Teaching Practical Physics Anywhere

2nd Edition
by Joe Brock
edited by Lara Mathews

IOP Institute of Physics
Acknowledgements

This book has been made possible by the combined efforts of many people.

**Philip Hardy** who has made the ramblings of a slightly confused physics teacher into a coherent project by finding equipment, making something new from random bits and pieces, sourcing it all for the best price, and finally checking, packaging and shipping it.

**Lara Mathews** who turned up out of the blue to save us. She has worked tirelessly to try the experiments, develop them so that they work with the equipment we’re taking out, and photograph them with students. Most importantly though, she converted a book that was in Brock Font and full of scrappy diagrams into a text that is both readable and full of photos.

**Mike Branfield** whose calm demeanour helped to keep us all from a nervous breakdown.

**Gary Mathews** who produced some brilliant new diagrams for the redesigned book.

**The students of Collyer’s** who got involved, added their enthusiasm and their faces to the project and produced some excellent experimentation.

**Pippa & Ian Howard** who were the inspiration for the first book in The Gambia.

Thank you to you all.

Joe Brock
The Story So Far...

The main aim of this project is to bring practical physics to students regardless of where they are studying and what facilities they have available to them. This started its life as a following a conversation with a Collyer’s student who was going out to The Gambia on an educational project with a charity called PAGEANT. We supplied a minimal amount of equipment initially and hurriedly written book. The equipment was deliberately chosen so that it could be purchased locally in the future and with the idea that teachers would start to bring their own ideas to the classroom as to how they can use everyday objects to teach scientific principles. So for instance a straw can be used to show standing waves rather than an expensive and complicated series of kit such as a vibration generator and signal generator.

Having run the project in a small way for the first year the list of experiments grew, the book was rewritten and we went out to The Gambia the following year. This time we ran 4 seminars where teachers from 10 different schools attended each one. Each teacher had a day’s training and was given a set of equipment (all basic everyday stuff) to take away with them. At the end of the day each teacher presented one particular area of physics to a group of pupils so that they could try out the ideas that they had learnt during the day.

In this way we reached a significant number of schools in a short time. Having written a report for Physics Education the Institute of Physics decided to sponsor the project with a view to creating a model of excellence but this time in Tanzania. Our charity contact this time was The Friends of Amani - a centre for disabled children in Morogoro.
The Tanzania project initially was to ship out four boxes of equipment to supply four schools in the Morogoro area with a significant amount of science equipment still along the lines of everyday items that could be purchased locally in the future.

This went so well that this year we are hoping to identify and set up a training centre in Morogoro with a view to get teachers to come in from the surrounding area to learn how to use practical as the means for teaching physics. Again the intention will be that any teacher attending training will return to their school with a package of equipment to help them get started with practical teaching. Morogoro is a reasonably large town a few hours drive west from Dar Es Salaam and is particularly suitable for the project as it has a number of secondary schools and a teacher training college.

The long term aim is for this to become a model for Physics education across Tanzania and to this end we are keen to show government institutions how effective and relatively inexpensive this method of teaching can be.

The book has now been completely redesigned by Lara Mathews incorporating photos from the project in action.

Physics is the most fascinating of subjects that can be brought to life by the imagination of teachers and students when they use practical as the way to teach ideas and applications.
May 2010

Dear Brave Teacher,

It is our pleasure to give you what we believe to be a very useful set of equipment to teach some basic and not so basic Physics.

We have tried to think of equipment that will allow you to do as many different experiments as possible and hope that some of the ideas included in this book will spark off ideas of your own.

With the equipment provided you should be able to do every experiment in the book.

We have also included some special items to inspire awe and wonder.

However, we hope that the main emphasis is on fun and the children doing as much as it is possible to do. We don’t want the equipment to become like a treasured possession which never comes out of its box and stays pristine for the rest of its life. Just like a useful book the equipment should be used over and over again by the children so it stays useful but looks a little battered round the edges.

Some of the very basic equipment will need replacing on a regular basis such as straws etc but we hope that you will be able to maintain your ability to teach Physics by letting the children experiment.

Good luck, we hope you will enjoy it.

Yours faithfully,

Joe Brock
Head of Faculty for Science and Maths

Philip Hardy
Science Technician

The College of Richard Collyer
Hurst Road, Horsham, RH12 2EJ
Contents

EXP 1   Friction
EXP 2   CD Hovercraft
EXP 3   Forces and Motion
EXP 4   Lever Law
EXP 5   Pulleys as Force Multipliers
EXP 6   Syringes and Hydraulics
EXP 7   The Strength of Shapes
EXP 8   A Paper Bridge
EXP 9   Up and Down Things
EXP 10  Centre of Mass (Gravity)
EXP 11  Stability and the Centre of Gravity
EXP 12  Toppling the Centre of Gravity
EXP 13  Measuring Human Reaction Time
EXP 14  Velocity and Speed
EXP 15  Average Speed
EXP 16  Acceleration – Getting Faster
EXP 17  Acceleration and Mass
EXP 18  A Balloon Rocket
EXP 19  A Water Rocket
EXP 20  Paper and Bernoulli
EXP 21  Carburettors and Bernoulli
EXP 22  Balancing a Pea on Air
EXP 23  How Does a Plane Fly?
EXP 24  Energy
EXP 25  Conduction of Different Solids
EXP 26  Convection
EXP 27  Who is the Most Powerful Pupil?
EXP 28  Making a Cotton Reel Tank
EXP 29  Efficiency of a Car Down a Track
EXP 30  Measuring Elastic Potential
EXP 31  Elastic Band Efficiency
EXP 32  Pressure of a Drawing Pin
EXP 33  Gases and Pressure
EXP 34  Syringes and Gas Laws
EXP 35  Surface Tension
EXP 36  What is a Wave?
EXP 37  Ringing a Bell
EXP 38  Categories of Wave
EXP 39  The Speed of Sound
EXP 40  The Speed of Sound (Continued)
EXP 41  The Range of Hearing
EXP 42  Record Player
EXP 43  Rules for Ray Diagrams (Real Images)
EXP 44  Rules for Ray Diagrams (Virtual Images)
Try Galileo’s thought experiment with marbles and a track.

You will need: V track and a marble.

Hold the track up in a U-shape and drop the marble from one end.

If there was no friction the marble would always get to the same height on the track and it would keep moving up and down in the track forever.

There is a little friction, however, so the marble keeps rocking back and forth to almost the same height as before, and eventually it will stop.

Make the track a little less steep on one side. The marble goes further along, until it gets to almost the same height on the track.

Make the track even less steep on one side. The marble goes even further until it gets to the almost same height.

Now put the track flat on one side. The marble will try to go on forever as it will never reach the same height and it has leftover energy.

Conclusion:

Even if it seems like an object will go on forever, if there is friction it will lose energy and eventually stop.
So how do we get rid of friction?

Try this CD hovercraft.

Blow up the balloon, then put it down on a flat surface. Give it a push – it goes for a long time!

Conclusion: With no friction to stop something it will keep going forever.

Newton’s 1st Law: An object will continue at a constant velocity (or be at rest: \( v = 0 \text{ ms}^{-1} \)) if the resultant force on it is zero.
A force is a push or pull and is measured in Newtons (named after Isaac Newton).

Newton’s 1st Law: An object will be stationary or moving with a constant velocity if the resultant force on it is zero.

Turning things (things that go round in a circle) also obey this law. Try this experiment:

Get the first student to push near to the door hinge but show that the second student can ‘balance’ the first student’s force with just his little finger. How? Is student 2 superhuman? How could you make it more difficult for student 2? Move student 1 away from the hinge (the pivot).

So the effectiveness (moment) of a force is dependent on the distance of the force from the pivot. Student 2’s little finger force is able to balance student 1’s huge force because it is so much farther from the pivot. So:

$$\text{Moment} = \text{force} \times \text{distance from pivot}$$

We have balance (equilibrium) when student 1’s moment equals student 2’s moment.

In the diagram student 2’s moment is pushing the opposite way to the way a clock’s hands move, so it is called an anticlockwise moment. Student 1 is pushing the same way as a clock’s hands move so it is called a clockwise moment. For equilibrium (balance):

$$\text{Anticlockwise movement (ACM)} = \text{clockwise movement (CM)}$$

This is called lever law – and all with just a door!
Get students to try to balance two different masses by putting them at different distances from the pivot. Make up a table of situations where there is equilibrium.

Notice the distance to centre of masses:

\[ d_1 \quad d_2 \]

Forces become more effective (their moment is greater) the further they are from the pivot.

If the anticlockwise moment (ACM) equals the clockwise moment (CM) there is equilibrium.

Try to find equilibrium for yourself. Put a ruler on a pivot and add masses to the top.

See if you can get it to balance for yourself!

So if the tin opener is not accelerating it must be in equilibrium. So the moments either side of the pivot are the same.

\[ F_1 \times d_1 = F_2 \times d_2 \]

If \( F_2 \) is the force at the cutting edge and \( d_2 \ll d_1 \) then \( F_2 \gg F_1 \) i.e. \( F_2 \) is large.

In fact \( F_2 \) is so large it can easily cut through the metal of this tin.
Let’s say we want to transfer 1200J of energy.

\[
\text{Energy} = \text{Force} \times \text{Distance}
\]

\[
1200J = 1200N \times 1m
\]
\[
= 600N \times 2m
\]
\[
= 300N \times 4m
\]
\[
= 120N \times 10m
\]

Look as we increase the distance the force required to transfer that energy gets less. This is why it is easier to push things up a ramp than to lift them directly.

\[
\begin{align*}
\text{Force needed} & = 1200N \\
\text{Force needed} & = 600N
\end{align*}
\]

So anything that increases the distance over which we apply the force means we need less force to transfer the energy.

NOTE: In real life there’s some friction to overcome, so the efforts will be greater than quoted.

Pulleys do this for us. Look what happens when we use two strings between the pulleys:

This means that whatever distance the Effort force moves the load (weight) only moves half (± 2 strings) that distance. So we only need 600N to lift 1200N. The effort moves twice the distance with half the force.

Try the experiment using 2, 3 and 4 pulleys and see how the force needed changes.
In liquids molecules are closely packed together so liquids are almost incompressible.

This means that the pressure in a liquid is the same throughout its volume, assuming there isn’t a large change in depth like there is in an ocean.

Hydraulic systems can be used as force multipliers. Here the output (larger) piston has 5 times the area of the input (smaller) piston.

So a 200N push on the brake pedal of a car becomes a 1000N (5 x 200N) push on the brakes.

Remember, \( P = \frac{F}{A} \) and the pressure is the same throughout the system.

So with 5 times the area you get 5 times the force. A small push becomes a large push.

Careful here though. We are not creating energy. The distance moved by the bigger force will be 5 times less.

\[
\text{Energy transferred} = \text{Force} \times \text{distance}
\]

With 5 x F and d/5 we could get the same energy out as we put in but not more. In practice there is a lot of friction and energy as usual is wasted.

Try getting one pupil to push on the big syringe and one to push on the small syringe. Even if the pupil with the big syringe is very strong, the pupil with the small syringe is going to win!

Friction prevents any useful quantifiable experimentation taking place.

Note:

\[
\text{Pressure (P)} = \frac{\text{Force (F)}}{\text{Area (A)}}
\]

so

\[
F = P \times A
\]
There are two shapes that can make a material seem very strong – circles and triangles.

Here are a couple of experiments to help you explore the possibilities.

Try cutting the paper into 2cm strips and then folding the paper into coiled cylinders or triangular prisms. The best shapes to use are cylinders. Just nine cylinders of 1cm diameter can support a student’s weight.

Take a little care to make them all the same height.

Mission 1:
Support a student 2cm off the ground using only a board of wood of approximately 30cm x 30cm and two sheets of A4 paper.

Give students clues if they require them but they might come up with new and innovative ideas if you don’t.

Look, this student is supported by less than one piece of A4 paper! Great!
Mission 2:
Who can make the strongest bridge between two supports 15cm apart? The supports can be books and should be about 6cm high. Pupils should all be given 3 sheets of A4 paper and a tiny amount of sticky tape.

The load must not be above the supports in any way. The bridge which can support the heaviest load without collapsing is the strongest.

A4 paper is very strong if it is folded many times. Corrugations can be used in bridge building as they use the triangle shape. Set the mission and who knows what your students will come up with!

A surprisingly heavy weight can be supported on just paper.
Another condition for equilibrium (balance, when the resultant force of something is zero) is when UP forces = DOWN forces.

For this experiment you will need:
- 1 metre rule
- 2 Newton meters
- 1 set of weights
- String

2. Set up the experiment so that the string is holding up the Newton meters so that they are level, and so that the ruler is level.

3. $F_1$ and $F_2$ are up forces. You can tell because if you remove one or the other or both then the bottom ruler falls down, so they must be pulling up. Move the weight ($F_3$) across the bottom ruler and record the values of $F_1$, $F_2$, and $F_3$.

4. Make a table of your results:

<table>
<thead>
<tr>
<th>$F_1$</th>
<th>$F_2$</th>
<th>$F_1 + F_2$</th>
<th>$F_3$</th>
</tr>
</thead>
</table>

$F_3$ will come out a little bit less than $F_1 + F_2$. Why?

5. The weight of the ruler is also one of the down forces.

\[
\text{UP} \quad \text{DOWN} \\
F_1 + F_2 = F_3 + ?
\]

<--- Weight of rule

6. Conclusion:

Up = Down for equilibrium.
When we studied moments (EXP 3) did you notice we looked at the distance to the centre (not the edges) of the mass? The centre of mass is a very important property. It is the point at which gravity appears to act on an object.

To find the centre of mass of an object you will need: card, string, a weight, a pin.

This is what you will need to do:

1. Cut a strange shape out of card (letters are good).
2. Poke a hole in the card with the pin and wiggle it so that it’s just loose.
3. Let the card hang.
4. Dangle the weight on a string from the pin and draw a line along the string on the card.
5. Find another point and poke the pin through again. Repeat steps 3. and 4. The lines will cross somewhere.
6. Try a third point and the string line should cross the same point.

The point where all the lines cross is the centre of gravity.
Some objects have a centre of gravity that’s not actually inside the object. Think about an n or o shape.

Try the experiment again with this shape (probably good to demonstrate this to the class).

Now this is particularly useful in high jump. Look at the shape high jumpers make to get over the bar. It’s called the Fosbury Flop.

Because the jumper makes an n shape they do not have to get their centre of gravity over the bar so they can get over a higher bar and win the competition.

If they just jumped… look:
EXP 11  Stability and the Centre of Gravity

1. If you want an object to be stable its centre of gravity (C of G) must act through a line that is within the support points.

2. If the object is standing then the C of G must be directly above the base of the object (the part that is touching the ground) for it to be stable. If the object is hanging the C of G must be below the support point for it to be stable.

3. The object shown here is very stable as the heavy forks bring the centre of gravity to below the point where the pin touches the glue stick. You can wobble this object and despite being supported by a thin pin it will not fall over.

4. A leopard asleep in a tree. He hangs his legs, tail and head as low as he can. In this way his centre of gravity is below the top edge of the branch, so he is stable. He can sleep without fear of falling off. This one is obviously awake!

5. Try this experiment – you will need a pulley with a hook, some slotted masses and some string.

   The Students’ Mission: Try to get your pulley to run between two people on the string. Unfortunately, the pulley keeps falling over – it is unstable. The centre of gravity is above the string (support point). What could we do to try to get the centre of gravity below the string?

6. When we add masses, we make the C of G change to below the string:

   C of G is now below the support point, so the pulley is stable.
Try this C of G experiment. You will need:

- A plastic bottle
- Water

Look at how different amounts of water affect the centre of gravity and how far the bottle will tip before it falls over.

1. Put a little water into the bottle. Push the bottle and see how far you can tip it before it topples over.

2. Put some more water in. The centre of gravity is higher this time, so the bottle topples over more easily.

3. Now fill it up completely. When the bottle is full, it topples over almost straight away. This is because the centre of gravity is high.

4. The higher the C of G the easier it is for an object to fall over.

This is why racing cars are the shape they are. Buses can topple more easily as their Cof G is higher. They can’t go round corners as quickly as racing cars.

5. This toy bird has heavy weights in the ends of the wings so its centre of mass is its beak. That means it can balance on its beak and it looks like it is flying!
EXP 13  Measuring Human Reaction Time

Who has the fastest reaction time and how fast is it?
There’s an equation that relates how far something falls ($x$) and how long it takes ($t$).

\[ x = \frac{1}{2} at^2 \]

\[ 2x = at^2 \]

\[ \frac{2x}{a} = t^2 \]

\[ t = \sqrt{\frac{2x}{a}} \]

The ruler test: Get a friend to hold a ruler so that the 0 mark is level with the top of your hand. When they let go try to grab the ruler as quick as you can. Use the table below to see your reaction time.

<table>
<thead>
<tr>
<th>Reading/cm</th>
<th>Time/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>0.11</td>
</tr>
<tr>
<td>8</td>
<td>0.13</td>
</tr>
<tr>
<td>10</td>
<td>0.14</td>
</tr>
<tr>
<td>12</td>
<td>0.16</td>
</tr>
<tr>
<td>14</td>
<td>0.17</td>
</tr>
<tr>
<td>16</td>
<td>0.18</td>
</tr>
<tr>
<td>18</td>
<td>0.19</td>
</tr>
<tr>
<td>20</td>
<td>0.20</td>
</tr>
<tr>
<td>22</td>
<td>0.21</td>
</tr>
<tr>
<td>24</td>
<td>0.22</td>
</tr>
<tr>
<td>26</td>
<td>0.23</td>
</tr>
</tbody>
</table>

Now, the acceleration due to gravity is $9.81 \text{ms}^{-2}$, so for a given distance we can calculate how long it takes to fall.

Any more than 26cm and you must have fallen asleep! Any really quick times (6cm or less) and you just had a lucky guess.

Who’s the fastest in the class and how fast are you?
What does this mean when you are timing short distances on your stop clock?

Your reaction time becomes significant.
Who is the fastest? You will need a sports tape measure and stop clocks.

1. Measure out a distance to run with the tape measure (50 to 100m).
2. Time each student with a few stop clocks.
3. Show that taking an average of the times is a good idea. Talk about ignoring the times where someone has made a mistake (this is called an anomalous result).

Record the results in a table like this one:

<table>
<thead>
<tr>
<th></th>
<th>Time 1</th>
<th>Time 2</th>
<th>Time 3</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fred</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Isobel</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Andrew</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

How do we work out the speed?

\[ \text{Speed} = \frac{\text{distance}}{\text{time}} \]

e.g.

\[ \frac{100\text{m}}{20\text{s}} = 5\text{ ms}^{-1} \]

It might be nice to show here how quickly a cheetah might cover this distance.

(Cheetah max. speed \(26 \text{ ms}^{-1}\)).

Velocity is just speed with direction i.e. you have to say whether it’s + or - .

\[ -5\text{ ms}^{-1} \quad +5\text{ ms}^{-1} \]
EXP 15 Average Speed

1. In fact, when you work out a speed you are working out an average speed. If you think about it, when you do a race against time you go slowest at the start, you get faster, reach maximum speed then carry on at maximum speed.

2. Try to measure instantaneous speed (use a sports tape measure and four stop clocks).
   Position students along the 100m with their stop clocks and get them to shout ‘stop’ when they stop their clocks as the runner goes past.

3. Set up the experiment like this:

   
   ![Diagram of experiment setup](image)

   *START*

   25m 25m 25m 25m

   

4. This way the next person can start their stop clock then shout ‘stop’ when the runner goes past again.

   \[
   \text{speed} = \frac{25m}{\text{time}}
   \]

   In fact, to get instantaneous speed you need to time over tiny distances. Where is the runner going fastest?
Try this experiment accelerating a toy car. You will need:

- Toy racing cars
- Track
- Blu Tack
- 2 stacks of slotted masses
- Elastics

Make an elastic bridge using one elastic and both of the slotted mass stacks. Put some Blu Tack on the back of the car to help weigh it down. Pull the car back by about 3cm and then let go. Make sure when you pull the car back that the elastics start off taut and that the masses are evenly placed on each side of the track.

Now try pulling it back by the same amount, but use two elastics instead. Now you’ve applied twice the force. How does it accelerate now?

Try it again with 3 elastics on the bridge. How does it accelerate now?

How about with 4?

Conclusion:

If more force is applied the car accelerates more. Acceleration is proportional to force:

\[ a \propto F \]

This is Newton’s 2nd law of motion.

Something else affects the acceleration of the car – what is it?
This time we’re going to see what happens if you change the mass. You will need:

- Toy racing cars
- Track
- Blu Tack
- 2 stacks of slotted masses
- Elastics
- Ball bearings

1. Choose how many elastics you will use on the bridge. Do not change this once you have started the experiment! Two is a good suggestion.

2. Add Blu Tack to the car. Then pull it back about 3cm and let it go.

3. Now stick a ball bearing on the front of the car using the Blu Tack. Pull it back again and let it go. So, how does it accelerate this time?

4. Keep trying, adding more and more ball bearings each time.

So, with more Blu Tack (i.e. more mass) the acceleration will be less.

As mass goes up acceleration goes down. Acceleration is inversely proportional to mass

\[ a \propto \frac{1}{m} \]

In fact, acceleration is:

\[ a \propto \frac{\text{force}}{\text{mass}} \]

or

\[ a = \frac{F}{m} \]

with the right units.
To make a balloon rocket you will need a balloon, a piece of paper, sticky tape and string.

If students make these you could set up a competition to see whose balloon rocket is the fastest.

Roll the paper up into a cylinder and use the sticky tape rolled back on itself to stick the balloon and the paper together. Blow up the balloon, thread the string through the paper and get ready to let go of (launch) the balloon.

The balloon rocket shows that before release the total momentum is zero because it’s not moving. After release the total momentum is still zero as the balloon has positive momentum and the air has an equal amount of negative momentum. So the total is still zero.

An alternative explanation is that the balloon applies a force to the air forcing it out backwards. The air in turn applies and equal amount of force on the balloon pushing the balloon forwards.

In collisions and explosions momentum is always conserved i.e. it is the same afterwards as it was before.

Newton’s 3rd Law:
Every force has an equal and opposite force.

These pairs of forces are always the same type of force, same size of force, act for the same time in the same plane and act on different objects in opposite directions.
EXP 19  A Water Rocket

Have a go at making this great water rocket!
Fill the rocket bottle with water and then attach to the pump via the tube. Start to pump air into the rocket using the pump. You will know if this is happening correctly if you can see the air bubbling through the water. Keep pumping until the rocket shoots off.
A foot or hand pump may be used.

Try filling with varying amounts of water, i.e. quarter full, half full etc. Get the pupils to predict what will happen by varying the amounts of water.

Careful here, do not get above the rocket. Stand well away!

Newton’s 3rd law offers an explanation. When the pressure is too much for the tube to stay in the bottom of the rocket, the rocket pushes water down out of the bottle. The equal but opposite force pushes the rocket up therefore making it launch into the air.

Talk about the problems faced by rocket engineers. A rocket has to have enough fuel, but the problem is it also has to lift the fuel too. A real dilemma!
Paper and Bernoulli  

**EXP 20**

1. Take a piece of paper and place it in front of your mouth. As expected, it dangles down.

2. Blow hard above the paper. The fast flowing air creates a low pressure and the paper is forced upwards by the greater pressure below. This is called the Bernoulli Effect.

---

Carburettors and Bernoulli  

**EXP 21**

1. Cut a straw half way through, bend it and place it in a glass of water. If you blow very hard a low pressure is created above the break in the straw and atmospheric pressure pushes water up the tube. The fast flowing air then breaks it into a fine mist. The mist has a large surface area to volume ratio which makes it excellent for a fast reaction such as an explosion. This is how carburettors work in a car with the water replaced with petrol.

DO NOT do this with petrol - it is extremely dangerous.
Can you balance a pea in an air stream? You will need a straw, a pea (or similar) and a good pair of lungs.

Blow hard, but make sure the pea can’t go down the straw.

You don’t want it going down your wind pipe!

It’s easier with a bendy straw.

See if you can balance the pea at an angle.

But why doesn’t the pea just topple off to the side?

This low pressure effect (the Bernoulli Principle) takes over again.

The pea wobbles left and right. Here the pea is to the left and so the fast air is to the right of it. The fast moving air creates low pressure. The still air to the left is at a higher pressure. This pushes the pea right, back into the air column.

Here the pea is to the right and so the fast air is to the left of it. The fast moving air creates low pressure. The still air to the right is at a higher pressure. This pushes the pea left, back into the air column again. So the pea wobbles back and forth but stays in the air flow.
A plane is held up by air molecules. Again it’s all down to the Bernoulli Principle.

The plane wing has a special shape in section (when you cut through it). It’s called an aerofoil.

Air is forced to flow faster over the top. Air flows more slowly underneath as it has less distance to travel in the same time.

This means the molecules have more collisions underneath the wing than on top so there is higher pressure underneath than on top and the wing is forced upwards.

The faster the air flow the greater the force pushing the plane upwards, i.e. the greater the LIFT.

Faster planes have a less obvious aerofoil. When they fly more slowly they can’t get enough lift from their wings so they fly at an angle with their nose pointed up. Unfortunately this air also acts to push the plane backwards and so slows it down.

Have a go at making your own paper plane from one sheet of A4 - there are instructions at the back of the book!
Energy can be stored. Stored energy is called potential energy (PE). Stretched or squashed things store elastic PE. Food and fuels store chemical PE.

Things at a height store gravitational PE.

Energy is indestructible – you can’t make it or destroy it.

When we use energy it changes from one form to another. Each time it changes some energy is wasted. Energy is like money - as it spreads out it becomes less useful.

This toy bow and arrow converts Elastic PE to kinetic energy (KE).

This cell stores chemical PE.

The energy will convert to electrical energy if the cell is put in a circuit.

This candle converts chemical PE in the wax to thermal energy (heat) and light.

This school electric car’s battery converts chemical PE to KE.

This microphone changes sound energy to electrical energy.

The wind up mechanism in this old clock stores elastic PE and converts it to KE very slowly.
Conduction of Different Solids

1. Metals are good conductors of heat as their electrons are free to move around. This means they can pass on the energy easily. Other materials lock their electrons into position so are poor conductors of heat.

2. See how different metals conduct heat for yourself! Get some rods of metal with one end painted black, and lay them down in a line so that the painted bit is in the sun and the unpainted bit is in shadow.

3. Which conducts the heat energy the quickest? Feel the ends of each rod to feel which is the best conductor.

4. Is it warm, i.e. a good conductor?
   - OUCH! TOO HOT!
   - Is it cool, i.e a poor conductor?
   - NO PAIN!

Convection

1. Cut out a spiral of paper and attach a piece of cotton to the centre.

2. Hold the spiral above something hot (a black metal plate in the sun is good).

3. As the hot plate heats the air above it the spaces between molecules increases and the air becomes less dense. It starts to ‘float’ upwards above the more dense air surrounding it. This is called convection. Cooler volumes of fluid will sink as they are denser than the surroundings.

4. Convection only occurs in fluids (gases and liquids) because the molecules have either no force or very weak forces between them and so are free to spread out or squash back together.
EXP 27 Who is the Most Powerful Pupil?

Pupils can be made to gain gravitational potential energy (GPE) by making them stand on a stool or chair.

The height of the chair should be measured in metres (m). One student should measure exactly one minute on a stop watch.

One student should hold the chair to make sure it does not fall over!

Pupils should step up and down as many times as they can in one minute (60seconds).

\[ GPE \text{ gained each step} = mg \]

For example:

\[ GPE = 40\text{kg} \times 9.81 \times 0.5\text{m} \]
\[ = 200 \text{ Joules} \]

Note: No cheating, the pupil has to stand up straight legged.

\[ Total \text{ energy transferred} = GPE \text{ gained each step} \times \text{no. of steps in a minute} \]

For example:

\[ Total \text{ energy} = 200J \times 16 \text{ steps} \]
\[ = 3200J \]

\[ Power = \frac{\text{Total energy}}{\text{Time}} \]
\[ = \frac{3200}{60} \]
\[ = 53.3 \text{ Js}^{-1} \]
\[ = 53.3 \text{ W} \]

So who is the most powerful pupil?

Some pupils may have more mass but move slowly.

Some may be lighter but move more quickly.

The active student should step up on the chair, stand up straight, and then step back down again.

The College of Richard Collyer
Making a Cotton Reel Tank

EXP 28

1. A cotton reel tank is a machine that converts elastic potential energy (EPE) into kinetic energy (KE).

2. To make a cotton reel tank you will need a matchstick, elastic band, a piece of candle, and either a second match or a wooden dowel.

3. Cut a groove in the candle piece to hold the dowel or match. Thread the elastic band through the middle of the reel (a paper clip is useful here).

4. Pull the band through.

5. Slot the match through on the far side, wind it up and watch it go. You could even have races to see which tank can convert from EPE to KE the quickest i.e. which is the most powerful.

6. Here is a two-match version which works just as well.
EXP 29  Efficiency of a Car Down a Track

1. You will need a toy car, a track, a ruler, stop watch, scales or read the mass of car from sticker underneath it.

2. Set up your track and mark out 1m along the horizontal section. Measure the height (h) of the car at the top of the slope.

3. The car has GPE at the top of the slope where
   \[ GPE = mgh \]

4. The car has KE along the horizontal section where
   \[ KE = 0.5mv^2 \]. Velocity can be calculated using \( v = \frac{x}{t} \) where \( x = 1m \) and \( t \) is measured on the stop watch.

5. Total energy in = GPE
   Useful energy out = KE
   Efficiency = \( \frac{\text{Useful Out}}{\text{Total In}} \times 100\% \)
   \[ = \frac{KE}{GPE} \times 100\% \]

6. Energy cannot be made or destroyed so where’s the energy gone? It has been transferred to thermal energy via the force of friction.
In this experiment students will find the amount of EPE stored in an elastic band, measure how much of it can be converted into GPE via KE and finally work out how efficient it is at converting energy.

Load the elastic band with a number of weights from 1N to 10N. For each weight \( F \) measure the extension \( x \) (the difference between its loaded length and its original length at the start).

Repeat the experiment, but now unload it from 10N to 1N.

Record both loading and unloading extensions.

The area under the unloading curve is the energy available for flicking.

The area can most easily be calculated by approximating the curve to a triangle where area lost equals area gained. The energy stored is the area under the triangle.

The area represents the energy, stored as elastic potential energy, that can be recovered (translated).

\[
\text{Area} = \cdot \text{base} \times \text{height} = \cdot Fx
\]
EXP 31 Elastic Band Efficiency

1. This is good fun. Get the pupils to flick an elastic band from the top of the ruler to the ceiling. When they get the band to touch the ceiling they should make a note of the extension (x) required to get it to do this.

2. Watch out! The band should touch the ceiling very gently, not bash into it.

3. Measure the height between the top of the ruler and the ceiling (h).

4. Measure the mass of 100 similar elastic bands and divide by 100 to get the mass (m) of one of them. Calculate GPE:

\[ GPE = mgh \]

where h is the height from the top of the ruler to the ceiling (see box 3) and \( g = 9.81 \text{ m/s}^2 \)

5. Calculate the Elastic PE by estimating a triangular area.

\[ Efficiency = \frac{GPE}{EPE} \times 100\% \]
Pressure of a Drawing Pin

1. What’s the difference between force and pressure? Show the students a large weight (heavy rock or book) and a drawing pin. Then ask for a volunteer...
   
   *Do not actually do what’s next!*

2. Choose a student.
   
   Imagine you have to hold up the heavy object by balancing it on a drawing pin. The teacher has to have a drawing pin facing down, and the student gets a drawing pin facing up.
   
   The student is lucky and the teacher is unlucky.
   
   Ask them if they know why.

3. When the teacher tries to hold up the object it hurts!
   
   There is a lot of pressure here. There is a large weight, so a large force but there is also very little contact area at the point of the pin.

4. Now the student tries, and it’s fine. Painless!
   
   There is not much pressure here. There is still a large weight and so large force but there is a large contact area at the head of the pin.

5. So the student is happy but the teacher is not. The teacher is experiencing a lot of pressure. The same force is applied but the contact area for the teacher is smaller than for the student.
   
   **Pressure** = \( \frac{\text{Force}}{\text{Area}} \)
   
   Units in \( \text{Nm}^{-2} \)

6. A sharp knife has less contact area with the thing it is cutting so for a given force the pressure is greater. So a sharp knife cuts more easily. Eskimos’ snow shoes and camels’ feet (that stop them sinking into the snow or sand) are examples of more area, so less pressure.
### Gases and Pressure

<table>
<thead>
<tr>
<th>Step</th>
<th>Description</th>
</tr>
</thead>
</table>
| **1** | Gases exert a pressure because their molecules are whizzing around and bashing into the surface of the container that holds them. As they hit they apply a force over an area.  
\[ \text{Pressure} = \frac{\text{force}}{\text{area}} \]  
so the molecules exert a pressure.  
The ball shown here applies a force over the area of the floor and so acts like molecules bashing against a container wall. |
| **2** | There are three ways for a gas to exert more pressure. We could introduce more molecules. More molecules would hit more often and so increase pressure exerted. We could do this by pumping more gas into a container. |
| **3** | We could increase the speed of the molecules so they hit the container harder and more often. We could do this by increasing the temperature of the gas (make it hotter). |
| **4** | We could reduce the area over which the molecules are hitting the walls. We could do this by squeezing the container that holds the gas, i.e. reduce the volume of the container. |
| **5** | You can increase the speed of the molecules by increasing their temperature.  
Here we are heating a sweet tin enough to blow the top off. This could just as easily be done on a fire, but don’t get above it! |
| **6** | Note that you will probably have to put in a little water to help increase the volume. This is because water increases a lot in volume when it turns to steam. This helps increase the pressure enough to blow the lid off and it happens a lot more quickly. |
| **7** | So an increase in temperature \((T)\) leads to an increase in pressure \((p)\) enough to blow the lid off.  
In fact if we measure temperature in Kelvin (rather than °C) then double the temperature gives double the pressure.  
In fact: Pressure is proportional to Temperature for a fixed volume and mass of gas  
\[ p = \text{constant} \times T \] |
1. Trap a fixed amount of air inside a syringe by placing your finger over the end. We now have a fixed amount of gas molecules as they can’t escape.

2. What will happen to the pressure (p) inside the syringe if you squeeze the syringe to half its volume? Halving the volume doubles the pressure – you can feel it pushing back.

3. If we quarter the volume the pressure goes up by 4 times. You can really feel it now!

4. What if you squeeze the syringe to its original volume? Pressure will be 4 times more. Look:
   \[ V \times \frac{1}{2}, \quad p \times 2 \]
   \[ V \times \frac{1}{4}, \quad p \times 4 \]
   Can you see the relationship?

5. The famous scientist Robert Boyle spotted it. He saw that for a fixed amount of gas molecules:
   \[ pV = \text{constant value} \]

6. Look:
   \[ p \times 2 \times V \times \frac{1}{2} = pV \]
   \[ p \times 4 \times V \times \frac{1}{4} = pV \]
   For a fixed mass of gas at a constant temperature the relationship is always the same.

7. So the equation for a fixed mass of gas at a constant temperature is:
   \[ pV = \text{constant} \]
   It is named Boyle’s Law after Robert Boyle.
Surface tension is caused by the fact that molecules of gas near the surface of a liquid do not attract the liquid molecules at the surface as much as other liquid molecules.

Look at how drops of water form on certain plants. The surface tension pulls water into the simplest shape – a perfect sphere – a shape of least surface area/volume ratio.

This same surface tension pulls water up thin tubes. This is called capillary action and plants use it to help them transport liquids up and down the stem.

Usually it is not possible to make a film of water as the surface tension is too great so it rips the film apart. However, if we add detergent to water it can decrease surface tension by tenfold. It’s still there though.

Try this experiment:

1. Twist a piece of single strand wire to make a large loop about 8cm in diameter.
2. Make a smaller loop of cotton.
3. Dip both into a water/detergent mix. Make sure it is not too foamy! The wire loop should form a film.
4. Break the film inside the cotton loop using a pin and see what happens!
What is a Wave?

1. Ask the class for ideas - spend a quick 5 minutes brainstorming then move on.
   Don’t say what’s right or wrong, but repeat all ideas to the class so everyone can hear and spark ideas off each other.
   Ignore anyone’s answers if they haven’t waited with their hand up to ask.

2. Try the Mexican wave – you will need: 1m ruler, stop clock, tape measure.
   The wave goes from Student 1 (e.g. Fred) to Student 2 (e.g. Lizzie). Get Fred to stand up and lift his hands quickly, and then sit down. When the student next to Fred sees him do it, he must do the same. Keep going until you get to Lizzie!

3. Does everyone end up on Lizzie? No! So what actually moves? In this case information, that the person next to you has stood up and then sat down.
   A wave is a way of transferring information!

4. What’s the world record for 100m? 9.8s. So the average speed of a 100m runner is about 10ms⁻¹, 20mph. Note max is probably 12-13ms⁻¹ i.e. 24-25 mph.
   Note ms⁻¹ to mph conversion is about x2
   USEFUL!

5. So, what is the speed of a Mexican wave?
   Get the class to close their eyes. “I want you to imagine a football stadium which is probably = 500m round (I know it depends on how high you are in the stands but run with me on this). Everyone put your hands up. When I say so imagine the start of the Mexican Wave. Imagine it going round the stadium. When it gets back to where it started put your hands down. I’m going to time how long you reckon it takes to get round.”
   Now here everyone will have a different opinion but go for an average. It’s quite likely you’ll get times of between 10-30s. Go for the average say 20s.

6. How fast is that Mexican Wave travelling?
   \[ v = \frac{x}{t} \]
   (or if you haven’t done this ask how many meters per second the wave is doing).
   \[ \text{Wave velocity} = \frac{500m}{20s} = 25\text{ms}^{-1} \]
   About 50mph (cheetah type speeds)
   Look, maximum human velocity is about 25mph.
So the wave can transfer (transport) information and it can do it quickly - faster than we can run!

The wave speed is dependent on how fast we react to the person next to us. What if we had a load of fit, young, fast people to do it? Let the students try! Get a student to measure the distance the wave travels in the class, and get a student to time it.

Show on the board how fast it goes. It’s surprisingly quick.

Waves can transfer more than information.

Get the pupils to stand in a long corridor or just use the lab. Put a bell on the opposite side of the room, To ring that bell requires energy. “I want to ring that bell without moving from this spot. How can I do it?” Give the students a clue by getting the big spring out.

Some bright spark might say, “tell a pupil” to do it. YES, this is good although not what is intended for the demo. (It’s good because your voice produces a sound wave, which travels through the air transferring information to the pupil’s ear. Information is transferred by waves.)

EXP 37  Ringing a Bell

By flicking the spring from far away the KE from the teacher’s hand travels up the spring by PE, and when it gets to the other side it flicks the bell. The bell converts the elastic energy to sound energy. The spring has transported energy from the teacher to the bell. The thing the wave travels through is called the medium. In this case the medium is the spring. Does the spring all end up at the far end? No! It’s the energy wave that travels and not the medium.

Conclusion:

Waves transfer energy or information.

It is the energy/information that travels not the medium.

Waves can travel quickly.

![Diagram of a bell ringing]
There are two ways to get a wave to travel up this long spring. Any ideas as to what the two ways are? Take ideas from the students.

As before, if the wiggle / disturbance /displacement is perpendicular/at right angles to the direction of wave travel/propagation. This is called a transverse wave.

If the wiggle/flick is in line with the direction of wave travel. This is called a longitudinal wave.

Now it’s quite difficult to see a longitudinal wave, but try making one with a slinky. Shove a stiff piece of A4 card in the slinky then make some waves and listen.

Most waves, such as light, radio, waves in the sea, etc, are transverse waves but a few very important ones e.g. sound, are longitudinal. Sound waves move by squashing and stretching (called compressions and rarefactions) the spaces between molecules. Note that molecules themselves don’t get stretched or squashed.

All waves of the electromagnetic spectrum are transverse e.g. light, radio and X-ray to mention but a few. For the EM spectrum an electromagnetic field is moving which strangely can move through nothingness, i.e. they can move through space.

Let’s look more at how light and sound behave.
EXP 39 The Speed of Sound

For this experiment you will need: a hammer, retort stand base, tape measure, 25 stop clocks and a student to record results.

Pupils walk/rotate/
walk/rotate with metre
rule to measure out
total distance

Raise hand = Ready
Drop hammer = Go
Agree on this before
the student sets off!
Raise hand = Also ready
See drop hammer = Start timing
Hear hammer = Stop timing

Be careful not to hit the retort stand base too hard!

The good news here is that you can just about trust a good student with a hammer and retort stand base, so you can be at the timing end with all the pupils to organise them. This is more likely to lead to success.
For this experiment you need all the equipment that you used in EXP 39, plus a large wall.

This time the sound wave travels there and back. Everyone can see easily when the hammer hits and it’s much easier to start clocks together. The wave travels double the distance to the wall, in this case 200m.

Hit it once and wait for the echo. Use this to get into a rhythm so you hit it as the echo returns. By doing this you can measure the time it takes to go there and back 10 times. Remember though, count 0 to 10 to get 10 travels, starting on the 0 and ending on the 10. 1 to 10 only travels 9 times.

Total distance = 10 x 200m
              = 2000m

Total time = 5s

Speed of sound:

\[
\frac{2000m}{5s} = 400ms^{-1}
\]

Note: Depends on air pressure because this determines how close the air molecules are.
Sound exists at all sorts of frequencies, but humans can only hear some of them (20Hz – 20kHz). Sound that is higher than 20kHz cannot be heard by humans at all, and is called ultrasound. Sound lower than 20Hz also cannot be heard, and it is called infrasound.

Bats and some birds use ultrasound. Bats use it to hunt by screeching in ultrasound. If there are moths nearby the ultrasound will bounce off them and come back to the bat’s ear, then the bat knows where they are.

Scans for unborn babies use ultrasound, as X-rays are too dangerous to sensitive multiplying cells in the foetus. All the men see the umbilical cord in the scan and mistakenly say ‘that’s my boy’.

Moths have a special kind of “ear”, which has a simple structure so the moth can tell when a bat uses ultrasound. The moth quickly flies in a different direction to try to get away from the bat.

Scans for unborn babies use ultrasound, as X-rays are too dangerous to sensitive multiplying cells in the foetus. All the men see the umbilical cord in the scan and mistakenly say ‘that’s my boy’.

Elephants use infrasound.

Sometimes a family of elephants will suddenly stop moving and turn one way when we hear nothing. They are communicating at frequencies below 20Hz that we cannot hear. Scientists recorded a female elephant going through her oestrous cycle and played it to some male elephants a few kilometres away with interesting results.

Whales use a huge range of sound including infrasound to communicate over long distances.

Dolphins also use sound to communicate. They can use that bulbous head (the organ inside is called a ‘melon’) to focus the sound, a bit like burning things with a magnifying glass. Some scientists believe they can use this to stun fish with sound.
You don’t need a fancy record player to play a song – you can make a paper record player!

For this experiment you will need a record, a base, a sharp pin, paper, sticky tape and Blu Tack.

The records are attached to a cotton reel which can turn freely on a metal spoke which is attached to a wooden base. When you try to play your record make sure the base is held firmly so the record does not slip!

Make your paper cone out of a very large sheet of paper using the sticky tape to tape it closed. Tape a pin pointy side out on the thin side of the cone. Use the sharpest pin you can find! Next, weigh down your cone by sticking a lump of Blu Tack near the pin on the inside.

Hold the cone lightly at the wide end and lay the pin gently into the groove of the record. Angle the pin about 45° to the horizontal, and make sure the pin is running straight in the groove. Turn the record with your finger. These records are 45rpm, which means they must turn 45 times every minute. Try asking your students to work out how long one full turn should take (Answer: 1.3s).

Enjoy the music!
When we do experiments with light waves it is useful to draw diagrams of what the light rays are doing. These are called ray diagrams. How do we do this? Let’s look at some rules about drawing ray diagrams:

1. **The Principal Axis.**
   The principal axis goes through the middle of the lens or mirror.

2. **The Focal Point.**
   This is where the lens or mirror focuses light from a distant (parallel rays) object.

3. Any ray passing through the focal point on the way to the lens/mirror will travel parallel to the principal axis upon refraction/reflection.

4. Any ray travelling parallel to the principal axis on the way to the lens/mirror will pass through the focal point on refraction/reflection.

5. Any ray that passes through or reflects from the centre of the lens/mirror will carry on in the same direction or reflect back along the same line.

6. So by combining rays 1, 2 and 3 we can see that the image will look like this. The image forms where rays from one point of the object come back together.
The rules for ray diagrams here are almost exactly the same. However, the rays will diverge (spread out) rather than converge, so they ‘appear’ to come from an imagined spot.

Any ray travelling parallel to the principal axis on the way to the lens / mirror will appear to have come from the focal point on refraction reflection.

Any ray passing through the focal point on the way to the lens/mirror will travel parallel to the principal axis upon refraction/reflection.

Any ray that passes through or reflects from the centre of the lens/mirror will carry on in the same direction or reflect back along the same line.

Again, by combining the three rules we get the diagram.

A convex mirror is the same. Have a look at the back of a spoon!
Just like a ball bouncing off a wall, waves reflect off things. If we want to see how reflection works, we can pick a wave we can see, like light!

Try this demonstration:
Ask pupils to find a relationship between the incoming ray \((i)\) (incident) and the reflected ray \((r)\). They should find that \(r = i\).

Not that exciting in itself but it has some exciting consequences.

Now try this demonstration (it’s probably best as a demo unless you have lots of mirrors):
Adjust the three ray boxes so they all three rays converge (focus) onto one point.

Think if we had a lot of small mirrors. All the rays focus on one point.
Ask if anyone recognises this shape yet.

Lots of mirrors approximate a rounded surface - it’s a parabolic reflector!

Parabolic reflectors can be used to gather energy from a large area and focus it all onto one point.

Satellite receiver dishes are parabolas. The receiver is placed in front of the parabola, at the focus point.
Here’s a lovely example of \( r = i \). It is used in submarines and at horse races – it’s a periscope!

A useful box to use for making your periscope is a tall juice box, but you can always make your own box too.

Make your periscope like this:

This is what your periscope should look like from the outside:

Light comes in through the hole in the top and out at the bottom (other side!).

Use your periscope to see over tall things. If you are short, use it to peek over the tall pupils’ heads!
EXP 47 Reflection (Continued)

1. Does reflection depend on wavelength (is it affected by wavelength)?
   Repeat the demonstration with the mirrors but this time place them on an A3 piece of paper and put different colour filters in front of the ray boxes. First 3 blue, then 3 green, then 3 red. Mark on the paper where the focus point is each time.
   The focus point should not change. Reflection angles are not affected by wavelength (colour). This is important.

2. So we have something that can focus light and focused all colours on the same point. We’ll come back to why this is so important after refraction.

3. Parabolic reflectors are used to pick up the tiny signals from satellites out in space and focus the energy on one point where the receiver is.

4. When ornithologists want to record bird song they use a parabolic reflector to focus the sound, a weak sound can be picked up a long distance away.

5. Watch a cat’s ears; they use parabolic reflectors to focus the sound down their auditory canal.

6. Demo: Get the class to have parabolic reflectors for ears. Cup your hands behind your ears to parabolic reflect the sound. Now make a loud ‘BUP’ sound. Great!
   Cup your hand round the back of your ear, then pull your ear forward.
Images in a Plane Mirror

EXP 48

1. Remind pupils that angle of incidence (incoming angle) \( i \), equals angle of reflection \( r \). 
   \[ i = r \]

2. Try getting a small coin. Place one coin between you and the mirror. Then by looking in the mirror and then past it try to put the other coin where the image of the first is.

3. Try this experiment – burning a candle underwater.

4. Here the pupils see the lighted candle superimposed on the unlit one and as you fill the beaker with water the flame continues to burn. Candles must be identical and wicks lined up.

5. Your mind believes light to travel in straight lines so your eye ‘sees’ the image at B. It’s a virtual image, since light doesn’t actually come from there.

6. Tell pupils to look out for writing on the front of ambulances. Why are they the wrong way round?
Refraction or bending of waves occurs because of a change in speed. It’s easiest to see this with light waves but it occurs in all types of waves.

What causes the bending, why does a change of speed cause a change in direction?

Look at this line of people walking side by side on concrete. On concrete they can walk quickly but when they get to the mud they slow down. The change in speed causes a change in direction.

Light travels more slowly through glass and water than through air.

Note the ‘normal’ line is a line that is at right angles to the boundary between glass and air (or any boundary).

Experiment:
Try looking at someone’s eyes through a glass block as they twist it from side to side. The eyes look as if they are moving around the head!

Experiment:
Place a pencil in a beaker half full of water. Move the pencil from side to side.

Light bends away from the normal line

Note the ‘normal’ line is a line that is at right angles to the boundary between glass and air (or any boundary).
Experiment: What effect does angle have on the amount of bending?

The greater the angle the more the light gets bent.

Experiment: Combining a few refractions.

Look, the light has got nearer.

Experiment: Looking at lenses

Try different lenses here. Ask pupils what determines how much the light is bent by the lens. It’s not the thickness of the lens but the curvature.

This is starting to look a bit like a lens!

This pattern is slightly different (it’s converging) as the boundary going into the glass is not parallel to the boundary coming out of the glass.

It’s the curvature that matters, not the thickness.

Weak lens

Strong lens
Most of the lensing done by the eye is done by the cornea (front surface of the eye), and the lens only does the fine adjustment for near or far.

Light is focused onto the retina (the light detectors). All the information detected by the retina is then sent to the brain through the optic nerve. Where this enters the retina there are no receptors, so you have a blind spot.

Get the students to experience their blind spot. There is a page for this at the back of the book, but it works on any blank paper, just draw two spots 10cm horizontally apart. Cover your right eye and look just at the spot on the right holding the paper about an A4 length away from your face.

Looking at near things:
Near light is very diverging. The curved (fat) lens bends the diverging incoming light, which needs lots of bending to get it to focus.

Looking at far things:
Far light is nearly parallel. The muscles controlling the lens make the lens thin. The parallel light does not need much bending to get it to focus.

We can demonstrate how the eye looks at near and far things by trying EXP 52, the Fluorescein Eye.
The Fluorescein Eye

1. The fluorescein makes the light inside the eye show. Instead of fluorescein you can also use diluted milk.

2. Move the angle poise near or far from the 'eye' and see it focused or not as the beam becomes more or less parallel.

3. This eye can also be used to show long or short sight corrections.

4. Glasses for short-sighted people:

5. Correct with a diverging lens

6. Glasses for long-sighted people:

Correct with a converging lens

1. Bright beam of light from angle poise lamp

2. Spherical flask with water and fluorescein

3. Converging lens stuck to flask with blu tack

4. Light focussed here

5. Short-sighted:

6. Light is focussed short of the retina

7. Cornea/lens is too strong

8. Long-sighted:

9. Light is focussed past the retina

10. Cornea/lens is not strong enough
The pinhole camera is great, as it gives you an ‘image’ of sorts without the need for a lens. However, to see it you need to have a dark lab, as the amount of light coming through that small hole is only tiny.

You can get visible images in a lighter lab if you have very bright objects to look at e.g. angle poise lamp etc.

The best thing to look at is a carbon filament lamp, as it shows the filament very nicely on the pinhole camera. However, these are quite specialist and you may not have one, so make do with what you’ve got.

Toilet rolls are good for the body, black thick greaseproof paper for the back. You’ll need optic (big) pins to make the holes. Remember, pins are sharp!

Elastic bands are useful.

Now put together all the components like this:

Now you can use your pinhole camera!

This gives a dim but sharp picture as only one ray from each point reaches the screen.

The lightbulb is throwing out lots of rays but only very few get through the pinhole.
What happens if we introduce another pin hole?
Get students to try it.
With 2 pinholes we get 2 pictures.

Explanation: Now we have 2 places that 2 single rays can get through so we get two dim but sharp images.

Get the pupils to make more holes.
Lots of pin holes. It all starts to overlap with lots of pictures of the lamp. It gets difficult to make out one picture from another.

Get the pupils to make one big hole with their finger.

How do you get all the images to focus back onto one point? Use a lens!

Explanation:
Rays A and B, which would have formed two pictures in separate places are brought together, as are all the rays, to form a bright focused image.

Note: Lens focal length has to match approximately the length of the pinhole camera. Photosensitive paper can be used to take photographs.
EXP 55 The Eye as a Pinhole Camera

This is a great demonstration, but be careful!
Don’t poke your eye when you are holding things close to it!

For this experiment you will need a wooden block with a pin stuck on it and a card with a pinhole placed behind it.
Place the block up near to your eye. You should see an image of the pin upside down through the pinhole.

Turn the card and block round.
You will not be able to see the pin clearly, if at all.
A combination of refraction and total internal reflection can lead to some interesting phenomena.

‘The City in the Sky.’ This has been seen by many travellers in certain weather conditions.

Imagine a car driving in the city with its headlights on. Two lights would be seen in the same way as a city in the sky. Could it be a UFO?

What if a car is driving over tarmac on a hot day? Here the hot tarmac causes different densities of air above the road. Light from the car is refracted and then totally internally reflected. The eye sees the car image coming from the road. The mind interprets it as a reflection from water on the road (same as water in a desert).

This is a picture of the Mojave Desert in Nevada, U.S. It looks like there is a lake in the desert, but of course, it is just a mirage!
Telescopes help us to see a long way away. Most telescopes are used to see things in space. Light has to get to the telescope from a very long way away, and telescopes have to be designed so that they collect the light in the right way to make a good image.

Get the pupils to imagine they are building their own telescope. Ask pupils which they would use and why: Reflection of refraction?

We can also focus using reflection using parabolic mirrors.

Reflection is not wavelength dependent.

What would happen if we looked at a star through a refracting telescope?

The image would appear blurred as the red is focused at a different point to the blue.

So decent/large telescopes use parabolic reflectors/mirrors to focus the light to get a clear crisp image for all colours.

Ask pupils who answer this question about why you can’t focus on red and blue at the same time?

The answer is that with a refracting focus (as with a lens) blue is focused at a different point to red because:

The amount of refraction (bending) is wavelength dependent.

Light coming from a distant star is white of sorts… well, at least it consists of different wavelengths of colour.

Interestingly, a squid’s eye also uses reflective focussing.

These telescopes are known as the Very Large Array.

They are in Socorro, New Mexico, United States.
Imagine a runner. His step length is 2.5m and he takes 2 steps a second.

What is his speed? Many pupils will work this out intuitively.

2.5m a step
2 steps a second

5 meters per second

But how did you work it out? You multiplied.

\[ \text{Speed} = \text{steps per second} \times \text{step length} \]

The same happens in waves. Imagine a wave:

There are 2 waves a second.

Wavelength = 2.5m

So, wave speed = 5 ms\(^{-1}\)

In the electromagnetic spectrum wave speed (c) is a constant value of 300,000,000 ms\(^{-1}\).

This means for higher wavelengths the frequency is lower and vice versa.

\[ c = f \times \lambda \]

\[ 300,000,000 = 30,000 \times 10,000 \]

\[ = 300,000 \times 1,000 \]

\[ = 3,000,000 \times 100 \]
Many waves (apart from sound) are part of the electromagnetic spectrum. They all travel at the same speed: the speed of light.

Because they all travel at the same speed, as wavelength goes up the frequency goes down (see EXP 58).

All EM wavelengths can travel through a vacuum, through nothingness, through space. Sound can’t do this.

Radio waves
- Bounce off the atmosphere so you can talk to yourself as the radio waves bounce back round the Earth, if you have a powerful enough transmitter.
- Radio is used to talk to satellites, and communication on space missions as well as radio stations on the ground.

Microwaves
- Mobile phones
- Microwave ovens to cook your food.
- Scientists detect microwave emissions from space, used to support the Big Bang theory.
The College of Richard Collyer

Joe Brock and Lara Mathews

I R to detect casualties under rubble – camera converts IR to visible so we can see it
• remote controls on TV
• night vision
• helps with muscle problems
• reconnaissance planes photograph airstrips where ground is cooler where planes have been i.e. they leave an IR shadow.

UV
• sun beds for tanning
• security pens
• detecting forged bank notes
• biological washing powders absorb UV (invisible light) and retransmit it as visible light i.e. appearing to give out more light than it takes in – appearing 'whiter than white'

This is one of the first X-ray photographs ever taken. It was made by the scientist Wilhelm Röntgen, of his wife's hand. You can see the ring on her hand!

This dog has had its photo taken with an IR camera. You can see the hottest bits are the eyes and mouth, where the image is glowing yellow/white.

Gamma rays
• treatment of cancer by killing cells if given a high enough dose
• sterilising food by killing off of bacteria

X rays
• which go through soft tissue well, but not so well through bone – lets you see into the body
• given out by very hot objects e.g. stars collapsing

Watch out! Some EM waves can be dangerous:
• microwaves cook you
• Infra Red (IR) burns you
• UV gives you skin cancer and can damage your eyes
• X rays can destroy or alter nuclei of cells
Standing waves are not strictly on the specification but they can lead to excellent discussions about wavelength/frequency/pitch and amplitude. They are also a lot of fun to watch!

For this experiment you will need some white rubber cord, a pulley, some slotted masses and vibration equipment.

When you vibrate one end of the cord standing wave patterns begin to appear. Standing waves have parts where the cord moves a lot (antinodes) and parts where it does not move at all (nodes). Depending on how fast you vibrate it you can get different numbers of antinodes and nodes.

The standing wave pattern also depends on the tension of the cord. You can vary the tension by changing the number of masses you use. Try using different tensions and see how this affects the standing wave.
Standing Waves on a Guitar

Waves bounded by either end of the cord are moving backwards and forwards to give the stationary pattern seen.

Stationary waves are very important in musical instruments.

Try this experiment:
- Get the fundamental wave on the equipment. Kill the fundamental with your fingers by pinching the cord.
- Get the next wave up on the equipment. This time pinch the cord exactly in the middle of its length and show that the wave continues as it isn’t trying to move at this point anyway.

Harmonics:
Get a guitar and pluck one string to get the fundamental note.

Now place a finger gently on the string exactly half way between the bridge and neck. As you pluck the string remove the finger. Listen for a high bell-like note. This is called a harmonic note.
**EXP 62 Straw Flutes**

1. This next bit is great fun, but only suitable at the end of the lesson. Once the kids make straw flutes there’s no peace!

2. This is an example of standing waves down a tube. It’s the same principle as the rubber cord with the waves produced by a reed and bounded by the tube of the straw.

3. To make straw flutes all you need are some plastic straws and some scissors.

   Use the scissors to cut the edges off one end of the straw in a V-shape. Flatten the V with your fingers.

   Put the V in your mouth and try to blow it so that it vibrates.

4. Next, try cutting holes in the tube. The wave is bounded by the nearest openhole to the reed. So by covering more holes wavelength increases and frequency/pitch drops.

5. To get different notes try cutting the tube shorter, so reducing wavelength and increasing frequency.

   Use blunt scissors for this and be careful not to cut yourself!

6. An elephant trunk is a fixed length so it can only ‘trumpet’ certain waves.
1. The wave inside a straw flute exists as a pressure wave and at the same time as a motion wave. This is a model clarinet (closed tube) not a flute (open tube), so its wave pattern is:

2. Look one wave folded back on itself.

3. So the straw flute has a maximum wavelength that is 4 times the length of the straw.

4. Remember our runner example from EXP 58? We learned the equation

\[ c = f \]

We can use this equation to get the frequency from the length of the straw.

5. For a straw of 10cm (0.1m)

\[ \cdot = 4 \times 0.1 = 0.4 \]

speed of sound in air = 330ms⁻¹

Frequency \[= \frac{c}{\cdot} = \frac{330}{0.4} = 825\text{Hz} \]

6. Middle C is 261.63Hz

This is around the frequency of B above middle C

Use this table to look up some frequencies.

<table>
<thead>
<tr>
<th>Note</th>
<th>Pitch/Freq</th>
<th>Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>G</td>
<td>392.00</td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>440.00</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>493.88</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>523.25</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>587.33</td>
<td></td>
</tr>
</tbody>
</table>

7. Use \( c = f \cdot \) to help you choose where to put your holes.
EXP 64 Elephants and Tubes

1. Ever heard an elephant trumpet? Listen closely, only certain notes are heard, they go up in steps not in a continuous way. Why are only certain notes possible?

2. As with the straw flute only certain waves will fit exactly into his/her trunk, so only certain frequencies of standing wave will be heard.

3. Demonstrate the whirling tube.
   This is good with a hoover tube or similar. Tubes of around 0.8m are good, open both ends.
   Swirl it slowly to get a low note and faster to get the harmonics. Note only certain frequencies are heard. It’d be difficult to get the fundamental but all higher harmonics starting from length of tube = • are possible.

4. Open tubes (the flute) have these wave patterns:

   - **LOW NOTE**
     (can’t get this because of laminar flow)
     - \( l = 0.5 \bullet \)
     - \( l = \bullet \)
     - \( l = 1.5 \bullet \)

   - **HIGH NOTE**
     - \( l = 2 \bullet \)

5. This is just like the elephant’s trunk. Only certain frequencies/notes are possible.

6. The swirling pushes air down the tube. The corrugations (ridges on the tube) cause eddies (little currents of air) which vibrate the air. At certain frequencies the waves exactly fit into the length of the tube.
The Doppler Effect

1. Get a pupil to do an impression of a racing car driving past.
   - NEEEEEOWWWWWW
   - High note ! Low Note

2. Why does the note change? Is it that the car happens to change speed just as it passes you? No, it’s the same for everyone no matter where they stand.

3. Get a buzzer and connect it to a battery with long flexible wires. Whizz the buzzer around your head and get the pupils to listen to the note.
   - Great demo, but be careful to check the wires, as the buzzer could by off
   - (9V PP3 with a 6V buzzer works fine.)

4. Get the pupils to identify when the note is higher and when it is lower.
   - HIGHER NOTE - Coming towards them
   - LOWER NOTE - Going away from them.

   Why does this happen?
   - The buzzer is always making the same frequency sound/same wavelength.

5. Buzzer coming towards you
   - Sound waves get squashed up so pitch appears to increase ÖNEEEEEEC
   - Buzzer going away from you
   - Sound gets stretched out so pitch appears to decrease ÖYOWWWWC

6. This effect is called the ÖDoppler EffectÖ. The same effect happens with light and has been one of the major pieces of evidence to support the Big Bang theory of the universe.

   Next time you are on a swing try screaming and get your mates to listen.
If the universe started with a Big Bang then things would fly off from the explosion with various different velocities. It’s like the start of a race.

Imagine a race between a cyclist, a slow car and a racing car. Ready, Steady, GO!

The racing car, which is going the fastest, has got the furthest. The slow car has travelled less distance and the cyclist that is going the slowest has travelled the least distance.

Now imagine you were in the slow car and you looked out the back. What would you see? You’d see the cyclist being left behind. If you couldn’t tell that you were moving AWAY you’d see the cyclist reversing away from you.

Now imagine you’re in the slow car and you looked out of the front. What would you see? You’d see the racing car moving AWAY from you.

So, whichever way you looked you’d see things moving away from you.
Now, remember the Doppler Effect. If something’s giving off a wave and moving away from you its wavelengths get spread out. Remember the racing car noise?

This happens with light waves too. If a thing that’s emitting light is moving away from you the light wavelength increases, it becomes redder than it should be.

‘How do we know how red it should be?’ is a question for pupils to ask. (If it comes up). Just say for now that it’s to do with a thing called the ‘Hydrogen emission spectrum’. Avoid this if you can.

We’re on the Earth moving through space at 28,000 ms-1 or 14,000 mph (incredible speeds) but can you tell this sitting here in the classroom? NO. So we’re like the slow car in the race. We’re moving but we can’t tell.

If there was a Big Bang (a big race) the where ever we look we’d see things moving away from us. Is this the case?

Well yes it is, to a point. Everywhere we look we see galaxies and stars where light appears ‘redder’ than it should be. This is called Red Shift.

The only way this can happen is that everything around us is moving ‘relative to us’ away. Also we find by observation that things further away from us are moving away faster.

The Big Bang theory suggests that this is because everything started moving at the same time (a big explosion), and just like the start of a race with the racing car, which has got furthest away by going the quickest.

One last little aside. Some stars when we look at them are constantly shifting to red, then to blue, then to red and so on. Why would this be? Are they constantly going away then towards us again? They must be orbiting something. What could it be? A black hole perhaps?

This is a very famous image known as the Hubble Ultra Deep Field Image. It shows young galaxies from a very long way away. The light from there has taken a long time to get to us, so the galaxies look a lot like they would have looked around the time of the Big Bang.
**EXP 68** Space Telescopes vs. Terrestrial Telescopes

1. What are the problems faced with telescopes that are mounted on the Earth?

2. The song ‘Twinkle Twinkle Little Star’ gives us a clue.

   Stars don’t twinkle! It’s the atmosphere that’s constantly moving (because of convection) that distorts the light from the star. This is a real problem when we’re trying to see detail from distant objects.

3. The other problem is that the atmosphere absorbs a lot of the electromagnetic spectrum e.g. UV light and X-rays. This is good for life on Earth but bad for astronomers who may be trying to see these wavelengths as evidence for astronomical events. A star collapsing into a black hole may emit X or even gamma rays. You would not witness this even using a terrestrial (ground based) telescope.

4. So what can astronomers do about it? Well we can put telescopes on mountains where the atmosphere is thinner to reduce the effects but we still have the absorption problem.

5. We can send telescopes into space.

   No atmosphere – good news.
   Very expensive – bad news.

6. There are many telescopes in space, such as:

   - Hubble Space Telescope - HST
   - Infra Red Astronomical Satellite - IRAS
   - Cosmic Background Emissions – COBE

   There are even clusters of detectors that work together to get 3D data from the solar wind from the sun.

7. There’s a lovely story about the HST concave mirror problem. The mirror had a problem (the spare didn’t), but they didn’t find out until it was up in space… what a nightmare!

   They had to go up and do a repair, which was not possible without the shuttle.

These pictures were taken with the Hubble Space Telescope. Left is the Tarantula Nebula, and below is the Eagle Nebula.
This is really great fun to work out from a couple of pieces of knowledge and some simple maths.

Ask pupils how long it takes for the Sun’s light to get to the earth (take guesses).

Answer: 8 minutes \((8 \times 60 = 480\text{s})\)

Ask how fast light travels (take guesses).

Answer: \(300,000,000 \text{ ms}^{-1}\)

What’s the relationship between velocity, distance and time?

In a year = \(2\pi r\)

\[x = vt\]

Distance \((x)\) travelled

\[x = 300,000,000 \times 480\text{s}\]

\[= 144,000,000,000\text{m}\]

So how far is the Sun from us?

So we’re travelling at:

\[v = \frac{x}{t} = \frac{904,778,684,200\text{m}}{31,557,600\text{s}}\]

\[= 28,670 \text{ ms}^{-1}\]

\[= 14.300 \text{ mph}\]

Amazing! You can’t tell, can you?
**EXP 70  Leeuwenhoek’s Microscope**

Twist a single strand of wire so that you get a loop at the end of about 3mm across.
Dip the loop into water and a small droplet will form in the loop.
Use the droplet as a magnifying glass to look at objects close up.

**EXP 71  White Light and Colour**

White light is all the colours of the rainbow (Red, Orange, Yellow, Green, Blue, Indigo and Violet, ROYGBIV) added together. We can see this if we split them up using a pen tube to refract the light. Different colours refract by different amounts and so the light splits into a spectrum.

**EXP 72  Invisible Writing**

Draw with a red pen on a white surface. Look through the green filter. You can still see the pattern. Hold up a red filter and the pattern should disappear.

Why does this happen? The white background reflects all colours. The red writing reflects only red light. The filter only lets through red light so the red writing appears on a red background. It disappears!

**EXP 73  A Cat’s Sight**

Cats only see a few colours, not as many as humans.
Light is a transverse wave, but its displacement is in many different directions.

This is a wave of light travelling to the right. See how the displacements are in many different directions? It is made up of these:

With displacements in many different directions the light is called unpolarised. We can put it through a filter that will allow through displacements in one plane only.
As there is less energy coming through the filter than hitting it, the intensity of the light drops.

Polarising also occurs when light is reflected from a smooth surface e.g. car windscreens, the surface of water.

If another filter is introduced and is the same way up as the first one then the polarised light can still get through.

However, if the filters are at right angles to each other (perpendicular) then no light can get through. Total darkness!
Polarising Filters

1. Look through two polarising filters. Rotate one filter a full circle and watch what happens.

Here the two filters have their plane of polarisation in line and light gets through both.

2. Here the two filters have their angle of polarisation perpendicular to each other so no light gets through both and the scene is dark.

Polarisation on Reflection

1. Light is polarised on reflection so the light being reflected from the surface of this fish tank is polarised but the light coming from the fish is not.

2. If we put a polarising filter so that its plane of polarisation is perpendicular to the reflected light the reflected light can no longer be seen and we see the fish below more clearly.

An LCD display uses reflection from a back surface and a polarising filter to block out light to show numbers on a calculator. You can see how it’s polarised using one filter.

4. Place the filter perpendicular to the polarised light coming out of the calculator and the screen disappears.
EXP 77 Other Uses of Polarisation

1. Get a piece of sticky tape and fold it over and over on itself. Place it between two polarising filters and see the pattern.

2. Rotate one filter and see the pattern change. The sticky tape changes the plane of polarisation for different wavelengths (colours) by different amounts. You can make some excellent art with this effect.

3. Look at this sample of polythene. The colours gather at the most stressed part of the sample. This technique can be used to analyse stress patterns in complicated shapes. There is usually a stress concentration at any nicks, scratches or breaks in the material.

4. You can see the stresses this ruler has gone through in manufacture. The process has left its mark in the polarised light.
If you hit a piece of wood a wave travels up and down the length of the wood. The wave travelling up interferes with the wave travelling down and a standing wave is produced.

The points of constructive interference are called antinodes (where the wave is big).

The points of destructive interference are called nodes (where the waves have cancelled each other out).

So, no vibration is occurring at $ullet$ 1 or ! 1, but lots of vibration is happening at the ends and at the middle.

Now if we support the wood below the nodes where nothing is happening, the waves/vibrations are unaffected and the note of the balafon rings on. However, if we support the wood anywhere else the vibrations are killed and the note stops. We get a dull ‘thunk’ sound.

The length of wood controls the frequency of the note. See how the blocks of wood are tied with string only at • 1 and ! 1 on this balaton?

Have a go at making one!
You will need either a dark room for this or a dark box that you can look into.

Young’s double slits uses this equation:

\[ \frac{x}{D} = \tan \left( \frac{s}{D} \right) \]

Where does this equation come from? If we shine monochromatic light (one colour) through two slits that are \( s \) distance apart we have two coherent sources of light. The central maximum is where the two waves have travelled the same distance, so they are in phase and add up to a bright spot. Another spot appears \( x \) away from the central maximum where the path difference = \( \cdot \) i.e. the waves are back in phase so they add up.

\[ D \]

Now, the little triangle and the large dotted triangle are called \( \text{similar triangles} \) (same angles, same ratio of sides).

\[ \frac{x}{s} = \sin \left( \frac{s}{D} \right) \quad \text{or} \quad \frac{x}{D} = \tan \left( \frac{s}{D} \right) \]

If \( D \) is huge (a few metres) compared to \( s \) (fractions of a mm) then \( \cdot \) is very small.

For small \( \tan \left( \frac{s}{D} \right) \approx \frac{s}{D} \)

i.e.

\[ \frac{x}{D} = \tan \left( \frac{s}{D} \right) \quad \text{or} \quad \frac{x}{D} \approx \frac{s}{D} \]
**EXP 80 Measuring the Wavelength of Light**

For this you will need to use this formula:

\[ \lambda = \frac{x s}{D} \]

Use this to remember it: too much \( x \) leads to excess (xs) drinking (D)!

If we can measure \( x \), \( s \) and \( D \) in Young’s Double Slit Experiment then we can find the wavelength of light. Excellent!

When you do this experiment remember to have the screen about 4m away from the laser pen.

(WATCH OUT! In this picture we have not made sure that \( D \) is big – you cannot measure it like this in the experiment!)

For the diffraction slits you can use a special double slit slide, or you can make your own:

Use a microscope slide painted black, then make two tiny, straight scratches 0.25mm apart.

So you have slits at 0.25mm separation (\( s = 0.25 \times 10^{-3}m \)). You need to measure \( D \), but remember it should be at least a few metres.

You should see fringes of light like this:

Now measure across 10 of them (from the middle of the fringes) and divide by 10 to get fringe separation \( x \) (\( x \) will be around 1mm approximately).

Use \( \lambda = \frac{x s}{D} \) to find the wavelength of light.

The answer should be around 650nm, which is 650 \( x \times 10^{-9}m \).
This is a great demo for schools that have no radioactive sources. The nuclei of radioactive elements are unstable. There’s a chance that they may decay and emit a radioactive particle.

There are two things that determine how radioactive a sample is:

- The chance of decay ($\bullet$). The higher the chance the more particles will be emitted over a given time.
- The number of radioactive atoms you may have ($N$). The more atoms you have the more particles will be emitted over a given time.

The chance of decay never changes as it is part of the make up of each atom. The number of radioactive atoms will decrease as more and more of them decay. The lovely thing is that dice do the same.

If we say that throwing a six represents the atom decaying and the number of dice represents the number of atoms then we can do the following experiment. Each throw represents a step in time.

You will need 100 dice.
Count the dice (there may be a few missing). Throw them all and count the number that come up six. Remove these dice from the experiment. Re-throw the remaining dice and again count and remove the sixes. Continue until you get down to only a few dice.
Don’t worry if the number of sixes doesn’t fit the pattern exactly. That’s a good thing, radioactivity does the same. Point out to students that activity \((A)\) (the number of sixes) is given by:

\[
A = \text{chance of decay} \times \text{number remaining}
\]

So if you had 60 dice:

\[
A = \frac{1}{6} \times 60 = 10
\]

Now we need to plot a graph of number remaining \((N)\) against throw number. For this you will need graph paper, pencils and rulers.

A beautiful exponential decay curve. (Don’t go through each point – draw a smooth curve that follows the trend).

Don’t worry too much about getting into what ‘exponential’ means. Analyse the graph like this:

The equation \(A = \cdot N\) leads to this graph.
And this graph has a special property:

The time it takes to halve the remaining number of atoms never changes. It’s called the half life and has the symbol $T_1$ (this is not $T \times \ast$, treat $T_1$ as a single symbol).

It is related to the chance of decay ($\ast$) in the equation below:

$$T_1 = \frac{0.69}{\ast}$$

But don’t tell them this yet!

Go back to the graph and using different start and stop points find a value for $T_1$ from your results. Ignore any $T_1$s that seem inaccurate (i.e. are different from all the others). What value of $T_1$ do you get?

A good value would be around 4.2, but anything near 4 is good.
Ask the students if they can find a relationship between \( T_1 \) and \( \cdot \). To get them to do this ask what would happen to \( T_1 \) if we made the chance of decay greater e.g. by throwing coins instead of dice, where ‘heads’ = decay. If they can’t think of the answer then you can do this extra experiment.

If we double the chance of decay (\( \cdot \)) then the value of \( T_1 \) halves.

So \( T_1 \) is inversely proportional to \( \cdot \).

\[
T_1 \propto \frac{1}{\cdot} \quad \text{or} \quad T_1 = \text{constant}
\]

Rearranging

\[
T_1 \cdot \cdot = \text{constant}
\]

There’s a lot of maths that we can use to prove this (note \( \ln2 = 0.693 \)) and we could go into it but don’t bother if the syllabus does not require it).

Try a slightly different experiment now. You will need 100 dice, graph paper, pencils and rulers.

Repeat the previous experiment but double the chance of decay by removing dice if they come up with a 6 or a 3 (\( \cdot = 1/3 \)). Plot the graph again. Find \( T_1 \).

Using your two sets of results, find the constant.

I’ve done some approximately here:

\[
4.1 \times \frac{1}{6} = 0.699
\]

\[
2.1 \times \frac{1}{3} = 0.69
\]

Average \( A \) 0.69

So in fact the equation becomes:

\[
T_1 = \frac{0.69}{\cdot}
\]

Plotting activity (\( A \)) against throws gives the same exponential decay graph with the same values of \( T_1 \) (try it if you like). You will find it’s less convincing due to the random nature (random in that you do not know which dice will decay) of decay. However, in real life we actually take this reading with a Geiger counter. To count actual undecayed atoms would be impossible and take a very long time.
### EXP 82 Circular Motion

**1.** What affects the amount of force needed to keep something moving in a circle? Something going round in a circle is constantly changing direction. It takes more force to change the direction of a bigger mass.

**2.** The faster something is moving round the circle the more quickly it is changing direction. So, going faster means more force is required. If something is going round a smaller radius it is changing direction more quickly, so a smaller radius means more force is required.

**3.** So is $F \propto m$?

$F \propto v$?

$F \propto 1/r$?

Let’s try an experiment to find out.

**4.** To try Whizzo Bungs you will need: String, tube, bung, 100g (1N) masses, stop watch, ruler, scales.

The string should be about 1.5m long. Tie one end of the string to the bung, thread the other end through the tube then tie it into a loop so you can hook the masses on it. When you use the Whizzo Bung hold onto the tube and swing the bung around the top of your head in big circles.

**5.** To do the experiment:
1. Measure the mass of the bung.
2. Whizz the bung around your head trying to keep the speed constant.
3. Keep the weights at a constant height but not by holding them, just by whizzing the bung around.
4. Time how long it takes for the bung to complete 10 circles. Divide by 10 to get (T) (count 1, 2, …, 10).
5. At the end of each set of 10 grab the string to keep (r) so you can measure it.
6. Repeat for weights between 1N and 6N (F).
7. Calculate $v = 2r/T$
8. Draw a table $m = ? g$
9. Compare $mv^2/r$ to $F$. They should be the same. Be careful with metres.

**6.** Use this table for your results.

<table>
<thead>
<tr>
<th>$T/s$</th>
<th>$r/m$</th>
<th>$2\cdot r$</th>
<th>$2\cdot r/T$</th>
<th>$mv^2/r$</th>
<th>$F$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**7.** Conclusion: The force ($F$) required to keep something of mass ($m$) going round a circle of radius ($r$) at a speed ($v$) is given by:

$$F = \frac{mv^2}{r}$$

If you are careful this works very well.
**Sticky Balloon**

**EXP 83**

1. Rub a balloon on your head.
   Electrons are rubbed onto the balloon.

2. Touch the balloon onto the wall.
   Electrons are repelled from the wall so the wall becomes positive and the balloon is attracted to the wall.

**Dancing Crumbs**

**EXP 84**

1. Break off a few crumbs from a biscuit onto a plate.

2. Stretch cling film over the plate.

3. Rub the cling film with a tissue.
   Electrons are rubbed onto the clingfilm, the saucer’s and crumbs electrons are repelled making them positive.

4. Watch the crumbs jump and dance.
   The crumbs jump up to the negative, gain electrons, become neutral and fall down.
**EXP 85  Bending Water**

You will need a polythene strip, a cloth, water and a bottle. First, rub the strip very fast with a cloth.

Now watch what happens when you put the strip next to a thin stream of water:

Water bends as the negative (-ve) charge is attracted towards the positive (+ve) polythene strip. They get nearer than the repelled +ve charges, so they are attracted more than the +ve charges are repelled, and the water bends.

**EXP 86  Attraction and Repulsion**

This time you will need two polythene (opaque) strips, two acetate (see-through) strips, two watch glasses and a cloth. Put the watch glasses back to back and lay a polythene strip over the top so it can rotate freely. Rub the end of the other strip with the cloth then put it near and see what happens.

Like charges repel!  

Try the experiment again, this time with the acetate strips:

Once more with one acetate strip and one polythene strip:

Opposites attract, like (similar) charges repel!
When you put a weight on a spring the spring extends – it gets longer. This ‘extra’ length is called the extension (x).

The amount a spring extends for a given weight is called its stiffness.

Investigation – finding the stiffness of different spring arrangements:

Load up the spring with the weights. For different weights 100g – 600g (1N – 6N) measure the extension.

Get a table of the results:

<table>
<thead>
<tr>
<th>Force/N</th>
<th>Extension/m</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>…</td>
</tr>
<tr>
<td>2</td>
<td>…</td>
</tr>
<tr>
<td>…</td>
<td>…</td>
</tr>
<tr>
<td>6</td>
<td>…</td>
</tr>
</tbody>
</table>

To find the gradient: Gradient = up/along

Repeat the whole experiment for 2 springs in series and parallel.

Remember to keep your results for EXP 88 and 89!

So,

\[
\text{stiffness} = \frac{\text{up}}{\text{along}} = \frac{F}{x}
\]

\(k\) is measured in Nm^{-1}
EXP 88 Simple Harmonic Motion with a Spring

1. Hang a 500g mass from a spring attached to a branch of a tree. Pull the mass down (not too far) and let it go. Time 10 full bounces of the spring (from a start, back to the start).

2. It should take the same time for small oscillations as it does for big oscillations. This is called ‘isochronous’. All simple harmonic oscillations are isochronous.

3. How can this be? The mass has further to travel if you pull it down further to start with BUT the spring also puts a larger force on the mass so it accelerates more. This compensates for the longer distance, so the time for one oscillation ($T$) stays the same.

4. Investigation: The effect of mass on the time for one oscillation. You will need springs, masses and stopclocks. Vary the mass between 100g and 600g. Time 10 oscillations then $100$ to get ($T$).

5. There are two things that affect the time for one oscillation. What do you think they are? Mass ($m$) and stiffness of the spring ($k$). In what way do you think they will affect it? What will more mass make the oscillations time ($T$) do? What will a stiffer spring make the time ($T$) do?

6. Investigation: The effect of mass on the time for one oscillation. You will need springs, masses and stopclocks. Vary the mass between 100g and 600g.

7. Now plot some graphs. So,

$$T = 2\pi \sqrt{\frac{m}{k}}$$
Repeat your spring mass investigation, but this time using string and masses to create a pendulum.

Only swing the pendulum a small amount, otherwise the string starts to go slack and the pendulum misbehaves.

This is also an isochronous oscillator. What factors do you think will affect the time for one oscillation? Possibly mass \( m \)? Possibly length \( l \)?

Time 10 oscillations for different lengths of string. Divide by 10 to get \( T \). Measure \( l \) to the centre of mass of the masses.

Make a results table, and then use it to plot two graphs:

\[
\begin{array}{|c|c|}
\hline
l/m & T/s \\
\hline
& \\
\hline
\end{array}
\]

In fact,

\[ T = 2: \sqrt[4]{\frac{l}{g}} \text{ where } g = 9.81 \text{ ms}^{-2}. \]

So the gradient of \( T \) against \( \sqrt{l} \) gives:

\[
\frac{T}{\sqrt{l}} = \frac{2}{\sqrt{g}}
\]

Check your graph to see if this is true.
<table>
<thead>
<tr>
<th>Item</th>
<th>School Kit x 3</th>
<th>Teacher Training</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Leslie cube Tin can</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>Laboratory thermometer 150mm green spirit</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>Ball &amp; ring expansion kit</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>Black paint block</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>Graph paper 2/10/20 ream</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>Protractors 100mm dia</td>
<td>30</td>
</tr>
<tr>
<td>7</td>
<td>Set Squares 60’ 145mm hyp</td>
<td>24</td>
</tr>
<tr>
<td>8</td>
<td>Erasers 30 x 20 x 8mm</td>
<td>40</td>
</tr>
<tr>
<td>9</td>
<td>Sharpeners Single hole metal pencil</td>
<td>14</td>
</tr>
<tr>
<td>10</td>
<td>Drawing compass 100mm</td>
<td>30</td>
</tr>
<tr>
<td>11</td>
<td>Plastic pockets</td>
<td>100</td>
</tr>
<tr>
<td>12</td>
<td>Triple beam balance</td>
<td>1</td>
</tr>
<tr>
<td>13</td>
<td>Periodic table chart 720 x 520mm</td>
<td>1</td>
</tr>
<tr>
<td>14</td>
<td>9mm dowel 150mm long</td>
<td>20</td>
</tr>
<tr>
<td>15</td>
<td>Wood V blocks 100x30x50mm</td>
<td>20</td>
</tr>
<tr>
<td>16</td>
<td>NYLON G clamps small 75mm mouth</td>
<td>20</td>
</tr>
<tr>
<td>17</td>
<td>Boyle’s law indicator</td>
<td>1</td>
</tr>
<tr>
<td>18</td>
<td>Calculator Albertz 2</td>
<td>1</td>
</tr>
<tr>
<td>19</td>
<td>Slinky</td>
<td>1</td>
</tr>
<tr>
<td>20</td>
<td>Personnel scales Newtons</td>
<td>1</td>
</tr>
<tr>
<td>21</td>
<td>100ml measuring cylinder</td>
<td>2</td>
</tr>
<tr>
<td>22</td>
<td>Marble</td>
<td>6</td>
</tr>
<tr>
<td>23</td>
<td>Balloons</td>
<td>250</td>
</tr>
<tr>
<td>24</td>
<td>Corks 16mm (diameter small end)</td>
<td>20</td>
</tr>
<tr>
<td>25</td>
<td>CDs</td>
<td>20</td>
</tr>
<tr>
<td>26</td>
<td>Araldite (2 x resin &amp; bonding tubes)</td>
<td>1</td>
</tr>
<tr>
<td>27</td>
<td>1m ruler</td>
<td>40</td>
</tr>
<tr>
<td>28</td>
<td>Knife edge/pivot, Moldings 50mm</td>
<td>20</td>
</tr>
<tr>
<td>29</td>
<td>String ball 500g</td>
<td>1</td>
</tr>
<tr>
<td>30</td>
<td>Scissors economy</td>
<td>12</td>
</tr>
<tr>
<td>31</td>
<td>Single pulley</td>
<td>20</td>
</tr>
<tr>
<td>32</td>
<td>Double pulley</td>
<td>1</td>
</tr>
<tr>
<td>33</td>
<td>1 kg hanger and mass set</td>
<td>10</td>
</tr>
<tr>
<td>34</td>
<td>1ml syringe</td>
<td>10</td>
</tr>
<tr>
<td>35</td>
<td>20ml syringe</td>
<td>10</td>
</tr>
<tr>
<td>36</td>
<td>3mm clear plastic tube, metres</td>
<td>5m</td>
</tr>
<tr>
<td>37</td>
<td>A4 paper ream</td>
<td>1</td>
</tr>
<tr>
<td>38</td>
<td>Newton meters 10N/100g</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td><strong>39</strong></td>
<td>Optics pin</td>
<td>100g</td>
</tr>
<tr>
<td><strong>40</strong></td>
<td>White card 280g a sheet</td>
<td>100</td>
</tr>
<tr>
<td><strong>41</strong></td>
<td>Cotton reel</td>
<td>30</td>
</tr>
<tr>
<td><strong>42</strong></td>
<td>Pencils HB</td>
<td>150</td>
</tr>
<tr>
<td><strong>43</strong></td>
<td>2 litre pop bottle (empty)</td>
<td>1</td>
</tr>
<tr>
<td><strong>44</strong></td>
<td>30cm ruler Polythene</td>
<td>60</td>
</tr>
<tr>
<td><strong>45</strong></td>
<td>50m sports tape</td>
<td>1</td>
</tr>
<tr>
<td><strong>46</strong></td>
<td>Stop watch, basic</td>
<td>10</td>
</tr>
<tr>
<td><strong>47</strong></td>
<td>Stop watch batteries</td>
<td>10</td>
</tr>
<tr>
<td><strong>48</strong></td>
<td>Toy car</td>
<td>2</td>
</tr>
<tr>
<td><strong>49</strong></td>
<td>Car track Cunduit lid CEF</td>
<td>1</td>
</tr>
<tr>
<td><strong>50</strong></td>
<td>Blue tack 120g</td>
<td>6</td>
</tr>
<tr>
<td><strong>51</strong></td>
<td>Sticky tape roll</td>
<td>6</td>
</tr>
<tr>
<td><strong>52</strong></td>
<td>Rokit kit</td>
<td>1</td>
</tr>
<tr>
<td><strong>53</strong></td>
<td>Foot pump (michelin)</td>
<td>1</td>
</tr>
<tr>
<td><strong>54</strong></td>
<td>Bendy straws (large dia) 250 pk</td>
<td>2</td>
</tr>
<tr>
<td><strong>55</strong></td>
<td>500ml plastic measuring beaker</td>
<td>2</td>
</tr>
<tr>
<td><strong>56</strong></td>
<td>Polystyrene ball 25mm diameter</td>
<td>20</td>
</tr>
<tr>
<td><strong>57</strong></td>
<td>Bouncing ball</td>
<td>2</td>
</tr>
<tr>
<td><strong>58</strong></td>
<td>Matches, large box cooks</td>
<td>1</td>
</tr>
<tr>
<td><strong>59</strong></td>
<td>Conducting bars 5Pk Al,Cu,Fe,brass, glass</td>
<td>1</td>
</tr>
<tr>
<td><strong>60</strong></td>
<td>Aluminium plate 100 x 250mm</td>
<td>1</td>
</tr>
<tr>
<td><strong>61</strong></td>
<td>Black metal plate 150mm2</td>
<td>1</td>
</tr>
<tr>
<td><strong>62</strong></td>
<td>Candles</td>
<td>6</td>
</tr>
<tr>
<td><strong>63</strong></td>
<td>Rubber band tub</td>
<td>1</td>
</tr>
<tr>
<td><strong>64</strong></td>
<td>Match sticks</td>
<td>500</td>
</tr>
<tr>
<td><strong>65</strong></td>
<td>Drawing pin</td>
<td>2</td>
</tr>
<tr>
<td><strong>66</strong></td>
<td>Empty syrup tin</td>
<td>1</td>
</tr>
<tr>
<td><strong>67</strong></td>
<td>Rubber bung 19/22.5mm pk10 dia single hole</td>
<td>1</td>
</tr>
<tr>
<td><strong>68</strong></td>
<td>Brass tube (pk 300mm) for bung 5/4.1mm</td>
<td>1</td>
</tr>
<tr>
<td><strong>69</strong></td>
<td>Capillary tube</td>
<td>1</td>
</tr>
<tr>
<td><strong>70</strong></td>
<td>Glass / plastic cappillary tube</td>
<td>1</td>
</tr>
<tr>
<td><strong>71</strong></td>
<td>Detergent small bottle</td>
<td>1</td>
</tr>
<tr>
<td><strong>72</strong></td>
<td>Cotton thread, reel</td>
<td>1</td>
</tr>
<tr>
<td><strong>73</strong></td>
<td>Wire 0.6m length</td>
<td>0.6</td>
</tr>
<tr>
<td><strong>74</strong></td>
<td>Vinyl record</td>
<td>1</td>
</tr>
<tr>
<td><strong>75</strong></td>
<td>Long self tapping Screw</td>
<td>2</td>
</tr>
<tr>
<td><strong>76</strong></td>
<td>Washers</td>
<td>3</td>
</tr>
<tr>
<td><strong>77</strong></td>
<td>Strong convex lens FL 150mm</td>
<td>1</td>
</tr>
<tr>
<td>Code</td>
<td>Item Description</td>
<td>Quantity</td>
</tr>
<tr>
<td>------</td>
<td>-------------------------------------------------------</td>
<td>----------</td>
</tr>
<tr>
<td>78</td>
<td>Plano concave FL 150mm</td>
<td>1</td>
</tr>
<tr>
<td>79</td>
<td>Flat mirrors A6 size</td>
<td>5</td>
</tr>
<tr>
<td>80</td>
<td>Laser</td>
<td>3</td>
</tr>
<tr>
<td>81</td>
<td>Large Parabolic mirror 300mm dia</td>
<td>1</td>
</tr>
<tr>
<td>82</td>
<td>Small mirrors ct down A6</td>
<td>2</td>
</tr>
<tr>
<td>83</td>
<td>Black card pk100</td>
<td>1</td>
</tr>
<tr>
<td>84</td>
<td>Double sided tape</td>
<td>1</td>
</tr>
<tr>
<td>85</td>
<td>Coloured filters</td>
<td>6</td>
</tr>
<tr>
<td>86</td>
<td>Coin (old pennies)</td>
<td>2</td>
</tr>
<tr>
<td>87</td>
<td>Small glass pain</td>
<td>1</td>
</tr>
<tr>
<td>88</td>
<td>Acrylic block 115 x 65 x 20mm</td>
<td>1</td>
</tr>
<tr>
<td>89</td>
<td>Prism Glass R/angle 50mm size</td>
<td>1</td>
</tr>
<tr>
<td>90</td>
<td>Lens Biconvex 100mm FL</td>
<td>10</td>
</tr>
<tr>
<td>91</td>
<td>Greaseproof paper 457mm x 710mm</td>
<td>50</td>
</tr>
<tr>
<td>92</td>
<td>Pin Dressmakers 30mm 40g pack</td>
<td>1</td>
</tr>
<tr>
<td>93</td>
<td>Wooden block 50 x 50 x 50 mm</td>
<td>1</td>
</tr>
<tr>
<td>94</td>
<td>Grey box sig gens</td>
<td>1</td>
</tr>
<tr>
<td>95</td>
<td>3mm rubber cord 2m</td>
<td>1</td>
</tr>
<tr>
<td>96</td>
<td>Whirling tube</td>
<td>1</td>
</tr>
<tr>
<td>97</td>
<td>6V Buzzer</td>
<td>1</td>
</tr>
<tr>
<td>98</td>
<td>AA batteries pk 4 Duracell</td>
<td>1</td>
</tr>
<tr>
<td>99</td>
<td>4 x AA cell holder, press stud</td>
<td>1</td>
</tr>
<tr>
<td>100</td>
<td>Heavy duty PP3 clip(press stud)</td>
<td>1</td>
</tr>
<tr>
<td>101</td>
<td>2 section terminal block</td>
<td>2</td>
</tr>
<tr>
<td>102</td>
<td>2 core cable 2m</td>
<td>1</td>
</tr>
<tr>
<td>103</td>
<td>Screwdriver (v.small)</td>
<td>1</td>
</tr>
<tr>
<td>104</td>
<td>Wire (1mm diameter) 1m</td>
<td>1</td>
</tr>
<tr>
<td>105</td>
<td>BIC pen as prism (red)</td>
<td>10</td>
</tr>
<tr>
<td>106</td>
<td>Polarising filters slide type</td>
<td>2</td>
</tr>
<tr>
<td>107</td>
<td>Red laser pointer</td>
<td>3</td>
</tr>
<tr>
<td>108</td>
<td>AAA Duracell for laser pk4</td>
<td>1</td>
</tr>
<tr>
<td>109</td>
<td>Young’s slits</td>
<td>1</td>
</tr>
<tr>
<td>110</td>
<td>Dice</td>
<td>120</td>
</tr>
<tr>
<td>111</td>
<td>Whizzo bung</td>
<td>1</td>
</tr>
<tr>
<td>112</td>
<td>Tissue (box)</td>
<td>1</td>
</tr>
<tr>
<td>113</td>
<td>Cling film (roll)</td>
<td>1</td>
</tr>
<tr>
<td>114</td>
<td>Cloth for rubbing (lab coat rag)</td>
<td>1</td>
</tr>
<tr>
<td>115</td>
<td>Watch glasses</td>
<td>2</td>
</tr>
<tr>
<td>116</td>
<td>Slide file binders</td>
<td>2</td>
</tr>
<tr>
<td>117</td>
<td>Springs (bag 100)</td>
<td>1</td>
</tr>
<tr>
<td>118</td>
<td>Ticker tape machine</td>
<td>1</td>
</tr>
<tr>
<td>119</td>
<td>45 record</td>
<td>2</td>
</tr>
</tbody>
</table>
All photos by the Collyer’s team unless otherwise credited:

- **EXP 11** Leopard in Tree; U.S. Fish and Wildlife Service
- **EXP 47** Ultrasound Scan; Sam Pullara
- **EXP 56** Mirage in the Mojave Desert; Mila Zinkova
- **EXP 57** Very Large Array, New Mexico; Wikipedia user Hajor
- **EXP 57** Bigfin Reef Squid; Nick Hobgood
- **EXP 59** Thermogram of a Small Dog; NASA/IPAC
- **EXP 59** Mobile Phone; Jon Jordan
- **EXP 59** X-Ray of Anna Röntgen; Wilhelm Röntgen
- **EXP 67** Hubble Ultra Deep Field; NASA and the European Space Agency
- **EXP 68** Tarantula Nebula; The Hubble Heritage Team
- **EXP 68** Eagle Nebula; NASA, Jeff Hester, and Paul Scowen (Arizona State University)
This paper aeroplane design is called the Arrow. It is one of the most popular and recognisable planes out there, and with a little careful folding it flies brilliantly!

Start with a plain piece of A4 paper. Fold it in half along its length and flatten it out again. This way you can see a crease where the middle of the paper is.

Fold the two top corners of the paper down towards the crease to form two folded triangles.

Fold the top edges of those triangles down towards the crease again so that you have this shape:

Now fold the top edges of that shape towards the crease again, so that you have this shape:

Fold the entire piece of paper in half now, along the original crease you made. Fold it so that these pieces are on the outside.
Now when you lay the plane down you will see that it unfolds itself so that the back of the plane forms an “M” shape, like in this picture.

That middle bit of the “M” is the bit you need to hold when you are throwing the plane.

Throw the plane and watch it go! If it doesn’t fly straight away, you need to bend the back of the wings a bit to help it go straight. If it dives, bend the wings up gently. If it shoots straight up and then crashes, bend the back of the wings down a bit.
For more information about IOP’s education projects in Africa and for access to other educational resources, contact:

Dr Dipali Bhatt-Chauhan
International relations manager

Institute of Physics
76 Portland Place, London W1B 1NT, UK
Tel +44(0)20 7470 4800
Fax +44 (0)20 7470 4848
E-mail dipali.bhatt-chauhan@iop.org

www.iop.org/international
www.iopblog.org

Registered charity number: 293851
Charity registered in Scotland: SC040092