Greenhouse effect in a bottle
How to simulate the effect of increased CO_2 level on Earth's temperature

Drill a small hole in the cap of two plastic 750ml drinks bottles and insert a thermometer into each. Label the bottles as EXP (experimental) and CTRL (control) Fig 1. Carbon dioxide (CO_2) is to be added to the EXP bottle and the caps must NOT be airtight, so the pressure in the bottles is the same during the experiment. CO_2 is a rather "heavy" gas that will stay in the lower part of the EXP bottle.

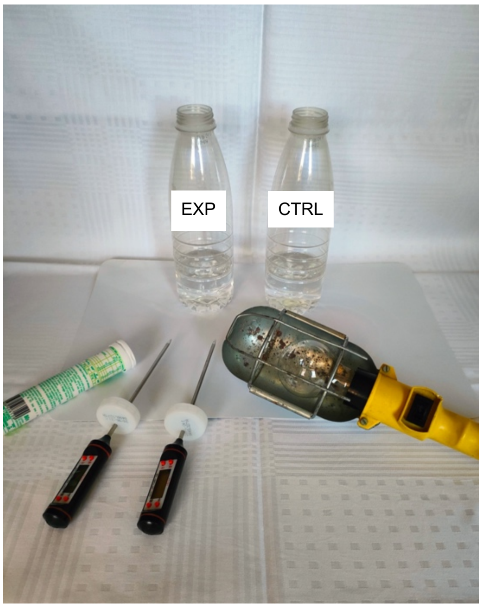

Fig.1 The equipment
(Photo: Giulia Realdon CC BY-SA)

Pour 250ml of tap water into each bottle and check that the thermometers don't touch the liquid. To ensure the water is at the same initial temperature, mix the water before pouring it into the bottles.

- Ask the students to measure and record the initial air temperature in the two bottles.

Open the EXP bottle, add two effervescent tablets and close it quickly.

- Ask the students to observe what is happening in the EXP bottle and to predict the result of the observed chemical reaction ('*fizzy' tablets release a gas in water*). Fig 2.
- Ask the students to identify the composition of the effervescent tablets and discuss with them the chemical reaction between effervescent tablets and water (*effervescent tablets contain an organic acid and a base, e.g., citric acid and sodium bicarbonate, that react with water releasing carbon dioxide:*
  $3NaHCO_3\ (aq) + C_3H_2OH(COOH)_3\ (aq) \rightarrow$
  $3H_2O\ (l) + 3CO_2\ (g) + C_3H_2OH(COONa)_3\ (aq)$

Warning: This reaction is endothermic, so the temperature in the EXP bottle will drop a little before stabilizing.

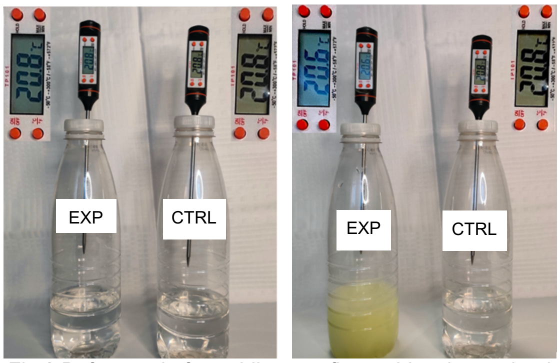

Fig.2 Before and after adding two fizzy tablets in one bottle
(Photo: Giulia Realdon CC BY-SA)

Place an incandescent lamp so that it projects light and heat onto the two bottles or, on warm days, expose the two bottles to direct sunlight. Take care that students don't touch or get too close to the lamp.

- Ask the students to predict if there will be any difference in the temperature between the two bottles
- Ask the students to record the temperature inside the two bottles every 3 minutes for 15 minutes and enter the data into a time/temperature graph (*the temperature in the EXP bottle will be higher than that in the CTRL bottle. At the end of the experiment, the temperature difference between the bottles can range from 2°C to 4°C, depending on the power of the hot bulb).* Fig.3

Fig.3 Exposed to the light of a hot bulb, the two bottles show a different temperature increase
(Photo: Giulia Realdon CC BY-SA)

- Ask the students to comment on the graph and to explain the temperature difference between the bottles (*possibly they will link the higher temperature in the EXP bottle with the presence of more CO_2 in this bottle than in the CTRL bottle*).

- Ask the students if they have heard about the greenhouse effect and prompt them to say what they know about this phenomenon.
- Ask the students to link the phenomenon observed in the bottles with the global warming due to the increased CO_2 level in the atmosphere.

The back up

Title: Greenhouse effect in a bottle

Subtitle: How to simulate the effect of increased CO_2 level on Earth's temperature

Topic: A simulation where students test the effect of increased CO_2 on the heating of the air in a bottle, This introduces the students to the phenomenon of global warming.

Age range of pupils: 11 years upwards

Time needed to complete activity: 40 minutes

Pupil learning outcomes: Pupils can:
- explain the problem of global warming and its link to atmospheric CO_2 (and - to a lesser extent – to other greenhouse gases);
- explain that CO_2 can be produced by different processes (burning, chemical reactions);
- explain that the presence of CO_2 in a closed system (the bottle) can produce warming of the air contained in the system when exposed to a heat source;
- explain that a similar process, the greenhouse effect, happens on the Earth, where the heat from solar radiation is "trapped" by CO_2 present in the atmosphere;
- explain that atmospheric CO_2 level is rapidly increasing due to human activities (fossil fuels burning, transportation, food and other goods production, …);
- explain the need to reduce CO_2 production through more sustainable ("net zero") processes and technologies.

Context:
Global warming due to increased greenhouse gases in the atmosphere is a concept known only in general terms and sometimes misrepresented in the media. Moreover, this problem – despite robust scientific evidence - is sometimes denied on the basis of ideological prejudices.

Following up the activity:
Ask the students to explore the problems caused by global warming and the need to reduce CO_2 production to limit its dangerous effects on the environment and human life.
The concept of tipping points in Earth's climate can also be introduced with the Earthlearningidea: https://www.earthlearningidea.com/PDF/301_Tipping_points.pdf

Underlying principles:
- The *greenhouse effect* occurs because solar radiation enters the atmosphere and is partly reflected by Earth's surface, atmosphere, and clouds. Lower energy radiation (heat), reflected from the surface, may encounter greenhouse gas molecules in the atmosphere, which absorb heat and re-radiate it back to the surface. The heat appears to be "trapped"; it cannot return to space and so warms the surface and lower atmosphere.
- These gases, called greenhouse gases, are water vapour, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_20), chlorofluorocarbons and other minor components.
- Without CO_2 and the other greenhouse gases, the Earth would be too cold for life to exist but the abundance of these gases has dramatically risen since the industrial revolution, from around 1750. Fig.4

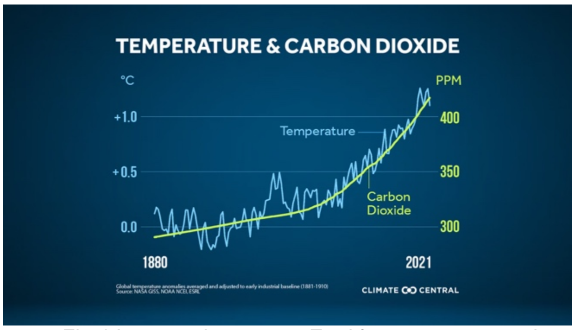

Fig 4 Increase in average Earth's temperature and atmospheric CO2 level
(*Image: Climate Central, permitted use*)

- Apart from water vapour, not related to human activities, the most abundant and persistent greenhouse gas is CO_2, produced mainly by the burning of fossil fuels, industrial processes, farming, and land use.
- The excess heat in the atmosphere has caused an increase in the average global temperature, known as *global warming*, leading to rapid climate change, which is dangerous to the environment and to most living organisms, which have evolved under more stable climatic conditions.

Thinking skill development:
The approach to the greenhouse effect with the use of a physical model helps students to understand a phenomenon far from their personal experience.
The different heating rate in the bottle with the addition of CO_2, in comparison with the control bottle without the addition of CO_2, can elicit a cognitive conflict. The link with the world-wide phenomenon of global warming implies bridging capacity.

Resource list:

- two transparent plastic bottles (e.g., 750ml) with a small hole in the cap (enough to fit a thermometer suspended in the bottle)
- two thermometers
- tap water
- effervescent tablets (or 1 teaspoon of bicarbonate and ½ cup of white vinegar)
- a hot bulb lamp or a sunny day
- a stopwatch
- pen and paper to record the data and draw a graph

Useful links:

- Another Earthlearningidea on the greenhouse effect: https://www.earthlearningidea.com/PDF/310_Greenhouse_effect.pdf
- Greenhouse effect simulation https://phet.colorado.edu/en/simulations/greenhouse-effect (also available in different languages)
- Video on greenhouse effect for younger students: https://climatekids.nasa.gov/greenhouse-effect/

Source: Giulia Realdon, University of Camerino, UNICAMearth group, Italy.