PHYSICS on Stage 3

Demonstrations and teaching ideas

selected by the Irish Team

“In the matter of physics, the first lessons should contain nothing but what is experimental and interesting to see. A pretty experiment is in itself often more valuable than twenty formulae extracted from our minds.”

Albert Einstein

A. Moszkowski 1970 *Conversations with Einstein* (Horizon Press) p67

PHYSICS ON STAGE 3

Team and contributors

The POS3 team (left to right): Jennifer Egan, Joanna Dullaghan, Paul Nugent, Alison Graham, Eilish McLoughlin, Tim Roe, Nancy Roe and Sean Fogarty.

The POS3 contributors: Sean Fogarty, Paul Nugent, Alison Graham, Eilish McLoughlin, Jennifer Egan, Tim Roe, Alison Hackett, Ian Elliott, Eamonn Cunningham and Vida Given.

Disclaimer

The National Steering Committee for Physics on Stage 3 (POS3) has made every effort to ensure the good quality of the information presented in this publication. Teachers should ensure the safety of the demonstrations in their own laboratories. This document has been produced by volunteers and, thanks to our sponsors, is distributed free of charge. It is intended as a support resource for teachers of physics and is not published for profit.

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Any comments or suggestions would be welcomed by the committee and can be sent to Alison Hackett, Physics on Stage 3, c/o Department of Experimental Physics, University College Dublin, Belfield, Dublin 4.

http://ireland.iop.org/pos3/

PHYSICS ON STAGE 3: Contents

Physics on Stage 3, Noordwijk, the Netherlands, 8–15 November 2003

"The wealth of ideas and material on display is staggering, and in my 18 years of teaching I have not attended anything quite like this. There are so many new experiments and approaches that can be used in the class that I feel I have learned more 'tricks of the trade' in one week than I did in all my previous years' teaching."

Sean Fogarty, Irish delegate

What is Physics on Stage?

Physics on Stage (POS) is a unique Europe-wide programme that aims to raise public awareness of physics and related sciences by bringing physics teachers together for a week, allowing them to exchange ideas and assess the current situation in physics education. POS3 was hosted by the European Space Agency (ESA) at its European Space Research and Technology Centre in Noordwijk, the Netherlands. Some 400 delegates from countries all over Europe set up their national stands to display physics experiments of various kinds.

The Irish stand at POS3.

Ireland takes a prize

The centrepiece of the Irish stand was a demonstration of the Coriolis effect. Tim Roe, a retired physics lecturer from GMIT, brought a model that splendidly demonstrated the effect that's responsible for causing the rotary movements of the atmosphere associated with weather patterns. The device even shows the different rotations set up in the northern and southern hemispheres. Tim's model deservedly won the award for "most original demonstration of a scientific principle". Other countries' demonstrations, in keeping with the show's theme, Physics and Life, included a full model of the workings of the inner ear on the Greek stand and another illustrating the principles behind the MRI scanner on the Belgium stand.

Tim Roe and the Coriolis effect.

Broken hardware experiments

Many stands made use of materials that are commonly available by scavenging old appliances, such as computers and microwaves. For example, the Czech stand had a range of experiments performed using items rescued from defunct computer CD and hard drives – colour mixing, magnetism, gyroscopes and the conversion of mechanical energy to electrical energy were all demonstrated with this equipment. These were just a few of the hundreds of good ideas and nice tricks to be seen at the fair – far too many to mention here.

Vaclv Piskac recycling hardware.

Performances and workshops

Time was set aside for performances, presentations and workshops. The performances covered all areas of physics with titles such as "Simple experiments on the physics of vision", "Food for life" and "Alice in quantum-land". They used a variety of methods from large-scale demonstrations and theatrical performances to audience participation, all to convey information about the principles of physics. The workshops, which everyone was encouraged to attend, covered topics such as "New resources for science teachers", "Training", "Equipment", "Performance in teaching" and "Research links" – all areas that could result in improved pan-European science education.

A physics performance at POS3.

At the time of going to print the next European Conference for Physics Teachers is planned to be called Science on Stage. This will be held on 21–25 November 2005 at CERN with the theme Science for Humanity. Details can be found at www.physicsonstage.net.

This project was made possible by the generous sponsorship of Discover Science and Engineering, Physics on Stage and the Institute of Physics in Ireland. The Department of Education and Science kindly provided substitution cover for the four full-time teachers who attended the conference.

The gratitude of the thousands of teachers and educators who receive this free booklet of demonstrations and teaching ideas must principally go to the very hard-working authors: Paul Nugent, Sean Fogarty, Alison Graham, Jennifer Egan, Eilish McLoughlin, Vida Given and Tim Roe. They all work full time, yet, despite this, they produced this excellent selection of demonstrations selected from the Physics on Stage 3 (POS3) conference. This meant testing and developing the demonstrations and creating images for them. This publication would not exist without their very professional commitment. The team has also been most generous giving their time to present many of these demonstrations at physics and science teachers' conferences and in-service meetings in both the Republic of Ireland and Northern Ireland.

The seven mentioned above were delegates at POS3, but the Irish delegation also included Joanna Dullaghan and Nancy Roe, whom we thank for their time and dedication. Our congratulations to Tim Roe for being the creator and presenter of the excellent Coriolis demonstration, which won one of the main prizes at POS3 (p56).

Gerard McMahon deserves special thanks for his very hard work as the secretary of POS3 in the early stages, including arranging the mailing of a request for demonstration submissions from physics teachers in every school, setting up the first website and making many of the first communications with POS3.

Thanks are due to Eilish McLoughlin for taking on the role of treasurer and to Eamonn Cunningham, former POS treasurer, for remaining on the committee and providing guidance and help with the financial management of POS3. Our thanks also go to the other committee members, who helped with planning for POS3 and with editing: Ian Elliott, Michael Grehan, John Hennessy and Diarmuid O Leary. Special thanks go to Daniel Robinson for his excellent artwork on the eye and to Michael Grehan for his help with some of the digital images.

The National Steering Committee for POS3 would also like to thank the following institutions and people for providing meeting rooms and resources to help with this project: Tim Regan, physics coordinator, Second Level Support Service; Anna Walshe, Junior Science Support Service; Dublin City University Physics Department; Belvedere College Dublin; University College Dublin Department of Experimental Physics.

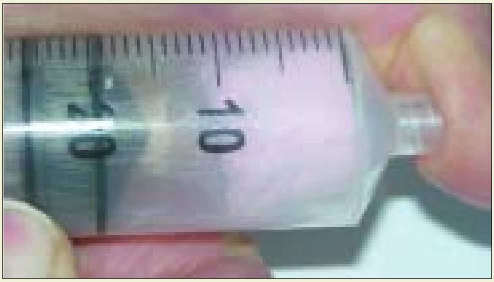
Thanks are also due to the management of the following schools: St Dominic's High School, Santa Sabina, Sutton, Co. Dublin; Sandford Park School, Ranelagh, Co. Dublin; St Mary's, New Ross, Wexford; and St Joseph's Cluny, Killiney, Co. Dublin.

Alison Hackett Chair, Physics on Stage 3
Paul Nugent Delegation chair, Physics on Stage 3

The incredible shrinking marshmallow

Spain/Austria

At constant temperature, volume increases as pressure decreases



Background

Boyle's Law states that when the temperature is held constant, the volume of a gas is inversely proportional to its pressure.

Follow these steps

1 Place a cylindrical marshmallow inside a large plastic syringe.
2 Place your thumb over the end to seal the nozzle.
3 Push the plunger in and then out and note what happens now.

So what happened?

The marshmallow shrinks when you push the plunger in but then regains its original size when you pull the plunger out again.

The structure of a marshmallow is such that there are many bubbles of air trapped by sugar molecules. There is a fixed number of air molecules inside the marshmallow–syringe system.

As the plunger is pushed in, the pressure inside the syringe increases and the bubbles of air decrease in size, therefore the volume of the marshmallow decreases. Exactly the opposite then occurs when the plunger is pulled outwards.

Eventually the marshmallow responds less well because bubbles of gas inside it have been punctured because their internal pressure is much greater than the external pressure.

You will need...

- ✔ a large plastic syringe
- ✔ fresh marshmallows

Note: you can also perform this demonstration with a wine-bottle pump (used to expel air from a wine bottle to prolong the life of the unfinished wine)

What next?

Boyle's Law can also be demonstrated by placing a marshmallow or a partially inflated balloon inside a bell-jar and then evacuating the jar – the marshmallow/ balloon swells as the pressure is reduced.

Surprisingly, this also works well with ice cream.

Can you feel the force?

The Czech Republic

You can really experience and feel atmospheric pressure

You will need...

- ✔ a large paperclip
- ✔ a CD
- ✔ a piece of string
- ✔ a large sheet of newspaper

Background

We live at the bottom of an ocean of atmosphere. Atmospheric pressure is equivalent to the weight of 10 tonnes over a square metre.

Follow these steps

1 Attach the CD to the string using the paperclip.
2 Feed the string through a small hole in the centre of the sheet of newspaper.
3 Place the newspaper flat on the ground without allowing any wrinkles.
4 Exert a firm upwards tug on the string.

So what happened?

It is surprisingly difficult to lift the newspaper because of the atmospheric pressure acting on it.

The balloon ‘sucked’ into a bottle

Belgium

Witness the effects of atmospheric pressure

You will need...

- ✔ a bottle
- ✔ a balloon
- ✔ a piece of string
- ✔ boiling water

Background

This experiment is a variation on the egg-in-a-milk-bottle experiment, which is often used to demonstrate the effect of atmospheric pressure. In this version a water-filled balloon is used.

The advantage of the balloon is that its size can be adjusted by changing the amount of water in the balloon, allowing it to be customized to fit whatever bottle you have.

Follow these steps

1 Attach a piece of string to the neck of the balloon.
2 Pour some boiling water into the bottom of the bottle.
3 Place the balloon over the neck of the bottle so that it makes an airtight seal.
4 Allow the water to cool.

So what happened?

As the temperature falls the warm vapour condenses and the internal pressure drops, so the balloon is sucked (or, more correctly, pushed by external pressure) slowly into the bottle. If you stand the bottle in cold water you can speed up the process.

The experiment proceeds slowly compared with the demonstration that uses an egg and burning methylated spirits in a milk bottle. Students therefore have more time to observe what is going on and work out what might be happening.

The string attached to the balloon makes it easy to remove the balloon from the bottle at the end of the experiment.

What next?

This can lead to a discussion about atmospheric (condensing) engines, which were the first type of steam engine that worked on this principle and were first used in coalmines.

Pressure with a difference

Belgium

Pressure is dependent on depth

You will need...

- ✔ a sealed container (e.g. a sweet tin)
- ✔ a piece of wooden dowel
- ✔ a container of water

Background

The pressure exerted on a fluid depends on the depth of the fluid.

Follow these steps

1 Glue a piece of dowel to the centre of the tin (see picture).

2 Make two holes in the lid of the tin, about 1–2 mm in diameter, one each side of the dowel, about halfway between the rim of the tin and the dowel. The holes and dowel should all lie along a straight line.

3 Ask the students what will happen if you lower the tin into the water while keeping the tin level.

4 Do it and see if the water enters the tin via the holes.

5 Repeat the exercise, this time tilting the tin slightly as you lower it so that one hole is higher in the water than the other. Will the water enter the holes this time?

So what happened?

Once the tin has been lowered into the water, the surface tension of the water at the holes and the pressure of the trapped air prevent the water from entering the tin.

If, however, you tilt the tin so that one of the holes is higher in the water than the other, the water enters the lower hole and bubbles of air come from the upper hole.

Why? The holes are at different depths, so the pressure at the upper of the two holes is less than that at the lower hole. This causes the water to enter at the lower hole at the same time as air is forced out of the upper hole.

What next?

See what happens if you make the holes bigger.

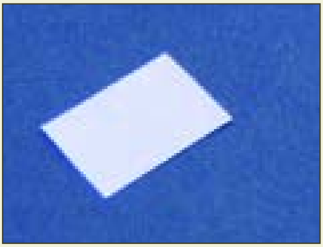
Air race between identical pieces of paper

The Czech Republic

Air resistance has less effect on dense objects

You will need...

- ✔ a coin
- ✔ two small pieces of paper (same weight and dimensions)



Background

A skydiver relies on air resistance to allow him/her to fall through the air for several seconds before deploying a parachute.

Follow these steps

1 Place a small piece of paper on a large coin.
2 Drop the coin and paper as well as an identical piece of paper at the same time.
3 Watch which piece of paper reaches the floor first.

So what happened?

The paper on the coin reaches the floor first because it does not experience the slowing-down effect of air resistance as much as the piece of paper without the coin.

What next?

This leads on neatly to a discussion of slipstream, coefficients of drag aerodynamics, etc.

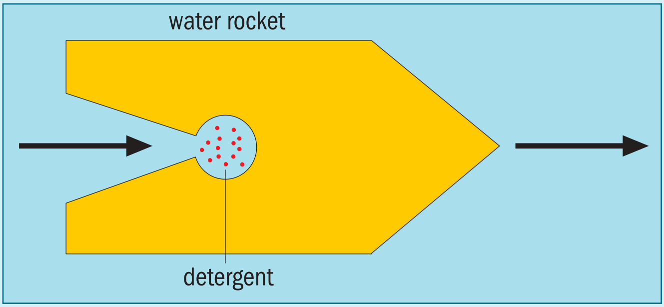
Water rocket

Austria

Breaking surface tension

You will need…

- ✔ a bowl of water
- ✔ some card
- ✔ a pair of scissors
- ✔ some washing-up liquid



Background

Some small insects can walk on the surface of water owing to surface tension.

Follow these steps

1 Using the template shown, cut out a paper rocket.
2 Place the rocket onto the surface of the water.
3 Put a drop of washing-up liquid in the central circle of the rocket (dip a pencil into the detergent then dip it into the water inside the circle) and watch what happens.

So what happened?

When the detergent is added it locally reduces the surface tension of the water. Owing to the shape of the card, the rocket shoots forward.

What next?

Try repeating this exercise several times in the same water. You will find that it only works two or three times before there is too much detergent present. Adding more has no effect – now the surface tension is low all over the surface.

If you push the wall, will it move?

Ireland

For every action there is an equal and opposite reaction

Background

This uses a simple classroom optical lever to demonstrate Newton's Third Law and the microscopic flexures of masonry walls created by human-scale contact forces.

Follow these steps

1 Upturn the bin, place a flat, smooth surface on top of it and position it about 0.5 m from a masonry wall.
2 Attach the small mirror to the pin with Blu-Tack.
3 Place a metre stick on its edge on top of the flat surface, one end attached to the wall with Blu-Tack.
4 Rest the other end of the metre stick freely on top of the bin.
5 Place the pin and mirror between the metre stick and the flat surface so that the end of the stick rests freely on top of the pin and mirror.
6 Position the laser pointer in the retort stand, directing the beam onto the mirror.
7 Position a second metre stick, to act as a scale, in the line of the reflected beam.
8 Observe the reflected spot on the scale.
9 Get a student to push against the wall and watch the reflected spot move up and down on the scale.

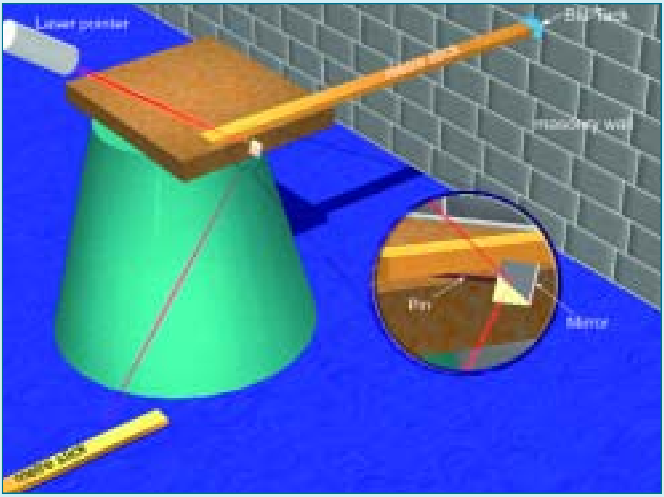
You will need...

- ✔ two metre sticks
- ✔ Blu-Tack
- ✔ a straight pin
- ✔ a small piece of mirror or CD (1 × 1 cm)
- ✔ a laboratory bin
- ✔ a laser pointer
- ✔ a retort stand
- ✔ a flat, smooth surface (e.g. hardback book)
- ✔ a masonry wall

So what happened?

According to Newton's Third Law, for every force (or action) between two bodies there is always an equal but opposite force (or reaction). So, as you push against the wall, the wall yields.

As the wall flexes, the first metre stick moves back and forth, rotating the pin and mirror and thus deflecting the laser spot at varying angles back to the scale.



What next?

Ideally, use a wall that you can both push and pull.

You can read more about this demonstration in

Daniel L MacIsaac and Michael Nordstrand 2001 Demonstrating and measuring the flexure of a masonry wall *Phys. Teach.* **39** 212.

Has Newton's Law gone wrong?

Slovakia

Acceleration due to gravity acts at the centre of gravity of an object

You will need...

- ✔ a metre stick
- ✔ several coins

Background

Objects come in all shapes and sizes. When we apply Newton's law we assume that all of the mass is in the centre.

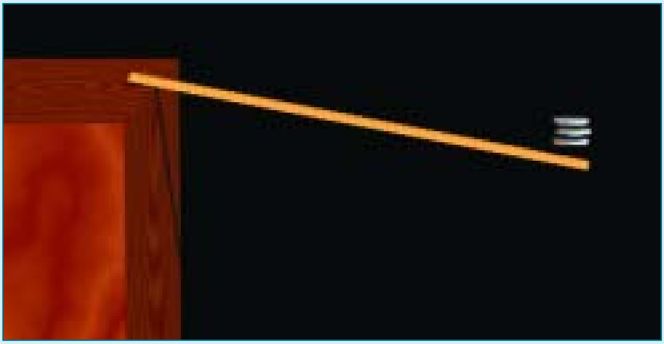
Follow these steps

1 Rest one end of a metre stick on the edge of a bench.
2 Support the free end of the stick with your hand so that it remains level with the top of the bench.
3 Pile two or three coins on the free end of the stick.
4 Let go of the stick and allow it to fall a short distance before catching it again.
5 Watch (and listen) to discover what happens.

So what happened?

You should hear the sound of the coins landing on the stick after you catch it. The coins must be falling at a slower rate to that of the metre stick. However, how can this be true if the acceleration due to gravity is the same for all objects, as Newton's Law of gravity tells us? Was he wrong?

Newton was not wrong. In this case the centre of gravity of the stick is at its midpoint and it is here that the acceleration due to gravity is the standard 9.8 ms^{-2}. The outer end of the stick, as it falls, is actually rotating about the suspended end on the bench. This end is 50 cm farther away from the centre of gravity, so its total acceleration (angular and linear) will be greater and it moves faster than the coins, which are accelerating at 9.8 ms^{-2}.



What next?

Discuss how pole vaulters can curve their bodies over the bar so that their centre of gravity is below the bar.

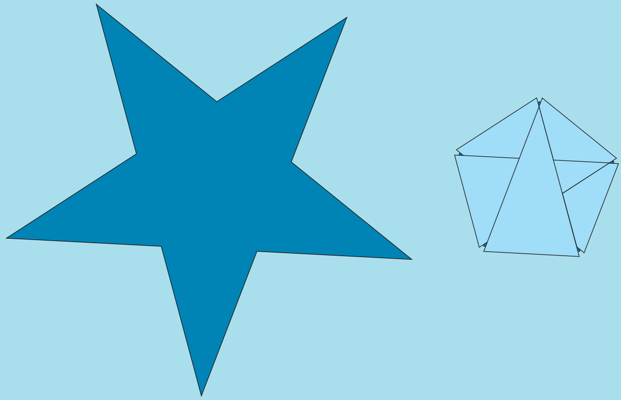
Opening flowers

Austria

Capillary action

You will need...

- ✔ a bowl of water
- ✔ some paper (coloured, if possible)
- ✔ a pair of scissors



Background

Plants rely on capillary actions to draw water up through a network of thin tubes.

Follow these steps

1 Using the template shown, cut out some paper flowers.
2 Fold in the points of each flower across its centre.
3 Place the flowers onto the surface of the water and watch what happens.

So what happened?

The base of the flowers absorbs the water and the water moves out through the petals in a capillary action. As the petals become soaked with water they open out owing to the force of the water travelling through the paper fibres.

What next?

Discuss whether this experiment would work with plastic flowers.

Can you balance six nails on one?

Hungary

Puzzle stimulates discussion on balance and centres of gravity

You will need...

- ✔ seven nails (6 inch/15 cm)
- ✔ a small block of wood

Follow these steps

1 Hammer one of the nails into the block of wood.
2 Pose the following problem: how do you balance the other six nails on top of the one in the wooden block?

So what happened?

Did any of the students figure it out? This is how it's done:
1 Lay the six nails flat on the table.
2 Arrange the nails as shown in the picture at top right. "Three heads are better than two" may be a useful way to remember the arrangement at each end.
3 Gripping the arrangement at the centre, carefully balance it on the upright nail.

How can a balloon lift a glass?

Slovakia

Pressure and friction conspire to produce an entertaining effect

You will need...

- ✔ a drinking glass
- ✔ a balloon

Follow these steps

1 Place the balloon inside the glass.
2 Slowly inflate the balloon.
3 Holding just the neck of the balloon, lift the glass.
4 Ask the students to explain what they see.

So what happened?

A seal is formed between the glass and the balloon. The resulting frictional force, due to the increased pressure, is greater than the weight (downward force) of the glass, so the glass doesn't slip off the balloon.

What next?

Discuss whether this would work with a paper bag, or if there was a layer of oil between the glass and the balloon.

Anyone for tennis?

Belgium

Acceleration due to gravity is independent of the mass of an object

You will need...

- ✔ three identical tennis balls
- ✔ some water
- ✔ a needle and syringe (for filling one of the balls with water)

Background

Students intuitively expect heavy objects to fall faster than light ones.

Follow these steps

1 Out of view of the students, inject one tennis ball with as much water as it will hold.
2 Ask a student to drop two normal tennis balls from the same height and note whether or not they hit the ground at the same time.
3 Then ask them to hold two tennis balls, one of which you have filled with water, to feel the difference in weight.
4 Get them to drop the two different tennis balls from an equal height and note when they hit the ground.
5 Ask the students to try to explain what they see.

So what happened?

Students will expect the heavier of the two different balls to hit the ground first. In fact they should reach the ground at the same time.

This exercise is used to demonstrate how gravity is independent of the mass of an object. As the balls are the same size, students can ignore differences in air resistance, etc.

Safety note

- Remove breakables from the vicinity and do not stand over the balls as you bounce them.

What next?

There is a link to the video clip of the hammer and the feather being dropped on the moon, which demonstrates the same principle. You can see the video clip (broadband is required) at http://www.hq.nasa.gov/office/pao/History/alsj/a15/a15v_1672206.mpg.

"Bouncing balls" follows on from this experiment.

Bouncing balls

Belgium

Conservation of momentum – the effect of collisions

You will need...

- ✔ a tennis ball
- ✔ a basket ball
- ✔ a lofty room (e.g. a sports hall)

Safety note

Remove breakables from the vicinity and do not stand over the balls as you bounce them.

Background

Momentum is the product of mass and velocity.

Follow these steps

1 Drop the tennis ball and the basketball independently from the same height and see how high they both bounce.
2 Hold the tennis ball on top of the basketball, then drop them both at the same time.
3 Watch how high the two balls bounce now.

So what happened?

If the tennis ball bounces off the top of the basket ball then it bounces high into the air – approximately nine times as high as previously.

This is a demonstration of conservation of momentum. Some of the momentum from the basket ball is transferred to the tennis ball, thereby causing the tennis ball to bounce higher.

There are also other reasons why the ball bounces higher, such as the different sizes, elasticity and air resistance of the two balls.

What next?

A number of people have looked at the maths of this exercise. You can find out more at http://physics.ucsd.edu/students/courses/fall2001/physics2a/tennis-basket-balls.pdf and at http://www.physics.otago.ac.nz/teaching/PHSI110/jakub/Momentum.html.

Which syringe is easiest to push?

Austria

Force is proportional to area if the pressure is constant

Follow these steps

1 Connect the apparatus (see diagram), filling the syringes and plastic tubing with water. The nozzle of each syringe should be of equal size to connect the plastic tubing.

2 Hold a syringe in each hand and press evenly on them.

3 Note which syringe plunger is easier to push down. You may need to swap the syringes from one hand to the other to notice the difference, because the difference in the strength of your hands may counteract the difference in force required.

4 Try varying the amount of water in the system. About a third full should work best. If there is too little water it can be difficult to detect the difference in forces required. The greater the difference in the size of the two syringes the easier it will be to detect the difference in force required.

So what happened?

The plunger of the smaller syringe is easier to push down. As the pressure remains constant the force required is proportional to the area of the syringe.

You will need...

- ✔ two syringes of different sizes (e.g. 5 and 20 ml)
- ✔ some plastic tubing
- ✔ some water

What next?

This is a good introduction to hydraulics, as used in the brakes of a car, as the basic principle is the same.

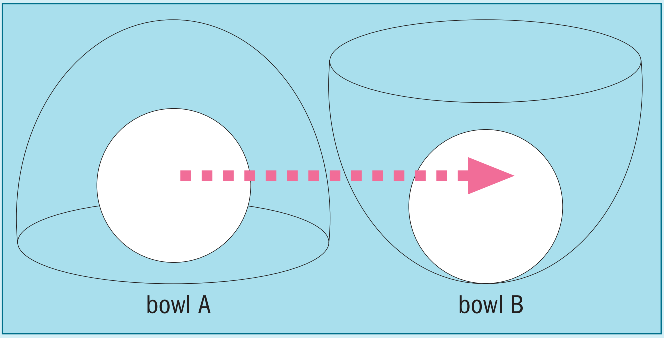
Centripetal force

Ireland

Forces acting on rotating objects

You will need...

- ✔ two circular bowls (Danone yoghurt comes in an ideal plastic container; see picture)
- ✔ a table-tennis ball or marble



Background

When going round a corner quickly in a car you feel as if you are pushed to the outside of the bend. In fact the car is exerting a force on you, called centripetal force, which makes you go round the corner with the car.

Follow these steps

1 Put the ball under one of the containers, placed face down.

2 Ask a student to move the ball from this container to the other container without touching the ball or the empty container.

So what happened?

You may have to give the student some clues. They need to move the first bowl in a circular motion, spinning the ball round fast enough that it moves up the sides of the bowl. This will allow them to lift the bowl quickly while the ball is still forced against the sides and place it over the other bowl, allowing the ball to drop into the second bowl without them having to touch either the second bowl or the ball.

Centripetal force, which keeps the ball against the sides of the first bowl, is responsible for preventing it from dropping out of the bowl until the student stops moving the bowl in a circular motion.

What next?

When a hammer thrower releases the hammer, in which direction does it go?

This experiment can also lead to a discussion about governors used in engines, such as those on steam engines (e.g. the threshing engines seen at field days).

Soap bubbles and films: 2-D and 3-D shapes

Spain

Surface tension determines the shape of soap films

Soap solution

You will need...

- ✔ some glycerine (~650 ml; can be purchased from a pharmacy)
- ✔ some water (~2 l)
- ✔ some washing-up liquid (~1.1 l)

Follow these steps

1 Stir the glycerine, water and washing-up liquid (proportions of about 1:4:2) for about 10 min.

Note: Too many bubbles forming at the top make it harder to get good shapes.

2 The solution can be stored in a sealed container (e.g. an empty water bottle). In time, some of the water may evaporate, so add more, as required.

Note: There are other recipes for soap solutions that can be found on the Internet. If your tapwater is hard you may need to use bottled water to create the bubbles.

2-D shapes

You will need...

- ✔ some coathanger wire
- ✔ some thread
- ✔ four pieces of clear Perspex (~10 × 20 cm each)
- ✔ a drill
- ✔ seven screws

Follow these steps

Demonstration 1

1 Make a wire circle and tie a piece of thread across it.

2 Dip the wire circle and thread into the soap solution.

3 Break the bubble on one side of the thread and note what happens to the thread.

Demonstration 2

1 Drill two Perspex sheets at the four points of a square and join the sheets with the screws through these holes, leaving a gap of about 2 cm, so that the screws form the edges of a cuboid shape.

2 Similarly, drill through three points of a triangle on the other two sheets so that the screws form the edges of a triangular prism shape.

3 Dip the 3-D shapes into the soap solution and note where the film forms.

So what happened?

The bubbles always move to reduce the surface area to a minimum, so the thread moves to minimize the size of the film; and, for both the square and the triangle, instead of being formed at the outside of the screws, the film comes in to the centre, forming 120° angles.

Soap bubbles, continued...

3–D shapes

You will need...

- ✔ soap solution
- ✔ some coathanger wire, solder and soldering iron; or a straw kit (used to create molecular shapes); or a magnetic kit (e.g. Cultimo Magnetic Construction Set; see right)

Follow these steps

1 Construct a 3-D pyramid and a 3-D cube (see pictures, right) using the magnetic kit and coathanger wire.
2 Dip the pyramid into the soap solution and note where the films form.
3 Burst some of the sides of the bubble and note what happens.
3 Dip the cube into the soap solution and note where the films form.

So what happened?

The bubbles always move to reduce the surface area to a minimum, so the films all form at the centre of the structures.

What next?

Ask students to measure the distances on the 2-D structures around the outside of the triangle/square where they expected the film to form. Compare this to the film of the bubble formed.

Moments on a wheel

The Czech Republic

The turning effect depends on the distance from the axis

You will need...

- ✔ a CD
- ✔ a marker pen
- ✔ some small round magnets
- ✔ a retort stand

Background

Pupils should know that:

1 the moment of a force = force × perpendicular distance from the axis;

2 the principle of moments states that in equilibrium the sum of the clockwise moments equals the sum of the anticlockwise moments.

This experiment allows pupils not only to verify the principle of moments but also to see that the turning effect depends on the perpendicular distance from the axis without doing calculations.

Follow these steps:

1 Draw a grid of equally spaced squares on the silver side of the CD (1 cm square).

2 Support the marker pen in the clamp of the retort stand.

3 Balance the CD using the marker pen as the axis.

4 Attach two magnets, each side, at a fixed number of squares away from the axis along the diameter of the CD.

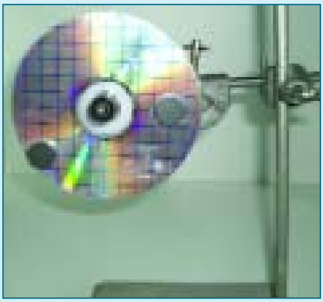
So what happened?

Note that the CD will become unbalanced. The direction of the moment of the force created by the magnets can easily be seen, thus introducing the terms "clockwise" and "anticlockwise" as applied to moments.

Ask pupils how to get the CD to balance again. This is simply done by putting two magnets on the opposite side of the CD at an equal distance from the axis.

The principle of moments can then be verified by using different numbers of magnets at various distances from the axis.

Younger pupils should use different numbers of magnets at various distances from the axis. Ask them to bring the CD back into balance using only one magnet on the opposite side to check that they have understood the principle of moments.



Ask older pupils what will happen when the CD is in equilibrium if one set of the magnets is moved to the edge of the CD. The obvious answer is that the CD will become unbalanced.

However, this is not the case if the magnets are moved down (see picture). The perpendicular distance is the same, though the actual distance (the radius of the circle) has increased.

This clearly shows that the moment is calculated using the perpendicular distance and not the actual distance.

What next?

This can be compared to a bicycle wheel and shows why it is best for the footrest on a bicycle to be able to swivel so that the maximum distance (i.e. the diameter) is always obtained and thus the maximum turning effect is obtained using the minimum of force.

This can then be followed with mathematical calculations on moments.

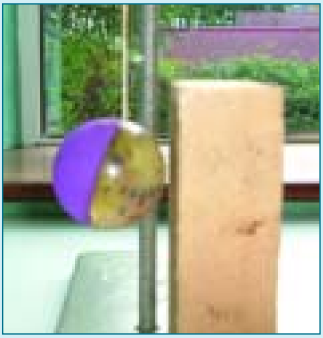
Impulse and momentum

UK

A change in momentum is greater when there is a rebound

You will need...

- ✔ two balls of similar size and mass (one should be elastic and rebound well and the other inelastic with little or no rebound)
- ✔ a retort stand
- ✔ a block of wood



Background

Momentum = mass × velocity and is a vector quantity.
Impulse = change of momentum.

This experiment is used to show that, since momentum is a vector quantity, the change of momentum is greater when there is a rebound (i.e. a change in direction).

Follow these steps:

1 Cut the two balls in half and, using one half of each, glue two halves together to make a composite ball, embedding one end of a length of string in the middle.
2 Suspend the composite ball from the clamp of the retort stand.
3 Set up the block of wood a short distance away from the ball so that the top of the wood is level with the ball.
4 Using one side of the ball, raise it through a fixed height from the top of the wood and then let it drop to see if it has enough force to knock over the wood.
5 Repeat this process using the other side of the ball.

So what happened?

The wood should be knocked over much more easily by one side of the ball than by the other. This is because the elastic ball rebounds on impact with the wood, thus causing a bigger change in momentum due to the direction change, while the other ball does not rebound and therefore has a smaller change in momentum.

What next?

This can be shown to have many applications in sports like tennis and squash.

20 density

The mystery of the vanishing liquid

Ireland

Different liquids are made up of different-sized molecules

You will need...

- ✔ two graduated cylinders (the smaller the better)
- ✔ some alcohol (any type)
- ✔ some water

100 ml water	+	100 ml alcohol	=	? ml

Background

Matter is made up of molecules of various sizes. When different-sized molecules are mixed, the smaller ones can occupy the vacancies between the larger molecules.

Follow these steps

1 Measure equal amounts of water and alcohol and note the volumes poured (the smaller the volumes the better – say 100 ml of each).

2 Add the contents of one of the cylinders to the other and measure the total volume of the mixture.

So what happened?

The total volume of the mixed liquids should be about 5% less than the sum of the previous two volumes, because the smaller molecules of the water occupy some of the vacancies between the larger alcohol molecules.

What next?

The same principle can be illustrated by using materials where the students can see the individual units that make them up (e.g. grains of rice or dried peas take the place of the molecules in water and alcohol).

Discuss how quicksand and avalanches are examples where particles can behave like fluids.

White ball, black ball

Belgium

Particles can behave like fluids

You will need...

- ✔ a container and lid
- ✔ some rice
- ✔ a black ball-bearing
- ✔ a white polystyrene ball

Background

This exercise introduces density and flotation and shows how, under some circumstances, particles can behave like fluids.

Follow these steps

1 Pour the rice into the container.

2 Hide the white ball just below the surface of the rice, then place the black ball on top.

3 Show the container to the students.

4 Put the lid on the container and then give the vessel one vigorous vertical shake. (Some special magic words might help here!)

So what happened?

The heavy black ball-bearing sinks into the rice whereas the light polystyrene ball floats to the surface. To the students the ball appears to have mysteriously changed colour.

Making a turbine from a plastic cup

Belgium

Convection currents are created in warm air

You will need...

- ✔ a plastic drinking cup
- ✔ a pencil or pin
- ✔ a heat source (e.g. a radiator)

Background

Warm air rises.

Follow these steps

1 Make a number of L-shaped incisions (all along the same orientation) in a very light plastic drinking cup and fold back the flaps that are created as a result (see picture).

2 Place the cup, upturned, onto a pin, pencil tip or other pointed support on which it can turn freely.

3 Place the apparatus over a source of heat, such as a radiator.

So what happened?

The rising hot air escapes sideways from the holes and the resulting force causes the cup to rotate.

What next?

Discuss how steam turbines operate using the same principle.

The blue spiral flame

Austria

An introduction to ignition temperature/activation energy

Follow these steps

1 Clamp the tube in a spiral (see figure).

2 Place the candle on the heat-proof mat at the lower end of the tube and light it.

3 Darken the room.

4 Drop about 2 ml of propanone from the pipette into the top end of the tube.

5 Stand clear and watch what happens.

So what happened?

A bright-blue flame spirals up the tube with a “whoosh”. The propanone is a volatile liquid, so it vaporizes and mixes with the air as it flows down the tube.

When the mixture reaches the flame, the ignition temperature is exceeded and the propanone reacts with the oxygen in the air. This is an exothermic reaction, so it spreads back through the tube as a blue flame, which winds its way to the top.

The air expands out of the tube with an impressive sound, which increases in pitch as the length of the resonating column of air above the flame gets shorter.

You will need...

- ✔ 1–2 m of clear Perspex tubing (5–10 cm wide)
- ✔ propanone (acetone)
- ✔ a glass pipette
- ✔ a night-light candle
- ✔ matches
- ✔ a heat-proof mat

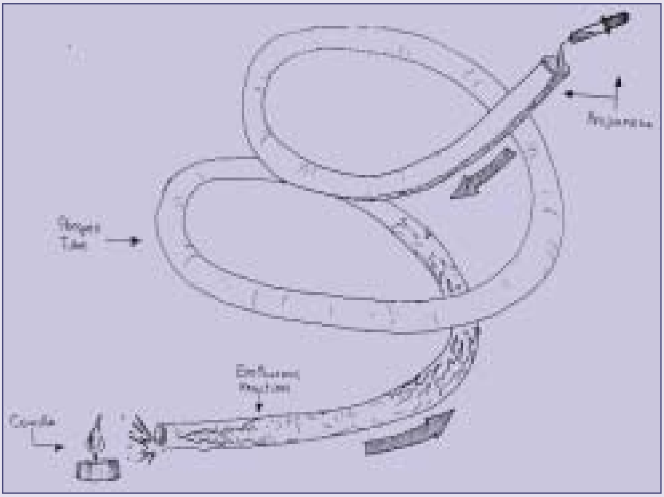
What next?

If you want to do it again it works best if you blow through the tube first to make sure that it is full of air containing oxygen.

Find out more about activation energy by looking into how the diesel engine works.

Safety notes

- Don’t be tempted to use a plastic pipette to put the propanone into the tube. It’s a volatile liquid so will tend to vaporize with the heat from your hand and squirt out.
- Don’t use too much propanone or the liquid will catch fire at the end of the tube
- Place the candle on the mat. Excess propanone may catch fire as it drips out of the tube but will burn safely on the mat.



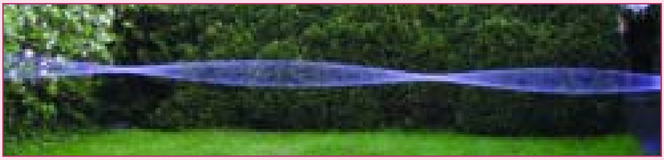
Standing waves in elastic

The Czech Republic/Spain

Standing waves in an elastic string

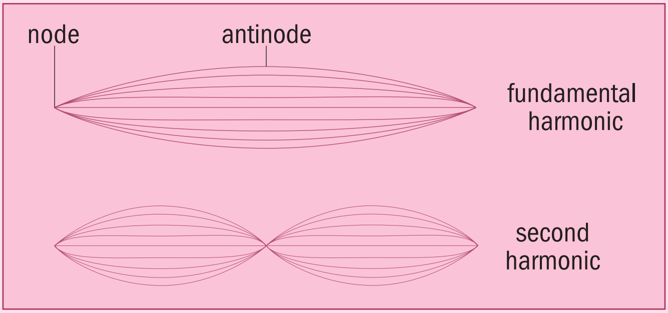
You will need...

- ✔ a battery-operated fan or toothbrush
- ✔ some plastic tubing
- ✔ a matchstick
- ✔ some hat elastic (~1.5 m)



Background

The term standing wave is applied to a resonant mode of an extended vibrating object. The resonance is created by the constructive interference of two waves travelling in opposite directions, but the visual effect is that of an entire system moving in simple harmonic motion.



Follow these steps

1 Insert a piece of match into the tube on the fan/toothbrush so that it wobbles.
2 Attach one end of the thread to the vibrating end of the toothbrush/fan and the other to a fixed object.
3 Apply tension to the thread by pulling on it with your finger and thumb.
4 Using varying degrees of tension, set up a standing wave on the thread to demonstrate nodes and antinodes.

So what happened?

This shows how standing waves can be set up on the strings of musical instruments. Different modes of vibration can be obtained by varying the type of thread/string used, the degree of tension applied and the length of the thread/string.

The flame tube

Germany

Standing waves in a tube of gas

Safety note

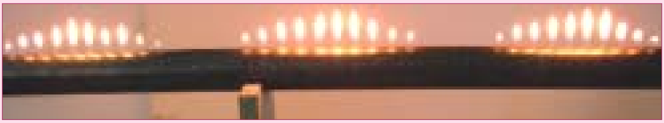
Once the gas is on, light the jets to prevent unburned gas from escaping and open the lab door to vent any fumes.

You will need...

- ✔ a metal pipe (2 m long, 3 cm wide)
- ✔ some flammable gas (e.g. natural, butane)
- ✔ an end cap
- ✔ some hosing
- ✔ a flow valve
- ✔ a signal generator
- ✔ a loudspeaker (3 cm in diameter)
- ✔ a rubber diaphragm (e.g. a latex glove)
- ✔ wooden supports
- ✔ a microphone
- ✔ an amplifier

Background

An acoustic standing wave is set up in a pipe with regions of low and high pressure. The pipe is filled with gas that escapes through evenly spaced holes. The escaping gas is ignited to show a flame pattern of varying heights along the pipe.



Follow these steps

1 Drill some holes (1–2 mm wide) on one side of the pipe.
2 Place the pipe (holes upwards) onto the supports.
3 Weld an end cap onto one end of the pipe, with a connector to attach the hosing and flow valve to the gas cylinder.
4 Fix the diaphragm to the other end of the pipe and position the loudspeaker against it.
5 Connect the loudspeaker to the signal generator.
6 Open the flow valve to fill the pipe with gas.
7 Wait 10 s or so until the gas has displaced the air.
8 Light all of the gas jets.
9 Turn on the signal generator and set it at maximum amplitude.
10 Adjust the gas flow until you see a reasonable variation in flame height.
11 Vary the driving frequency and observe different resonant frequencies.

So what happened?

About 2 to 10 wave crests are observed in the 200–600 Hz range. The maximum flame height shows a region of maximum displacement and minimum pressure – an antinode. The opposite situation is a node.

The separation between the nodes equals half a wavelength of the standing wave and depends on the frequency of the sound wave. The pipe is closed at each end, so nodes should be observed at both.

What next?

Both rhythm and frequency response can be seen nicely in music. An oscillator or a voice introduced using a microphone and amplifier can be used as a simple source for the loudspeaker.

You can measure the velocity of sound in a gas by recording the wavelength, λ, of the standing wave at different resonant frequencies, f ($v = f \times \lambda$).

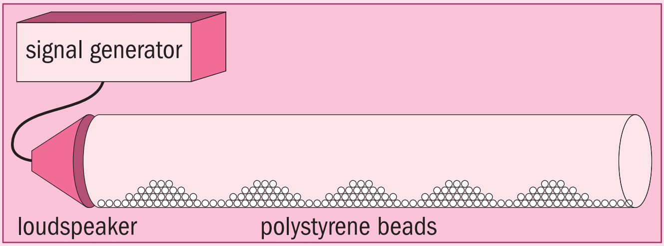
Kundt's tube

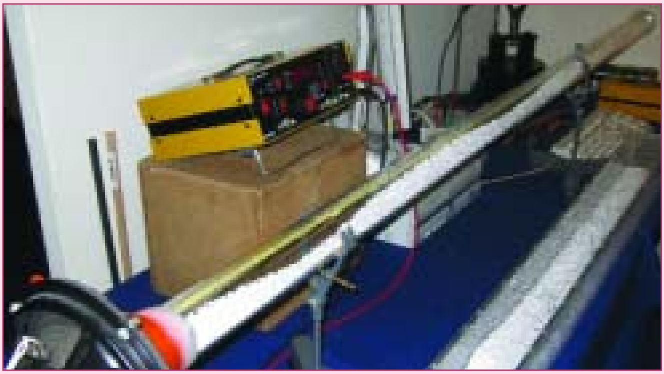
Luxembourg

Standing waves in a column of air

You will need…

- ✔ a sound/signal generator
- ✔ a loudspeaker
- ✔ a transparent plastic pipe (50–100 cm)
- ✔ some small polystyrene beads (at least 2 mm in diameter)
- ✔ a filter funnel
- ✔ an adjustable plunger
- ✔ dry cork dust or lycopodium powder
- ✔ a metal rod with an end cap
- ✔ a piece of leather cloth coated with resin





Follow these steps

1 Scatter a thin layer of polystyrene beads as uniformly as possible inside the pipe along its length.

2 Attach the loudspeaker to one end of the pipe and close the other end with an adjustable plunger (the pipe is closed so that the resonances exist at odd multiples of one-quarter wavelength).

3 Switch on the signal generator at maximum amplitude and then vary the frequency.

4 Observe the standing waves in the air column.

Background

This is a dramatic demonstration and is effective in providing an introduction to standing sound waves.

So what happened?

The driving frequency forms standing wave patterns in the air column inside the tube. The beads show the position of the nodes and antinodes by forming piles at the node locations.

What next?

Try using dry cork dust or lycopodium powder instead of polystyrene beads.

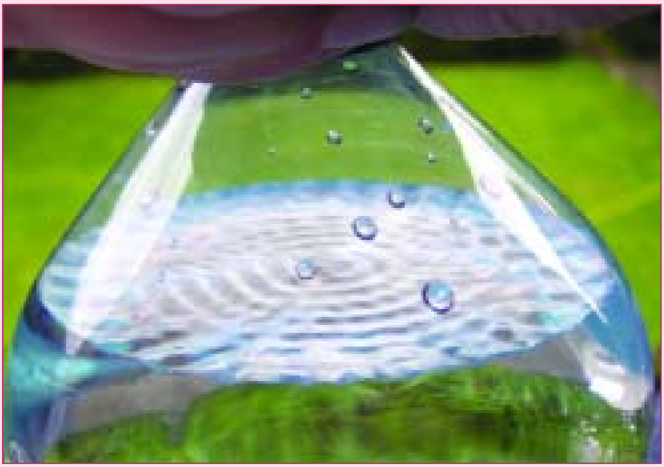
Vibrations can also be generated by fitting a metal rod with an end cap into the tube and stroking the end with a piece of leather cloth coated with resin, or stroking the tube with a violin bow.

This set-up can be used to measure the velocity of sound in air by recording the wavelength (λ) of the standing wave at different frequencies (f) ($v = f \times \lambda$).

A storm in a bottle of water

UK

Interference in an everyday context



You will need...

- ✔ a 2 litre bottle of water (in our experience, River Rock works best)

Background

This demonstrates standing waves in two dimensions.

Follow these steps

1 Hold the bottle by the neck with one hand.

2 Give the bottle a firm knock about midway along its length using the knuckles of your other hand.

So what happened?

A definite note is both felt and heard, but more dramatically a beautiful interference pattern can be seen on the surface of the water inside the bottle.

What next?

See whether it matters if the cap is removed or the water level changed.

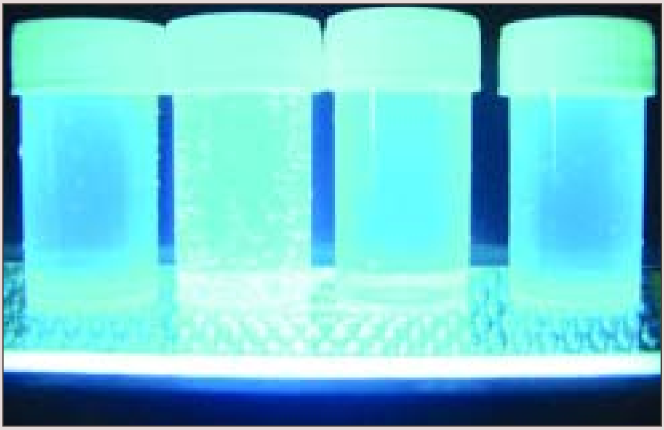
Which one is the tonic water?

Bulgaria

Fluorescence

You will need…

- ✔ four identical bottles with screw tops, three containing water and one containing tonic
- ✔ an ultraviolet lamp



Background

Ultraviolet light is invisible to the human eye but you can still see its effects.

Follow these steps

1 Present the four bottles to the class and ask them to check that one contains tonic and the others tap water.
2 Bet them (a week's homework!) that, without touching the bottles, you can identify which contains tonic.
3 Get a student to muddle them up out of your sight.
4 Shine the ultraviolet light on the apparently identical bottles.

So what happened?

The tonic fluoresces bright blue in the ultraviolet light so is easily identified. A component of tonic water (quinine) absorbs the ultraviolet light, which is not visible to the human eye, thereby exciting its electrons. This is an unstable state, so the electrons emit energy as photons of light in the blue end of the visible spectrum. The bottle containing the tonic therefore emits a blue light under the ultraviolet lamp.

What next?

Discuss why white materials dazzle in a disco.

Also, try viewing a passport/drivers' licence/euro note under ultraviolet light.

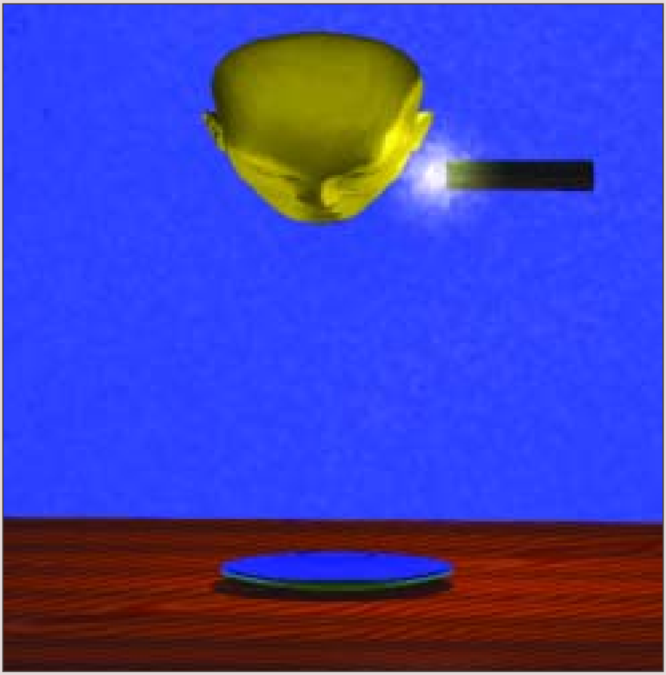
Dirty mirror

The Czech Republic

An unusual method to demonstrate interference

You will need...

- ✔ a concave shaving mirror
- ✔ a torch
- ✔ some dirt



Background

Interesting effects are created when thin films are illuminated.

Follow these steps

1 Sprinkle a thin layer of fine dirt onto the shaving mirror. A suspension of fine mud or chalk smeared onto the mirror and allowed to dry should also work, while a film of milk allowed to dry on the mirror is a good alternative.

2 Remove the head of the torch to expose the bulb, which should be clear so that the filament acts as a small point-source of bright light. Look directly at the mirror while holding the light source close to your temple.

So what happened?

You should see a pattern in the mirror consisting of bright and dark bands due to reflections from different heights on the surface, in an effect known as thin-film interference.

What next?

If you use a plane mirror you will need to hold it a bit farther away from you to see the effect clearly (about 1.5 m should be fine).

The closer you bring the light source to your eye, the better is the interference effect. In fact, if the light is in front of your eye, a circular pattern can be seen provided that the bulb is not so bright as to dazzle you.

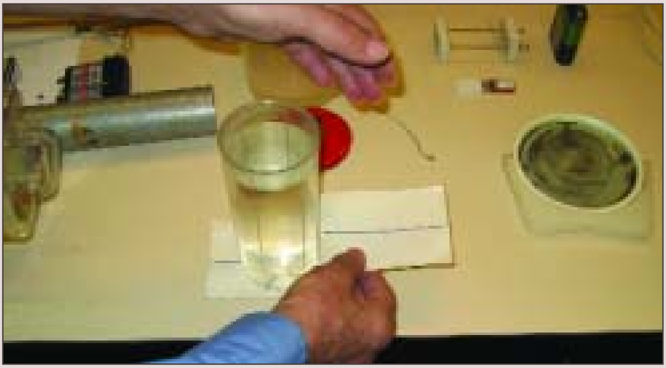
Real depth and apparent depth

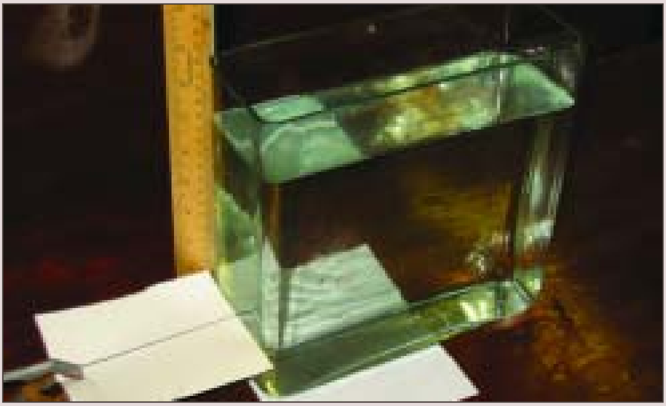
The Czech Republic

Finding the refractive index of a liquid

You will need...

- ✔ a deep glass container
- ✔ two pieces of paper





Background

Look down at your feet when you're standing in a swimming pool to see an example of refraction.

Follow these steps

1 Draw a straight line on both pieces of paper.
2 Place one of the sheets under the glass container.
3 Looking down into the container from above, raise the second sheet of paper until the two lines appear to coincide with no parallax.
4 Record the real and apparent depths.
5 Calculate the refractive index from the formula:

$$\text{refractive index} = \frac{\text{real depth}}{\text{apparent depth}}$$

So what happened?

The light travels more slowly through the water than through the air so the wavefront changes direction.

What next?

To improve the accuracy of this experiment, use a deep container with straight sides, such as a chromatography jar. You may wish to use a waterproof card placed in the water to eliminate any errors due to the refractive index of the glass in the bottom of the container. If the glass is thin compared with the depth of the water there will not be a significant error in your calculation.

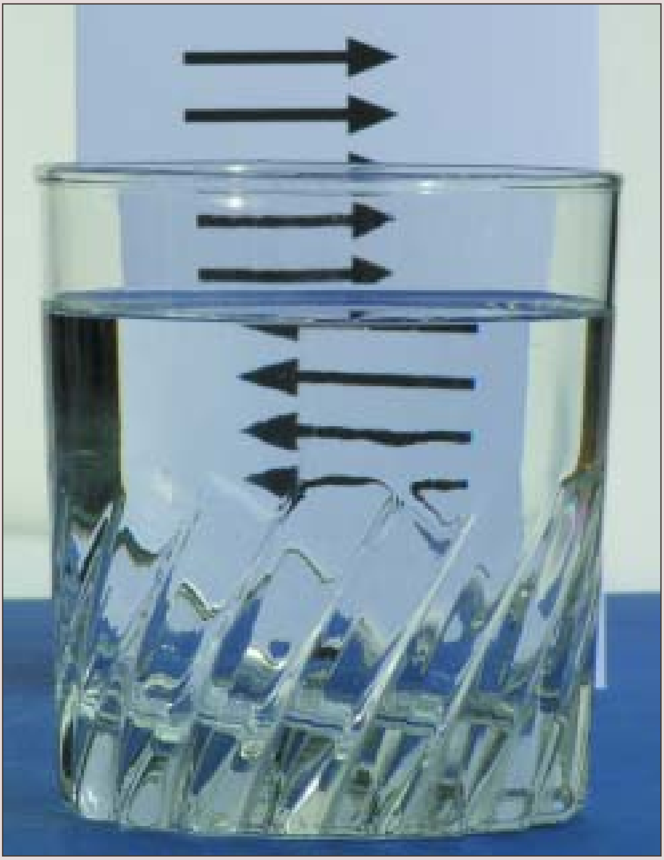
The water lens

The Czech Republic

Lenses can be made of many different materials

You will need...

- ✔ a glass of water
- ✔ a piece of card with an arrow drawn on it



Background

This demonstration shows the inversion of images and also that lenses can me made from several materials other than glass.

Follow these steps

1 Place the card behind the glass of water.

2 View the arrow through the water.

So what happened?

The direction of the arrow is reversed when viewed through the water. This is a simple way to introduce the way in which lenses work.

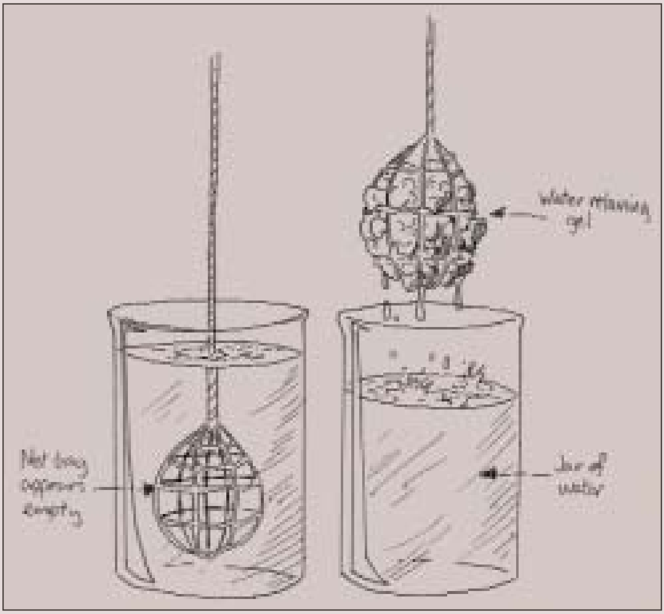
What next?

Further work can be done by producing ray diagrams for the water lens.

Disappearing crystals

Ireland

An intriguing introduction to refraction and refractive index



Background

The speed of light depends on the type of material that it's travelling through.

You will need...

- ✔ a container of water
- ✔ a small net bag to hold crystals (e.g. the type in which vegetables and fruit are often sold)
- ✔ a piece of string to secure the net
- ✔ Chempak Supergel crystals or equivalent (sold in garden centres to conserve water in hanging baskets, etc)
- ✔ a spoon

Follow these steps

1 Soak a few of the crystals in lots of water. Water that has been boiled and cooled works best as the gel formed contains fewer air bubbles, which are easily visible because the refractive index of air is so different from that of water.

2 Use a spoon to transfer some of the gel to the net bag.

3 Tie the bag at the top with string and lower it into the container full of water until it is completely immersed.

4 Note what happens to the appearance of the gel in air and in water.

So what happened?

The gel is visible when held in the net bag in air. However, when immersed in water the bag looks empty. The refractive index of the gel is the same as that of the water. When immersed in water, light is not refracted at the junction between the gel and the water, so the junction can't be seen.

What next?

Explore the refractive index of various materials.

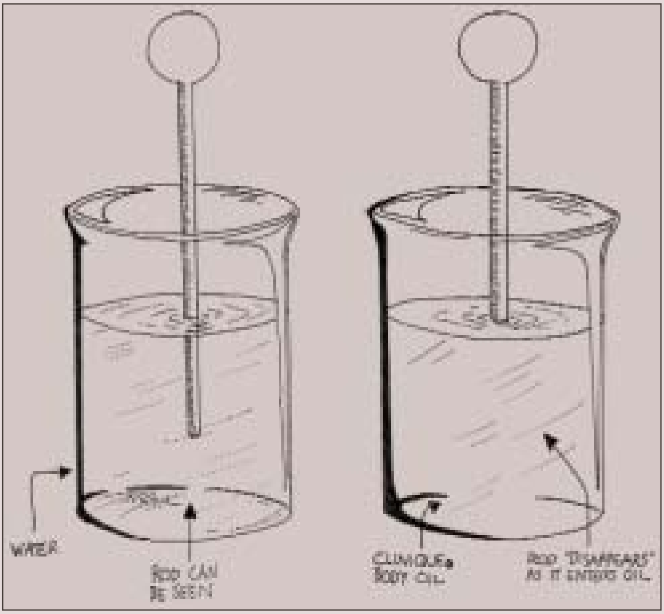
Disappearing glass rod

Bulgaria

Another illustration of refraction and refractive index

You will need...

- ✔ two glass rods
- ✔ two small beakers
- ✔ Clinique body oil (or a cheaper alternative, if you can find one)



Background

Solids and liquids can have the same refractive index.

Follow these steps

1 Put water into one of the beakers and the body oil into the other.

2 Slowly lower a glass rod into each and record what happens.

So what happened?

The rod is visible in the water because glass and water have different refractive indices. The light rays are refracted as they pass from one to the other, so the junction between the two is easily seen. The rod seems to disappear as it enters the body oil, because this has the same refractive index as the glass.

What next?

This can lead to an explanation of how this technique is widely used in forensics to establish the precise source of fragments of glass found at a crime scene (e.g. from a particular type of car headlamp or window). The glass fragments are placed in standard oils of known refractive index. The oil in which the fragments "disappear" has the same refractive index as the glass.

How to make a wooden mirror

Slovakia

An unusual way to illustrate total internal reflection

You will need...

✔ a thin piece of wood
✔ a polythene pocket
✔ a container of water

Background

Total internal reflection can occur when a ray of light passes from water to air.

Follow these steps

1 Pose the question: how can you make a mirror from a piece of wood?
2 Place the wood in the polythene pocket and then into the water, making sure that no water is able to enter.
3 Vary the angle of the wood in the water. At a particular angle the part of the wood that is submerged will act like a mirror.

So what happened?

At a particular angle, total internal reflection occurs in the layer of air, between the wood and the polythene, so that it behaves like a mirror.

What next?

See what happens when you put your finger into a glass test tube and then lower it into a beaker of water.

Images in a shiny can

The Czech Republic

You can't trust images reflected from a curved surface

You will need...

- ✔ a shiny can
- ✔ some cocktail sticks

Background
This exercise will give the students an understanding of how images are formed at curved surfaces.

Follow these steps
1 Ask the students to form patterns with the cocktail sticks while not looking at the sticks themselves but using only the reflection in the can to guide them.

So what happened?
Curved mirrors produce distorted images.

What next?
A similar exercise can be carried out using concave mirrors.

Investigating colour

Ireland

How are colours made using stage filters?

You will need...

- ✔ some red, green and blue stage filter paper
- ✔ a pair of safety spectacles
- ✔ a colour table to view with the spectacles and fill in (see table). You can create the table using colour marker pens or by printing one out (Paint Shop Pro or similar software may be useful)

Colour	Red	Green	Blue	White

Background

All colours can be made from the three primary colours: red, green and blue.

Follow these steps

1 Cut the filter paper so that it can be inserted inside the safety spectacles.

2 Ask the students to view each of the colours in the table through each of the colour filters and with no filter, then record whether each colour appears light, medium or dark.

3 Review with the students how the colours appear.

So what happened?

Coloured light is made up of red, green and blue light. When you look at a yellow object through a primary blue filter, only blue light is allowed through, so that is the colour that the object appears to be. When you look through a primary red filter at a primary blue object, the object will appear black or at least very dark, because the red filter does not allow the blue light from the object through. (Primary colour filters work best.)

What next?

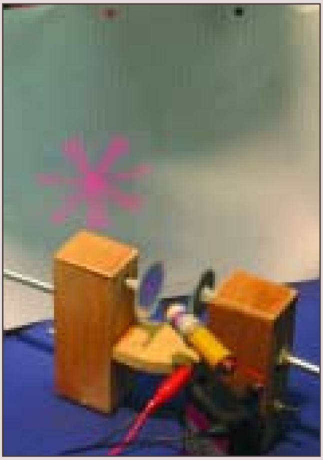
Put the students into teams of three, each student wearing a red, green or blue pair of spectacles. Then hold up objects of different colours and ask them to identify the colour of each object.

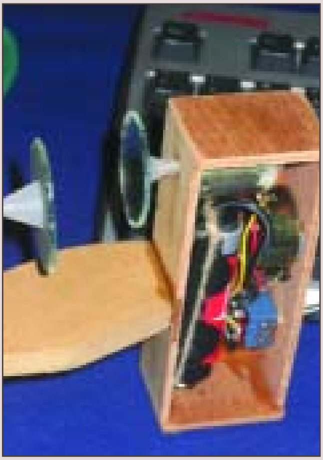
This exercise leads nicely into looking at how the eye sees colour; examining colour blindness; and investigating how colour is created on a television screen.

Laser show

Greece

Simple apparatus for a laser light introduces reflection





You will need...

- ✔ two dental mirrors
- ✔ two DC electric motors
- ✔ two plastic pipette droppers
- ✔ two 1.5 V batteries and holders
- ✔ two DPDT switches
- ✔ two 2.2 kΩ potentiometers
- ✔ a piece of white paper to act as a screen

Follow these steps

1 Mount a mirror on the end of the axle of each electric motor. The plane of the mirror must be tilted slightly with respect to the axle of the motor. To achieve this, use the end of a plastic dropper pipette cut at the required angle and glued to the back of the mirror with epoxy glue. The tip of the pipette should fit snugly onto the axle.

2 Wire each motor to a 1.5 V battery. The motor speed can be controlled by a 2.2 kΩ potentiometer in the circuit. Varying the speed of the motor will allow you to change the laser pattern produced. A switch to reverse the direction of each motor should also be included.

3 Arrange the mirrors and laser so that the laser light reflects from one mirror back onto the second one before hitting the screen. Arranging the apparatus for the first time may take a bit of fiddling about. Once you have found an arrangement that works, attach the components to a base.

Background

A simple laser light show can be created by shining a pocket laser onto a set of rotating mirrors.

So what happened?

As you vary the speed of the motors and the direction of the laser light, different patterns are created on the screen.

Hot headlamps

The Czech Republic

An everyday application of reflection of light in concave mirrors

You will need...

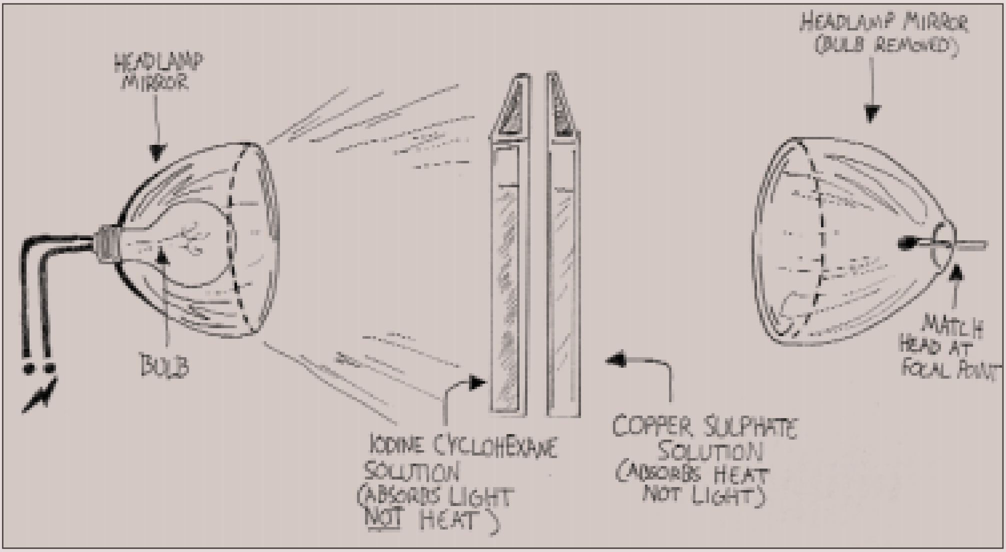
- ✔ two car headlamps (the older round ones are probably the best – not the sealed units – available reasonably from scrapyards)
- ✔ some matches
- ✔ four panes of glass
- ✔ some waterproof sealant in a gun
- ✔ a dilute solution of copper sulphate (~0.2 Molar)
- ✔ a solution of iodine in cyclohexane (~1 Molar)
- ✔ a power pack
- ✔ two retort stands

Follow these steps

1 Remove the bulb and the reflector in front of the bulb from one of the lamps.
2 Clamp this lamp.
3 Clamp the second lamp directly facing the first about 0.5 m away from it.
4 Connect the power pack to the back of the second lamp to illuminate the bulb.
5 Hold a match in through the hole at the back of the first lamp so that the match head is roughly at the focal point of the mirror and watch what happens.
6 Place a line of sealant along three sides of two panes of glass and place a second pane of glass on each, thus making two narrow containers that can hold liquids. Allow them to dry.
7 Fill one of the containers with dilute copper sulphate solution.
8 Grind iodine crystals with a pestle and mortar and add cyclohexane to them to make a dark purple solution. Then pour this solution into the second container.
9 Repeat step 5, first with the copper sulphate solution and then with the iodine solution between the two headlamps.

Safety notes

- When connecting the power pack, take care not to exceed the voltage of the bulb (usually 12 V).
- Copper sulphate and iodine are both toxic, so use gloves.
- Don’t put your finger in the hole at the back of the headlamp to feel if it is hot – it is.



So what happened?

When the match head is held at the focal point of the lamp it smoulders then bursts into flame. The bulb at the focal point of one mirror produces visible light and infrared radiation, which are reflected off the mirror in a parallel beam to the other mirror. Here they are reflected into the focal point, where the match head is.

This is the principle behind some types of solar power stations. The copper sulphate solution absorbs infrared but only a little of the visible light. The light is reflected to the focal point of the mirror but the match doesn't ignite.

The iodine absorbs most of the visible light but not the infrared. Only a little light passes through to be reflected off the mirror but the match still lights, showing that the infrared passes through the solution and is reflected into the focal point.

After a few "ignitions" the second mirror can get very sooty and doesn't work as well, so clean both mirrors periodically with a soft cloth.

What next?

This can lead on to solar power, the visible spectrum and infrared radiation.

40 light

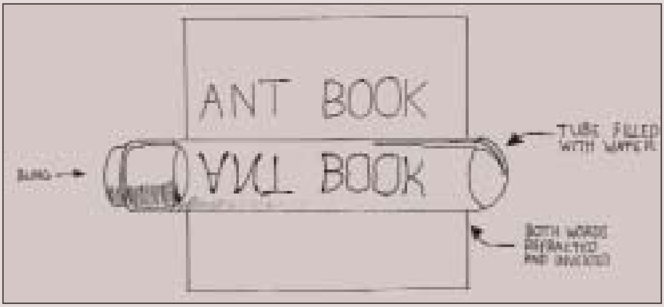
Words in a tube

The Czech Republic

Refraction and lenses

You will need...

- ✔ a test tube or boiling tube and bung
- ✔ water
- ✔ words written on a sheet (see diagram)



Follow these steps

1 Fill the tube with water and insert the bung securely.
2 Hold the tube horizontally, over the words.
3 Move the tube up and down (towards and away from your eyes) until you can see the words.
4 Describe what you see.

BOOK	WAY
HIDE	PRAM
BED	MUST
DOCK	SAY
DEED	START
CODEX	LAMP

So what happened?

It will appear that one word in each pair is inverted while the other is not. In fact, both words are inverted but the words are chosen so that one is formed entirely from symmetrical letters, so that it appears the same when inverted.

So many school experiments are very predictable, whereas this simple activity will really surprise and stimulate thought and discussion to determine what is happening.

What next?

An alternative means of illustrating the same point is to write CARBON DIOXIDE on one side of a bottle and then rotate it so that you are viewing the words through the bottle.

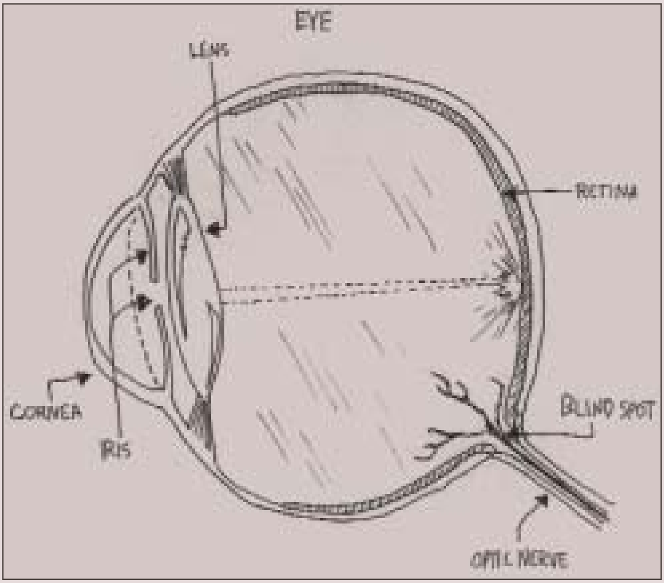
How the eye works: introduction

Bulgaria

How the different parts of the eye and brain contribute to vision

You will need...

- ✔ an overhead projector and screen
- ✔ small circles of red and green filter (diameter ~2 cm)
- ✔ green and red filters (106 and 139 from suppliers of filters for stage lighting)
- ✔ an image from the Internet (www.ebaumsworld.com/manillus.html)
- ✔ for each person, a square of black card (~4×4 cm), a pin, a rubber band, two matches and a long measuring tape
- ✔ some plain white paper
- ✔ a thick black marker pen
- ✔ an optician's Snellan chart



Background

The following experiments are equally relevant to physics students studying the refraction of light by lenses and to biology students studying vision. They have the enormous dual advantages of involving students actively in the experiments yet requiring only very simple equipment.

The nine experiments show in turn how the following parts of the visual system contribute to human vision: the aqueous humour, the pupil, the lens, the retina, the rods, the cones and the brain.

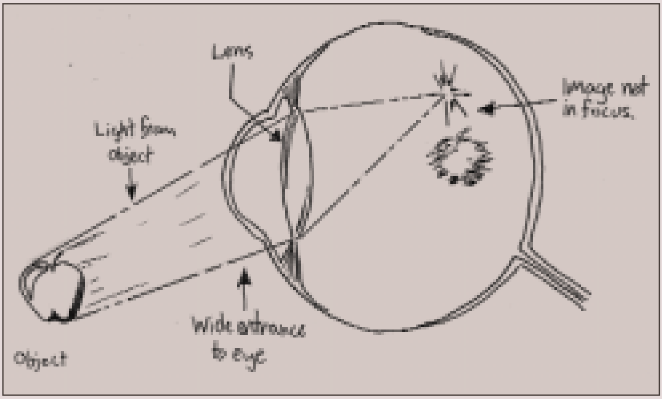
The retina is the layer of cells in the eye that are sensitive to light, including the rods (black-and-white vision) and the cones (colour vision). The fovea is the place on the retina where the cones are concentrated and where the image is focused for the best vision when you look directly at something. The brain also plays a vital role in the amazing sense of vision.

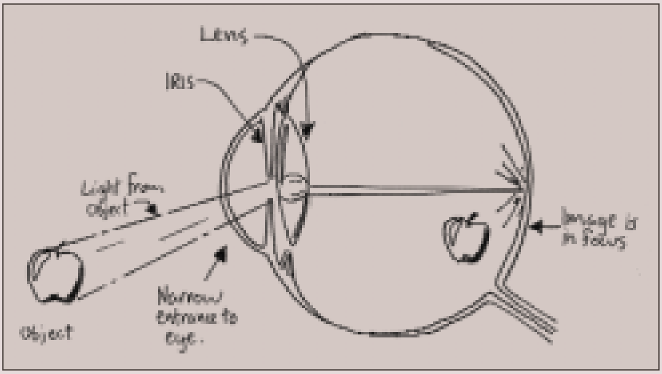
How the eye works, continued...

Pupil: why have a narrow entrance to the eye?

Follow these steps

1 Make a small pinhole at the centre of the card.
2 Without the card, focus on an object at the front of the room and hold the pin in front of you at arm's length.
3 Still focusing on the distant object, bring the pin closer and closer until it goes out of focus.
4 Note how far away the pin is when this happens.
5 Now focus on the same distant object as before but view it through the hole in the card.
6 Move the pin closer and closer as before, noting the distance at which it becomes out of focus.



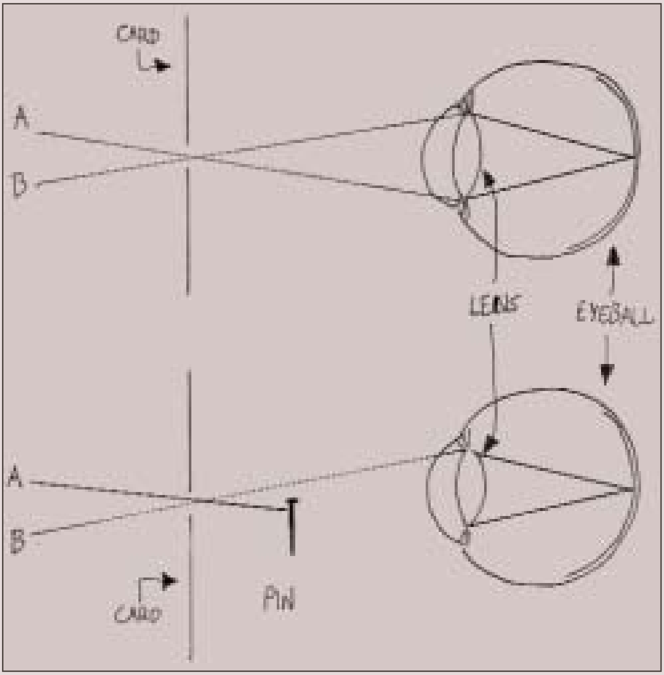


So what happened?

The pin remains in focus much closer to the eye when you look through a small hole. A much greater depth of field is in focus when the entrance to the eye is smaller. The small entrance to the eye means that the light coming from both objects (the distant object and the pin) is much more similar, so the depth of focus is greater (see figure).

How the eye works, continued…

Lens: what kind is it?



Follow these steps

1 Look through the pinhole in the card at the brightly lit screen in front of the overhead projector.
2 Hold the pin between one eye and the card.
3 Move the pin around until you can see the shadow (image) of the pin.
4 Move it up and down slightly and record what you notice.

So what happened?

The shadow of the pin is inverted. This can only be explained if the lens in the eye is a convex lens and the pin is blocking some of the rays of light entering the eye (see figure). Images on the retina are normally inverted and the brain turns them upright. The shadow of the pin is really the same way up as the pin, so it looks inverted.

Aqueous humour: is the eye full of fluid?

Follow these steps

1 Illuminate the screen with the overhead projector.
2 Use the pin to make a small hole in the centre of the card.
3 Hold the card in front of one eye and look through the hole at the brightly lit screen.
4 Keep looking for at least 1 min.
5 Describe what you see.

So what happened?

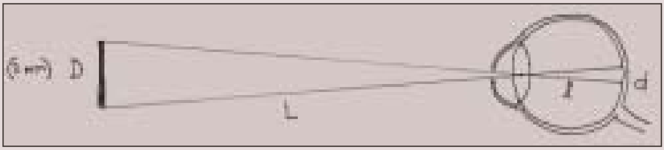
You will see “floaters” – strands and particles moving around in the fluid of the aqueous humour. This fluid plays an important role in maintaining the shape of the eyeball, which is essential if the image is to be focused precisely by the lens onto the retina.

The pressure of the fluid is accurately maintained by a duct, but it is important in middle age to get this pressure checked to screen for a condition called glaucoma, which can do permanent damage to sight if left untreated.

44 light

How the eye works, continued...

Retina: how far apart are the rods and cones?



Follow these steps

1 Place a sheet with two parallel black lines 2 mm apart at the front of the room
2 Ask who can distinguish the two separate lines.
3 Measure the distance from the sheet to the farthest students who can distinguish the two lines.
4 Take eyeball length to be approximately 20 mm and use geometry (see diagram and formula) to determine the distance between the light-sensitive cells.

$$\frac{L}{D} = \frac{l}{d}$$

where $l = 20$ mm, $D = 2$ mm and L = distance measured.

So what happened?

You should calculate the distance between the light-sensitive cells to be approximately 8–10 µm.

This simple activity involving the whole class has the added bonus of showing that geometry does actually have its uses.

What next?

If you can get hold of an optician's Snellan chart, the students can measure their own visual acuity, which they always enjoy.

Retina: where are the blood vessels?

Follow these steps

1 Hold the card in front of one eye with the other eye closed.
2 Look through the hole at the brightly lit screen.
3 Vibrate the card quickly while still looking through the hole.
4 Note what you see.

So what happened?

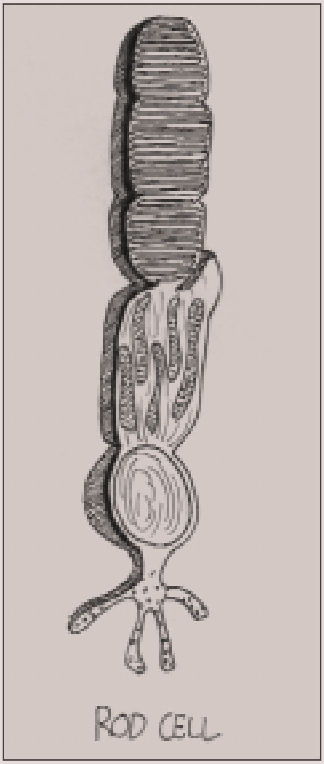
The retina is made of living cells, so it has blood vessels to supply these cells with the food and oxygen that they need to survive. Normally the image of these blood vessels is there all of the time and the brain ignores it, but in this experiment the messages are so confused that this does not occur and you can see them.

How the eye works, continued…

Rods: how do they work?

Follow these steps

1 View the Internet image on the screen for 1 min (see www.eyetricks.com/jesus.htm).
2 Remove the image and stare at the white screen.
3 Note what you see (try blinking).



So what happened?

You will clearly see an after-image of Jesus Christ.

The rods – the most numerous of the light-sensitive cells in the retina – contain a pigment, rhodopsin, which is sensitive to light. When the pigment is exposed to light it breaks down, causing an impulse to pass along the optic nerve to the brain.

When you stare at the original image, the bright parts cause the rhodopsin in the corresponding cones in your retina to break down and send messages to the brain. The dark parts of the image emit no light, so the corresponding rods send no messages.

When the image is removed, the rods that were receiving no light (corresponding to the dark areas of the original image) start receiving light, causing rhodopsin to break down and messages to be sent to the brain, so these areas look bright.

However, the rhodopsin in the rods that were originally receiving light has been broken down and has to be reformed before it can be broken down again and messages can be sent to the brain. When the image is removed, these areas thus appear darker. The result is an after-image of the original.

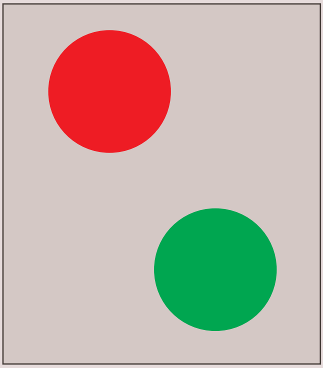
How the eye works, continued…

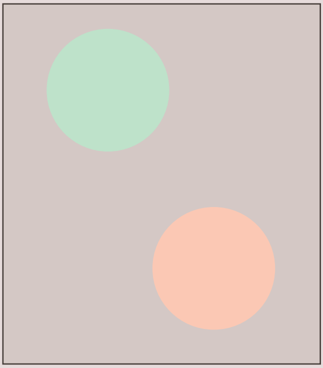
Cones: how do they work?

Follow these steps

1 Project two small circles of red and green filter placed side by side.
2 View the screen for 1 min.
3 Remove the colours.
4 Record what you see.

Note: If filters are not available, this also works with squares of vividly coloured paper held in strong light for 30–60 s.



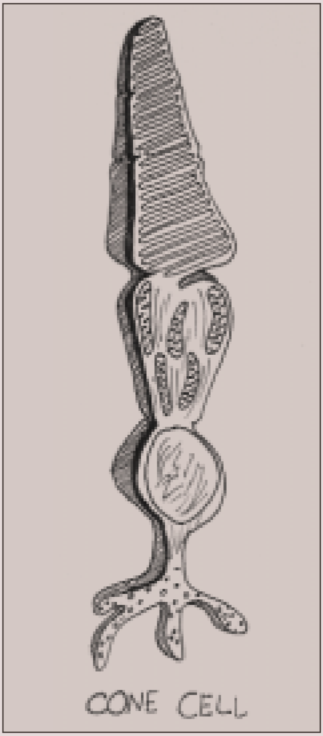


So what happened?

Most people see red where it was green and green where it was red.

There are three types of cone in the retina – sensitive to each of the three primary colours. After staring at red for a while, the red-sensitive cones are less sensitive because some of the pigments in them have been broken down, so when the colour is removed and the retina is bombarded with white light (containing all three primary colours), the messages sent from the green- and blue-sensitive cones are stronger for a while. Similarly, after staring at green, it is the red and blue cones that send most messages.

Some people claim instead that they see the complementary colours (i.e. cyan where there was red and magenta where there was green), but they may have been physics teachers used to looking at their results with the eye of faith. There is also likely to be some individual variation, depending on which part of the retina the image was focused on.

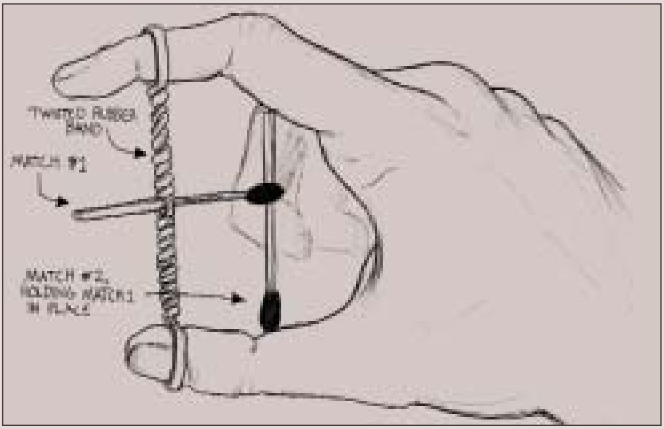


How the eye works, continued...

The brain: what is its role in vision?

Follow these steps

1 Place a rubber band over the thumb and first finger of one hand in a "C" shape.
2 Place a match between the strands of the band and twist it round many times.
3 Place a second match between the thumb and forefinger so that it holds the first match in place and prevents it from turning.
4 Half rotate the first match and then let go.



So what happened?

It appears as if you are rotating one match through the other even when you watch quite closely. The wound-up elastic in fact rotates the match back to its original position each time it is let go, but this movement is too quick for the eye to respond to, so the brain makes the logical interpretation that the match is being rotated in a circle.

Fovea: what is it for?

Follow these steps

1 Repeat the experiment on p42 but look more carefully.
2 Look for a clear area in the centre of the retina with no blood vessels – the fovea.
3 View the letters projected onto the screen from an OHP.
4 Stare at the centre letter.
4 Note which letters either side of the centre letter is out of focus.

E M C L I A G D F H J K B N F X R

So what happened?

The fovea is at the centre of the retina where there is the highest concentration of light-sensitive cells, especially the cones for colour vision. This is why the best vision is at the centre of the field of view (the central letter) while vision deteriorates farther from the centre as the image lies farther and farther from the fovea.

The electrostatic shoelace

The Czech Republic

An everyday example of electrostatics

You will need...

- ✔ a synthetic shoelace

Background

Electrostatic charges can be produced by friction. Like charges repel.

Follow these steps

Stroke a shoelace between your thumb and forefinger several times, then hold it a few centimetres from the end.

So what happened?

The shoelace becomes electrostatically charged and stands upright. Several types of shoelace may need to be tested to find one that works well.

What next?

Try charging different materials.

Repelling straws

Spain

Like charges repel whereas unlike charges attract

Background

There are two kinds of charge: positive and negative. Forces of repulsion and attraction appear with like and unlike charges. Charging by friction is useful for charging insulators: rubbing a plastic straw with fur gives the straw a negative charge; rubbing the straw with silk gives it a positive charge.

Follow these steps

1 Fix the screws near the long sides of the frame (see picture).
2 Attach the fishing line between the pairs of screws to make taut supports for the straws (preferably use three).
3 Charge the straws by friction, rubbing one with fur and one with silk.
4 Rest one of the straws across the wires.
5 Bring the second straw close to the first one and see what happens.
6 Charge a third straw by rubbing it with silk and place it between the other two.
7 Note what happens to the first two straws.

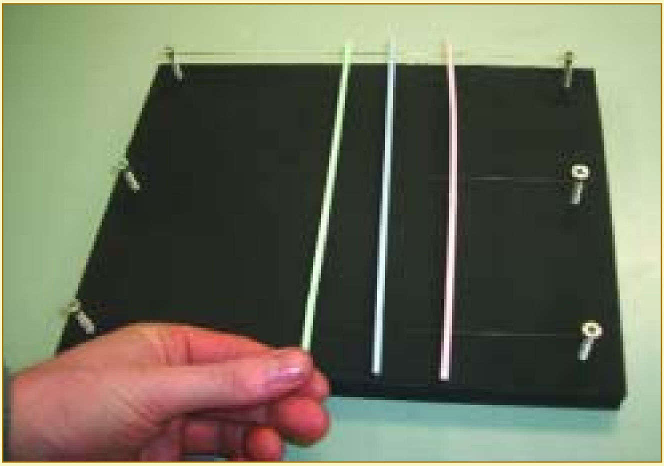
You will need...

- ✔ a wooden frame (about 20 × 30 cm)
- ✔ six screws
- ✔ some fishing line (1 m)
- ✔ three plastic straws
- ✔ different cloths (e.g. silk, fur, wool)

So what happened?

Rubbing one straw with fur and one with silk means that they have opposite charges so they attract each other.

Charging two straws with the same material means that they will have like charges and will therefore repel each other.



What next?

Try using different coloured straws to distinguish between positive and negative charges. Also try different types of material and then determine what type of charge is on each of the straws.

This exercise can also be extended to show charging by induction.

Seeing alternating current in a bulb

Belgium

Mains current is alternating

You will need...

- ✔ a clear light bulb
- ✔ a powerful magnet
- ✔ a mains source

Background

Mains supply electricity is an alternating current with a frequency of 50 Hz.

Follow these steps

1 Connect the light bulb to the mains supply.

2 Bring the magnet close to the glowing bulb.

So what happened?

The filament vibrates when the magnetic field is present.

In the presence of the magnet, the filament of the bulb acts as a conductor in a magnetic field and therefore experiences a force.

The alternating nature of the current produces a varying force, resulting in the vibration of the filament.

The effect is best seen in a bulb that has a long filament, which can be found in certain ornamental bulbs. An ordinary candle bulb can also be used.

What next?

You can use a convex lens to project a magnified image of the filament onto a suitable screen or wall, thereby making the vibrations easier to see.

Making a simple induction motor

Hungary

How does an induction motor work?

You will need...

- ✔ wire coiled round an iron core (12,000 turns; use a demountable transformer kit)
- ✔ an aluminium can
- ✔ a 1 mm thick aluminium ring
- ✔ a 6–12 V AC power supply
- ✔ a pencil
- ✔ a piece of BluTack

Background

This is a simple induction motor that can be made if you have a demountable transformer kit.

Follow these steps

1 Mount the coil on one arm of the core.
2 Remove the top of the can.
3 Position the pencil pointing upwards with the BluTack.
4 Place the inverted can over the pencil so that it balances on the pencil tip and can rotate freely.
5 Position the can so that one end of the transformer core faces it.
6 Shield half of the core that is facing the can with the aluminium ring.
7 Connect the coil to the power supply and see what happens.

So what happened?

The can rotates owing to electric currents in the can induced by the magnet.

What next?

For an explanation of the principle behind this type of induction motor, see any text on shaded-pole induction motors. These motors are common – they are used to drive washing-machine pumps and the cooling fan of overhead projectors.

The Darlington trio

The Czech Republic

A simple circuit demonstrates several electrical phenomena

Background
The configuration of the circuit is known as a Darlington trio.

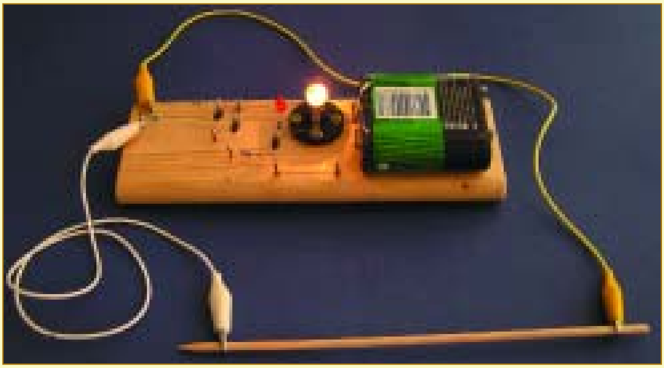
Follow these steps
1 Set up the circuit shown in the diagram.
2 Place the leads of A and B across the wooden skewer.
3 Hold lead A (let lead B hang in air) then rub your foot on the ground.
4 Move a charged object close to lead A.

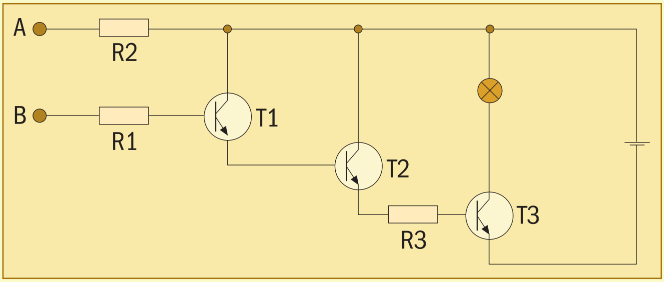
So what happened?
The amplified output of the first transistor is fed onto the base of the second transistor, so there is a cascade effect. The circuit can detect currents in the order of nanoamperes.

When the leads are placed on the wood, the bulb lights up, showing that wood is not a perfect insulator.

When you hold lead A, let lead B dangle and rub your foot on the ground, the bulb lights because the circuit is able to detect the static electricity generated.

When you move a charged object close to lead A, the bulb lights only when the charge moves.





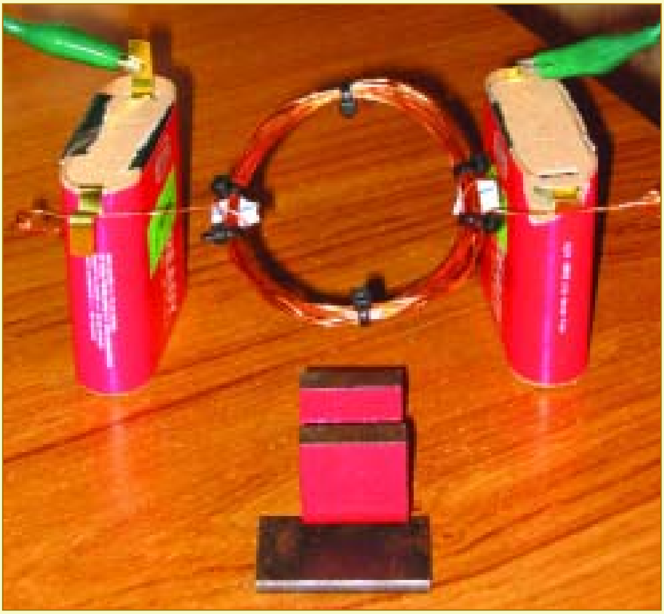
You will need...
- ✔ three transistors (BC337 or BC547)
- ✔ resistors (R1 = 10 MΩ, R2 = 1 MΩ and R3 = 15 kΩ, but their values aren't critical)
- ✔ a.35 V/0.2 A light bulb
- ✔ a 4.5 V battery
- ✔ a wooden skewer

What next?
Sockets can be added to the circuit so that it can be connected to a digital voltmeter and a cathode-ray oscilloscope to measure currents and view signals.

Making a simple electric motor

Slovakia

How does an electric motor work?



You will need...

- ✔ some lacquered copper wire
- ✔ two bicycle/head torch batteries (4.5 V)
- ✔ a strong magnet
- ✔ some sandpaper
- ✔ a piece of cable

Background

Using a few inexpensive components, it is easy to construct a simple electric motor.

Follow these steps

1 Using the lacquered copper wire, make a coil of about 10 turns (the ends of the wire will form the axles of the coil).
2 Remove all of the lacquer coating from one of the axles using the sandpaper.
3 Remove the lacquer from only one side of the other axle.
4 Bend the battery terminals so that they can support the ends of the coil.
5 Place the coil so that one axle sits in the positive terminal of one battery and the other sits in the negative terminal of the other battery.
6 Complete the circuit by connecting the two batteries with a piece of cable.
7 Place the magnet near the coil and give the coil a single turn by hand.

So what happened?

The coil receives torque for only half of each rotation and its angular momentum is enough to keep it turning.

Bottle race

Belgium

The effect of a vortex in a liquid

You will need:

- ✔ two 250 ml drinks bottles
- ✔ some parafilm or duct tape
- ✔ some water

Background

See what happens to water when you empty the bath.

Follow these steps

1 Pour water into one bottle so that it is three-quarters full.
2 Tape the two bottles together (see picture).
3 Ask the students to time how long it takes the water to flow from one bottle to the other when the bottles are inverted.
4 Repeat the experiment but this time give the water some angular velocity by moving the bottles in a circular motion before inverting them.
5 Again, get the students to time how long it takes for the water to run through to the second bottle.

What next?

If you make two sets of this apparatus you can have a race. Let the students figure out how to get the water to transfer faster.

So what happened?

The water is transferred faster from one bottle to the other after you generate some angular velocity.

The angular momentum of the water creates a vortex at the neck of the bottles, thus allowing air to move up easily through the centre of the vortex and the water to move down the sides into the empty bottle. The less chaotic motion at the neck of the bottles therefore allows the water to flow faster.

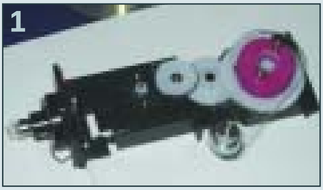
Broken hardware experiments

The Czech Republic

Making useful physics demonstrations from discarded equipment

Background

There are many experiments that can be devised using the bits and pieces that can be salvaged from old computers and other hardware. Here we show three uses for the remains of an old CD drive.



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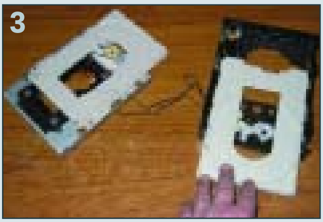

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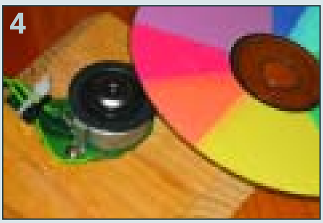

4

Follow these steps

1 Remove the gears and motor that operate a CD drive (pictures 1 and 2).

2 Wire the motor up to a 6 V bulb and add a handle so that the motor can be turned easily.

3 Turn the handle and note what happens.

4 Next, connect together the motors of two CD drive trays (picture 3).

5 Open one drive manually and see what happens to the other.

6 Apply different coloured stickers to a CD and place it on the motor that spins a CD when it is playing (picture 4). Note that these motors are complicated stepper motors that require a 6–12 V AC supply to get them to spin for this experiment unless their own electronics are adapted to operate them.

7 See what happens to the colours when the motor is turned on.

You will need:

- ✔ the remains of two old CD drives
- ✔ a 6 V bulb
- ✔ some old CDs
- ✔ some CD labels
- ✔ some coloured stickers (you can use CD label printing software to make these)

So what happened?

When the handle is turned the gears turn the motor at high speed and electricity is generated, thereby lighting the bulb. This simple apparatus is useful to demonstrate the conversion of mechanical energy to electrical energy.

Depending on how the two CD drive motors are wired together, opening one tray manually generates enough electricity to open or close the other. This again demonstrates the conversion of mechanical energy to electrical energy.

In the final set-up the motor and CD allow you to make an electrically driven Newton's disk. The colours should appear white when the motor is turned on.

The Coriolis effect

Important for an understanding of the movement of large-scale weather systems

Background

All places on the Earth have the same rotation rate of one revolution per day. However, the linear speed of a place depends on its latitude: places on the equator move at 1670 km/h while those near the pole have nearly zero speeds (see red arrows in Figure 1).

When an object moves north or south and is not firmly connected to the ground (air, artillery shells, etc), it keeps its initial eastward speed as it moves.

If the object is launched north from the equator, it will eventually be going faster east than the ground beneath it and will seem from the ground to be moved east by a mysterious "force" (see black arrow).

Objects moving towards the equator will eventually be moving slower than the ground and will appear to deviate to the west (see yellow arrow). In reality there is no force involved – the ground is simply moving at a different speed than at the starting point.

Thus air moving towards the poles appears to curve to the east and air moving towards the equator appears to curve to the west. This means that, for a low-pressure system in the northern hemisphere, motion is inwards and counterclockwise (figure 2). The Coriolis effect is strongest at mid-latitudes.

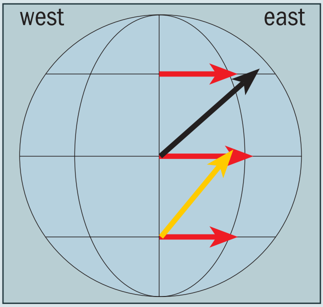

Figure 1: Apparent deflection of objects on northerly trajectories.

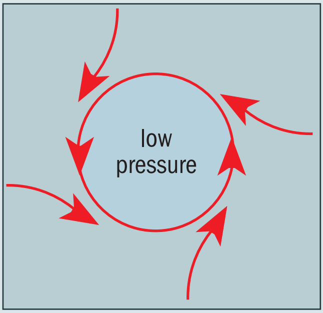

Figure 2: Vortex created in a low-pressure system.

What next?

In small-scale systems, like water draining from a sink or a bath, the Coriolis effect is usually overwhelmed by local variations, such as residual currents or irregularities in the shape of the container. It is only by very careful elimination of these factors that the Coriolis effect can be observed in the laboratory.

The rotation of the Earth does, however, influence the direction of rotation of large weather systems and large vortices in the oceans, because these are very long-lived phenomena and so allow the very weak Coriolis force to produce a significant effect with time.

Gustave-Gaspard Coriolis of Paris published his explanation of the effect in 1835. For more information, see http://www.physics.ohio-state.edu/~dvandom/Edu/newcor.html.

See pvii for a picture of the winning Coriolis demonstration from Ireland.