Secondary Education Pack

At Chillistick we are passionate about dry ice! It is a great material to demonstrate scientific principles for students of all ages. It is also brilliant as a means of adding pizazz to open days and assemblies. This booklet is our attempt to provide a one stop shop for all things dry ice.

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At Chillistick we are passionate about dry ice! It is a great material to demonstrate scientific principles for students of all ages. It is also brilliant as a means of adding pizazz to open days and assemblies. This booklet is our attempt to provide a one stop shop for all things dry ice. Alas, it is not perfect… if you see new ways of using dry ice in schools and would like to add to this document (and receive acknowledgement) or if you have spotted errors please let us know by sending a note to us at: **info@chillistick.com**

We would also love to get feedback, photos and well, anything… thanks and have safe dry ice fun!

Chillistick gratefully acknowledges help from:

Faye James Evergreen Jennifer Hughes, Lindsay Turner and her students at Farnborough Hill School, Science staff at Charterhouse School for help with the Magnesium Volcano experiment, staff and students from St Hilary's School, Godalming, Grey House School, Hartley Witney and Yateley School, Yateley.

Dr Cristina Lazeroni, University of Birmingham and the Institute of Physics for promoting the use of cloud chambers in schools.

Notes on the use of this booklet

Each experiment is given with estimated times, equipment, objectives and discussion points. Most of the equipment required is available in the Chilly Science Pack Education Pack. Please follow all safety guidelines and complete a Hazard Assessment; in the Safety Information section is a sample hazard assessment and a databank to help you use this product safely.

Each experiment can be performed separately, to make sure nothing is missed out we have repeated discussions on sublimation and safety. Depending on the age of the students you may wish to let them carry out these experiments in small groups. Most of the practical work has relevance to students of all ages; teachers will know how much detail to delve into, most of the experiments can be carried out within one or two lessons and the experiments generally flow together as we have tried to show in the text.

Lightweight gloves providing short term (up to 10 seconds) insulation without compromising dexterity. Intended for picking up individual pieces of dry ice, and putting into vortex generators, for example. Not intended for scooping large amounts or for holding for more than 10 seconds. These gloves also make an effective demonstration of gas evolving from the dry ice in the self-inflating balloon experiment.

The Chilly Science Pack contains:

- 1 x vortex ring generators
- 1 x safe explosion canister
- 1 x Jug/launcher
- Water Rocket Bottle
- 1 x polycarbonate scoop
- 1 x ice cage
- 5 x chillisticks
- 1 x bubble mixture
- 1 x 10 Litre container
- 5 x sets of lightweight blue gloves
- Instructions

You will also need to order a dry ice pack directly from Chillistick Ltd on 0203 4329412 or go to dryice.education. Sizes available are from 5kg to 30kg depending on what you require – give us a ring to discuss. We accept Purchase Order numbers from schools.

Please note that the dry ice will only last for a few days and so it is important to ensure that delivery is made on the best day for your schedule. Deliveries can be made by courier to arrive Tuesday to Friday and we can also offer AM and pre 10AM deliveries for a supplement, please go to dryice.education to get the latest information.

To get the most out of the pack we recommend that the dry ice is shared across a number of classes and age groups and so this will require some co-ordination within the school.

The Ice Pour is a high-tech storage system that might help in this regard - it will hold 1kg of dry ice for several days:

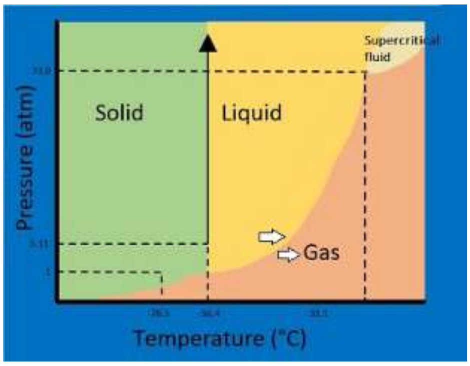
Introducing dry ice and carbon dioxide

Dry ice is the solid form of carbon dioxide (CO_2). At atmospheric pressure it exists as a solid at -79°C. Dry changes from a solid to a gas without passing through a liquid phase, this phenomenon is called sublimation.

The lack of liquid phase (at atmospheric pressure) combined with the cold temperature are why it is called 'dry' ice - it has nothing in common with ordinary 'water' ice.

Dry ice is made from carbon dioxide gas, which is pressurised and refrigerated until it becomes a liquid. This liquid is pumped into a machine called a 'pelletiser' where the pressure is rapidly reduced to atmospheric pressure. When this occurs some liquid carbon dioxide vaporises and the remaining liquid freezes into carbon dioxide 'snow'.

This snow-like solid carbon dioxide is compressed into solid pellets, slices and blocks of dry ice. This diagram shows the phases of CO_2 with temperature and pressure:



Of interest to us is what happens at atmospheric pressure and this shows that CO_2 only exists as solid or a gas. Dry ice sublimes to CO_2 gas and the heat of sublimation required for this phase change is how the remaining dry ice maintains its temperature of -79°C. Of note is the triple point, where CO_2 exists in all three phases at -56°C and a pressure of just over 5 bar.

In the UK all dry ice is made from recycled CO_2 which is manufactured as a by-product of the manufacture of hydrogen from fossil fuels, the overall equation is:

$$CH_4 + 2H_2O \longrightarrow CO_2 + 4\,H_2$$

(Incidentally the hydrogen is then used in the Haber process to fix nitrogen for the fertiliser industry, which helps to feed 1/3rd of the world's population.)

Carbon dioxide plays a crucial role in the carbon cycle – the process by which carbon is recycled between the environment and living organisms:

Carbon enters the atmosphere as carbon dioxide from respiration and combustion.

- Carbon dioxide is absorbed by plants to make carbohydrates and oxygen via photosynthesis.
- Animals feed on plants containing carbon compounds, most of the carbon consumed is exhaled as carbon dioxide formed during respiration. The animals and plants eventually die.
- The dead organisms decompose and the carbon in their bodies is returned to the atmosphere as carbon dioxide. In some conditions decomposition is prevented. The plant and animal is then converted to coal, oil and gas - fossil fuels, which will release carbon dioxide if burned.

CO_2 is one of the primary greenhouse gases in the Earth's atmosphere and scientists have shown that the increase in CO_2 gas in the environment due to the combustion of fossil fuels is having serious consequences for our environment.

Please note, the dry ice supplied by dryice.education comes from recycled sources.

Uses of dry ice

The most common use of dry ice is to package items that need to remain cold or frozen, such as biological samples and perishable goods. It is also used to quickly freeze items including foods, pharmaceuticals and laboratory biological samples. Other uses of dry ice are fog machines in theatres, removing warts, freeze branding animals (which does not hurt the animal or damage the skin), blast cleaning, keeping food cold on aeroplanes, food processing such as making ice cream and oh yes, teaching!

Floating Bubbles

We think this is a good visual experiment for students of all ages to start learning about dry ice. Levitating soap bubbles leads on to a discussion about dry ice subliming to a gas and also provides visual confirmation about the relative molecular weight of CO_2 and air. It also looks good!

What You'll Need

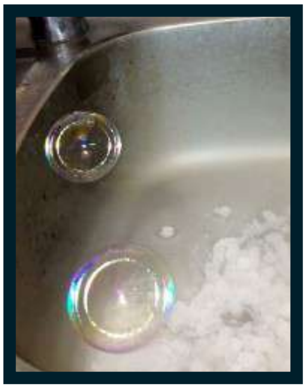
Large container which has a water-tight base, the 10 Litre container from the Chilly Science Pack is ideal, (or consider using a laboratory sink with the plug in

Bubble Solution (provided with the dry ice kit)

Plastic Scoop/Cup (provided with kit) or similar Pyrex container

Time

5-10 mins +class discussion



Instructions

Place around 100 grams of dry ice in the polycarbonate scoop provided in the pack (approx. half-full). If you do not have this you can use a ceramic coffee mug or plastic drinking glass and half fill with ice. **Please do not use a glass container unless you know that it is Pyrex.**

Place the cup in the 10 Litre container, or in a sink with the plug in. Wait five minutes to allow the dry ice to start to sublime to invisible CO_2 gas.

Invite several students to blow bubbles into the box using the bubble kit provided in the pack. Some of the bubbles will float and bob up and down. If you do not have any bubble mixture you can make your own:

70ml washing up liquid

30ml glycerol

I litre of tap water

If you do not have a convenient sink or box, you can use the dry ice container itself, as this will always be full of CO_2 gas. Don't forget to replace the lid on the box after the demonstration to help preserve the ice.

Class Discussion

Why are the bubbles floating?

The atmosphere above the dry ice will be high in CO_2 so when bubbles filled with air at molecular weight 29 comes in contact with CO_2 with molecular weight 44 the bubbles float on the heavier gas.

Where is the CO_2 gas coming from?

The heat from the room causes the dry ice to sublime to CO_2 gas.

Does the breathe we exhale differ from the 'average' air in the room?

When we exhale we breathe out a small amount of CO_2 gas and water vapour.

Why do the bubbles bob up and down?

The CO_2 gas is a fluid – to test this gently stir the CO_2 in the sink or lift and lower the box and observe how the bubbles respond. This is like a boat on an ocean moving with the water.

What do the components in the bubble solution do?

The washing-up liquid reduces the surface tension of the bubble by about 1/3 and so allows the bubble to expand. The glycerol reduces water evaporation from the bubble surface and so helps prevent the mega bubble from popping too soon.

Self Inflating Balloon

In the Floating Bubbles experiment we said that the dry ice sublimes from a solid to a gas. Ask the students to suggest how this can be proved? We need to contain the dry ice in a system so that we can observe what happens to any gas produced. Here's one simple method.

We suggest that this experiments be done in parallel with some of the other demonstrations as it requires occasional observation over around 20 minutes.

What You'll Need

1. Gloves
2. Saucer

Time- 10-20 minutes

Instructions

Place around 2 - 3 pellets of dry ice inside one of the blue gloves supplied with the hardware pack and tie a knot in the end.

If you use 2 -3 pieces of dry ice there is no danger of the hand balloon bursting – please be careful not to add more than this!

Meanwhile place a piece or two of dry ice in a saucer and leave on a table in open view.

Over about 10 minutes the glove will inflate into a rather horrible looking swollen hand! As the dry ice sublimes the glove gets larger, eventually all the dry ice will have disappeared, the students can judge this by shaking the glove the dry will rattle inside the glove.

After about 10 minutes the glove will be full of CO_2 gas and the dry ice will have disappeared. Meanwhile the ice left on the plate will have become smaller and will eventually disappear.

Class Discussion

What happened to the dry ice on the plate?

The dry ice disappears in the space of about 10 minutes. Where did it go? Matter cannot be made or destroyed (this is called The Law of Conservation of Mass), so it must have been converted into something we cannot see. Ask the students to consider what this might be. The dry ice converts to CO_2 gas without going through a liquid phase. Normal ice melts to a liquid. Dry ice misses out the liquid state and turns into a gas at atmospheric pressure. This is called **SUBLIMATION**. When a solid changes to a gas without passing through the liquid phase it **SUBLIMATES**. There is no liquid phase, and this is why it is called 'dry' ice!

More advanced classes might like to take up the challenge of measuring the volume of gas produced from a known weight of dry ice.

Why does the balloon get bigger?

The energy from the warm air in the room is making the dry ice sublime, and the volume difference between solid dry ice and CO2 gas is about x 840 fold, so the balloon gets bigger.

How can the inflation of the balloon be increased?

Dry ice will sublimate quite quickly at room temperature, where the difference in temperature is about 100°c (from -79°c to +20°c). If the temperature difference increases, for example by placing into a cup of hot water, then the dry ice sublimates at a faster rate. Even just breathing on a piece of dry ice will accelerate the process. To increase the speed of inflation place the balloon in a hot water bath or under a hot tap. An interesting way to inflate the balloon is to add some water with the dry ice in the glove, tie a knot and then place it in a microwave and heat in 10-second spurts. (Dry ice is transparent to microwaves – so you need the water to transfer energy to the dry ice).

Is the weight of the CO_2 gas in the glove different from the weight of the dry ice?

The conservation of mass is a law of science - the weight of the balloon plus the ice should be exactly the same as the weight of the balloon inflated with CO_2 gas. If you have very accurate scales it might be a quick experiment to carry out. If there is a difference in weight it is likely to be because the balloon material is gas-permeable!

Would this be a good method of measuring the molar gas volume of CO_2?

More advanced classes might like to take up the challenge of measuring the volume of gas produced from a known weight of dry ice. (See Measuring The Molar Volume of CO_2 experiment).

Using the volume of the balloon to determining molar volume will create errors as the pressure of the contained gas is above atmospheric pressure to balance the compression from the stretched balloon material. Also, the balloon material in this case is permeable to gases and so even as the hand is inflating it is loosing CO_2 through the skin. Ask the students to calculate the volume of gas that they would expect to be produced from a known weight of dry ice.

The Hovercraft

This is another way of showing the sublimation of dry ice and how a small film of gas reduces friction. A piece of dry ice can be shown to almost float across a bench top, the heat from the surface maintains a small gas cushion, just like a hovercraft. Please remind students not to pick the ice up and should the ice fall on the floor leave it there to sublime.

Time

5 minutes plus class discussion

What You'll Need

Piece of cloth, paper towel

Flat laboratory bench

Instructions

Using a piece of cloth or thick paper towel to protect your hands, rub a piece of dry ice against a flat table top for about 20 seconds; the pressure will cause the dry ice to form a flat side against the table. If you now push the flattened piece of ice it will slide along a smooth table top like a hovercraft.

If age appropriate you can ask students to flick the small piece of ice along the bench using a ruler or a book so that they can see how easily it moves.

Discussion Topics

Why does the ice move so easily?

CO_2 gas is subliming from the solid and so provides a small layer of gas between the table top and the dry ice so greatly reducing friction, like a hovercraft.

How could you make the hovercraft work better/worse?

Change the temperature of the surface, hotter will mean more sublimation and lower friction. Colder will mean the opposite. You could test this by chilling down part of the surface using some dry ice, and then launching the hovercraft at this patch. the cold section should act like brake.

Engineers and scientists are constantly working to reduce friction in machinery of all types to save on material and energy costs.

Consider devising a method to do this in a bigger way using pellets. We haven't managed this yet, but it would be impressive to show students how to slide a payload of books, for example, across a desk! We will credit any suggestions in our next booklet….!

The Safe Explosion

Everyone likes a pop and this is safe way of achieving this in a classroom.

What You'll Need

Ice Scoop — supplied in the science pack

Safety Glasses

Time

2 minutes

Instructions

Set this experiment on a table at the front of the class and ensure that everyone is at least 2 metres away. The demonstrator must wear eye protection. The canister used in the experiment is designed so that when the pressure reaches a certain point the top will pop off and travel about 1 - 2 metres vertically - it is safe to carry this out in a laboratory but please do not use any other container unless you know it will release pressure safely.

Place 3 - 5 dry ice pellets in the polycarbonate scoop supplied in the kit and immediately firmly push the red plug into the top of the glass. Step back a few metres and wait … As the dry ice sublimates the pressure from the gas builds up and the lid pops off. Part of the fun of this demonstration is the uncertainty on the timing, the looser the lid the quicker it will be released, the more firmly it is pushed on the longer it takes to pop and the more satisfying the result.

Once the red plug is in position you may find it easier to turn the assembly over and push down on the base of the scoop to fully insert.

Discussion Topics

Why did the plug 'blow up?'

The dry ice sublimated from a solid to a gas and the gas takes up slightly more than 850 times the volume of the solid, so the pressure rises eventually removing the lid. **If this experiment was performed using a screw-on bottle lid then the pressure would continue to rise until the bottle ruptures, which leads to a potentially dangerous explosion - please never do this.**

Crystal Growth

Science is often about careful observation and this simple experiment is an object lesson in patience! Areas covered include: Water crystal growth, humidity, concept of sublimation, observation of phase change.

Time - 20minutes

What You'll Need

Scales (accurate to 1 gram)

Safety Gloves (provided with the science pack)

Plastic Scoop/Cup (provided with kit) or similar Pyrex container

Magnifying Glass (magnifying app on a smart phone for tech wizards)

Instructions

If the students are old enough to understand that they must not pick up the ice, then each student or small groups of students can be given 2 - 3 pellets on a dish or dark card. The dark background will provide a contrast to enable the students to see the dry ice clearly. For younger students perform a class demonstration.

Using the gloves provided or a scoop weigh out around 5 grams of dry ice pellets from the storage box provided into a plastic or Pyrex glass container. (Make sure the lid is placed back on the dry ice box.) If you don't have scales then count out 3 - 4 pieces of 9mm dry ice pellets, this will be roughly 5 grams.

Instruct the students not to touch the ice but to observe what they see, tell them to be careful not to breathe on the dry ice pellets. After 1 minute they should be able to see a flaky layer starting to grow from the surface of the dry ice - ask them to consider what this might be (tiny water crystals). If available use a magnifying glass and they will see these crystals growing over the next few minutes, consider using a magnifying app on a smart phone to take some photos. After 10 minutes the dry ice will be covered in a layer of these beautiful crystals. Eventually the dry ice will completely sublime and then the water crystal will melt leaving a few drops of water. Here is a very nice video of this: http://goo.gl/ei8jGu

One of the most notable features of dry ice is that at atmospheric pressure it **SUBLIMES** from a solid to a gas without passing through the liquid state. At normal pressure most chemical compounds and elements possess all three states, each produced at a different temperature.

Class Discussion

Use microscope with screen viewer if available!

Usually the transition from the solid to the gaseous state requires an intermediate liquid state. When you heat molecules up they take up more space and move around faster. We use heating and cooling to change the states of matter.

For example; if we **MELT** a (solid) water ice cube it turns into liquid water and if we **EVAPORATE** the water it turns into a gas - water vapour. To reverse these effects, if we CONDENSE the water vapour it will turn back to water and if we **FREEZE** the water it will turn back to ice.

In a solid the molecules are tightly packed together and can hardly move. A solid keeps its own shape unless we cut it or shape it ourselves.

Generally anything you can take hold of is a solid. The molecules in a liquid are not so tightly packed, they can move a little - liquids are 'runny' and flow downwards. They take the shape of the container they are in.

The surface of a liquid stays level. Gas molecules have lots of energy and move around very quickly in a random fashion. Gases are all around us, spreading into any empty spaces, most gases are invisible like CO_2.

Where did the water come from to produce the water crystals?

Water is all about us in the air, it is measured as humidity, (mass of water per mass or volume of dry air.) A hot humid day will produce more moisture than a dry cold day as the humidity will be higher. When this air is cooled, for example by contact with dry ice, it reaches its 'dew point' and this is when the air releases moisture as condensation. When observing the surface of the dry ice we are seeing the air chill and release its moisture which almost immediately freezes into delicate cluster of ice crystals on the surface of the dry ice.

This phenomenon occurs in nature when it is sometimes called 'hoar frost'. The name 'hoar' comes from an Old English adjective for showing signs of old age, and is used in this context in reference to the frost that makes trees and bushes look like they have white hair!

Why is it called 'dry ice'?

To distinguish from 'water ice' or 'wet ice' ! When dry ice is packed in boxes of valuable items there is no liquid phase and so there is no residual liquid to risk spoiling the packed item. There is a very small amount of water condensed from the surrounding air but this is negligible.

Could the students see the CO_2 gas as it sublimed?

CO_2 gas is invisible as are most gases. Importantly the components of air (nitrogen, oxygen and small amounts of other gases) are invisible - which is just as well otherwise we would have a hard time seeing things! Visible gases are limited to the halogen family.

Can students think of other materials which sublime?

Water ice does! Items left in the freezer which are not wrapped tightly will look unpalatable, this is because the water crystals on the surface have started to sublime from ice to water vapour. This is sometimes referred to as 'freezer burn'. Freeze drying is a process which takes advantage of this phenomenon. Food and other items are quickly frozen and placed in a vacuum that encourages the sublimation of the ice crystals. With a majority of the water removed flowers, herb and many foods can be stored for years without deteriorating. You can buy freeze dried fruit in pouches, these can be re-hydrated into a smoothie and then used to make a fruit ice cream! – see 'Making Instant Ice Cream' chapter.

Chemists use sublimation to purify compounds: typically a solid is heated under vacuum, under this reduced pressure, the solid volatilises and condenses as a purified compound on a cooled surface, leaving a non-volatile residue of impurities behind. Once heating ceases and the vacuum is removed, the purified compound may be collected from the cooling surface.

Iodine also sublimes on gentle heating.

Dry ice will sublimate quickly at room temperature as measured in the experiment where the difference in temperature is nearly 100°c (from -79°c to +19°c).

If the experiment was conducted in a hot space the temperature difference increases and the rate of dry ice sublimation proceeds more quickly.

In this experiment we specified the use of a plastic or Pyrex container. Why is it necessary to use Pyrex glass or plastic as the container material?

Pyrex glass has a low thermal expansion coefficient and can therefore resist changes in temperature because it expands to a small extent when heated and shrinks to a small extent when cooled. Normal glass, also known as soda lime glass, does not like rapid changes in temperature and will crack easily and should never be used with dry ice.

Screaming Metal

This is a quick and dramatic demonstration which illustrates how sound is generated and provides a hint about loudspeaker design. It's also a little creepy… well certainly annoying.

What You'll Need

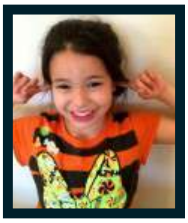
Large spoon (or preferably a large metal surface)

Hot Water

Tongs (or gardening gloves)

Time

2 minutes



Instructions

There are a number of ways of getting a screaming sound from dry ice. Place a couple of pieces of dry ice on a paper towel and place on the bench top. Press a spoon firmly against the ice, you will hear a high-pitched screeching sound. Better still, if you have a large metal surface hold a piece of dry ice in a pair of tongs and press against the metal surface for a few seconds. A baking tray works very well.

If you do not have tongs use thick gardening gloves to hold the dry ice, or as a last resort use several pieces of paper towel folded to provide insulation for your hand whilst you push the dry ice onto the metal surface. Please note that paper towels should not normally be used to handle dry ice however in this case you are only holding the dry ice for a few seconds to create the screaming noise so the paper towels will provide adequate insulation.

Class Discussion

What is making the noise?

Contact with the relatively hot metal is causing the dry ice to sublime. The escaping gas pushes against the metal causing it to vibrate like a loud speaker (in this case a horrible loud speaker!).

What happens when the spoon is placed in hot water and then put against the ice?

If you keep the spoon pressed against the ice the noise will diminish, why is this? (less sublimation as the spoon surface gets colder.

- Using a large metal object (with a large thermal mass) has the advantage that the screaming goes on for longer.

Why metal?

Metals are good conductors and so as the metal is chilled by the dry ice, more heat is being conducted to this cold spot so prolonging the sublimation. You can get the screaming effect with plastic but it is very short-lived, because plastics are not good conductors.

Making Fog 1

The class will love this!

Rate of sublimation is dependent on temperature. Why are clouds white?

What You'll Need

Safety gloves (provided with the science pack

Plastic Jug (provided in pack) or large pyrex container (200ml)

Time - 20 minutes

Instructions

Add a small quantity of dry ice (4-5 pieces of ice, around 10-15g) to the container and then add around 100ml of cold water (no more than 5°C). You will immediately see bubbles as the dry ice sublimates and the formation of a very faint cloud of mist at the surface of the liquid.

Challenge the students to explain what is happening and ask them to speculate on what would happen with warmer water.

Repeat this experiment using progressively warmer water; we suggest around 20°C and again at around 50°C. The last demonstration will produce a very impressive 'cotton wool' cloud. As the water gets hotter the students should observe that the amount of fog is increasing. You can repeat the last demonstration with around 50g of dry ice and 250ml of hot water (scale down a little if your container is smaller).

Ask the students to see if they can make coloured fog. For example by adding food colouring. If the teacher judges it safe, allow student volunteers to pour the fog from the jug.

Discussion Topics

What is happening here?

All liquids evaporate to some degree creating a vapour above the surface of the liquid and the hotter the liquid the more evaporation will occur. The pressure exerted by a vapour in equilibrium with the liquid phase of the same substance is called the Vapour Pressure. Consider a kettle of water – you can start to see vapour coming out of the spout as it heats up the water, the vapour pressure is increasing;

when the kettle boils the pressure of the water vapour is the same as atmospheric pressure.

When we add dry ice to water we start to interfere with this system.

The bubbles of CO_2 gas leaving the dry ice are very cold, (around -79°C). When the bubbles hit the surface of the liquid they are still very cold (even though they have been warmed up slightly in passing through the water) and start to chill the vapour and air immediately above the liquid surface.

Cold air cannot hold as much water as warm air and so some of the water vapour condenses into small water droplets that we see as fog. This creates an aerosol of tiny water droplets that scatter light and look like mist, which is what it is!

This now means that the vapour pressure of water has fallen and so the liquid immediately starts to evaporate more liquid to vapour to re-establish the correct vapour pressure. This in turn is condensed and so the cycle continues. In effect by putting dry ice into a glass of water we have created a pump that moves water in a liquid to water as tiny droplet in an aerosol – pretty cool!

The hotter the liquid the greater the formation rate of white mist. The white fog is caused only by the water droplets and not by CO_2 gas, which is invisible.

There is a second effect going on here and that is that as the CO_2 bubble hits the surface of the water it is increasing the surface area of the liquid by atomising the water and this is adding to the vapour and fog formation.

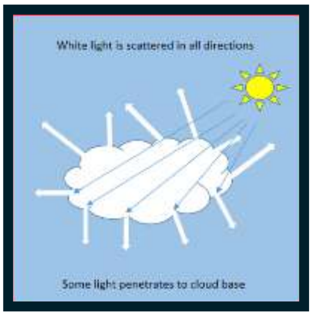
Can you make the fog different colours?

The white colour of the fog is due to the size of the water droplets not the colour of the liquid. It's always white (unless you shine coloured light at the fog).

If anyone can make a coloured fog please let us know and we will provide you with a place of honour on our website!

The white colour of the fog is due to the size of the water droplets not the colour of the liquid. It's always white (unless you shine coloured light at the fog). If anyone can make a coloured fog please let us know and we will provide you with a place of honour on our website!

This is why clouds are always white: a water droplet inside a cloud is large enough to scatter light of all colours (different wavelengths). In a cloud there are millions of water droplets some of which will have frozen and light from the sun will be scattered many times before passing through the cloud and scattered light of all wavelengths is white in colour.



Light travelling through very big clouds is so reduced that the clouds appear darker. A good clue that rain may be on the way!

How do you know that CO_2 gas is invisible?

Our breathe contains CO_2 gas and is invisible (but see next question). Also in the **Crystal Growth** experiment the students were asked to see if they could observe CO_2 gas leaving dry ice.

Most gases are invisible - ask the students if they can think of gases that can be seen, (this is limited to the halogens and their compounds: chlorine, bromine and iodine).

Would any gas cause the formation of the mist?

Only cold gases! Ask the students to think of an experiment to test this. One answer is to state what happens when they open a can or bottle of soda drink that has CO_2 gas dissolved into the liquid - they will see bubbles coming to the surface but no mist. This is because CO_2 gas in this case is not cold enough. On a cold day you can see your breath - this is because we breathe out warm humid air and this is chilled and condensed by the ambient cold air causing the formation of the water aerosol, which scatters light to provide a white mist.

Pouring CO_2 & Fire Extinguishers

This is a fun demonstration particularly if someone is celebrating a birthday and a cake and candle is available – put the candle out without blowing by pouring an invisible gas over the cake! This introduces the concept of combustion and fire extinguishers and also shows that CO_2 and water vapour are heavier than air.

What You'll Need

Safety gloves (provided with science pack

Plastic Jug (provided in pack) or large pyrex container (200ml)

Ice Cage (provided with science pack)

Polycarbonate scoop (provided in pack) or ceramic mug

Time

10-15 minutes

Try with birthday cake and candles

Instructions

Place 10 - 20g of dry ice in the jug and cover the top of the jug with a cloth or paper napkins. Prepare this before the class starts so that the dry ice has sublime completely and filled the jug to the brim. As CO_2 gas is invisible the jug will now appear empty. **Timing is important: if you prepare this too early the CO_2 gas will diffuse away, and if you leave it too late there will be residual dry ice pellets spoiling the illusion. Suggest prepping 10 minutes before the demonstration.** Pour the 'empty' jug over a lit candle and extinguish the candles. This is also a nice effect if it is someone's birthday and you have a cake available!

Repeat this demonstration this time adding a small quantity of dry ice to the jug and pour hot tap water over it, approximately in the ratio of 30g of dry ice to 200ml of water. You will immediately see white 'smoke' being produced. Hold the jug and tilt it a little being careful not to pour any liquid out. The white vapour is an aerosol of tiny water droplets being carried in a stream of CO_2 gas. Observe as the gas flows out of the jug and sinks to the floor.

For younger students you can fill the ice cage supplied in the science pack with dry ice and repeat the experiment. The Ice Cage retains the dry ice in a safe enclosure so that it will not escape. In this way you could give the students a 'fog shower' by pouring the fog over them as you go around the classroom – taking care not to tip out the water, (the ice cage will keep all the dry ice imprisoned and is an important safety feature, particularly in this case.) For younger students we have found that this is very popular.

Pour the CO_2 and moisture mix over the flame of a candle and watch it go out. The flame will be extinguished as the area is starved of oxygen.

Class Discussion

Why is the fog flowing downwards?

The fog is heavier than air. The fog consists of CO_2 gas (which we know is invisible) and water droplets. CO_2 gas is 50% heavier than air. (Molecular weight of air is 29; molecular weight of CO_2 is 44.)

Why did the candle go out?

Fuel needs oxygen to burn and a candle is no different. When the CO2 fog pours over the flame it pushes the air away and so starves the flame of oxygen and hence the flame is extinguished.

How do candles work?

You may wish to ask the students to think about how a candle works. Candles are amazing - lighting systems which carry their own fuel! The chemical energy contained in the wax is melted by the heat of the flame and this liquid fuel travels up the wick by capillary action until it reaches the flame where it burns locally heating more wax and so keeping the system going!

Fire Extinguishers

Ask students to carefully examine the fire extinguisher in the classroom. Some fire extinguishers release CO_2 gas which is heavier than air and therefore displaces oxygen at the base of a fire. CO_2 gas is also non-toxic and so does not present a new hazard to fire fighters. CO_2 gas is not always the correct choice for putting out fires, this is because CO_2 gas leaves a fire extinguisher at high velocity and whilst it starves flames of oxygen it can also push ignited materials such as paper and actually spread the fire! CO_2 is great for dealing with electrical fires as the oxygen is displaced quickly and the CO_2 gas dissipates without causing further damage to electric equipment. There is a special type of fire involving the metal where CO_2 would be a terrible choice for reasons discussed in the Magnesium and Dry Ice Volcano experiment.

You can identify which agent is stored in a fire extinguisher from the colour: (black) contain carbon dioxide and are used on flammable chemical or electrical fires. Other extinguishers contain water (red), cream (foam) or dry powder (blue).

Out of interest CO_2 is stored as a liquid in a fire extinguisher. How is this possible with all this talk of sublimation? It's all to do with pressure and can be explained by looking at the CO_2 phase diagram in the section 'Introducing Dry Ice and Carbon Dioxide' at the front of this booklet.

Spooky Scene — Big Fog Effects

This is the one you have to do - it creates a wow factor that students from 6 to 18 will love! Ideal for an assembly.

What You'll Need

10 Litre Plastic Container (with pack or similar large container

Polycarbonate scoop (provided in pack) or ceramic mug with handle is ideal

Mop and bucket

Supply of hot water (the temperature of a cup of tea 80°C)

Time

5-10 mins per demonstration

Students at Farnborough Hill

Safety: as with all experiments the supervisor will prepare appropriate safety procedures according to School guidelines. In this experiment it is important to ensure that no students put their hands into the bucket. The demonstration will produce CO_2 gas which in large concentrations is an asphyxiant. Good ventilation is a must, so windows and doors should be left open. A calculation on the safe release of CO_2 is provided in the discussion.

Instructions

We suggest that you use the demonstrations suggested in the Small Fog Effect section as a useful warm-up. There is plenty of dry ice in the box for practice purposes.

To make a **BIG** fog effect that will get people talking place a towel on a table top or elevated platform and use the 10 litre plastic container supplied with the Science Pack.

Place 500 grams of dry ice in the bucket, this is approximately two scoop-fulls from the polycarbonate scoop supplied in the Science Kit.

(HINT: bulk density of dry ice pellets is about 1, a small ½ pint ceramic coffee mug with handle makes an ideal dry ice scoop and holds about 250g).

Add 2 litres of boiled water from the kettle that has rested for 3 minutes; if you do not let the water cool down the fog generated will 'lift off' like a cloud. This is a **BIG** effect, and the temptation is to stop pouring! The fog effect will spread over 5 – 10 metres and placing it on an elevated surface hopefully everyone will be able to see the fog flow downwards on to the floor.

Class Discussion

Is this safe?

We know that the fog contains CO_2 gas and tiny water droplets - could this be dangerous? CO_2 gas is heavier than air and therefore displaces air at low levels. In a low level space without ventilation there would be a risk of suffocating (asphyxia) due to depleted oxygen, (please see the fire extinguisher experiment). In a classroom with plenty of ventilation and a small amount of CO_2 gas as specified in this activity this is not a problem. At theatres and venues which use dry ice for fog effects calculations are performed to confirm that the ice can be used safely. In certain situations CO_2 monitors are installed to warn people if the level becomes dangerously high.

You might want to ask older students to estimate the safety of using dry ice with this hazard in mind. Safe working limits are set for all kinds of chemicals provided by the Health and Safety Executive. Useful safety information for all chemicals can be found in their Material Safety Data Sheets. The data of interest is the exposure limits for CO_2 gas:

long term exposure limit = 9,150 mg/m3 (8 hours)
short term exposure limit = 27,400 mg/m3 (15 minutes)

Assume with reasonable ventilation that your classroom/laboratory has 10 air changes per hour, this is usual for a correctly ventilated work space. The concentration in the room should always be a small fraction of the short-term exposure limit.

1. Estimate classroom size: Vm3
2. The dry ice will sublime over a period of 5 minutes (ask students to check this timing as it will vary with water temperature).
3. Calculate concentration: = (dry ice used in mg)/((volume of room m3)x(air changes per hour).

For a classroom of 70m3 subliming 1kg of dry ice with 10 air changes the concentration is: 1,428mg/m3.

What does this mean?

If the CO_2 gas is immediately well mixed with the rest of the air in the classroom then it can be argued that the average concentration over 15 minutes is 1,428/3 = 476mg/m3. As the CO_2 gas takes time to mix with the air in the classroom the average figure will be between 476 and 1,428 for a 15-minute time period and as can be seen this is a small fraction of the safe exposure limit over this period of

27,400mg/m3. However take care: if the sublimation occurs within a small container and there is little mixing, because a lid is added for example, then the local concentration will be much higher. Also the concentration near the floor will be higher than near the ceiling.

How much CO_2 is being produced by people breathing in the room?

On average each of us breathes 1kg of CO_2 per day, so an assembly with 50 people for one hour will produce 2kg of CO_2 - more than the weight of dry ice used in the demonstration.

The Rocket

The world of rockets is fascinating, this simple experiment is a taster, if you get hooked there are many excellent online resources some of which are given in these notes. Our rockets are good fun to use and improve - they also make a pretty good water pistol. This experiment illustrates Newton's Third Law in action and the forces acting on a rocket. Students can observe and record measurements and analyse their results, then discuss how to improve the flight and test their hypotheses. There is enough dry ice to perform many dozens of launches.

What You'll Need

Rocket bottle, Jug Launcher, Funnel Loader, Dry Ice, water, safety glasses, deserted playground/field, tape measure (optional) and paper towels or similar.

Time

30 minutes

Please prepare your own safety procedure and hazard assessment. In particular you should only use the type of plastic bottle described in this section, they have a nozzle which will relieve at a safe pressure. Under no circumstances should a bottle with a conventional blanked off screw cap be used as this will lead to an explosion. If in doubt call us before proceeding and we will advise on this important safety point: 02034 329412.

Instructions

You can carry out this demonstration in a large sports hall or preferably in an outside playing area. The bottle rocket is propelled by a small amount of water being thrust out of the nozzle at pressure created by the sublimation of a small amount of dry ice to CO_2 gas.

The supervisor should wear safety glasses and lightweight gloves. All other spectators should stand behind the supervisor a distance of at least 4 metres.

Here is the general procedure, have everything in place - once dry ice is added to the bottle it is important to move quickly otherwise you will not create enough pressure in the rocket.

1. Ensure that you have a playing field or similar to yourselves. Ask the children to line up 3 – 4 metres behind you. On a flat surface fill the bottle with xx ml of cold water (about 1/5th full).
2. Wearing safety glasses and using the funnel put 5 good pieces of dry ice in the top of the bottle. You will see some fog starting to form.
3. Place the plastic bottle plug so that it rests on the top of the bottle and then place the jug over the bottle. As you push down on the jug you will push the plug into the bottle. Do this as firmly as you can.
5. Grasping the neck of the bottle turn the jug and bottle over whilst holding the jug by the handle. Do this so that the rocket is never pointing at anyone.
6. Holding the launcher jug by the handle aim the rocket at an angle of about 45 degrees into the field (and away from the children).
7. The rocket will fly off after about 20 - 60 seconds. The plug will be trapped in the launcher jug and can be re-used. Most of the water will be caught by the jug even though it is quite possible that the demonstrator may get a bit wet.
8. Measure how far the rocket went to determine who wins.
9. Consider experiments to investigate air resistance, e.g. would a nose cone make the rocket go further? Perhaps taping the red lid supplied in the Primary Science Kit

The pressure will build in the bottle as the hot water helps to sublime the dry ice. Eventually (after about a minute depending on water temperature, nozzle condition and quantity of dry ice added) the pressure will be large enough to open the pop valve from inside and immediately the compressed gas will expel the water through the nozzle. Most of the water expelled by the rocket bottle will be caught in the launcher, however a small amount could go anywhere so you will have a little drying up to perform.

The force of the water and gas leaving the bottle will have an equal and opposite force on the bottle which will cause it to move forward in the general direction that it is pointed. If you follow these directions the rocket will expel the water and will travel a short distance.

The time to launch is variable and will depend on the energy contained in the water (a combination of temperature and volume) and how much dry ice is added (more dry ice means a bigger sublimation surface).

Please Note: If you do not add enough hot water or dry ice the pressure may not be sufficient to open the valve. If the nozzle has not opened and bubbling in the bottle has stopped (after about 4 minutes) then the demonstrator, whilst wearing gloves and safety glasses, must firmly grasp the bottle and release pressure by twisting the cap, this is safe and is much the same as opening a bottle of soda which has been shaken. You may prefer to do this at the end of class. So secure using a bottle.

WARNING: If you add to much dry ice there is a risk that the water will freeze. This will prevent the nozzle from opening and may lead to the bottle exploding. For this reason please use only hot tap water and dry ice as shown in the table. As there is a chance that the rocket nozzle may get damaged, please only use once.

You can repeat this experiment and challenge the students to improve on the distance and flight of the rocket.

Most students will suggest altering the amount of dry ice and the amount of water. They could compile their result as follows:

Dry ice Weight	Length of all pellets (cm)	Angle from horizontal	Distance of rocket (m)
	3		
	5		
	10		

Class Discussion

What is happening?

The energy from the hot water is subliming the dry ice to CO_2 gas and so the CO_2 molecules are moving much more quickly. The gas takes up a much larger volume than the solid, so the pressure rises until it is sufficient to force the valve open. By placing the rocket with the nozzle at the bottom of the pitcher the water is forced out of the nozzle. The mass flow of the water leaving the bottle causes it to launch upwards, an example of Newton's Third Law in action. There are three forces acting on the rocket:

Gravity: the mass of the bottle and contents times the acceleration of gravity .

Thrust: expelled water and compressed CO_2 gas.

Drag: the force of air pushing back against the surfaces of the bottle.

Would more ice make the rocket go further?

You need the minimum ice necessary to generate enough pressure to defeat the valve. Any more is just going to add to the weight of the rocket in flight, examination of the nozzle shows that all dry ice is retained within the bottle - wasted payload as we rocket scientists call it!

Would making the water hotter help?

The temperature of the water speeds up time to launch, but will not make the bottle fly further.

How about adding more water?

The mass flow of water creates the thrust to get the rocket moving. Once the pressure inside the bottle has reached atmospheric pressure any remaining water will be a dead weight reducing the rocket flight.

Our suggestion is to optimise the distance travelled (our record is 10 metres!), but please tell us how you get on. It is surprising how little water is needed to get the rocket to fly.

What about the nozzle?

The stiffer the nozzle valve the larger the pressure in the rocket and the greater the action caused as the water and compressed gases exhaust. (Please do not try and make the nozzle harder to open by using glue etc., as this would lead to higher pressures in the bottle which would become unsafe.)

What about Angle of launch?

This will have a large effect on distance travelled: 45 to 60 degrees to the horizontal will yield the best results - just make sure that the nozzle is covered with water so that in the moment when the valve opens all the water is expelled. In our instructions we suggest holding the jug launcher however building a simple launch platform is a good idea as you can then get repeatable results.

The rocket is a plastic bottle – how can we make it fly better?

The plastic bottle is a lousy flyer and will be rather erratic, sometimes it will sail 10 metres other times it might not leave the launcher. Improvements to the aerodynamics would be gratefully received - we would love your ideas! Consider moving the centre of gravity towards the middle by using a nose cone. Also how about adding some tail fins to stabilise the flight but consider that this will require a different launch method. You might also want to experiment with curved tail fins so that the rocket rotates which might also increase flight stability. Another project to consider is to add wings to the bottle so that once launched it will glide....

How about a different design?

If the nozzle cap is replaced by a plug such as a wine cork then this provides some advantages.

The centre of gravity is moved along towards the front of the bottle which will help with flight stability. If you want to try this out we suggest a 2 litre soda bottle and a tight fitting cork.

When the cork is pushed out by the pressure all of the contents of the rocket will be expelled from the bottle including any residual dry ice, also, unlike the previous design, the weight of the plastic nozzle is removed.

If you decide to try this you will need to launch vertically and will need to do this outside. The demonstrator will need to prepare a new safety procedure and hazard assessment - **not included in these notes!**

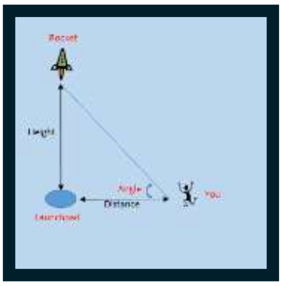
At this point you are in the wonderful world of water bottle rocket technology and a nose cone, fins and recovery system will not be far off! Please send us photo updates of your success.

How can you measure the height that a rocket will fly if launched vertically?

This is called the rocket's apogee.

You need to use trigonometry!

Stand a safe distance from the launch area (10 metres) and measure the angle that the rocket reaches at the top of its flight. The height will be:



Ask the students to consider the effect of wind on this measurement.

There are many resources online for looking at water rockets, here a couple of really good ones [1234]

1 http://goo.gl/qal8Fn
2 http://goo.gl/YnYe5v
3 http://goo.gl/Bepjb6
4 http://goo.gl/KzjFiL

Your photo here! Please send in photos and your experience with the rocket, we will post on our website.

Make A Comet

Comets come in all shapes and sizes; they are often referred to as "dirty snowballs" as first described by the renowned US astronomer Fred Whipple. At their core is a nucleus composed of a mixture of rock, dust, water ice, and frozen gases such as carbon dioxide, carbon monoxide, methane, and ammonia.

The dry ice pack provides an opportunity to make a comet – a working model with gas jets just like those in space!

What You'll Need

1 litre of water (comets have lots of water)

2 cups of soil (minerals and dust)

Safety Glasses

Thick gloves for holding comet (heavy duty gardening gloves not the lightweight gloves provided with the kit)

Plastic bag

Large food mixing bowl

Polycarbonate Scoop (from the chilly science pack)

Dry Ice 400g-600g (2-3 scoops)

Time

20 minutes

Instructions

Place the plastic bag in the mixing bowl and add the water and soil. Mix thoroughly to create a muddy slurry. Add the dry ice to the bag using the scoop provided with the Chilly Science Pack. Add the ice slowly so that you do not get large amounts of smoke and gas leaving the bag. Wearing thick gloves continue to mix the contents of the bag and slowly add more dry. After a short time the contents will start to freeze. Open the plastic bag and tip the solid mass into the mixing bowl. This is what a comet looks like! There will be dry ice and water ice bonding the other ingredients together. You may wish to pour some water over the comet so that you see jets of smoke and gas leaving the comet.

When finished leave the comet in the bowl and allow the dry ice to sublime. You will eventually have a muddy slurry to dispose of - pour this back where you got the soil from.

Class Discussion

How big are comets?

Comets come in all sizes, usually they are bigger than the one you made, typically they are the size of a city! They fly through our solar system all the time.

How realistic is our comet?

photos courtesy Sam Dimbylow, Yateley School, Hampshire

Comets come in all shapes, sizes, some of them are darker, some of them are lighter, producing more gas, shooting out jets from different locations, in this sense the comet made is an accurate model. Comets also have traces of other materials such as organics, amino acids and methanol. We did not add them to the comet made in the classroom as we need to dispose of the model once it has melted and this is best done by returning the soil to its source without contaminating it.

How are comets formed?

Comets are left over from the formation of stars and planets billions of years ago. Particles of dust and ice agglomerate slowly and over millions of years get bigger and bigger. When the gravitational attraction from a large passing body, like a star, becomes strong enough, some large pieces of ice get pulled away from the cloud and towards the Sun.

As the ice and dust ball approaches the Sun it begins to melt, the melted ice becomes a gaseous tail that extends away from the source of the heat pushed out by the Sun's solar wind.

A comet's motion and path is dictated by the forces of gravity acting on it from all the planets and stars it passes. When a comet is in our solar system, most of the gravity affecting the comet's motion is due to the Sun. As a comet gets closer to the Sun it moves faster and faster, because the closer an object is to the Sun the stronger the Sun's gravity acts on it. As well as moving faster near the Sun, the comet's tail will grow in length since more of the ice will be evaporating.

Bubble Monsters

What You'll Need

Safety Gloves (provided in the pack. Suitable for picking up a few pieces of dry ice for a few seconds)

10Lt Plastic Container (provided in the pack)

Scales (accurate to 1 gm (optional))

Polycarbonate Scoop (from the chilly science pack)

Bubble Solutiion (provided in the pack). Or make your own by mixing 70ml washing up liquid, 70ml glycerol (or glycerine) and 1Lt of hot tap water

Here are a couple of fun demonstrations: use the gas produced from the dry ice to generate a lot of foam consisting of bubbles and then make one mega bubble. Warning: this is a bit messy so please carry out on an easy-to-clean surface!

Time

20 minutes

Instructions

Carry this demonstration out in an area where it is easy to clean up spills. Younger students love to pop the bubbles made so consider access for the class.

Add ½ scoop of dry ice, (around 100g) to every 1 litre of hot tap water in the 10 litre container. You will immediately see bubbles as the dry ice sublimates and the formation of a white cloud. Immediately add a glug of bubble solution.

The fog will be replaced after a moment or two with a continuous tube of bubble foam which will quickly overflow the container – this always gets a good reaction!

Invite students to pop some of the bubbles and release the white water vapour/CO_2 fog.

Class discussion

What's happening here?

As the dry ice sublimates in the soapy liquid, the gas becomes trapped in the bubbles and is released when it's popped.

Why do bubbles form?

This happens when there is a balance between two competing forces: the force exerted on the inside wall of the bubble and the liquid surface tension which is trying to squeeze the bubble.

Instructions

Soak the strip of cloth in the bowl of detergent and then run it around the edge of bowl so that there is some bubble solution wetting the entire rim - be careful not to drop any bubble solution into the bowl. Timing is essential with this demonstration, so when everything is ready add a full cup of dry ice (about 200g) to the bucket and immediately add about 1 litre of warm/hot tap water. Do not add very hot water as the fog creation will be too large and it will be hard to create the mega bubble.

To make a mega bubble you will need:

- **White Bucket** (which contains the hardware science pack)
- **Strip Of Cloth** (approx. 30 cm in length)
- **Small Bowl** (or saucer)
- **Bubble Solution**
- **Polycarbonate plastic cup** (supplied with science pack)

Immediately drag the taught cloth over the top of the bucket making a film of detergent.

This takes a number of goes to get right and we find it easier using glycerol bubble solution, rather than just washing-up liquid. If you have problems getting the bubble film to form make sure you are pressing down firmly with the cloth as you sweep over the top of the bucket. As the dry ice continues to sublimate, the bubble film fills and grows, often it bursts at which point the contained water vapour/ CO_2 fog spills out and down onto the table top.

Here's how it should look, note the bubble mixture cloth we used:

Class discussion

What do the components in the bubble solution do?

The washing-up liquid reduces the surface tension of the bubble by about 1/3 and so allows the bubble to expand. The glycerol reduces water evaporation from the bubble surface and so helps prevent the mega bubble from popping too soon.

When the mega bubble burst why did the contents fall downwards?

The fog contained in the mega bubble is water vapour and CO_2 gas, which are heavier than air.

Climb The pH Scale

What You'll Need

- **Universal Indicator**
- **Alkali** (eg Sodium Hydroxide)
- **Small Bowl** (or saucer)
- **Suitable Glass Flask**

Time

15-20 minutes

Instructions

Half fill the container with hot water and add a few drops of universal indicator. The water will turn green indicating that it is neutral. Add a small amount of sodium hydroxide to the liquid and observe a colour change from green to blue/purple. Add a few pieces of dry ice and watch it bubbling away and changing the colour - you should observe it going back up the pH scale past green to red indicating that it is acidic.

Class discussion

What's happening?

Universal indicator changes colour on contact with acids or alkalis and is a gauge of a liquids pH. (A measure of the concentration of hydrogen). Sodium hydroxide is a strong alkali and so the colour changes to blue/purple as the pH of the liquid rises. Carbon dioxide dissolves slightly in water forming carbonic acid and this will eventually result in a colour change from alkali through neutral to acidic:

$CO_2 + H_2O \rightleftharpoons H_2CO_3$

What does this tell you about your favourite soda drink?

Why is this important?

CO2 is a major source of ocean acidification, scientists estimate that 30–40% of the carbon dioxide released by human activity dissolves into the oceans, rivers and lakes thereby reducing pH levels. This is thought to have negative effects on sea creatures and coral growth.

Smoking Vortex Rings

This demonstration illustrates the phenomenon of the toroidal or vortex ring, which is formed quite widely in nature but is normally not visible. Students will have seen people blowing smoke rings from cigars in films. You don't need to smoke to get this effect, you just need some dry ice!

What You'll Need

- **Vortex Ring Generator** (provided in the Science Pack)
- **Cardboard Box** the dry ice was delivered in (optional)
- **Safety Gloves** (provided in the pack)
- **Polycarbonate Scoop** (provided in the pack)
- **Warm Tap Water**
- **Candle** (optional)
- **Matches** (optional)

Time

20 minutes

Instructions

For this you will need to use the vortex ring generators supplied in the Chilly Science Pack.

There are five units in the pack each four of them have one hole and one has two holes. Take one of the single-hole generators and clip the lid on. When the plastic side of the container is compressed a stable vortex toroidal structure of air leaves the exhaust port. You can blow out a candle out on a table and by placing the hole near to a volunteer's face they will feel a slight breeze when the side of the generator is quickly squeezed. It is a truly dull demonstration!

We can use dry ice to visualise what is happening. Peel the cap off the generator and add around 100ml of warm/hot tap water. Replace the lid and wearing the gloves supplied drop 3 - 5 pieces of dry ice through the hole in the lid. Smoke consisting of water droplets and CO_2 gas will start to pump out of the exhaust hole of the generator. You will notice that the hole is off-centre and the reason for this is to create a weir inside the generator where the smoke an accumulate. Hold the generator on its side with the hole nearest to the top and squeeze the sides of the generator; as you repeat this you will start to see smoke rings (donuts) appearing. It is interesting to observe how the smoke ring develops – its gets bigger in diameter and moves more slowly as it gradually reaches the floor. In the Chilly Science lab we have a dingy tea-room and the diffuse lighting on offer is perfect for observing these smoke rings.

If age-appropriate you can pass the generators around the class. Students may wish to experiment to see the best way of observing these rings. Firing them vertically upwards may work if the student is in the right position.

You may wish to experiment with some black card or a cardboard box for optimum viewing.

One interesting exercise is to make two vortex rings collide, if you do this you will see that they combine to form a bigger ring! One of the generators has two holes punched in it, and the idea is that it will produce two identical rings simultaneously traveling along the same path, if the students are patient they will see the rings coalescing.

You can also make a larger device....! A cardboard box works very well and one was supplied with the dry ice box. Locate the centre of one long side of the box and cut a hole of around 9cm in the middle, position the box on a table with the hole pointing upwards. Tape up all the gaps around the box. Fill the scoop supplied in the Science Kit with dry ice to a height of around 3cm and then half-fill the beaker with hot tap water and slide into the box through the hole. As the box fills with fog you will start to see it coming out of the hole. You can pulse the side of the cardboard box and this will send larger vortex rings up to the ceiling. For best effect you must let the box refill between pulses, typically 5 - 10 seconds.

You will have to cut the tape to get the scoop back!

Class discussion

Nature loves vortex rings, most of the time we cannot see them but they are formed from interactions between fluids and an opening/orifice. They can be formed in the same fluid as in the class demonstration; they can also be formed with different fluids such as air in water. Some of the best examples can be seen online: try searching for dolphins/whales and vortex rings. You will see a dolphin breaking up a large ring into smaller rings – the reverse of what we did with the two-hole vortex generator. Volcanoes emit vortex rings consisting of particles of ash. You may occasionally see smokers making smoke rings – to do this they must shape their mouth (the orifice) and exhale quickly to create the desired effect, which probably takes years of practice - crazy habit!

Is this like a normal wave?

Unlike a sea wave, or sound wave whose motion is only apparent, a moving vortex ring actually carries the spinning fluid along. We know this because we can see the dry ice smoke moving in the air with our experiment.

Why does the ring stop?

The mist generated by the dry ice will evaporate and disappear, but the vortex ring also breaks down as friction between air molecules in the ring slows the structure. The temperature and humidity of the room will also effect the duration of the ring.

Ask the students to consider effect of size of orifice on smoke rings generated. You may wish to ask them to carry out an experiment where they gradually increase the size of the hole in the cardboard box from 5 to 15 cm - please let us know what they find out. If you have access to a workshop you may also wish to alter the size of the holes in the vortex generators.

Why does the ring stop?

The mist generated by the dry ice will evaporate and disappear, but the vortex ring also breaks down as friction between air molecules in the ring slows the structure. The temperature and humidity of the room will also effect the duration of the ring.

Ask the students to consider effect of size of orifice on smoke rings generated. You may wish to ask them to carry out an experiment where they gradually increase the size of the hole in the cardboard box from 5 to 15 cm - please let us know what they find out.

Freezing Solution

This experiment is a means of observing the effect of cold temperatures on a range of everyday items. A freezing solution is made for this purpose by adding dry ice to a pure alcohol. This is strictly a project for older students and the supervisor should have control of the freezing solution at all times. There will be some residual alcohol on items dipped into the freezing solution and so under no circumstances should food/ fruit items be consumed after dipping. Care must be taken to ensure that the freezing solution does not come into contact with skin, as it would result in a cryogenic burn.

When the experiment is finished leave the alcohol uncovered in a safe place overnight until all the dry ice has sublimed and the alcohol has returned to room temperature. At this point it can be poured back into the bottle for re-use. Please do not add dry ice into the alcohol bottle.

What You'll Need

Large Pyrex beaker preferably 500 to 1000ml, or large steel vacuum insulated container.

Pure alcohol with a freezing point below -79C (e.g. isopropyl alcohol freezing point -89°C) **Poison not for consumption.**

Dry ice scoop (ceramic mug with handle, plastic, Pyrex)

Eye protection

A small hammer

Protective gloves (thick leather gardening gloves are fine, not the ones provided with the kit which are intended for handling one or two pellets.)

Metal tongues for handling cold objects.

Various items for dipping, (e.g. piece of lettuce, flowers, slices of fruit, marshmallows, rubber balls, red, orange LEDs)

Paper/absorbent towels

Some balloons

Time 30-40 minutes

Instructions

Use high purity alcohol, if it is diluted with water the freezing point rises and the dry ice makes a sludge.

Place the Pyrex beaker in an aluminum foil baking tray or similar in a fume cupboard or other well-ventilated area. The tray will retain liquid in the event of a spill or breakage. Pour around 200ml of the alcohol into the beaker. Using a scoop carefully add small amounts of dry ice two to three pieces at a time.

The amount of dry ice and alcohol to add will depend on the size of the beaker, the aim is to half-fill the vessel with the freezing solution.

There will be bubbling as CO_2 gas sublimes from its solid state and this may lead to some foaming as the alcohol gets colder. If you have not used pure alcohol the mixture will become thicker taking on the appearance of a gel - pure alcohol will remain in a liquid state.

Continue to slowly and carefully add pieces of dry ice to the alcohol. When the bubbling subsides you will have dry ice floating in very cold alcohol and if the dry ice and alcohol are in thermal equilibrium then the alcohol will be at -79°C.

Whilst the freezing solution is cooling a simple demonstration can be performed to demonstrate the 'Liedenfrost effect'. We suggest this should only be shown to older students as the object here is a discussion on safety and younger students may mistakenly get the impression that it is safe to pick up very cold or hot objects.

Having explained that dry ice is very cold and gloves should always be worn it is in fact completely safe to hold one small dry ice pellet in your hand for up to 5 seconds. The reason for this is that the warmth from the hand sublimes a small amount of dry ice creating a thin layer of CO_2 gas between your skin and the dry ice. Gas is a poor conductor of heat and so this thin layer insulates your hand from the cold dry ice for a short period of time. This is an example of the Liedenfrost effect.

Another example of the Liedenfrost effect that many will have seen is when a frying pan is heated until very hot, at which point when a few drops of water are added they bead and bounce around on the hot surface. The water is cushioned by a layer of steam which is why it moves around easily, the steam insulates the remainder of the droplet and so it takes longer to evaporate these droplets than would be the case if the pan was not so hot!

The reason for performing this demonstration at this point is to contrast dry ice pellets with the freezing solution; the 'heat transfer' to the freezing solution is greater than to the dry ice as there is no insulating gas barrier, for this reason the freezing solution is much more dangerous than the dry ice pellets even though both are at the same temperature.

The Experiment

To start with, partly inflate a balloon and tie it off. Dipping the balloon into the freezing solution will make the balloon shrink. When the balloon is returned to room temperature it recovers its original size.

Select a fresh flower or green leaf and using tongues carefully dip the leaf into the liquid and keep it there for about 20 seconds. Astonishingly the flowers or leaves can be shattered, broken and snapped apart.

Repeat this with a range of materials, such as pieces of lettuce and slices of fruit. After a period most of these items will become brittle tapping them on a hard surface will cause them to break. If you decide to use a larger item, such as a banana, then you immersion will have to be for several minutes.

If the students are nearby put the banana skin in a transparent plastic bag to prevent shards of frozen skin from hitting anyone.

Using tongs place a bouncy ball, squash ball or piece of rubber into the freezing solution for about 3 - 5 minutes. remove and dry off on the paper towels and then see what happens when you try and bounce the ball.

It is possible it will brittle enough to snap, it will certainly behave in a different way.

Using tongs dip an illuminated LED into the freezing solution and ask the students to observe what they see, this works best with the Pyrex beaker! (The LED will get brighter and the light emitted will move to a higher energy level from red through orange to green.)

Discussion Topics

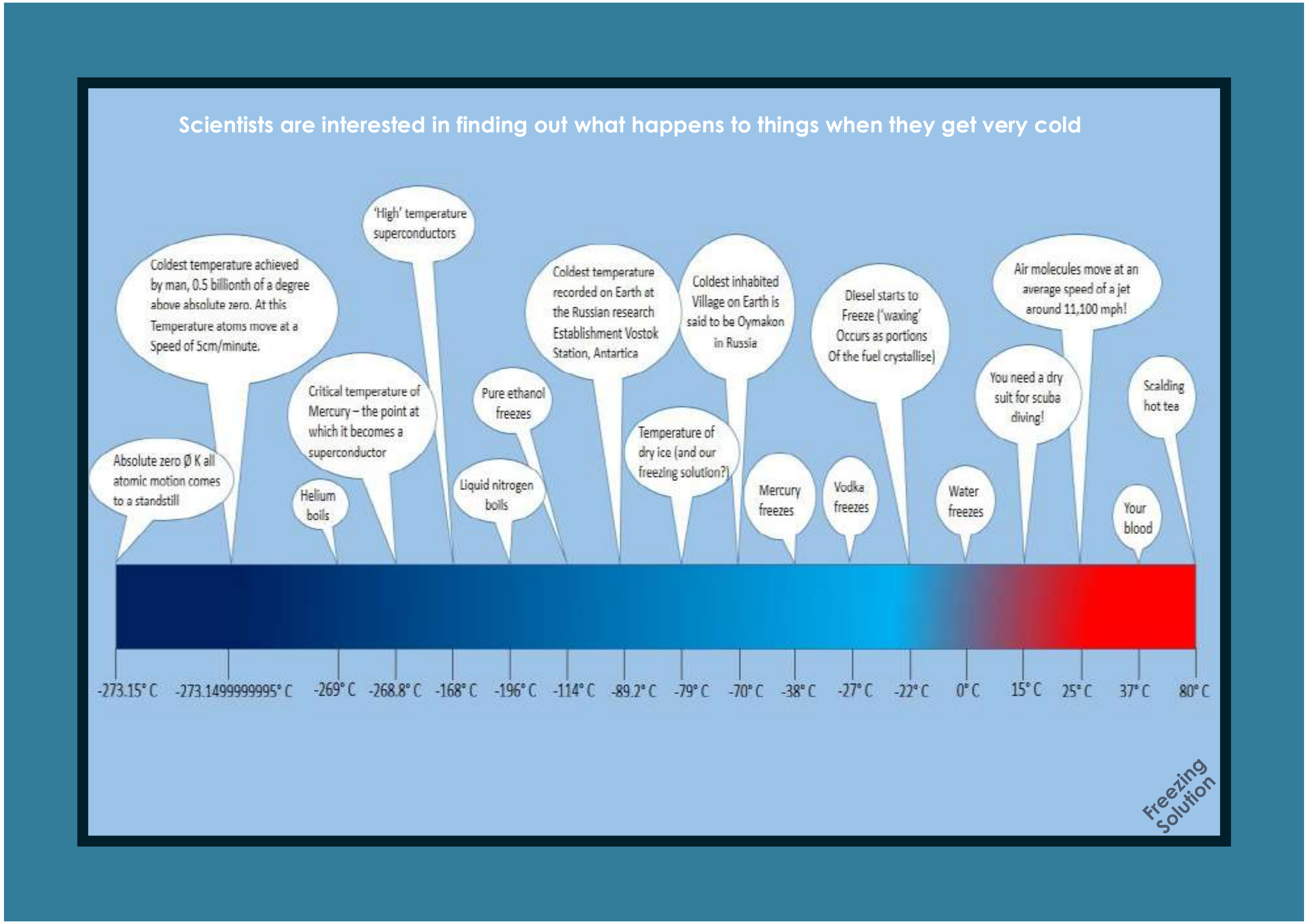
In this experiment the alcohol was in thermal equilibrium with dry ice and so the alcohol was at a temperature of -79° C. The temperature inside a domestic freezer is around -18°C. In industry the process of freezing very quickly is often referred to as flash freezing, and is used to stabilise all kinds of goods including foods and biological samples. The technique was developed by Clarence Birdseye in the US - no prizes for guessing his interest!

The main reason this technique is used in food and medicine is that water contained within the sample is frozen vey quickly and prevents the formation of large water crystals. If a sample was frozen slowly then the water in a sample would lead to the growth of larger ice crystals which will damage cell membranes. This is the reason why ice cream made with dry ice tastes so good – water crystals in the ice cream are much smaller than those made from industrial machines and so this tastes smoother and creamier in the mouth!

Other methods for rapidly chilling products include air blast freezing with a vacuum and liquid nitrogen; the objective in these cases is the same – to prevent formation of large water crystals.

Why did the balloon shrink?

When the air in the balloon gets colder the molecules in the air slow down so they exert less pressure inside of the balloon. Since there's less pressure inside the balloon it shrinks until it reaches a new equilibrium with the outside pressure.


Scientists are interested in finding out what happens to things when they get very cold
Absolute zero Ø K all atomic motion comes to a standstill
Coldest temperature achieved by man, 0.5 billionth of a degree above absolute zero. At this Temperature atoms move at a Speed of 5cm/minute.
Helium boils
Critical temperature of Mercury – the point at which it becomes a superconductor
'High' temperature superconductors
Liquid nitrogen boils
Pure ethanol freezes
Coldest temperature recorded on Earth at the Russian research Establishment Vostok Station, Antartica
Temperature of dry ice (and our freezing solution?)
Coldest inhabited Village on Earth is said to be Oymakon in Russia
Mercury freezes
Vodka freezes
Diesel starts to Freeze ('waxing' Occurs as portions Of the fuel crystallise)
Water freezes
You need a dry suit for scuba diving!
Air molecules move at an average speed of a jet around 11,100 mph!
Your blood
Scalding hot tea
-273.15° C
-273.1499999995° C
-269° C
-268.8° C
-168° C
-196° C
-114° C
-89.2° C
-79° C
-70° C
-38° C
-27° C
-22° C
0° C
15° C
25° C
37° C
80° C
Freezing Solution

Why did the flowers/lettuce/fruit slices freeze?

Ask the students why the flowers and other items froze. Flowers, fruit etc. contain a lot of water, and we know water freezes into ice at around 0°C.

What happened to the rubber ball?

There is no water in the rubber so why did it change properties when it got colder? The rubber acts very differently when it gets cold. The molecules in the rubber don't want to move when they're cold; they want to stay close together, it is very hard to bend the rubber when it is cold.

Why did the LED change colour?

As the temperature drops electrical conductivity increases and so more current passes to the LED which makes the light brighter. Also as temperature falls the emitted wavelength gets smaller and so there is a shift in colour towards the violet end of the spectrum.

Other questions for students:

- Why use an alcohol, why not just put items into the dry ice?
- Why use pure alcohol? See temperature at which vodka freezes.
- What is the temperature of the alcohol once the bubbling has subsided?

The Cloud Chamber

A Cloud Chamber is a device used to detect ionizing particles and to determine their trajectories; it does not show the particles themselves, but where they have been. Dry ice is an essential element in the functioning of a cloud chamber.

A cloud chamber is a sealed chamber that is cooled so that super-saturation of alcohol or water vapour will occur within it. This means that when an ionizing particle travels condensation will occur about the nucleus of the ions it produces - these are called condensation nuclei, as the vapour in the chamber is on the verge of condensing, much in the same way that water vapour condenses around dust particles in the atmosphere to form clouds. This condensation trail leaves a fine mist that we can see which tells us where the particle was/originated from and the path it has taken from then.

A difference in temperature between the top (heater) and the bottom (dry ice) of a sealed container full of alcohol produces a supersaturated environment necessary for the mist (or cloud) to be formed.

Dr. Cristina Lazzeroni from the University of Birmingham runs a cloud chamber loan scheme and organizes demonstrations. For more information please go here:

http://goo.gl/RFGqWK

Cloud Chamber

The Institute of Physics has been promoting cloud chambers in schools through its Teacher Network. They can also help with demonstrations through their CPD programme. This paper shows how to construct a cloud chamber and includes a very useful video: http://goo.gl/sThDfk. Further refererence:- http:www.nuffieldfoundation.org/practical-physics/diffusion-cloud-chamber

Fizzy Fruit

What You'll Need

- Pressure Cooker
- Paper Towels
- Grapes and other fruit
- Small cup of water
- Garden Gloves
- Polycarbonate Scoop (supplied with Pack)

This experiment is intended to show that pressure is necessary to make liquids fizzy. For this you will need an ancient piece of scientific equipment – a pressure cooker!

A safe way of achieving a moderate pressure - it is possible that there is one in the kitchens...

Time Preparation time 5 mins
Cooking time 1-2 hrs

Instructions

As this experiment takes some time we suggest that it is prepped at least an hour before the class starts.

Open the pressure cooker and place a plastic or Pyrex saucer filled with about 200 grams of dry ice (equivalent to filling the cup provided in the education kit). The reason for the saucer is to prevent the base of the cooker from getting too cold. Above the filled saucer place a piece of polystyrene sheet or cardboard. The purpose of this layer is to prevent fruit and other items from touching the dry ice and freezing. On top of the polystyrene place plastic containers holding washed fruit, and a cup with water and preferably a fruit cordial dissolved into it.

Assemble the pressure cooker using the heaviest weight and leave to one side for at least 60 minutes. Whilst waiting you may wish to carry out the smoking drink experiments as this emphasises the need for pressure in creating fizzy drinks.

After at least one hour open the pressure cooker and remove the items. Be careful not to touch the exterior of the pressure cooker as this will be very cold from the dry ice and you may see frost on the outside at the base - use garden gloves if you need to touch the outside of the pressure cooker.

Invite volunteers to drink the liquid to see if it is fizzy. The water in the fruit (grapes are best) will also have absorbed some CO_2 gas, and this will provide some entertaining diversion as fizzy fruit is rather unusual. If you have time consider experimenting with other fruit – P.S. Fizzy bananas are horrible!

Class Discussion

How does the pressure cooker work?

It increases the temperature at which water boils and so speeds up cooking times.

Could you do this experiment in a sealed container?

No! The pressure cooker has been designed to safely handle moderate pressures, please do not use any other container to maintain a pressure as this could lead to an explosive situation as pressure builds due to dry ice sublimation.

Why is the fruit fizzy?

This is due to absorption of CO_2 gas into water; this uptake is enhanced by lower temperatures and higher pressures.

Fruit Cloud & Smoking Drinks

This demonstration allows you to offer a smoking drink to deserving students of all ages.

What You'll Need

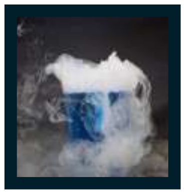
- **Ice Cage** (provided with pack)
- **Cordial** (we like blackcurrant!)
- **Pitcher** provided with pack (please ensure it has been thoroughly washed)
- **Cups** for each student
- **Large Black Bucket** (provided with science pack)
- **Chillisticks** (provided with pack)
- **Hot Water**

Instructions

Put some cordial into the washed clean jug provided with the Chillistick pack. Once prepared ask the students if they can smell the drink – how near do they need to get to smell the drink?

Time 10-15 minutes

Load the ice cage as follows:



The Ice Cage is made from very strong polycarbonate. It has our safety valve system so that you can add dry ice to the cage and then put the cage into any drinking vessel or container you wish. The liquid will contact the dry ice within the cage giving a great smoke effect. The ice will not fall out as it is trapped so that this device can be used for pitchers/jugs of all types. See the photos above.

Before Use

- Wash the Ice Cage – it is dishwasher safe, drain and dry thoroughly.
- Please note that the Ice Cage has a flexible valve at one end, this valve is used to load dry ice into the Ice Cage, once loaded the dry ice can only leave by evaporation.
- A loading tube is supplied as part of the kit, see photo above.

Using the Ice Cage

- The Ice cage is filled by pushing the loading tube through the safety valve, see middle photo above.
- Wearing the gloves provided. Open the box of ice and scoop ice into the cage via the loading tube.
- When the Ice Cage is half full remove the loading tube and the ice cage is ready.

Drop the filled ice cage in to the filled pitcher, you will see the characteristic white fog develop. Your students should also be able to smell the drink as the aroma is being spread by the fog.

The dry ice is food grade and provided everything is clean there is no reason why the students shouldn't be allowed a drink.

When pouring from the pitcher some fog will carry over into the glass. No dry ice will go into the glass as this is being contained with the ice cage.

For a more spectacular effect (perhaps an assembly) you could create a fruit cloud…. Fill the large white plastic bucket half-full with very hot tap water, or water which has boiled and been allowed to rest for 3 minutes and place somewhere prominent. Add to this about 1/3rd of a bottle of squash. Using the polycarbonate cup provided in the pack fill in the ratio of one full cup (about 200g) to one litre of hot water. The hotter the water the better the cloud effect, but please do not use boiling water.

The fruit aroma should be very apparent! Note: this is not intended for drinking.

Also included in the education pack are 5 chillisticks. They have been included to show a solution to a problem and not to be used for serving cocktails! It is not safe to put a piece of dry ice in a drink as there is a chance that it might be swallowed, so how do you make it safe? The chillistick is hollow and is designed to trap some dry ice behind a flexible plastic valve. This loaded chillistick can be put in individual drinks and provide a safe fun effect at a wide range of social occasions. The only way the dry ice can leave the chillistick is by subliming to CO_2 gas!

Class discussion

CO_2 gas is dissolved into all carbonated fizzy drinks and dry ice is CO_2 in its solid form so if we drink a lot of soda we burp!!

Why is the smell of the flavoured liquid so apparent?

It is all about surface area. The diameter of the liquid droplets in the fog are about 20 microns (20 x10^{-6}m). We estimate that the volume of atomized liquid in the fog is 2ml. From this we can estimate the surface area of the fog and see how it compares with the static liquid surface in the original container.

Assuming a container with a diameter of 10cm we estimate that the cloud has a surface area over 300 times bigger than the original surface area. Some of the liquid in these tiny spheres will evaporate and some of these tiny droplets are bound to find their way up your nose! Some students might like to take this calculation on…..

Is the drink fizzy?

Probably not. If you leave dry ice in a small quantity of liquid for an extended time it will become slightly carbonated. For CO_2 gas to dissolve into a liquid you need low temperatures and high pressure, this is how fizzy drinks are made. We are adding dry ice to liquid at atmospheric pressure, so we only have low temperatures to help, and this is why you will only detect a small amount of fizziness when the liquid is very cold. But see the fizzy fruit experiment!

What happens if we put this in a fizzy drink?

Would you believe it – the drink will go flat! This is because the bubbles from the dry ice pull CO_2 which has been absorbed in the soda out of solution.

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Making Sorbet

The most delicious demonstration we have! This works well as an end-of-term treat or perhaps for an open day/sports day crowd-pleaser. Hopefully most of the class can enjoy this non-dairy treat, but please check for fruit/food allergies.

Mrs Zoe Edwards of Wycombe Abbey School made ice-cream for a school event using pre-mixed Smoothies and dry ice:

'it went brilliantly! We had run out of 40 litres of smoothie an hour into our 2 hour time slot - it was so successful that we had a queue forming 10 minutes before we opened the first carton! The dry ice was perfect. I am hoping to do the same activity next year as it is such a winner.'

What You'll Need

- 750ml Smoothie
- 100g Sugar
- 250g Dry Ice
- **Food Processor** (with blade fitting to break up dry ice pellets)
- **Spoons & Bowls** (disposable)
- **Gelatin** (1 pack unflavoured)

Sufficient recipe for a class of 30 students to each have a taste, scale up in proportion for larger quantities.

Photo Courtesy of The Greyhouse School, Hampshire

Time 10-15 minutes

Here's the science:

When the ice cream mixture is chilled water ice crystals start to form and this continues through the chilling process. When an ice crystal is formed it attracts surrounding moisture to it and therefore grows in size. The objective is to create lots of small ice crystals so that the resultant ice cream feels smooth and creamy in your mouth, rather than fewer larger water ice crystals that will feel gritty and sharp in the mouth. For this reason it is necessary to chill down the contents as quickly and evenly as possible. We do not want to risk anyone putting dry ice in their mouths so it is important to wait at least one hour before consuming. The sorbet must therefore be stored in a freezer, however if you do this it will turn rock hard and be horrible. This is where gelatin comes in. The collagen in the gelatin softens the mixture allowing the sorbet to be spoon cut from the freezer. Food grade dry ice for chilling down is a good choice as it is very cold and can be mixed into the bulk of the mixture. Dry ice works best with fruit flavoured ices and sorbets, this is because any residual CO_2 absorbed into the smoothie from the dry ice causes a slight tartness on the tongue due to formation of carbonic acid with water which complements fruity flavours.

When using dry ice in food preparation, you need to take exactly the same precautions as you would with boiling water, naked flames, hot pans and baking trays straight out of the oven. Don't let it come into direct contact with your skin or you will get a burn.


photo courtesy of Farnborough Hill School, Hampshire

Instructions

Wear blue gloves provided and eye protection. (In the photo the demonstrator is not wearing either, idiot.) Weigh out the dry ice pellets and place in the food processor. Blitz for about 10 seconds which will render the dry ice to powder (the consistency of icing sugar is ideal). Please examine this powder to satisfy yourself that there are no large lumps of dry ice remaining. If you do see residual pellets you will need to blitz again.

- Pour smoothie mixture into a bowl and add the sugar, mix thoroughly to ensure that the sugar has dissolved.
- Let the gelatin soften in 1/4 cup of the smoothie, then gently heat until it is dissolved at which point add to the balance of the smoothie. (If you do not add the gelatin you will end up with a rock hard ice the following day!)
- Add about half the dry ice to the smoothie, sugar and gelatin mix and mix either using a whisk, or if you prefer mix using the food processor.
- You will see a column of white fog leaving the mixture and you should pick up the aroma of the smoothie.
- When the smoking has died down remove the bowl and add small amounts of additional powdered dry ice, continually stir with a wooden spoon or whisk. You will start to see that the smoothie is becoming a thick liquid and that the dry ice is causing it to foam and bubble in the bowl. Add more dry ice bit by bit until you see that the smoothie mix has set like an ice cream.
- Put the sorbet in a freezer for one hour or longer to ensure that all the dry ice has sublimed before serving.

We find it easier and more fun to use a whisk to combine the dry ice to the smoothies mixture. If you prefer to use a food mixer a wide diameter food processor works fine, however an upright liquidiser design does not mix as well and when we tried with this machine the dry ice fog pumped liquid out of the top and over the demonstrator.

Some of the carbon dioxide evolved from the dry ice will absorb into the mixture and will provide a very small amount of fizz – be prepared for applause!

The Volcano — Magnesium & Dry Ice

This is a beautiful demonstration in which magnesium burns in the absence of air; it is an illustration of the relative position of magnesium and carbon in the reactivity series.

An experiment plan with safety assessment; included below is a suggested procedure however this may not be rigorous enough for your school, so as with all these demonstrations, please follow best practice allowing for your specific circumstances.

Good ventilation, as some MgO vapour will be generated consider carrying this out in a fume cupboard or near to appropriate extractor fan. Please note that if not contained the fumes could trigger the fire alarm system.

We recommend that you conduct a test run with a colleague prior to presenting to a class to ensure that sensible safety measures have been taken. In particular please ensure that students are seated at a safe distance.

What You'll Need

Magnesium Ribbon or Fillings 5-10g should be plenty. (The powder will start to burn more readily than the ribbon.)

A large inert fireboard on which to place the experiment

Thick Gloves (leather garden gloves are fine)

Ignition Source (a Bunsen burner or small blowtorch work well; please note that an ignited taper will not be sufficient to start reaction)

Dry Ice Pellets 3-5 g

Tongs

Eye Protection

This experiment examines the relative reactivity of magnesium and carbon. In this experiment magnesium is oxidised with oxygen stored in the dry ice:

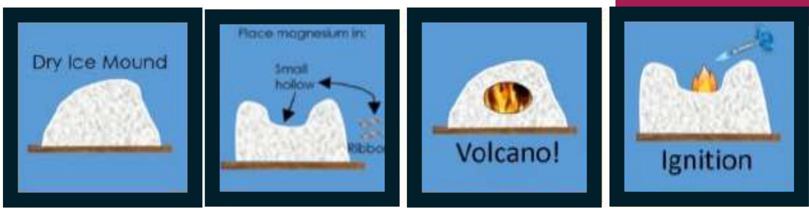
$2Mg + CO_2 \rightarrow 2MgO + C$

The result is magnesium oxide, which is a white powder and elemental carbon, which is black. One of the key points is setting up the experiment so that it will work with the dry ice pellets.

Time **20 minutes set up, combustion and examination of residue**

Instructions

We suggest that on a large piece of inert fire resistant board you pour a pyramid of dry ice pellets weighing 3 - 5kg. Wearing gardening gloves create a small hollow about 1 - 2cm deep, something like a volcano in appearance and place magnesium ribbon or turnings into the hollow (shown in the diagram opposite).



The reaction between magnesium and dry ice is exothermic and so energy is released. The magnesium sitting in the dry ice needs to be ignited to overcome the excitation energy of the reaction, and for this we recommend a bunsen burner or blowtorch, * please make sure that you are wearing safety glasses and gloves! * The magnesium will not ignite as it does in air and may take 2 – 10 seconds to catch. (Even though the magnesium is not covered at this moment it is trying to burn in an atmosphere of CO_2.) Once ignited use a pair of tongs to push the edges of the pyramid on to the burning magnesium. The magnesium will react with dry ice producing a bright flame that will be visible through the pyramid, the flame burns at about 2000°C.


Ignition has just been accomplished


This photo shows the covered pyramid with the reaction in full swing; please note the quantity of fumes being released.

Class discussion

What is happening?

Magnesium is more reactive than carbon as can be seen from the following table, which shows the reactivity order for some metals and also the position of carbon:

Potassium	Most reactive	K
Sodium		Na
Calcium		Ca
Magnesium		Mg
Aluminium		Al
Carbon		C
Zinc		Zn
Iron		Fe
Tin		Sn
Lead		Pb
Hydrogen		H
Copper		Cu
Silver		Ag
Gold	Least reactive	Au
Platinum		Pt

Magnesium will take oxygen from carbon for this reason resulting in magnesium oxide and elemental carbon.

Metals such as platinum and gold are very stable and do not oxidise, whereas at the other extreme potassium will burn on being exposed to air and for this reason is stored in oil.

CO_2 fire extinguishers

In an earlier experiment we mentioned that CO_2 is good at putting out some fires as it removes oxygen. Do you think it would be good at putting out a magnesium fire? Certainly not based on this experiment! The same applies to other fires involving metal which are able to steal the oxygen from the CO_2 so making the fire much worse.

Carbon is produced as a by-product – why doesn't this burn?

Even before the magnesium is covered with dry ice pellets it is sitting in an atmosphere of CO_2. When the carbon is first produced as a by-product of the main reaction between magnesium and dry ice there is no available oxygen to burn the carbon.

How much dry ice is used in the reaction?

If 5g of Mg is used then this is 5/24 = 0.21 gmols of magnesium. According the equation this will consume (0.21/2) gmols of dry ice, which is a weight of (0.21/2) * 44 = 4.62 g of CO_2. (m.w. of CO_2 = 44, m.w. of Mg = 24)

How much dry ice is lost due to heat?

Heat of reaction is -810kJ/mol. In the case above this will release: 810 * 0.11 = 89.1kJ.

The heat of sublimation of CO_2 is the energy required to convert solid dry ice to gaseous form at -79° C, this is 571kJ/kg. So if all the heat of reaction is consumed in this task the maximum conversion is:

89.1/571 = 156g of dry ice.

We know that the actual conversion will be less than this because some of the energy from the reaction is given off as light and also some of the energy would be consumed in heating the CO_2 produced to some temperature above -79°C.

When the demonstration has been completed and a few minutes have past open up the volcano with gloves and remove the now cold ball of carbon and magnesium oxide. Recover the remaining dry ice and put back in the storage box provided – there are so many other experiments! *Obviously you cannot use this recycled dry ice for making sorbet or for the drinking demonstrations due to the risk of contamination.*

Measuring Molar Volume Of CO_2

In this experiment the students will determine the molar volume (L/gram-mole) of carbon dioxide at room temperature and pressure by assuming that it behaves like a perfect gas.

The measured values can be compared to the value for an ideal gas leading to a discussion about errors in the experiment.

Background Information

In 1810 an Italian scientist called Amedeo Avogadro proposed that at the same temperature and pressure equal volumes of all gases contain the same number of molecules. In the years to follow other scientists worked out that at Standard Temperature and Pressure (which is 1 atmosphere and 273K, (0° Celsius)) one gram-mole of a perfect gas occupies 22.4 litres and contains 6.02×10^{23} molecules; this number is known as Avogadro's constant in his honour.

If you have two of something you call it a pair.

If you have twelve of something you call it a dozen.

If you have twenty of something you call it a score.

If you have 602,000,000,000,000,000,000,000 of something you call it a mole!

Mole Day is celebrated by some each year in honour of the unit; the date is derived from Avogadro's number, 6.022×10^{23}, the day starts at 6:02 a.m. and ends at 6:02 p.m. on October 23rd!

What You'll Need

- **200 – 400mL Flask** (Erlenmeyer style is ideal)
- **Cling Film** or aluminium foil
- **Measuring Cylinder** (100ml graduated is ideal)
- **Balance Accurate** to 1/100 gram
- **Dry Ice Pellets** 2 – 3cm length (2 grams is plenty for any container up to 500mL)
- **Gloves** (supplied in kit) or tongs

Time **15-25 minutes**

For the practical depending on number of measurements. More time will be required for the analysis of results and discussion.

Instructions

During this experiment, a piece of dry ice is placed in a flask and undergoes sublimation. The carbon dioxide gas so produced will fill the flask and displace the air that was in the flask, (from previous experiments we know that CO_2 gas is heavier than air). See pouring CO_2 and Fire Extinguishers.

Students will need to account for the mass of air in the "empty" flask.

In comparing measured results with the standard for an ideal gas the students will also need to allow for the temperature adjustment from 0°C to the conditions in the laboratory.

Procedure:

1) Weigh the flask, which has been fitted with a piece of cling film or foil. The purpose of the foil is to reduce loss of CO_2 gas from the flask.

2) Place dry ice pellets equivalent to a length of 2cm in the flask.

3) Leave the cover off the flask while the dry ice sublimes.

4) Immediately after the dry ice has disappeared cover the end of the flask with the same piece of cling film (or foil) and measure the mass using the analytical balance. Record this value on the data sheet.

5) Fill the flask to the brim with water and carefully wipe off excess water from the outside of the flask. Measure the volume of water contained in the flask using a measuring cylinder. Depending on the size of the flask you may need to empty the measuring cylinder several times. Note the total volume of water on the data sheet.

6) As an option you can repeat steps 1 through 5 with an additional sample of dry ice to obtain two measurements.

Measuring Molar Volume Of CO_2

	Action	Experiment 1	Experiment 2
1	Mass of flask, cover and air (g)		
2	Mass of flask, cover and CO_2 (g)		
3	Volume of flask (mL)		
4	Calculate the mass of the air contained in the flask by using the density of air at ambient temperature (0.001225 g/mL) and the volume of the flask determined in 3. (g) (3)(0.001225)		
5	Determine the mass of CO_2 in the flask by adding the difference between the mass of the flasks with and without the CO_2 to the mass of the air calculated in step 4. (g) (2 - 1) + 4		
6	Calculate the gram-moles of CO_2 contained as gas in the flask. The molar mass of CO_2 is 44 (12 + 2 x 16) 5 ÷ 44		
7	Determine the molar volume of CO_2 (the volume occupied by one mole) by dividing the volume of the flask by the moles of CO_2 that were contained in the flask. Convert the value of the volume obtained for the flask from mL to liters. (÷1000) to keep units consistent. (L/gram-mole) (3÷ 1000) ÷ 6		
8	Average molar volume (L/gram-mole)		
9	Temperature in laboratory (K)		
10	Calculate corrected Ideal molar gas volume. The true value for the molar volume for any ideal gas at standard conditions (1 atmosphere pressure and 0°C) is 22.4 Litres; use the ideal gas law to adjust based on the temperature in the laboratory. (gram-moles/L) 22.4(9/273)		
11	% error from ideal gas 100(10- 8)/10		

Class Discussion and background

Perhaps plot the results % for the whole class. Ask students to see if there are any trends, for example are results consistently lower or higher than ideal gas results? Was there a difference between the first and second experiment?

Think of errors in the procedure and other reasons to explain the results.

Some reasons why the molar volume is lower than for an ideal gas:

In step 9 of the experiment the students measured the temperature in the laboratory. Was this correct or should they have measured the temperature in the flask? The CO_2 gas from the dry ice would be very cold and this means that the measured ideal molar volume would be higher than it actually was within the flask therefore making the result appear lower than it is. Also, this temperature is changing all the time as the flask and contents warm up, perhaps one solution is to cover the flask carefully and leave to stand for a period until it and the contents have warmed to ambient.

When the volume of the flask was determined was there residual water left in the flask for experiment 2? Ask students to look at the results and see if there is a trend to support this theory.

With reference to the **Crystal Growth Experiment** do you remember water ice crystals forming on the surface of the dry ice? This water was condensed from the air. Did you notice any water ice crystal on the dry ice at the bottom of the flask? Probably not as the CO_2 should have pushed the air away, however if there were any water crystals formed this would introduce error into the measurement.

Some reasons why the molar volume is greater than for the ideal gas:

When the dry ice was subliming in the flask how do you know all the air was expelled? CO_2 is heavier than air and will expel air as it evolves from the dry ice however is it possible that there will be back mixing at the opening of the flask?

Is it hard to judge the moment that the dry ice has completely sublimed? As soon as this happens the pumping of CO_2 gas ceases and this will encourage air to diffuse back into the flask. In the Freezing Solution chapter mention is made of the speed that molecules travel at ambient conditions – average speed of air molecules is the speed of a jet engine. You would therefore expect some air to get into the flask.

In the **Pouring CO_2 and Fire Extinguisher** experiment the CO_2 gas is seen to act like a fluid, (which it is!). If the flask filled with CO_2 is not handled very gently prior to weighing it is likely that CO_2 gas will be spilled, just as would be the case if it were full to the brim with water. In this case air would fill the lost volume, making the molar volume appear higher than it is.

How do you know you added enough dry ice to the flask?

You need enough dry ice so that on sublimation it generates sufficient CO_2 gas to fill your flask several times over. In this way there is a reasonable chance that the air will be pushed out by the heavier CO_2. Assuming CO_2 gas behaves like a perfect gas then it is possible to estimate the amount of dry ice needed. Carbon dioxide has a molecular weight of 44 and so 44g of CO_2 gas will occupy 22.4 litres at STP if we assume that it follows the Ideal Gas Law:

$P_1V_1/T_1 = P_2V_2/T_2$

$1 \times 22.4/273 = 1 \times V_2/(273 + 20)$

44g of CO_2 gas occupies 24 litres at 20°C, typical ambient temperature in a lab.

Mass of dry ice needed for the experiment = (44/24,000)(Volume of you flask in mL)
(2)

You can weigh a piece of dry ice, or estimate its weight based on density. Dry ice supplied in the kit has a diameter of 9mm and has a density of 1.5g/cm^3.

Can you think of another way to measure the volume of the flask?

Hint: Density of water at ambient is 1g/ml.

Is Carbon Dioxide a perfect gas?

We think so! In chemistry terms this means that the gas conforms to the ideal gas law, which was used in step 10 of the data sheet. The actual molar volume of CO_2 at atmospheric pressure is 22.3L/gram-mole. Some gases deviate from the ideal gas law particularly at higher pressures.

Material Safety

IDENTIFICATION OF THE SUBSTANCE PREPARATION AND OF THE COMPANY

Product name Carbon Dioxide (Solid)
Chemical formula CO_2
Company identification See footer
Emergency phone nos 08433 192919/0845 130 3280

COMPOSITION/INFORMATION ON INGREDIENTS

Substance/Preparation Components/ Impurities Substance contains no other components or impurities which will influence the classification of the product
CAS Nr 124---38---9
EEC Nr 2046969
(from EINECS)

HAZARDS IDENTIFICATION

Hazards identification Refrigerated solidified gas. Contact with product may cause cold burns or frostbite. In high concentrations sublimed vapour may cause asphyxiation.

FIRST AID MEASURES

Inhalation of sublimed vapour In high concentrations may cause asphyxiation. Symptoms may include loss of mobility/consciousness. Victim may not be aware of asphyxiation. Low concentrations of CO_2 cause increased respiration and headache. Remove victim to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artificial respiration if breathing stopped.
Skin/eye contact with Carbon Dioxide (Solid) Immediately flush eyes thoroughly with water for at least 15 minutes. In case of frostbite spray with tepid water for at least 15 minutes. Apply a sterile dressing. Obtain medical assistance.
Ingestion Ingestion is not considered a potential route of exposure.

5 FIRE FIGHTING MEASURES

Specific hazards None
Hazardous combustion products None
Suitable extinguishing media All known extinguishers can be used.
Specific methods Water on Solid Carbon Dioxide increases sublimination. Higher risk of asphyxiation.
Special protective equipment for fire fighters In confined space use self---contained breathing apparatus.

ACCIDENTAL RELEASE MEASURES

Personal precautions Evacuate area. Use protective clothing. Wear self---contained breathing apparatus when entering area unless atmosphere is proved to be safe. Ensure adequate air ventilation.
Environmental precautions Try to stop release. Prevent from entering sewers, basements and workpits, or any place where its accumulation can be dangerous
Clean up methods Ventilate area.

HANDLING AND STORAGE

Handling and storage Use only properly specified equipment which is suitable for this product. Contact your supplier if in doubt. Refer to suppliers container handling instructions. Keep container in a well ventilated place.

EXPOSURE CONTROLS/PERSONAL PROTECTION

Exposure limit UK: STEL; 15000ppm; LTEL: 5000ppm
Personal protection Ensure adequate ventilation. Protect eyes, face and skin from contact with product.

PHYSICAL AND CHEMICAL PROPERTIES

Molecular weight 44
Melting point ---56.6°C
Boiling point ---78.5°C (sublimes)
Critical temperature 30°C
Relative density, gas 1.52 (air=1)
Relative density, liquid 1.03 (water=1)
Relative density, solid 1.87 (water=1)
Vapour pressure 20°C 57.3 bar
Solubility mg/l water 2000 mg/l
Appearance/Colour Translucent white solid
Odour No odour warning properties
Other data Gas/vapour heavier than air. May accumulate in confined spaces, particularly at or below ground level.

STABILITY AND REACTIVITY

Stability and reactivity Stable at atmospheric pressure and ---78°C. At normal temperatures product sublimes into Carbon Dioxide gas. Contact with solid can cause embrittlement of structural materials.

TOXICOLOGICAL INFORMATION

General High concentrations of sublimed vapour cause rapid circulatory insufficiency. Symptoms are headache, nausea and vomiting, which may lead to unconsciousness.

Suggestions for inclusion in Risk Assessment for dry ice

1 = low 5 = high

Activity	Hazard	Action	Harm	Likelihood	Risk Rating	Risk Acceptance
Before Use		Prepare a hazard and COSHH assessment and any other documentation that is required by law and good practice. These notes are intended as a guidance, conditions and uses specific to your venue must be taken into account here.				
Delivery of dry ice	Broken container leading to potential risk of frostbite from prolonged contact with naked skin	Only trained staff to open dry ice package. Dry ice packages sent to schools will be delivered in polystyrene boxes with safety information labels. If box is damaged beyond use, i.e. it is no longer a safe container then don't use product and contact Chillistick for replacement.	3	1	1	Yes
Storing dry ice	Uncontrolled access to dry ice container	Always keep dry ice container in the same pre-agreed location. Ensure access is limited to trained staff.	3	1	1	Yes
Removing dry ice from storage container	Frostbite from prolonged exposure	Always use lightweight gloves (supplied with ice) or scoop - never touch dry ice with bar hands. If using Ice Pour decant dry ice from poly box using appropriately sized scoop, available from Chillistick Ltd				

Suggestions for inclusion in Risk Assessment for dry ice

1 = low 5 = high

Activity	Hazard	Action	Harm	Likelihood	Risk Rating	Risk Acceptance
Creating CO_2 gas with smoke effects	Asphyxiation due to high concentration of CO_2	Check venue has adequate working air conditioning or has other good ventilation. Ensure fog creation takes place so that 10kg of dry ice are sublimed over a period of half an hour. Short term CO_2 gas exposure limit is 27,400 mg/m3 (15 minutes) long term exposure limit = 9,150 mg/m3 (8 hours). In case of doubt contact Chillistick before use.	4	1	1	Yes
Accidental spillage of dry ice	Someone picks up dry ice with bar hands - risk of frostbite	Each lesson has one named person responsible for dry ice, see form at end of this document. Use Ice Pour or similar storage device to avoid possibility of breaks and spills. Provide lightweight gloves for staff.	3	1	1	Yes
Transporting dry ice	Risk of asphyxiation	Where possible store dry ice in a separate compartment isolated from the driver. If this is not possible always store dry ice in a well insulated box, always ensure that fresh air vents are open and that the window is also partially open.	4	1	1	Yes
Disposal	General	Any unwanted dry ice will sublime naturally, leave in a secure well-ventilated space.	1	1	1	Yes

Re-Order Dry Ice And Hardware

There are several ways to re order products. Visit our website at www.dryice.education, email: sales@dryice.education or contact us on 0203 4329412.

Please note that the dry ice will only last for a few days and so it is important to ensure that delivery is made on the best day for your schedule. Deliveries can be made by courier to arrive Tuesday to Friday and we can also offer AM and pre 10AM deliveries.