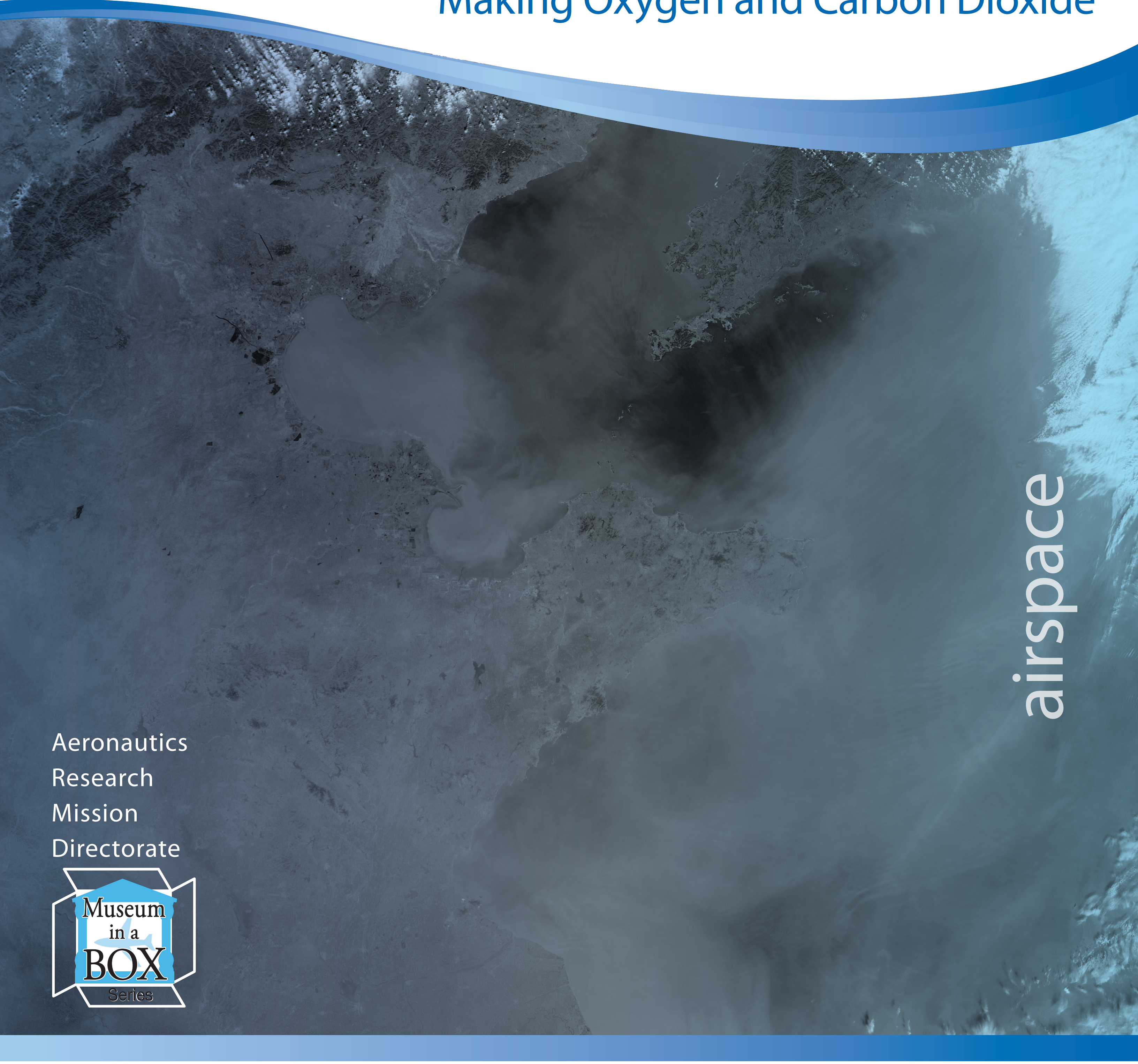
National Aeronautics and Space Administration

GRADES K-12

# Making Oxygen and Carbon Dioxide



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# Making Oxygen and Carbon Dioxide

## Lesson Overview

In this lesson, students will learn about properties and changes of properties in matter, transfer of energy, chemical reactions, geochemical cycles, changes in environments and environmental quality as they witness two methods of producing oxygen and carbon dioxide, two gases vital to life cycles on Earth. Then, they will learn how to test for each of these gases using standard scientific principles.

## Objectives

Students will:

1. Learn how oxygen can be produced via the chemical reaction between yeast and hydrogen peroxide.

2. Learn how carbon dioxide can be produced via the chemical reaction between baking soda and vinegar.

**Materials:**

In the Box

Safety goggles
Plastic beaker
Measuring spoon
Re-sealable plastic bags
Yeast
Baking soda
Wooden splints
Matches or lighter

Provided by User

A glass of water
Hydrogen peroxide
Vinegar

**GRADES K-12** **Time Requirements:** 40 minutes

# Background

The Earth's atmosphere is comprised of sixteen different gases (Fig. 1), each of which plays an important role in sustaining life on Earth. While Nitrogen is Earth's most abundant gas and used by every living organism to generate proteins, the two that are the subject of this lesson are oxygen and carbon dioxide.

| Gas | Percentage |
|---|---|
| Nitrogen ($N_2$) | 78.084% |
| Oxygen ($O_2$) | 20.946% |
| Argon (Ar) | 0.9340% |
| Carbon Dioxide ($CO_2$) | 0.039% |
| Neon (Ne) | 0.001818% |
| Helium (He) | 0.000524 |
| Methane ($CH_4$) | 0.000179% |
| Krypton (Kr) | 0.000114% |
| Hydrogen ($H_2$) | 0.00055% |
| Nitrous Oxide ($N_2$0) | 0.00003% |
| Carbon Monoxide (CO) | 0.00001% |
| Xenon (Xe) | 0.000009% |
| Ozone ($O_3$) | 0.000007% |
| Nitrogen Dioxide ($NO_2$) | 0.000002% |
| Iodine ($I_2$) | 0.000001% |
| Ammonia ($NH_3$) | trace |

**Fig. 1** Gaseous composition of the Earth's atmosphere (dry)

## Oxygen

Oxygen was discovered almost simultaneously by two different scientists, Carl Wilhelm Scheele from Sweden and Joseph Priestley from England, both around 1773. It is the third most abundant element in our galaxy, with only hydrogen and helium having a greater presence. While oxygen makes up just 21% of the Earth's atmosphere, it accounts for nearly 50% of the Earth's crust and almost 66% of the human body's mass! For mammals, oxygen is a vital component of life. It is in the air we breathe and the water we drink. It is necessary for a fire to burn and for rust to form. Without it, we simply wouldn't exist.

### Oxygen ($O_2$)

At the pressures and temperatures found on the Earth's surface, oxygen atoms are typically found joined together in pairs with a double bond, making the oxygen we breathe, $O_2$ (Fig. 2). This means there are two oxygen atoms in each molecule.

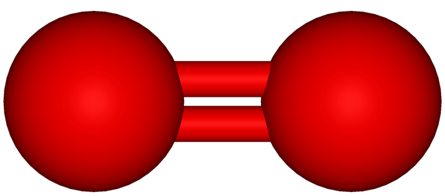


**Fig. 2** An $O_2$ molecule consisting of two oxygen atoms

### Ozone ($O_3$)

Another form of oxygen that is vital to life on Earth is $O_3$, more commonly referred to as ozone. It is comprised of three oxygen atoms joined together with single bonds (Fig 3). The vast majority of ozone gas is found anywhere from 10 to 20 kilometers (12 to 19 miles) above the Earth's surface and is commonly referred to as the ozone layer. Its primary role is to absorb the ultraviolet light being produced by the Sun and to prevent that ultraviolet light, or UV light, from reaching the Earth's surface. Without ozone, many more harmful UV-B rays (the ones that cause sunburn and skin cancer) would reach the Earth's surface with serious detrimental effects to all living organisms.

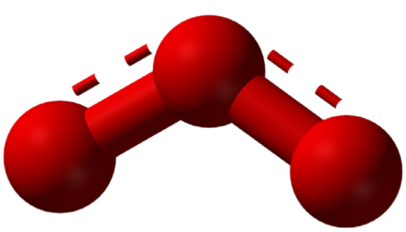


**Fig. 3** An $O_3$ (ozone) molecule consisting of three oxygen atoms

Like many things, ozone can be beneficial or detrimental, depending upon its location. While it is helpful in the upper atmosphere to block UV rays, it is extremely dangerous to life at ground-level.

In industrialized nations, manufacturing processes and automobile engines generate large quantities of ozone gas. With a strong breeze the gas is dissipated and cannot accumulate, but on calm days, ozone levels can increase to create smog, potentially making it harmful to the health and well-being of plants and animals (including humans), as well as reducing visibility. Areas such as the Los Angeles basin in California are well known for their smog days. While smog is predominantly ozone, it is technically referred to as phochemical smog, as it also contains other chemical pollutants such as nitrous oxide from vehicle exhausts and volatile organic compounds from paints and other aerosol products.

## Carbon Dioxide & Greenhouse Gases

Carbon dioxide gas (Fig. 4) is released during the combustion process and as such is naturally released by volcanoes and hot springs, as well as from man-made furnaces and combustion engines. It is also released into the air by living organisms, including humans, as a large component of expelled breath.

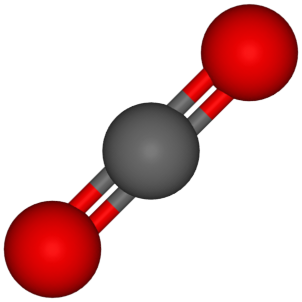


**Fig. 4** A carbon dioxide gas molecule

While mammals breathe in oxygen and breathe out carbon dioxide, plants perform the opposite process. Plants and algae absorb carbon dioxide in order to produce a sugary substance on which they can feed. (This is referred to as photosynthesis and also requires energy from the Sun.) In addition to absorbing carbon dioxide, the photosynthetic process also releases oxygen as a "waste" product, which ultimately helps clean the air for mammals and produces more oxygen for us to breathe.

Unfortunately there are times when the quantity of carbon dioxide produced is greater than that which can be disposed of through photosynthesis. In this situation, the carbon dioxide accumulates in the upper layers of the atmosphere which, if left unchecked, can greatly change the environment in a way that impacts all life on Earth.

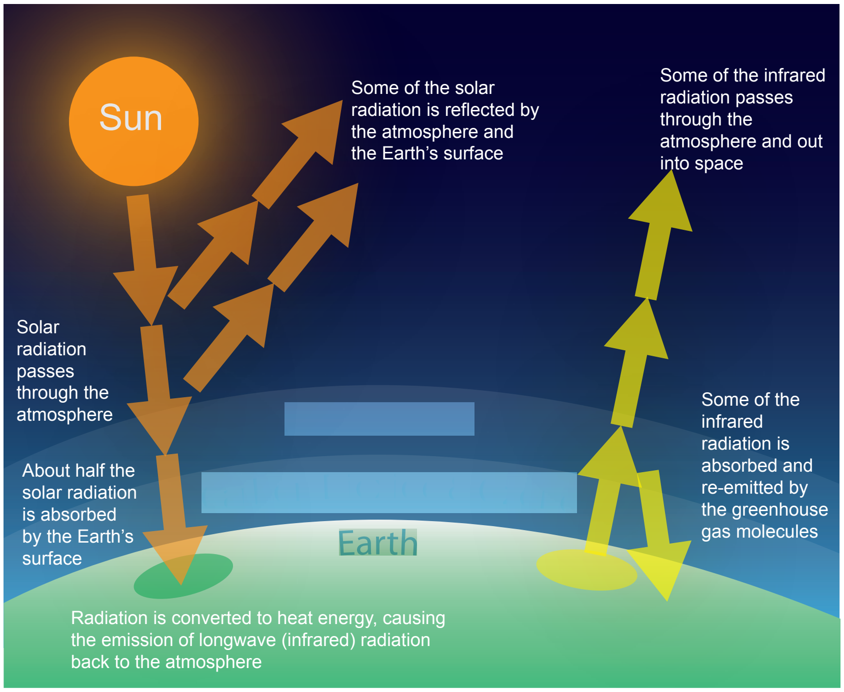



**Fig. 5** The greenhouse effect

The Earth is heated by energy from the Sun. In a normal environment, the majority of the Sun's rays bounce off of the upper layers of the atmosphere and never reach the Earth's surface. The rest warm the Earth and then rise, with most leaving the atmosphere. With an increased level of carbon dioxide however, that rising heat cannot leave and is forced to stay in the atmosphere, slowly increasing the average temperature of the planet (Fig. 5). This is almost identical to how the glass in a greenhouse works, trapping the Sun's rays and keeping the air inside the greenhouse warm.

During the 20th century, Earth's average temperature has risen about 1.1°F (0.6°C). Since the 1990's that rate has accelerated, and NASA scientists have predicted that the globe will continue to warm over the course of the century. NASA's Langley Research Center's Science Directorate is a unique NASA organization devoted to discovering how the Earth and its atmosphere are interacting and changing, including what that means for the health of the planet. They search for and create better ways of gathering, measuring and analyzing atmospheric data so that others can better understand and track the effects of human activity on the atmosphere.

Although excessive quantities of carbon dioxide are often harmful, there are times when we can put its properties to good use. A perfect example of this is the fire extinguisher. Carbon dioxide gas is heavier than oxygen and as such, it sinks, displacing any oxygen that may be below it. When sprayed onto a fire, the carbon dioxide gas displaces the oxygen (which is required for a fire to burn), smothering the burning object and stopping the fire.

## Yeast, Peroxide, Baking Soda & Vinegar

The activities on the following pages use a variety of household products to demonstrate how $O_2$ and $CO_2$ gases can be produced and detected. The following is a brief explanation as to why these gases are released when combining peroxide with yeast, and baking soda with vinegar.

Yeast contains a chemical called catalase whose purpose is to prevent toxins from becoming poisonous by converting them into harmless chemicals. One such toxin is hydrogen peroxide ($H_2O_2$). In order to prevent the yeast from becoming poisoned when coming into contact with peroxide, the catalase converts it into oxygen and water ($2H_2O_2$ --> $2H_20 + 0_2$). Human bodies also contain catalase which is why we see bubbles after pouring hydrogen peroxide onto a cut. The catalase is preventing our bodies from being poisoned and the bubbles you see are oxygen being released while the liquid, now just water, falls harmlessly away.

Baking soda on the other hand ($NaHCO_3$) releases carbon dioxide in a chemical reaction when mixed with vinegar ($HC_2H_3O_2$). Baking Soda is a base, which in chemistry means it can readily accept hydrogen ions. (In certain scenarios, such as this one, it can also be referred to as an alkali.) Vinegar however is an acid, the opposite of a base. Whenever a base and an acid combine, they react, sometimes explosively, but always producing a different chemical in the process. When baking soda and vinegar combine there is actually a two-stage process that takes place. First, the vinegar reacts with sodium bicarbonate (the primary ingredient in baking soda) to form a mixture of sodium acetate and carbonic acid. Carbonic acid is incredibly unstable however and immediately breaks down into carbon dioxide and water.

$NaHCO_3 + CH_3COOH$ --> $CH_3COONa + H_2CO_3$ ... and then $H_2CO_3$ --> $H_2O + CO_2$

or

Baking Soda + Vinegar --> Sodium Acetate + Carbonic Acid ... and then Carbonic Acid --> Water and Carbon Dioxide.

# Activity 1 A Demonstration on Producing Oxygen

**GRADES K-12**

## Time Requirements: 20 minutes

## Materials:

In the Box

Safety goggles
Plastic beaker
Measuring spoon
Re-sealable plastic bag
Yeast
Wooden splints
Matches or lighter

Provided by User

A glass of water
Hydrogen peroxide

Worksheets

None

Reference Materials

None

## Key Terms:

None

## Objective:

In this activity, students will learn about properties of objects and materials, properties and changes of properties in matter, chemical reactions and energy transfer, as they see how oxygen can be produced via the chemical reaction between yeast and hydrogen peroxide.

## Activity Overview:

Students will watch a demonstration in which yeast and hydrogen peroxide are combined to produce pure oxygen. This will be confirmed by use of a glowing splint, a commonly used test for oxygen.

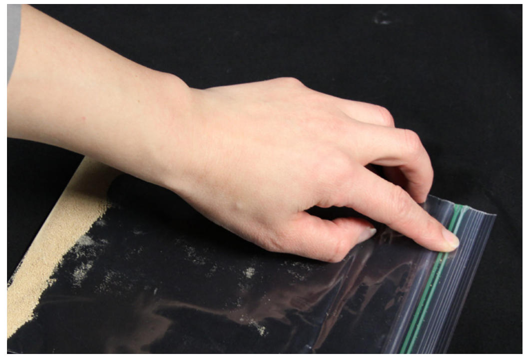
*Caution: This activity uses an open flame and as such, care should be taken to avoid an unwanted fire. This is especially true when it comes to disposing of the materials afterwards. Ensure that the wooden splint is thoroughly soaked in water before disposal to prevent re-ignition while in the waste receptacle.*

1. **Using the Background information provided, discuss the science behind greenhouse gases, global warming and how correct levels of both carbon dioxide and oxygen are vital to the health of our planet.**

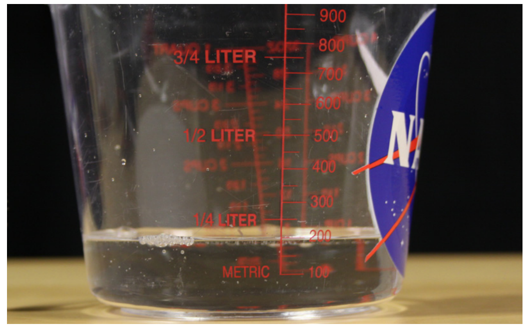
2. **Explain that in this activity you will demonstrate how to produce pure oxygen using yeast and hydrogen peroxide.**
   *You may wish to explain that yeast is used in the making of bread and is responsible for creating all the little holes in each slice.*

3. **Place 2 teaspoons of yeast into a re-sealable bag and ensure the yeast falls to the bottom.**

4. **Next, place the bag flat on the table and squeeze out as much air as possible. This is to make the oxygen production more visible.**



5. **Using the plastic beaker, measure and pour 200ml of hydrogen peroxide into the bag and seal it as quickly as possible.** Explain to the students that the peroxide is activating the chemicals in the yeast which make it produce oxygen. *If you discussed bread earlier, you can follow up by explaining that the little holes in each slice were made of bubbles of oxygen.*




6. **Allow the students to move in closer to watch as the bag begins to inflate.** Once fully inflated, invite the students to gently touch the bag. It should be quite warm to the touch. *This is because heat is released by the catalase in this exothermic (heat producing) chemical reaction.*

7. **Next, light the end of a wooden splint, allow it to burn for a few seconds and then blow it out.** Explain to the students that if there is pure oxygen in the bag, the splint will reignite due to it being in the perfect environment for fire.

8. **Open the bag and slowly insert the splint; it should reignite quite quickly.** *If appropriate for the age of the students, invite them to blow out the flame from the splint and reinsert it into the bag. This can be repeated multiple times before the oxygen level in the bag is depleted.*

*CAUTION: Do not let the splint touch the side of the bag. It will melt the bag on contact.*

9. **Once you have finished demonstrating this activity, insert the burned end of the splint into the glass of water and allow it to soak completely before throwing it away.** You can also discard the yeast by rinsing it down a sink.

*CAUTION: Failure to follow this step has led to small fires where the splint has re-ignited due to the oxygen-rich bag and the splint being disposed of together in the same waste receptacle.*

## Discussion Points:

1. **Why did the splint re-ignite when placed in the bag?**

   *For a fire to exist, three things are required: (1) Fuel, which in this scenario was the carbon molecules of the wooden splint, (2) heat, produced by the glowing embers, and (3) oxygen. The bag contained an oxygen-rich environment which, when combined with the other two factors, caused a fire to start.*

2. **What was the difference between the oxygen in the bag and the air outside the bag?**

   *The oxygen in the bag was almost 100% pure, whereas the oxygen in the air outside was mixed with other elements, mainly nitrogen. Typically, the air we breathe contains only 21% oxygen which, while sufficient to support an already-burning fire, is insufficient to re-ignite a smoldering ember.*

3. **Why did the bag become warm to the touch?**

   *Almost every time there is a chemical reaction, there is also a transfer of heat either to or from the substance. In this case, the chemical reaction was exothermic, meaning that it released heat, which warmed the oxygen being produced.*

4. **What was the chemical reaction that took place here?**

   $2H_2O_2$ --> $2H_2O + O_2$.

MUSEUM IN A BOX

# NATIONAL SCIENCE STANDARDS K-4

## SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

## PHYSICAL SCIENCE

- Property of objects and materials

# NATIONAL SCIENCE STANDARDS 5-8

## SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

## PHYSICAL SCIENCE

- Properties and changes of properties in matter
- Transfer of energy

# NATIONAL SCIENCE STANDARDS 9-12

## SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

## PHYSICAL SCIENCE

- Structure and properties of matter
- Interactions of energy and matter

## SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology
- Chemical reactions

# Activity 2 A Demonstration on Producing Carbon Dioxide

**GRADES K-12**

## Time Requirements: 20 minutes

## Materials:

In the Box

Safety goggles
Plastic beaker
Measuring spoon
Re-sealable plastic bag
Baking soda
Wooden splints
Matches or lighter

Provided by User

A glass of water
Vinegar

Worksheets

None

Reference Materials

None

## Key Terms:

None

## Objective:

In this activity, students will learn about the properties of objects and materials, properties and changes of properties in matter, chemical reactions and energy transfer, as they see how carbon dioxide can be produced via the chemical reaction between baking soda and vinegar.

## Activity Overview:

Students will watch a demonstration where baking soda and vinegar are combined to produce carbon dioxide. This will be confirmed by use of a burning splint.

CAUTION: *This activity uses an open flame and as such, care should be taken to avoid an unwanted fire. This is especially true when it comes to disposing of the materials afterwards. Ensure that the wooden splint is thoroughly soaked in water before disposal to prevent re-ignition while in the waste receptacle.*

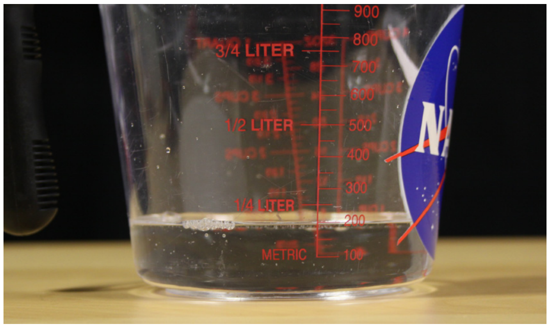
1. **If Activity 1 has not already been completed, use the Background information provided to discuss the science behind greenhouse gases, global warming and how correct levels of both carbon dioxide and oxygen are vital to a healthy planet.**

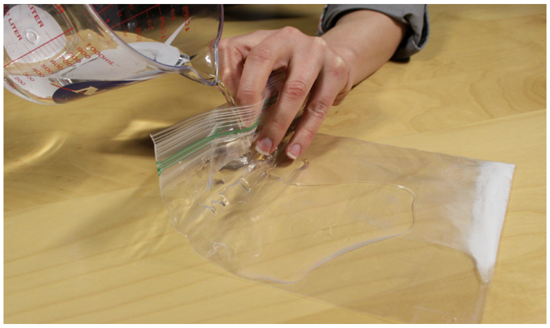
2. **Explain that in this activity you will demonstrate how to produce pure carbon dioxide using baking soda and vinegar.**
   *You may wish to explain that baking soda is used in cooking to create foods which need to rise, such as cakes.*

3. **Place 1 teaspoon of baking soda into a re-sealable bag and ensure the soda falls to the bottom.**

4. **Next, place the bag flat on the table and squeeze out as much air as possible.** This is to make the carbon dioxide production more visible.

5. **Using the plastic beaker, measure and pour 200ml of vinegar into the bag and seal as quickly as possible.** Explain to the students that the vinegar is reacting with the chemicals in the baking soda which make it produce carbon dioxide. *If you discussed cooking earlier, you can follow up by explaining that the gas produced builds up inside the cake, pushing it upwards and out of the pan.*



6. **Allow the students to move in closer to watch as the bag begins to inflate.** Once fully inflated, invite the students to gently touch the bag. Being an endothermic reaction, it should be quite cool to the touch.

7. **Next, light the end of a wooden splint and allow it to burn for a few seconds.** Explain to the students that if there is pure carbon dioxide in the bag, the splint will immediately extinguish due to there being virtually no oxygen, which is necessary for fire.

8. **Open the bag and slowly insert the splint; it should extinguish immediately.** *If appropriate for the age of the students, invite them to relight the splint and reinsert it into the bag. This can be repeated numerous times if desired.*

*CAUTION: Do not let the flame touch the side of the bag. It will melt immediately.*

9. **Once you have finished demonstrating this activity, insert the splint into the glass of water and allow it to soak completely before throwing it away.**

## Discussion Points:

1. **Why did the splint extinguish when placed in the bag?**
   *For a fire to exist, three things are required: (1) Fuel, which in this scenario was the carbon molecules of the wooden splint, (2) heat, produced by the glowing embers, and (3) oxygen. The bag contained almost no oxygen, which forced the fire to extinguish immediately.*

2. **What was the difference between the carbon dioxide in the bag and the air outside?**
   *The carbon dioxide in the bag was almost 100% pure, whereas the level of carbon dioxide in the air is less than 1%. This low level of* $CO_2$ *is not enough to prevent the oxygen in the air from permitting a fire to burn in Earth's normal atmosphere.*

3. **Why did the bag become cool to the touch?**
   *Almost every time there is a chemical reaction, there is also a transfer of heat either to or from the substance. In this case, the chemical reaction was endothermic, meaning that it absorbed heat, which cooled the carbon dioxide gas being produced.*

4. **Can you name a device that uses carbon dioxide with similar effect?**
   *Fire extinguishers (specifically the black-colored ones) use a chemical reaction to produce large quantities of carbon dioxide. When dispensed, it smothers the fire, preventing oxygen from being able to reach it. As such, the fire goes out. This is used primarily on electrical fires where a water-based extinguisher would be dangerous.*

# NATIONAL SCIENCE STANDARDS K-4

## SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

## PHYSICAL SCIENCE

- Property of objects and materials

## SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology

# NATIONAL SCIENCE STANDARDS 5-8

## SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

## PHYSICAL SCIENCE

- Properties and changes of properties in matter
- Transfer of energy

## SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology

# NATIONAL SCIENCE STANDARDS 9-12

## SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

## PHYSICAL SCIENCE

- Structure and properties of matter
- Interactions of energy and matter
- Chemical reactions

## SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology

# Reference Materials

**Fig. 1** Gaseous composition of the Earth's atmosphere (dry)

| Gas | Percentage |
|---|---|
| Nitrogen ($N_2$) | 78.084% |
| Oxygen ($O_2$) | 20.946% |
| Argon (Ar) | 0.9340% |
| Carbon Dioxide ($CO_2$) | 0.039% |
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| Nitrogen Dioxide ($NO_2$) | 0.000002% |
| Iodine ($I_2$) | 0.000001% |
| Ammonia ($NH_3$) | trace |

**Fig. 2** An $O_2$ molecule consisting of two oxygen atoms

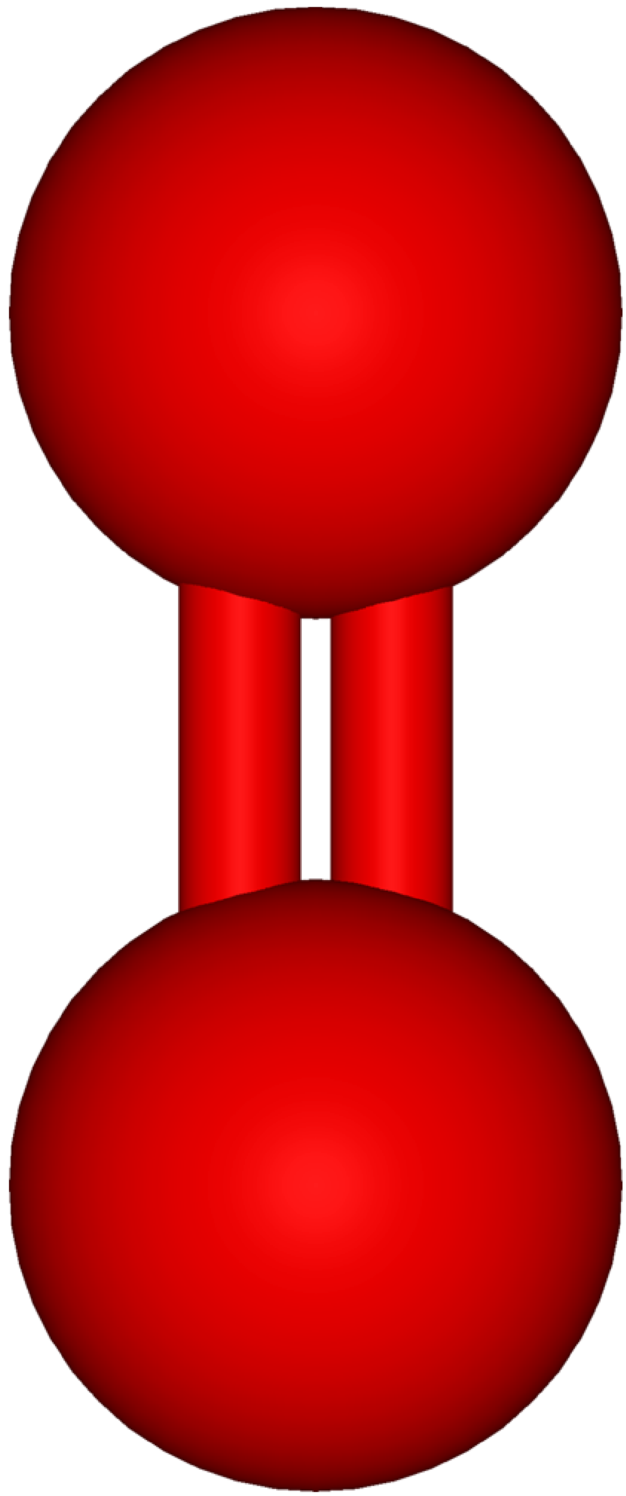


**Fig. 3** An $O_3$ (ozone) molecule consisting of three oxygen atoms

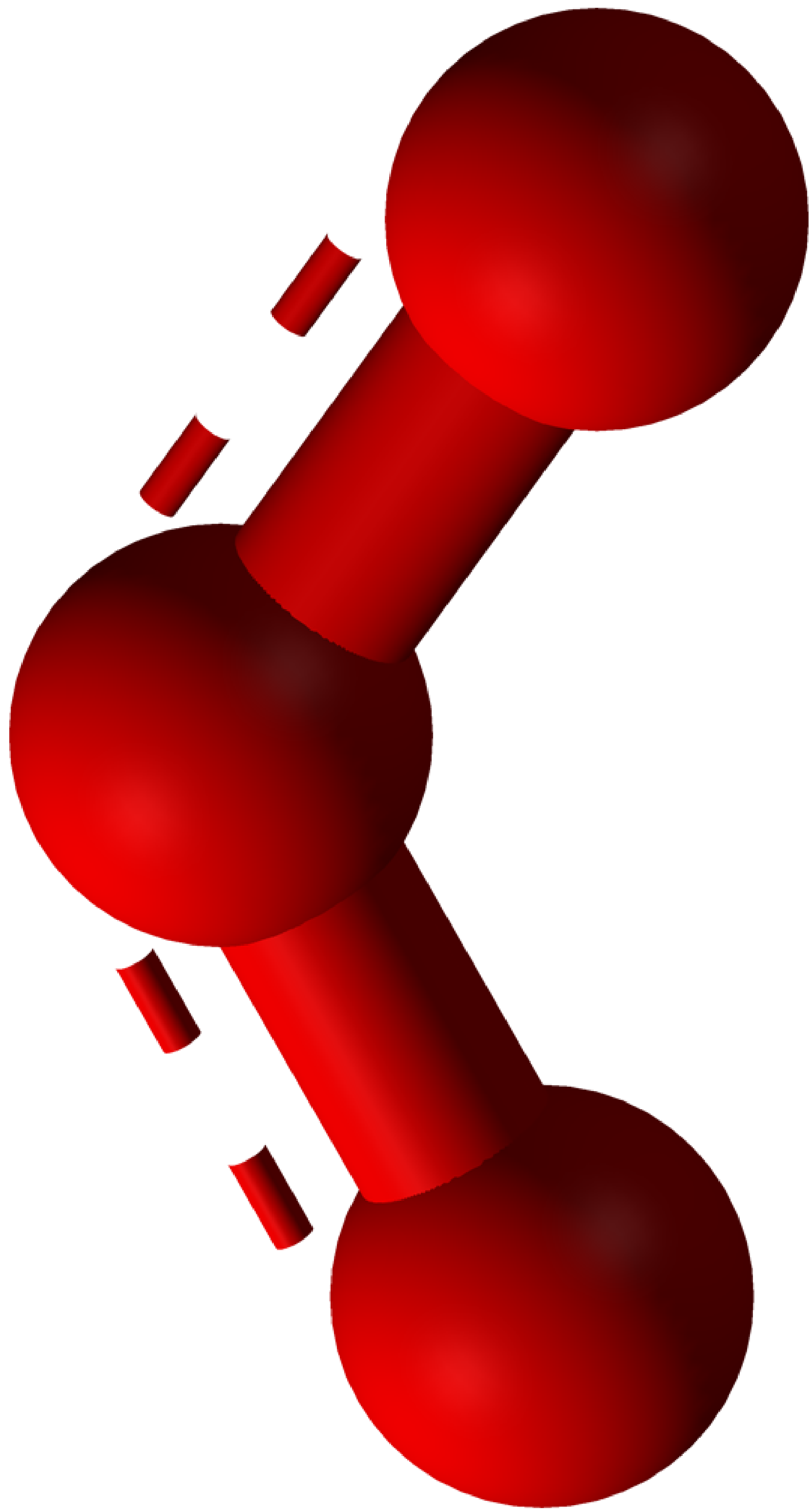


**Fig. 4** A carbon dioxide gas molecule

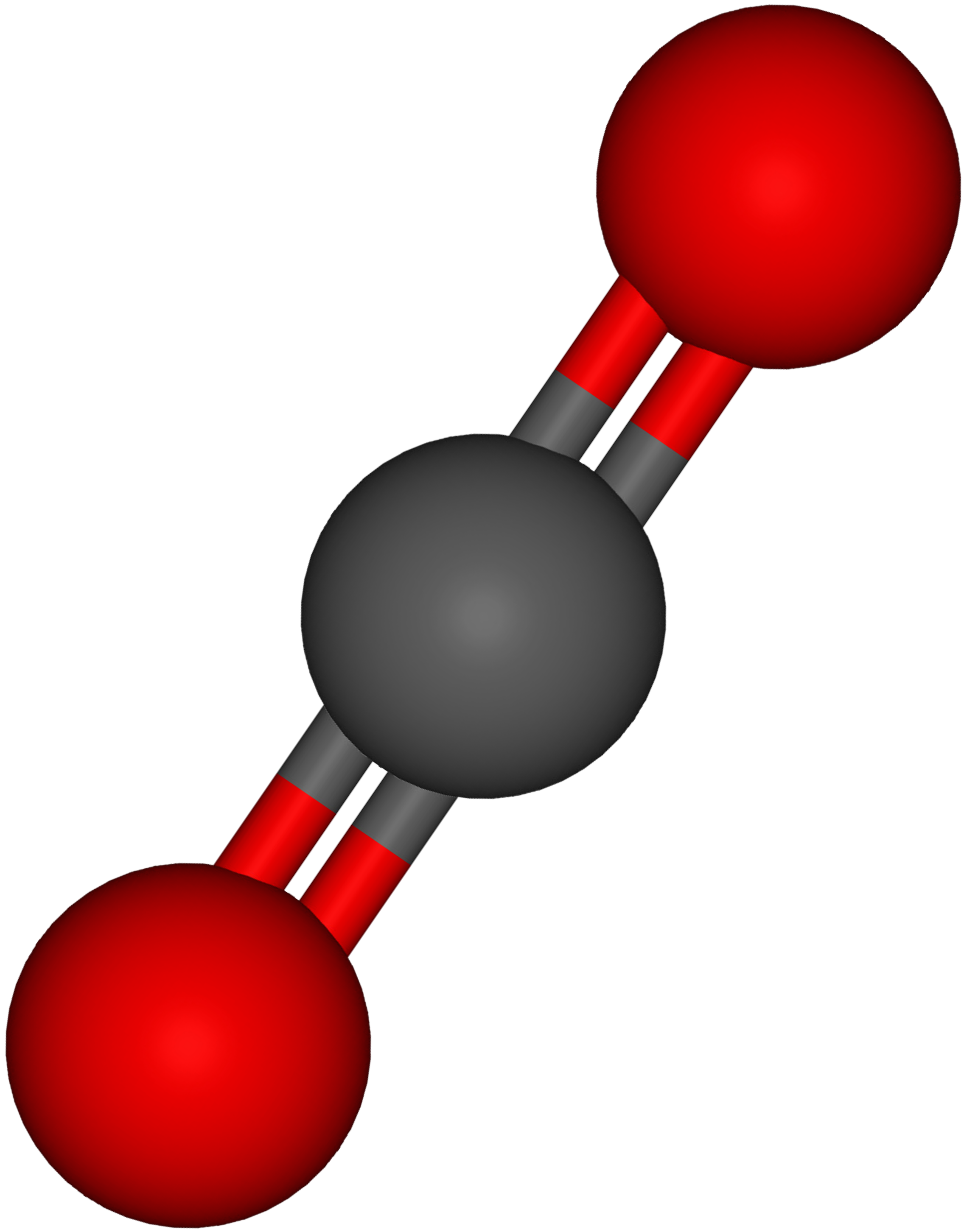
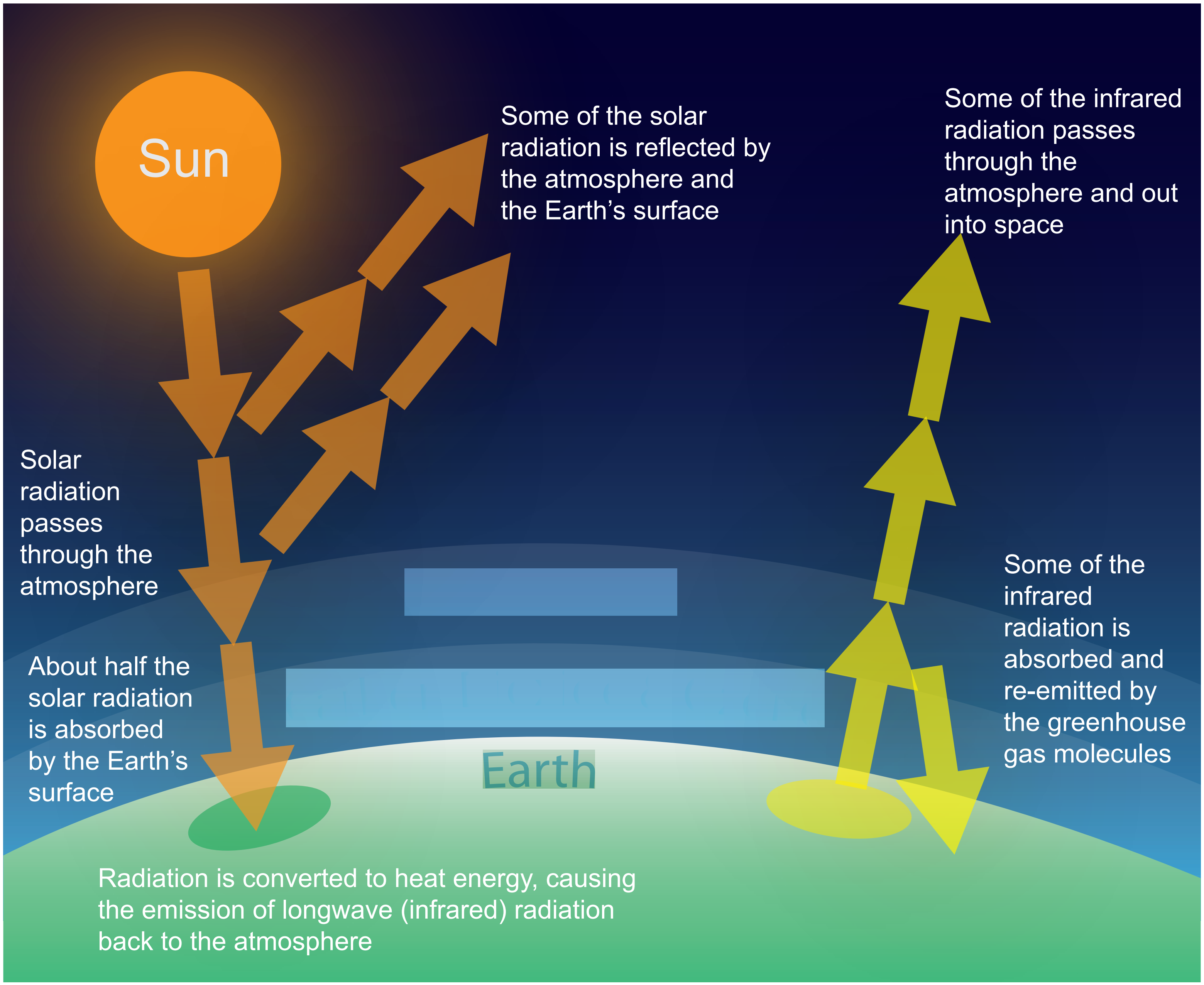


**Fig. 5** The greenhouse effect



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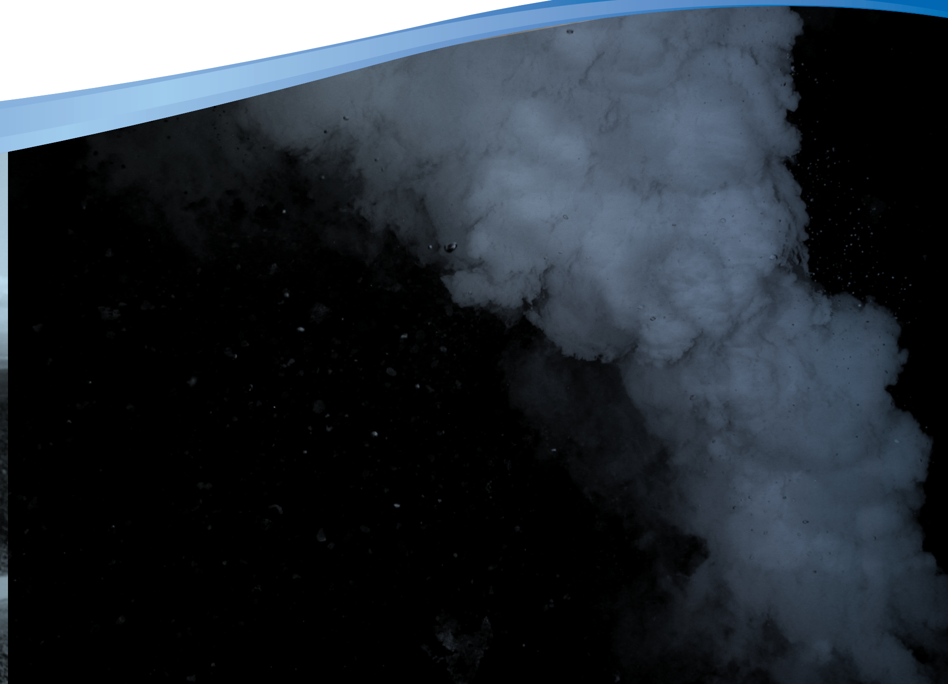




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