

# PHYSICS

*on Stage 2 & 3*

**Demonstrations and teaching ideas**  
selected by the Irish teams



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# PHYSICS

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## Foreword

It is a pleasure to introduce this science teaching resource which presents demonstrations and teaching ideas prepared and selected by the Irish Science on Stage committee and delegates that attended either the **Physics on Stage 2** festival at ESA-ESTEC (Noordwijk) the Netherlands from 2-6 April 2002 or the **Physics on Stage 3** festival held in ESA-ESTEC (Noordwijk) the Netherlands from 8-15 November 2003.

The Physics on Stage programme was initiated in 1999 by representatives of the CERN, ESA and ESO Outreach Departments, in response to the European Commission's Call for Proposals for the European Science and Technology Week 2000. The Physics on Stage Programme evolved into the **Science on Stage** programme and two international festivals have been held, Science on Stage 1 in CERN (Geneva) Switzerland on 21-25 November 2005 and Science on Stage 2 in ESRF/ILL (Grenoble) France on 2-6 April 2007. Since 2008, Science on Stage Europe ([www.science-on-stage.eu](http://www.science-on-stage.eu)) have coordinated the International festivals, with Science on Stage 2008 held in Berlin Germany on 23-26 October 2008 and Science on Stage 2011 planned for Copenhagen, Denmark on 16-19 April 2011.

The Irish participation in this project and the reprinting of this resource is made possible by the generous sponsorship of the Second Level Support Service, Junior Science Support Service, Discover Science and Engineering, Institute of Physics in Ireland, Centre for the Advancement of Science and Mathematics Teaching and Learning (CASTeL) and EIROforum European Science Teachers' Initiative (ESTI) (a partnership between CERN, ESA, ESO, EMBL, ESRF, ILL, EFDA and supported by the European Commission). We would like to gratefully acknowledge the support provided for teacher substitution by the Department of Education and Science through the Second Level Support Service.

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 team of contributors: Paul Nugent, Michael Grehan, Angela Kelly, Alison Hackett, Patrick Lyne, Brendan O'Donoghue, Elaine Collins, Ian Elliot, Sean Fogarty, Alison Graham, Jennifer Egan, Tim Roe, Eilish McLoughlin, Eamonn Cunningham, Rory Geoghegan and Vida Given. All of the teachers involved work full time, yet, despite this, they tested and produced this excellent collection of demonstrations selected from the Physics on Stage conferences and this publication would not have happened without their very professional commitment.

It has been my pleasure to work with these inspiring science teachers and educators and I hope you will find this publication an invaluable classroom resource. For further information on Physics on Stage/Science on Stage in Ireland and for electronic copies of all the POS/SOS booklets, please visit: [www.scienceonstage.ie/](http://www.scienceonstage.ie/)

Dr. Eilish McLoughlin

Chairperson Science on Stage National Steering Committee

CASTeL, DCU

February 2010.

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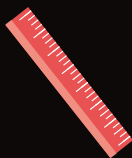
Foreword

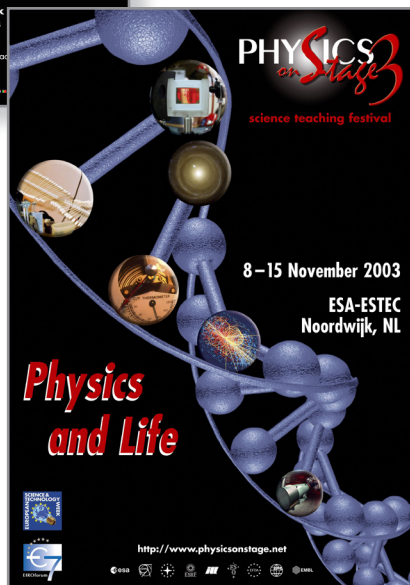
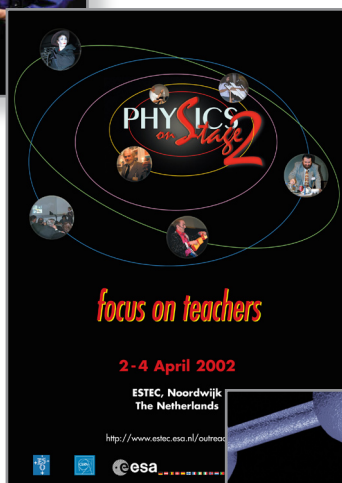
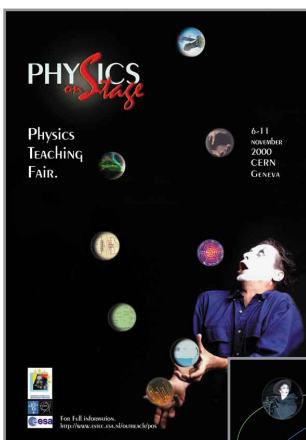
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# **Physics on Stage 2**

## **2002**

**Demonstrations  
&  
Teaching Ideas**

**Selected by the  
Irish Team**

The National Steering Committee for Physics on Stage 2 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 is a voluntarily produced document that is intended as a support resource for teachers of physics and is not published for profit.

Physics on Stage 2 gives permission to educational organisations to reproduce material from this book without prior notification provided it is for the purposes of education, is not for profit and suitable acknowledgement to Physics on Stage 2 is given. Physics on Stage 2 would be grateful to receive a copy of any other publication using material reproduced from this book.

As numerous people contributed to this book, it was necessary to accommodate a variety of presentation styles. Any corrections or suggestions would be welcomed by the committee and can be sent to:

Alison Hackett, Physics on Stage 2, c/o School of Science and Technology,  
Dun Laoghaire Institute of Art Design and Technology, Dun Laoghaire, Co Dublin.

## **Contributors**

Paul Nugent  
Michael Grehan  
Angela Kelly  
Alison Hackett  
Patrick Lyne  
Brendan O'Donoghue  
Elaine Collins  
Ian Elliott



# PHYSICS

## *on Stage 2*

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### **Experiments**

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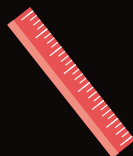
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**This project was made possible by the generous sponsorship of Forfás, Physics on Stage and the Institute of Physics in Ireland.**

As the only member of the team involved in Physics on Stage 2 who was not working in a voluntary capacity it seems appropriate that I use this space to formally thank those involved. It was a privilege to have worked with a team who are all in full time demanding positions yet so selflessly gave their free time to the Physics on Stage 2 project.

Firstly, sincere thanks to Paul Nugent and Michael Grehan who as well as being involved at almost every other stage of POS2, produced at least 90% of this document. This included testing, developing and writing up a great number of the demonstrations and working on it right through to the final stages of production. This publication would not have happened without their very professional commitment.

The gratitude of all the team must go to Brendan O'Donoghue as secretary of POS2. Brendan was greatly involved in the initial stages, which included arranging the mailing of a request for demonstration submissions for POS2 from physics teachers in every school. He carried out all the complex and lengthy communications with POS2 and the organisation of the delegates' trip to Holland.

Angela Kelly was the only delegate who was also at the first Physics on Stage and our thanks to her for once again taking part in POS2 and also for great help in producing the first document that went to POS2 with the delegates.

From the demonstration submissions the committee selected Patrick Lyne and Elaine Collins as POS2 delegates. Thanks for their time, effort and full participation in the event and also to Patrick for the section on web sites in this publication.

The treasurer Eamonn Cunningham provided invaluable support with management of the finances and a reassuring experience with the detail having also acted as treasurer for POS1. Our thanks to Eamonn.

As the first Physics on Stage 2 contact, Ian Elliott spent considerable time finding a committee who would act for POS2. Thanks are due to Ian for providing the initial 'bridge' as secretary from POS1 and for his help and always sound advice.

Andy Shearer was in the difficult position of being based at NUI Galway but taking part in an essentially Dublin based project. Thanks to Andy for his help and also to his colleague Symeon Charalabides for setting up the web site.

The National Steering Committee for Physics on Stage 2 would also like to thank the following institutions and people for contributing their time and resources to help us with this project:

Leo Enright; Tim Regan and Pdraig O Léime (the Physical Sciences Initiative).  
Dun Laoghaire Institute of Art Design and Technology; Dublin Institute for Advanced Studies;  
Dublin City University; NUI Galway; Trinity College Dublin Physics department; the management of the following schools: Sandford Park School, Ranelagh, Dublin; Coolmine Community School, Coolmine, Dublin; St Dominic's High School, Santa Sabina, Sutton, Dublin; St. Mary's Secondary School, Macroom, Co. Cork, Loreto Secondary School, Wexford; Ronan Jacob, Belvedere College Dublin. Special thanks are due to Fr Leonard Moloney SJ for the use of the facilities at Belvedere College Dublin for committee and lab meetings.

Alison Hackett    **Institute of Physics in Ireland**    Co Chair, Physics on Stage 2



**The Irish delegation to Physics on Stage 2 (l to r) Patrick Lyne, Michael Grehan, Brendan O'Donoghue, Elaine Collins, Angela Kelly, Paul Nugent.**

## What's this?

A booklet of practical ideas for teachers of Physics and Junior Science.

## Who's it from?

A group of Irish science teachers who took part in the second Physics on Stage conference with the help of Forfás, the National Steering Committee of Physics on Stage and the Institute of Physics in Ireland.

## Where and when was that?

300 physics educators from 23 countries were guests at the European Space Agency's facility: ESTEC in Noordwijk on the coast of Holland from April 2-6, 2002.

## Why the booklet?

- ❖ While you may be using many of these ideas already we hope you'll find some useful items to add to your physics demonstrations and your students' experimental work.
- ❖ We hope that more teachers may like to get involved in the range of science education events sponsored by some of Europe's large research facilities.
- ❖ To invite teachers to contact us with more ideas or requests for information and so encourage more networking between science teachers in Ireland.

## How can more teachers get involved?

By contacting us or by going to the websites of the European research organisations where you will find contact addresses for more information.

The Physics on Stage website is [www.physicsonstage.net](http://www.physicsonstage.net) and it has links to the other organisations. The Irish site is at <http://www.pos.ie>

We may be contacted by sending an e-mail to [alison.hackett@iop.org](mailto:alison.hackett@iop.org)

## Which organisations are behind all this?

Physics on Stage was initially launched by the three agencies noted below with support from the European Union and the other participating organisations.

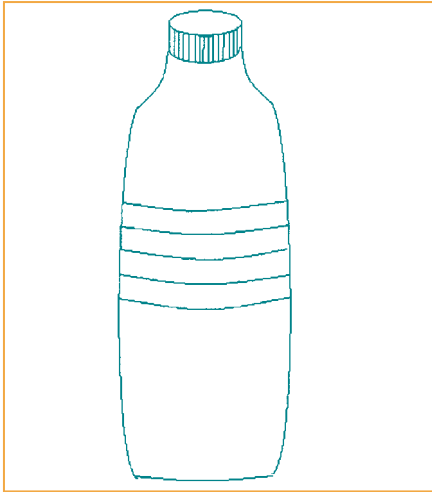
<b>ESA</b>	The European Space Agency	<a href="http://www.estec.esa.nl">http://www.estec.esa.nl</a>
<b>ESO</b>	The European Southern Observatory	<a href="http://www.eso.org">http://www.eso.org</a>
<b>CERN</b>	The European Centre for Particle Physics	<a href="http://welcome.cern.ch">http://welcome.cern.ch</a>

Other participating organisations were:

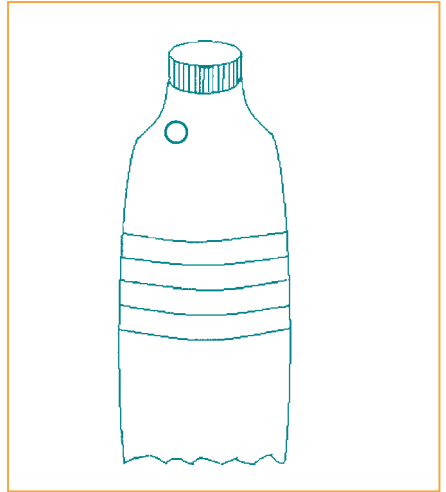
<b>EPS</b>	The European Physical Society,
<b>EAAE</b>	The European Association for Astronomy Education,
<b>EMBL</b>	The European Molecular Biology Laboratory and
<b>ESRF</b>	The European Synchrotron Radiation Facility.

## Demonstration of atmospheric pressure

Cut the base off a plastic water bottle but keep the lid screwed tightly on.



Cut out a small hole (that can be closed off using your forefinger) near the lid.



Place the bottle in a larger non-transparent container filled with water.



Lift the bottle slowly out of the water with the hole at the top uncovered.

The bottle appears empty.

Lift the bottle slowly out of the water with your finger covering the small hole at the top and the bottle appears full.

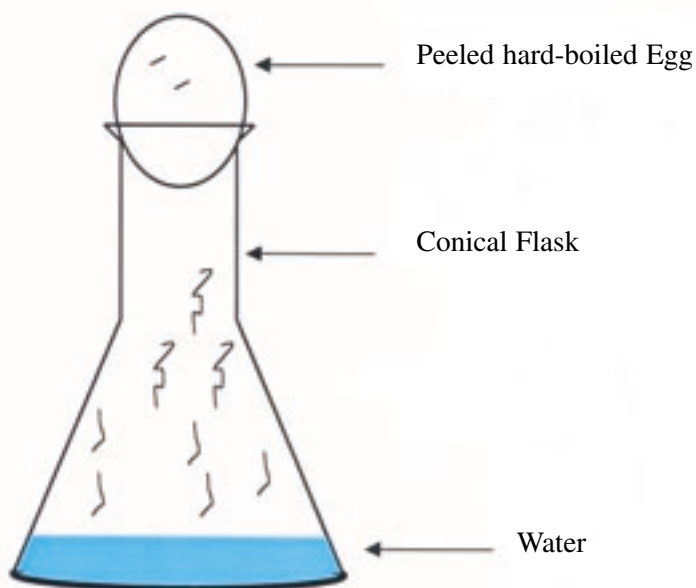
## Atmospheric pressure

### Procedure

- (1) Place some water in a conical flask.
- (2) Heat the water until it boils.
- (3) Place a hard-boiled egg (*one that has the outer shell removed*) on top of the flask.
- (4) Ensure that the egg stops the steam from escaping by placing it firmly on the flask.
- (5) Wait and observe.

### Result

The egg will fall into the flask illustrating atmospheric pressure.



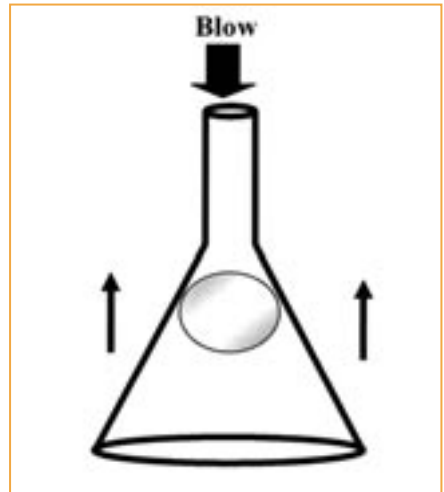
## ***Bernoulli effect 1: ping-pong ball in funnel***

**ITALY:** Marisa Sasso and team

Place the Ping-Pong ball into the funnel.

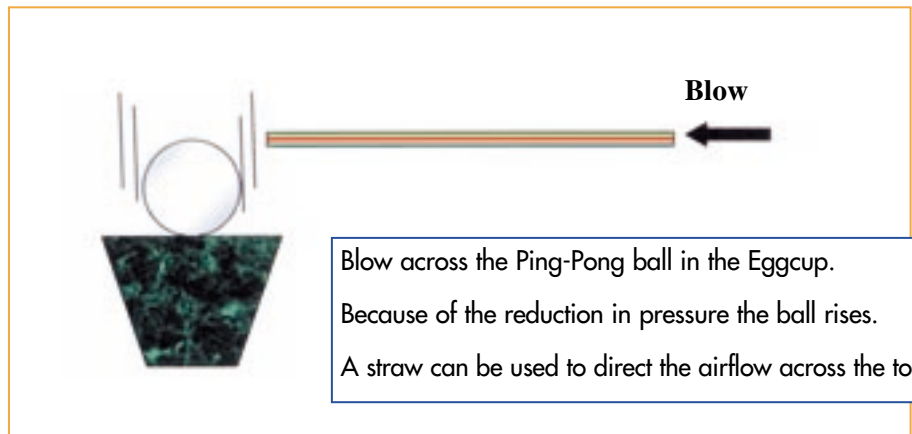
Blow down.

The ball rises due to the reduced pressure.



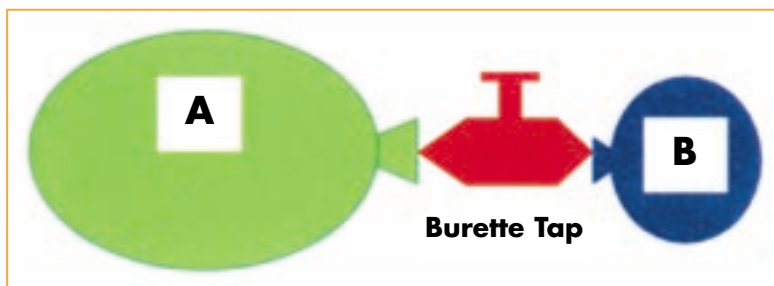
## ***Bernoulli effect 2: ping-pong ball in eggcup***

**ITALY:** Marisa Sasso and team



## Communicating balloons

**NETHERLANDS:** 'Discovery Game' Piet Blankert and Johan van de Adel



Balloon A is well inflated, Balloon B is partially inflated

**What happens when the tap is opened?**

- (1) A gets smaller B gets bigger
- (2) A gets bigger B gets smaller
- (3) They become the same size
- (4) There is no change

**Answer:** The hardest part of blowing up a balloon is near the beginning, this is because there is a strong resistance caused by the elasticity of the rubber.

Different results can be achieved depending on how much air is in B.

These results can be counter-intuitive and will hopefully promote thought and discussion amongst students.

**Further topics:** Elasticity, Materials Pressure, Atmospheric Pressure, etc.



## *The Bernoulli effect 3: the slipstream*

### IRELAND

**Blow Hard**



Place a card/sheet of glass/  
or best clear Perspex about  
5cm wide in front of the candle.

Blow hard – the candle flame  
flickers towards the obstacle.



**Blow Hard**

Place a glass bottle  
in front of the candle.

This time the candle flickers away.

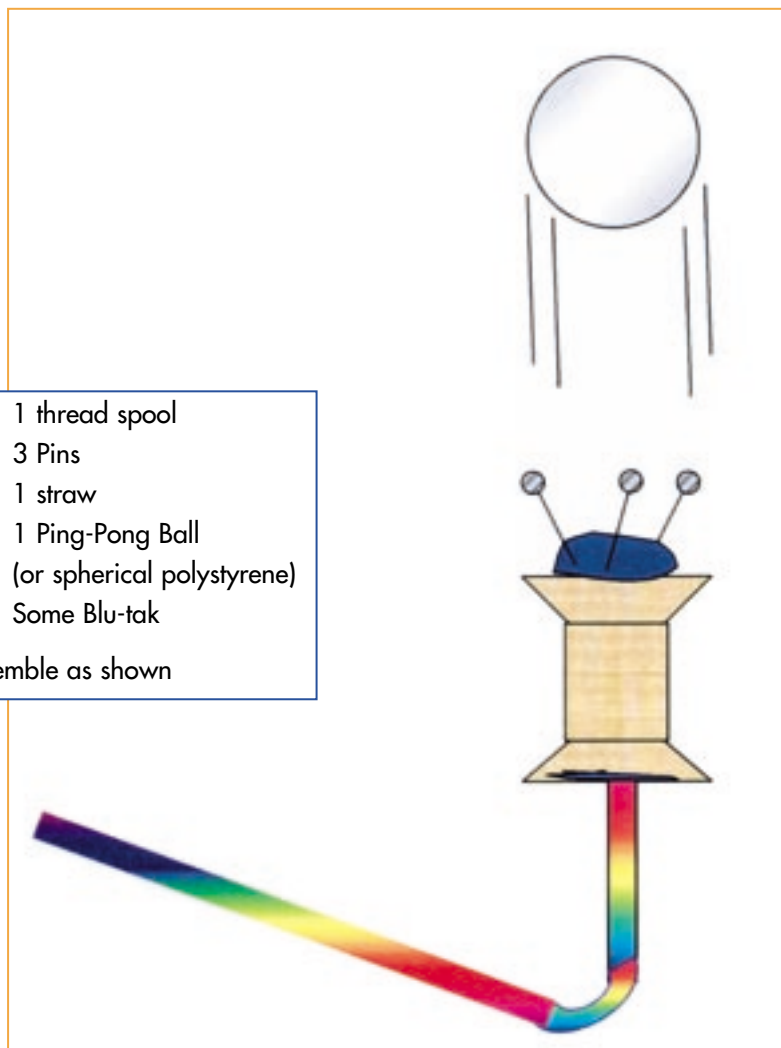


## ***The Bernoulli effect 4: the pipe***

**IRELAND:**

Use: 1 thread spool  
3 Pins  
1 straw  
1 Ping-Pong Ball  
(or spherical polystyrene)  
Some Blu-tak

Assemble as shown

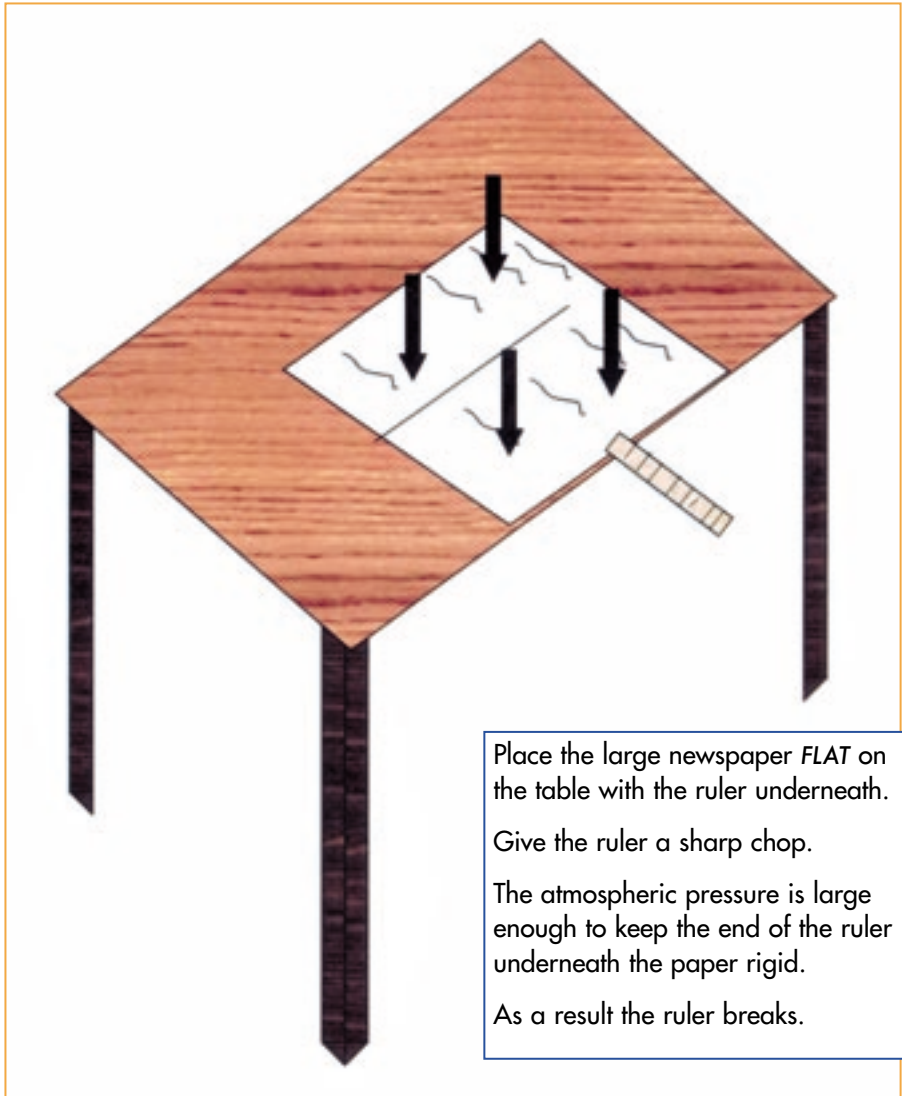


A simpler version can be made using just a polystyrene ball and a straw with a bend.

**Further Topics:** Aerofoils, Spoilers, Shower Curtains, Atomisers, etc.

## *The atmospheric karate chop*

**IRELAND:**



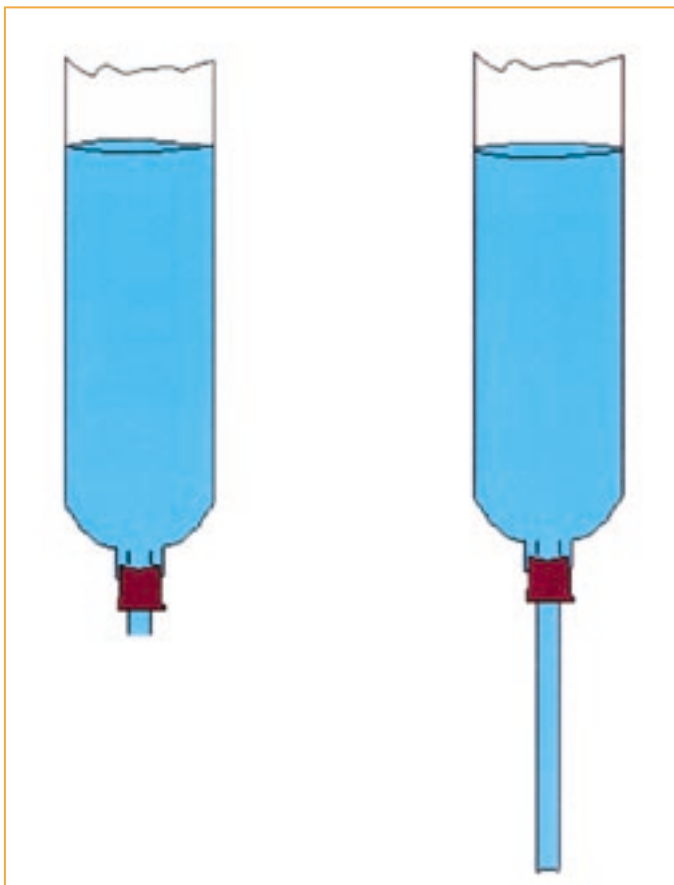
Place the large newspaper *FLAT* on the table with the ruler underneath.

Give the ruler a sharp chop.

The atmospheric pressure is large enough to keep the end of the ruler underneath the paper rigid.

As a result the ruler breaks.

## Pressure



**Will one bottle empty faster than the other if the same volume of liquid is in both?**

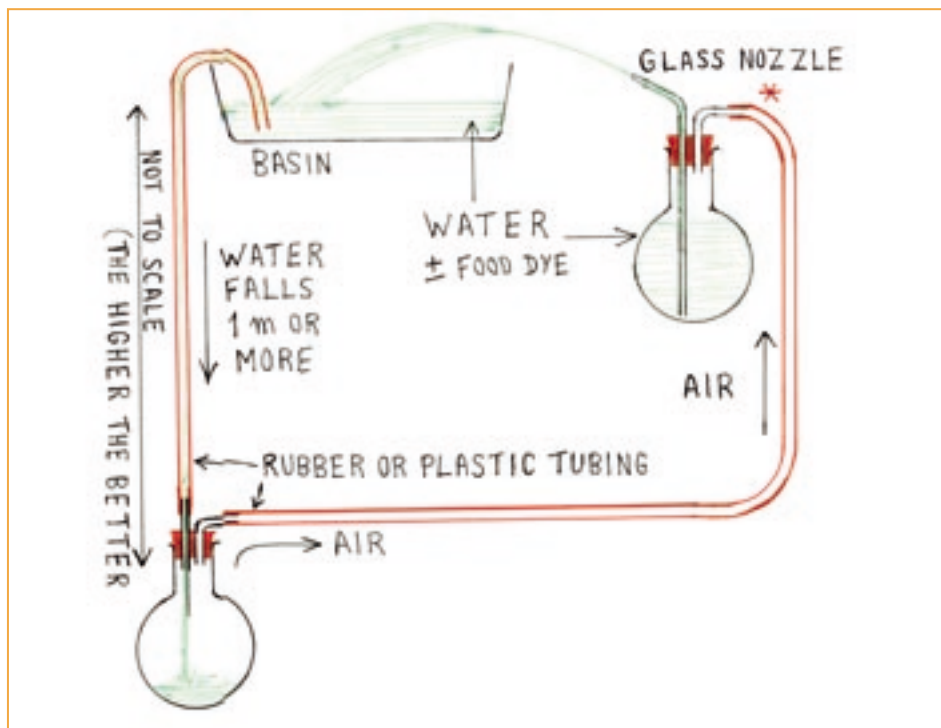
Use plastic soda bottles with the base cut off for this demonstration.

The rate at which water flows out of the bottle is proportional to the pressure at the bottom of the exit tube.

The pressure at the bottom of a column of water is proportional to the height of the column of water above it.

## 'Heron's Fountain' [Heron is also known as Hero of Alexandria]

**SWEDEN:** Per Olaf Nilsson demonstrated a more elaborate version



A small fountain sprays water into a basin. The fountain is supplied by a flask of water **below** it. Water from the basin drains into second flask which is lower down. Ask students how the water has enough energy to spray out of the fountain at the top. We made this simple version using only standard laboratory items. It was also very easy to start by sucking air through the plastic tube at \* then it ran for about 10 minutes before the flasks needed to be exchanged. Try increasing the height of the head of falling water. We used:

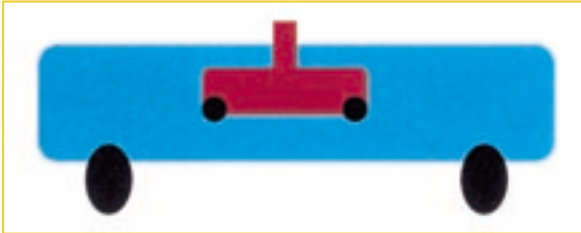
2 flasks (1 litre or 500 ml, conical or flat bottomed, what the heck?)

2 two-holed rubber bungs to fit the flasks.

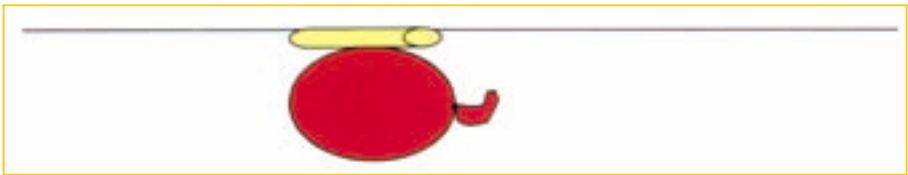
2 metre, or so, of plastic or rubber tubing to fit the glass tubing.

1.5 m of 6mm glass tubing, cut into 4 pieces and worked as shown.

## ***Newton's third law***



1. Place a wind-up toy clockwork train on a track with wheels.
2. Set the train to move forward and see the track moving backwards.

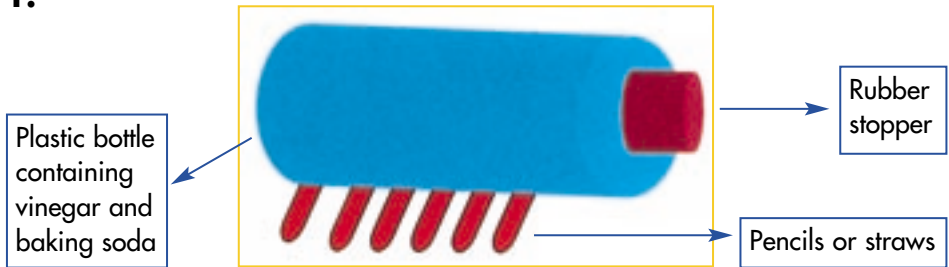


1. Attach a balloon to a straw and pass a piece of wire through the straw so that it is free to move along the wire.
2. Release the air from the balloon and notice that the balloon moves in the opposite direction to the direction of the air being released.

## Newton's third law

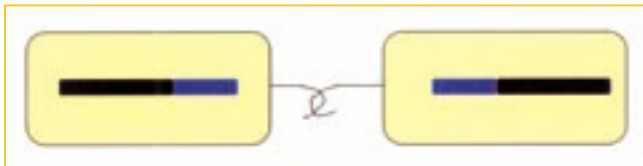
**For every action there is an equal and opposite reaction**

**1.**



Place a teaspoon full of baking soda and 10mls of vinegar inside the plastic bottle. Quickly replace the rubber stopper. After a few seconds the build up of pressure from the carbon dioxide causes the stopper to fly off in one direction while the bottle shoots back in the opposite direction. By placing the bottle on rollers such as pencils the effect is enhanced.

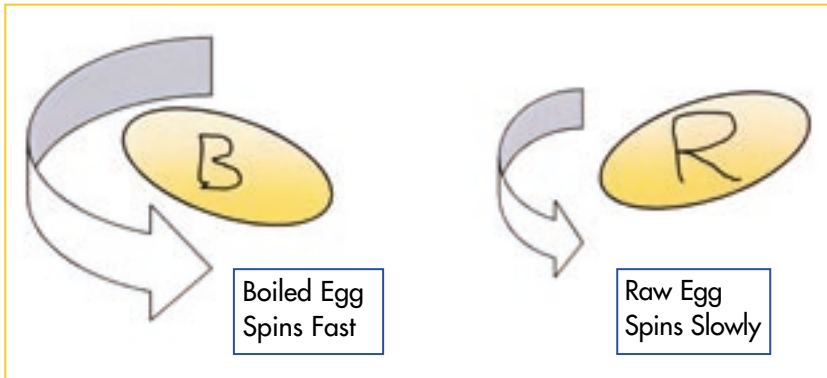
**2.**



By using two spring balances Newton's third law may also be simply demonstrated. Pulling on the spring balances should lead to the same reading on each one.

## Eggsperiment 1: spinners

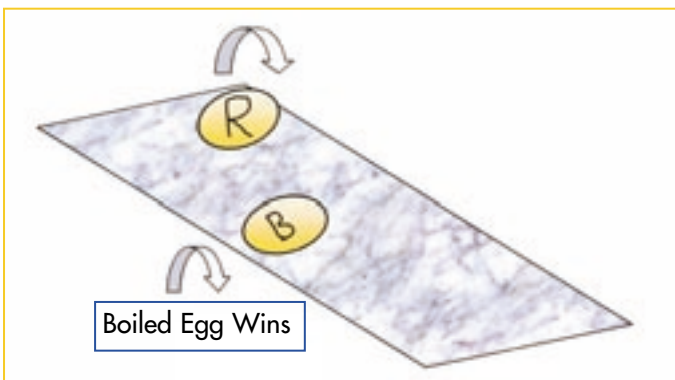
**NETHERLANDS:** 'Discovery Game' Piet Blankert and Johan van de Adel



Spin two eggs one boiled, one raw.

The liquid in the raw egg also needs to rotate, so the egg spins irregularly and more slowly than the cooked egg.

## Eggsperiment 2: the great egg race

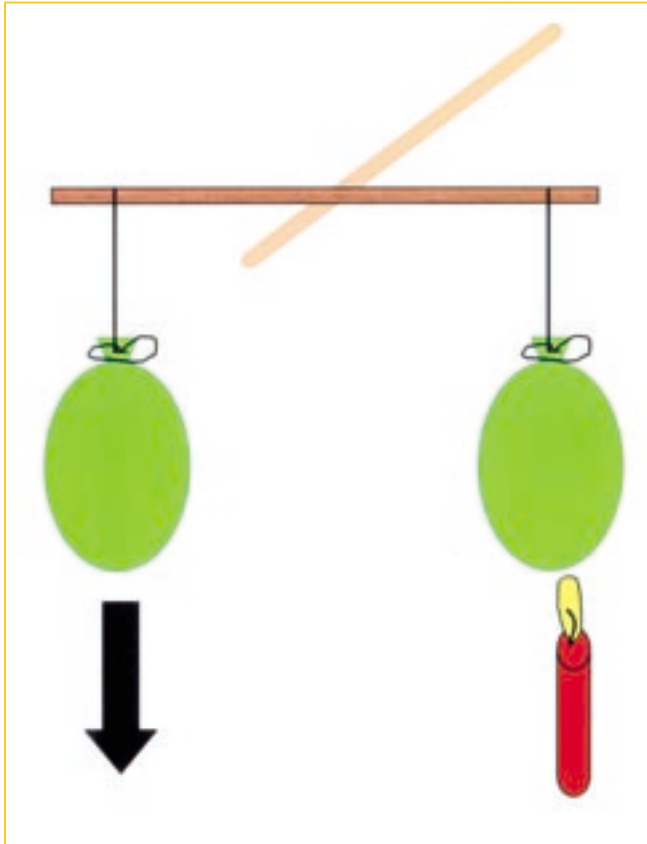


**Further Topics:** Linear Motion, Rotational Motion, Inertia, etc.



## *To show air has mass*

**SPAIN:** 'Teaching Physics with a Smile' by Rafael Garcia Molina



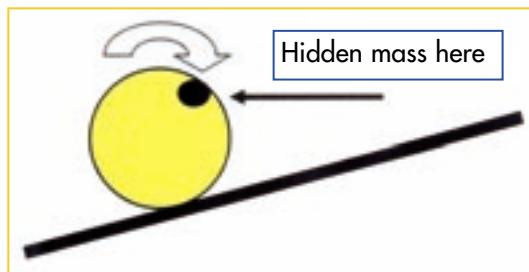
Balance a metre stick as shown.

Burst the balloon.

The balloon on the left swings down as this side is now heavier.

## Roll uphill can

**SPAIN:** 'Teaching Physics with a Smile' by Rafael Garcia Molina



Place a weight inside the biscuit tin (a magnet is ideal).

The tin will roll up the slope (at least half a turn!), appearing to defy gravity.

Alternatively, the tin can be made to roll away on it's own if placed on a level surface.

**Further Topics:** Centre of Gravity, Equilibrium, Rotational Energy, etc.

## Roll back can 'the perfect pet'

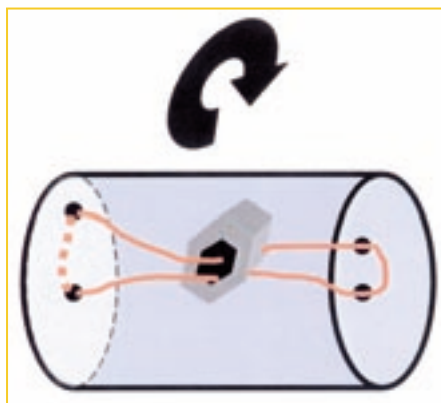
**ITALY:** Marisa Sasso and team.

Punch two holes in each end of the can.

Loosely fit the band and weight

When the tin is pushed away the band tightens

When the tin stops, the elastic unwinds and the can rolls back.



**Further Topics:** Potential Energy, Kinetic Energy, Motion, Engines, etc.

## ***Surface tension – ‘water-knot’***

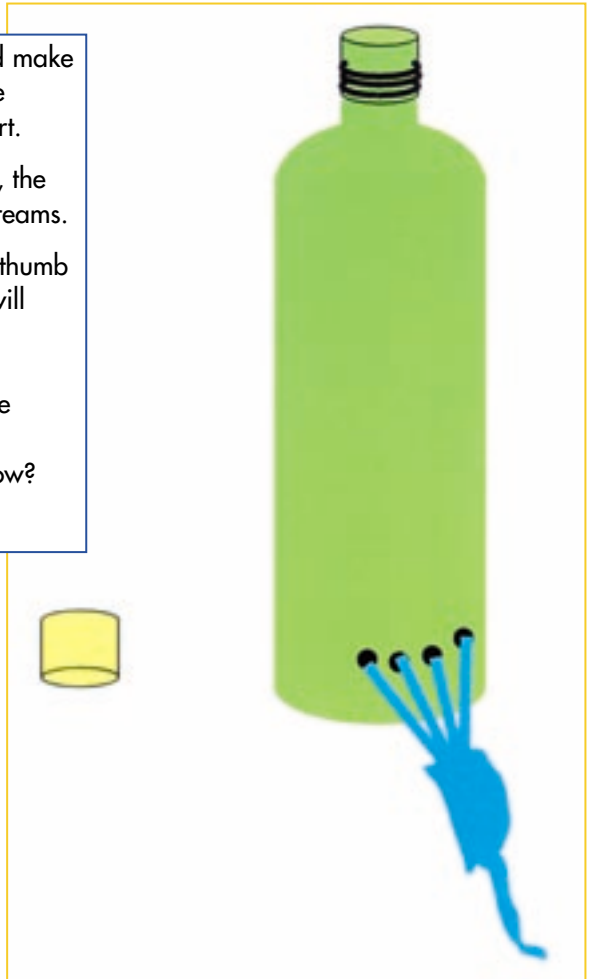
### **ITALY:**

Take a plastic bottle and make 5 straight holes near the bottom about 5mm apart.

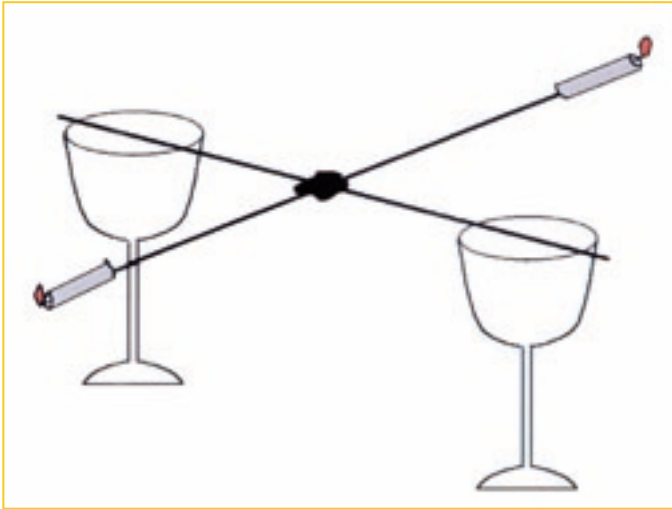
Fill the bottle with water, the water comes out in 5 streams.

Pinch the jets with your thumb and forefinger the jets will form one.

Fill the bottle and put the top on.  
What happens to the flow?  
Why?



## ***Forces***



Use kebab sticks and blue tack to assemble this demonstration. Candles will oscillate when lit demonstrating balance.

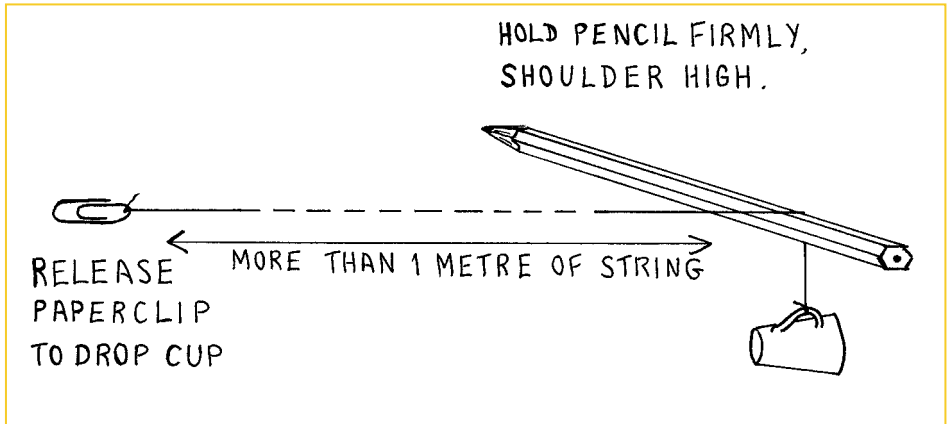
## ***Balancing cola cans***



Cola can balances on it's side when filled sufficiently with liquid.

## *The paperclip and the falling teacup*

**SWEDEN:** Per Olaf Nilsson



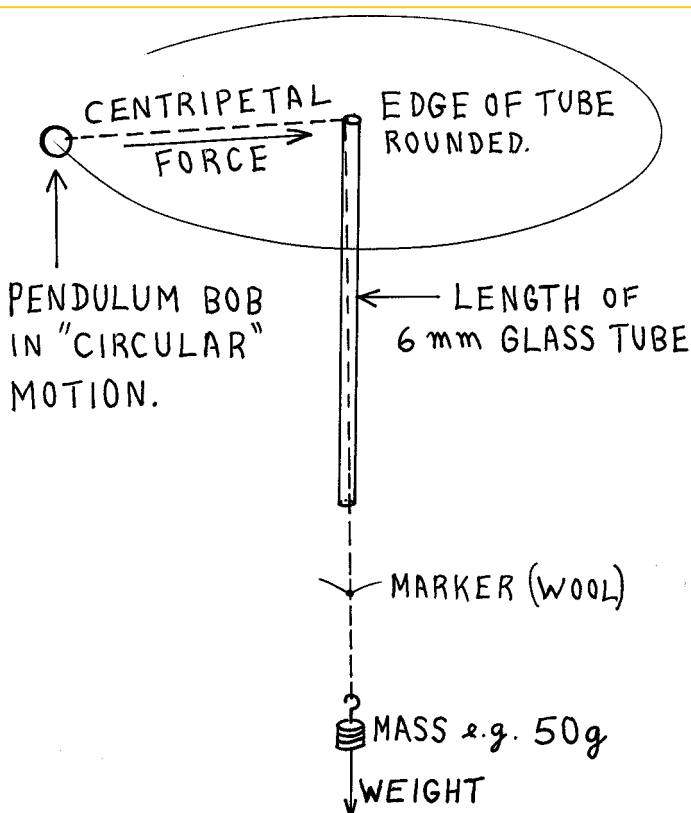
Take about 1.5 metre of string. Tie one end to the handle of a (cheap) teacup and the other to an ordinary paperclip. Hold a pencil horizontally in one hand – at shoulder height. Hold the paperclip in the other hand and draw the string across the pencil until the cup is hanging about 1.5 metres above the floor.

(A soft mat under the cup is reassuring while you practice this.) Ask your students to predict what will happen if you release the paperclip. Let go. We usually ended up with at least three turns of string around the pencil and we haven't broken the cup yet – but imagine the delight of our students if we do!

This may lead to a discussion about angular momentum. As the radius of the paperclip's rotation about the pencil decreases, what happens to its angular velocity?

## A simple model of planetary motion

A handy way of looking at bigger and smaller orbits. How do the periodic times compare? How does the energy vary? What happens if we increase or decrease the centripetal force on the satellite?



Forget Biro tubes. We get good results with about 150mm of 6mm glass tubing and the main thing is to *round the edges* of the glass at both ends by softening in a Bunsen flame. Pass about 1 metre of fine string or strong thread through the tube. Attach a pendulum bob or other small mass to one end and a weight carrier of mass about 50g to the other end. Hold the tube upright, give the bob a whirl and use a slight movement of the tube to keep it moving in a "circle" of about 500mm radius. Then hold the tube more steadily and see the satellite spiral into smaller orbits as it loses kinetic energy. At the same time the weight carrier loses potential energy. May be compared to planets or satellites and may also be related to electrons in different energy levels as atoms absorb or emit light.

## The inclined plane

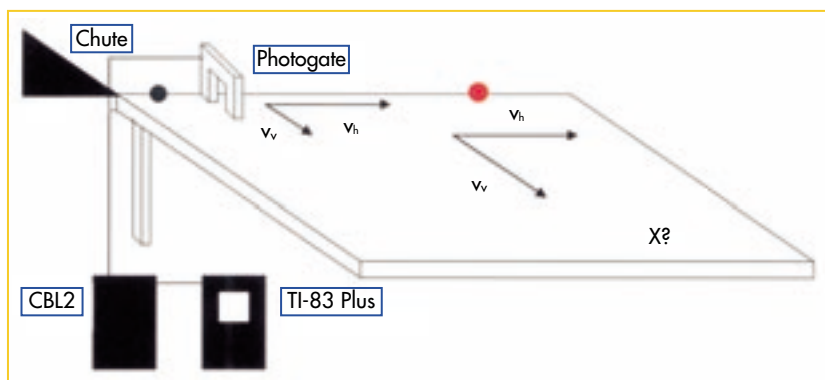
This apparatus can be used to show that:

1. Acceleration due to gravity is independent of mass.
2. Vertical acceleration is independent of the horizontal component of velocity.

### Background

Pupils studying motion often have great difficulty in accepting that acceleration due to gravity is independent of mass, or the independence of vertical and horizontal motion.

The apparatus depicted here is a simple way to illustrate these points. Such a demonstration may be done quantitatively, with the use of photogates and data logging equipment, or qualitatively, by simple repetition and observation.



(Note: The chute must direct the ball-bearing straight across the top of the inclined plane, i.e. to ensure it possesses no vertical velocity component at the start of its motion on the plane.)

## To show that acceleration due to gravity is independent of mass

### Procedure 1

Two ball bearings with different masses are simultaneously released from rest at the top of the slope and allowed to roll freely down the incline. (If the slope is too long, the larger ball bearing moves ahead of the smaller due to differences in the effects of wind resistance depending on surface area and mass.)

The process is repeated several times by the pupils, using a selection of different size ball bearings. For practice, the motions of two ball bearings of the same mass can be compared with each other first, and then pupils compare the motions of those with differing masses.

The pupils quickly establish the truth of the proposition that the acceleration down the inclined plane is independent of mass.

### Historical Perspective

The pupils can be required to research the work of Galileo and his use of the experimental method in overturning the Aristotelian proposition that acceleration during freefall did indeed depend upon mass.



## To show that vertical acceleration is independent of the horizontal component of velocity

### Procedure 2

A chute is fixed to the top of the plane pointing directly across the slope. A ball bearing released from this acquires a horizontal velocity before it experiences the slope of the plane. If one ball is released from this while another is allowed to roll straight down the plane it can be seen that they both arrive at the bottom together provided the second ball is released at the precise moment the first comes off the chute.

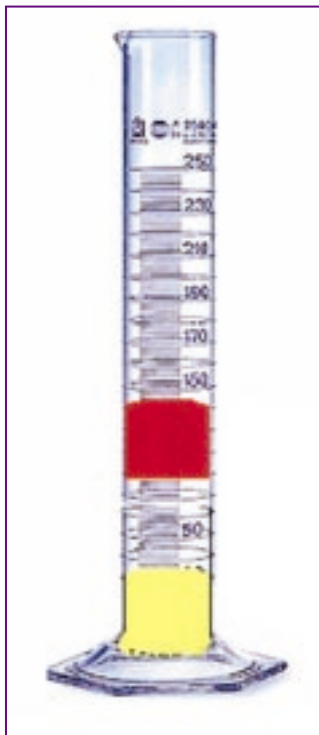
### Development

By releasing the ball bearing from higher and higher up the chute, greater and greater horizontal velocity components can be obtained.

If a photogate is used to calculate the horizontal velocity component of a ball bearing released from the chute at the top of the plane, students can try to make predictions about where the ball bearing will roll off the edge at the bottom of the plane (based upon their knowledge of the time taken to reach the bottom).

This practical allows pupils to quickly grasp the ideas involved in orbits, and the dependence of orbiting objects on their horizontal velocity components. This has proven to be an excellent introduction to Kepler's Laws and planetary motion generally.

## *To illustrate the relative densities of liquids*



### **Explanation**

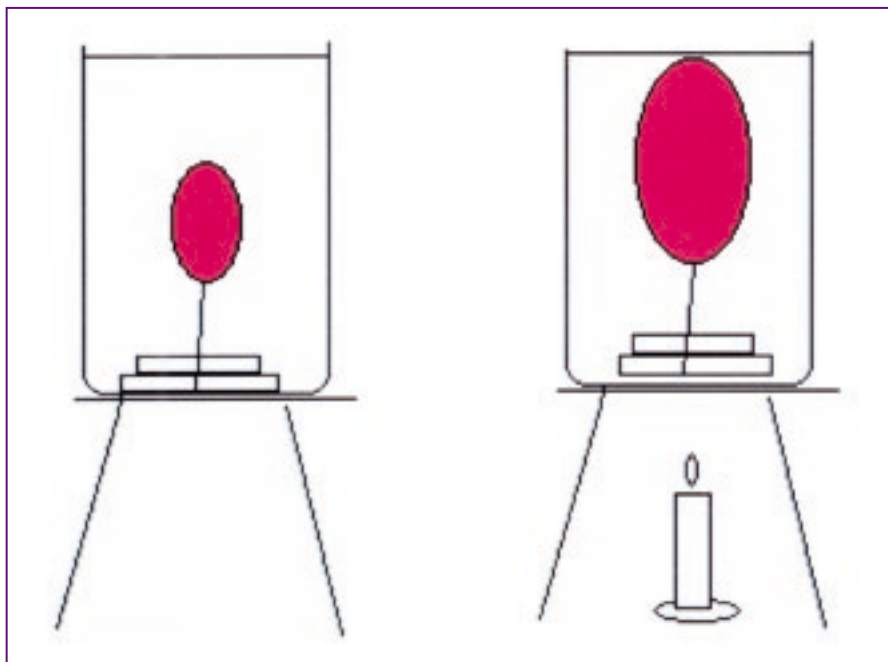
Each of the three liquids shown has a different density, with the least dense floating on the top.

Lamp oil       $0.8 \text{ g/cm}^{-3}$

Water       $1.0 \text{ g/cm}^{-3}$

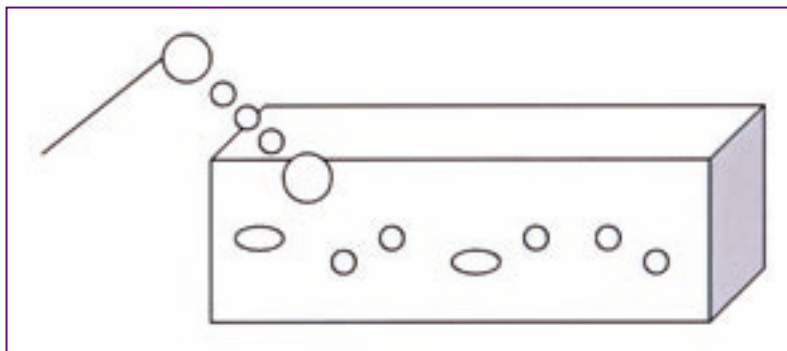
Sugar syrup       $1.3 \text{ g/cm}^{-3}$

## ***To demonstrate the effect of heat on the density of gases***



The balloon on the left is submerged in a beaker of ice-cold water. When the water is boiled, the gas is heated and it expands.

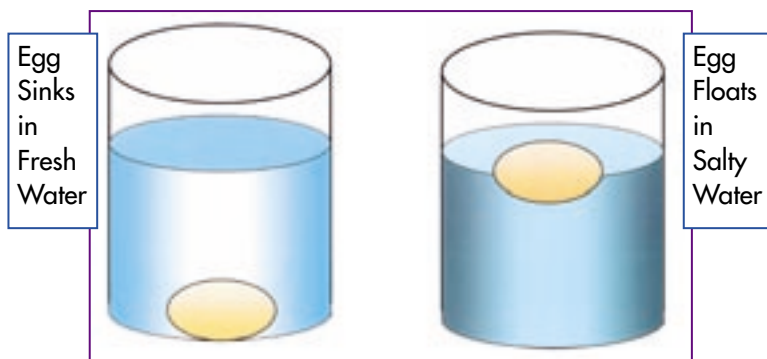
## ***To show that carbon dioxide is denser than air***



1. Place some dry ice in a clear plastic container.
2. Blow some soap bubbles into the container and see them 'hover' over the layer of cold carbon dioxide which has settled at the bottom of the container.

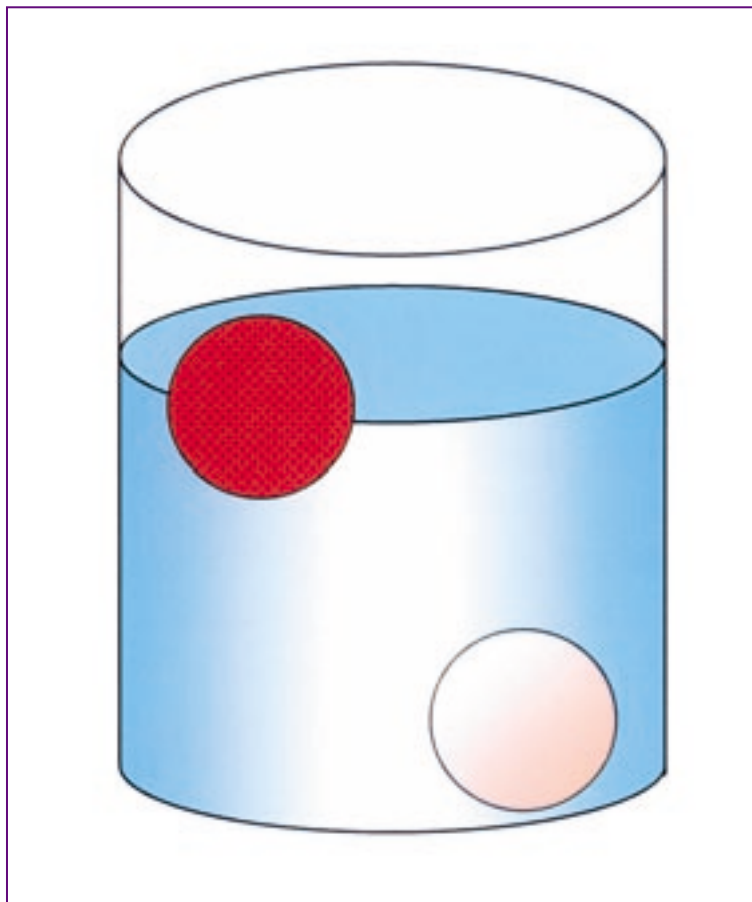
## ***Eggsperiment 3: sinking eggs***

### **IRELAND:**



## ***The sinking orange***

**IRELAND:**

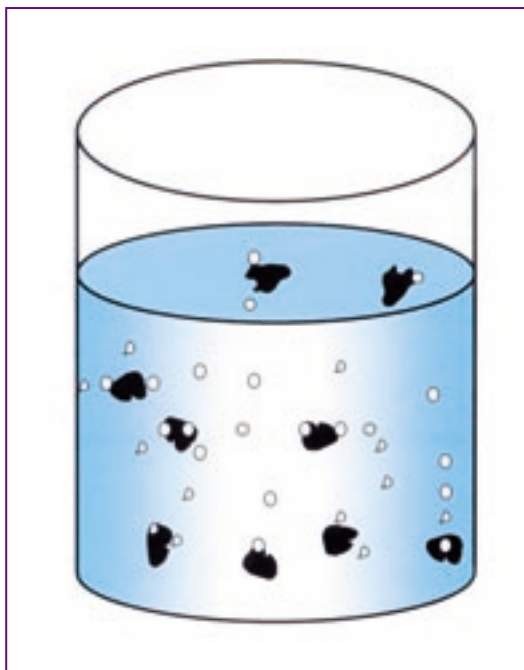


The orange with the skin floats because air is trapped inside.  
When the orange is peeled it sinks.

The peel itself will also float until it dries out, then it sinks!

## ***Raisin' the Raisins***

### **IRELAND:**



Place some raisins in some fizzy soda.

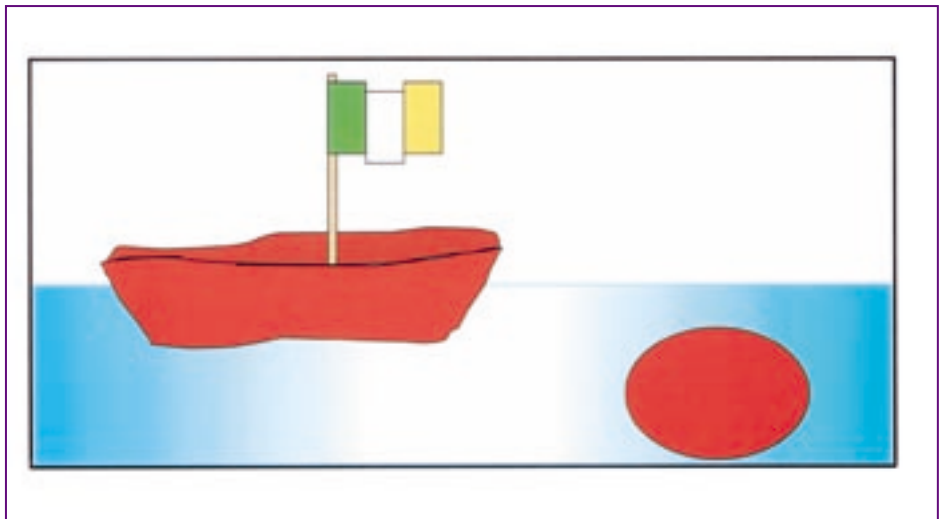
As they sink bubbles of  $\text{CO}_2$  gather on the surface of the raisins, causing them to float.

When the bubbles reach the surface they burst so they sink again.

This continues as long as the soda stays fizzy.

## ***The boat and ball***

**IRELAND:**

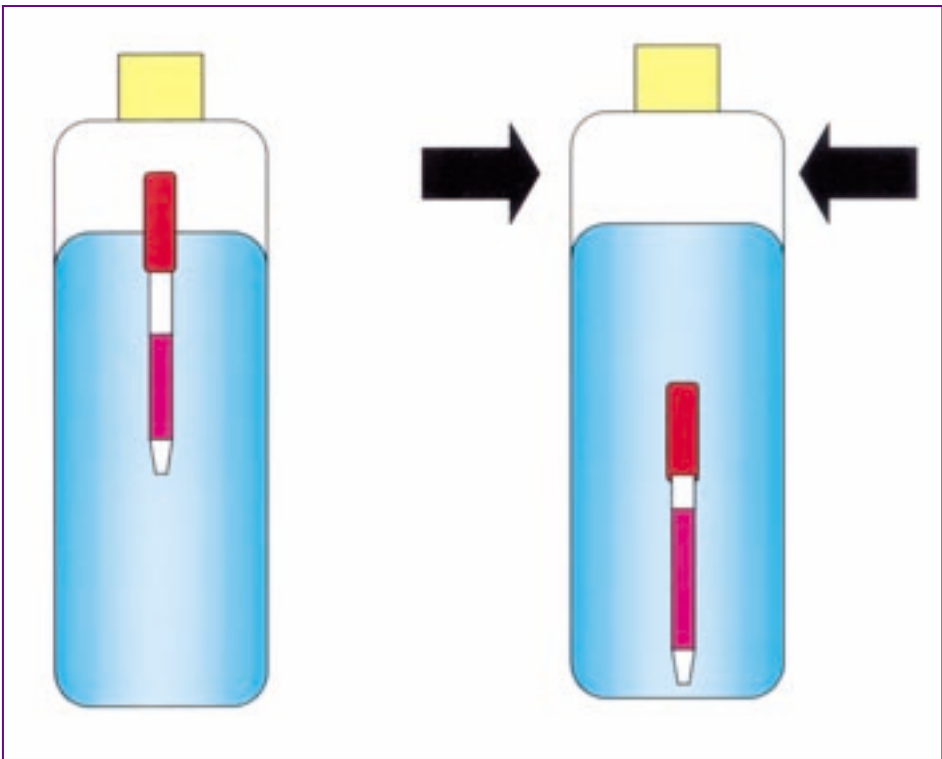


The boat and ball both made from Plasticine, each have equal masses (weights), but because of it's shape the boat floats, while the ball sinks.

**Further topics:** Density, Buoyancy, Materials etc.

## ***Cartesian diver using dropper and food dye***

**IRELAND:**



Fill the dropper with as much coloured water as possible.

When you squeeze the shoulders of the bottle you will see the dye expand.

The trapped air above it compresses.

The density of the diver increases and it sinks.

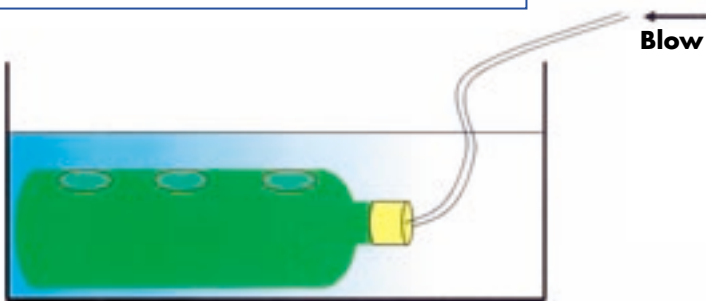
Release the pressure and it floats back to the surface.



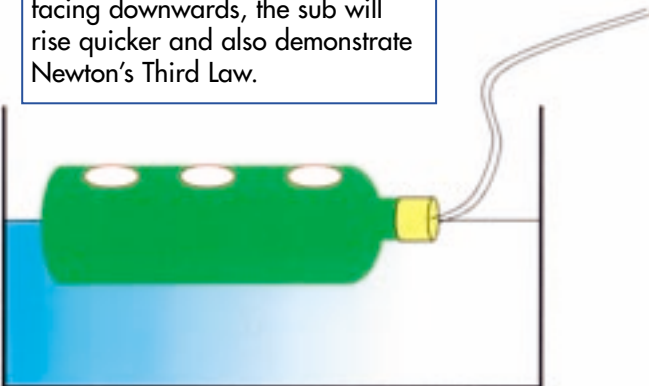
## ***Submarine model to demonstrate density and floatation***

### **IRELAND:**

The bottle models the ballast tanks on a Submarine. By controlling the amount of air in the tanks the submarine sinks to different depths. Blu-tak can be used to seal the tube in the bottle top. First sink the bottle. The bottle fills with water. Blow into the bottle. Air is pushed out and the bottle rises.



By placing the bottle with the holes facing downwards, the sub will rise quicker and also demonstrate Newton's Third Law.

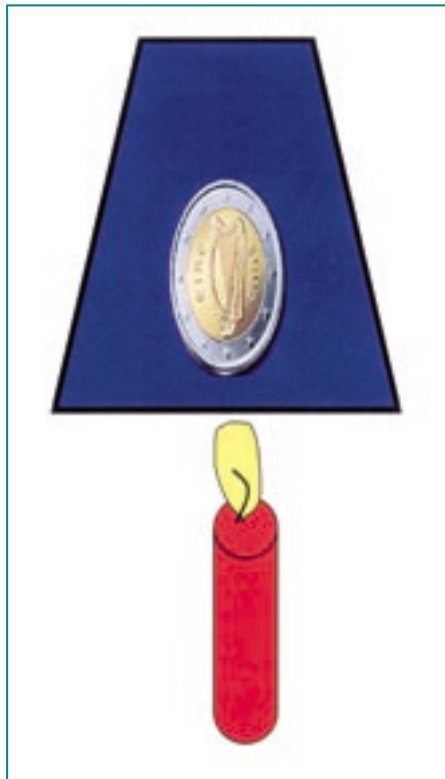


# 4 H E A T

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## *To show metals are good conductors of heat*

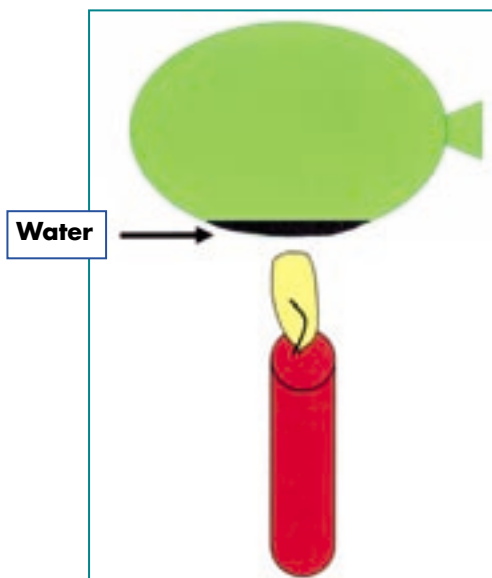
**BULGARIA:** M Cerna and team



Heat the card directly underneath the coin.  
The coin conducts the heat away from the card.

## ***The balloon that doesn't burst***

**SPAIN:** 'Teaching Physics with a Smile' by Rafael Garcia Molina



Secretly place some water in a darkly coloured balloon.

Slightly blow up the balloon and tie it.

Holding steadily, heat the balloon below the water.

Amazingly the water's heat capacity is so high the balloon is slow to burst.

## Hero's Engine

### BULGARIA:

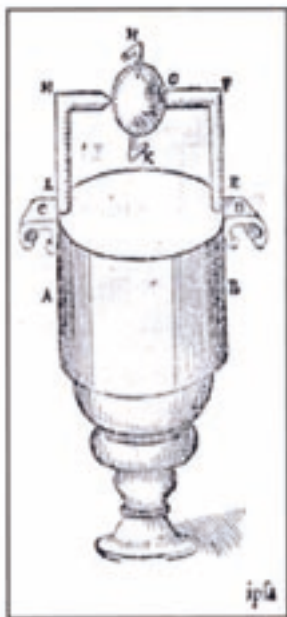
Punch two holes tangentially into an unopened drink can, and empty the can. Bend the ring and tie with thread.

Fill the can with water up to the level of the holes.

Heat the can – When steam starts to leave the holes it will spin in the opposite direction to the steam.

Inserting straws or tubing as shown can increase the effect.

It is based on Hero's steam toy, which he called the 'Ball of the Winds' developed 1500 years before James Watt's concept.



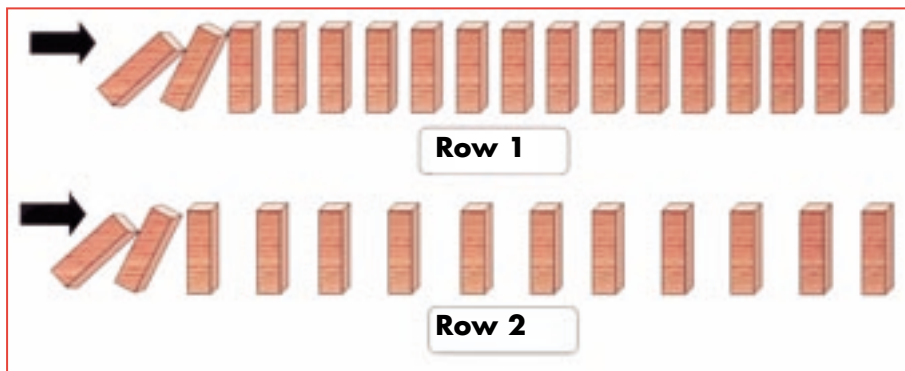
### Turbine

When the can is empty, place a weight (or magnet) on the bottom of the can so that it can sink into water. As the water enters the holes, the can will spin in the opposite direction as above.

**Further topics:** Newton's third Law, Conservation of momentum, Steam Engines Sprinklers, etc.

## *Jenga Blocks: to show sound travels faster in solids than in liquids/gases*

**IRELAND:**



Line up the two rows of blocks as shown.

Row 1 represents a solid.

Row 2 represents a liquid/gas where the particles are spaced further apart.

Knock the two rows together.

The wave will pass faster through Row 1.

## *To verify the wavelength of electromagnetic waves using a microwave cooker*

**BELGIUM:** 'The Speed of Light: 6 Ways to Measure it' by Bernadette Anbergen



Remove the rotary tray from the microwave.

Spread the grated cheese on the plate  
(marshmallows or chocolate can also be used).

Read the frequency output from the back of the oven  
(usually 2450MHz) ( $f$ ).

Switch on for 20-40 secs.

There will be melted cheese at the antinodes of the standing wave.

Measure the distance between the two nearest antinodes ( $D$ ).

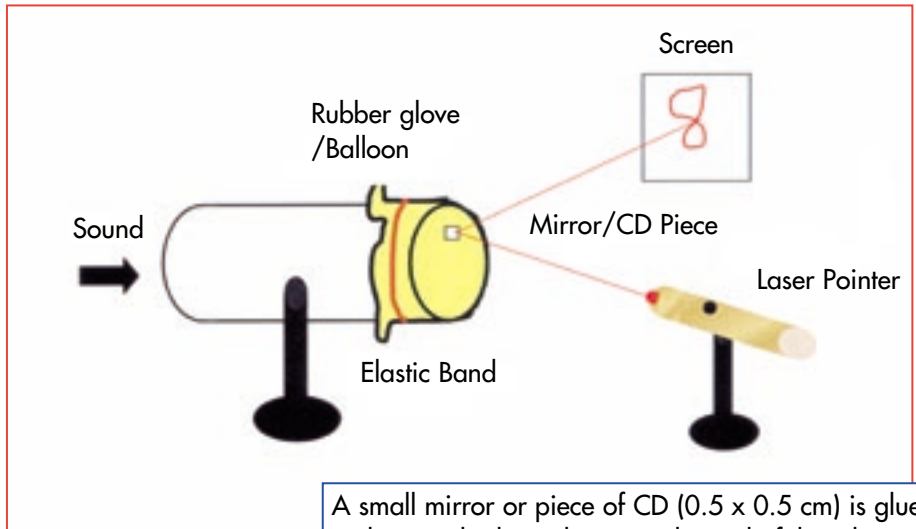
$$\lambda = 2 \times D$$

$$v = f \times \lambda$$

Typical measurements give a result of  $3.2 \times 10^8$  m/s.

## *To show sound is a waveform*

**GREECE:** Elias Kalogirou



A small mirror or piece of CD ( $0.5 \times 0.5$  cm) is glued to the stretched membrane at the end of the tube.

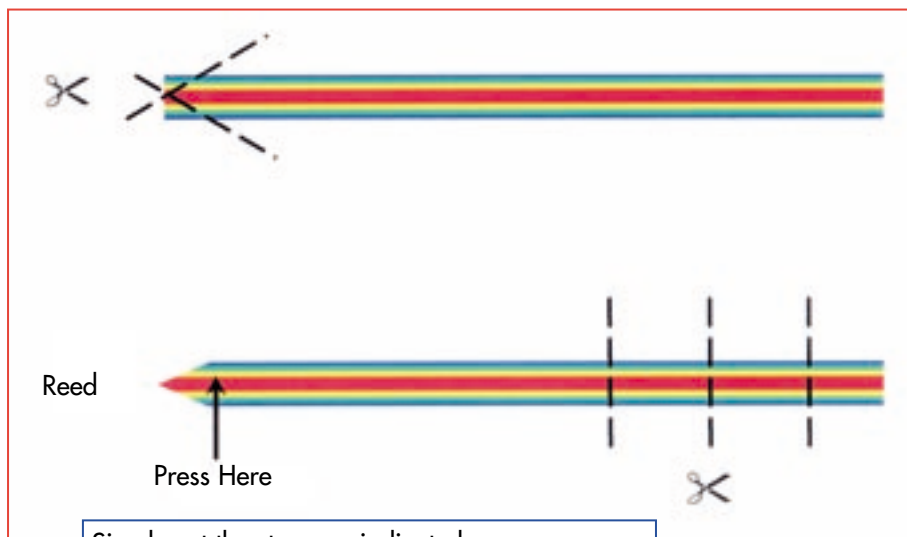
Sing a scale at the open end. Certain frequencies will give complex wave forms.

Louder sounds produce larger vibrations.

**SAFETY NOTE:** Remind students of the danger of looking into a Laser Beam. Use stands to reduce the movement of the tube and laser.

## ***To make a musical whistle from a drinking straw and show frequency varies with length***

**UK:** Susan Anne McGrath



Simply cut the straw as indicated.

It may be necessary to press at the base of the reed to produce the note.

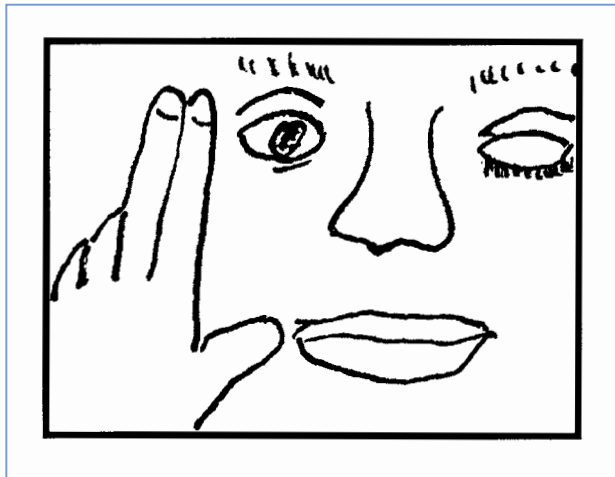
As the straw is cut the note increases in pitch.

It is possible with different lengths to play a tune.



## ***Diffraction using fingers***

**IRELAND:**



Close one eye.

Place two fingers close together.

Rest the fingertips on your eyebrow.

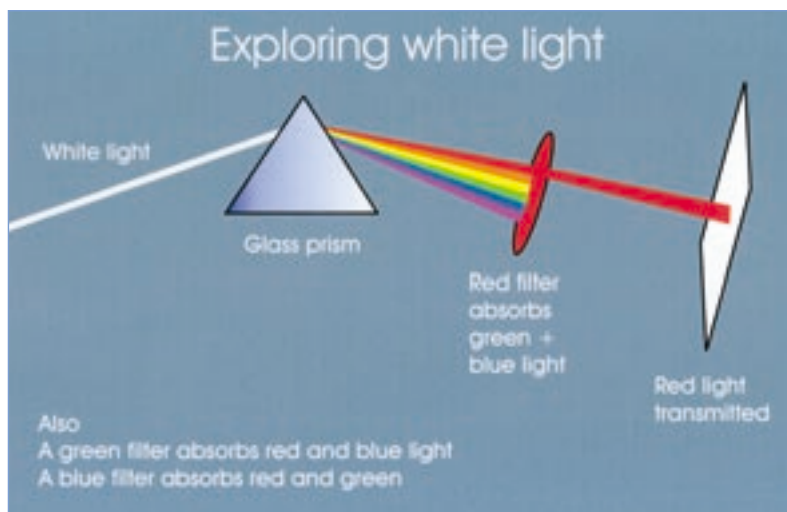
View a light source through the slit in your fingers.

The very narrow lines are a diffraction pattern.

## EASY COLOUR

The next five items are simple modifications of standard experiments. These methods make use of readily available or cheap materials. Good quality *COLOUR FILTERS* have many uses and a handy source is to cut up the large sheets available for a few Euro each from theatre lighting suppliers such as Stage Lighting Centre off Pearse St. Dublin (01-677 3044). Choose colours carefully from the large range available. I find these three in the LEE Filters series work well: Nos : 106, 139 and 363. They are *PRIMARY RED*, *PRIMARY GREEN* and *SPECIAL MEDIUM BLUE*.

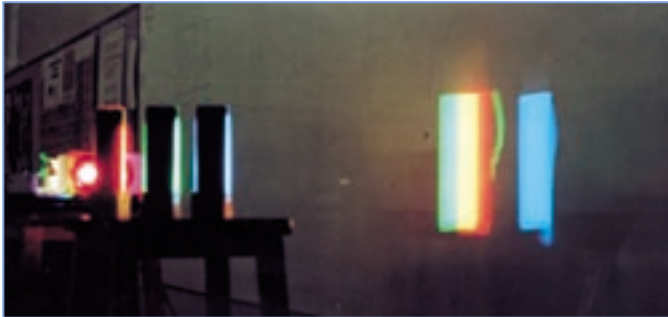
### EASY COLOUR 1: Exploring white light



No need for specialised equipment. One easy way to get a narrow beam of parallel white light is to tape two small pieces of opaque card to an empty 35mm slide mount with a gap just less than 1mm between them. Put the slide in the projector, place a triangular glass prism a few cm in front of the projector lens to get a spectrum on a screen or the ceiling. For best results rotate the prism to get the minimum angle of deviation and focus the projector. Now ask your students what a red filter does to white light. Introduce one and see how only the green and blue are absorbed – and so on for the other primary colours.

(To use an overhead projector instead, get two opaque cards about A4 size and place them on the stage with a gap of a few mm between them. Again hold a prism in front of the lens and adjust the gap, and the focussing, to get the clearest spectrum on a screen or ceiling.)

## ***EASY COLOUR 2: Colour mixing – all done by mirrors***



Make a transparency with **RED**, **GREEN** and **BLUE** filters, side by side. For a 35mm slide you need only three pieces of filter about 15mm x 30mm. These may be slightly overlapped and fitted into, or taped onto a 35mm slide mount. For the OHP version take a sheet of card at least 300mm x 300mm and cut three similar holes. Tape sheets of red, green and blue filter over the three holes. Place your three coloured windows on the stage of the OHP.

In a reasonably dark room shine the three colours on the wall. Give three students a mirror each. Invite one to intercept the red beam and reflect it onto the ceiling. Ask what will happen if red is mixed with green. Invite second student to reflect the green beam so they overlap. The yellow usually comes as a surprise. Repeat for other combinations until a reasonable white light is achieved.

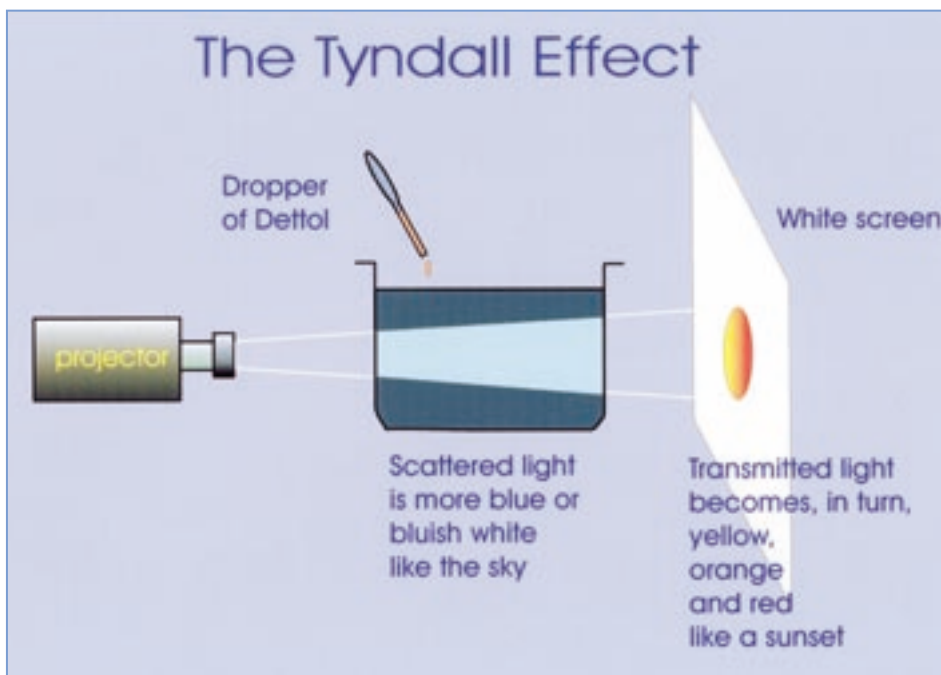
### **Adding primary colours of light**

We get the three secondary colours



Red + Green + Blue = White

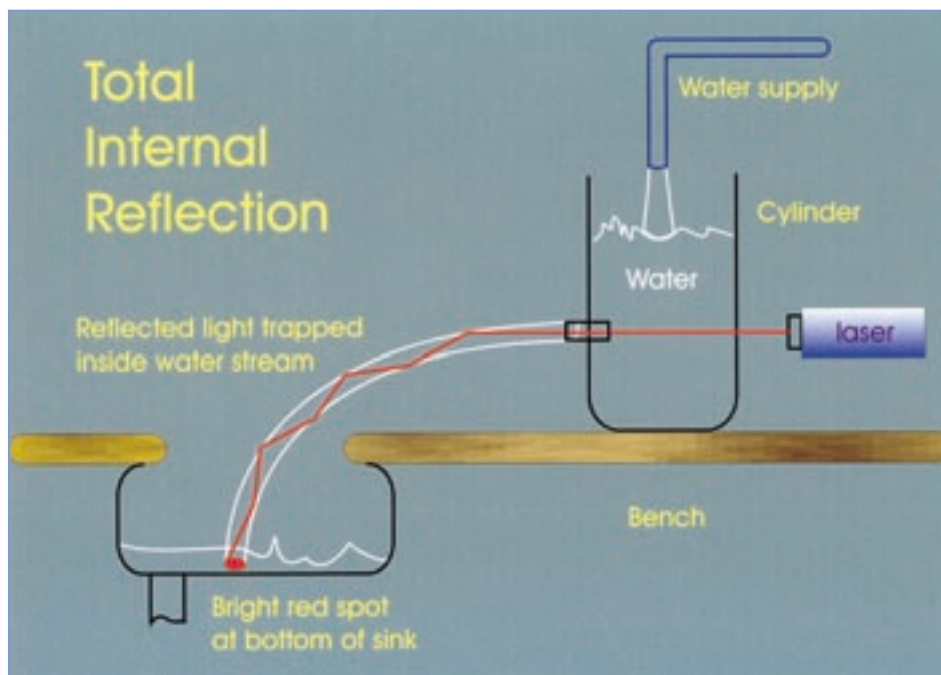
## ***EASY COLOUR 3. Why are sunsets red?***



This illustrates the effect of fine particles on long and short light waves, as first explained by John Tyndall from Leighlinbridge, Co. Carlow.

Place a trough of water in front of the lens of a projector. A transparency with a circular hole in the centre is optional and gives a suitable beam of light. Note the colour of the circle of light on a screen. Now use a dropping pipette to add Dettol gradually to the water. Note when the beam scatters enough light to become visible through the side of the trough. Does the *scattered* light have a bluish tinge? Watch the colour of the *transmitted* light on the screen change as more Dettol is added. Discuss wavelengths of red and blue light and the particle size in the colloidal solution. Also, why are rear foglamps red?

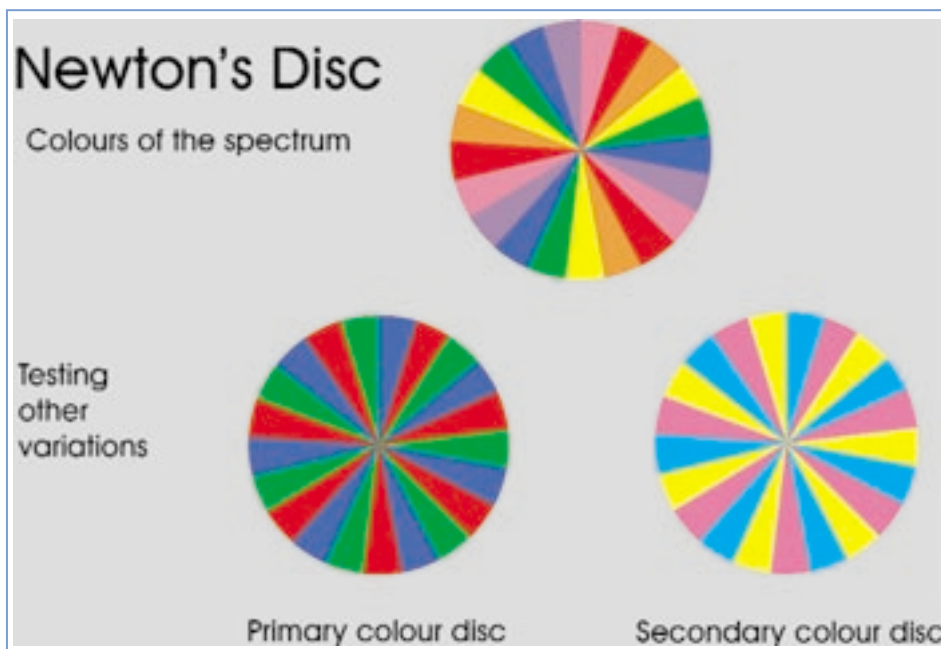
## ***EASY COLOUR 4. Red light on tap***



Drink a bottle of mineral water! Cut a small circular hole in the side of the bottle. It helps to fit a centimetre or so of plastic tubing or drinking straw (not too narrow) in the hole. Stand the bottle beside a sink and under a tap so that a steady stream of water pours into the sink. Now shine a laser beam through the bottle and out into the water stream. Note how the water acts as a light guide.

**SAFETY NOTE:** Take care, as always, that the laser beam does not enter anyone's eye.

## ***EASY COLOUR 5. Tough competition***



Invite students to make a variety of discs with coloured segments. One way is to provide plenty of brightly coloured paper, some backing card and scissors. If possible let some students, in school or at home, use the drawing tools of a computer package to print out circles of coloured segments. They can guess the best shades and proportions of red, orange, yellow, green, blue, indigo and violet to include. Not easy – choose bright shades for a start.

Now for the competitive bit: Supply a few battery powered fans (available for a few Euro in pound shops or gadget shops) and some pieces of Blue tack.

Invite each group to spin their Newton's disc on a fan, observe all the results and award prizes to the closest approximations to white – the most successful spin doctors!

## ***Estimating the speed of light from some measurements with a laser diode***

### **GREECE:**

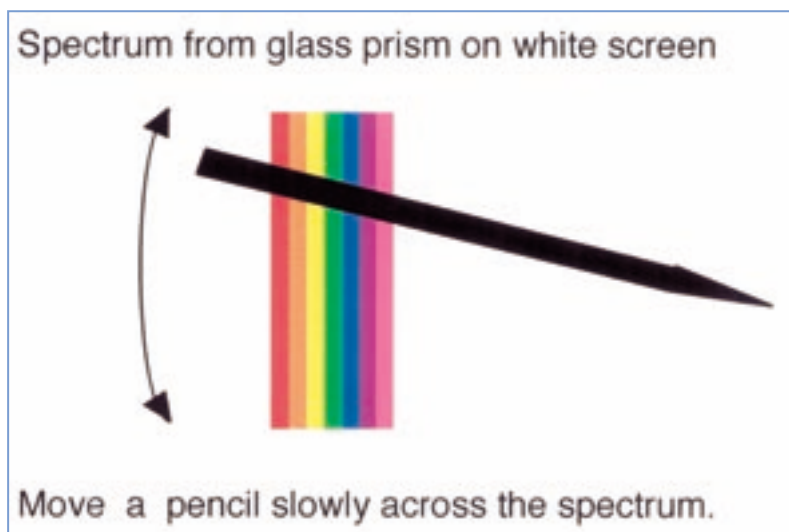


We can verify an order of magnitude for the speed of light by measuring the wavelength of red light from a laser pointer and the striking voltage of the laser diode.

The author made a diffraction grating of 0.16mm line spacing, by using a drawing package on a computer and printing out the result to make a 35mm slide. We found that a diffraction grating of 300 lines per mm worked very well. Even a pair of homemade Young's slits worked. A 9V battery is connected across a potentiometer. The variable output is measured on a voltmeter and supplied to the laser diode. The minimum voltage at which the laser strikes (giving a very faint light intensity) is recorded. The energy of an electron passing through this potential difference gives the approximate energy of the photons emitted. This is divided by Planck's constant to give the frequency of the red light. Also the spacing between the interference fringes produced by the grating is recorded and this is used to calculate the wavelength of the red light. The product  $f \times \lambda$  is our approximation of the speed of light.

## ***A Spectrum with a surprise***

**POLAND:** Jerzy Jarosz and Aneta Szczygieska



Among various light and vision demonstrations this illusion came as a surprise. Persistence of vision is well known. Movies and Television depend on this time delay in our vision. Surprisingly however the delay seems to be different for different colours. In a darkened room use a triangular prism to show the visible spectrum on a screen in the usual way. Hold a straight stick in front of the the spectrum, so it hides a bit of each colour. Then start moving the stick from side to side and note what you see. The stick appears to bend noticeably – but only while moving across the colours. It seems that the red, green and blue cones in the eye take different times to reset. Molecules of different pigments are being bleached and reformed many times per second in the retina.



## ***Geometric optics with a laser pointer***

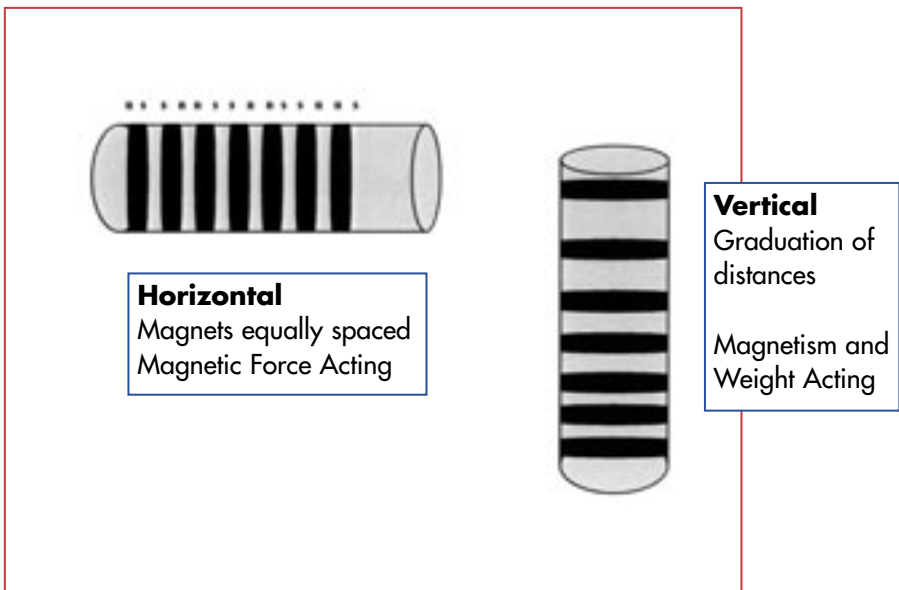
### **GREECE:**



The photograph, taken at the Greek stand, shows three optics experiments attractively crafted in wood and presented in wooden cases. Each experiment contains a laser pointer built into a movable wooden carriage which can slide or rotate into different positions. The student can use the laser to direct many different incident rays, in turn, onto a curved metal surface representing a concave or convex mirror. In this way she can observe and plot the paths of various reflected rays and discover for herself the ray diagrams seen in textbooks.

## *Magnetic forces using button magnets in a test tube*

**CZECH REPUBLIC:** Leos Dvorak and team



Button Magnets 12.5mm dia (available from Peat's) fit neatly into the test tube.

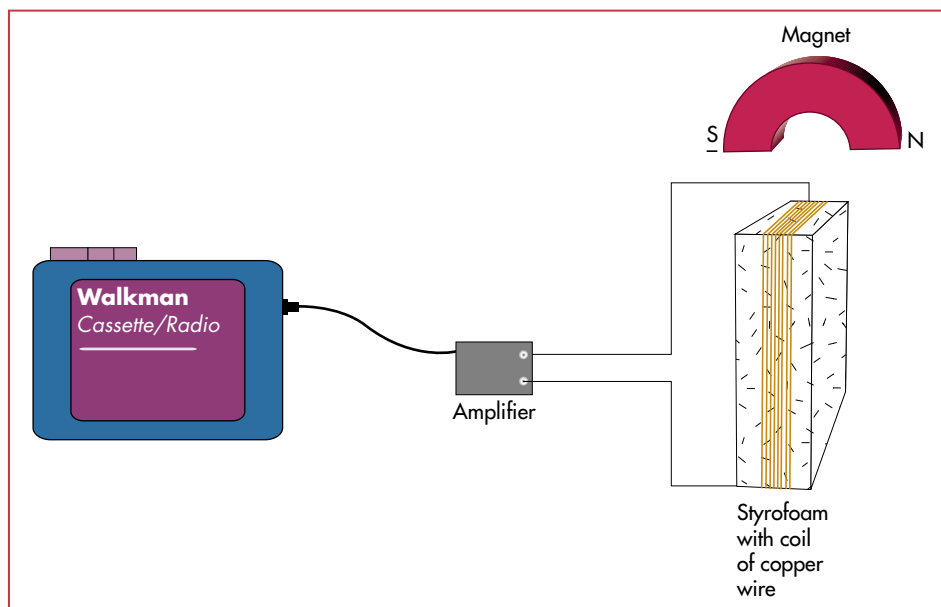
By placing the magnets in pairs there will be twice the distance in the horizontal case.

The vertical case provides a useful analogy for the graduation in density of the atmosphere.

**Further topics:** Newton's Third Law, Magnetic Damping, etc.

## *How to build your own loudspeaker*

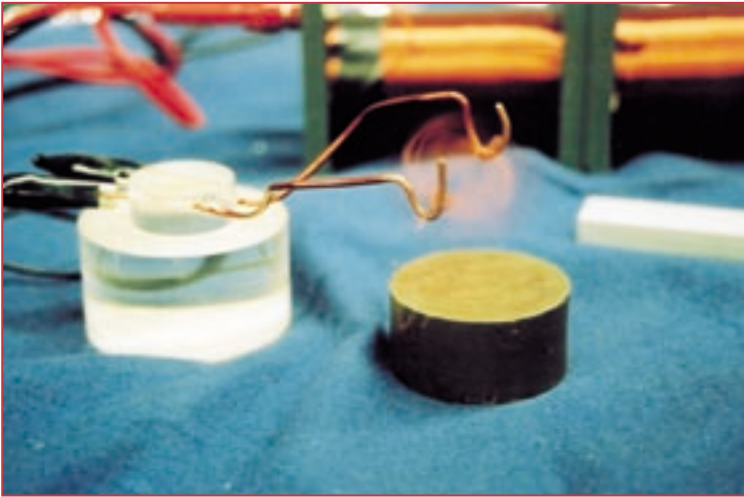
### **CZECH REPUBLIC:**



1. Connect a piece of copper wire to a walkman radio/cassette player at the earphone outlet.
2. Connect this wire to an amplifier (e.g. 6V to 15V) and then to a piece of styrofoam.
3. Wind the copper wire around a piece of styrofoam several times to make a coil of wire and tape it in place to the styrofoam.
4. When the radio is playing hold a magnet close to the copper wire and hold this next to your ear to hear the sound being transmitted.

## ***A simple demonstration motor with a twist!***

**DENMARK:** Klaus Seiersen and others



A coil of copper wire rotates in the field of a permanent magnet when connected to a 9V battery. But where is the commutator? The photograph shows the arrangement used by our Danish colleagues. Our version had a coil of 10 turns between two ceramic magnets. The armature is simply a coil of enamelled wire with two straight ends. The ends rest on two thicker pieces of copper wire bent into U shapes and connected to the poles of the battery. The trick is that at one end of the armature you scrape off all the enamel insulation but at the other end you remove the insulation along one side of the wire only. So the coil receives torque for only half of each rotation – and its angular momentum is enough to keep it turning.

## ***Gedanken (thought) experiments with a sheet of A4 paper***

### **Q1. The size of atoms**

The length of an A4 sheet is 0.297 metre. If you keep cutting the long side of the sheet in half, how many cuts can you make before you reach atoms?

### **Q2. The Age of the Universe**

Suppose that the thickness of a sheet of paper represents a human lifetime of 70 years.

What would be the height of a stack of paper representing the age of the universe (14 billion years)?

### **Q3. Filling cylinders**

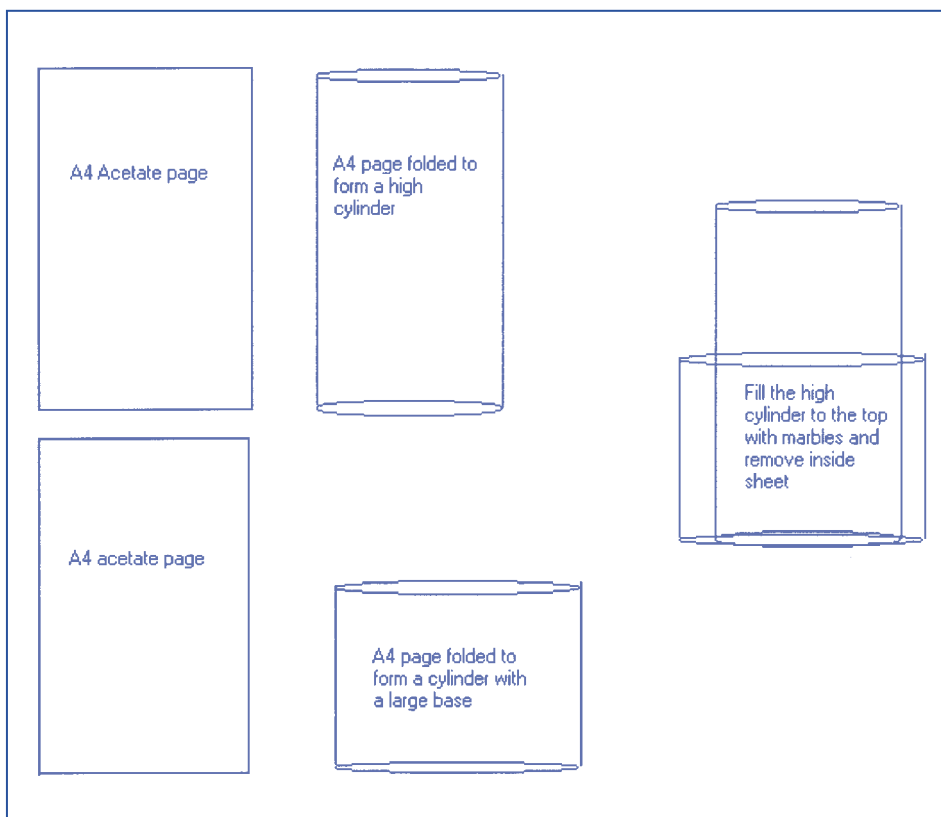
Take two A4 sheets of paper and make two cylinders, the first of height **a** and the second of height **b** where **a** and **b** are the lengths of the long and short sides of the sheets. Fill the first cylinder to the brim with peanuts (or something similar) and transfer the contents to the second cylinder. Why is the second cylinder not filled?

Solutions at end of chapter.

## ***To show that objects with the same surface area have different volumes***

### **Procedure**

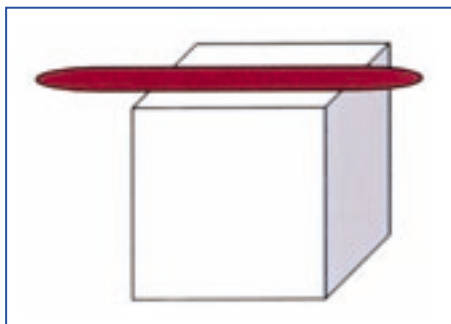
Take two acetate pages and form two cylinders as shown.  
Fill the taller cylinder with a series of marbles.



### **Conclusion**

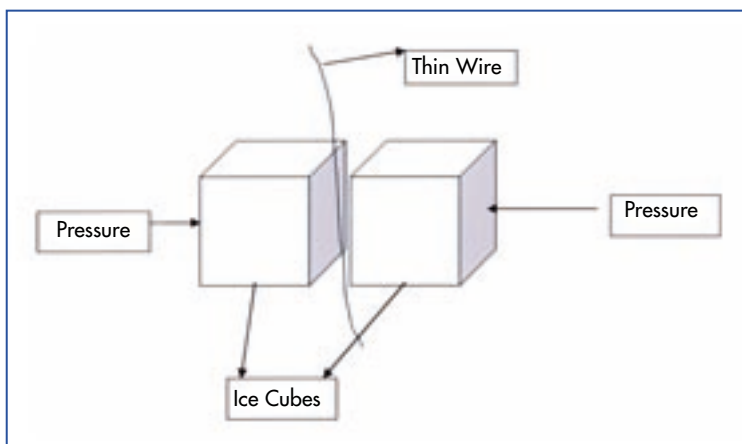
Both sheets have the same area but a different volume.

## ***Can you pick up a cube of ice with a matchstick?***



Try sprinkling some salt on the ice cube first and then leave the match stick sitting on it for a few seconds. Then try lifting it up – the match stick is frozen to the ice.

## ***The effect of pressure on the melting point of ice***



By applying pressure to the two ice cubes (by squeezing together in the palm of the hand) the melting point of the ice is lowered. This allows for a layer of water to form between the two ice cubes. When the pressure is then released the melting point once again being raised allows for the ice to refreeze, thus sticking the wire in place.

## ***To show the amazing elastic properties of a balloon***



1. Blow up a balloon.
2. Take a sharp wooden skewer and very slowly push it in through the balloon and out the other side without the balloon bursting. (This takes some practice!)
3. The balloon does gradually deflate over time as the seal is not perfect around the wooden stick but it lasts long enough to be impressive.



## Electroless plating

### Background

Electroless Plating is the controlled autocatalytic deposition of a metal film by the interaction of a metal salt and a reducing agent. The plating process occurs on the catalytic surface, or on a suitable activated surface.

The reaction can be summarised using



Electroless copper and Nickel deposition have become of great significance in the electronics industry.

The reducing agent traditionally used was Formaldehyde. But recent research has found this to be a carcinogen and alternative reducing agents have been explored.

Most current baths use either Glyoxylic acid or hypophosphite as the reducing agent.

It is possible to make-up these electroless metal baths by purchasing the various chemicals, but they are also commercially available.

### Teaching aspect

#### ❖ Discussion on oxidation and reduction reactions

Dipping the coin in acid to remove the metal oxide is an example of an oxidation/reduction reaction. E.g.  $\text{NiO} + \text{H}_2 \rightarrow \text{Ni} + \text{H}_2\text{O}$

#### ❖ The plating reaction

The  $\text{Ni}^{2+}$  ions come from the Ni salt ( $\text{NiSO}_4$ )

Electrons supplied from the reducing agent (It becomes oxidised and supplies two electrons) instead of the conventional battery.

Resulting in Ni adhesion on the surface of the substrate (coin).

Overall reaction  $\text{Ni}^{2+} + 2e^- \rightarrow \text{Ni}$



### Requirements

- ❖ Fume hood required. These baths operate at temperatures of 80-90°C
- ❖ Plating usually complete after 5 minutes.
- ❖ For both the cleaning and activation it is best to dip the metal requiring plating into a solution of dilute acid dip for approximately 20 seconds.
- ❖ Hot plate recommended for heating the solution uniformly.

## Materials



Use a glass bottle  
(a *Martini bottle* seems  
to be the best!) and fit  
a tube through a stopper.  
Fill the bottle completely  
and then demonstrate  
that glass is a flexible  
material by squeezing  
on the outer sides of the  
bottle forcing the liquid  
to move up the tube.

(By holding your hands around the bottle to warm the liquid this could also be used to show expansion of liquid due to heat.)



Demonstrate the material properties of kitchen roll by cutting a potato with a knife on a piece of kitchen roll and the kitchen roll remains uncut.

## *Some exceptionally cool websites*

- ❖ **[www.en.eun.org/vs/physics/physics.html](http://www.en.eun.org/vs/physics/physics.html)** An excellent resource for physics teachers on all matters related to physics. This umbrella website contains links to many general sites including European schoolnet and Physics On Stage.
- ❖ **[www.fearofphysics.com/](http://www.fearofphysics.com/)** This site illustrates physics in action. It is a visual and non-technical way to see the laws of physics. Particularly appropriate and useful for most students.
- ❖ **<http://www.eps.org/>** European Physical Society click on the EPS Biographies of Physicists and download some hot free A3 posters.
- ❖ **<http://public.web.cern.ch/Public/>** A very interesting guide to CERN Don't miss the link for CERN in 2 minutes all you need to know but read quickly!
- ❖ **<http://www.lightlink.com/sergey/java/index.html>** an exceptional site containing a set of 23 Physics based Java applets by Sergey and Tanya Kiselev highly entertaining.
- ❖ **[www.physlink.com](http://www.physlink.com)** Provides daily news on a variety of topics including astronomy and includes online educational references.
- ❖ **[www.exploratorium.edu](http://www.exploratorium.edu)** contains an array of physics links. Particular attention should be shown to the Learning studio link and the Observatory link which provide a guide to Astronomy resources.
- ❖ **<http://www.psi-net.org>** An excellent site designed specifically for Irish teachers as part of the Physical Sciences Initiative (PSI). Special attention should be paid to the experiments available at **<http://www.psi-net.org/physics/s3/s3index.htm>**
- ❖ **<http://home.a-city.de/walter.fendt/phe/phe.htm>** Interesting Java Applets and descriptions are provided on topics such as mechanics, waves, electricity, optics, relativity, radioactivity and spherical astronomy. A particularly useful applet is provided on the electrical motor.
- ❖ **<http://physicsonstage.net>** Contains background information to Physics on Stage2, including Presentations, Performances, The Fair, and Workshops.
- ❖ **<http://education.iop.org/>** The Institute of Physics Website. Lots of useful resources, downloadable articles from "Physics Education" and information on "Paperclip Physics Competition". **<http://www.tcd.ie/IOP/schools.html>** details on school affiliation, lectures, video loan scheme, courses and careers in Physics in Ireland.
- ❖ **<http://www.physics.org>** easily searchable site on all aspects of physics. Results are generated according to the age/knowledge of the user.

## ***Facts of life the Universe and everything...***

**You are** the same age as the universe. The fundamental particles which make up the atoms in your cells were made in the Big Bang.

**The Galaxy** is a hundred thousand light years across. The most energetic cosmic ray particle yet discovered seems to itself to take just 30 seconds to cross it.

**A Clock** on the equator runs slow compared with one on the pole.

**Antimatter** is all around us – but in tiny quantities. Hospitals use it in PET (Positron Emission Tomography) Scanners.

**60 Billion** neutrinos pass straight through each square centimeter of our bodies each second.

**IT Takes** the energy output of at least one power station to keep the traffic lights in the British Isles operating.

**One Kilogram** of butter stores as much energy between its atoms as the same quantity of TNT.

**Moving Ions** change the electrical potential of heart cell membranes by about 140mV – and the heart beats!

**If you** keep cutting the long side of an A4 sheet in half, after 31 cuts you start to cut atoms.

**If a human** lifetime of 70 years is represented by the thickness of a sheet of paper, then a stack of paper representing the age of the universe will reach a height of 20Km.

*Some facts reproduced with kind permission from The Institute of Physics.*

## ***Answers to thought experiments with a sheet of A4 paper***

### **A1. The size of atoms**

**Answer: 31**

The size of a carbon atom =  $10^{-10}\text{m}$

$2^{10} = 1024$  so 10 cuts reduces the length of the side by 1024

Cut	Length in metres
0	0.297
1	$1.485 \times 10^{-1}$
11	$1.450 \times 10^{-4}$
21	$1.416 \times 10^{-7}$
<b>31</b>	$1.383 \times 10^{-10}$
32	$0.6915 \times 10^{-10}$

✂

### **A2. The Age of the Universe**

**Answer: 20km**

A ream (500 sheets) of  $80\text{g/m}^2$  paper is 5cm thick  
so one sheet is 0.1mm thick.

No. of sheets =  $14,000,000,000 / 70 = 200,000,000$

Height of stack =  $20,000,000\text{mm} = \mathbf{20\ km}$

### **A3. Filling cylinders**

The length of the sides of an A4 sheet are in the ratio  $1:\sqrt{2}$   
(for information on standard paper sizes see  
<http://www.cl.cam.ac.uk/~mgk25/iso-paper.html>)

Vol. of a cylinder = Area of base  $\times$  Height

Vol. of 1st cylinder =  $\pi (\mathbf{b} / 2 \pi)^2 \times \mathbf{a}$

Vol. of 2nd cylinder =  $\pi (\mathbf{a} / 2 \pi)^2 \times \mathbf{b}$

Vol. of 2nd cylinder / Vol. of 1st cylinder =  $\mathbf{a} / \mathbf{b} = \sqrt{2} = 1.414 > 1.00$

**Project suggestion:** Students make a large Art Work poster using a collage of photographs, dates and information demonstrating the place of physics discovery in context with literature, art, history, politics etc.

Art	Michaelangelo	Rembrandt	Turner	Picasso	Hockney
	1472 1480	1606 1632	1775	1881	1937
Boticelli paints Birth of Venus					
Vermeer					

Physics	Copernicus: Earth and Planets move around the sun		Babbage Computer		Rutherford discovers nucleus	
	1543	Newton's Laws Motion & Gravity	1834	1909	Atom Split	1938 1960
	1593	1687	1750	1905	Special Theory of Relativity	
	Galileo Theory of Telescope	Franklin discovers Electricity		1st Laser built		

Music	'Dafne' 1st Opera		Mozart		Stravinsky	
	1597	Bach & Handel	1756	1882	Tchaikovsky	
	1659	1685	1770	1840		
	Purcell	Beethoven		1924		Gershwin

Politics	Elizabeth 1st defeats Spanish Armada	1588	Ulster Plantations	1609	French Revolution	1789	1848	World War I	1914	Atom bomb	1945
	George Washington 1st president USA										
	Karl Marx Communist Manifesto										

Exploration	Columbus reaches America		Captain Cook sails into Botany Bay		Tutankhamun discovered	
	1492	1600	1770	1909	1922	
	East India Company formed to trade with India		Peary reaches North Pole		Amundsen reaches South Pole	



# **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.lop.org/pos3/>

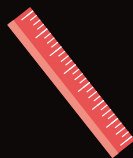


# PHYSICS

## *on Stage 3*

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# **PHYSICS ON STAGE 3:** The conference vi

**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.**

# PHYSICS ON STAGE 3: The conference **vii**

## **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.



**Vaclav 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](http://www.physicsonstage.net).

# PHYSICS ON STAGE 3: Acknowledgements viii

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.

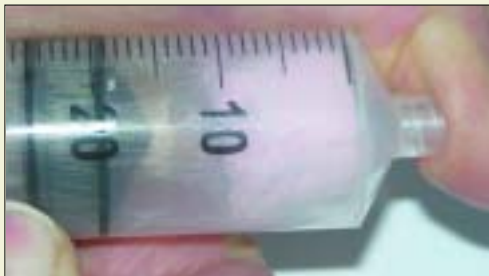
Thanks are also due to the management of the following schools: St Dominic's High School, Santa Sabina, Sutton, Co. Dublin; Sandford Park School, Ranelagh, Co. Dublin; St Mary's, New Ross, Wexford; and St Joseph's Cluny, Killiney, Co. Dublin.

**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.

# 2 pressure

## 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.

# 4 pressure

## 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.

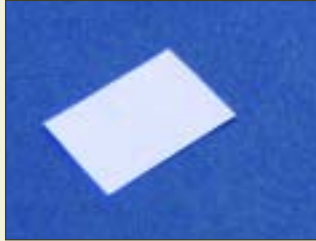
## Air race between identical pieces of paper

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.

# 6 forces

## Water rocket

Austria

### Breaking surface tension

#### You will need...

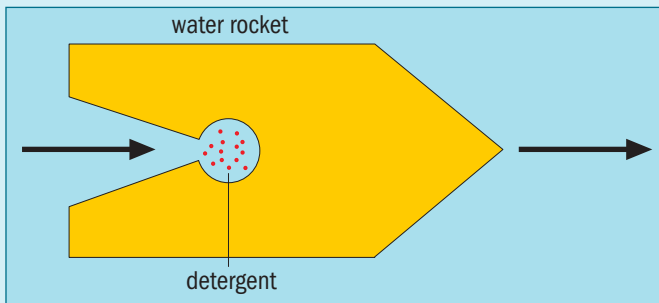
- ✓ a bowl of water
- ✓ some card
- ✓ a pair of scissors
- ✓ some washing-up liquid

#### 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.

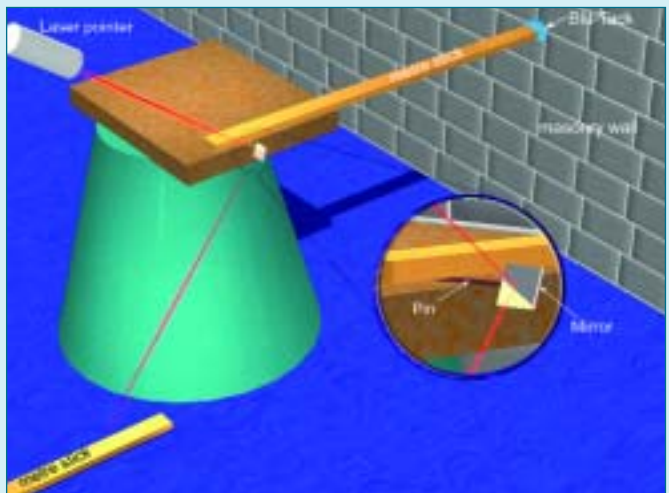
### You will need...

- ✓ two metre sticks
- ✓ Blu-Tack
- ✓ a straight pin
- ✓ a small piece of mirror or CD ( $1 \times 1$  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.

# 8 forces

## 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  $9.8 \text{ ms}^{-2}$ . 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  $9.8 \text{ ms}^{-2}$ .



#### 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...

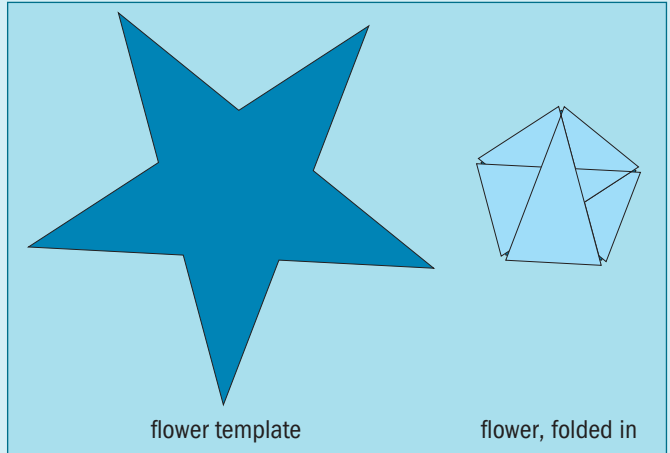
- ✓ a bowl of water
- ✓ some paper (coloured, if possible)
- ✓ a pair of scissors

### 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?

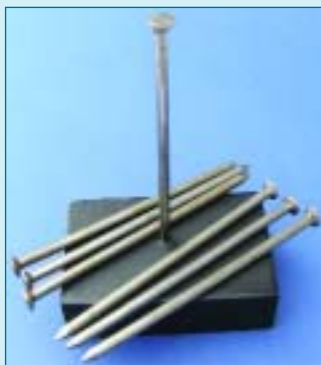
Discuss whether this experiment would work with plastic flowers.

# 10 forces

## 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.



# 12 forces

## 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](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/PHS1110/jakub/Momentum.html>.

# 14 forces

## 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.



#### 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.

#### 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.

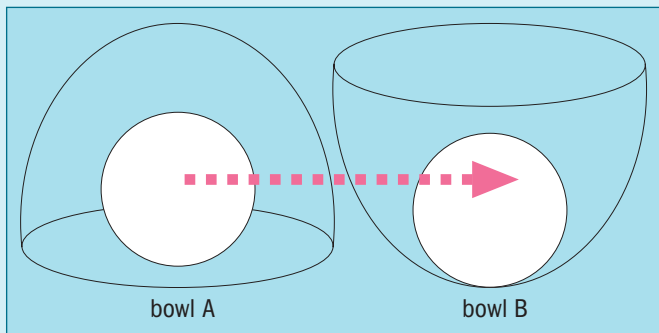
## Centripetal force

### 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).

# 16 forces

## 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.



# 18 forces

## 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  $\times$  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



### 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.

### Background

Momentum = mass  $\times$  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.

### What next?

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

# 20 density

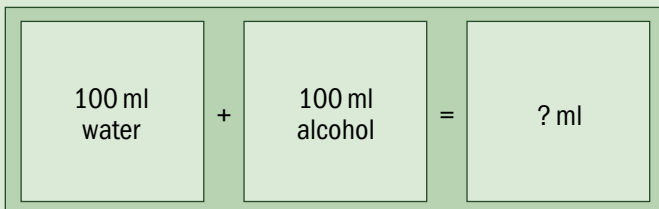
## The mystery of the vanishing liquid

### 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



#### 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.

# 22 heat

## Making a turbine from a plastic cup

### Belgium

### Convection currents are created in warm air

#### You will need...

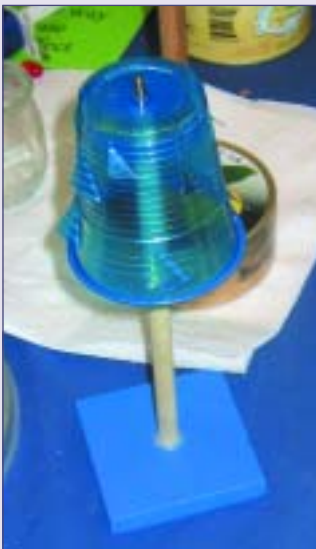
- ✓ a plastic drinking cup
- ✓ a pencil or pin
- ✓ a heat source (e.g. a radiator)

#### 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

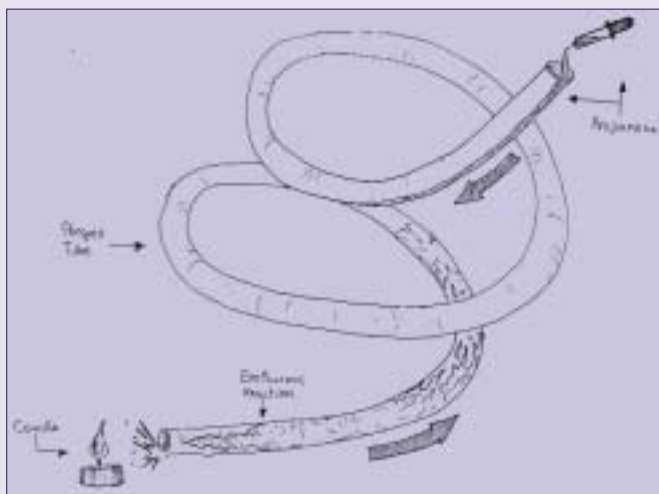
#### What next?

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.



# 24 waves & sound

## 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)

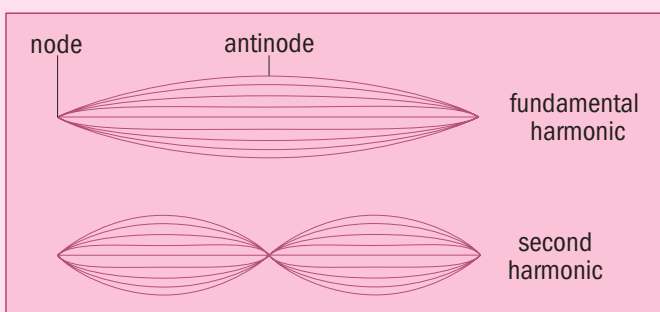
#### Background

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.

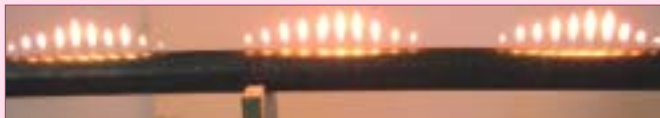
## The flame tube

### 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,  $\lambda$ , of the standing wave at different resonant frequencies,  $f$  ( $v = f \times \lambda$ ).



# 26 waves & sound

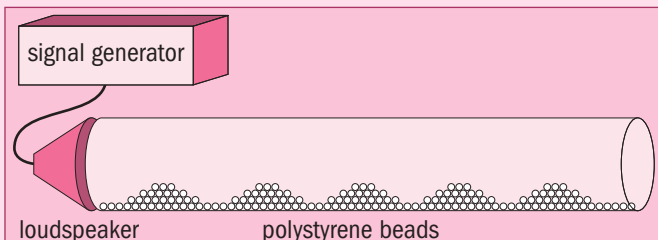
## Kundt's tube

### 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 ( $\lambda$ ) 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

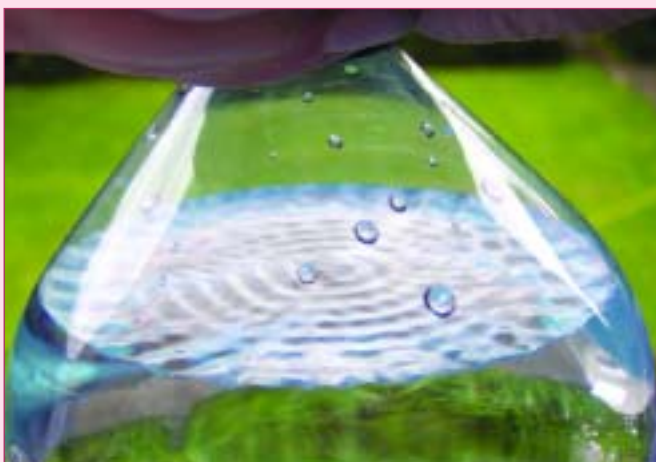
- 1 Hold the bottle by the neck with one hand.
- 2 Give the bottle a firm knock about midway along its length using the knuckles of your other hand.

### 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.



# 28 light

## Which one is the tonic water?

Bulgaria

Fluorescence

### You will need...

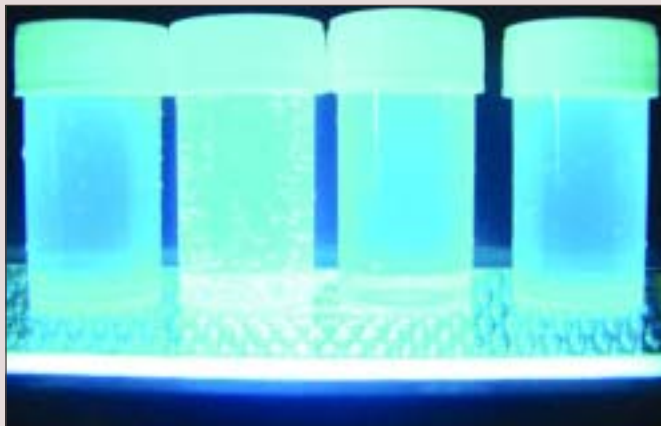
- ✓ four identical bottles with screw tops, three containing water and one containing tonic
- ✓ an ultraviolet lamp

### 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

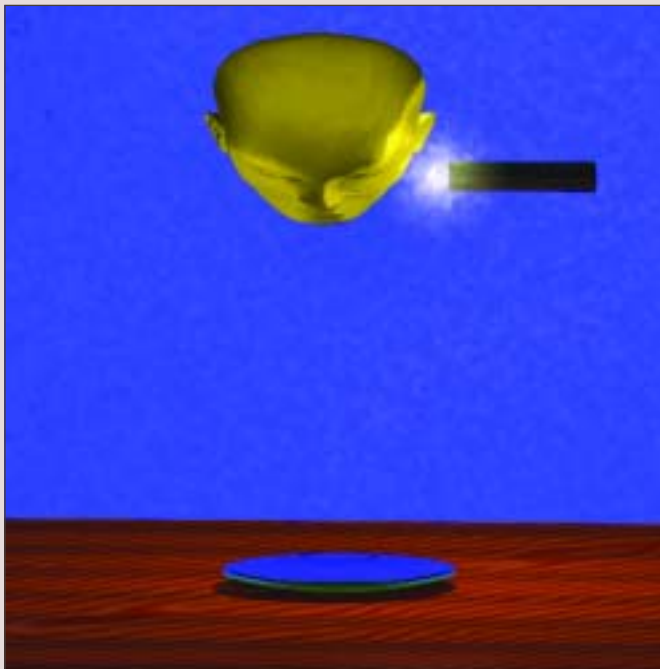
## Background

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.

# 30 light

## 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.

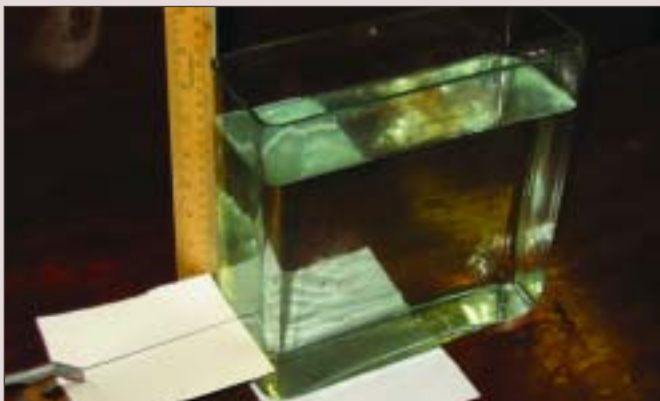
#### Follow these steps

- 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 be made from several materials other than glass.

## Follow these steps

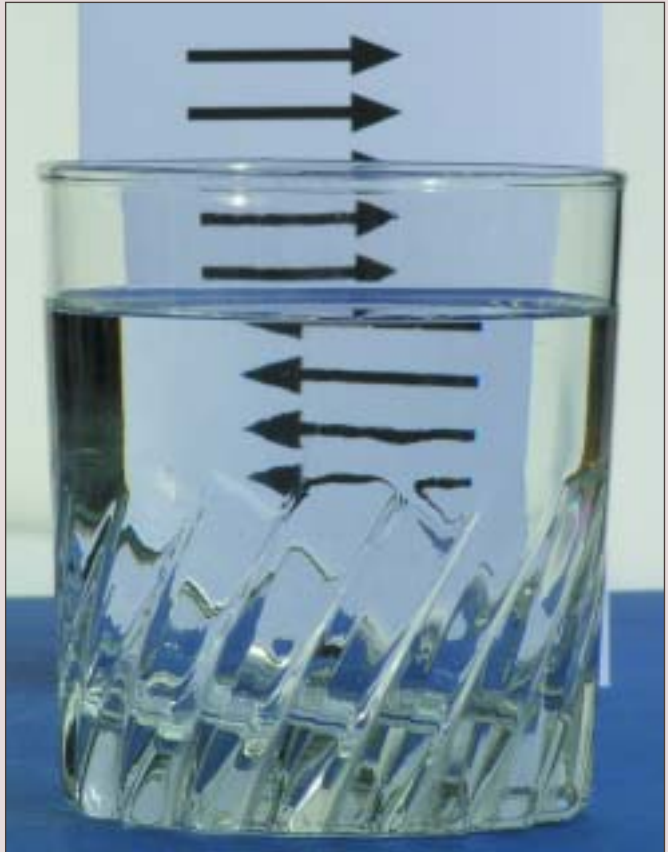
- 1 Place the card behind the glass of water.
- 2 View the arrow through the water.

## 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?

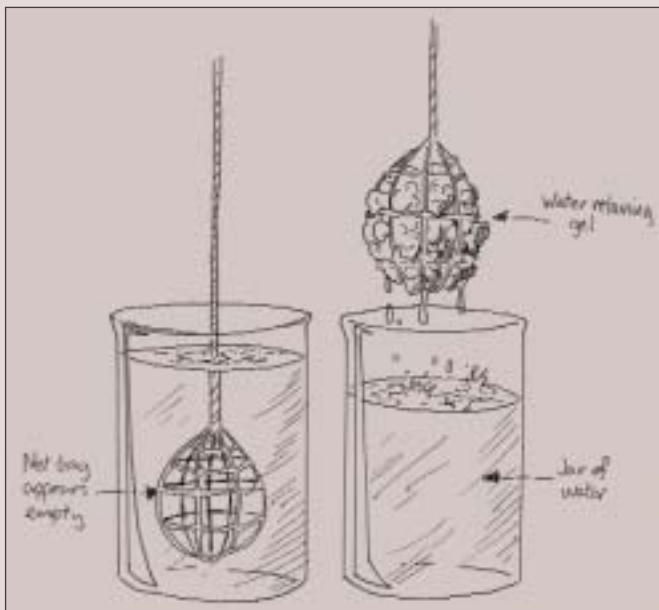
Further work can be done by producing ray diagrams for the water lens.



## 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...

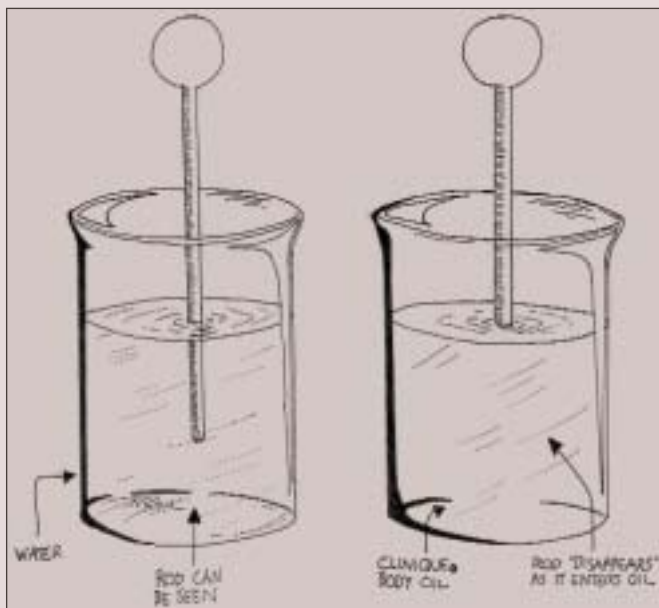
- ✓ two glass rods
- ✓ two small beakers
- ✓ Clinique body oil (or a cheaper alternative, if you can find one)

## 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.

# 34 light

## 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?

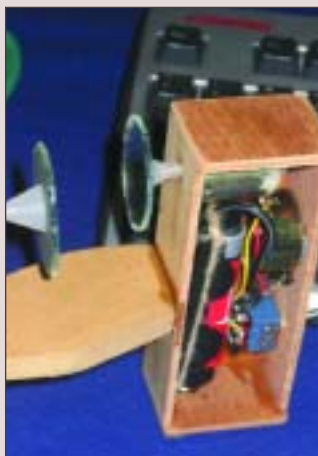
Put the students into teams of three, each student wearing a red, green or blue pair of spectacles. Then hold up objects of different colours and ask them to identify the colour of each object.

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 k $\Omega$  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 k $\Omega$  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.

# 38 light

## Hot headlamps

The Czech Republic

### An everyday application of reflection of light in concave mirrors

#### You will need...

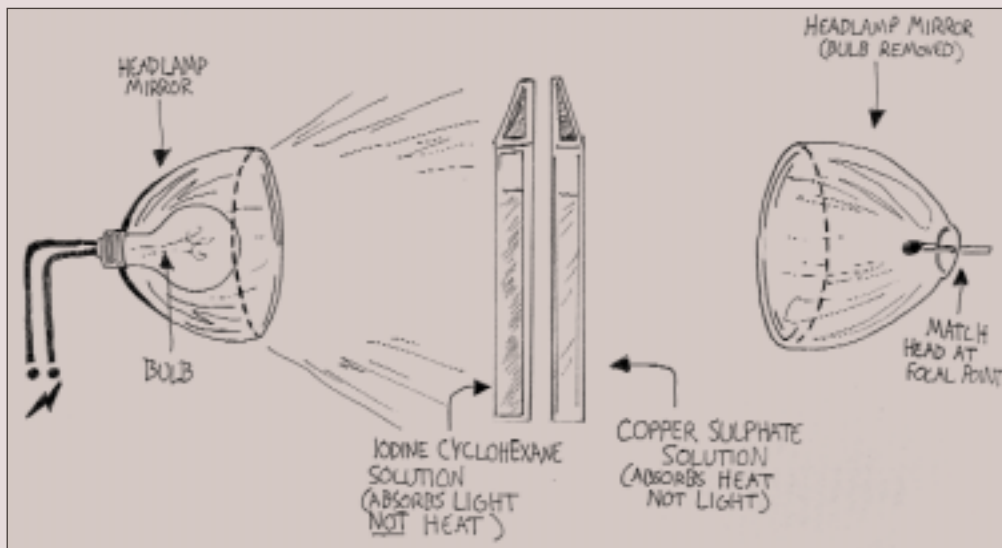
- ✓ two car headlamps (the older round ones are probably the best – not the sealed units – available reasonably from scrapyards)
- ✓ some matches
- ✓ four panes of glass
- ✓ some waterproof sealant in a gun
- ✓ a dilute solution of copper sulphate (~0.2 Molar)
- ✓ a solution of iodine in cyclohexane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

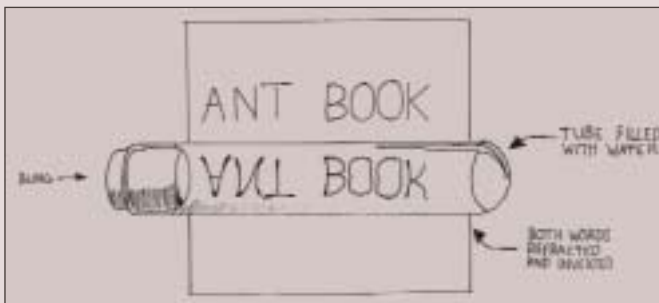
## Words in a tube

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.

### 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.

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

### 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.

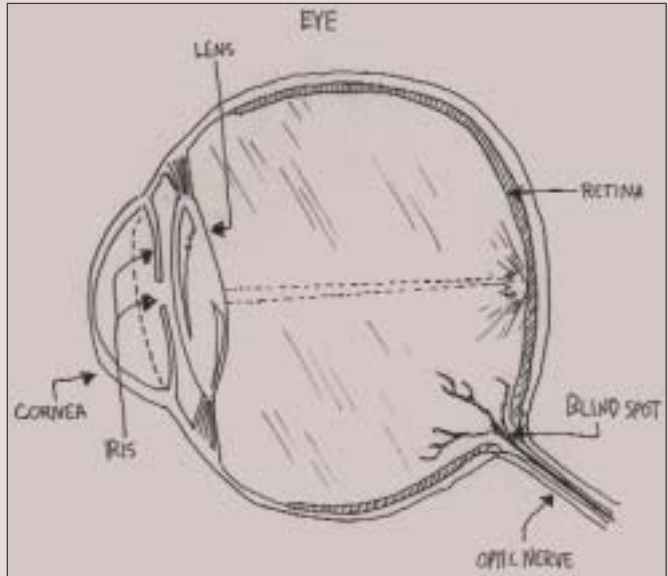
# How the eye works: introduction

## 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](http://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.

# 42 light

## How the eye works, continued...

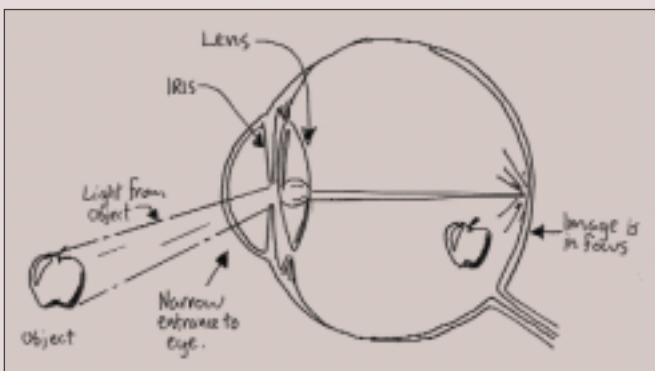
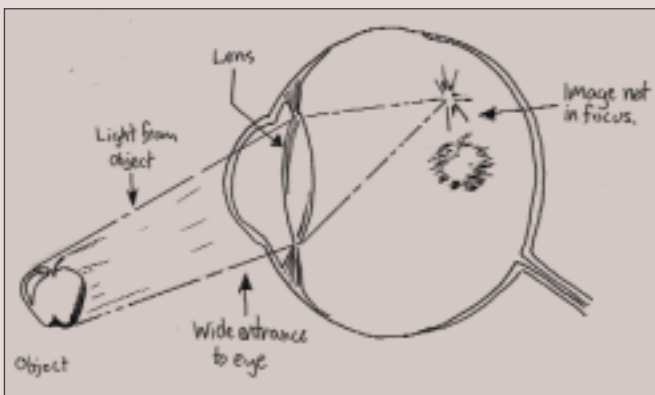
### Pupil: why have a narrow entrance to the eye?

#### 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?

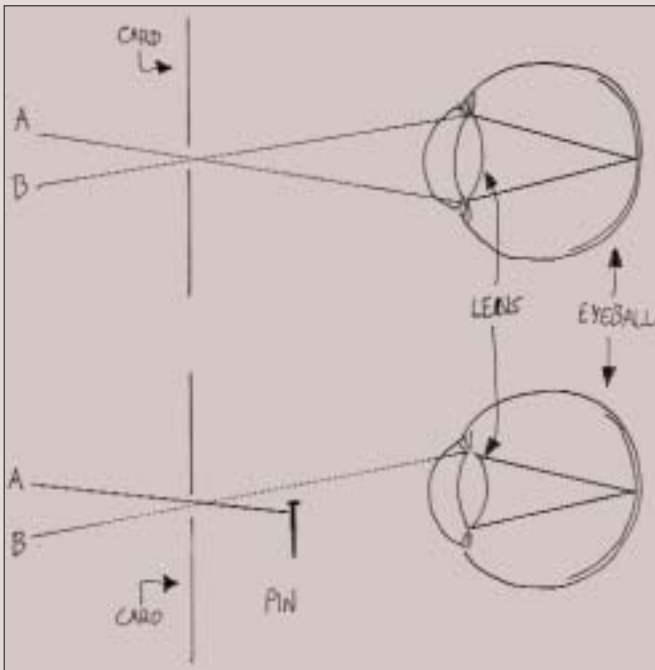
The pin remains in focus much closer to the eye when you look through a small hole. A much greater depth of field is in focus when the entrance to the eye is smaller. The small entrance to the eye means that the light coming from both objects (the distant object and the pin) is much more similar, so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

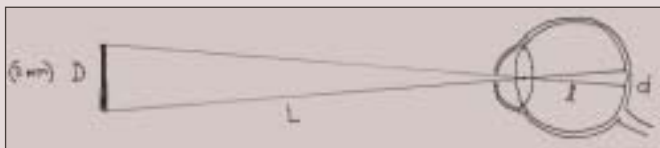
You will see “floaters” – strands and particles moving around in the fluid of the aqueous humour. This fluid plays an important role in maintaining the shape of the eyeball, which is essential if the image is to be focused precisely by the lens onto the retina.

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  $8\text{--}10\text{ }\mu\text{m}$ .

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](http://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.



# 46 light

## How the eye works, continued...

### Cones: how do they work?

#### Follow these steps

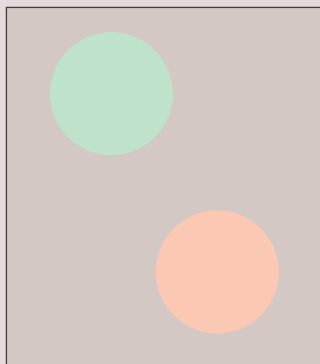
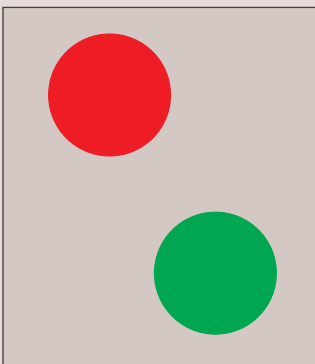
1 Project two small circles of red and green filter placed side by side.

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.

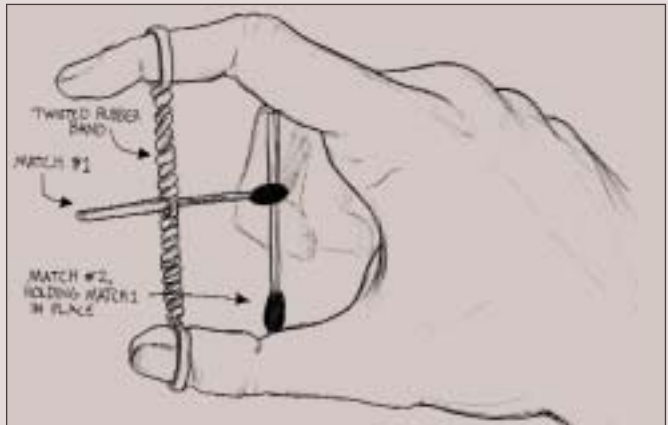


## How the eye works, continued...

### 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.

# 48 electricity & magnetism

## 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.

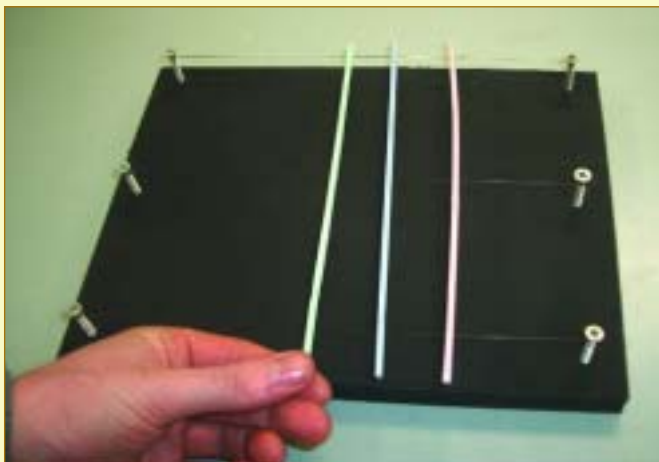
### You will need...

- ✓ a wooden frame (about  $20 \times 30$  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.



# 50 electricity & magnetism

## 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.

# 52 electricity & magnetism

## The Darlington trio

### The Czech Republic

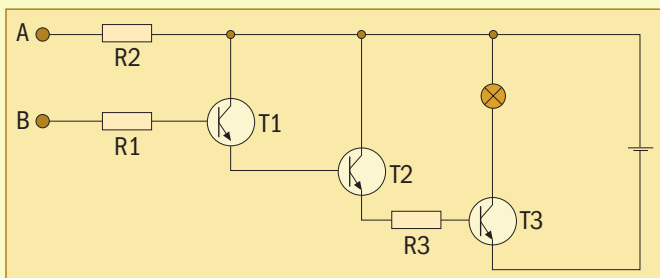
A simple circuit demonstrates several electrical phenomena

#### 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 ( $R1 = 10\text{ M}\Omega$ ,  $R2 = 1\text{ M}\Omega$  and  $R3 = 15\text{ k}\Omega$ , but their values aren't critical)
- ✓ a 3.5 V/0.2 A light bulb
- ✓ a 4.5 V battery
- ✓ a wooden skewer

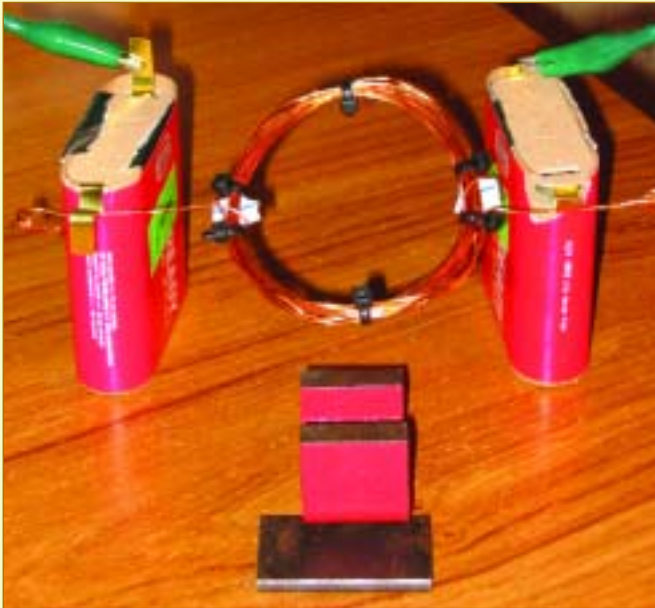
#### What next?

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.

### So what happened?

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

### 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.

# 54 miscellaneous

## 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

##### 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.

##### 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.



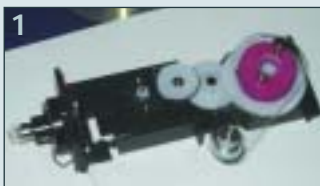
# Broken hardware experiments

## 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.



#### 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.



# 56 miscellaneous

## The Coriolis effect

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

### Background

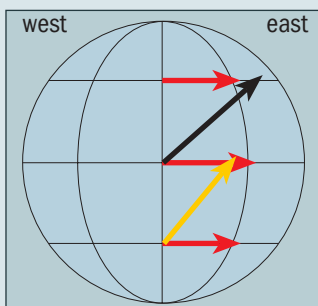
All places on the Earth have the same rotation rate of one revolution per day. However, the linear speed of a place depends on its latitude: places on the equator move at 1670 km/h while those near the pole have nearly zero speeds (see red arrows in Figure 1).

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.

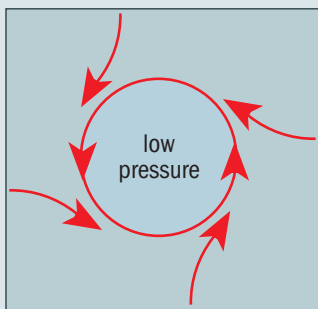
If the object is launched north from the equator, it will eventually be going faster east than the ground beneath it and will seem from the ground to be moved east by a mysterious “force” (see black arrow).

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



**Figure 1: Apparent deflection of objects on northerly trajectories.**



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

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.

### 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.



