivity} \times \sigma T^4 \\ &= 0.8 \times 5.67 \times 10^{-8} \times 4500^4 \\ &= 18\,600\,435 \text{ W} \\ &= 19\,000\,000 \text{ W or } 19 \text{ MW } (2 \text{ s.f.})\end{aligned}$$

**Question 2**

SL HL Difficulty:

750 W of solar radiation is incident on 1 m$^2$ of a planet's surface. If the temperature of the planet is constant, and it absorbs 250 W of the incident radiation per square metre, how much radiation is reflected and what is the planet's albedo?

| | Reflected radiation | Albedo |
|---|---|---|
| A | 250 W m$^{-2}$ | 0.33 |
| B | 500 W m$^{-2}$ | 0.33 |
| C | 250 W m$^{-2}$ | 0.67 |
| D | 500 W m$^{-2}$ | 0.67 |

1 D ✓

2 A

3 B

4 C

## Explanation

The sum of the absorbed radiation and reflected radiation is equal to the radiation incident on the planet.

The reflected radiation is:

$$750 - 250 = 500 \text{ W m}^{-2}$$

$$\begin{aligned}\text{albedo} &= \frac{\text{total scattered power}}{\text{total incident power}} \\ &= \frac{500}{750} \\ &= 0.667 = 0.67 \text{ (2 s.f.)}\end{aligned}$$

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**Question 3**

SL HL Difficulty:

The 1 solar constant ✓ is the amount of energy incident on 1 $m^2$ of the surface of the Earth's atmosphere in 1 second.

**Accepted answers and explanation**

#1 solar constant

solar constant, S

**General explanation**

This is the definition of the solar constant, S.

**Question 4**

SL HL Difficulty:

The solar constant on a planet is 590 W $m^{-2}$. Determine the average intensity (power per unit area) of the radiation arriving normally at the surface of the planet. Give your answer to an appropriate number of significant figures.

The average intensity of the radiation is 1 150 ✓ W $m^{-2}$

**Accepted answers and explanation**

#1 150

150 watts per metre squared

150 watts per square metre

**General explanation**

S = 590 W $m^{-2}$

$$\begin{aligned}\text{average intensity} &= \frac{S}{4}\\ &= \frac{590}{4}\\ &= 147.5\ \mathrm{W\ m^{-2}}\\ &= 150\ \mathrm{W\ m^{-2}}\ (2\ \text{s.f.})\end{aligned}$$

**Question 5**

SL HL Difficulty:

Calculate the solar constant for a planet that is $1.1 \times 10^{11}$ m from the Sun. The Sun emits $3.9 \times 10^{26}$ J of energy every second. Give your answer to an appropriate number of significant figures.

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The solar constant is 1 2600 ✓ $\text{W m}^{-2}$

**Accepted answers and explanation**

#1 2600
2,600
2600 watts per metres squared
2600 watts per square metre

**General explanation**

$$\begin{aligned} A &= 4\pi r^2 \\ &= 4\pi \times (1.1\times 10^{11})^2 \\ &= 1.521\times 10^{23}\ \text{m}^2 \end{aligned}$$

$$\begin{aligned} S &= \frac{3.9\times 10^{26}}{1.521\times 10^{23}} \\ &= 2565\ \text{W m}^{-2} = 2600\ \text{W m}^{-2}\ (2\ \text{s.f.}) \end{aligned}$$

B. The particulate nature of matter / B.2 Greenhouse effect

# Energy balance in the Earth surface–atmosphere system

B.2.7: Greenhouse gases B.2.8: Absorption and emission of radiation B.2.9: Resonance and molecular energy level models B.2.10: Enhanced greenhouse effect

## Learning outcomes

By the end of this section you should be able to:

- Explain why some gases in the Earth's atmosphere absorb infrared radiation and others do not.
- Apply a resonance model and an energy level model to explain the greenhouse effect.
- Solve energy balance problems where energy is exchanged between the surface and the atmosphere of a body.

The Moon is about $4.0 \times 10^8$ metres away from the Earth. The Moon and the Earth are approximately the same distance from the Sun, yet, the average surface temperature of the Moon is about –20 °C, while on the Earth it is about +20 °C. **Figure 1** shows the Sun, the Earth and the Moon.

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If both bodies are approximately the same distance from the Sun, what is the reason for the huge difference in temperature?

**Figure 1.** Why is the Moon much colder than the Earth?

## The greenhouse effect

The greenhouse effect is the name given to the mechanism where some of the incoming radiation from the Sun is trapped within the Earth surface–atmosphere system, thus increasing the overall temperature of the system. The atmosphere is the layers of gases that surround the Earth.

We can calculate the temperature of a black body with the same dimensions as the Earth but with **no atmosphere**.

The average energy incident per metre squared per second on the Earth is 340 W m$^{-2}$ (section B.2.1 (/study/app/math-aa-hl/sid-423-cid-762593/book/energy-from-the-sun-id-43771/)). Given that the average albedo of the Earth is about 0.30, we can calculate the amount of incident energy that is absorbed by the Earth's surface:

$$\begin{aligned}\text{proportion of power absorbed} &= 1-\text{albedo}\\ &= 1-0.30\\ &= 0.70\end{aligned}$$

$$\begin{aligned}\text{power absorbed} &= 340\times 0.70\\ &= 238\text{ W m}^{-2}\end{aligned}$$

The Earth absorbs this incident power and then re-emits it in all directions. Assuming that the Earth behaves like a perfect black body, and that the luminosity of a black body is equivalent to its power emitted (section B.1.5 (/study/app/math-aa-hl/sid-423-cid-762593/book/black-body-emission-id-43785/)), we can calculate the theoretical surface temperature of the black body with a luminosity of 238 W m$^{-2}$ (assume an area, $A$, of 1.0 m$^2$):

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$$L = \sigma A T^4$$

$$T = \sqrt[4]{\frac{L}{\sigma A}}$$

$$= \sqrt[4]{\frac{238}{5.67 \times 10^{-8} \times 1.0}}$$

$$= 254 \text{ K or } -19\ ^\circ\text{C}$$

This is approximately equal to the temperature of the Moon. Why is the Earth's average temperature higher than this?

## Worked example 1

Using 254 K as the temperature of the Earth and Wien's law (section B.1.5 (/study/app/math-aa-hl/sid-423-cid-762593/book/black-body-emission-id-43785/)), calculate the wavelength at which the maximum intensity of radiation is emitted, then use the internet to find out what region of the electromagnetic spectrum this corresponds to.

$$T = 254 \text{ K}$$

$$\lambda_{\max} T = 2.9 \times 10^{-3} \text{ m K}$$

$$\lambda_{\max} = \frac{2.9 \times 10^{-3}}{T}$$

$$= \frac{2.9 \times 10^{-3}}{254}$$

$$= 1.1 \times 10^{-5} \text{ m (2 s.f.)}$$

This is in the **infrared** region of the electromagnetic spectrum.

Most of the electromagnetic radiation absorbed by the Earth is in the visible light region of the spectrum. This radiation is then re-emitted as infrared radiation. Infrared is absorbed by the greenhouse gases in the Earth's atmosphere.

The greenhouse gas particles in the atmosphere re-emit this energy in all directions. Some of the energy is re-emitted out to space and some is re-emitted back towards the Earth, thus trapping the energy in the Earth surface–atmosphere system.

The Earth's atmosphere is the reason why the Earth's temperature is higher than that of the Moon.

Student view

**Video 1** shows the processes of absorption, reflection and re-emission that combine to produce the greenhouse effect.

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**Video 1.** The greenhouse effect.

This process is known as the natural greenhouse effect. It is essential for keeping the temperature of the Earth in the narrow range of temperatures that will support life as we know it.

Natural variations and human activity have increased, and continue to increase, the concentration of greenhouse gases in the atmosphere, leading to the enhanced greenhouse effect.

## The greenhouse gases

The gases that make up most of the Earth's atmosphere are nitrogen and oxygen. They do not absorb infrared radiation. The greenhouse gases that do absorb infrared radiation are carbon dioxide ($CO_2$), methane ($CH_4$), nitrous oxide ($N_2O$) and water vapour ($H_2O$).

Click on each section of the pie chart in **Interactive 1** to see the percentages of the gases in the atmosphere.

Student
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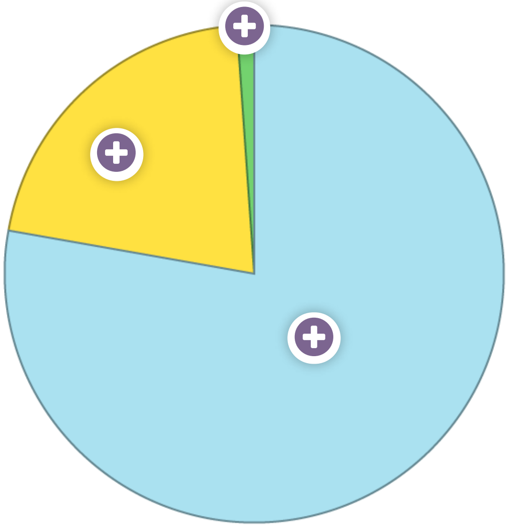

**Interactive 1.** The Composition of the Earth's Atmosphere.

More information for interactive 1

An interactive pie chart divided into three sections, each represented by a different color. The largest section is shaded in blue, occupying more than half of the chart. The yellow section takes up a significant portion but is smaller than the blue section. A very thin green slice is positioned between the yellow and blue sections, representing a much smaller proportion compared to the other two.

Three interactive hotspots represented by plus signs are placed within different segments of the chart. When clicked, these hotspots provide additional details about the represented data. The blue section contains hotspot 3, which reads, 78% Nitrogen. The yellow section includes a hotspot 2, which reads, 21 % Oxygen. The smallest green section has hotspot 1 which reads, 1 % Other gases, including carbon dioxide, water, nitrous oxide, and methane.

This interactivity helps in understanding the gases and the percent of the gases in the atmosphere.

The concentration of greenhouse gases in the atmosphere is affected by natural processes and human activities that release and absorb the gases from the atmosphere. These processes are summarised in **Table 1**.

**Table 1.** Processes that affect the concentration of gases in the atmosphere.

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| Gas | Natural processes | Human activities that contribute to the enhanced greenhouse effect |
|---|---|---|
| Carbon dioxide $CO_2$ | **Released** by plants and animals during respiration<br>**Absorbed** by plants during photosynthesis<br>**Absorbed** by oceans | **Released** by combustion of fossil fuels for transport and electricity production<br>Deforestation results in fewer plants available to **absorb** the $CO_2$ by photosynthesis<br>Climate change increases the temperature of the world's oceans, thus reducing their capacity to **absorb** $CO_2$ |
| Methane $CH_4$ | **Released** by natural processes in wetlands<br>**Absorbed** by natural processes in the soil and the atmosphere | **Released** by animals such as cows, which are farmed for food<br>**Released** by processes related to the storage and processing of crude oil and natural gas<br>**Released** by waste disposed of in landfill sites |
| Water vapour $H_2O$ | **Released** and **absorbed** naturally as part of the water cycle | **Released** due to increased global temperatures increasing evaporation during the water cycle<br>**Released** during fossil fuel combustion |
| Nitrous oxide $N_2O$ | **Released** by bacteria in soil and oceans<br>**Absorbed** by bacteria | **Released** during fossil fuel combustion<br>**Released** during the production of fertilisers used in farming |

## Creativity, activity, service

**Strand:** Creativity
**Learning outcome:** Demonstrate engagement with issues of global significance

While many people are aware of the need to reduce the emission of greenhouse gases in order to slow the rate of global warming, many also believe that the actions of one person are insignificant.

Design an activity to inform members of your community about how their actions can have an impact on global warming.

There are different sources for all of the greenhouse gases. Different geographical regions produce different amounts of each, from naturally occurring sources and human sources. However, the effects of the greenhouse gases are global.

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### International Mindedness

Use the simulation The Carbon Map (https://www.carbonmap.org/) to investigate the following:

- Which parts of the world are historically responsible for $CO_2$ emissions.
- Where most fossil fuels are extracted and which countries are the biggest consumers.
- Where the remaining fossil fuel reserves are in the world.
- Which countries are most at risk from the effects of global warming.

This tutorial (https://www.theguardian.com/news/datablog/interactive/2012/mar/29/carbon-map-infographic-world) will guide you through using the simulation.

In some developing countries, there are still people who do not have access to mains electricity. Their leaders argue that the need to help their citizens is more important than the need to help solve a problem that they did not create.

Whose responsibility is it to reduce the production of greenhouse gases and slow down the rate of global warming? You could write a balanced argument on this subject, or have a class debate.

# Why do some gases absorb radiation while others do not?

## The resonance model

All objects have a natural frequency of vibration (subtopic C.4 (/study/app/math-aa-hl/sid-423-cid-762593/book/the-big-picture-id-43788/)). This includes molecules. If the incident radiation has a frequency equal to that of the molecules' natural frequency of vibration, the molecules absorb the energy and resonance occurs. This means that the amplitude of vibration of the molecules is maximum.

The natural frequency of vibration of the greenhouse gases is within the range of frequencies of infrared radiation. So the greenhouse gases absorb this radiation. Other gases, such as oxygen and nitrogen, have a different natural frequency of vibration so they do not absorb a significant quantity of infrared radiation.

The natural frequency of vibration of the greenhouse gases is not within the range of frequencies of visible light. This means visible light is not absorbed and these gases are transparent to visible light.

Student view

Click on the drop-down menu in **Interactive 2** to select the type of incident radiation and see what happens to the vibration of the carbon dioxide molecule ($CO_2$), shown by the O and C spheres connected by bonds.

Incident radiation

**Interactive 2.** The resonance model.

More information for interactive 2

The interactive simulation, the resonance model, allows users to explore how different types of electromagnetic radiation interact with a carbon dioxide molecule. The interface provides a dropdown menu labeled "Incident radiation," offering several options, radio waves, microwaves, infrared, visible light, ultraviolet, X-rays, and gamma rays. Selecting one of these options changes the type of radiation the carbon dioxide molecule is exposed to. The molecule is visually represented by a central carbon (C) atom connected to two oxygen (O) atoms by flexible bonds on the right and left sides, which can vibrate in response to the applied radiation.

As users choose different types of radiation, they can observe changes in the molecule's behavior. Some types of radiation cause the molecule to vibrate more, while others have little or no effect. The vibrations are depicted as oscillatory movements of the oxygen atoms relative to the carbon atom. Infrared radiation, for example, induces noticeable stretching vibrations, demonstrating how $CO_2$ absorbs energy in this range of the electromagnetic spectrum. Other types of radiation, such as visible light or radio waves and the other given radiations, do not produce significant molecular movement, reinforcing the idea that molecular absorption depends on the frequency of the incident radiation.

This simulation helps learners understand the concept of molecular resonance and how different wavelengths of radiation interact with matter. It illustrates the role of infrared radiation in greenhouse gas absorption, a fundamental principle in climate science. By experimenting with different radiation types, users can see why infrared radiation is particularly effective at causing molecular vibrations that contribute to the greenhouse effect by trapping heat in the atmosphere. The simulation also explains why other forms of radiation, such as X-rays and gamma rays, do not cause these specific molecular motions but interact differently with matter.

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## Molecular energy levels

Light can exist as a wave and as a particle, called a photon, which has a specific amount of energy depending on the frequency of the light (subtopic E.1 (/study/app/math-aa-hl/sid-423-cid-762593/book/the-big-picture-id-43191/)).

Molecules can be interpreted to have discrete energy levels and they can only exist at these set energy levels. The exact molecular energy levels available are dependent on factors beyond the scope of the DP physics curriculum. If a photon energy matches the gap between molecular energy levels the photon will be absorbed and the molecule increases its energy. At some later point in time, the molecule will drop back down an energy level and re-emit the photon in a random direction.

Nitrogen and oxygen molecules have gaps between energy levels that are different to the photon energies of ultraviolet or infrared radiation, therefore no interaction occurs.

### Making connections

A deeper understanding of vibration and resonance will be developed in topic C (/study/app/math-aa-hl/sid-423-cid-762593/book/the-big-picture-id-43161/), and a deeper understanding of atomic energy levels in topic E (/study/app/math-aa-hl/sid-423-cid-762593/book/the-big-picture-id-43191/).

# Energy balance in the Earth surface—atmosphere system

The principle of conservation of energy states that energy cannot be created or destroyed, but only transferred (subtopic A.3 (/study/app/math-aa-hl/sid-423-cid-762593/book/the-big-picture-id-43083/)). This principle can be applied to microscopic systems and macroscopic systems, including that of the Earth surface–atmosphere.

Over billions of years, natural changes have occurred on Earth, such as changes in the terrain, changes to the Earth's atmosphere, and reduction of carbon dioxide due to the decrease in volcanic activity. These changes happened over a very long period of time.

In recent years, human activity has led to huge changes in the Earth's atmosphere in a relatively short period of time, trapping a larger proportion of incident radiation, resulting in global warming.

While, historically, the temperature of the Earth has fluctuated, these fluctuations occurred over very long periods of time. The graph in **Figure 2** shows how the global average surface temperature has increased significantly in a very short period of time, providing evidence that this change has been caused by human activity.

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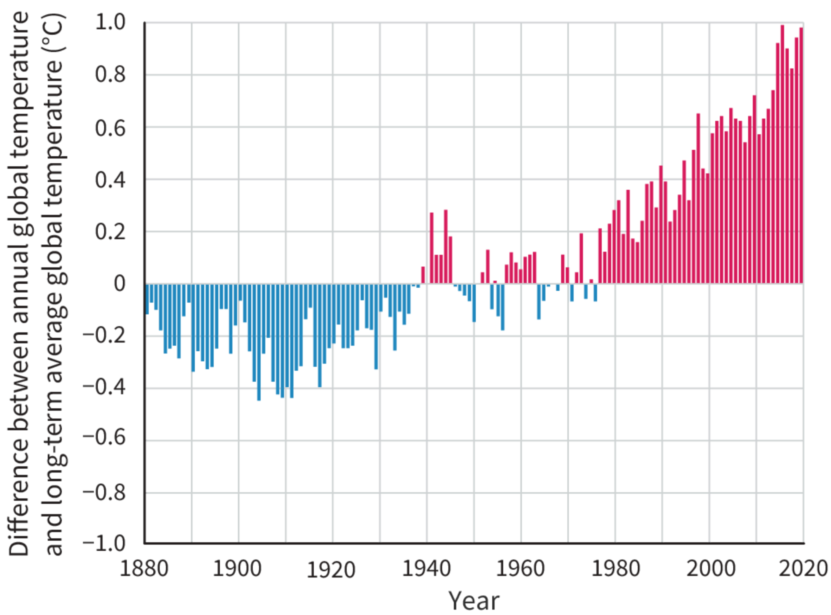


**Figure 2.** Change in mean global temperature of the Earth.

More information for figure 2

The image is a bar graph depicting changes in the global average surface temperature from 1880 to 2020. The X-axis represents years, starting from 1880 and ending in 2020. The Y-axis shows the difference in degrees Celsius between annual global temperatures and long-term average global temperature, ranging from -1.0°C to 1.0°C.

The bars from 1880 to around the mid-20th century are mostly below the 0°C line, indicating cooler-than-average temperatures. In contrast, from around 1980 onwards, the bars are mostly above the 0°C line, showing an increase in temperature. The graph highlights a significant warming trend, particularly as the bars increase sharply in height in the last few decades, with the highest rises observed closer to 2020. This trend visually aligns with historical data suggesting a rapid increase in global temperatures, supporting the notion that human activity has contributed to global warming.

[Generated by AI]

Scientists make many of their predictions about the future of the Earth's climate based on past data and advanced computer models. Use the simulation in the activity in the next section to observe the effect of greenhouse gas concentrations on the equilibrium temperature of the Earth.

## 5 section questions

**Question 1**

SL HL Difficulty:

Identify which of the following is **not** a greenhouse gas.

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1 Nitrogen, $N_2$ ✓

2 Carbon dioxide, $CO_2$

3 Water vapour, $H_2O$

4 Nitrous oxide, $N_2O$

### Explanation

Nitrogen is not a greenhouse gas as it does not absorb infrared radiation.

#### Question 2

SL HL Difficulty:

The increase in the greenhouse effect due to human activities is called the 1 enhanced ✓ greenhouse effect.

#### Accepted answers and explanation

#1 enhanced

#### General explanation

The natural greenhouse effect keeps the temperature of the Earth at a suitable level to support life. Human activity has increased the concentration of greenhouse gases in the atmosphere, leading to the enhanced greenhouse effect.

#### Question 3

SL HL Difficulty:

Identify which of the following activities does **not** contribute to the enhanced greenhouse effect.

1 Volcanic eruptions ✓

2 Intensive farming of animals for food

3 Use of fertilisers for farming

4 Cutting down trees to make space for urban developments

### Explanation

Volcanic eruptions release carbon dioxide and water vapour that contribute to the natural greenhouse effect, but they are natural phenomena and do not contribute to the enhanced greenhouse effect.

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**Question 4**

SL HL Difficulty:

When the 1 frequency ✓ of the radiation incident on a molecule is equal to its natural frequency, 2 resonance ✓ occurs.

**Accepted answers and explanation**

#1 frequency

#2 resonance
resonance vibrations

**General explanation**

If the energy incident on the gas molecules in the atmosphere has a frequency equal to that of the molecules' natural frequency of vibration, the molecules absorb the energy and resonance occurs.

**Question 5**

SL HL Difficulty:

If the energy of a 1 photon ✓ incident on a molecule is equal to the difference between two molecular 2 energy ✓ levels, it will be absorbed by the molecule.

**Accepted answers and explanation**

#1 photon
photon of light

#2 energy

**General explanation**

If the energy of a photon incident on a molecule is equal to the difference between two molecular energy levels, the molecule will absorb it and move to a higher energy level, before returning to the original energy level and re-emitting a photon of equal energy in the process.

B. The particulate nature of matter / B.2 Greenhouse effect

# Activity: Effect of greenhouse gas concentrations

B.2.7: Greenhouse gases B.2.10: Enhanced greenhouse effect

Student view

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Activity

- **IB learner profile attribute:** Inquirer
- **Approaches to learning:** Thinking skills — Asking questions and framing hypotheses based upon sensible scientific rationale
- **Time required to complete activity**: 30 minutes
- **Activity type**: Individual activity

Before starting, note that the tool to control the greenhouse gas concentration is a slider. How can you move the slider by the same amount each time?

You can make the simulation larger by clicking on the three dots in the bottom right-hand corner and selecting the Full screen option.

1. Choose the 'Waves' option.
2. Click on the 'Energy Balance' button, then click 'Start Sunlight'.
3. Observe the intensity of the incoming sunlight and the infrared radiation.
4. Observe the 'Energy Balance' arrows. What are their relative lengths? What is the net energy transfer?
5. When the 'Energy Balance' arrows have stopped moving and the thermometer has reached a stable temperature, measure the surface temperature of the Earth by reading the thermometer.
6. Repeat for other positions of the 'Greenhouse Gas Concentration' slider.
7. Plot a scatter graph of equilibrium (surface) temperature against greenhouse gas concentration. (You will need to use the system you devised at the start of the activity to devise a scale for the greenhouse gas concentration axis.)
8. Describe the pattern shown by the graph.

Student
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# Summary and key terms



- Emissivity is the ratio of the power emitted per unit area by an object to the power emitted by a perfect black body of the same size and temperature.
- Albedo is the ratio of the average energy reflected off a macroscopic system to the energy incident on the system.
- The solar constant represents the average intensity of electromagnetic radiation incident on the Earth's outer atmosphere. This value changes throughout the year which is why we state an average value.
- Due to the Earth being a rotating sphere, the mean value of the incoming intensity of sunlight is $\frac{S}{4}$ or 340 W m$^{-2}$.
- The natural greenhouse effect is essential for sustaining life on the Earth. Human activities, such as the combustion of fossil fuels, increase the concentration of greenhouse gases in the atmosphere, leading to the enhanced greenhouse effect.
- The greenhouse gases are carbon dioxide, nitrous oxide, methane and water vapour. Their concentrations in the Earth's atmosphere are affected by natural processes and human activity.
- The greenhouse gases absorb infrared radiation because its frequency is the same as the natural frequency of the greenhouse gas molecules. The radiation is absorbed and resonance occurs.
- Another explanation for why the greenhouse gases absorb infrared radiation is that the difference in the atoms' energy levels is equal to the energy carried by a photon of infrared radiation, and the photon is absorbed.
- The law of conservation of energy can be applied to the Earth surface–atmosphere system to explain why its thermal equilibrium is at risk.

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## Key terms

**Review these key terms. Do you know them all? Fill in as many gaps as you can using the terms in this list.**

1. The emissivity of an object tells us how close an approximation the object is to a .
2. The closer the albedo of an object is to 1, the more the object radiation.
3. The is the average intensity of electromagnetic radiation incident on the Earth's outer atmosphere.
4. reduces the amount of removed from the atmosphere, thus contributing to the greenhouse effect.
5. The Earth's surface absorbs mainly and emits .

infrared radiation | black body | enhanced | carbon dioxide | solar constant | visible light | reflects | Deforestation

Check

**Interactive 1.** Greenhouse Effect: Understanding Key Terms.

B. The particulate nature of matter / B.2 Greenhouse effect

# Checklist

Section Student... (0/0) Feedback Print (/study/app/math-aa-hl/sid-423-cid-762593/book/checklist-id-43775/print/) Assign

## What you should know

After studying this subtopic, you should be able to:

- Outline what emissivity is.
- Outline what albedo is and explain why the Earth's albedo varies.
- Define and calculate the solar constant, $S$.
- Explain why some gases in the Earth's atmosphere absorb infrared radiation and others do not.

Student view

- Apply a resonance model and an energy level model to explain the greenhouse effect.
- Solve energy balance problems where energy is exchanged between the surface and the atmosphere of a body.





# Investigation



- **IB learner profile attribute:** Inquirer
- **Approaches to learning:** Research skills – Combining different ideas in order to create new understandings
- **Time to complete activity:** 2 hours
- **Activity type:** Group activity

## Your task

The natural greenhouse effect is essential in order to provide the conditions necessary for life on the Earth. But what, exactly, are these conditions?

Research and use your prior knowledge to describe the conditions needed for life. Then carry out detailed research about the natural sources of the greenhouse gases, using the information in section B.2.2 (/study/app/math-aa-hl/sid-423-cid-762593/book/energy-balance-in-the-earth-surface-atmosphere-id-43773/) as a starting point.

You can explore this issue with **Video 1** and the articles linked below.

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**Video 1.** What is the Natural Greenhouse Effect?

- *National Geographic* article on the Greenhouse Effect (https://education.nationalgeographic.org/resource/greenhouse-effect/)
- *National Geographic* article on The Greenhouse Effect and Our Planet (https://education.nationalgeographic.org/resource/greenhouse-effect-our-planet/)
- *Integrated Carbon Observation System* (ICOS) article on About Greenhouse Gases (https://www.icos-cp.eu/science-and-impact/climate-change/ghgs#).

### Theory of Knowledge

Western industrialisation was built on fossil fuels. How can we decide if it is ethical to deny developing countries the same use of fossil fuels?

Apply the information you find to explain how it is possible that the phenomenon that provides the conditions required for life on the Earth is the same phenomenon with the potential to destroy life on the Earth.

### Making connections

How are developments in science and technology affected by climate change? How do developments in science and technology affect climate change?

B. The particulate nature of matter / B.2 Greenhouse effect

# Reflection

Student view

## Teacher instructions

Section Student... (0/0) Feedback Print (/study/app/math-aa-hl/sid-423-cid-762593/book/energy-balance-in-the-earth-surface-atmosphere-id-43773/print/) Assign

The goal of this section is to encourage students to reflect on their learning and conceptual understanding of the subject at the end of this subtopic. It asks them to go back to the guiding questions posed at the start of the subtopic and assess how confident they now are in answering them. What have they learned, and what outstanding questions do they have? Are they able to see the bigger picture and the connections between the different topics?

Students can submit their reflections to you by clicking on 'Submit'. You will then see their answers in the 'Insights' part of the Kognity platform.

## Reflection

Now that you've completed this subtopic, let's come back to the guiding questions introduced in The big picture (/study/app/math-aa-hl/sid-423-cid-762593/book/the-big-picture-id-43134/).

- How does the greenhouse effect help to maintain life on Earth and how does human activity enhance this effect?
- How is the atmosphere as a system modelled to quantify the Earth—atmosphere energy balance?

With these questions in mind, take a moment to reflect on your learning so far and type your reflections into the space provided.

You can use the following questions to guide you:

- What main points have you learned from this subtopic?
- Is anything unclear? What questions do you still have?
- How confident do you feel in answering the guiding questions?
- What connections do you see between this subtopic and other parts of the course?

Once you submit your response, you won't be able to edit it.

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Submit

**Rate subtopic B.2 Greenhouse effect**

Help us improve the content and user experience.

Student view