mobile science experiments
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This is a collection of experiments that might be useful for “mobile science”. They assume a context in which teachers, instructors, mentors, explainers, call them what you will, are trying to bring the experience of science to others, probably children but not necessarily. In this assumed context, neither equipment nor scientific knowledge may be plentiful, but enthusiasm and resourcefulness are not. The experiments are in loose groups around various physical principles, so that they can form the basis for a sustained set of investigations in which the learners can take responsibility and have a justified sense of achievement for their results. The intent is to develop some sense of the connectivity of simple and largely familiar phenomena, with some surprises along the way. Single experiments could be used in demonstrations or shows if time is short, but the heart of science is learning and experimentation and this takes time. Detailed instructions are not given; many of the experiments can and should be improvised with whatever is available. At the end of each section are some key words that point to the physical principles involved, and which can be researched further for more detail at whatever level is appropriate. Access to the Internet is very helpful; there are many excellent education sites, especially Wikipedia and various NASA portals. Finally there are some more detailed notes on the experiments, which may be helpful to leaders, but are pitched at a more sophisticated level than the experimental descriptions.
These experiments have been drawn from many sources; very useful collections are Robert Ehrlich’s books “Turning the World Inside Out” and “Why Toast Lands Jelly-side Down”, which give more physical and mathematical detail on many of the experiments I have given here in simplified forms. Other good sources are Ehrlich’s “What If – Mind-Boggling Science Questions for Kids”, Suplee’s “Everyday Science Explained”, Walker’s “The Flying Circus of Physics”, Swartz’s “Back of the Envelope Physics” and Epstein’s “Thinking Physics”.
Forces and how things move

*Keywords:* Force, momentum, acceleration, inertia, air resistance, equivalence principle, simple harmonic motion, feedback.
What does it take to break an egg?

You can throw an egg at a sheet held at its corners and the egg won’t break – as long as you catch it before it hits the floor!

Holding the sheet with its bottom edge folded up will usually catch the egg.

Why doesn’t the egg break? Is it because the sheet is “soft” – what does this mean?

What does this experiment tell you about the differing effectiveness of seat belts and air bags in cars?

What you need...
An egg
A bedsheets
What does it take to break an egg?

MORE INFO

It takes force to break an egg, not speed. Force and acceleration (or deceleration) are directly related by Newton’s Second Law:

\[ \text{force} = \text{mass} \times \text{acceleration} \]

In the case of the sheet, its “softness” means that the egg slows down gradually over some distance, and the forces are smaller than they would be if the egg hit a wall.

In a car, braking gradually and hitting a wall are clearly quite different experiences, even if you start from exactly the same speed.
What’s your weight really?

Do some deep and quick knee bends on a bathroom scale.

What happens to the reading on the scale?

Where does the extra weight come from? Did you just get fatter?

See how heavy you can make yourself, and whether there is a limit and why.

Does this experiment have anything to do with astronauts being “weightless” in space and “weighing less” on the Moon?

What you need...

A bathroom scale
What's your weight really?

MORE INFO

This is the Third Law again. The bathroom scales are recording the force that is necessary to keep you up; if the scales vanished suddenly, you would accelerate downwards at the acceleration due to the gravity of the Earth at its surface, usually called $g$. So although the scale reads in kilograms (mass) it is actually measuring a force and converting it to a mass via:

$$\text{mass} = \frac{\text{force}}{g}$$

By accelerating yourself on the scales you are changing the forces; the limit is set by the strength of your muscles. If you could double your weight, you would be temporarily accelerating upward at $g$ and (if you could keep it up!) would leave the planet.
Where is the force?

You need two spring balances. A simple spring balance from an angling store, for weighing fish, would be fine.

First, attach one end of the balance to something fixed (say a wall) and pull on the balance.

Now, give the same pull on two joined balances, with the end of the further one fixed.

Do you think the readings on the balance will be:
(a) equal but half the first time?
(b) equal but the same?
(c) something else?

Make your prediction and explain before you do the experiment.

What does this tell you about the forces acting at the wall?

What would happen if the wall moved somewhat?

What you need...

2 spring balances
Where is the force?

MORE INFO

We think of force as something that takes a sweat to apply, so in this experiment it is a surprise to find that there are other forces present. The easiest way to understand the other forces that appear in this experiment is to note that nothing accelerates. From the Third Law, this means that the forces on each junction in the set-up must add to zero.
Movement means weight?

Attach a weight to a spring balance.

Take readings when the weight is still, jerked up, dropped, or whirled.

Weigh a swinging pendulum.

Explore what kinds of movement change the weight.

Where does the extra weight come from? This shows that there are forces associated with movement; why seat belts are useful or cars fly off the road at corners.

What you need...

A spring balance
A weight
Movement means weight?

Weight is an everyday term for the force that is needed to lift a mass against gravity. A spring balance measures force, not mass. Accelerating objects requires force and this registers on the balance.

The case of curving motion shows that acceleration can mean a change in direction of movement, as well as a change in speed. This is why Newton’s First Law says that object will move in a straight line at uniform speed, unless acted upon by forces.
Spin from nowhere

This works best with the sort of straw that has concertina-like areas in it so that it can be bent easily.

Bend the straw twice in right angles so that when you blow into it, it whirls round and round, apparently driven by the jet of air escaping.

Where has the spin come from?

Attach a very light plastic bag over the end of the straw.

What happens now and why?

This experiment shows that deflecting the air requires a force and is the basis of why aeroplanes fly – their wings deflect the air.

What you need...

Drinking straw with concertina bend
Think of the air striking the bend in the straw and changing direction. It exerts a force doing this, just as a car would if it hit a wall and bounced off sideways. Some of the force (since it is a vector) is directed in a way that accelerates the straw to spin. Adding the bag neutralizes the force exerted at the bend as the air strikes the bag.
Do heavy things fall faster than light things?

Seems obvious that they do, for example a sheet of paper flutters to the ground more slowly than a phone book falls.

But try dropping the sheet of paper and the phone book together with the sheet of paper on top of the book.

Try variations on this, crumpling the paper for instance.

*It demonstrates that all objects probably fall at the same rate apart from air resistance – which is what uses up a lot of fuel in a car and makes cycling against the wind tiring.*

Try to streamline some light objects, using various shapes with the weight fixed, so that the air no longer delays them.

What you need...

- A phone book
- A sheet of paper
- Various objects of differing weight and shape
Do heavy things fall faster than light things?

Identifying friction (air resistance in this case) as a complication to underlying simpler forms of motion was a great conceptual advance. Dynamics obeying Newton’s Laws is quite difficult to demonstrate experimentally because of the pervasive effects of friction. However, the fact that objects of the same mass fall with the same acceleration (frictional effects eliminated) is a much deeper truth, called the Principle of Equivalence.

It amounts to the identity of the inertial mass (the mass that appears in Newton’s Law III) with the gravitational mass (the mass that appears in Newton’s Law of Gravitation). This identity (which has been experimentally checked to high precision) means that a gravitational field can always be “removed” by free fall, an observation that is the starting point for Einstein’s theory of general relativity.
Astronauts are weightless in space?

They really aren’t much further away from the centre of the earth than we are, so gravity must be about the same. But things float about in their space capsules.

Try this messy experiment: Fill a paper cup with water and make a small hole in the side so the water comes out in a nice jet.

Now, drop the cup from a sufficient height to have time to see what is happening.

What happened to the jet and why?

How does this relate to astronauts’ experience?

What you need...
A paper cup
A pin or similar
Astronauts are weightless in space?

The force acting on the astronauts (their weight) is given by $F = \frac{GMm}{R}$, where $G$ is the gravitational constant, $M$ the mass of the earth, $m$ the astronaut’s mass, and $R$ the distance from the centre of the Earth. Since the astronauts are only about 10% further away from the centre of the Earth than they would be standing on the ground, they are not weightless for this reason. Rather, they are in free fall; as they swing around the earth they fall freely inwards, but are also carried sideways by the steady orbital speed, to make their circular orbit.

This is a more fundamental answer than another one, which would say that the astronauts experience no force because the gravitational and centrifugal forces are equal. The centrifugal force is a fictitious force; it has no physical cause and can be eliminated by choosing the correct frame of reference. Thus someone sitting on a merry-go-round experiences a centrifugal force, since their frame of reference is attached to the merry-go-round; but someone on the outside sees that the force is merely a fiction that is introduced to explain why it takes an effort to stay in one place on the merry-go-round.
A candle seesaw

This simple machine is fun to make and to explain, but don’t burn the house down!

First trim a candle so it has a wick sticking out at each end.

Now balance it with a nail or needle through its middle, so that it makes a seesaw.

Light the wicks and observe.

After a while the candle starts seesawing regularly – why?

Who pushed it?

Why does it swing to and from at the rate it does, rather than faster or slower?

Is the rate steady?

What you need...

A candle
A lighter
A nail or needle
A candle seesaw

MORE INFO

What we have here is a mixture of two very common aspects of motion in the world: regular oscillations, like a pendulum or a weight on a spring; and “feedback” – some aspect of the motion feeds back into the system and affects the state of motion.

The seesawing arises because inevitably one end of the candle burns somewhat faster than the other. The candle then tilts, the flame at the low end melts more wax, and the candle swings back. This is the feedback. The swinging motion is an overshoot because of the inertia of the candle; once it starts swinging, it rises an approximately equal distance beyond the balance point before its kinetic energy is exhausted.
Keywords: Angular momentum, kinetic energy, conservation of momentum, conservation of energy, torque, centrifugal force.
Bikes and balance

These two experiments can lead on to examining the apparently simple business of riding a bicycle, but are surprising as well.

They need a bicycle wheel and axle, easily removed from most bikes. Both can also be done with a toy gyroscope.

a. Hold a spinning bicycle wheel by the axle ends and try to steer it.

b. Suspend a spinning bicycle wheel by a cord attached to one end of the axle.

If a gyroscope is available, other experiments are possible that use its stability – balancing it on a taut string, for example.

What you need...
- A bicycle wheel and axle
- A cord or rope
- A gyroscope (optional)
Bikes and balance

The surprising thing about spinning wheels is that they do not respond to twists in the way you expect. In a mathematical treatment this needs concepts like torque which are not that simple.

However by thinking carefully about how the twists affect the various parts of the rim of the wheel, the result is less surprising.

The steering of a bicycle is only partly a result of the spin of the wheels (as is apparent from the fact that you can balance and steer a bicycle when it going very slowly).

There is a clear explanation of the principles at [http://socrates.berkeley.edu/~fajans/Teaching/Steering.htm](http://socrates.berkeley.edu/~fajans/Teaching/Steering.htm)
Whirling weights

This is a variant of the “ice skater” effect. It needs a simple apparatus in which a small weight is whirled horizontally at the end of a strong cord, lifting a weight hanging vertically. The hanging weight should be about twice the mass of the whirling weight. The cord should be passed through a small length of plastic pipe, with carefully smoothed edges to reduce friction, and whirled by the pipe.

First, experiment with how to whirl the weight to keep the hanging weight steady.

Where does the force come from to hold up the weight?

When it is whirling steadily, have an assistant pull down gently on the hanging weight, to shorten the horizontal length of cord.

What happens? The whirling weight spins much faster – why? It has more energy when it spins faster – where did this energy come from?

What you need...
Two small weights
A strong cord
A plastic pipe
Whirling weights

MORE INFO

The “ice skater” effect occurs when a spinning skater pulls in her arms and spins even faster. The experiment is a version of this that doesn’t require a skater.

Angular momentum is conserved as the radius of the circle is reduced; this means $rpm \times radius^2$ is constant, so the rpm must rise as the radius is reduced.

Since the weight is moving much faster, it must have more kinetic energy; the necessary energy comes from the work that is done in pulling the weight down. The skater does work in pulling in her arms against centrifugal force.
Whirling water

Whirl a full bucket of water over your head without getting wet. Best practised outside on a warm day, but indeed it is possible!

Is this because the water doesn’t have time to fall out of the bucket? Or is it being pressed against the bottom of the bucket as it is whirled?

Think about the forces you experience in a swing. This effect is the reason that car-racing tracks have steeply cambered sides, but the cars don’t fall off. Skateboarders exploit these forces in a half pipe.

What you need...

A bucket
Water
Whirling water

This is all about centrifugal force. This is a confusing concept because it is what physicists call a fictitious force; it is not a force of nature with a cause like mass or electric charge. Rather, it arises for the person experiencing it because they are rotating, i.e. travelling in a circle (or some part of a circle, as on the swing).

On the swing, your body wants to go straight ahead (inertia) but the swing insists on going in a circle. Hence the force exerted on you (and vice versa) by the swing.

The force, although called fictitious in a technical sense, is quite real enough to break the support of the swing, for example. Once the support breaks, of course the forces experienced by the swinger will (temporarily!) vanish.
Hero’s engine

This is a very ancient machine, perhaps the first steam engine. We won’t use steam though.

Punch two holes in opposite sides of an empty fizzy drink can, angling them so that water emerges more or less at a tangent to the can.

Fill the cans with water and suspend the can from a cord or fishing line.

The can begins to spin – why?

Try the opposite experiment, of submerging the can when empty.

Do you think it will start to spin? Which way?

What you need...
An empty soft drink can
Water
A cord or some fishing line
This can be thought of in several ways; it exemplifies conservation of momentum, for instance. Perhaps the simplest is to notice that since a force must act on the water to make it fly out of the holes, by Newton’s laws an equal and opposite force must act on the can.

The inverse experiment is quite tricky to do (you need to make sure the can enters the water upright, probably by weighting the bottom suitably).

This experiment is related to the question of the “inverse lawn sprinkler”, a puzzle originally suggested by the famous physicist Richard Feynman. This is still a controversial question, as a web search will soon show!
Simple machines

**Keywords:** Work, power, friction.
Many everyday gadgets use the same simple principles. Things like a screw, a door handle, or a knife, are machines using these principles. We are used to thinking of machines as being big complicated things, but many of these things are built from many parts, which are based on simple principles that have been known for a very long time. Digging with a spade uses leverage, hammering in a nail uses leverage and a wedge, the gears on a bicycle use leverage.

The basic machines are:

- the lever, which is used to increase a force;
- the inclined plane (like a playground slide) which is used to do work gradually;
- the wedge, which is usually used to increase force gradually;
- the screw, which is a wedge wrapped around a cylinder so that the wedging action can be obtained from a circular motion;
- wheels, which allow linear motion without sliding (wheels also use leverage to help with friction in the axles – this is why the size of wheels matters); and
- pulleys, which swap force for distance (so you can lift a heavy weight with a combination of pulleys but the weight moves a smaller distance up than you pull down).

Look carefully at some familiar everyday machines; maybe take them apart if it is safe. A bicycle uses several of these principles, for example. Try to work out how they use the principles of the six basic machines.
From the point of view of physics, the essence of these machines is that they play off the various components of work against each other. Work is technically defined as force times distance, so a pulley system is designed to use a small force acting through a large distance to achieve the same amount of work as a big force acting through a small distance.

This is helpful because a human can only produce so much force! Humans also have limitations in power, which is the rate of doing work. So, to lift a heavy weight takes a certain amount of work, but we can produce this work gradually, reducing the power required, if we push this weight up an inclined plane. If we push it on rollers, we don’t waste energy on friction.

Applying these principles is how ancient civilizations were able to build enormous structures like the Pyramids.

Our modern civilization still uses all these simple machines but has a source of unprecedented power – oil.
Friction, inertia, or why things don’t move

Keywords: Friction, inertia, bollard friction, pulleys, angular momentum, mechanical advantage
Piles of money

Make a small regular pile of similar coins on a smooth surface, then flick another coin at the bottom of the pile.

With a little practice, you’ll find that you can knock the bottom coin out without disturbing the rest of the pile.

Why?

Try various sizes of coin to flick, and various surfaces

What you need...

Coins
This is partly about inertia, the desire of things not to move! It’s also about static and dynamic friction.

Generally there is more friction when something is not moving on a surface, compared to the friction once it starts to move.

When the bottom coin in the pile is struck, and starts to move, the friction that “attaches” it to the upper coins is reduced. Also, the upper coins are more massive and so have more inertia. There just isn’t enough friction for the bottom coin to move the pile.
A simple Newton’s Cradle

Now use the same coins and surface and arrange three or four in a line, touching.

Flick a coin hard at one end of the line, in the same direction as they are lined up.

The coin at the other end flies off! Why?

It’s said you can pull a tablecloth off a table quickly and leave all the plates and saucers behind (don’t try this at home) – the reasons are the same as we have seen in these two little experiments.

What you need...

Coins
A simple Newton’s Cradle

What else would you expect to happen? Perhaps the whole row of coins should move?

The answer turns out to be that both energy and momentum are conserved in the collision; you might try the maths for the simple case of two coins colliding.

Newton’s Cradle is an executive toy, consisting of a row of steel balls suspended by cords adjacent to each other and touching. Striking a ball at one end causes the one at the other end to fly off.
Making ladders less lucky

Everyone knows you have to be careful to place a ladder against a wall so it’s stable. Investigate this carefully with a toy ladder, or one you’ve made yourself, and some weights.

Use a protractor to measure the angle at which the ladder slips. Vary the heights of the weight, and the surface on which the ladder rests (rough or smooth).

You might even try putting wheels on the bottom of the ladder, possibly by fixing it to a toy car.

Can you devise a safe rule for placing a ladder? (Physicists first worked out the full theory of the ladder in 1995 so this isn’t a trivial experiment!)

What you need...

A ladder
A protractor
Wheels (eg toy cars)
Making ladders less lucky

MORE INFO

You might think you could just work out the forces acting on the floor and the wall, get the consequent frictional forces, and find out if they balance. More exactly, we need the horizontal forces to balance (the force against the wall, and the friction at the floor), the vertical forces (the force against the floor, and the friction at the wall), and finally there should be no torque, or the ladder would rotate. This means we have only three conditions and four unknowns (the two horizontal and two vertical forces).

It turns out you have to take account of elasticity of the wall and floor, in other words how they deflect under load and the extra forces they introduce. A lot of physics for a simple problem!
Haul away!

Use some small pulleys, weights (known!) and cords to investigate how the weight that can be lifted depends on the number of pulleys.

This could be done by hanging a known weight at one end, and using the several others at the other end to find the smallest one that will just lift the weight. Probably the ratio of the “lifted” weight to the “lifting” weight is a good thing to evaluate.

You will probably find that, as you increase the number of pulleys, there is limit to how effective the system is – the problem is friction in the pulleys. Try to explain this in more detail.

What you need...

Some small pulleys
Some known weights
Some cords
As in many problems in mechanics, thinking about energy is helpful.

To raise a weight through a fixed distance \( h \) takes a certain amount of energy \( E \). This must be equal to a force times a distance. If you just lift the weight with one pulley, the force is \( E/h \) – the force you apply acts through a distance \( h \). If you use two pulleys, you’ll have to pull twice as far, in other words the force acts through twice \( h \); the required force is thus \( E/(2h) \), and is halved.
Tie her up, sailor

This is a familiar but surprising example of friction. Simply wrapping a cord around a cylinder a few times can hold a heavy weight – this is called “bollard” friction because boats are moored in this way around special posts called bollards.

Theoretically, the weight that can be held by a bollard rises very rapidly (“exponentially”) with the number of turns; after a few turns, it hardly matters how smooth the bollard is, as you would know from looking at the bollards that can hold big ships.

Use weights, cord and a home-made bollard to find out how the weight that can be held depends on the number of turns around the bollard.

Compare different kinds of bollard (rough and smooth).

What you need…

Weights
Some cord
Differing home-made bollards
Tie her up, sailor

MORE INFO

Where does the frictional force come from that makes a bollard work?

It’s because the rope presses against the bollard, and the friction is proportional to this pressing force. The frictional force turns out to depend on the tension in the rope at any point, and this frictional force acts to reduce the tension.

This kind of feedback means that the tension reduces very rapidly with the length of rope that is wrapped around the bollard. This rapid reduction in tension means that the amount of the load that finds its way to that part of the rope is also getting smaller, in other words the load is being supported by parts of the rope nearer the load.

The effectiveness of the bollard is why sailors tie up a moving boat by gradually adding turns; adding them all at once might break the rope as the boat is brought to a sudden halt.
Saved by the spin

_Bollard friction is the principle behind this surprising experiment; it takes a bit of practice but it shows two basic pieces of physics at work._

Attach something heavy (a model warrior might add interest!) to something light (perhaps his sword?) with a cord. Some experimenting will be needed to get the right weights.

Pass the cord over a fixed cylinder (a pencil would do) with the warrior suspended vertically and the cord going off more or less horizontally to the sword. Again, experiment with the relative lengths of cord.

When this is all set up correctly, you will find that if you drop the warrior, the sword end of the cord wraps itself swiftly around the pencil and stops the fall!

_There are two things at work here – bollard friction (experiment 5) and the “ice skater” effect._

**What you need…**

A heavy object
A light object
Some cord
A pencil (or other cylinder)
Saved by the spin

Once the sword starts to fall, it also starts to rotate around the pencil. In fact, because the warrior is also falling, the length of string shortens and the sword has to rotate more rapidly, because of conservation of angular momentum (the ice skater effect). As a result, several turns of string get wrapped around the pencil and bollard friction stops the warrior.
Water and floating things

Keywords: Archimedes’ Principle; hydrostatics; Pascal’s Law; surface tension; capillary action; thermal conductivity; angular momentum; vorticity; Rayleigh-Taylor instability, pressure, volume, Boyle’s Law.
It’s Archimedes

I’m out in the middle of a lake in my boat and I throw a large rock overboard ... does the level of the lake rise or fall?

Now try the experiment in a full glass of water with a toy boat; for a clear result, you need the volume of the “boulder” to be a significant fraction of the volume of water in the glass.

An ice cube floats in a full glass of water - will it overflow as the ice cube melts?

Try this one as well.

What you need...
A glass of water
A toy boat
A ‘boulder’
An ice cube
Both of these experiments illustrate Archimedes’ ancient principle, which is that a floating body displaces its own mass of the liquid in which it is floating.

Assuming the boulder, in the first example, is more dense than water, it follows that it must displace a greater volume of water when it is floating (with the help of the boat) than when it lies on the bottom of the lake.

The ice cube, by contrast, simply turns into water when its melts and so the volume of water in the glass remains the same (apart from rather small effects arising from the changes of volume associated with changes of temperature in water).
It’s Archimedes again

Weigh a suitable weight on a spring balance as it is lowered into a bucket of water. It’s best to use something fairly bulky and light that will still sink.

*So, what do you observe?*

Another way to do this would be to balance two weights on a cord over a pulley, and then lower one of the weights into the water.

**What you need...**
- A spring balance
- A bucket of water
- A cord (optional)
- A pulley (optional)
It’s Archimedes again

MORE INFO

The weight seems lighter when submerged because of Archimedes again. A cork, for example, would appear to weight nothing in this experiment – why?
...and again!

Submerge your fist in a bowl of water resting on sensitive scales.

What happens to the apparent weight of the water?

What you need...

A bowl of water
Sensitive scales
...and again!

MORE INFO

Archimedes again! An extra force is necessary to submerge your fist, which is slightly buoyant.
The rising egg

Float an egg in a bowl of water.

Now pour a gentle stream of water onto the tip of the egg.

Before you do this – what do you expect to happen? But what does? The egg rises up in the stream of water.

What you need...

An egg
A bowl of water
The rising egg

This seems to be a combination of the streamlined shape (so the downward force is small) and the squeeze on the bottom of the egg, caused by the stream of water stopping in the bowl.
The right egg to drop

Another egg experiment. You need an uncooked egg and a hard-boiled egg.

How can you tell which is which without breaking the shell?

Spin an egg around a short axis on a smooth surface, stop it momentarily, and let go. One of the eggs starts spinning again.

Which one? Why?

What you need...

An uncooked egg
A hard-boiled egg
The right egg to drop

MORE INFO

The liquid egg can carry on spinning inside the shell, even when the shell is momentarily stopped. Friction does the rest.
The “Cartesian Diver”

This is a famous one – see www.fatlion.com/science/cartesian.html for example. The idea is to make a small squashable submarine that is “neutrally buoyant” in the jargon (neither floats nor sinks).

An example would be a medicine dropper with some water in it. A home-made version is a small length of a drinking straw, sealed at one end with glue and sealed and weighted at the other end with some putty or Blu-Tak.

Put the submarine in a plastic drink bottle, the sort you can squeeze somewhat, and fill with water and seal.

Now squeeze the bottle. You should find that your submarine sinks.

Let go of the bottle and it rises again.

What you need...

A drinking straw
Glue
Putty or Blu-Tak
A plastic drink bottle
Water
The “Cartesian Diver”

This is our old friend Archimedes at work again. Because the submarine is squeezable, squeezing the bottle makes the submarine smaller and so, in effect, denser. It then sinks! (This experiment also illustrates that water doesn’t compress much.)
Full to the brim, and beyond

Water has a skin – you’ve perhaps seen pond insects that can run across the surface of water, or seen how insects struggle with an apparently sticky substance when they get wet.

A good way to see this skin is to fill a glass completely with water. You want to keep the rim dry, so fill it nearly to the top and then increase the height gradually by sliding small weights, like coins, into the glass (you mustn’t make waves).

With care you can get the water level appreciably above the sides of the glass and you can see how the water bulges inside its skin. This is “surface tension”.

What you need...
A glass of water
Small weights, eg coins
Surface tension arises because a molecule of water at the surface doesn’t have neighbours to all sides. It therefore has fewer “bonds” to other molecules.

To stretch the “skin” means doing work – applying a force – so bonds can be broken on submerged molecules and promote them to the surface. Thus the skins appear to have strength.
Floating steel

You can, with care, float a needle on water. Just putting the needle on the surface breaks the skin and the needle sinks, of course.

With care you can rest the needle on a piece of tissue paper on the surface. The tissue paper gets saturated and sinks after a while, leaving the needle resting tranquilly on the water surface!

One thing that soap does to clean things is to reduce its surface tension. This is so it can “wet” fabrics – otherwise the water won’t go into the spaces in the fabric, because its skin won’t bend enough.

Float some tiny particles on the surface of water – ground pepper is good, so is dust. Now drop a tiny amount of liquid soap amongst the particles.

What you need...
- A needle
- A container of water
- Tiny particles such as pepper or dust
- Liquid soap
Floating steel

MORE INFO

This is why it’s called “tension” – there’s a force acting along the surface. It’s why the surface tries to get spherical, as you saw in experiment 7.
Build your own whirlpool

Fill a bottle with water; turn it upside down, the water falls out. Easy. Usually it glugs out with water taking turns falling out with air getting in.

Why is this?

Now get the water spinning in the bottle as you invert it – a whirlpool forms and the water runs out smoothly and slowly.

Why? Does the water still spin after it leaves the bottle? Does it speed up as the bottle empties?

Try this with various sizes of hole for the water to leave through, perhaps using a capped bottle with progressively bigger holes drilled in the cap.

Investigate the effect on the whirlpool of how much the water has to shrink its “orbit” as it gets out, using bottles with differently-sloping necks.

What you need...

A bottle of water
A drill
Build your own whirlpool

MORE INFO

The shape of the neck the key to this simple phenomenon; in a narrowing bottle, the water would have to spin faster (just like the ice-skater effect). The only place to get this energy is by falling, but the water may not fall far enough for the spin it wants to acquire; the only way it can get out is to give up its spin to the water higher up the bottle. This is done by friction and takes some time. It’s also why the water doesn’t spin after it leaves the bottle.
Another wet experiment (possibly). Place a thin piece of cardboard (something like an index card) over a half-full glass of water. With a little care you can turn the glass upside-down and the card will keep the water in the glass.

*Why doesn’t the water just fall out?*

Try various stiffnesses of card; you should find that the stiffer card won’t do the trick, so the secret is in the flexibility of the card.

Try varying how full the glass is as well; the trick works better for a stiff card if the glass is fuller.

**What you need...**

Cardboard of various thickness
A glass of water
This is the clue to this one; the pressure of the remaining air in the glass is reduced because the card bulges down a little, increasing the volume of the air slightly. The pressure difference between inside and out is enough to hold the water in. If there is less air in the glass, less of a bulge is enough to achieve the needed pressure difference.
The invulnerable balloon

This one shouldn’t make a puddle. Blow up a balloon and put a match next to the taut skin; it bursts, of course.

Now fill the balloon with water so the skin is just as taut and repeat the experiment.

What happens? Why?

What you need...

Balloons
Matches
Water
The invulnerable balloon

The clue is that in the second case, the match has to heat the water as well as the balloon.
Air and flying things

Keywords: Air pressure, atmosphere, pascal, suction, siphon, Bernoulli’s principle, vortex ring, speed of sound.
Air. Insubstantial stuff, everywhere, you never really notice it?

Try this. Place a long ruler on a table, most of it on the table, covered with a close-fitting large sheet of paper (something floppy like newspaper is good).

Now give the protruding edge of the ruler a sharp downward blow, maybe with a hammer (if you don’t want to keep the ruler!).

**What you need...**

- A long ruler
- A table
- A large sheet of newspaper or similar
- A hammer
Air and flying things

Heavy air

MORE INFO

The air doesn’t have time to get under the paper, so in effect you are trying to lift a column of air, as far up as the top of the atmosphere, sitting on the paper. This is quite heavy!
Collapsing can

Here’s your very own steam engine. You need a metal can with a well-fitting screw-on lid of some kind. These sorts of cans are often used for nasty liquids so make sure yours is properly empty.

Heat some water in the open can until plenty of steam is emerging, then screw the lid on tightly. Wait for the implosion!

This is air pressure at work again. How?

What you need...

A metal can with a screw-on lid
Water
A source of heat
Collapsing can

The steam condenses back into water and leaves a vacuum in the can, and the external air pressure does the rest.

Good old fashioned steam engines work like this too, not by using the expanding hot steam.
Sucker!

Sucking water up a straw – easy and familiar! But how does it work? Try these experiments to get some insight into what’s happening.

a. Use two straws, one in the liquid, one out. Suck as hard as you can, you won’t get a drink! Why?

b. Put a straw through a small hole in the cap of a bottle half-full with water, and seal the straw into the hole with plasticine or similar. Now try to suck some water out.

c. A variation on this is to try to suck out of a small carton of juice, when the straw fits tightly in the hole. This time, you get some juice while the sides of the carton collapse, but after a while you can’t get any more.

d. This is a fiddly one but worth a try. Make the longest straw you can by fixing straws together. Making the joins waterproof is the challenge! – something like all-weather sticky tape, or waterproof glue, is the thing to try. Now try to suck water up the mega-straw. What’s the longest straw that you can still get water up? Why is there a limit?

What you need...
- Straws
- Water
- A bottle with lid
- A small carton of juice
- All-weather sticky tape
Sucker!

**MORE INFO**

The basic piece of physics here is that you are making a bit of a vacuum in your mouth, and air pressure then pushes the liquid through the straw.
The big guy always wins

Now you’re an expert in joining straws, try this experiment with an unexpected result.

You need to be able to join two balloons through a straw, with some kind of valve so the balloons are sealed off from one another. The trick is to blow up the balloons (one a lot more than another), seal them off, join them by the straw, and then undo the seals. The trickiest bit is sealing the straw into the balloons, which you may have to do when they are blown up.

Now, before you undo the seals, agree on what’s going to happen – the big balloon will obviously blow up the little one, right?

Now try it and see, and explain the result.

What you need...

Two balloons
A straw
Some kind of valve
The big guy always wins

MORE INFO

This one is always surprising. The reason is connected to another simple observation, which is how hard it is to blow up a balloon initially. The pressure is higher in the small balloon. This is because stretching the balloon needs a certain force (pressure times area) and the area of the small balloon is smaller so the pressure has to be higher.
Bernoulli blasters

Here are some unexpected results of moving air.

Attach a light ball (like a table tennis ball) to a string, and bring it close to a stream of water from a tap, for example.

Why does the ball move closer to the water?

Suspend two sheets of paper and blow between them.

What happens – how does it relate to the ball experiment?

Apparently moving air produces forces and a lot of people think (mistakenly) that this kind of force makes aeroplanes fly. If you have good lungs, you should be able to blow over a coin and get it to jump a surprising distance.

What you need...

A light ball
Some string
Water
Two sheets of paper
Bernoulli blasters

MORE INFO

This is called the Bernoulli effect, and generically it means the pressure is lower in moving air. In a simple way, it results from the air trading the energy associated with pressure, for energy associated with motion.
The perfect paper plane

A web search on this topic will get you a lot of answers! Try www.paperairplanes.co.uk for example.

The reason we want to play with these planes is to notice how different they all seem to be, and yet they still fly. Notice that they don’t have that special wing cross-section that you may think is essential to flying! In fact they all fly by the simple and universal principle of deflecting the air.

See www.grc.nasa.gov/WWW/K-12/airplane/ for some great resources to explore flight further.

What you need...

A computer with an Internet connection
Air resistance

Do heavy things fall faster than light things? Seems obvious that they do, for example a sheet of paper flutters to the ground more slowly than a phone book falls.

But try dropping the sheet of paper and the phone book together with the sheet of paper on top of the book.

Try variations on this

It demonstrates that all objects probably fall at the same rate apart from air resistance – which is what uses up a lot of fuel in a car and makes cycling against the wind tiring.

Try to streamline some light objects so that the air no longer delays them.

What you need...

A sheet of paper
A phone book
Assorted light objects
How fast is sound?

*Sound travels very quickly, right? But with this classic experiment (Newton is said to have done it in the cloisters of his Cambridge college) you can measure it too.*

You need a big open space, something like a metronome or clock to give regular ticks, and some way of making a noise in synch with the ticks (clapping might do, or banging a drum...up to you).

The principle is clever but simple. The noisemaker moves further and further away from the observer. At first, you see the action of making the noise at the same moment as you hear it, but then there is a delay. However, eventually the delay is equal to the tick period and seeing and hearing get back in synch.

Now you know the speed of sound – it’s the distance between the noisemaker and you, divided by the period of the metronome (or other tick-maker).

What you need...

- Metronome or clock
- A big open space
- Something that makes a loud noise
How fast is sound?

Now the clever bit is that you don’t have to time a small interval (one tick) accurately; as long as the tick-maker is regular, you can time, say, 100 ticks and then divide the answer by 100. This means you don’t need a fancy stop-watch, which Newton didn’t have. (Just for orientation, if you are working with around one tick per second, you’ll need to be separated by at least 300 meters, so you need quite a loud noise. Have fun!)

If you use an echo, as Newton did, then you only need half the distance. But will you need a louder or softer noise? Think about it.
Smoke rings

Let’s start with making “vortices” in water. One way of doing this is to fill a straw with coloured water (food dye) and pinch off one end. Submerging the other end in clear water, and giving the straw a swift squeeze, should propel pretty little “smoke rings” into the water.

Can you see how they are spinning?

Now try to make a vortex cannon to fire real smoke rings. The principle is to use a rigid cylinder (something like a tin can with the ends cut off, but be careful of the sharp edges). One end has cardboard with a “suitable” circular hole, the other end is covered with something you can whack (stretching a balloon over the end works well).

Fill the cannon with smoke, say from an incense stick. Now experiment with the launching hole size to get good smoke rings.

You can also fire invisible but detectable projectiles such as scented air!

Why do the smoke rings stay together as they travel? Study them carefully. They are like whirlpools joined end to end in a doughnut shape.

What you need...

A straw  Cardboard
Food dye  A balloon
Water  Incense stick or similar
A rigid cylindrical object
Smoke rings

More Info

Because the air in the vortex is spinning, it can’t mix with the surrounding air that isn’t spinning. It’s difficult to get rid of spin, as in the case of the whirlpool in the bottle.
Colour and light

Keywords: ??
Make your own rainbows

You’ve surely seen the rainbow in a mist of water from a garden sprinkler or some similar source of water droplets. Try to investigate this systematically.

With some care it’s possible to suspend an almost spherical droplet from something like a medicine dropper. You need to copy the circumstances of the ordinary rainbow, so try to rig up a dark box into which a tiny shaft of sunlight can enter and strike the droplet. There needs to be another hole where someone can look into the box.

You should see the whole range of colours, depending on the angle between your eye and the sun. Experimenting with a mist of water from a sprinkler can produce a “complete” rainbow.

What shape is it? How does this relate to the shape of full-size rainbows?

What you need...
A medicine dropper
A box
A sprinkler
Surprises from simple lenses

You need a simple magnifying glass; fix it into a box so it projects onto something translucent, like waxed paper, at the far end.

When you have it correctly set up, a sharp (but upside down image) will appear on the waxed paper. You now have a model of a camera, or indeed of the eye.

Now we are going to try the experiment of making the lens half its size, first by covering half of it, and then by covering it with a sheet of cardboard with a hole in it smaller than the lens.

Before you do this, predict the result and agree on why it should happen.

What you need...
A magnifying glass
A box
Waxed paper or similar
Cardboard
Surprises from simple lenses

The job of a lens is to bring light to a focus, and it doesn’t have to be round to do this. Lenses are round because they are easiest to make that way, with technology that is quite old. In fact if lenses are needed that aren’t round, they are usually cut out of a round one.
The pinhole camera

If you have worked through the first experiment, you’ve probably wondered if you need the lens at all.

Try to replace the lens end with just a small hole (almost a pinhole will do). Not much light will get through, so use at a bright scene (maybe even the sun, with care) and shade the waxed paper end.

Does this function as a camera too? Why don’t we need the lens? Why, indeed, do we need the lens in real cameras?

What you need...

Your materials from experiment 2
As you will have seen, a pinhole can make an image, but it is very faint. A lens does the same thing, but gathers much more light.
Mr Saussure’s cyanometer

The sky is blue – not true, it has a very wide range of shades even within what are called “blue”. And at sunset and sunrise it is different yet again. It makes you realize how unobservant we often are.

To investigate this systematically, you would try to make an old and marvellously-named device called a cyanometer. Basically it is a colour wheel of shades of blue through to white; the trick is to be able to make successive shades of blue that are very close together.

One way to do this is to choose differences in shade that are actually indistinguishable when the colour wheel is held some distance away. The inventor of the cyanometer, Saussure, had over 50 different shades. You may be able to do this with watercolours, or, if you have access to a computer, with by using one of many graphics packages that gives easy digital control over a colour wheel. In use, the trick is to compare one colour at a time against the sky, at a fixed distance from the eye, blocking off the others.

What you need...

Paper or cardboard
Watercolours and a brush OR
A computer, graphics package and printer
Systematic observations of the sky from horizon to zenith, at different times of day, and in different weather, will show that the sky is nothing like as simple as just blue. If you can compare urban and city locations you will see the effects of air pollution as well, as well as weather.
Puzzles
Some puzzles to think and argue about

a. A large parrot is being transported by air when it escapes and starts flying around the cabin. Does the aircraft weigh less while the bird is flying?

b. Can you cool down the kitchen by opening the door of the fridge?

c. Will a bobsleigh go faster with more people in it?

d. We can extract energy from the tides but where does that energy come from?

e. Are astronauts weightless in orbit because they have escaped the gravity of the Earth?

f. Oil has transformed our civilization because of the enormous energy it makes available in small volumes. Where does all the energy locked up in oil come from?

g. If air pressure is so huge, why don’t we all collapse inwards like the can in the experiment?

h. How does a real submarine control whether it floats or sinks?

i. Remember our model of the human eye, just a lens in a box. It made an image that was upside down. If the model is correct, why don’t we see everything upside down?

j. We can get energy from tides. Tides are caused by the Moon. If we had loads of tidal power stations, what would happen to the Moon? Would it fly off or get closer to the Earth?