how tall are you in nanometres?

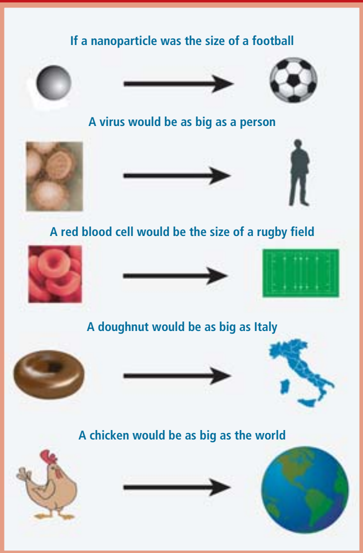
What happens in this experiment?

For most of us it is very difficult to have an idea of how different the scale of the nanoworld is from our daily macroscopic scale (that is, larger than about 1 mm). The goal of these two activities is to help you understand how different these two scales are.

The naked eye is not able to see objects smaller than about ten micrometres (10 μm = 0.01 mm). But atoms or viruses are much smaller than 10 μm. The most convenient unit to measure such small things is the nanometre. 1 nm = 0.000 000 001 m, or one billionth of a metre. Despite being so small, modern science and technology can investigate and manipulate nanometre-sized objects.

Science and technology can investigate and manipulate objects as small as a few nanometres (nano-objects). Special tools and equipment, such as scanning probe microscopes (SPM), are needed to work with these objects. These particular tools are able to investigate different properties of nano surfaces and show different images of the nanoworld. More information about such microscopes can be found in the activity 'Magnetic probe'.

At the nanoscale many common materials exhibit unusual physical or chemical properties. In fact, nano objects can demonstrate behaviours that would be completely unexpected at the microscopic or macroscopic scales. For example, silver and gold nanoparticles have size-dependent properties: their different colours depend on the size and shape of each particle. This was used in the Middle Ages by the makers of stained glass. These clever craftsmen were using nanotechnology without knowing it!



There are two ways of creating nano-objects:

- The first one is top-down nanofabrication in which scientists use bigger objects that are processed with a nanotool to shape them into smaller objects. Similar to the way an artist creates a sculpture from a block of marble.
- The second one is bottom-up nanofabrication in which individual atoms are assembled to build bigger structures. In theory, if a drop of water has around 10^{21} atoms (that's a 1 followed by 21 zeros!) and it takes one second for a scientist to manipulate a single atom, it would take 300 million million years to make this single drop. Scientists therefore need to study so-called 'self-assembly' processes, which build structures without having to manipulate each individual atom. Although less developed, this method holds great promise for the future.

timefornano

1

from 8 years

how tall are you?

You will need

- The ‘how tall are you in nanometres’ height chart

What you can do

How many nanometres are there in your height?

- Fix the height chart vertically on a wall.
- Lean your back against the height chart and stand up straight.
- Get one of your friends to mark your height on the chart.

How tall are you in nanometres? In metres?
Are you super tall or is a nanometre super small?

- A human hair is between 0.1 and 0.05 mm wide

How much is a human hair in nm?
Can you think of objects as small as 100 nm, 10 nm, 1 nm and even smaller?

What’s happening?

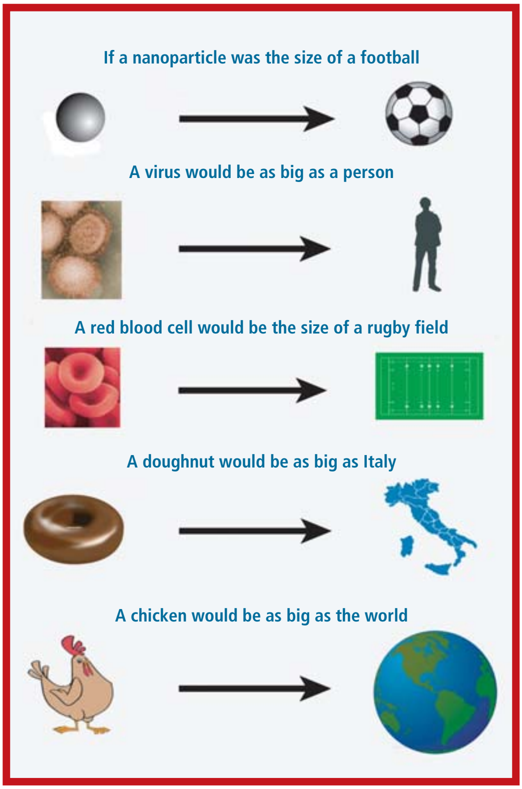
There are 1 000 000 000 nanometres (nm) in a metre. A nanometre is a unit for measuring very tiny objects such as **atoms** or **viruses**. It is much easier to say that a virus is 20 nm long than 0.000 000 02 m long!

Why nano is important?

Modern science and technology can investigate and manipulate objects as small as a few nanometres (nano-objects). Special tools and equipment are needed to work with these objects. Regular tools are too big.

At the nanoscale, many common materials have unusual physical or chemical properties.

Through nanotechnologies scientists and engineers can make new materials and tiny devices. For example smaller and faster computer chips or new medicines to treat diseases like cancer.



To find out more

- http://www.discovernano.northwestern.edu/index_html
- http://www.understandingnano.com/nanotech-applications.html
- http://www.generation-nano.org/

What does it mean?

An **atom** is the smallest component of matter. Chemical elements (for example iron, carbon or oxygen) are made up of a single type of atom, whereas chemical compounds are made of two or more different types of atom. There are more than a hundred different elements, and 94 of them occur naturally on Earth.

A **cell** is the basic structural unit of all living organisms.

A **virus** is a nanometre-sized infectious agent that needs to infect a cell in order to reproduce. Viruses cause diseases such as the common cold, influenza and AIDS.

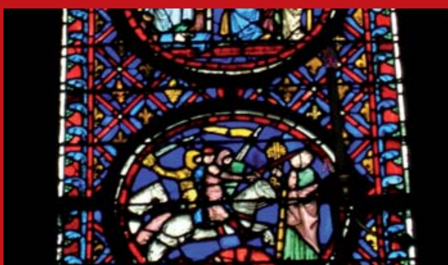
Cancer is the name given to any illness resulting from one of our body's own cells reproducing out of control.

dilution

Health and safety

The food colorant should not be swallowed

Some people may be intolerant to the food colouring. As a precaution we would recommend that if the colorant comes into contact with skin it is rinsed off immediately with copious amounts of water.



What happens in this experiment?

This experiment illustrates how we use different senses to detect different things and that just because one sense cannot detect something, it doesn't mean it isn't there.

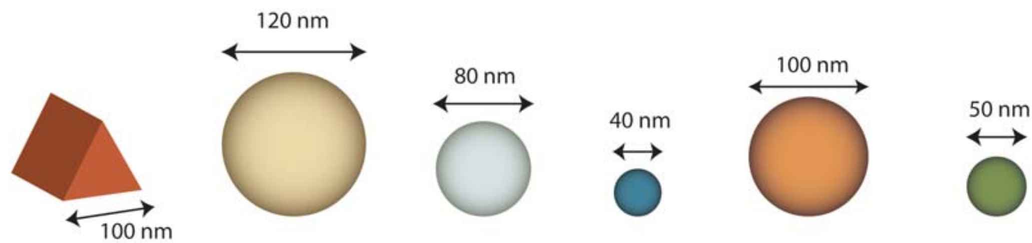
By performing serial dilutions of the food colorant the colour and smell will gradually fade. The colour will fade more quickly that the smell, illustrating that even though our eyes cannot detect the chemical responsible for the colour, it is still present, as verified by the smell.

Just like we use our eyes to see large things and our nose to smell small things, nanoscientists use special tools to analyse and manipulate things at the nanoscale. Atomic force microscopes can feel and move individual atoms, while special surfaces with nanotextures on them can repel water extremely efficiently.

This activity serves as a nice introduction for 'Activity 3: Magnetic probe' which illustrates how surfaces with nanostructures are examined.

Applications

Technologies based on the properties of nanoscale particles are not new. Since the Middle Ages some materials' properties and behaviours in relation to their size were already known, although they did not appreciate how small the particles were. Glaziers could create beautiful coloured glass for windows, for example in our medieval churches. These different colours were made by using the light-refracting properties of different sized gold nanoparticles. Glazed glasses displayed shining colours such as green, orange, purple and red.



Silver nanoprisms Silver spheres Gold spheres

Ideas for conducting the activity or discussion

This activity helps to illustrate how small the nanoscale is. Some examples you might like to give are:

- Our **nails** grow one nanometre each second.
- The virus most usually responsible for **the common cold** has a diameter of 30 nanometres.
- A **cell membrane** is around 9 nanometres across.
- The **DNA** double helix is 2 nanometre across.
- The diameter of one **hydrogen atom** is around 0.2 nanometres.

Encourage students/ participants to consider the things that they cannot see directly. Some examples could include the ozone layer, dyes in stained glass windows or the colloidal nature of milk.

Learning objectives or school curriculae

- An understanding of dilutions and concentration
- An appreciation of the size of the nano-scale.
- An introduction to colloids (a mixture with particles in the range of 10^{-9} and 10^{-6}m).
- An appreciation that different senses detect different things.

dilution

Health and safety

- Do not eat the food colorant!
- Some people might be intolerant of the food dye. If it comes into contact with skin, wash it off with lots of water.
- Avoid getting the food dye on clothes - it will stain!

You will need

- Some scented (this is important) food colouring
- A Pasteur pipette
- Nine test-tubes (from the kit) carefully filled with 9 ml of water and numbered 1 to 9

What you can do

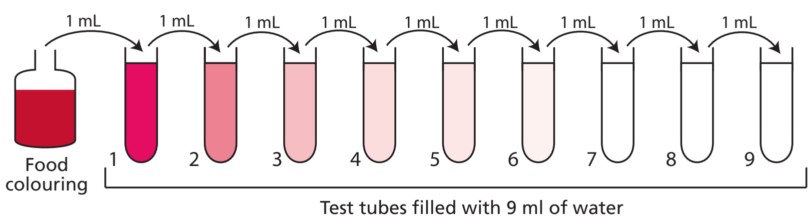
- With your Pasteur pipette, carefully measure 1 ml of your food colouring and add it to tube number 1.
- Mix the tube thoroughly so that the colour is even throughout.
- Smell the tube? What does it smell of? Does it smell the same as the original food colouring?
- Now take 1 ml of liquid from tube 1 and add it to the next tube. Keep doing this: dilute tube 1 into tube 2, tube 2 into tube 3, and so on, until you dilute tube 8 into tube 9. At each stage, repeat steps 2 and 3 before doing the next dilution.

At what point can you no longer see any red in the tubes?

At what point can you no longer smell anything in the tubes?

How can you explain the difference?

If you had not done the dilution like this and wanted to dilute 1 ml of the food dye to the same concentration as the last tube, how much water would you need?



What's happening?

In each tube the food colouring is ten times more dilute than the previous tube. By the time you reach the ninth tube the original food colouring has been diluted by a billion times, so for every part of food colouring there are a billion parts of water.

This experiment illustrates the sensitivity of our senses. Our sense of smell allows us to detect very dilute amounts of food colouring after we're no longer able to see any trace of it. We can only see relatively large objects, but our sense of taste and sense of smell can detect individual molecules which are just tens of nanometres in size.

To find out more

- http://www.nanoandme.org/nano-products/food-and-drink/
- http://www.nanooze.org/english/articles/5senses_noseknows.html
- http://web.mac.com/drshawn1/iWeb/Site/Serial%20Dilutions.html
- http://en.wikipedia.org/wiki/Colloidal_gold

What does it mean?

A **dye** is a chemical that changes the colour of something. Different dyes exist to change the colour of different things, so food dyes are different to clothing dyes which are different to dyes used in stained glass windows.

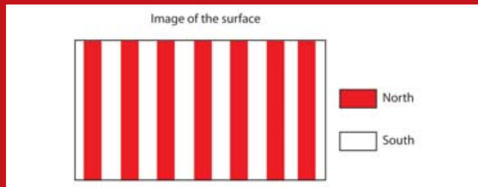
A **serial dilution** is the type of dilution that you just did. You use the diluted solution that you just made as the source for your next dilution. Using serial dilutions is much easier when you want to dilute something a lot.

Olfaction is the proper name for your sense of smell. A part of your brain called the 'olfactory bulb' is responsible for interpreting the smells that your nose detects. Interestingly, the olfactory bulb is strongly linked to a part of your brain that is responsible for remembering things. That's why certain smells can make you remember specific things clearly.

magnetic probe

Health and safety

This activity uses weak magnets, but these should not pose any health risk.



What happens in this experiment?

Objects with details at the nanometre scale are far too small for our eyes to see. So how can we tell what they look like? One way is by using a special tool called a Scanning Probe Microscope.

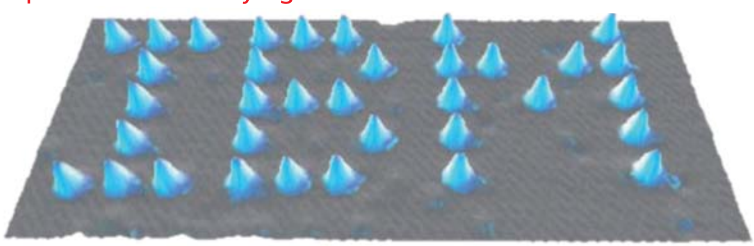
If you look really closely, you might be able to see tiny objects as small as 0.05 mm. But a nanometre is 0.000 000 001 m, which is one billionth of a metre. To put it another way, a human hair is as wide as 50 000 nm. A good light microscope used in schools can let you see details as small as 400 nm. But atoms can be 0.1 nm across, so we need special tools to see details at this scale.

Scanning probe microscopes work by running a probe across the surface of an object and 'feeling' all the bumps and shapes. This information is then fed to a computer which draws an image of the surface.

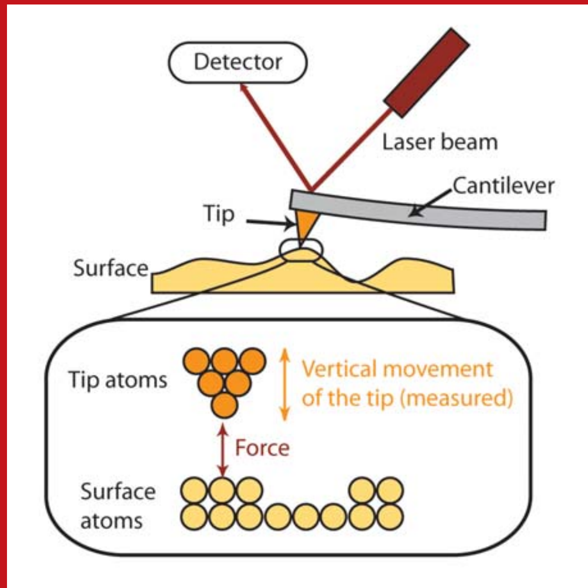
There are many different types of scanning probe microscopes, including:

1. Atomic force microscope
2. Magnetic force microscope

In the experiment you investigate the magnetic surface of your sheet. This is similar to how a real magnetic force microscope works. Using a magnetised probe, magnetic force microscopes are attracted to, or repelled from, the surface being examined. The attractions and repulsions are much weaker than those experienced in this activity. Fortunately, computers can detect the tiny movements of the probe as it is pulled towards and pushed away from the surface. By detecting how the probe moves up and down over the surface the computer can draw an accurate map of the magnetic surface of the specimen it is studying.



http://commons.wikimedia.org/wiki/File:Ibm_nm.PNG



inspired by
http://nano.tm.agilent.com/blog/wp-content/uploads/2007/06/how-an-atomic-force-microscope-works.bmp

Ideas for conducting the activity or discussion

- Ask students to 'probe' their surfaces and think about how the 'magnetic surface' might look different from the physical surface (topography).
- They might like to think about what common objects work by manipulating small magnetic fields; for example, hard disk drives (note that 'solid state' or 'flash' drives, like those found in new iPods, do not work via magnetism).
- Pictures 3 and 4 on the students' worksheet are of a computer hard disk. Picture 3 was taken with an atomic force microscope; picture 4 was taken with a magnetic force microscope.

Learning objectives or school curriculae

- Building on existing understanding of magnets and magnetism.
- Appreciation that microscopes do not have to detect light, but can detect other things.
- Understanding that objects at the nanoscale exert small local forces.

magnetic probe

You will need

- The magnetic surface to be investigated
- Magnetic probes
- Two bar magnets

What you can do

- Bring the opposite poles of your bar magnets close to each other.

Can you stop them from touching?

- Now turn one of the magnets around so that you are bringing the same poles together.

Can you make them touch?
What does it feel like?

- Take your magnetic probe and hold it with the dark magnetic side facing down. Run the 'probe' slowly across the magnetic surface from left to right as shown over the page in pictures 1 and 2.

What does it feel like?

- Now pull the 'probe' the other way - from top to bottom.

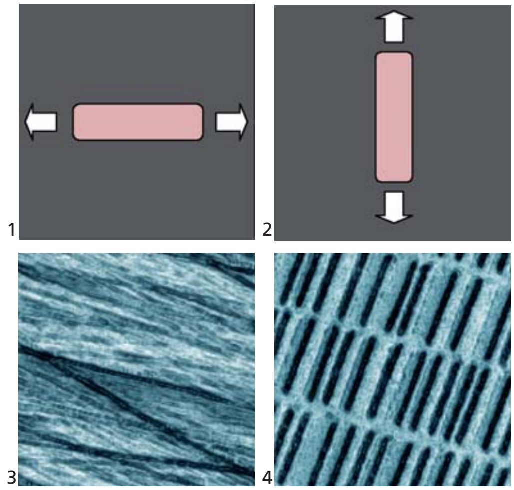
Does it feel the same? What's different?

- **Can you draw what you think the surface looks like?**
- **Can you think of anything that works by detecting pits in the surface of a material?**
- **What about something that works by detecting magnetic fields?**
- **Pictures 3 and 4 are of the same object. Picture 3 shows the physical surface of the object while picture 4 shows its magnetic surface. What do you think the object might be?**

What's happening?

You should feel the probe leap across the surface as you move it at right angles over the invisible magnetic stripes. This happens because it is repelled and then attracted by the different poles it encounters. When you drag the probe parallel to the stripes it feels smooth because it encounters equal attraction and repulsion at all times.

This is a model of how an **Magnetic Force Microscope** works.



To find out more

- http://www.ou.edu/research/electron/www-vl/afm.shtml
- http://www.mrsec.wisc.edu/Edetc/reprints/ST_0612_46.pdf
- Lego AFM: http://www.physics.unc.edu/~falvo/NUE/LEGO_AFM_WEBPAGES/web_files/nanoworld.html
- Explanation about Atomic Force Microscopy: http://www.nanoscience.com/education/AFM.html
- Explanation about Scanning Probe Microscopy: http://www.mobot.org/jwcross/spm/
- Black box: http://www.nnin.org/doc/SPM_TG.pdf

What does it mean?

Scanning probe microscopy (SPM) is the general name given to microscopes that investigate surfaces by using very small tips.

Atomic force microscopes (AFMs) pull a very finely-tipped probe over the surface of a sample. The probe moves up and down as it goes over hills and valleys on the sample. A laser shining on the back of the probe detects this up and down movement and sends the information to a computer. The tip is in direct contact with the surface and can move the atoms around.

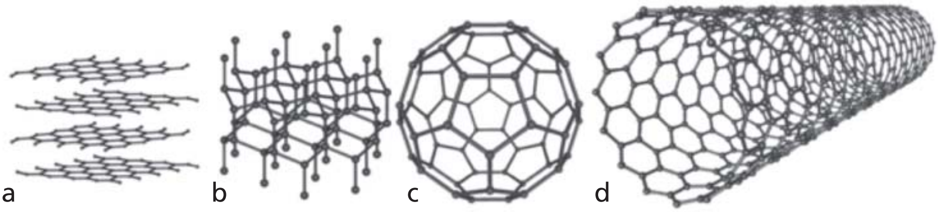
Magnetic force microscopes (MFMs) also work by pulling a tiny probe across the surface but the tip is magnetised. This means it is moved up and down by any tiny magnetic fields present on the surface of the sample. The tip is not in direct contact with the surface, but instead 'floats' about 10 nm above the surface.

What is a buckyball?

A buckyball is a tiny football-shaped molecule made of 60 carbon atoms arranged in 20 regular hexagons and 12 regular pentagons. Buckyballs are only one nanometre in diameter. The chemical formula of a buckyball is C_{60}.
Buckyballs were discovered in 1985 and named buckminsterfullerenes after the architect Richard Buckminster Fuller, who was famous for his characteristic dome structures. The name was later shortened to 'buckyball'. Buckyballs were the first molecule of the fullerene family to be discovered. All members of this family are cage-like molecules made entirely of carbon atoms arranged in hexagonal and pentagonal shapes, like a football. Carbon nanotubes, hollow tubular structures made up of carbon atoms, also belong to this family. Fullerenes have special properties due to the way their carbon atoms are arranged.

Forms of carbon

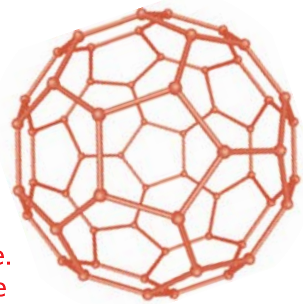
Carbon exists in numerous forms, one of which is fullerenes, which includes buckyballs and nanotubes. Carbon nanotubes are one of the most electrically and thermally conductive materials known. Other forms of carbon include diamond, the hardest natural material known on Earth, and graphite, one of the softest materials. These different forms are called allotropes, which refers to the fact that they are made of just one element, but that their structure is different.
Carbon allotropes have different properties because the carbon atoms are arranged differently at the nanoscale. In graphite (a), the carbon atoms are arranged in layered sheets of hexagons, with only weak bonds between the layers. The lead of drawing pencils is made of graphite: when using a pencil, the weak bonds are broken easily and the carbon layers are deposited on to the paper. In contrast, diamond (b) is the hardest material on earth. In the diamond structure, each carbon atom is bonded to four other carbon atoms, creating a rigid three-dimensional lattice which gives diamond its hardness. Buckyballs are ball-shaped molecules (c) and carbon nanotubes (d) are essentially a single layer of graphite rolled into a tube.



a b c d

http://commons.wikimedia.org/wiki/File:Eight_Allotropes_of_Carbon.png

Applications



Buckyballs and carbon nanotubes occur naturally. They can be found in very small amounts in soot and in outer space, and they are also created by lightning strikes. Scientists are studying how to make these tiny particles and how to use them to build other things.

Buckyballs are good lubricants because of their spherical shape. Researchers are investigating whether their hollow structure could be used for delivering medicine in the future. By attaching antibodies to a buckyball it might be possible to design treatments which will target areas of disease, delivering medications to just the right place.

Carbon nanotubes are very strong and light and can act as semiconductors or conductors. Research is being conducted into their use in flat screens where they would replace the current LCD and plasma technologies. Carbon nanotubes could also be used to store hydrogen, allowing the production of hydrogen–oxygen fuel cells, which could be used in emission-free cars.

'Buckypaper' is a paper made of carbon nanotubes and has potential for being used as an electromagnetic shield, for fire and lightning protection, or even as an artificial muscle that can potentially produce up to 100 times the force of a human muscle the same size.

Nanotubes can be used as very sensitive gas sensors for security and environmental applications. Finally, they are also used to strengthen composite materials.

These are just a few examples; fullerenes have many more potential applications and are expected to be an essential material in the future.

Ideas for conducting the activity or discussion

- Ask participants to gently squeeze the buckyball so that they can see how resistant it is.
- Ask them to guess about potential applications of buckyballs.

Learning objectives or school curriculae

- Fullerenes are among the first discovered and the most studied nano-objects.
- Fullerenes have a lot of different applications.
- Some elements, like carbon, can exist in different forms (allotropes).

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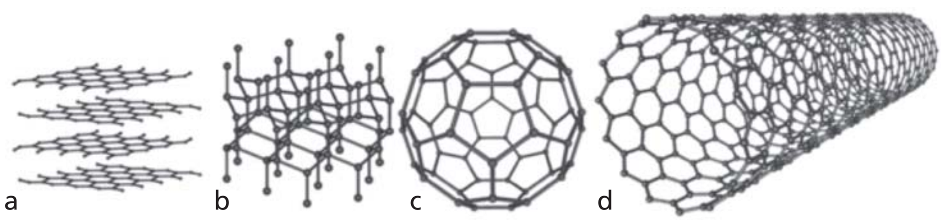
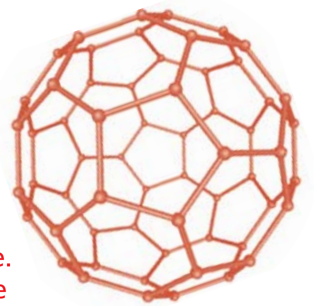


http://commons.wikimedia.org/wiki/File:Eight_Allotropes_of_Carbon.png

Applications



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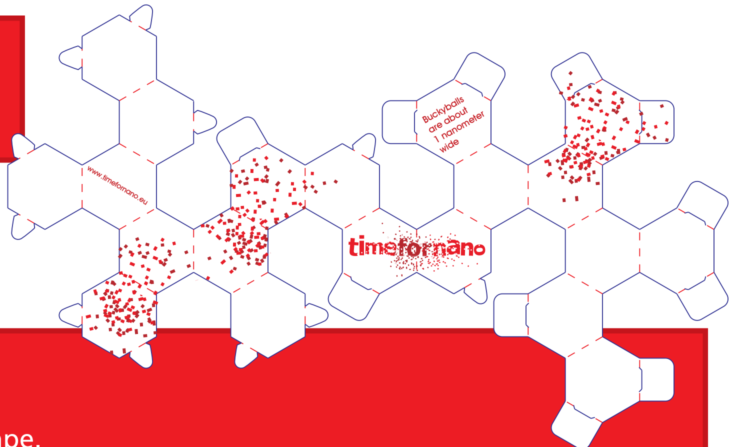
timefornano

4

from 8 years

buckyball



You will need

- Pre-cut buckyball template

What you can do

- Take the pre-cut paper shape.
- Fold it along the scored lines to make a model of a tiny, nanoscale molecule.
- Insert the tabs into the slots to hold it together.

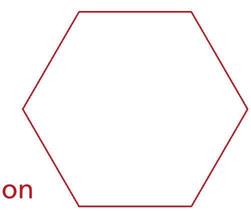
What does your model look like?

How many pentagons and hexagons can you count?

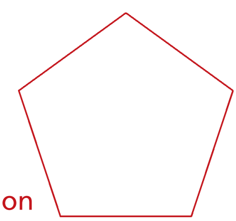
How many corners (which represent atoms of carbon) can you count?

Your model represents a buckyball that is just 1 nm across - can you think what buckyballs might be used for?

Hexagon



Pentagon



What's happening?

You have just made a model of a buckyball, a tiny football-shaped molecule made of 60 **carbon atoms** arranged in 20 regular hexagons and 12 regular pentagons. Buckyballs are only one **nanometre** in diameter!

Buckyballs were the first member of the 'fullerene' family to be discovered. Other famous members of this family are carbon nanotubes; long, hollow tubes made of carbon atoms. Fullerenes have special properties due to the way their carbon atoms are arranged.

Buckyball's hollow structure might make them useful for delivering medicine in the future.

Carbon nanotubes are very strong and light. They can be used to reinforce materials such as textiles or concrete, or strengthen sports equipment like tennis rackets. They can also conduct electric current. Researchers are studying ways to use carbon nanotubes in electronics, fuel cells and other applications.

To find out more

- http://www.science.org.au/nova/024/024key.htm
- http://mrsec.wisc.edu/Edetc/nanoquest/carbon/
- http://mrsec.wisc.edu/Edetc/IPSE/educators/carbon.html

What does it mean?

An **atom** is the smallest component of matter. Chemical elements (for example iron, carbon or oxygen) are made up of a single type of atom, whereas chemical compounds are made of two or more different types of atom. There are more than a hundred different elements, and 94 of them occur naturally on Earth.

Carbon is a naturally abundant element that occurs in many compounds.

The **fullerenes** are a family of cage-like molecules composed entirely of carbon atoms arranged in hexagonal and pentagonal shapes.

A **molecule** is a group of several atoms held together through very strong chemical bonds.

A **nanometre** is a billionth of a metre (0.000 000 001 m).

Carbon nanotubes are hollow tubes made of carbon. They are very strong and light and are used in some sport equipments.

5

instructions

ferrofluid

Health and safety

Ferrofluid needs to be handled with care and should not be shaken.

The test tubes should not be opened. If the ferrofluid breaks do not throw it in the sink; it must be disposed of as motor oil.

In case of contact with skin, wash with copious amounts of water and soap.

The ferrofluid inside the test tube is flammable

What happens in this experiment?

This experiment aims to show how the properties of a solid can change at the nanoscale.

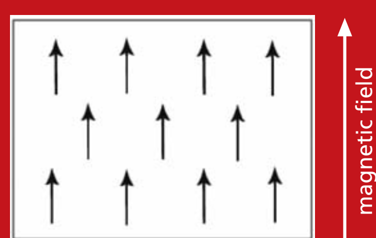
Ferrofluid is a suspension of magnetite nanocrystals which are around 10nm across. The crystals are covered by a membrane of special material, called a surfactant: a material that strongly reduces the attractive forces between nanocrystals. This isolates every single nanocrystal from the attractive forces of nearby nanocrystals and prevents them from clumping together and forming a single solid mass.

When there is no magnet present, ferrofluid particles move freely in the liquid. In the presence of a magnet, the particles are temporarily magnetised and the ferrofluid acts more like a solid. When the magnet is removed, the particles lose their magnetisation and ferrofluid behaves like a non-magnetic liquid again. This behaviour is called 'superparamagnetism'.

When an external magnetic field is applied, the originally random organisation of the nanoparticles changes and they immediately align to the magnetic field, becoming magnetic themselves. So ferrofluid is a liquid material that has solid properties when submitted to a magnetic field. But: ferrofluid is not a liquid magnet!

This is different from the magnetite sand which is always magnetised.

When all the nanoparticles are randomly organized in the absence of a magnetic field, the ferrofluid is a non-magnetic fluid



When all the nanoparticles are aligned in the magnetic field, the ferrofluid becomes magnetic

Applications

Making a ferrofluid is not quite as simple as mixing tiny particles into a liquid. The particles need to be so tiny that they cannot be made just by crushing or scraping a magnetic material but must be precipitated out of a solution.

Ferrofluids were originally developed in the 1960s at the NASA Research Centre, where scientists were studying different possible ways of managing liquids, especially fuel. In space there is no gravity so liquid materials do not stay in a glass and cannot be poured from one container to another! The scientists were able to make a new kind of liquid that can be driven and controlled through the application of a magnetic field.

Ferrofluid's proprieties make it useful for many different applications. Computer hard disk drives and other rotating shaft motors use ferrofluid in their seals, while loudspeakers use ferrofluid to dampen vibrations. In the future, ferrofluid may be used to deliver medications, using magnetic fields to carry the ferrofluid and medication to a specific location in the body. Using electromagnets and sensors, the thickness of ferrofluid can be controlled dynamically; some sports cars use this in their active damping suspension systems.

Some organisms use nanocrystals of magnetite. During migration, trout can orientate themselves using magnetite crystals in special cells in contact with their central nervous system that are used as a compass. The bacterium *Magnetotacticum bavaricum* is able to produce nano crystals of magnetite.

Ideas for conducting the activity or discussion

- You could ask the children what they think ferrofluid is and what is the difference between magnetite sand and ferrofluid.
- You could ask them what applications ferrofluid could have.

Learning objectives or school curriculae

- To introduce magnetism.
- To understand the different behaviours of matter at macroscopic and nanoscopic scales.
- To have an idea of how scientists and engineers are able to manipulate matter at the nanoscale.

timefornano

5

from 8 years

ferrofluid

Be careful!

DO NOT BREAK THE TUBES!
DO NOT OPEN THE TUBES!
DO NOT SHAKE THE TEST TUBES!
Handle with care. In case of contact with skin, wash with copious amounts of water and soap.
If the test tube breaks, do not throw the ferrofluid down a sink.
Do not bring the ferrofluid near a flame.

You will need

- Test tube containing black sand
- Test tube containing ferrofluid
- Blue button magnet
- A compass

What you can do

- Examine the tubes and their contents
  What is the main difference between the magnetite sand and the ferrofluid?
- Put the magnet close to the test tube containing the black sand, let it slide along the test tube. **How does the sand react?** Remove the magnet from the test tube, **what happens?**
- Try the same things with the test tube containing the ferrofluid and look at the resulting shape. **What does it look like?** Remove the magnet. **What happens?**
  Do ferrofluid and magnetite sand look the same then the magnet is near? What about when it is removed?
- Place the compass next to the magnetite sand. **What does the compass do?** Now shake the test tube and place the compass next to it. **What does the compass do now?**
- Now place the compass next to the ferrofluid. **What does the compass do?** Place a magnet next to the ferrofluid tube for a little while. Remove the magnet and quickly put the compass next to the tube. **What happens?**
  Do the magnetite sand and the ferrofluid have the same effect on the needle of the compass?
  Do you have any ideas what ferrofluid could be useful for?

What's happening?

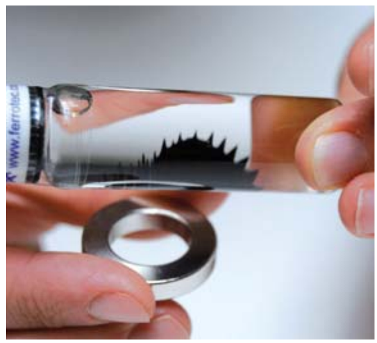
Ferrofluid and black sand are made of the exact same material: **magnetite**, an iron oxide. But, the ferrofluid is made of **nanometric** crystals of magnetite whereas black sand is made of macroscopic grains of magnetite.

This size difference explains why, when in the presence of a **magnetic field**, ferrofluid and black sand don't behave in the same way. Black sand, as shown by the compass, is permanently magnetic even in the absence of a magnet. Ferrofluid is a unique material that acts like a magnetic solid in the presence of a **magnetic field**, but like a non-magnetic liquid if there is no **magnet** around.

Ferrofluid has several potential technological applications in mechanics, industry, electronic devices and in the future, maybe even in medicine.

To find out more

- Art and ferrofluid: http://www.youtube.com/watch?v=CJGBy_yygaQ
- http://homes.nano.aau.dk/tgp/ferrofluid.pdf
- http://www.photonics.com/Content/ReadArticle.aspx?ArticleID=15447
- http://en.wikipedia.org/wiki/Ferrofluid



What does it mean?

Magnetite is a browny/ black iron oxide that is magnetic. Magnetite occurs in many different types of rocks and is an important source of iron.

A **magnet** is an object made of iron, steel, nickel or cobalt that creates an invisible magnetic field around itself.

A **magnetic field** is the region surrounding a magnet where its influence is detectable. Materials that can be magnets are attracted to magnetic fields.

A **compass** is a freely turning magnet which shows the direction of a magnetic field. If no magnet is around, the compass shows the direction of the magnetic poles of the Earth.

A **nanometre** is a billionth of a metre (0.000 000 001 m)

magic sand

Health and safety

Magic Sand is quite safe. However, care should be taken to ensure that it is not ingested or inhaled and that it does not come into contact with eyes. Prolonged exposure to skin should be avoided.

What happens in this experiment?

Magic Sand is regular sand (silicon dioxide: SiO_2) that has been coated with a special nano-coating. This nano-coating is hydrophobic ('water hating'). When Magic Sand is poured onto water it won't mix with the water but will float until the mass of the sand breaks the surface tension of the water, making the sand sink. The Magic Sand in the kit is made by exposing regular sand to vapours of trimethylsilanol $(CH_3)_3SiOH$.

Nanoscientists are interested in the coatings that make Magic Sand as they are within the nanoscale; that is a size range of 0.1 - 100 nm (that's ten billionths of a metre to ten millionths of a metre!).

Applications

Magic Sand was originally developed to trap ocean oil spills near the shore. By sprinkling Magic Sand onto floating petroleum, the Magic Sand would mix with the oil and make it heavy enough to sink.

Unfortunately, due to the expense of production it is not currently being used for this purpose. However, since Magic Sand never freezes, utility companies in the Arctic areas have tested it as a foundation for electrical boxes.

Ideas for conducting the activity or discussion

- Encourage participants to examine the sand in its normal (dry) state - it should appear identical to the sand on a beach (except for its colour!).
- Ask participants to experiment with the sand in water - what shapes can they make?
- Participants should try and think why the sand is behaving in this way.

Learning objectives or school curriculae

- An understanding of hydrophobic and hydrophilic forces.
- Appreciation that nanotechnology can be used to modify existing substances.

from 8 years

magic sand

Health and safety

- Do not eat the magic sand!
- Do not get the magic sand in your eyes!
- Avoid inhaling fine particles of sand
- Avoid prolonged contact between the sand and your skin

You will need

- Magic sand
- Water
- Glass (or other transparent material) container
- A spoon
- A fine sieve

What you can do

- Examine the sand
  Does it feel like normal sand? Does it behave like normal sand when it's dry?
- Pour the magic sand into the water
  What happens? Look at the surface of the sand in the water; do you notice anything? What might cause this effect?
- Put your hand into the water and lift out the sand
  What does it feel like? Is it still wet?
- Pour the sand slowly onto the water
  What happens and why is this?
- Pour a layer of sand onto the surface of the water. Gently push your finger into the layer of sand and pull it out again.
  Is your finger wet?
- Can you make a really skinny column of sand by the way you pour it?
- What happens if you pour the sand into the water through a straw or funnel? What happens if you pour out the water through a fine sieve?
- Put some dry sand on a piece of paper and drop water onto it using the pipette
  Does it act like sand on the beach?

Taking the magic out of your sand!

- Take a very small amount of magic sand to destroy. Sprinkle it onto the water's surface so it floats. Using the Pasteur pipette, squeeze a drop of liquid detergent onto the surface of the water.
  What happens?
- Now try the above experiment with a drop of vegetable oil
  What happens this time?

What's happening?

Magic Sand is regular sand (silicon dioxide: SiO_2) that has been coated with a special nano-coating. This nano-coating is **hydrophobic** ('water hating'). When Magic Sand is poured onto water it won't mix with the water, but will float until the mass of the sand breaks the surface tension of the water and the sand sinks. The Magic Sand in the kit is made by exposing regular sand to vapours of trimethylsilanol $(CH_3)_3SiOH$.

Oil is a common example of a hydrophobic material. If you pour some oil into a cup of water, it will float on the surface and tries to stick together away from the water. Magic Sand behaves in the same way, except it sinks because unlike oil, sand is denser than water.

Magic Sand was originally developed to trap ocean oil spills near the shore. By sprinkling Magic Sand onto floating petroleum, the Magic Sand would mix with the oil and make it heavy enough to sink.

What does it mean?

Sand is any particle between 60 μm and 2 mm in size. Smaller than this is 'silt' and larger is 'gravel'.

Silicon is a very common chemical element that is the basis of most of the minerals composing the rocks of earth.

Hydrophobic and **hydrophilic** literally mean 'water hating' and 'water loving'. Hydrophobic substances will not mix with water, while hydrophilic substances will. Oil and magic sand are hydrophobic. Ethanol, salt and sugar are hydrophilic.

Amphipathic substances can mix with hydrophobic and hydrophilic substances. Detergents are amphipathic and contain both hydrophilic and hydrophobic parts.

To find out more

- http://www.flyingcolours.org.uk/cgibin/item.cgi?ap=1&id=1457
- http://bit.ly/66XJ1N

hydrophobic textile

Health and safety

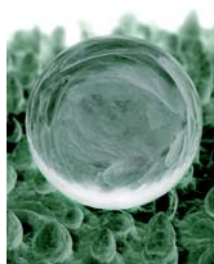
The textile should not be rubbed too much as it could damage the fabric

What happens in this experiment?

This experiment mimics the natural 'lotus effect' in which water is repelled by a surface.

Something that can repel water is known as 'hydrophobic' (from the Latin words 'hydro' meaning water and 'phobic' meaning hating). The 'lotus effect' is named after the leaves of the lotus plant which are particularly hydrophobic.

Lotus leaves repel water due to nanoscale structures on their leaves (see the image of the leaf above). Normally, surface tension affects only the top of a water droplet - the bottom sticks to whatever surface it is on. But on a lotus leaf something very different happens: nanoscale bumps on the leaf's surface prop the drop up, so it is almost entirely surrounded by air. This creates surface tension on all sides making the water bead up more tightly thus sticking to the leaf less.



Just a tiny movement of the leaf makes the water droplet roll smoothly off, taking any dirt particles with it, making lotus leaves self-cleaning. This protects the plant by removing dust, fungi, algae and spores.

Applications

Technologies inspired by the lotus leaf structure include self-cleaning windows and self-cleaning paint. For example, Lotusan® paint has been applied to over half a million buildings since its launch a decade ago.

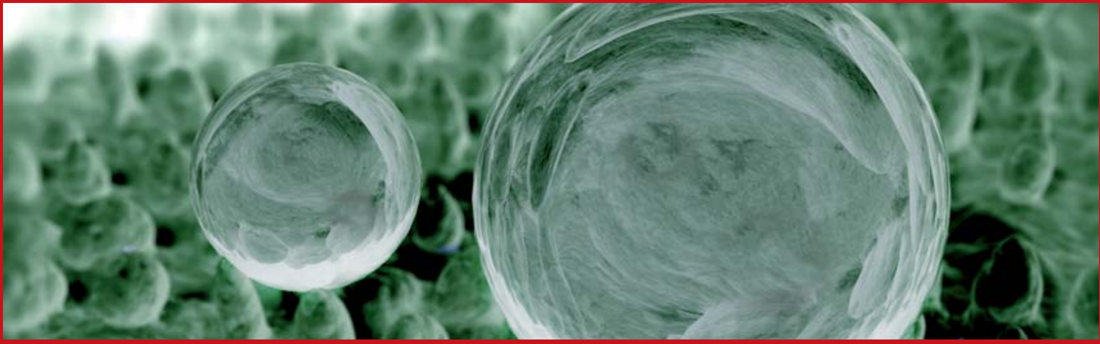
Fabrics coated with nanotextured surfaces aren't entirely self-cleaning. However, just a small amount of water will roll around the surface of the fabric attracting dirt particles. This means far less detergent and water can be used to clean these fabrics, which in turn is better for the environment.

Ideas for conducting the activity or discussion

- Ask participants how they think the lotus effect works and where they can see it in nature.
- Ask them of what kind of applications they can think of for hydrophobic surfaces.
- You could compare the hydrophobic textile with the next activity, 'anti fog', as it too is a self-cleaning technology, but one that works in the opposite way.

Learning objectives or school curriculae

- To understand how nanoscale structures affect the physical properties of a surface at the macroscale.
- To learn about hydrophobicity.
- To discover an application of nanotechnologies.



hydrophobic textile

Health and safety

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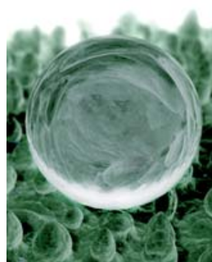

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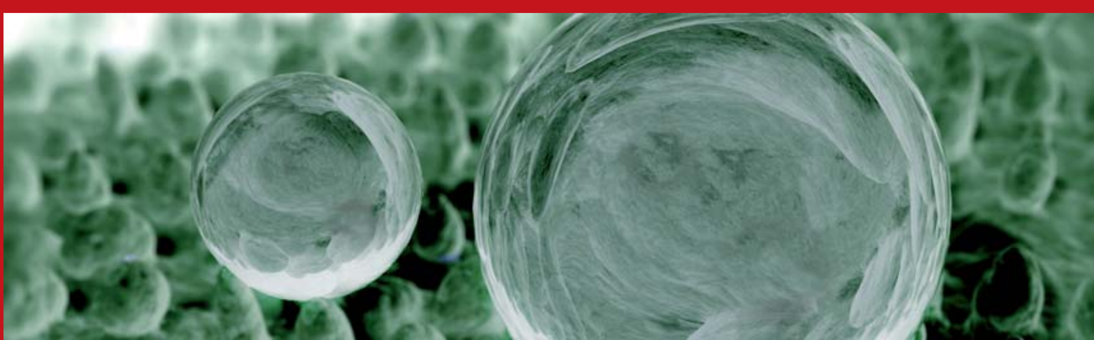


hydrophobic textile

Health and safety

Avoid rubbing too much the textile as it will damage its properties

You will need

- A piece of hydrophobic textile
- A Pasteur pipette
- Water
- A cabbage leaf

What you can do

- Take some water in your Pasteur pipette and place it, drop by drop, onto the surface of your fabric.

What happens to the water?
What happens to the fabric - is it wet or dry?

- Now sprinkle some chalk dust on the surface (don't rub it in as it will spoil the fabric) and drop some water over the surface

What happens to the dirt on the surface?

- Take the cabbage leaf and drop some water onto it with the Pasteur pipette

Is it similar to the fabric?
What do you think makes the fabric act like this?
Can you think of applications for this fabric?

What's happening?

Surfaces that can repel water are known as '**hydrophobic**' (from the Latin words 'hydro' meaning water and 'phobic' meaning hating). The 'lotus effect' refers to a particular type of very high water repellency found in nature. It is named after the lotus plant, whose leaves are very hydrophobic. This textile mimics the lotus effect.

When rain falls on the surface of the lotus plant, tiny nanostructures on the leaves keep the water droplets in a spherical form. This means the water droplets roll easily off the surface, picking up dirt particles as they go. This keeps the surface of the leaves clean and dry.

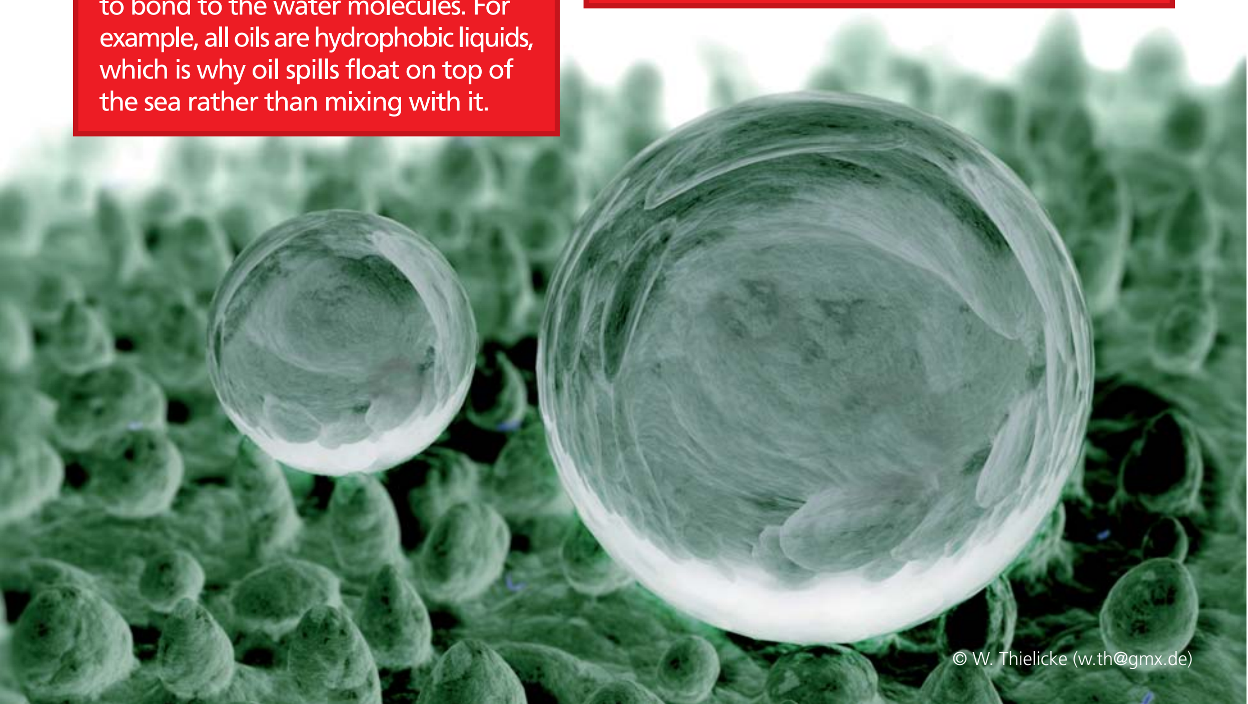
If you look carefully at the duck in the photo you can see that the water on its back is in the form of droplets. If the water was not like this it would get through the duck's feathers and the duck would get wet and cold. The duck's feathers are also superhydrophobic in part because of the structure of their wings at the nanoscale.

What does it mean?

Hydrophobic surface: A surface that wants to stay dry and will repel water without getting wet itself. More generally, a hydrophobic compound is a substance that can't be mixed or dissolved in water because it is not able to bond to the water molecules. For example, all oils are hydrophobic liquids, which is why oil spills float on top of the sea rather than mixing with it.

To find out more

- http://nanotechweb.org/cws/article/tech/16392
- http://www.lotus-effekt.de/en/faq/index.php
- http://live.psu.edu/story/34610
- http://en.wikipedia.org/wiki/Lotus_effect



Health and safety

Do not inhale the vapours of the aerosol.

Ensure the room is well ventilated during the anti-fog application.

Keep away from eyes and wear waterproof rubber gloves when applying the spray.

We advise that you prepare the glass outdoors or in a ventilated room before the children are present and at least half an hour before doing this experiment.

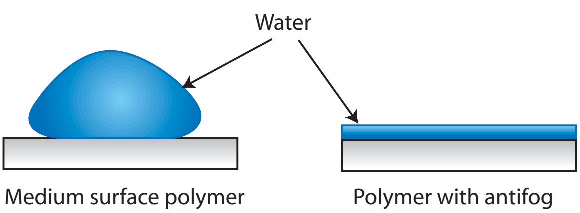
What happens in this experiment?

The anti-fog spray is composed of nano-particles suspended in an alcoholic solution. When the solution dries only the nano-particles stay on the surface while the alcohol evaporates.

Anti-fog agents create a thin film that does not allow the formation of water droplets. This film reduces the **surface tension** of the liquid (the surface tension is the result of the cohesive forces between the molecules that are responsible for the formation of spherical droplets). In the case of water its surface tension is very high. The angle of contact (the angle between the water droplet and the surface it is resting on) is much lower with the surfactant and water sprayed on the surface creates a thin layer instead of forming round droplets.

This is explained by the fact that the nano-particles applied to the surface by the anti-fog spray are **hydrophilic**. This means that they can bond with water molecules through weak chemical bonds called **hydrogen bonds**. The glass itself is slightly hydrophilic and the anti-fog spray increases this property. The water is therefore subjected to two different forces: reduced surface tension that tends to round off the droplets, and bonding to the anti-fog nano-particles that flattens them.

The result is a very thin layer of water on the surface of glass through which it is still possible to see. This type of technology helps prevent goggles used for skiing or swimming steaming up.



Anti-fog flattens the droplets of layer in a thin, transparent layer

Applications

Anti-fog sprays can be defined as a self-cleaning technology since they use the interaction between water and the surface to repel dirt or grease. Water-repellent textiles (see activity 7 on hydrophobic textiles) or water-repellent compounds (also called hydrophobic compounds) are also classified as self-cleaning materials although they work in the opposite way. Anti-fog spray reduces the contact angle between water drops and the glass surface and flattens them out; water-repellent textiles increase this angle and cause round drops that simply roll off the surface.

Why are they self-cleaning? In super-hydrophilic conditions cleaning occurs when the thin layer of water flowing on the surface washes away dust and dirt. Super-hydrophilic surfaces are also oleophobic, which means that they repel oil and grease which makes them in turn easier to clean. Super-hydrophobic coatings cause the formation of spherical droplets that roll off the surface, picking up particulate dirt in their path.

Anti-fog coatings are used to prevent fog forming on optical devices or windows. As they maintain a thin layer of water, hydrophilic coatings can also be used as lubricants and increase the durability and the resistance to abrasion of some materials. Finally, hydrophilic coatings of rubber can be use in sealant products to stop water leaks: the water is attracted to the coating, so less is available to flow through gaps.

If we can be sure that these types of products have no negative environmental impact, this nanotechnology presents a good solution for avoiding the use of large quantities of detergents, plastic and chemical products. Scientists are currently looking for a way to create a permanent anti-fog layer using silica nanoparticles that will last much longer than the anti-fog spray.

Ideas for conducting the activity or discussion

- You could try the anti fog on a mirror.
- You could ask the children in which situations they would have liked to have an anti-fog spray.

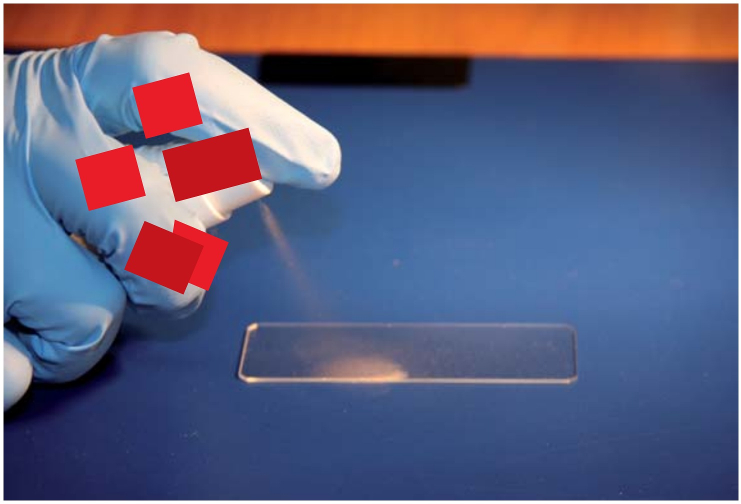
Learning objectives or school curriculae

- To understand how nanoparticles can be used to provide a coating that prevents fog formation.
- To have an example of an application of nanotechnology and nanoscience.
- To learn more about the hydrogen bonds that are responsible for some of the unique properties of the water molecule.

anti fog

You will need

- Anti-fog spray
- Two slides
- Protective glove
- Soft cloth



Health and safety

- **Do not inhale** the vapours of the aerosol.
- **Ensure** the room **is well ventilated** during the anti-fog application.
- **Keep away from eyes** and wear waterproof rubber gloves when applying the spray.

What you can do

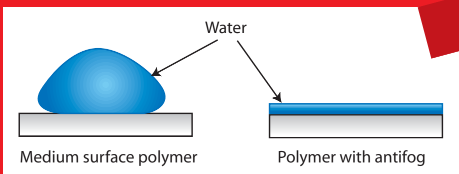
- Use a dry cloth to clean one slide well. Don't use liquid detergent!
- Put on protective gloves and then pick up the spray.
- Shake it and spray a thin layer of the liquid onto one side of the slide. Take care to avoid contact with eyes.
- Evenly distribute the film on the slide with a soft cloth before the anti-fog layer dries.
- Wait 30-60 minutes to let it dry.
- Breathe on the slide. **What do you notice?**
- To compare, breathe on a slide that has no anti-fog layer

Is there any difference between the two slides?

What's happening?

Anti-fog coatings prevent the formation of very small water droplets on glass or plastic surfaces. This compound, in general called a **surfactant**, creates a thin film that doesn't allow the formation of water droplets created by the humidity in your breath. The thin film is **hydrophilic**, or 'water loving', and causes water droplets to spread out evenly on the surface of the glass instead of remaining spherical.

Anti-fog coating is defined as a self-cleaning technology because it can help keep surfaces free of dirt and grease. In the field of self-cleaning surfaces, a substrate that remains clean can also be achieved with **hydrophobic** technology (see activity 7 on the hydrophobic textile). These two kinds of approach depend on how the nanodimensional structures of the surfaces interact with the external particles.



Anti-fog flattens the droplets of layer in a thin, transparent layer

To find out more

- Make your own anti-fog spray: http://www.articleslog.com/2007/12/10/97668 make-your-own-anti-fog-spray.html
- http://www.wordconstructions.com/articles/technical/hydrophilic.html
- On hydrogen bonds: http://www.elmhurst.edu/~chm/vchembook/161Ahydrogenbond.html

What does it mean?

Surfactant: the name comes from 'Surface active agent' and refers to all natural or synthetic substances that are able to reduce forces on the surface of a fluid (surface tension). These forces are responsible for the formation of spherical drops. Water has a very high surface tension and easily forms spherical drops due to chemical bonds called hydrogen bonds.

Hydrophilic surface: A surface with strong affinity for water. A hydrophilic compound can bond with water via hydrogen bonds and can be mixed or dissolved easily in water. Vinegar and fruit juices are examples of hydrophilic liquids which can be mixed with water.

Hydrophobic surface: A surface that has no affinity for water and will repel it without getting wet. More generally, a hydrophobic compound is a substance that can't be mixed or dissolved in water because it is not able to bond to the water molecules. For example, all oils are hydrophobic liquids, which is why oil spills float on top of the sea rather than mixing with it.

Health and safety

This experiment involves using hot water and naked flames. Appropriate care should be taken for both of these. Participants should be aware that the metal will be hot when in the water or the flame and should handle it with care (using gloves or tweezers).

What happens in this experiment?

Most metals are very hard and take a lot of effort to deform, but once they have been moulded into shape they will stay like that until another force changes them. Memory metals, or 'shape memory alloys' (SMAs) are different. They can be 'programmed' to remember a specific shape and if the metal is bent or deformed it quickly returns to its original configuration.

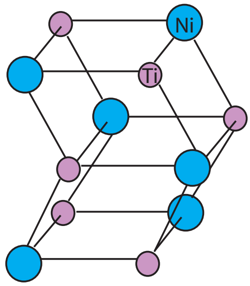
This is because memory metal has two distinct crystal structures at the nanoscale and can be made to flip between them. Both are regular lattices. The so-called 'parent' phase (or 'austenite' phase) occurs when the metal is at higher temperatures. When shaped at high temperatures the metal will 'remember' this shape. As the metal cools, its crystal structure changes to the second ('martensite') phase. Gentle heating of the metal makes it return to its original parent shape.

The memory metal that you have is called 'Nitinol' and it is an alloy of nickel and titanium.

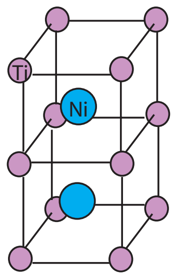
The transformation in both directions (martensite to austenite and vice-versa) is instantaneous. By making small changes in the relative composition of the Nitinol, the temperatures at which the two phases occur can be changed.

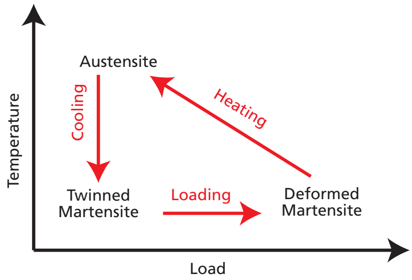
The Nitinol provided is in its martensitic phase at room temperature. It can be deformed at will before being heated, which will force it to return to its parent phase.

Martensite



Austenite





Applications

Glasses which are made of memory metal take advantage of a phenomenon called 'pseudoelasticity'. In this instance, the metal is in its austenite phase at room temperature and the martensitic phase is brought about by applying a stress, rather than cooling. When the stress is removed, the metal reverts to its austenite phase and its associated shape.

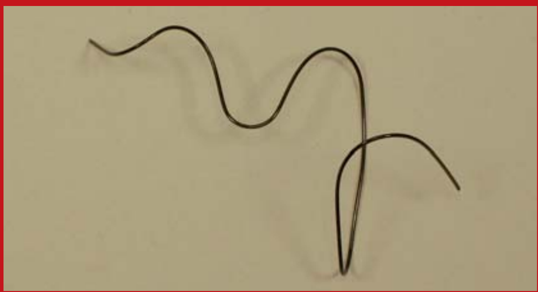
Nitinol is used in orthodontics for braces. Once the Nitinol is placed in the mouth its temperature rises to ambient body temperature causing it to contract back to its original shape. This results in a constant force being applied to the teeth. Nitinol wires do not need retightening as often as they can contract as the teeth move, unlike conventional stainless steel wires.

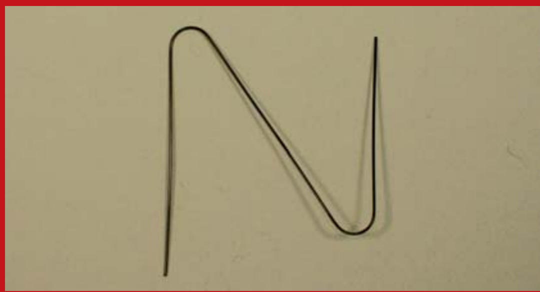
Ideas for conducting the activity or discussion

- Memory metal is good fun - let the participants see how much they can deform the metal; provided they don't tie it in a knot, it should return to its original shape when put into hot water.
- Ask participants what they think memory metal could be used for? It can be used in glasses, and also in stents. Stents are medical devices that help to keep open vessels within the body (such as veins or arteries). They can be inserted collapsed (in their deformed state) and then gently heated to make them expand (into their memory state). This helps reduce tissue damage while the stent is being put in place.

Learning objectives or school curriculae

- Basic understanding of the crystal lattice structure of metals.
- Understanding of the practical applications of shape memory alloys.





memory metal

You will need

- A piece of memory metal
- Hot water
- A Bunsen burner or other source of naked flame
- Tweezers to hold hot metal

Health and safety

- Be careful with hot water
- Be careful with naked flames
- Be careful handling the hot metal (use tweezers)

What you can do

Note: Use tweezers whenever you remove the wire from hot water, or hold it in the Bunsen burner flame

- Set your water bath to hot (about 70°C).
- Take your memory metal wire and make a note of its shape. Twist and deform the wire, but do not tie a knot in it! Now put the wire into the hot water.
  What happens?
  Does it remember its original shape?
- Make a bend in your wire. Hold the wire with tweezers and use your Bunsen burner to heat the bent bit of wire for 10-20 seconds. Place in the cool water.
- Now place it back into the hot water
  What happens?
- Take it out of the hot water and let it cool again. Twist and deform it again and place it back into the hot water.
  What shape does it adopt?
- Cool your water to 25°C. Twist your wire and put it in the cooler water.
  Does anything happen?
- Increase the temperature of your water bath by 10°C and try again. Keep doing this until something changes.
  What changes and at what temperature?
  What do you think is happening?
  How can you explain everything that is happening?
  Why do you think this type of wire is used in braces for teeth?

What's happening?

Most metals are very hard and take a lot of effort to deform, but once they have been moulded into shape they will stay like that until another force changes them.

Memory metals are different. They can be 'programmed' to remember a specific shape and if the metal is bent or deformed it quickly returns to its original configuration. They are called **Shape Memory Alloys**. The one you have in your hand is called **Nitinol**.

Memory metal has two distinct crystal structures at the nanoscale and can be made to flip between them. Both are regular **crystal lattices**.

What does it mean?

Shape memory alloy (SMA) is any metal that 'remembers' its original shape and if deformed can return to that shape after it is heated up.

Nitinol is a type of SMA made of nickel and titanium.

Crystal lattice is the regular arrangement of atoms making up an element or compound.

To find out more

- http://www.stanford.edu/~richlin1/sma/sma.html
- http://jmmedical.com/nitinol.html
- http://en.wikipedia.org/wiki/Nickel_titanium#Applications
- http://www.nitinol.com/nitinol-university/

Applications

Nanotechnologies can potentially be applied in many different scientific fields. In the near future a lot of scientific developments are expected as a result of these technologies.

- **Health:** Nanoparticles can be used as miniaturised diagnosis labs (called 'a lab on a chip'). These could help to discover illnesses earlier and find the best treatment method. Nanoparticles could also be used as medicines that specifically target diseased tissues such as cancer cells.
- **Environment:** Nanoparticles could be used as filters to clean up polluted land or water. Scientists also think that nanotechnology will improve the efficiency of solar panels.
- **Materials science:** Nanotubes of carbon are already used in sports such as tennis and sailing. A nanotube of carbon is 100 times stronger and six times lighter than steel. Some experts even estimate that a nanotube narrower than a human hair might be able to suspend a lorry trailer, although a nanotube that big has not yet been made to test this!
- **Computer science:** With nanoprocessors we would be able to make an electronic device as small as a credit card that could also be a cell phone, a video recorder, a camera, a GPS locater and even a credit card all in one.

These are only a few examples of what we hope will be possible with nanotechnologies and nanosciences. Many more applications are expected soon.

Ideas for conducting the activity or discussion

Here are a few numbers that you can discuss with the students:

- A human hair is between 50 000 and 100 000 nm wide.
- A red blood cell is around 7 000 nm in diameter.
- A typical bacteria measures around 1000 nm.
- Most viruses are between 10 nm and 250 nm in size.
- The DNA double-helix is approximately 2 nm wide.
- The typical diameter of an atom is between 0.1 and 0.5 nm.

You can also discuss of the other scales used for measuring distances such as kilometres and millimetres.

Learning objectives or school curriculae

- To understand how small a nanometre is through comparisons to everyday measurements such as height.
- To introduce the world of nanosciences and nanotechnologies.
- To understand the different prefixes used before a measure unit.