11. Sublimating carbon dioxide

Simple experiments to show the properties of dry ice and carbon dioxide

Overview

Solid carbon dioxide (aka 'dry ice') is an incredibly versatile substance and can easily be used in dramatic and thought-provoking demonstrations to enhance understanding of its physical properties.

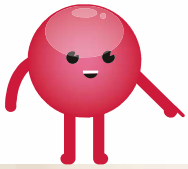
What's happening?

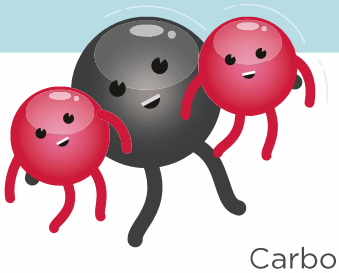
What is carbon dioxide?

Under standard conditions, (room temperature and pressure) carbon dioxide is an invisible gas all around us. We and most other animals exhale it as part of respiration and plants require it to survive and grow as part of photosynthesis. As with all materials, carbon dioxide is sensitive to pressure and temperature. When you cool down carbon dioxide gas, it turns directly into a solid.

Solid carbon dioxide can be used for many demonstrations taking advantage of its low temperature (-78°C) as well as its ability to turn directly into a gas at standard conditions (1 atm). When left on a surface, the solid carbon dioxide will slowly sublime into a gas, insulated by a 'blanket' of cold air which will slow down the sublimation. White mist will be observed about the solid, this is water vapour being condensed out of the air by the low temperature.

This process is often sped up by putting solid carbon dioxide into warm water. The increased number of collisions between molecules and therefore increased energy transfer means the solid sublimes far quicker, sending bubbles of carbon dioxide gas up the container. This is accompanied with a lot of mist and fog (condensed water vapour and aerosolised water droplets) being brought up by the flow of carbon dioxide.





Why is this important?

At high pressures but relatively low temperatures carbon dioxide becomes a supercritical fluid. This is a material which behaves like a liquid and a gas. Supercritical carbon dioxide is an important part of greener chemistry as it can act like a traditional solvent (able to dissolve other substances) for several chemical reactions, replacing other environmentally damaging chemicals and reducing waste. Supercritical carbon dioxide has also replaced harmful CFCs in manufacturing Teflon® and other fluoropolymers, which are incredibly important materials used in applications as wide-ranging as non-stick saucepans to medical implants. For more uses of carbon dioxide, see 'Further Ideas and Information'.

More stories to tell

Can you ever get liquid carbon dioxide?

The state that a substance is in (gas, liquid or solid) depends on two main factors: temperature and pressure. On earth, we are very used to the effects of changing temperature but we rarely change pressure. At 1 atmosphere, the average atmospheric pressure at sea level on earth, it is impossible for carbon dioxide to exist as a liquid and it only has two states: solid and gas. However, if you increase atmospheric pressure to just over 5 atmospheres (or above), carbon dioxide can exist as a liquid.

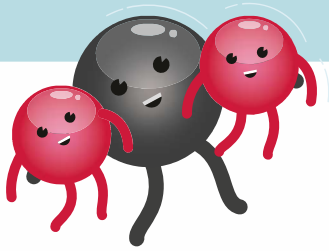
Why is carbon dioxide a gas?

The state of any material is controlled by its atomic structure and intermolecular forces. Strong forces between molecules generally result in liquids and solids (with high melting and boiling points) and weak intermolecular forces generally result in gases.

Carbon dioxide is formed of two oxygen atoms which are double bonded to a single carbon atom. The bonds between the carbon and oxygen atoms are known as covalent bonds which is where electrons in the outer shells of the carbon and oxygen atoms are shared. As both oxygen atoms also have two lone pairs of electrons, and areas of electron charge density repel each other, the carbon dioxide molecule is linear in shape. The lack of overall areas with high or low probability of electrons in the molecule means there are only weak intermolecular forces between molecules of CO_2. These weak forces result in CO_2 being a gas at room temperature and pressure. In comparison, the shape of the water molecule (H_2O) allows for stronger intermolecular forces (hydrogen bonding/dipole-dipole forces) and water is a liquid at room temperature and pressure.

The Activity

1. Solid carbon dioxide can simply be left on a surface and allowed to warm up and it will slowly disappear into thin air. Be aware that water vapour will freeze to the surface of the solid carbon dioxide which can be confusing, as this will melt when it warms up, seemingly leaving behind liquid carbon dioxide.



2. Pour a cup of solid carbon dioxide into a large (at least 2 L) vessel of warm water. This will cause the solid carbon dioxide to sublime into a gas rapidly, sending bubbles of carbon dioxide through the vessel. As the cold carbon dioxide meets the air it will produce copious amounts of water vapour mist, which (with care) can be poured over the audience!

3. Solid carbon dioxide can be left in a large pouring jug covered in cling-film and the collected, invisible carbon dioxide gas can be used to put out small candles (see 'Capturing Carbon Dioxide' Activity).

4. Take a single pellet of solid carbon dioxide and squeeze it under a large (two pence) coin or disk of metal warmed to body temperature. With practice and at the right angle the rapidly subliming gas can make a loud screeching noise.

5. Half fill a washing-up bowl (or similar sized/shaped vessel) with warm water. Rub the edges of the lip with a washing-up liquid/water mix and prepare a sheet of cloth longer than the width of the bowl with the same washing up liquid mixture. Add the solid carbon dioxide to the bowl and then slowly run the cloth over the top of the bowl, forming a soap film layer. The soap film will then form a giant bubble filled with cloud.

6. Put about 10 pellets of solid carbon dioxide into a balloon before tying off the end, the balloon will seem to self-inflate and burst if enough carbon dioxide is added.

Troubleshooting

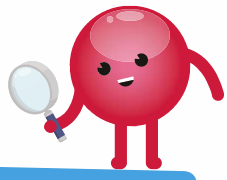
1. Always use pellets of solid carbon dioxide. Do not be tempted to invest in an on-site cylinder which generates carbon dioxide foam. It is not dense enough and most of the above experiments will not work as intended.

Health and Safety

Every delivery centre must undertake their own risk assessments for the specific audiences, locations and conditions they are presenting in. Sample assessments are available on The Secret World of Gases website. Below is a guide to the key risks and hazards:

1. Please see risks associated with handling solid carbon dioxide in 'Additional Resources'.

2. Assess whether additional PPE such as a face shield and thick gloves are required.



SECRET GAS FACT

All the dry ice on planet Earth has been artificially made, because as cold as it gets here, it doesn't naturally get to -78 °C, which is the freezing point of carbon dioxide.