Air separation units

The industrial process of extracting gases from the air

Overview

An Air separation unit (ASU) separates atmospheric air into its constituent parts including nitrogen and oxygen. This information refers to a 2 stage Cryogenic Air Separation process, the method developed by Carl von Linde in May 1895.

What's in the air?

Air is made up of several different gases, with the main components nitrogen (78%), oxygen (21%), argon (0.93%) and carbon dioxide (0.04%). A cryogenic Air Separation Unit (ASU) uses fractional distillation. Air inside the column is cooled and separated into its component parts by liquefying the oxygen and argon lower down the column, leaving nitrogen gas at the top.

How does the Air separation unit work?

The air entering the separation column first passes through an intake filter, which simply collects air from around one storey high removing any dust and large particles, before being compressed. As seen in activity 1, there are lots of different gases and air pollutants in the air that we breathe, and it's really important that the gases produced from the ASU are as pure as possible, as many of them are used in industrial chemical processes.

What happens next?

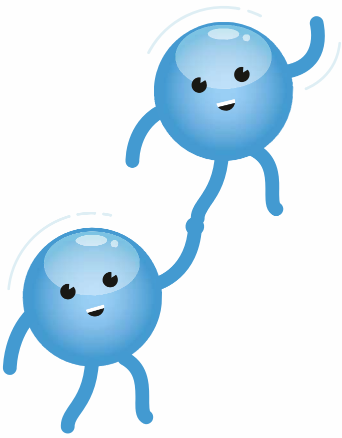
As the air is compressed, the water vapour in the air is condensed out. It is then passed through a molecular sieve bed, which removes any remaining water vapour as well as the carbon dioxide. Then it passes over a silica gel bed to remove hydrocarbons. After these processes only the main constituent parts of dry air remain: nitrogen, oxygen, argon, krypton, xenon, neon and helium.

How is it then separated?

The compressed, pure air is passed through a heat exchanger, simultaneously cooling the incoming air and warming the gas products coming from the process.

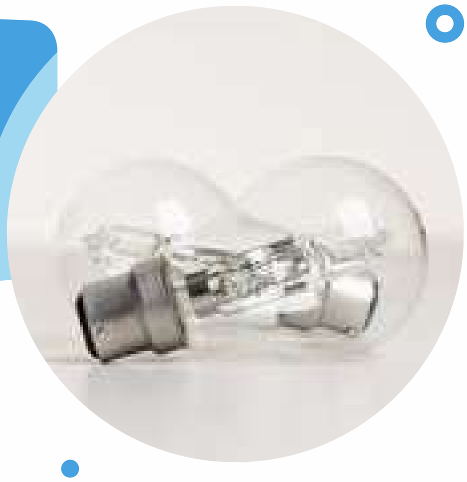
The cold air passes into a high pressure column where initial separation occurs resulting in oxygen-rich liquid air passing to the low pressure separation column. The liquid is then further distilled to separate the oxygen from the remaining nitrogen, and the resulting pure oxygen is collected in liquid and gas product streams.

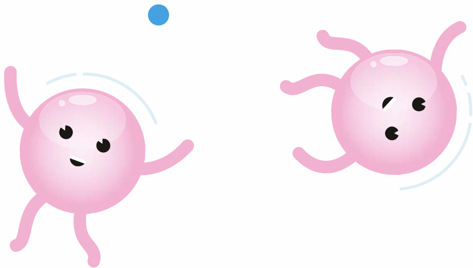
Argon can be processed from a third side-stream distillation column. The different liquid and gas products are then piped away from the columns at different pressures, depending on whether the ASU is set up to produce more pure oxygen or pure nitrogen. This is a multi-stage process, beginning with the air being compressed, and relying on the ideal gas laws, different chemical properties of the different gases, extremely low temperatures and the ability to very carefully control pressure. The supply of pure nitrogen is required for several industrial processes, including the manufacture of ammonia (Haber process) and nitric acid (Otswald process) among many others.



Argon and its uses

The lazy gas that's great for the price





Overview

Named from an ancient Greek word for its 'lazy', or inactive nature, argon is the third most abundant gas in our atmosphere.

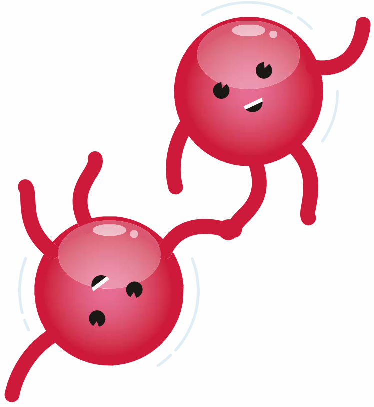
What is argon used for?

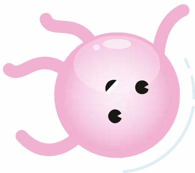
Because there's so much argon in our atmosphere (0.93% of the air around us), it's a readily available gas, and cheaper than other noble gases such as krypton and xenon for any industrial applications that need a gas that won't react easily. As well as industry though, argon can be found in the home, as it's often used in light bulbs and double glazing.

Light bulbs

The thin tungsten filaments in old-style incandescent light bulbs get so hot that they would rapidly burn away if oxygen were present inside the bulb. Options to avoid this are to create a vacuum, or to fill them with an inert gas. Using gas allows a higher operating temperature, and also means that heat more easily conducts away from the filament. Argon is better than nitrogen for this purpose, because it conducts less heat away from the filament, and reduces filament evaporation to extend the lifetime of the bulb. It is the most commonly used gas for this purpose, mixed with a little nitrogen to prevent it ionising. Krypton performs even better but is an expensive option. The distinctive traditional shape of light bulbs is also influenced by cost. Their shape was developed to reduce the volume of gas required to fill the chamber.

Compact fluorescent Lamps (the ones with coiled tubes) contain argon too. Here, the gas is doped with mercury vapour, which emits in the ultra-violet when releasing absorbed energy. This (invisible) ultra-violet light that causes the phosphorescent coating inside the bulb to glow brightly at wavelengths we can see.





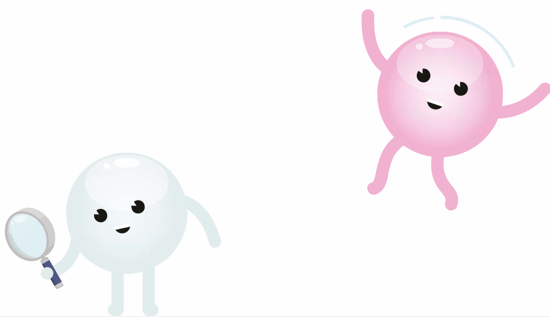
Double glazing

The space between panes of glass has traditionally been filled with dehydrated air, however argon is now the preferred choice as it has a 34% lower thermal conductivity. Argon's inert nature also means that it will not corrode window parts (the oxygen in air can lead to rusting). Krypton is generally too expensive to consider for double glazing, although some specialist situations and extremely high specification requirements do use it.

The same acoustic properties and longevity can be obtained by using less krypton than argon, meaning the windows can be made to the same specification, but thinner. Some double glazing uses a vacuum between the panes, which can also be advantageous when space is at a premium. However, the costs of this due to the technology and manufacture involved are considerably higher than using argon.

Gas metal arc welding

This type of welding works by creating a spark between an electrode and the material being welded. Atmospheric gases including oxygen and nitrogen can cause fusion defects or damage the material and equipment. For this reason, a shielding gas is used, being fed through the welding gun to flush air from the immediate area. Shielding gases are mostly argon, with small amounts of other gases as required to adjust their properties.



SECRET GAS FACT

Argon also finds use in the preservation of some of the world's most important documents. The 1297 copy of the Magna Carta, reissued by Edward I which became the foundation of English law, is encased in a specially designed frame filled with argon to protect it from any other elements.

Medical applications of gases

More than gas and air

Overview

Gases have been used in medicine since the 18th Century. The effective delivery of oxygen is particularly important, featuring in the World Health Organisation List of Essential Medicines.

Oxygen

Oxygen therapy is beneficial for many medical conditions. The gas may be delivered via mask (pictured), nasal cannula or within a hyperbaric chamber (the latter especially for young children). This is common practice especially for lung diseases including Cystic Fibrosis. Oxygen therapy has been in use since 1793 (for a case of Tuberculosis). A free oxygen clinic was opened in Bristol in 1799 to research its use.

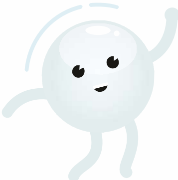
Oxygen can be delivered at concentrations up to 100%. However, note that percentages of oxygen over 21% (the level found in air) are classed as a drug, and high levels are toxic. There is also a fire risk with its use, especially in patients who smoke. It is important to warm the gas if it has been delivered from a liquid oxygen tank, as otherwise the cold temperature will cause frostbite in the lungs; oxygen has a boiling point of -183°C.

Laughing gas

Nitrous oxide (N_2O) was discovered in the late 18th Century by the English scientist Joseph Priestly, and has been in use for its anaesthetic qualities since 1844. It is colourless and non-flammable, with a sweet odour.

Nitrous oxide is still commonly used in medicine and can be used with other drugs as a general anaesthetic. It is most known for its use in dental applications and childbirth, where it may be referred to as 'gas and air' (a 50:50 mix of N_2O and O_2. It is also known as a recreational drug, with deaths having occurred from asphyxiation during use of 100% N_2O.

> “Heliox ($He + O_2$) is a gas mixture for use by patients having trouble breathing”



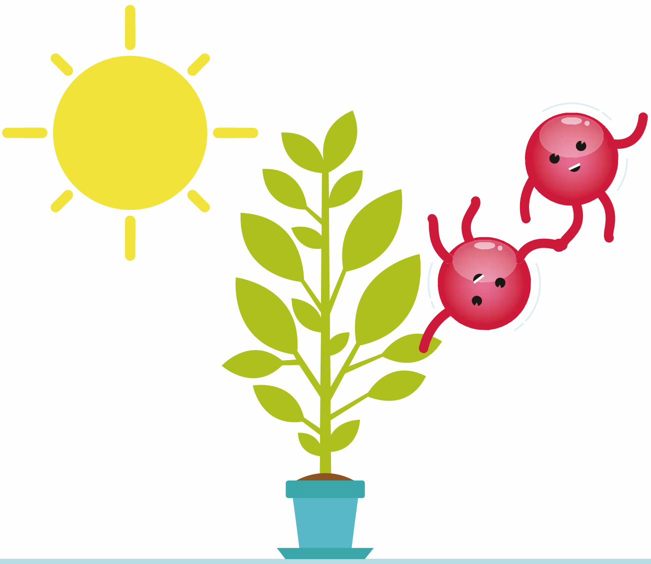
Breathe easy

Heliox ($He + O_2$) is a gas mixture for use by patients experiencing difficulty breathing. Helium is used for its low density, making it easier for the patient to inhale the oxygen into the lungs. It is commonly mixed as 79% He and 21% O_2, matching the O_2 content the air we normally breathe.

The low density of helium means that Heliox is more likely than air to experience laminar flow (i.e. without turbulence), allowing it to move with less resistance through the larger airways. However, for smaller airways, viscosity is the most important property and Heliox performs no better here than air.

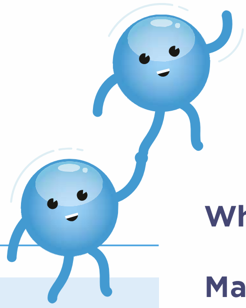
Insufflation

During surgery, carbon dioxide is often blown into the cavity to inflate the area to create more room to work for the surgeon. Although air can be used for this as well, studies have shown carbon dioxide insufflation is better than air insufflation when measured for post-procedural pain.



Superconductors

Weird and amazing, but requiring extremely low temperatures



Overview

Superconductors have zero resistance (not just low resistance). If a wire loop is made from a superconducting material, an electric current can pass through it indefinitely with no loss of charge once the power source is removed. Keeping superconductors at the temperatures they require to operate involves the use of cryogenic substances such as Liquid nitrogen and Liquid helium.

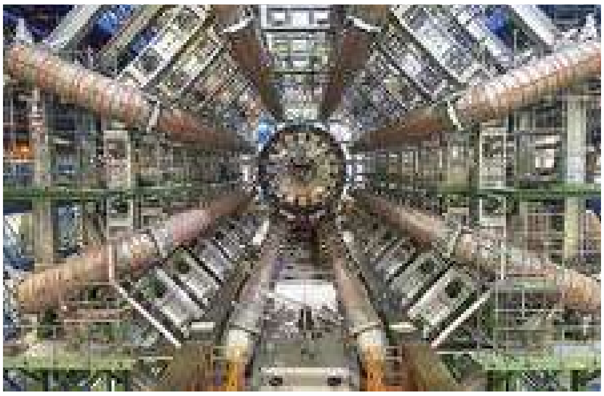
Superconductors are complicated! It's not a matter of just reducing temperature until resistance is zero; there is an abrupt change to superconductivity at a critical temperature as they undergo a transition to this new state. This critical temperature is always very cold. Liquid helium (usually) or liquid nitrogen is used to maintain temperature. People get excited about 'high temperature superconductors' (currently considered as over 30 °K = -243 °C) because keeping things this cold is difficult and expensive. Critical temperatures above -196 °C (the boiling point of nitrogen) are particularly desirable.

Where are Superconductors used?

Maglev trains

Maglev trains overcome friction by levitation using superconducting magnets. The first commercial maglev train in routine service was in the UK: a low-speed shuttle service from Birmingham airport to its railway station (1985 – 1995). There are currently operational services in China, Korea and Japan. Additional test tracks exist around the world, many of which are experimenting with the use of superconducting magnets. One test-train reached 603 km/h (375 mph) in Japan in 2015.

The two main types of magnetic levitation systems are Electromagnetic Suspension (EMS) and Electrodynamic Suspension (EDS). EMS systems use an electrical current to both initiate and



maintain the electromagnetic activity in the coiled wires in the track sides. EDS systems, however, use coiled superconductors in the track sides, which are cooled by liquid helium. This type of system can conduct an electrical current once the power supply has been switched off, due to the properties of super-cooled superconducting materials.

Japan plans to open the first commercial superconducting maglev service in 2027, designed to operate at speeds of up to 500 kph (311 mph). The train carries electromagnets in the sides of the carriages, with the resulting magnetic fields used to both lift and propel the train. Passive coils in the high track-sides experience inducted currents as the train passes. This creates magnetic fields which levitate the train. The effect is similar to the 'delayed falling' phenomenon seen when dropping a magnet down a copper tube. Powered electromagnets in the track-sides are used to move the train along the track by use of magnetic attraction/repulsion to the front and rear of the train. And it works well: the speed of acceleration/deceleration is actually limited only by the physical comfort of the human passengers.

MRI machines

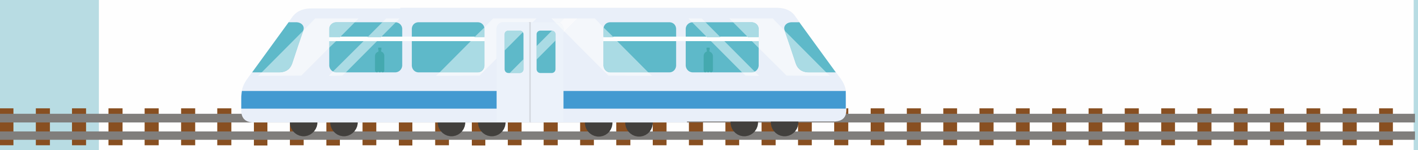
Magnetic Resonance Imaging (MRI) is used for medical imaging. It requires the creation of intense magnetic fields, which are used to align proton spins within the body. A radiofrequency field is then used to push the proton spins out of alignment. When this is turned off, they return to alignment, emitting energy that, along with the timing, can be used to identify the type of tissue they inhabit. Superconducting wires allow very powerful electromagnets to be created at relatively low cost, as they can carry very large amounts of current. The large majority of MRI scanners use superconductors. Liquid helium is used to cool the wires to below their critical temperature.

CERN

The LHC at CERN is one of the coldest places on Earth, with magnets operating at -271.3°C. That's colder than outer space; just 1.7°C above absolute zero. A closed system, it contains 120 tonnes of liquid helium to maintain these low temperatures.

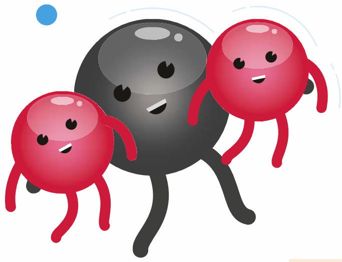
Thousands of electromagnets are used to accelerate and control the trajectories of particles speeding around the 27 km track of the Large Hadron Collider (LHC). All the main magnets are superconducting, using niobium-titanium (NbTi) wires at low temperature. If normal magnets were used, the accelerator would have to be 120 km long to reach the same energy.

Electromagnets are also used in the LHC detectors. By looking at how particles react to these fields, physicists can determine their identity.



Detecting gases

Sniffing the air



Overview

Gases can be dangerous for different reasons, from combustible gases to air pollutants. Many of the gases dangerous to human health are colourless, odourless and tasteless, so it is difficult to detect their presence without technological assistance.

As dangerous gases are usually reactive, detectors work by encouraging them to react in a safe and controlled way within the detector.

How can we detect combustible gases?

Undetected build-ups of combustible gases risk explosion and fire. Natural gas used in the home is mostly methane, which is both odourless and colourless. To help people identify leaks, the gas has a smelly molecule (2-methyl-2-propanethiol) added to it.

As burning is oxidation, combustible gases offer a way to detect themselves through oxidation, with a single detector. There are a few different types of these detectors.

Semi-conductor detectors: Semi-conductors are materials which can conduct electricity, or not, depending on conditions. Under normal conditions, oxygen associates with the semi-conductor surface, dragging on its electrons to prevent flow of current. Reducing gases interact with this surface-bound oxygen, releasing it and allowing current to flow.

Infrared detectors: Infrared detectors react to Infrared (IR) radiation. Hydrocarbon gases absorb particular wavelengths within the infrared range, so combustible gases such as methane or propane are picked up by this type of detector very quickly.

Catalytic sensors: Here, the detecting element contains platinum-coated wire, with a catalyst which promotes oxidation of gases. When this occurs, a change in resistance provides an electrical signal to be relayed to the user. Often, the detector must be heated to a high temperature. In this case, it is enclosed in a tiny cage which functions similarly to a Davy Safety Lamp to prevent explosion if combustible gases are present.

How can we detect air pollutants?

Air pollution is the single largest risk to world health. The World Health Organisation estimated it to be responsible for one in eight deaths worldwide in 2012. About three million of these were due to outdoor pollution such as dirty fuels and smoky cookers.

Every year in the UK, about 30,000 people die early due to poor air quality. It is thought to reduce UK life expectancy by six months. In the UK, the most harmful contributions to air pollution are from particulate matter and the gas ozone (O_3).

Ozone is beneficial high in the atmosphere, where it absorbs ultraviolet radiation. However, at ground level it is harmful to both humans and vegetation as it is a powerful oxidising agent. It can cause breathing problems, trigger asthma symptoms, reduce lung function and cause lung disease.

How do we detect and monitor ozone (O_3)?

Ozone is a pale blue gas. It has a sharp, pungent smell, reminiscent of chlorine or bleach and can be used as a disinfectant, killing bacteria and removing odours. It can be created by the action of lightning and can sometimes be smelled before a storm.

There are a variety of devices available to accurately monitor ozone levels:

1. Ozone absorbs ultraviolet radiation at 254 nm. A beam of ultraviolet (UV) light is fired at a UV detector (which is similar to an IR detector), and the absorption can be recorded. This is a nice method as absorbance at this wavelength is so specific to ozone.

2. Semi-conductors are used in a variety of gas detectors. Heated metal oxide sensors change their conductivity in the presence of ozone, relaying the news of its detection through changes in electrical current. The substrate must be heated to about 150°C.

3. Electrochemical detection: an electrode is exposed to the air, where reactive gases are reduced/oxidised on contact. This then creates a signal in the form of electric current which is relayed by the electronics.

Other gases:

Other air pollutants hazardous to human health include nitrogen dioxide (NO_2) and sulphur dioxide (SO_2). NO_2 is one of the more hazardous pollutants in the UK, released by diesel car engines. Long-term monitoring along the roadside is carried out using diffusion tubes. These small plastic tubes contain a steel mesh disc coated with triethanolamine (TEA), a chemical which absorbs nitrogen dioxide, so the exposure to NO_2 levels can be analysed.

Gases such as chlorine, nitrogen oxides and carbon monoxide can be detected using electrochemical detectors, although carbon monoxide is more commonly detected using semi-conductor devices. Carbon dioxide can also be detected using electrochemical sensors, despite not being electrochemically active! This is done by adding an additional step where the presence of CO_2 releases an electrochemically active molecule inside the detector.

You can track your region's air quality at https://uk-air.defra.gov.uk/latest/

HYMERA: Hydrogen fuel cell generator

Off-grid futures: hushed and clean

Overview

Small electric generators are noisy and dirty. Battery banks are often big, heavy and expensive. HYMERA from BOC is the world's first commercially-viable, low-carbon, hydrogen fuel cell generator. The HYMERA can produce up to 175 watts of peak power, which is enough to run a lighting system, security cameras or environmental monitoring equipment.

Where does the energy come from?

The HYMERA uses hydrogen gas from a cylinder to produce energy. This energy is locked up in the bond between the two atoms of hydrogen in the gas H_2. When hydrogen gas and oxygen from the air are combined, they produce water (H_2O). The bond energies in H_2O are less than the combined bond energies of H_2 and O_2, so there is some 'spare' energy to be transferred.

Why is this important?

Using hydrogen to produce energy is an exciting prospect, because it is the most abundant element in the universe. We already use it as a fuel in some applications, such as space travel. Space shuttles used hydrogen fuel, combining it with oxygen by burning. The explosive release of energy in a rocket creates a huge fiery blast, nicely demonstrating the energy that is available from the bond. However, the same reaction can be carried out without the ball of fire. Instead, that energy is converted to very usable electricity here on Earth.

What is a fuel cell?

Fuel cell technology converts chemical bond energies into electricity. The set up looks similar to a battery, hence the name. There are two electrodes: a negatively-charged anode, and a positively-charged cathode. These are connected in two different ways; an electrolyte (which is a liquid that certain molecules can pass

through), and a circuit that goes via the thing you want to power (e.g. a lighting rig).

The hydrogen gas is sent to the anode. Here, a chemical reaction (aided by a catalyst) strips the hydrogen atoms of their electrons:

$H_2 \rightarrow 2\ H^+ + 2e^-$

Both products now go to the cathode, but by different paths. Protons (H+) travel via the electrolyte. Meanwhile electrons (e-) whizz along the circuit, creating current and powering the lighting rig.

At the cathode, oxygen is available (from the air). Also, electrons have flowed here from the anode. Aided by another catalyst, the protons react with both oxygen and electrons to form water. It takes two hydrogen gas molecules and one oxygen gas molecule to create two water molecules:

$2\ H_2 \rightarrow 4\ H^+ + 4e^-$
$4\ H^+ + O_2 + 4e^- \rightarrow 2\ H_2O$

As the product is water, there is nearly zero pollution on-site, although it is important to note that energy is required to produce the hydrogen in the first place, which may be from polluting sources.

> "Fuel cell technology converts chemical bond energies into electricity"

Nitrogen and its uses

The most abundant gas in our atmosphere

Overview

Nitrogen is all around us, a colourless, odourless and unreactive gas. It is also fixed within many biological molecules. Its abundance and interesting properties make it important in several different applications and industries.

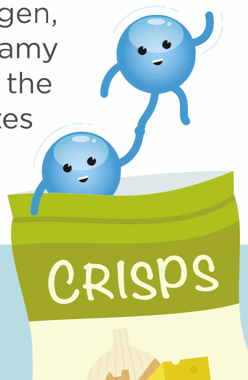
Frozen foods

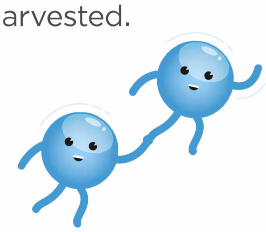
Nitrogen has a boiling point of -196 °C. There are several advantages to freezing foods at super-low (cryogenic) temperatures. For example, food that might otherwise take hours to freeze can be frozen in minutes, which means that lots of small ice-crystals form, rather than fewer, large ones. This reduces the damage the sharp crystals cause to cell and tissue structures and reduces the likelihood of the frozen food being mushy when defrosted. This is especially noticeable with soft fruits, which benefit greatly from liquid nitrogen freezing (berries can simply be sprayed with it as they move along a conveyor). Ice-cream can also be made using liquid nitrogen, the smaller ice crystals giving a creamy texture. Together these things help the frozen food retain moisture: it freezes before it can dry, and the reduced damage means that less fluid is released from the tissues.

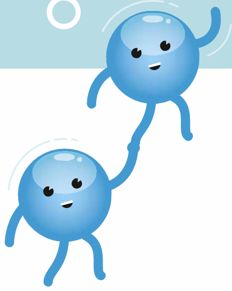
Crisp packets and salad bags

Crisp packaging uses nitrogen. So next time you pop a bag of crisps, have a think as to why the crisps are so well preserved. Salad bags are also packed in a protective atmosphere. Nitrogen gas is used for packaging for its non-reactive qualities. It slows the deterioration of these highly perishable foods and plumps up the bags to avoid damage from crushing.

Modified-Atmosphere Packaging (MAP) has hugely increased the variety of salad available in shops, allowing time for packaging and distribution of delicate leaves to supermarkets across the country. Nitrogen replaces the oxygen levels, which are kept very low to slow oxidation (which causes browning of leaves, see ‘Keeping food fresh’ activity). Carbon dioxide levels are often raised to reduce bacterial growth. Some bags even allow certain gases to slowly pass through, to adjust for the changing atmosphere due to the plant material’s living processes which continue after they have been harvested.







Fertilisers

Nitrogen is abundant in the atmosphere (78% by volume) and is required by growing plants. Howeve they cannot access it directly from the air, the nitrogen gas must first be 'fixed' into nitrates. This occurs as a natural process by lightning. It also takes place as part of biological processes in the soil by certain nitrifying bacteria.

Such bacteria are found in the roots of most legumes, making these plants an excellent choice for crop rotation as they can replace nitrogen lost from the soil.

The Haber - Bosch process was developed in the early 20th century as a way to fix nitrogen in industrial quantities. In this process, hydrogen and nitrogen are combined to form ammonia (NH_4). High temperatures, pressures, and catalysts are used to drive the reaction.

This allowed for rapid development of fertilisers, boosting the productivity of farmers across the world. This in turn played a major part in the world population boom. Nitrogen from the fertiliser is used in the plants to build important molecules like proteins, which animals, including humans, then eat and use to build their own bodies.

The future of crop superpowers?

Nitrogen uptake in plants is a limiting factor for agriculture. Nitrogen fertilisers are already used to excess. In fact 50% of the nitrates remain in the soil, where they can be washed through into rivers and lakes, causing undesirable algal blooms. As an alternative to fertilisers, scientists are exploring whether the ability of legumes to fix their own nitrogen can be transferred to other crop plants. Most plants (including all major crops) already have close relationships with fungi, involving common mechanisms to the legume's relationships with bacteria. This could increase yields, reduce cost to farmers, and reduce environmental pollution.

Electronics manufacturing

Nitrogen gas is used during the manufacture of high quality electronics within special chambers, allowing for higher-quality soldering of circuit boards. It is chosen for its properties as an inert gas, its role being to exclude oxygen from the system without affecting the process itself. Exclusion of oxygen prevents oxidation of the surface of the solder, allowing it to flow and break away more cleanly. Oxidation can also weaken the solder. The nitrogen atmosphere is also used to manage temperature.

Big chill for the Large Hadron Collider

10,000 tonnes of liquid nitrogen is used when cooling the Large Hadron Collider (LHC) magnets at CERN, a process that takes weeks to complete. The nitrogen is used to reduce the temperature of 120 tonnes of helium, which is then cooled further until it reaches the required operating temperature of -271.3°C. This process makes the LHC magnets one of the coldest places on Earth.

Nitrogen as future transportation fuel?

The nitrogen compound ammonia (NH_4) does not burn easily, but burns cleanly. The products of combustion are water (H_2O) and nitrogen gas (N_2). If ammonia could be used in place of carbon-containing fuels, it would be a way to reduce carbon emmisions. People are researching the use of ammonia as a fuel in cars, turbines and in other contexts. However, safety concerns and a current necessity to produce ammonia from natural gas cause problems for this as a realistic large scale future fuel.

Carbon dioxide and its uses

Much more than just a greenhouse gas

Overview

Carbon dioxide is a colourless, odourless gas that makes up only 0.04% of our atmosphere. It is well known as the gas we 'breathe out' and for its impact on climate, but there is more to carbon dioxide that meets the eye.

Fire extinguishers

Carbon dioxide extinguishers are under high pressure and contain liquid CO_2, which turns to a gas as it is depressurised on release. It is very cold when it comes out (never hold the nozzle on a CO_2 fire extinguisher!) and works because the gas excludes oxygen from the fire, oxygen being required for combustion. Carbon dioxide is heavier than air, and so doesn't immediately float away and the low temperature also helps cool the burning matter. CO_2 extinguishers are safe for use on electronics as the gas does not conduct electricity. In contrast, water extinguishers risk causing further damage and conducting electricity to bystanders.

Keeping cool

Dry ice (solid CO_2) is very cold: -78.5°C. It is easily transported in solid form and has the unusual property of sublimating, meaning it can undergo a phase change directly from a solid to a gas. This is where the 'dry' in its common name comes from. As it simply evaporates away, there is no mess and so dry ice is often useful for cooling items.

Solid CO_2 is used in the food industry to freeze products or keep them cool during shipment. It is often used to store and transport other temperature-critical items such as medical or pharmaceutical materials. In some countries, a pack of dry ice is even used to keep groceries cool for home delivery, although the risks associated with its very low temperature mean this is not considered safe in the UK.

Special effects

As dry ice sublimes, it releases freezing cold gaseous CO_2 into the surrounding air. The resulting drop in temperature causes water vapour in the air to condense out into tiny droplets of liquid water. This forms a cloud of tiny water droplets in the air, creating a foggy, smoky effect. The effect can be sped up by putting the dry ice in warm water. Being made of water, this 'smoke' does not have the same risks to health as traditional smoke machines. Dry ice is sometimes used to create a witches-brew effect in cocktails. However it is extremely important to ensure the dry ice is not consumed with the drink as its low temperature can freeze flesh on contact. In addition, gaseous CO_2 can take up 600 times more volume than the solid CO_2 and this expansion can distend and damage internal tissues and organs.

Fizzy drinks

Carbon dioxide easily dissolves in water and, as it has no taste or smell, it is perfect for use in fizzy drinks. The gas is pressurised into the drink until it is super-saturated. The drink is then squeezed into a can or bottle, which maintains the pressure and keeps the carbon dioxide in solution. When it is opened, the drink depressurises and the gas is released as bubbles.

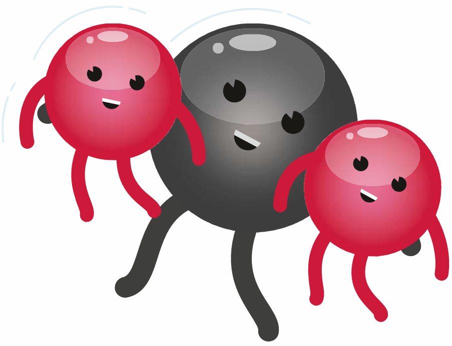
Once dissolved, carbon dioxide can dissociate to form weak carbonic acid. This gives an extra tingle to the drinks, like the effect of adding a slice of lemon.

The idea of fizzy drinks came from nature, as there are rare natural springs that release naturally effervescent water which comes from volcanic activity, for example, the spring where Perrier is bottled (although now the gas and water are captured separately and recombined).

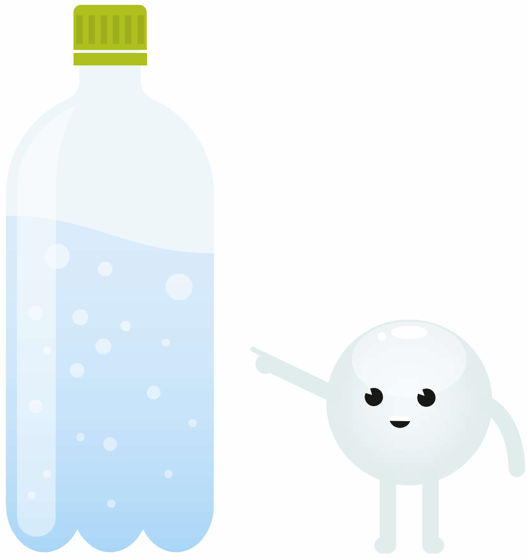
Carbon dioxide also has important roles to play in wine and beer making.

Oil wells

Carbon dioxide is used in the oil industry to help extract oil from old wells. The gas is pumped down into the well, where it dissolves into the oil, reducing its viscosity and so making it easier to pump. The magnitude of the effect will depend on the type of oil present. The



> As it easily dissolves in water and has no smell, carbon dioxide is perfect for use in fizzy drinks



pressure of the gas also helps support the well wall, although nitrogen is a cheaper option for this task.

Water treatment

Because carbon dioxide can dissociate in water to form weak carbonic acid, it can be used to neutralise alkali solutions. This can be used to effectively treat effluent from industrial processes and is more environmentally friendly than the mineral acids that may otherwise be used.

Cleaning

There is a variant of sand-blasting where small dry-ice pellets are blasted at the surface to be cleaned. The thermal shock can loosen dirt and the movement of gas as the CO_2 sublimes instantly on contact sets up mini shock-waves that are thought to be involved in the process of cleaning. The carbon dioxide cleaning agent itself then turns to gas and so usefully leaves no mess to be cleaned up.

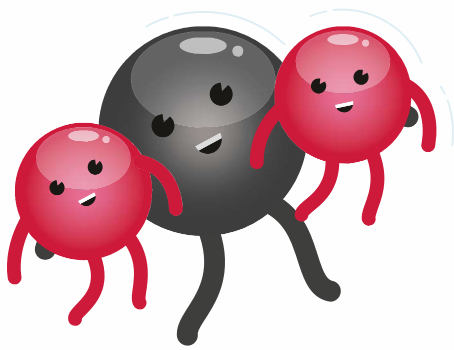
Food packaging

See 'Nitrogen and its uses' for why CO_2 is used in packaging of bagged salads.

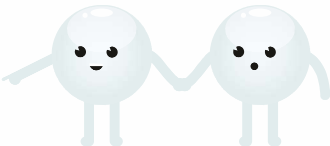
Carbon dioxide in the future:

Carbon dioxide has long been released into the atmosphere as a waste gas, leading to environmental pollution and climate change. The challenge is to find ways to use it so that it becomes a useful resource rather than a waste product.

Current research is focussing on looking for ways to cheaply convert carbon dioxide into carbon monoxide (CO). Carbon monoxide is more reactive and can serve as a carbon building block for manufacture of a wide variety of molecules utilised in the chemical industry and it can also be converted into hydrocarbon fuels.



Handy handbook definitions



Definitions

Acids, Alkali and Bases

An acid is a substance that donates a proton. In chemistry a proton is commonly represented by H^+ (a hydrogen atom without its electron). A base is a substance that can accept a proton. An alkali is a base that is soluble in water. The resultant solution is called an alkaline solution.

Common household acids include vinegar (acetic acid), lemons and citrus fruits (contain citric and/or ascorbic acid), ketchup (contains vinegar) and milk (contains lactic acid). Common household bases include baking powder, indigestion tablets, toothpastes and many cleaning products such as washing machine tablets. This is useful to know if you ever get stung! Wasp sting venom is alkaline so painful symptoms can be helped with vinegar, Bee sting venom is acidic so can be neutralised with bicarbonate of soda.

Catalysts

This is a substance that provides an alternative route for a chemical reaction to progress and is traditionally associated with speeding up the chemical reaction by lowering the energy required to activate the reaction. Catalysts are useful as they can also avoid dangerous or toxic by-products or favour a particular product if there is more than one possible outcome. Animals would never be able to breakdown food and extract energy from it quickly enough if it was not for the use of biological catalysts known as enzymes.

Distilling

A method of purifying liquids by heating and cooling which takes advantage of different boiling points to separate out different substances (See Liquid air activity).

Redox reactions

A redox reaction (sometimes called an oxidation-reduction reaction) refers to a certain type of reaction where electrons move between two substances. They're common in nature (e.g. burning of fossil fuels & corrosion of metals) and are a fundamental part of the process our bodies have to take in order to extract energy from the sugars and fats we eat (see Respiration below).

Redox reactions are always made up of two parts; One part loses electrons and is referred to as the oxidised half, the other part gains electrons and is referred to as the reduced half. A simple acronym to remember this is OILRIG (Oxidation Is Loss, Reduction Is Gain).

When a single substance is simultaneous both oxidised and reduced in a reaction, giving 2 different products, it is known as disproportionation (See Blazing Wotsits Activity).

Respiration

Respiration the biological conversion of chemical potential energy via the reaction between oxygen and organic (carbon containing) substances releasing carbon dioxide, water and energy. As this process continues for a short period after fresh fruit and vegetables are harvested, respiration is the main reason we require low temperatures and Modified Atmosphere Packaging (MAP) to keep our food fresh and prevent rapid deterioration before it reaches us (See Keeping Food Fresh Activity).

Things you should know

Getting to Grips with the Gas Laws

There are fundamental laws that describe the behaviour of gases in relation to volume, temperature, pressure and the number of particles present.

These laws describe 'ideal gases'. Particles within an Ideal Gas are assumed to move randomly and rapidly, they do not lose energy when they collide, they do not take up any volume themselves and have no intermolecular forces. So real gases often deviate from ideal behaviour, particularly at high pressures and low temperatures.

Nevertheless, these simple laws provide a good approximation to describe how most gases behave.

Boyles Law

Boyles Law is the relationship between the pressure and the volume of gases. The pressure the gas is under is inversely proportional to the volume it occupies, so long as the amount of gas and the temperature are kept constant. Put simply, pressure increases as the volume of a gas decreases. This is because, if you have a fixed number of gas molecules inside a container and you decrease the volume of that container, more molecules will hit the side of the container and so the pressure increases.

Boyles Law explains how breathing works in mammals. Muscles in the diaphragm contract causing the volume of the lungs to increase. As the lung volume increases, the air pressure inside the lungs decreases. This pressure difference between the air inside and outside the lungs causes air to flow in.

Charles Law

If you keep the pressure of a fixed amount of gas constant, the volume of gas depends on its temperature. The volume of a gas is often measured cubic decimeters (dm^3). 1 dm^3 = 1000 cm^3 (1 litre). If you were to plot a graph of volume of gas (dm^3) versus its temperature (°C), you get a straight line (although the slope of that line will vary depending on how much pressure the gas is under).

A demonstration of this is in the Shrinking balloons activity: decreasing the temperature of the gas inside the balloons causes a decrease in volume. This is also how hot air balloons work. Pressure is kept constant as the balloon stays in the same shape. Therefore, when air is heated by the burner and temperature is increased, the volume of air expands. Some of the air escapes out of the bottom of the balloon but the less dense air remaining inside the balloon makes the balloon increasingly more buoyant.

In fact, many gas laws were discovered by keen balloonists. Professor Charles himself applied this law to improving hydrogen and hot air balloons and airships.

Gay-Lussac's Law

Leading on from the work of Charles' Law, Gay-Lussac's Law (sometimes called the Pressure Law) describes the relationship between temperature and pressure of a gas. A fixed mass and volume of gas is directly proportional to its temperature. If you heat a sealed container of gas, the pressure will increase. Therefore hot air balloons are not sealed. They would rapidly burst as the pressure increases with increased temperature.

Avogadro's Law

Avogadros Law states that equal volumes of any gas, at constant temperature and pressure contain the same number of molecules.

The specific number of molecules can be worked out using Avogadros number, or Avogadros constant which is $6.022140857 \times 10^{23}$

A mole (mol) is a unit to measure the amount of a substance. Crucially I mole (mol) of a substance contains Avogadros number ($6.022140857 \times 10^{23}$) of particles (for example atoms, molecules, ions or electrons).

This number is unfathomably large! If you turned all the molecules in 1 mol of oxygen gas into pennies and set them side by side, the line of pennies would reach 1.29 million light years. This is far beyond our Milky Way galaxy (100,000 light years) and half way to the Andromeda galaxy.

Ideal Gas Equation

The Gas Laws above are brought together in the Ideal Gas Equation:

$$pV = nRT$$

Where:
p = Gas pressure measured in pascals (Pa) (newtons per square metre)

V = Volume measured in cubic metres (m^3)

n = Number of moles of Gas

R = The gas constant ($8.31441\ J\ K^{-1}\ mol^{-1}$)

T = Temperature measured in Kelvin (K) (°C + 273.15)

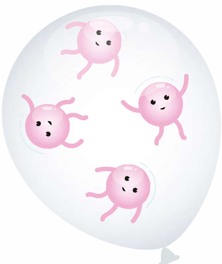
More about moles!

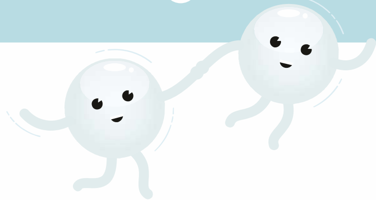
Regardless of the substance, one mole (1mol) of an element contains $6.022140857 \times 10^{23}$ of atoms, and one mole of a compound contains $6.022140857 \times 10^{23}$ of molecules of that compound.

1 mol = the mass in grams that is equal to the relative atomic mass of that substance. For simplicity, the following numbers refer to the most common particular isotope of each element.

Carbon has a relative atomic mass of 12.
Hydrogen has a relative atomic mass of 1.
Oxygen has a relative atomic mass of 16.

Therefore 12 g of carbon = 1 mol of carbon.





Gaseous elements are not always single atoms, but often binary molecules.
1 mol of hydrogen gas (H_2) = 2 g of hydrogen gas
1 mol of oxygen gas (O_2) = 32 g of oxygen gas

With compounds, we combine the relative atomic mass (Ar) of each atom to find the relative formula mass of the compound (Mr).
So, 18 g of water (H_2O) = 1 mol of water. (Mr = 1 + 1 + 16).
0.5 mol of carbon dioxide (CO_2) = 22 g of carbon dioxide. (0.5 * [12 + 16 + 16])

If we add all of the components of dry air together (nitrogen, oxygen, argon, carbon dioxide, the nobel gases & hydrogen) in their relative constituents, the average molar mass of air is 28.97 g/mol.

One mole of any gas also has a set volume. This volume is 24 dm^3 (24,000 cm^3) at room temperature and pressure (rtp). This volume is called the **molar volume of a gas**.

Therefore 1 mol dry air at room temperature and pressure, containing 28.97 g, would take up a volume of 24 dm^3. As 1 dm^3 = 1 litre, you can imagine this amount as 12 large (2 L) fizzy drink bottles filled with air.

Just remember Avogadros' number and the mind-blowing number of molecules inside those seemingly empty bottles.

Understanding Partial Pressure

When we have a mixture of gases in a container, the partial pressure of the individual gases in the mixture is the amount of pressure it would exert if it was allowed to fill the vessel by itself (under the same volume and temperature).

Explained well by Dalton's Law, the total pressure exerted by a mixture of gases is the sum of the pressures of each component (the partial pressure of each component).

If the overall atmospheric pressure on Earth is 1.00 atmosphere. The partial pressure of oxygen is 0.21 atm. However, 10 metres underwater = 2 atmospheres and the partial pressure of oxgyen in the same mixture = 0.42 bar

As partial pressure has implications in the way in which gases dissolve in liquids (described by Henry's Law), understanding how partial pressures change is essential in recreational and deep diving, in mountaineering and in many aspects of medicine such as anaesthetics.