WORKSHOP

Understanding the greenhouse effect

This resource is a guide for a professional development workshop for teachers, about the greenhouse effect. Teachers carry out different experiments in order to understand the greenhouse effect and the role of infrared radiation.

OVERVIEW

After expressing their conceptions of the greenhouse effect mechanism, the participants look for a way to demonstrate it through a simple experiment.

They then realize that there is no experiment feasible in the primary or middle school classroom capable of demonstrating it, and that the phenomenon can be studied in several ways: by means of an analogy, by means of a document review, or by means of an experiment highlighting the role of certain materials that are transparent for visible light and opaque for infrared light.

They discuss the benefits and limitations of each approach and develop a better understanding of the greenhouse effect.

This simulation also provides a good introduction to science teaching using an inquiry-based approach.

Summary

Resource
1st through 9th grades teachers
Duration: 3H + 1H optional

Subjects
Natural sciences
History

Pedagogical approach
Experimentation
Inquiry-based learning

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RESOURCE TYPE
Professional development resource.

PUBLIC
1st through 9th grades teachers.

DURATION
3 hours (+1 hour, depending on possible extensions).

SUBJECTS
Natural Sciences and History.

KEYWORDS
Greenhouse effect, greenhouse gases, CO_2, visible light, infrared light, atmosphere.

PEDAGOGICAL APPROACH
Experimentation, inquiry-based learning.

KNOWLEDGE GOALS

— Greenhouse effect
— Convection
— Radiation
— Visible light
— Infrared light

SKILL GOALS

— Implement an experimental protocol.
— Understand what a model is.
— Discuss the relevance of an analogy and its limitations.
— Represent results in graphical form and analyse them.
— Become familiar with science education through an inquiry-based approach.

REQUIRED MATERIAL (FOR EACH GROUP OR COLLECTIVELY)

— 3 identical light bulbs (at least 60 W, if possible 100 W; use incandescent or halogen bulbs instead of energy-saving lamps), mounted on a support that can be fixed and tilted towards the table.
(!) If the weather is sunny, the light bulbs are optional, since you can carry the experiments outdoors, under sunlight.
— 3 thermometers
— 2 transparent containers of the same volume and shape, one made of glass and the other made of plastic
— Modelling clay
— 1 infrared presence detector
— 1 cardboard tube ("toilet paper" type)
— Scotch tape
— 2 wooden boards
— 1 hair dryer
— 2 mugs
— 1 garbage bag
— 1 plastic bag of the "freezing bag" kind
— 1 glass bowl
— A CO_2 source (optional): CO_2 cartridge, chalk + vinegar...

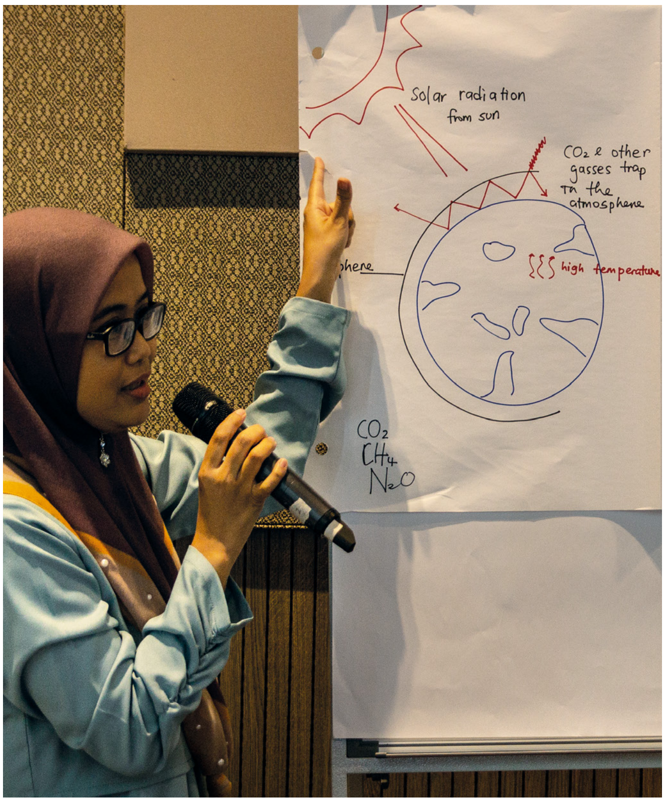
PROCEDURE 1

Initial representations of the greenhouse effect

Divide teachers into small groups (ideally, four people per group) and ask each group to, in five minutes, come up with an explanation of **what the greenhouse effect is, using a text or a diagram.**

Each group selects a representative to present its explanation. Encourage collective discussion by highlighting the similarities and differences between the different “models” presented.

At this stage, **do not suggest any corrections to the proposals being made.** It is not yet a matter of defining or explaining the greenhouse effect, but rather of emphasising the participants’ representations.



Point out that the way in which we present representations (oral, written text, diagram, etc.) is of great importance. It is frequent that people, when commenting orally a text or a drawing they have produced, offer an explanation different from the one provided by that text or drawing. Therefore, it is useful to systematically have the written materials commented on.

We can often find the same errors in the teachers’ initial representations:

— The greenhouse effect is confused with the absorption of UV rays by the atmospheric ozone. Climate change is, therefore, wrongly confused with the problem of the “hole” in the ozone layer.
— Rather than showing infrared radiation being emitted by the Earth’s surface, the diagrams frequently show visible radiation reflected from that surface.
— The greenhouse effect is presented as a static mechanism, not as a dynamic process resulting from a balance.
— When asked about the nature of greenhouse gases, they systematically name CO_2. Some other gases, such as methane, are more rarely referred. The greenhouse gas that is the most present (by far) in the atmosphere, water vapour, is almost never mentioned. We will discuss this again at the end of the activity.

At this stage, the general understanding of the phenomenon can be summarised as follows: **“atmospheric CO_2 traps the heat reflected back from the Earth’s surface”.**

PROCEDURE 2

Experimental highlighting of the greenhouse effect

Give the teachers ten minutes to imagine an experimental protocol for highlighting the greenhouse effect in the classroom (therefore, with everyday materials). Discuss proposals collectively.

They are often centred on two types of experiences:

— **Option 1:** Enclose CO_2 in a transparent container, exposed to light, and compare with an identical container, filled with air (with no particular CO_2 content), which serves as a control.

— **Option 2:** Build a basic glass greenhouse, expose it to light, and show it is warmer inside the greenhouse than outside.

Depending on the available equipment and time, you may consider carrying out the two experiments, consecutively or in parallel, or just one. In this case, prefer option 2, as it is more easily interpretable and feasible in class.

Make sure that everyone understands:

— The importance of a control experiment.

— The need to vary only one parameter at a time.

— The need for regular (written) readings during the experiment.

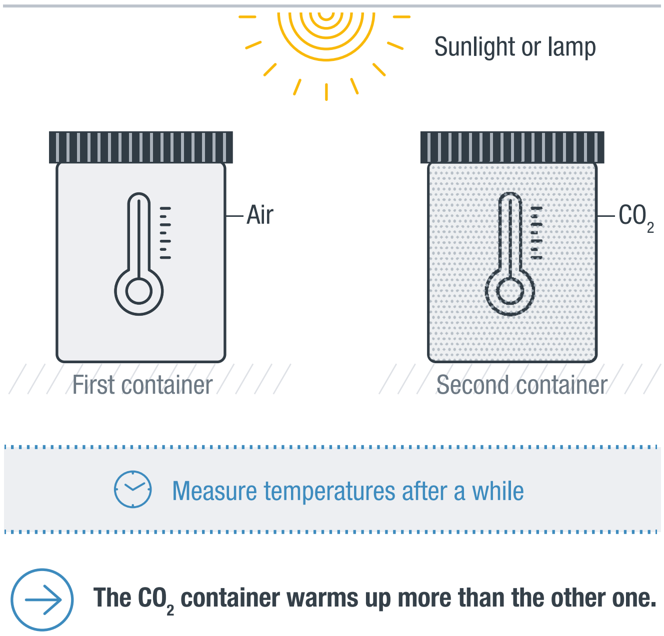
OPTION 1: HIGHLIGHTING THE RADIATIVE EFFECT OF A GREENHOUSE GAS SUCH AS CO_2

Trying to directly highlight the effect of CO_2 is tempting. The experiment presented here is often described in middle or high school textbooks (with some variations). However, it is not satisfactory, as we will see.

A closed, transparent container (usually made of glass) is exposed to visible radiation (lamp or sunlight). Next to this control container, an identical container is filled with CO_2 and subjected to the same radiation. The source of CO_2 differs between versions (CO_2 cartridge, chalk on which vinegar is poured, soda that is degasified, etc.).

After a while (at least 10 min), the temperature in both containers is measured. The enclosure containing CO_2 becomes warmer than the other one.

This result, which satisfies common sense, allows the group to conclude that **it has successfully highlighted the greenhouse effect of CO_2. However, this is not true.** Several different phenomena coexist and, at this scale,



the amount of CO_2 is so small that its radiative effects are negligible.

We measure an effect, certainly, **but it is not the greenhouse effect: we have simply shown that the thermal properties of CO_2 (its ability to conduct heat) are not those of air…**

This option is pedagogically interesting. It allows each group to:

— Set up an experimental protocol with a control experiment.

— Make measurements, report and interpret them.

However, it is scientifically unsatisfactory: the method is correct, but at this scale the measured effect is not the one intended.

OPTION 2: USING A GREENHOUSE AS AN ANALOGY

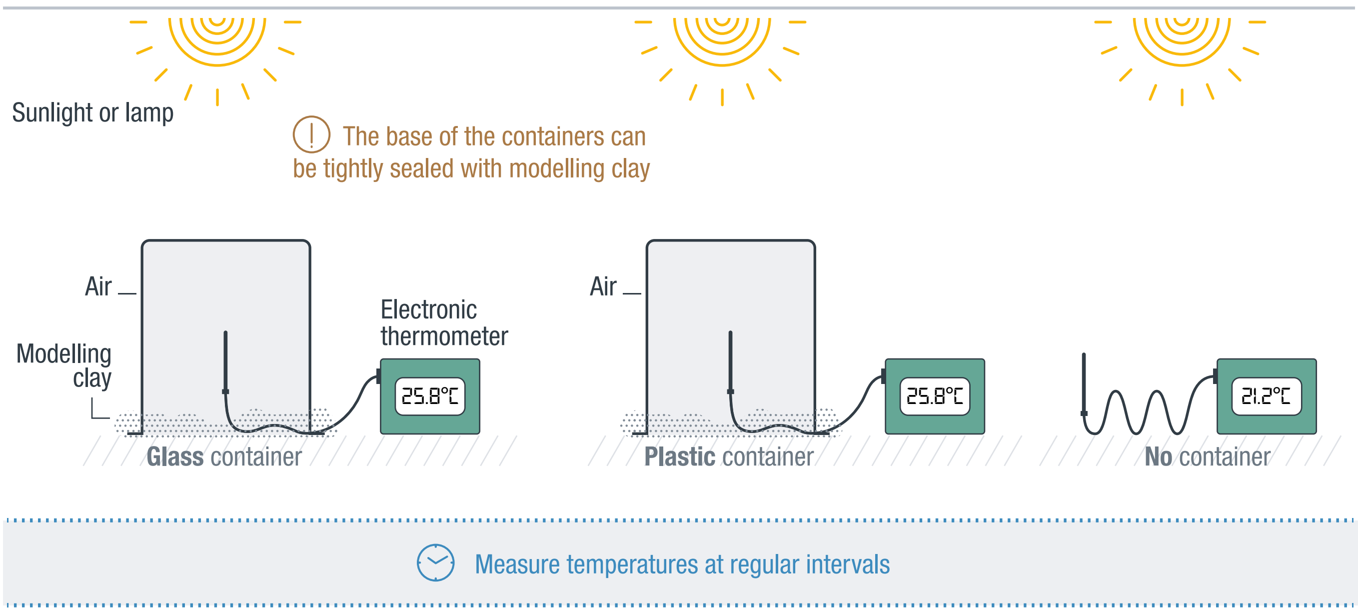
This option, more modest (it does not intend to demonstrate, but simply to illustrate), is, in our opinion, more interesting than the previous one. It is based on the assumption that the functioning of a greenhouse is similar to the atmospheric phenomenon known as the "greenhouse effect".

A basic greenhouse (a glass or plastic container) is exposed to light, while a control thermometer, placed outside, allows comparing the temperature evolution inside and outside the greenhouse. It is interesting to consider the role of the material: therefore, we use two greenhouses, one made of glass, the other made of polyethene (common transparent plastic).

Measure the temperature at regular intervals (designate someone to be responsible for these measurements and their written record).

The teachers notice that it is warmer inside the greenhouse.

One suggested interpretation is that heat is "trapped" by the wall. It is then explained that there are gases in the atmosphere that play the same role as the greenhouse roof and that, for this reason, are called greenhouse gases. **Such an analogy, if presented and assumed as such, is entirely acceptable in the classroom.**



The temperature is warmer inside the glass and plastic containers.

In this case as well, several effects coexist: the greenhouse effect and the containment. Without a cover, the hot air is evacuated by convection and replaced by colder air. This means it is normal for the thermometer to display a lower temperature outside than inside a closed enclosure, where air cannot be renewed.

Moreover, the comparison between the glass greenhouse (where, in theory, there is a "greenhouse effect", that is, an absorption effect of infrared radiation) and the polyethene greenhouse (where there is no greenhouse effect) shows a negligible difference. **The dominant effect is therefore containment**.

(!) Consider making a side comment on the history of science by mentioning the role of Svante Arrhenius, a Swedish chemist, who coined the expression "greenhouse effect", by analogy with the agricultural greenhouse.
Joseph Fourier's findings will be discussed later in the activity.

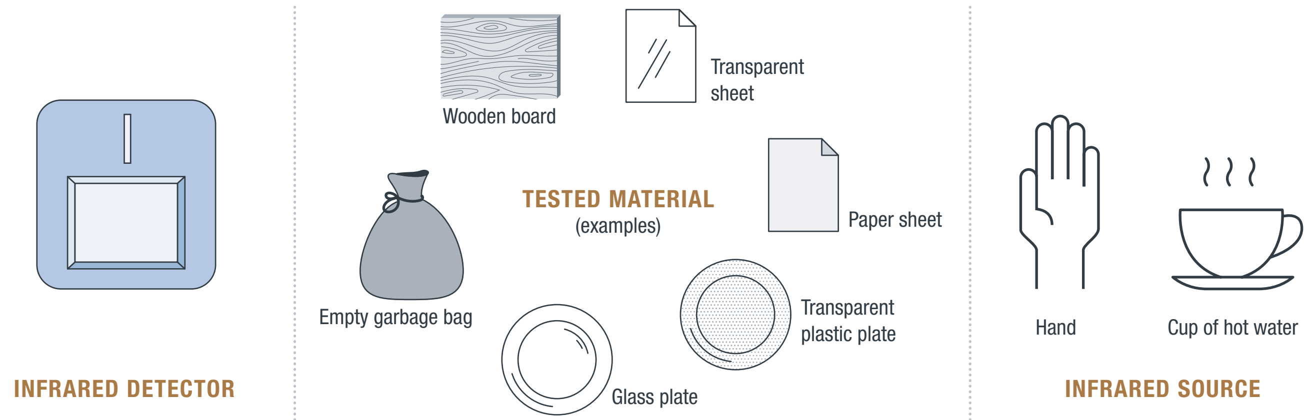
PROCEDURE 3

Proposing an experiment highlighting infrared radiation

After conducting a collective discussion on the advantages and disadvantages of the two previous experiments, explain that **no simple experiment, feasible in the primary or middle school classroom, can highlight the greenhouse effect due to CO_2.**

Then, propose **a new experiment, which does not show the greenhouse effect, but which helps understand some of the mechanisms involved in it** (do not name or explain such mechanisms for the time being. Afterwards, gather all the teachers around an experiment prepared in advance.

MATERIAL



It is very important that you place all the objects used in this experiment (boards, sheets, plates, bags, cups, water, etc.) at the location where you will carry out the experiment, at least one hour in advance, so that all of them are at room temperature.

A simple presence detector is surrounded by a cardboard tube to blind it to what happens around it. It is used to highlight infrared radiation and the fact that some materials can be transparent or opaque, under visible or infrared light.

The wooden board is used as a screen. It provides a uniform background, at room temperature, on which the detector is calibrated.

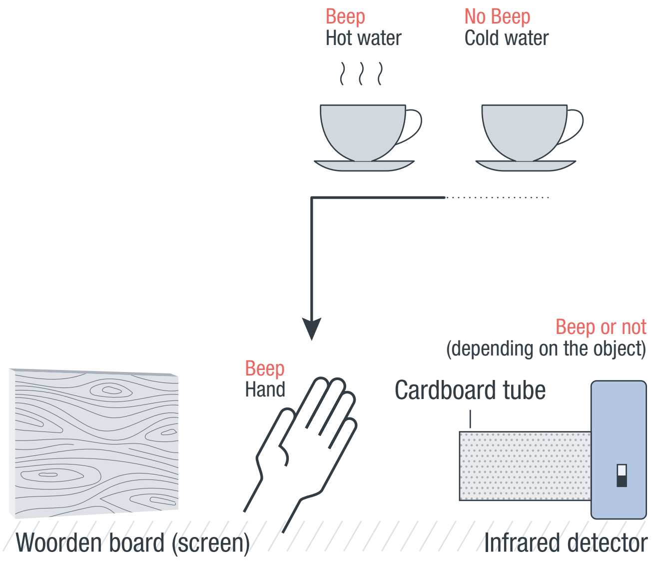
STEP 1 : UNDERSTANDING HOW A PRESENCE DETECTOR WORKS

1. Pass your hand in front of the presence detector : a beep is heard. Teachers are encouraged to interpret this sound : it simply means that a signal is transmitted between the hand and the detector. We know nothing about this signal, for now.

2. Repeat the same experiment, replacing your hand with a cup containing hot water (beep) and then with a cup containing water at room temperature (no beep) : it seems that the signal is linked to the object's temperature. The detector does not detect the presence of an object, but the presence of a hot object.

3. Place a cardboard plate (called the screen) in front of the detector, after heating it with a hairdryer. After a few beeps, the detector is silent, it is " thermalised ". From now on, the detector no longer detects the hand that is placed between it and the screen, because there is no longer a temperature difference between the temperatures of the cardboard plate and of the hand.

The detector does not detect a hot object " in absolute ", but only an object that is warmer than its environment.



Place hot and cold objects in front of the detector

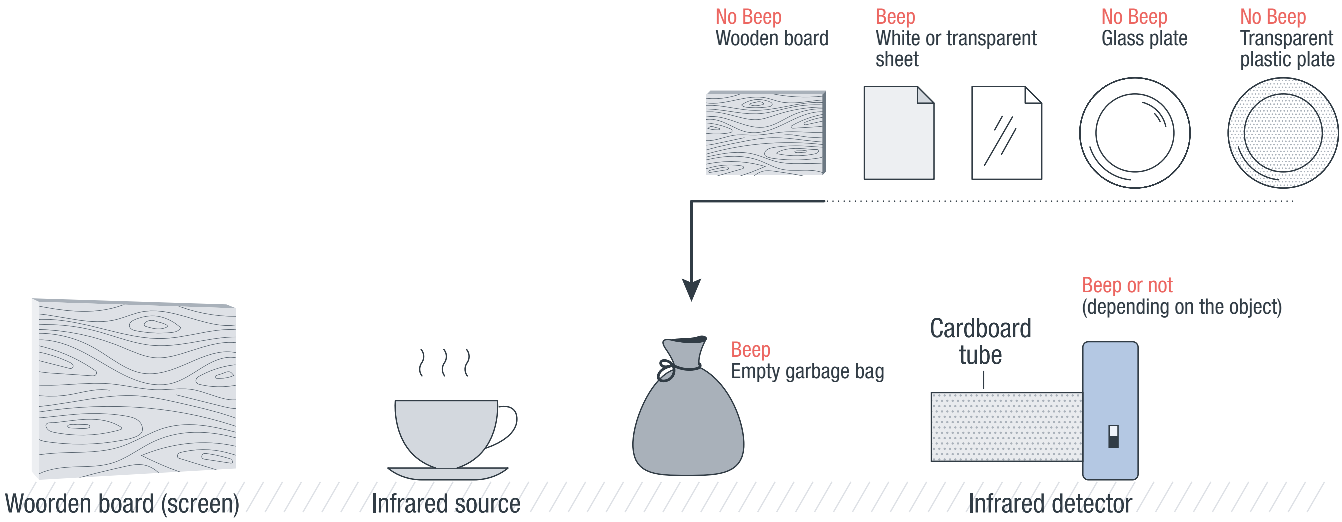
The detector beeps when it detects an object that is warmer than its environment

STEP 2 : MATERIALS AND THEIR BEHAVIOUR REGARDING THE DETECTOR

4. Now that the workings of the detector are well understood, the actual experiment can begin. After the screen cools down, the detector beeps again when one's hand passes in front of it. Proceed to place several different objects between the hand and the detector :
   - A wooden board,
   - A white paper sheet,
   - A transparent sheet,
   - A glass plate,
   - A sheet of cellophane,
   - A garbage bag, etc.

With some objects, the detector beeps, and with others, it does not. We conclude that **some objects can prevent the signal from getting through and others cannot.**

It can also be deduced that **the signal is not carried by visible light, but another component, to which our eyes are insensitive :** this radiation is called **infrared radiation**. Indeed, some objects are transparent to our eyes and nevertheless stop the signal (for example, a glass plate).



Place several objects between the infrared source and the detector

With some objects, the detector beeps, and with others, it does not

SCIENTIFIC BACKGROUND: THE SPECTRUM OF LIGHT

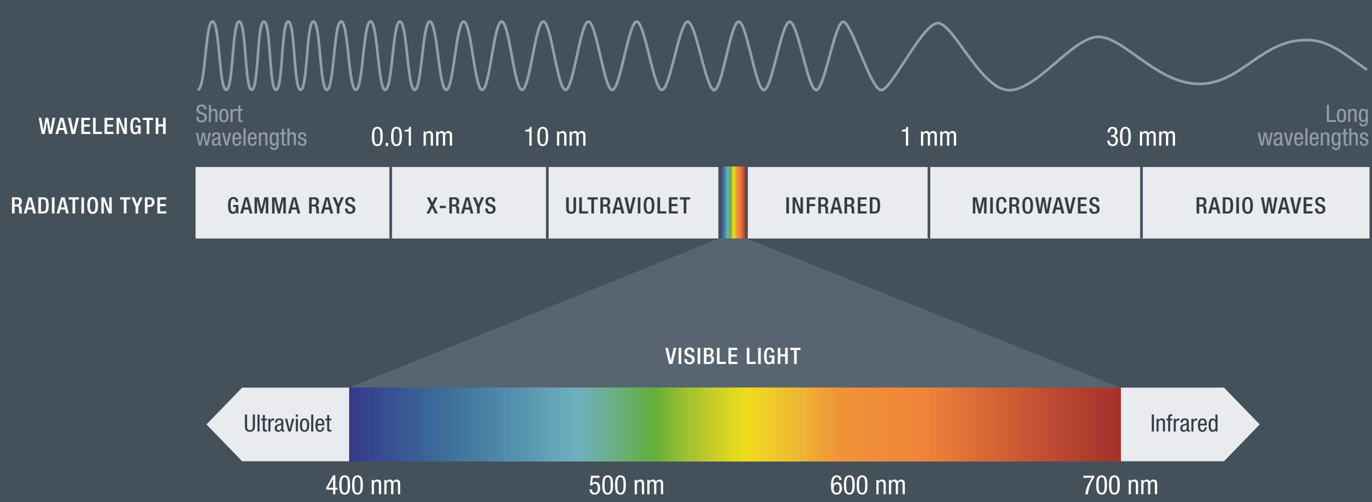
Our eyes are capable of seeing only part of the spectrum of light.

How is light structured into visible or invisible parts?

Light is composed of many radiations, of different wavelengths. When using a prism, the rays are more or less deflected according to their wavelength. We then see different colours (which correspond to different wavelengths), but some are invisible to our eyes.

What is it that we cannot see?

The figure below shows the spectrum of light, that is, its decomposition into different wavelength ranges. Only a very small part of the spectrum, between the 400 and 700 nm wavelengths, is visible to our eyes. Infrared light, with wavelengths longer than those of red, is invisible to us. However, they can be detected with other instruments, such as the one used in our experiment.



SCIENTIFIC BACKGROUND: THE BLACK-BODY AND THE EARTH

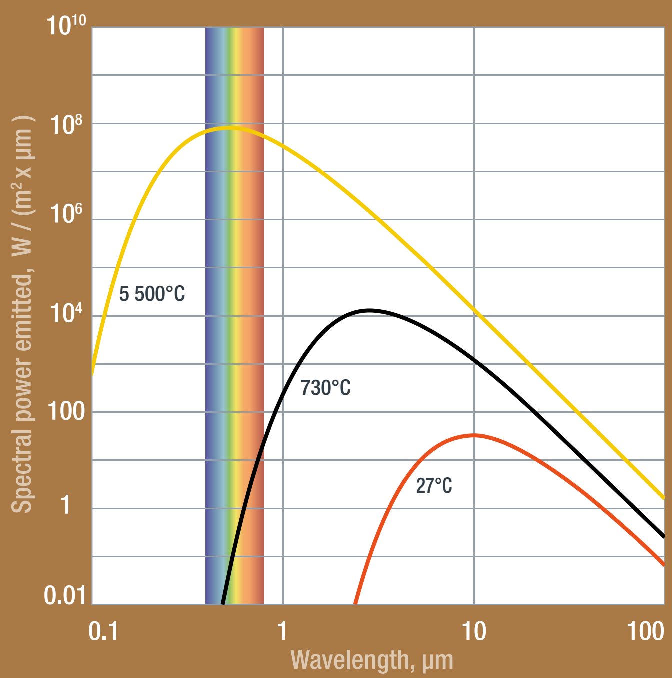
All objects, whatever they are, emit radiation, which depends on their temperature. This radiation is called "black body" radiation or "thermal" radiation.

The spectrum of a black body shows that it emits radiation in all wavelengths, from gamma rays (the most energetic) to radio waves (the least energetic). The proportion of energy radiated in a given wavelength range depends only on the temperature of the object.

Thus, the surface of the Sun, where the temperature is about 5500°C, emits mostly "visible" light (with a peak in yellow), some ultraviolet and infrared rays, and very little of other kinds of radiation.

An object at 27°C emits mainly infrared radiation.

In between, lava, that has a temperature of about 730°C, emits both visible radiation (we can see it, it is red) and infrared radiation (we can feel its heat).



Black-body spectrum

Radiation spectra emitted by a body at 5500°C (sun, yellow curve), 730°C (lava from a volcano, black curve), and 27°C (an object at 27°C, red curve)

How to read this graph?

Each curve corresponds to the spectrum of a black body at a certain temperature. It can be seen that the warmer a body is, the more radiation it emits (the curve is "higher" with respect to the y-axis).

Moreover, the warmer it is, the more its peak corresponds to a short wavelength (further to the left, with respect to the x-axis). Inversely, the colder it is, the more its peak is pushed towards the long wavelengths (further to the right).

The Earth is a black body with a surface temperature of about +15°C (currently +16°C, due to global warming). At this temperature, most of the radiation emitted by its surface is in the infrared range.

STEP 3: MATERIALS AND THEIR BEHAVIOUR REGARDING INFRARED LIGHT

5. Objects can be categorized:
- Some are transparent under visible and infrared light (for example, cellophane);
- Some are transparent under visible light, but opaque under infrared light (for example, "greenhouse" materials, such as glass);
- Some are opaque under visible and infrared light (for example, a wooden board);
- Some are opaque under visible light, but transparent under infrared light (for example, "anti-greenhouse effect" materials, such as a garbage bag).

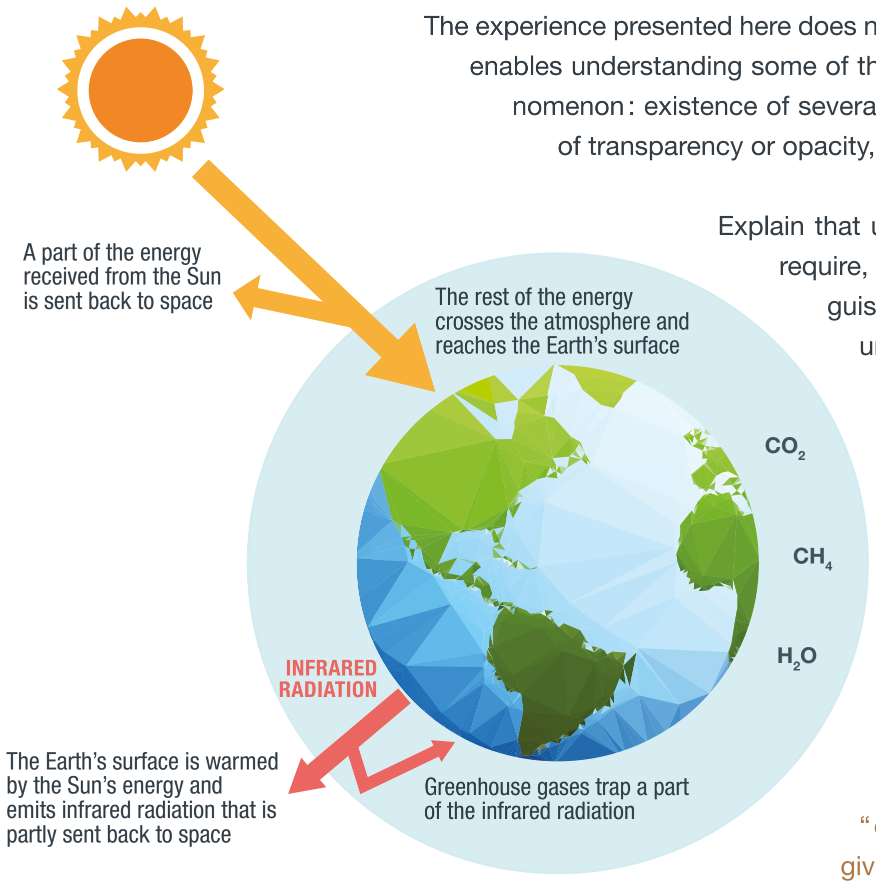
6. Turning back to the greenhouse effect, the group discusses the possible effect of a material that allows visible sunlight to pass through but absorbs infrared radiation from the Earth's surface.

7. The group then establishes the main stages of the greenhouse effect mechanism (see conclusion "what is the greenhouse effect").

The experience presented here does not show that CO_2 is a greenhouse gas, but enables understanding some of the concepts involved in this complex phenomenon: existence of several types of radiation, relativity of the notion of transparency or opacity, radiation balance...

Explain that understanding the greenhouse effect may require, depending on the level targeted, distinguishing a transient state from a steady state, understanding what a black body is, distinguishing effects in the upper and lower atmosphere, etc. You can establish a link with the importance of developing a conceptual framework (link to another professional development activity).

ⓘ You can make another side comment on the history of science and evoke the role of Joseph Fourier (thermal balance between gains and losses of energy in radiative form, the role of "dark heat", which is the name that was given at the time to infrared radiation).



Functioning of the Greenhouse effect

Adapted from an original infographics by Lannis
https://fr.wikimini.org/

SCIENTIFIC BACKGROUND
GREENHOUSE EFFECT

1. This phenomenon is caused by the fact that the atmosphere is essentially transparent to visible radiation but largely opaque to infrared radiation.

2. The Earth's surface (which includes the oceans, the cryosphere, the vegetation, the continents...) receives energy as visible radiation, which it partially absorbs. It is therefore warmed up and, behaving like a black body, it then emits infrared radiation towards space. In the absence of the greenhouse effect, this energy lost to space would exactly compensate the incoming energy, leading to a "no greenhouse effect" equilibrium: the temperature of the Earth's surface would be of -18°C.

3. In an atmosphere containing "greenhouse" gases: part of the infrared radiation emitted by the surface is absorbed by the atmosphere and then re-emitted in all directions, part of which towards the ground and part towards space.

4. Without greenhouse effect, the infrared radiation would be emitted directly towards space by the Earth's surface (which is warmer than the atmosphere). With greenhouse effect, the radiation emitted by the Earth's surface is "trapped" by the atmosphere, and it is the atmosphere (which is colder than the Earth's surface) that emits infrared radiation towards space. The radiation emitted by the surface-atmosphere system is thus weaker, due to the greenhouse effect.

5. The surface-atmosphere system loses less energy, and so it warms up until it reaches a new equilibrium temperature (+15°C for the natural greenhouse effect) at which gains and losses counterbalance one another.

(!) This elaborate mechanism is beyond reach for primary or middle school students. For them, a simple analogy may be more than enough. For example, it can be said that greenhouse gases in the atmosphere play the same role as a blanket worn on oneself: they trap part of the heat emitted by the Earth's surface (like the blanket traps part of the heat emitted by the body).

PROCEDURE 4

Conclusion : what is the greenhouse effect ?

At the end of the activity, revisit the representations initially expressed (texts, diagrams, and oral comments), and ask the group to correct them collectively and explain why some errors appear frequently :

— Confusion about “ reflection ” is promoted by the iconography that circulates (Internet, textbooks), in which the incident radiation coming from the Sun (visible light) and the radiation emitted by the Earth’s surface (infrared) are “ merged ” and represented with an angle that is consistent with the idea of reflection.

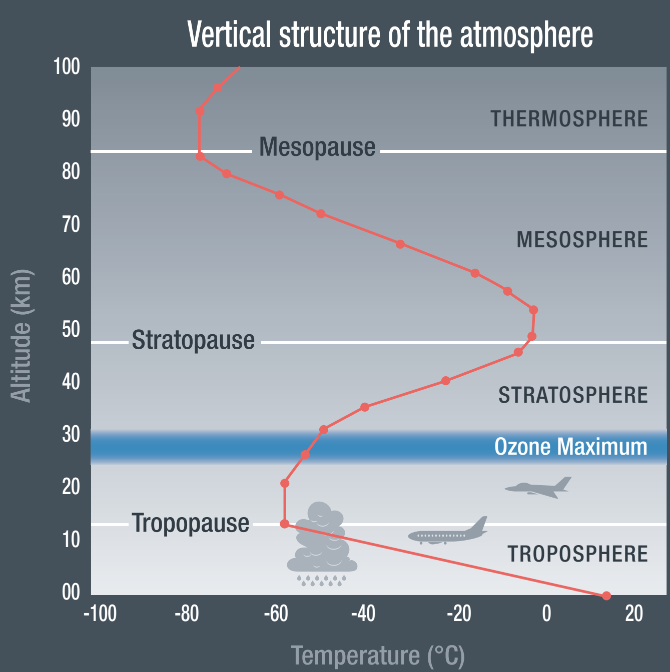
— The confusion about the ozone layer can be explained by several factors : in both cases, the explanation involves the presence of invisible light (UV, IR) and, in both cases, very specific components of the atmosphere (ozone, greenhouse gases). Moreover, both phenomena are associated with the general idea of anthropogenic pollution (chlorofluorocarbons, greenhouse gases), international negotiations, health or environmental risks... Finally, the fact that ozone itself is a greenhouse gas can lead to confusion, as can the fact that the replenishment of atmospheric ozone is affected by climate change. It is therefore not surprising that the two phenomena are so frequently confused.

The group then collectively creates a diagram, with a legend, depicting the greenhouse effect, such as the one presented above.

SCIENTIFIC BACKGROUND : THE OZONE LAYER

The composition of the atmosphere, as well as its temperature, varies with altitude. The lowest layer, in which we live and where most weather events occur, is called the troposphere. It represents more than 80% of the total mass of the atmosphere. It is thicker at the equator than at the poles.

Above it, we find the stratosphere, and within it the famous “ ozone layer ”, located at an altitude between 15 and 30 km. Ozone is actually present throughout the atmosphere, but its concentration is particularly high in this zone. Ozone absorbs UV rays emitted by the Sun and prevents them from reaching the Earth’s surface. The massive use of certain refrigerant gases (CFCs) results in the destruction of this ozone layer, which poses a significant threat to all earthly life. Since the Montreal Protocol was signed in 1985, the use of these gases is prohibited, and the “ hole ” in the ozone layer is gradually closing.



The example of the ozone layer shows us that the international community is sometimes capable of mobilizing and acting.

PROCEDURE 5

From the greenhouse effect to climate change

DOCUMENT REVIEW ON PAST CLIMATE VARIATIONS

An alternative to experimenting (or a complement) is studying the greenhouse effect using documents.
You can present, for example, curves, or data tables showing the past **evolution of the global average temperature and of atmospheric CO_2 concentration over the last 1000 years.**

We can see that the 2 curves follow each other and suddenly rise from the 19th century onwards, which allows introducing a study on the history of the industrial revolution, and thus **establish a link between global warming, demography, and the use of carbon-based energy sources.**

Such a document review enables working, on one hand, the notion of information source (where does this data come from? in what way can it be trusted?) and, on the other hand, causality. Here, we have highlighted the fact that 2 quantities vary together, which indicates that they *seem* to be connected, but this relationship is not established. Again, you must **clearly alert the teachers to this difference between correlation and causality.** For example, we can say "this study shows us that it seems there is a link between the two phenomena, and that this link deserves to be explored by other complementary studies, for example, an experiment to determine whether CO_2 is indeed a greenhouse gas".

To strengthen this idea, we can present a graph showing a surprisingly high positive correlation between chocolate consumption per capita in different countries and the number of Nobel prizes for these countries. The two curves are very well correlated, but it would be risky to conclude that eating chocolate helps to win the Nobel Prize! **A good correlation is not sufficient evidence of causality.**

To learn more

If an extra hour is available, you can deepen some concepts related to the greenhouse effect topic.
The total duration of the workshop, in this case, is approximately 4 hours.

ORBITAL FORCING

Depending on your confidence about this topic, you can talk about the natural causes of climate change, and in particular about orbital forcing, notably Milankovitch cycles (eccentricity of the Earth's orbit, variation of the angle of its rotation axis, precession of the equinoxes).

Highlight the different characteristic periods of these cycles, and how they are connected, and draw a parallel between these orbital forcings and past climate changes over the last 800,000 years. Inform the teachers that the Homo sapiens appears at a late stage (between -300,000 and -200,000 years), which excludes any human impact over the climate at that time. Draw attention to the amplitude of glacial-interglacial cycles, and the duration of these transitions. The teachers then realise that it is not so much the magnitude of the announced climate change that is new, but rather its speed, and relaunch the discussion over the consequences of these rapid changes (for example on biodiversity).

DOCUMENT REVIEW ON THE IMPACTS OF CLIMATE CHANGE

Revisit past climatic changes and the anthropogenic origin of the warming observed over the past century (see previous document review).

Ask teachers to list some of the already visible consequences of climate change. The most frequently mentioned are : **rising sea levels, melting glaciers and sea ice, population displacements, declining agricultural productivity, etc.**

Finally, conclude this workshop with a presentation of some documents (photos, graphics…) showing the various manifestations of climate change throughout the world.

"EVIDENCE" OF THE ANTHROPOGENIC NATURE OF CLIMATE CHANGE

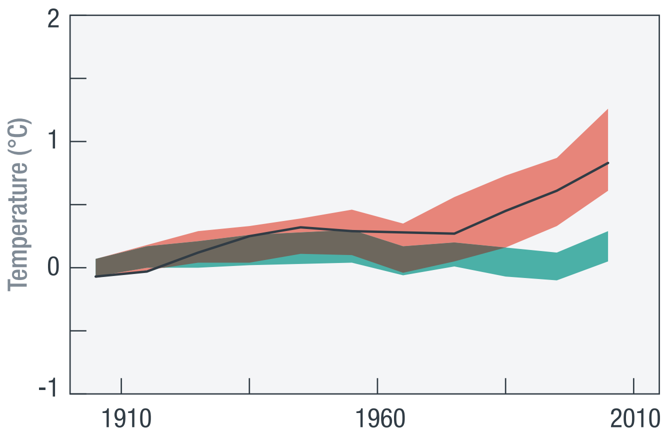
After ensuring that the greenhouse effect is well understood, insist that it is a natural phenomenon and mention specifically the role of water vapour as a greenhouse gas.

Revisit a long-standing argument presented by climate change sceptics (climate change is linked exclusively to solar cycles) and explain that it is "easy" to prove the opposite:

— If warming was linked to more energy coming from the Sun, then both the upper and the lower atmosphere would be warming up. This is not what we are witnessing: the lower atmosphere is warming up, and the upper atmosphere is cooling down.

— The greenhouse effect is the only known mechanism that can explain this phenomenon. Go back to the general diagram of the mechanism and explain that greenhouse gases prevent some of the infrared radiation, emitted by the surface, from reaching the upper atmosphere, thus causing a "low level" warming and a "high level" cooling.

At this point, and depending on the available time, you can address **climate models** (with supporting illustrations), including the fact that they **provide a good explanation for the warming observed over the last century if both natural effects and anthropogenic greenhouse gas emissions are included, but not if only natural effects are taken into account.**



Comparison of observed (black line) and simulated (green and red lines) global surface (combined land and ocean) temperature anomalies (given relative to 1880-1919 temperatures).
Adapted from IPCC's Assessment Report 5

Models using only natural effects
Models using both natural and anthropogenic effects

FOLLOW-UP WORKSHOPS

This workshop on the mechanisms of the greenhouse effect can be an interesting prelude to other workshops:

— A workshop focused on the relationship between climate, ocean and cryosphere.

— A workshop focused on the solutions (adaptation/mitigation).

ATTACHED DOCUMENTS

Slideshow (PDF; PPTX)

Office for Climate Education

"Parties should take measures [...] to enhance climate education", states Art.12 of the Paris Agreement. *"Educating the present and future generations about climate change, and teaching them to act with a critical mind and a hopeful heart, is essential for the future of humanity. Science education must meet the challenge [...]"*, recommend the 113 science academies of the world in their recent Statement on Climate Change and Education.

Replying to these urgent calls, climate scientists and educators established an **Office for Climate Education.** Teachers are key for implementing these recommendations, especially in primary and secondary schools. Hence, the office shall produce for them educational resources, based on an active pedagogy and pilot projects in inquiry-based science education. As IPCC produces "assessment reports" and "summaries for policymakers", the office shall in the coming years synchronously produce "resources and tools for teachers", focusing on the issues of adaptation and attenuation. It will pay special attention to developing countries.

Working closely with climate scientists, involving social scientists and educators, the Office for Climate Education has an executive secretariat in Paris and a global network of local or regional partners in over 60 countries already. The teaching resources will be conceived in a global frame, then be locally tested and adapted to particular situations. The numerous initiatives already taken in the same direction will be documented and publicised by the office.

The Office for Climate education started in 2018 with the support of public and private funds provided by French and German partners. It will amplify its action in proportion with its resources and develop partnerships, especially with IPCC and IAP for Science – the global federation of Science academies.

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IRD Institut de Recherche pour le Développement FRANCE

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ipcc INTERGOVERNMENTAL PANEL ON climate change

Sciences de l'environnement Institut Pierre Simon Laplace

PIK Potsdam Institute for Climate Impact Research

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