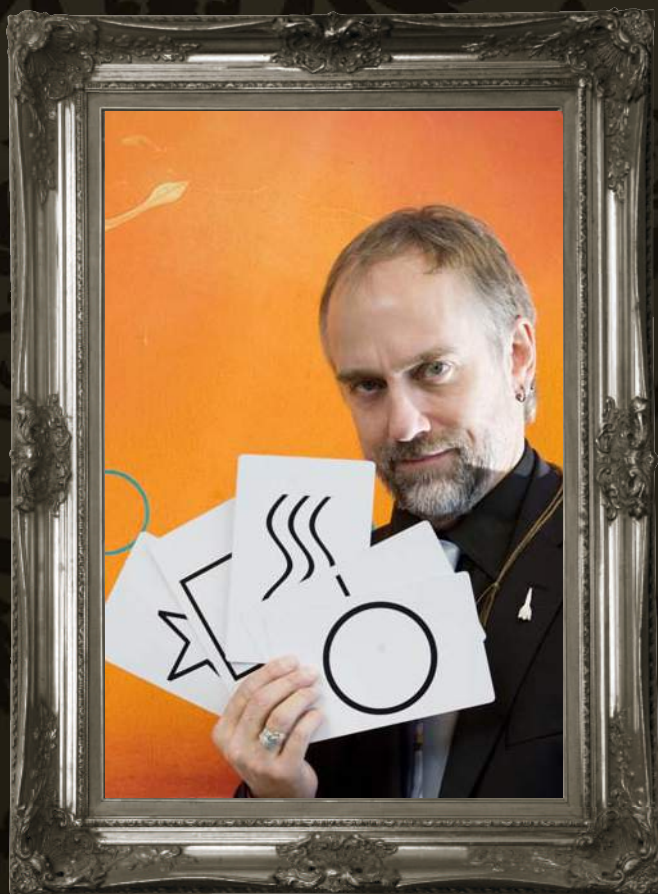




**CLEVER CONJURING
USING SECRET SCIENCE
& ENGINEERING**

PETER M^COWAN, MATT PARKER AND RICHARD GARRIOTT



Science and engineering represent great opportunities for magic. In this book you will find some amazing and easy-to-do magic tricks based on secret chemistry, physics, engineering and maths, so you can entertain your friends and explore some clever science and engineering too.

I've been a keen magician and collector of magic props all my life. The wonders of science and magic have inspired me throughout my career, from the mythological computer worlds I created in my Ultima video game series, to performing the first full magic show in microgravity when I visited the International Space Station in 2008.

Peter, Matt and I all share the vision that science and engineering are amazing and can lead to astonishing careers, but we also love to present entertaining magic too. It's never better than when you can turn your audience into scientists for a moment. In that flash of pure astonishment they ask themselves, "how can that happen?". We hope you learn from and have fun with this book. Just remember to keep the secrets and enjoy the science!

RICHARD GARRIOTT

magician, video games pioneer
and space explorer



THE DISAPPEARING COIN!

EFFECT:

You place a coin on the table right in front of your friends. Then, while they continue to stare right at it, the coin disappears from sight!

DESCRIPTION:

You take any standard coin and place it under a clear, empty drinking glass. The spectators can still see the coin clearly through the glass. Then you slowly pour normal water into the glass and as it fills up, the coin vanishes! The amazed audience can still see through the water and glass to where the coin used to be before it disappeared.

HOW IT WORKS:

When light passes through different substances it can be bent around. This is because light travels at slightly different speeds in different substances. The coin under the glass will actually look a bit distorted because the light is refracted slightly when it goes from the air to the glass (and then from the glass to the air again). However, your audience is used to this because they see glass doing this all the time. Water does the same thing, which is why objects can look like they're bending as they enter into water.

The speed that light goes in water is different to air (which is called the water's "refractive index") and at the water-to-glass boundary the change in speed is so great that the light from the coin gets so refracted it actually looks like it bounced back off the glass and stays in the water. This is called "total internal

refraction" and means that none of the light from the coin escapes from the sides of the glass. The coin is there, but light from it can't get out of the glass!

HINTS AND TIPS:

The light from the coin does eventually leave the glass. After it is totally internally refracted on the water-glass boundary, it then hits the top of the water and is refracted out of the water-air boundary. So if you look directly down, into the glass, you will once again see the coin. So you need to make sure your spectators are looking through the side of the glass.

For this reason it's best to use a tall glass with lots of water and have it as high as possible.





THE LEVITATING WHEEL!

EFFECT:

You hold a large bike wheel up from both ends of its axle. Then you let go of one end and the wheel continues to be suspended in mid-air even though nothing is holding it up!

DESCRIPTION:

You will need a normal bike wheel that has an axle running through the middle. Around each end of the axle you have a loop of rope to hold it. Get a volunteer to start spinning the wheel for you. Once it has reached a decent speed, lower and remove one of the support ropes: the wheel will continue to remain suspended in the air as if the rope was still there! It will even start to drift around to show that there is nothing attached to the free end.

HOW IT WORKS:

This only works when the bike wheel is spinning above a certain speed. If you try the trick with a stationary wheel, it will just

drop to the ground exactly as expected. Practice doing the trick with a helper until you find the speed above which the wheel will stay suspended in the air.

The spinning of the wheel causes something called the "gyroscopic effect". This is one of the reasons why it's very easy to stay on your bicycle when you're rolling along, but as soon as you come to a halt it's absolutely impossible to stay balanced.

Like moving objects have forward momentum, a spinning wheel has angular momentum as it rotates. For the wheel to tip, this angular momentum has to change to a new angle. Just as it is difficult to stop a large object that is moving toward you, it's hard to change the angle of a large spinning object. This will keep it suspended in the air until it slows down and drops.

HINTS AND TIPS:

The wheel still needs to be supported though. So when you remove one support there will now be twice as much weight on the other remaining support. If you are ready for this, you can make it look like it's not taking any extra effort at all to hold it in the air.

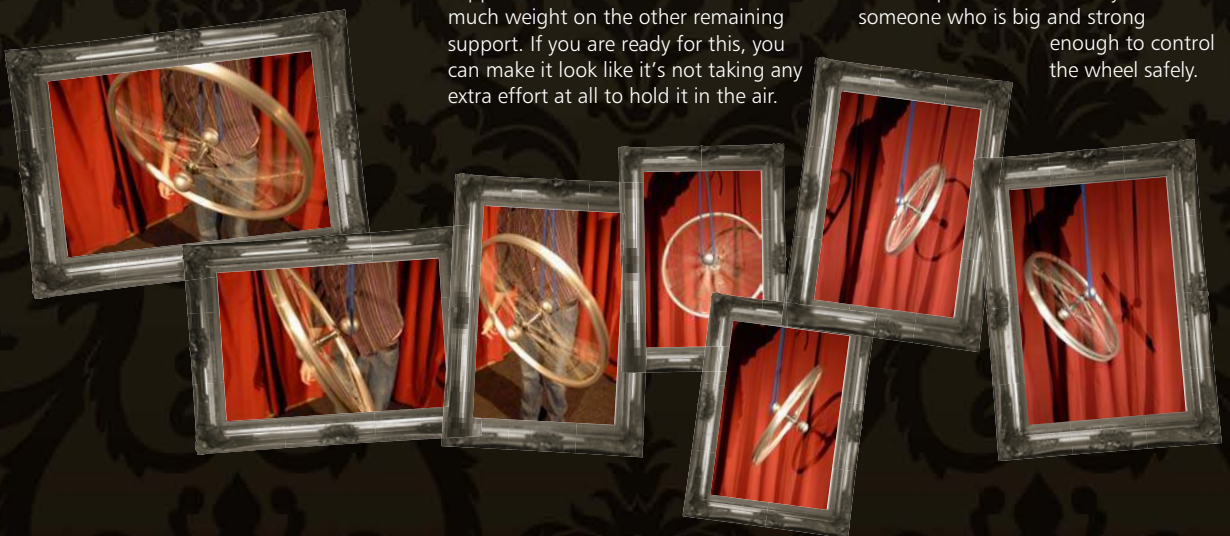
If you cannot get a bike wheel on an axle, remember that this trick works with any spinning object. If you attached a string to the base of a toy spinning-top, you can then suspend it sideways in the air.

When the spinning object is suspended from one end it will start to rotate slowly around that support point. This is called "precession" and if you're ready for it, you can make it look like you're demonstrating that there is nothing attached to the free end.

Makes sure you practise this trick with a helper to make sure you can handle the spinning bike wheel. You will also need to have a plan for how to stop the spinning wheel when the trick is over!

SAFETY:

A spinning bike wheel can do a lot of damage if you're not careful. Do not let your fingers go anywhere near the spokes as they could get seriously injured. Always perform this trick with a helper and make sure you have someone who is big and strong enough to control the wheel safely.





CUT IN HALF

EFFECT:

A volunteer tries to cut a piece of paper in half, only to discover that it's joined itself back into one piece!

DESCRIPTION:

You and a volunteer will both take a large loop of paper each and a pair of scissors. Then you will both cut right around the middle of the loop to produce two loops: which is exactly what your piece of paper will do. Theirs, however, will still be one continuous loop, only now it will be twice as long!

Then you can get two other people to try with two new loops. One of them will actually get two loops only they'll be joined together and the other will get one bigger loop but now there will be a knot tied in it!

HOW IT WORKS:

These are not normal loops, but rather they are twisted loops. The properties of twisted loops were first investigated by the mathematician August Möbius in 1858, so they are often called Möbius Loops.

The four loops are:

Zero Twists: This is the normal loop that you can successfully cut in half.

One Twist: This is the loop you give your first volunteer that, when cut in half, gives one bigger loop.

Two Twists: This will give two different loops, but they will be linked together.

Three Twists: This will give one big loop that will have a knot tied in it.

The act of twisting a loop before joining it together means that the left side of one end is connected to the right side of the other and vice-versa. This is why cutting it in half gives you one big loop. Two twists connects the left side back to the left side but only after it has been wrapped around the right side. Three twists again connects the left sides to the right sides, but it's also wrapped around itself; this becomes the knot when it's cut in half.

HINTS AND TIPS:

If the loops are sufficiently long, then it's difficult to spot that there are any twists in them. You can also experiment with using fabric or ribbon instead of paper as they can be easier to cut. In fact, if you use fabric and have a starting point, then your volunteers can just rip the loop in half with no need for scissors.

Before you try this magic trick, do a test-run with smaller loops of paper so you can easily see the twists and can clearly see what is happening when they are cut in half.

For the big magic presentation: make small secret marks on the loops, or use different colours, so you can easily spot which one has a certain number of twists.

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HISTORY:

The area of mathematics which looks at how shapes are linked and connected is called topology. August Möbius was one of the first mathematicians to develop topology.

Magicians have been using mathematical shapes in illusions for many years. In the early 1900s this Möbius loop trick was known as the "Afghan Bands".





THE VANISHING BOWL OF WATER

EFFECT:

A bowl full of water you are carrying vanishes in mid air.

DESCRIPTION:

A bowl sits on a tray carried by your assistant. You pour a glass of water into the bowl, cover the bowl with a cloth, and lift it from the tray. You step forward carefully with the cloth-covered bowl, so as not to spill a drop. Suddenly you toss the cloth into the air, and the bowl and the water disappear right in front of your audience's eyes.

HOW IT WORKS:

This is a classic of stage magic, updated to use the latest in polymer chemistry. There are two elements to the trick: some secret engineering to make the bowl vanish, and some clever chemistry to take care of the water.

Let's explore the engineering first. The bowl is actually permanently attached to the tray; this can be done simply using a drill and a bolt, or even using some high strength glue. What this means is that the bowl will remain attached to the tray even if the tray is turned on its side. The cloth you use to cover the bowl also has some secret engineering built in. A loop of stiff wire, the same diameter as the bowl, is attached to the underside of the cloth. This means that if you hold this wire loop it will look as if the bowl is there, under the cloth. This is what magicians call a 'form' – a simple wire shape to make people believe a whole object is there, when in fact it's not.

What these two bits of engineering allow you to do is show the bowl, cover it with the cloth (ensuring the form is

aligned with the actual rim of the bowl as you 'arrange' the cloth) and pretend to lift the bowl off the tray (actually just lifting the form in the cloth), while your assistant takes away the now supposedly empty tray. The way for the assistant to do this is by switching from the original two-handed hold on the tray to a single-handed hold, casually carrying the tray and bowl at their side, with the back of the tray to the audience so they don't see the bowl. We've now taken care of the bowl, but won't the water spill out when the tray is flipped?

Chemistry gets rid of the water problem. Secured in the bottom of the bowl is a disposable baby nappy (or diaper for any American readers). Modern nappies contain an amazing chemical: a harmless

superabsorbent polymer called sodium polyacrylate, $[-CH_2-CH(COONa)-]_n$, also known as 'wetlock' or 'waterlock'. A polymer is a long chain of repeating molecules (monomers) and in the case of sodium polyacrylate, because of the sodium, each of these molecules just loves to bond with water. The crystals of sodium polyacrylate can absorb around 200 times their mass in water, turning the crystals into a gel. Sodium polyacrylate was used by NASA in developing suitably absorbent long-term underwear for astronauts in space, so it can easily soak up and hold all the water you pour in from your glass, even if the bowl is upside down.





This effect is a lovely way of showing how 'magic' comes from combining different science and engineering areas. Many of the most important research projects being carried out today also rely on this sort of interdisciplinary blending.

HINTS AND TIPS:

It's best to attach the bowl towards one edge of the tray, it looks more natural but also gives you space to carry the cloth and the glass of water on the same tray.

The bowl can't be see-through, or else the audience will spot the nappy. If you use a cheap plastic bowl, make sure it doesn't let light through before you attach it.

When selecting a tray, steer clear of stainless steel. It's too hard to drill through, so use a cheap metal tray instead.

You can secure the nappy inside the bottom of the bowl by using plastic cable ties to attach it to the bolt.

Make sure the nappy is pressed down as flat as possible in the bowl. This increases the area that catches the water, and prevents the nappy ends peeking over the sides of the bowl!

Don't pour the water from too high up or it will splash all over the place.

Make sure you give the sodium polyacrylate time to absorb the water before tipping the tray/bowl on its side. Stall for time. For example, make a show of checking that every drop of water from the glass went into the bowl.

Practise the tray/bowl removal move with your assistant. Make it quick and natural looking.

When you're ready to move the tray and bowl out of sight, get your assistant to move quickly. Do it while everyone is watching you move forward with the cloth and wire form.





THE VANISHING HEAD AKA GHOST DRINK

EFFECT:

An object – for example a bottle of pop or a human head – is placed in a box. Amazingly, it becomes transparent or sometimes even vanishes!

DESCRIPTION:

Introduce your dematerialisation box. Objects placed within can, like ghosts, be made to fade into or out of reality. You can even control the power of the dematerialisation beam, from normal to vanish, by setting the dials on your amazing magical box appropriately.

HOW IT WORKS:

The basis of this effect is physics. The technique used is commonly known as 'Pepper's Ghost'. It was originally a theatrical technique, the 'Dircksian Phantasmagoria', invented by Henry

Dircks, but the chemist graduate John Henry Pepper refined it when he worked for the Royal Polytechnic in London in the 1800s. While Pepper tried his best to ensure that Dircks shared the credit, posterity knows the effect as Pepper's Ghost, and this is how it works.

A sheet of flat glass or Perspex lets light pass straight through, like a window. But that's only half the story. A beam of light striking a sheet of glass does two things – it's partially transmitted through the window, but it's also partially reflected. This is because the refractive index of air and glass is different. The light we see coming from the glass is a mixture of the light coming through it from behind, but also any light that's being reflected from in front of it. Now imagine we put a sheet of glass in front of you,

and tilt it 45 degrees to the right. Through the sheet of glass, you can see a brick wall facing you. Off to the right is an identical brick wall at a 90 degree angle to the first one, so that it also points towards the sheet of glass. Physics tells us that for reflection the angle of incidence is equal to the angle of reflection. So if we replaced the glass with a mirror, you would still see a brick wall – it's just that the brick wall you saw would be the one off to the right, reflected in the mirror.

Now, in your imagination replace that mirror with the sheet of glass again, and pretend we installed big stage lights pointing at each wall. We can use the lighting levels to control when the glass acts like a window and when it acts as a mirror. Remember, whenever we look at a sheet of glass, we will actually see a combination of the light that comes through it and the light reflected off it. This is where Pepper's Ghost starts its haunting.





If you turned up the lights illuminating the brick wall straight ahead of you, you would see the wall through the glass. If you then dimmed the lights on the wall in front of you but at the same time increased the light on the wall to the side, the total amount of light reaching your eyes would be the same, but now the glass would act as a mirror. You would see the wall off to the side. Now imagine you put a person in front of just one of the walls. In effect by fading the lights between the walls you could fade that person in or out of existence. That's how Pepper's Ghost works.

The same physics principles make the Vanishing Head work. First, make the box interior totally black, back and sides. Inside your box you put a sheet of well-cleaned perspex. This perspex is angled at 45 degrees to the front of the box, so when someone looks in from the front they see through the perspex to the back of the box, but are also

unknowingly getting a faint reflection of the side of the box. You can now let Pepper's Ghost materialise. With your audience looking in the hole in the front of the box you place an object at the back of the box – if the box is big enough you can even get someone to pop their head through a hole in the bottom. Now all you need to do is control the lighting. One simple way is to have a hole in the top and a battery-operated torch. First use it to illuminate the object at the back then tilt it to illuminate the appropriate side. The object at the back will vanish. Getting more technical, you could set up lights in the box. Then, as the lights illuminate the object at the back dim, the lights illuminating the side brighten. The effect is the same – controlling the relative amounts of light transmitted and reflected makes things seemingly appear or vanish.

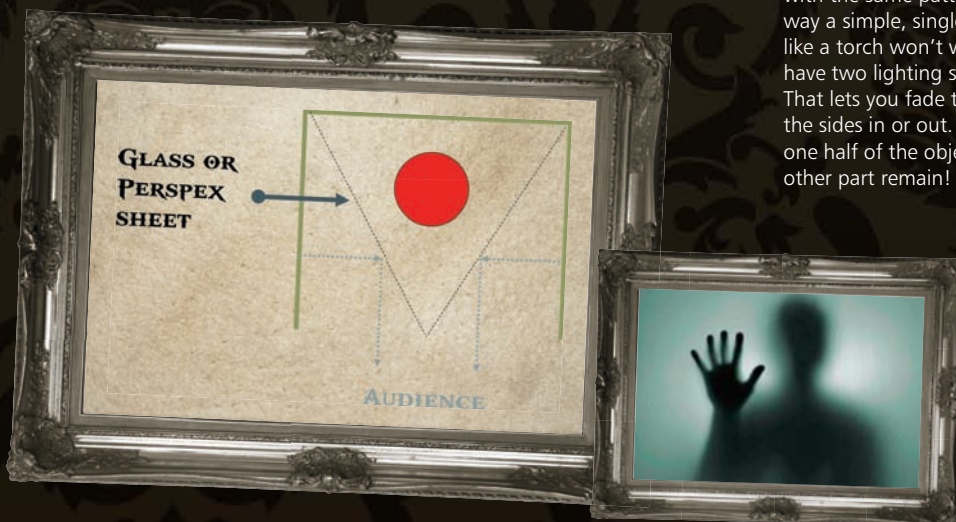
This ghostly technique is used in fun houses and amusement parks the world over, but it's also the basis for heads-up displays in aircraft. A suitably angled sheet of perspex reflects the brightly illuminated display of the cockpit instrument panel so that they are overlaid on the world the pilot sees directly in front of them.

HINTS AND TIPS:

It's best to do this in a darkened room, so there are no stray reflections.

If you're feeling up to it, you can use bold stripes or other patterns instead of a black background, so long as what is reflected from the side matches up exactly with the pattern at the back of the box.

You can also double up: to give more room in the box for objects (or a head), use two perspex sheets angled 45 degrees to the front hole, each reflecting a different side of the box with the same pattern. If you go this way a simple, single illumination source like a torch won't work, you need to have two lighting systems on either side. That lets you fade the two reflections at the sides in or out. This way can make one half of the object vanish and the other part remain!





THE UNBURSTABLE BALLOON

EFFECT:

You have the power to make a balloon invincible.

DESCRIPTION:

You subject balloons to various forms of abuse. Despite pins and other sharp objects being plunged into it, the balloon ignores the laws of nature and remains intact.

HOW IT WORKS:

This is a series of effects that take a well known phenomenon, balloon bursting, and applies a range of different forms of science and engineering techniques to prevent the pop! Each effect can be used to demonstrate a particular science subject, but as a whole they show that the same effect can be created with lots of different methods. The different approaches are detailed below, but first we need to ask: what makes a balloon burst?

Balloons are made of latex rubber. This means that if we were to look at a balloon really closely we would see billions of long chains of molecules, called elastic polymers, which stretch out to allow the balloon to inflate. To explore this, take a balloon and cover it in a regular grid of small dots. As the balloon inflates, this grid of dots will distort, showing where the molecules had to stretch the most. The round shape of the balloon means the polymers are really stretched around the middle of the balloon and less stretched at the ends. If a sharp object is poked into the areas where the molecules are most stretched, they can't stretch any further. So they give way, the air inside rushes out and...pop!

Physics version

It makes scientific sense to place your sharp object into the balloon at points where the stress is less, that's at the end points. If you take a long sharp bamboo cooking skewer and dip it in vegetable oil to lubricate the sharp end, you can pass it right through a reasonably well-inflated balloon from the knotted end to the far end. The balloon will be punctured, so eventually it will deflate, but your skewer will pass through safely. Do practise this first, though!

Chemistry version

Materials scientists combine physics and chemistry to create amazing new substances.

If we can add a material that will hold the polymer strands together we could pass a sharp object into the balloon.

This is exactly what you do when you secretly add a bit of clear adhesive sticky tape to the balloon surface for this other version of the effect. The tape is fairly invisible to the audience, and is made up of a cellophane film with a layer of adhesive. The molecules in cellophane don't stretch in the same way as latex, so if a hole is made in the cellophane tape it holds together. This, in turn, holds together the balloon surface underneath and allows the needle to pass through. Again, the balloon will be punctured and will eventually deflate, so hide it quick. This also helps keep that telltale tape from being discovered!

Biology and psychology version

This comes with a bang and a surprise. In actual fact you have two identical balloons, one inside the other. Roll up one un-inflated balloon and stick it





inside another, then unroll the inner balloon. When it's in place align their ends together, then slot a straw between the two balloons. Blow into the balloon as normal, keeping the straw to one side of your mouth. Most of the air will go to the inner balloon, but some will go into the outer balloon. When the inner balloon has reached a suitable size, use the straw to inflate the outer balloon just a little bit more. Then quickly remove the straw and tie both balloons shut. You now have two balloons, one inside the other, both well inflated. If you take a pin you can burst the outer balloon easily, but it will look undamaged. Thanks to human persistence of vision, where the brain retains a picture of things it's seen just before, the two balloons will look like the same balloon, with only a satisfying and convincing pop in between.

Mathematical version

This balloon penetration effect uses one of those long thin balloons that look like a sausage. You will also need a paper or cardboard tube that you can secure the balloon within. After you have mostly inflated this long thin balloon you squeeze it into your tube. The secret is that you twist the balloon as you put it into the tube, holding the bottom part of the balloon and twisting the top as it goes through. What this means is that although the audience thinks the balloon fills the whole space in the tube, in the middle it's twisted in a pinch. You can then safely put pins, skewers, or whatever you fancy right through the tube, missing the balloon. You can even pass the tube round for inspection. When you get it back remove all the sharp stuff, and as you take the balloon back out of the tube, untwist. You can then pass everything round

again for more inspection. There's no funny business to be found! Maths has made the impossible possible, but your secret is hidden in the twisted balloon.

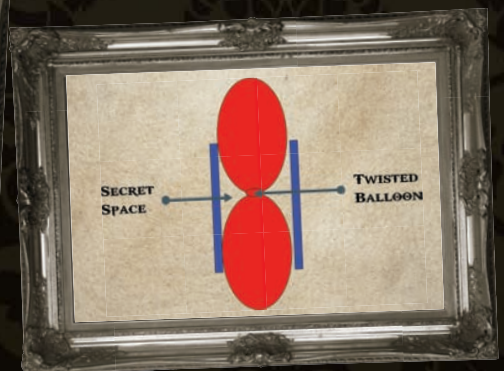
HINTS AND TIPS:

Inflate the balloon fully, then let about a third of the air out, so you can be sure you haven't stretched the balloon too much.

Make sure your skewer is sharp, and don't forget the oil to act as a lubricant.

For the psychology version, you could put a different coloured balloon inside, and do an amazing colour-changing balloon effect instead.

Don't forget, take care with sharp objects and bursting balloons.





THE PSYCHIC BOTTLE CRUSH

EFFECT:

Crushing a plastic drinks bottle from a distance demonstrates the amazing power of your mind.

DESCRIPTION:

You take an almost empty plastic drinks bottle and pour out the last remaining liquid. Then, while you or a spectator keep hold of the bottle, you proceed to crush it with the power of your mind!

HOW IT WORKS:

The secret is in the water that you pour out initially. It's warm water, so the air left in the bottle is much warmer than the surrounding air. Put the cap back on the bottle, and either hold the bottle by the cap yourself, or give it to a spectator to hold. As the warm air starts to cool, it will exert less pressure on the inside surfaces of the bottle. Normal air pressure outside the bottle will start to squeeze in on the plastic and crush it. You won't know when exactly this will happen; it will depend on relative air temperatures and the type of bottle you use, so you need to stall for time, making lots of magic gestures and so on till the crushing commences.

HINTS AND TIPS:

Don't use boiling water. It will melt the bottle and scald your hands. You just need warm water, and the Earth's atmosphere will do the rest.

Keep the warm water in the bottle for a while before you start so the air can heat up.

When pouring the warm water out of the bottle, keep the lid on first, turn it over then remove the lid. This way the hot air will stay in the bottle as the water pours out. Then put the cap back on quickly and perform the effect so the hot air inside doesn't escape or cool too much.

Don't do this outdoors on a cold day. The hot water will show as steam when you pour it out.

Normal air pressure can also crush a drinks can. You really need to heat up the air inside a lot, so that when it cools down there is a lot less pressure inside. Plastic bottles are a safer way to do the same science.

You can't be sure when the bottle will start to crumple, so keep sending waves of psychic power towards it. When the bottle does start to buckle, make a big thing of it. You really need to perform to make this work!

And of course, be careful not to burn yourself with hot water!





LEVITATION IN A GLASS OF WATER

EFFECT:

The power of your brain keeps water inside an upturned glass till you let gravity take its hold.

DESCRIPTION:

You fill a plastic cup with water, place a postcard over it and turn them upside down. When you remove your hand, the card and the water stay in place. The force of your will keeps them defying gravity until a spectator tells you to let go, at which point the card and the water instantly fall into the bowl below.

HOW IT WORKS:

This effect works with air pressure, but also takes a fairly well-known trick and extends it with a magical extra twist.

Take a plastic cup, fill it up halfway with water, then place a postcard over the entire mouth of the glass. Hold the card in place and turn the whole thing over smartly. The air pressure forcing up on the area of the card is greater than the force exerted by the water in the cup, so the card and the water stay in place. For those who haven't seen this phenomenon before it's quite magical, and for those who have...well you've a mind-control twist to add!

The water stays in place thanks to a combination of air pressure on the card and the vacuum in the cup behind it. These forces keep the card in place and prevent the water from pouring out. To be able to let the card and the water fall at your command, you need a bit of sneaky engineering. The cup has a small hole drilled in it. Use your thumb to cover this hole to prevent visible leaks when you fill the cup with water. Now go through the trick as normal, then when you decide to relinquish your mind control, remove your thumb from the hole. Air can now get into the cup and the vacuum is lost. The card and the water will now fall free as gravity intended.

HINTS AND TIPS:

Do this trick over a bowl or sink to prevent wet floors!

Using a postcard or some other type of glossy paper is important. Normal paper will absorb the water, go soggy and fall away. Messy!

If you want another way to show the power of air pressure take a ruler, place it on the side of a table so that about half of it extends off the side and cover the table end of the ruler with a sheet of newspaper. Then hit the ruler. What will happen? Spookily, the ruler will stay in place. The force of air pressure pressing down on the whole area of the newspaper sheet is more than enough to balance even a hardy hit on the ruler.

Want another example of how strange the effects of air pressure can be? Take a short strip of paper, hold it in front of your mouth and blow hard over it. Rather than bending down the paper will bend upwards! The air you blow over will be moving faster, and faster air exerts less pressure. The greater air pressure underneath pushes the paper upwards.





THE BAFFLING KNOT TRICK AKA CUT IN HALF BY ROPES

EFFECT:

A volunteer has two ropes tied around them. When the ropes are pulled tight they cut right through the volunteer, who then walks away unharmed!

DESCRIPTION:

A volunteer stands on stage while you and an assistant run two ropes behind them. You then tie the ropes around the volunteer so you are each holding two ends of either side of them.

When you and your assistant pull them tight simultaneously, they will

seem to go right through the volunteer, and then ropes that were behind them will now both be in front.

HOW IT WORKS:

When the ropes are passed behind the volunteer, it looks like both ropes start on one side and end at the other. However, each rope starts on a different side, goes behind the volunteer and then comes back out on the same side where they started.

To keep the ropes in this arrangement, you first need to hide a magnet inside each rope. This can be done by prying the threads of a rope apart, slipping in a strong "rare earth" magnet, and then tightening the rope back up.

Then when you tie the knot around the volunteer, each rope goes around the front of

the volunteer only, but the magnets keep a bit of the rope held behind them. When you pull the ropes tight, the magnets will separate and the ropes appear to quickly jump in front of the volunteer.

HINTS AND TIPS:

You need to make sure the ropes are exactly the same colour and length so the audience cannot tell which end is connected to which.

If the magnet looks like it might slip out, or causes the rope to be misshapen, it can be camouflaged by tying that bit of the rope in a knot. Several other knots at equal spaces along the rope will make sure attention is not drawn to the magnetic knot in the middle of the rope.

These knots actually make it easier to connect the magnets together. After you show the ropes separately to the audience, you can align them and run the ropes through your hand matching up each knot until you get to the middle. Do this while talking to the audience or your volunteer about the trick without looking at your hands. Once you have the two middle knots connected, walk behind the volunteer to give the other ends to your assistant and this is





when you can release the now-joined middle knots.

Make absolutely sure that you have only tied the ropes at the front and that the magnets at the back are not tangled or looped through each other. You don't want to hurt your volunteer actually tightening ropes around them! Have a secret code-word with your assistant that either of you can use if they notice the ropes are becoming tangled and you need to re-start the trick. It's better to make some excuses and re-do all of the ropes than to perform the trick incorrectly. An audience will never forgive you if you hurt a volunteer!

Rare earth magnets

Rare earth magnets are alloys of rare earth metals such as Neodymium and Samarium-cobalt which form incredibly strong magnets. Discovered in the 1960s they became affordable during the 1990s and are used in a high range of products such as computer hard-drives, electric motors and speakers. Without rare earth magnets, earbud headphones wouldn't be possible!

Danger:

Large rare earth magnets are attracted to metal and other magnets so powerfully they've been known to break people's bones that get in the way. There have even been deaths from people who accidentally swallowed rare

earth magnets that have then cause their internal organs to be stuck together.

What's not a knot?

Both magicians and mathematicians are fascinated by things that look like knots, but actually aren't. Magicians use them so something can look like it is securely tied, only for the 'knot' to come undone when it is pulled. Mathematicians have developed different ways of classifying knots but are yet to find one way that can determine if any tangle of rope is actually knotted or if it isn't. Knots are an ongoing area of mathematical research.





THE SMOKING FLASK (AKA 'STAGE SMOKE')

EFFECT:

A flask of solution changes colour while producing copious quantities of fog.

DESCRIPTION:

A large conical flask contains a light-green liquid. When some pellets are dropped in, the solution changes to a yellow, or eventually red, colour while producing huge amounts of mysterious white fog, like something from an episode of Doctor Who. This fog will pour out of the flask and drift spookily across tables and the floor.

HOW IT WORKS:

The flask contains some universal indicator and tap water (which is pretty much neutral). The pellets are dry ice which is carbon dioxide in its solid state. Carbon dioxide will freeze into a solid at temperatures below -78.5°C and go straight back into a gaseous state – known as sublimation – when it heats back up. The water warms the carbon

dioxide up and it is gaseous carbon dioxide that fumes out of the beaker looking like fog because of the water vapour in the air that condenses onto the cold carbon dioxide fumes. Because carbon dioxide is heavier than air and is still colder than the air in the room, the fog i.e. condensed water vapour will follow the trail of carbon dioxide fumes and sink down and flow across the floor.

As the gaseous carbon dioxide bubbles up through the water, some of it dissolves into solution. This causes a reaction producing carbonic acid, turning the indication yellow and eventually red. This is the same acid that is produced in carbonated "fizzy" drinks which uses dissolved carbon dioxide to produce the bubbles. This is why sparkling mineral water has a sharp, acidic taste.

CHEMICAL INFO:

$\text{CO}_2(\text{g}) + \text{H}_2\text{O}(\text{l}) = \text{CO}_2(\text{aq})$ (most CO_2 forms a 'hydrate' i.e. $\text{CO}_2(\text{H}_2\text{O})_6$)

only a small proportion actually reacts to form carbonic acid (H_2CO_3 a weak acid)

$\text{CO}_2(\text{g}) + \text{H}_2\text{O}(\text{l}) = \text{H}_2\text{CO}_3$

HINTS AND TIPS:

Dry ice is extremely cold and should be handled with great caution. If it contacts skin for too long it can cause severe freeze-burns. Always use insulating gloves when handling dry ice.

The gaseous carbon dioxide that is produced is heavier than air and will sink to the ground. This is not a problem if you are in a big room, but in a small enclosed space it could push all of the air out and you will suffocate. Always ensure ventilation windows and doors are open (if possible) have someone else around if you are producing a gas that displaces air.





INSTANT FREEZING WATER TRICK

EFFECT:

You take a container of water and touch the surface of it. Just by the power of your touch, the water freezes solid!

DESCRIPTION:

You start with a tray of water and then gently place a finger on the surface of the water. As your friends stare at it, ice starts to expand out from your fingertip until the whole block of water is solid ice. You don't even need to touch the water directly: take a bottle of water and pour it into a glass. As it pours into the glass it starts to freeze until there is a frozen block of ice in the glass.

HOW IT WORKS:

The liquid that you're freezing is not pure water and the resulting 'ice' is not actually frozen, it is just crystallised.

Instead of pure water, what you are using is a solution of water that contains sodium acetate. Sodium acetate is a salt, much like normal table salt except instead of each sodium atom being attached to a chlorine atom (giving sodium chloride, which is what you have in your kitchen), they are attached to acetate ions (the anion of acetic acid). Sodium acetate looks like normal salt and tastes just like salt (do not taste it though!) except with an acidic flavour (due to the reaction of the acetate ion with water/moisture to produce a weak solution of acetic acid i.e. vinegar!) as well. For this reason, sodium acetate is often used as flavouring on salt and vinegar crisps! If you check the ingredients on a savoury snack and see E262 listed, then that's sodium acetate that you're eating.

Like salt, you can dissolve lots of sodium acetate in water but eventually the water will reach a point where it cannot dissolve any more. However, if you heat this saturated solution up you can keep dissolving more and more salt into it. Once you've heating water up near its boiling point of 100C and dissolved in as much sodium acetate as you can, you then let the water cool back down again. All of the sodium acetate will stay dissolved but there is now much more than would normally be at low temperatures. This is called a super-saturated solution and the moment you give the sodium acetate a way to leave the solution, it will!

Sometimes, just touching the solution – or even bumping it – will cause all the sodium acetate to crystallise back out. To make sure it does this when you want, you can put a few sodium acetate crystals on the tip of your finger, or in the glass, so where the solution contacts them they start a chain crystallisation reaction.

CHEMICAL INFO:

Sodium acetate can be easily ordered through most chemical supply companies. If you talk to a science teacher they will be able to order it through the school's lab technician. They'll also have the equipment to safely heat and super-saturate a solution.

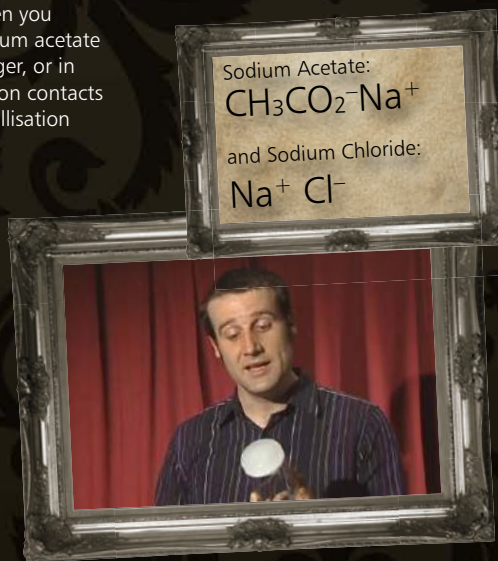
HINTS AND TIPS:

The sodium acetate will come out of super-saturated solution really easily if it contacts anything or is disturbed. Make sure you only put it in

new and completely clean containers. If you cool the containers, there is less chance of the sodium acetate coming out of solution. This can be a very difficult trick to perform because of how easily the sodium acetate comes out of solution.

When the sodium acetate solution 'freezes' it actually gives off a lot of heat! A reaction like this that produces thermal heat energy is known as an exothermic reaction. If you later apply heat to the crystallised sodium acetate, it will go back into solution ready to release that heat again when it re-crystallises. Re-usable heat pads are actually full of sodium acetate for this very reason!

Sodium Acetate:
 $\text{CH}_3\text{CO}_2\text{-Na}^+$
and Sodium Chloride:
 $\text{Na}^+ \text{Cl}^-$





THE TRANSITIONING BEAKER TRICK

EFFECT:

A glass container filled with clear, colourless liquid is briefly covered and suddenly it has been swapped for a flask full of opaque dark-blue liquid! It can then be changed back without anyone noticing the swap.

DESCRIPTION:

A conical flask (or beaker) is filled with clear liquids that resemble plain water. A cloth is placed over the flask or a piece of card is used to block it from the audience's sight. When this cloth or card is removed there will now be a different flask filled with an opaque dark-blue liquid. The cloth can be replaced and removed several more times and each time the flask will switch between the dark liquid one and the clear water one.

HOW IT WORKS:

The flask itself does not every change but the liquid inside it is undergoing an oscillating chemical reaction. Part of the time it contains elemental iodine and part of the time the iodine is dissolved in the solution as ionic iodine. Mixed in with the solution is an iodine indicator, which is basically starch. In the presence of elemental iodine the starch turns dark blue. Once the iodine goes into solution as ionic iodine the starch indicator goes back to being colourless.

You will need to have someone carefully mix the following potion:

10 cm³ 1 mol dm⁻³ sulphuric acid

25 cm³ 0.1 mol dm⁻³ potassium iodide

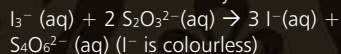
5 cm³ 0.1 mol dm⁻³ hydrogen peroxide (take care it can irritate the skin!)

10 cm³ 0.005 mol dm⁻³ sodium thiosulphate

1 cm³ starch solution

In the first, slow reaction, the tri-iodide ion is produced. $\text{H}_2\text{O}_2(\text{aq}) + 3 \text{I}^-(\text{aq}) + 2 \text{H}^+ \rightarrow \text{I}_3^- + 2 \text{H}_2\text{O}$ (I_3^- reacts with starch to produce the blue colour)

In the second, fast reaction, tri-iodide is reconverted to iodide by the thiosulfate.



HINTS AND TIPS:

After a while the solution will start to change colour more often as the frequency of oscillations increases. This means you'll have less and less time to do the swap until eventually, the solution will just stay in its dark-blue state.

If you watch the solution closely, you will see that it starts to change colour slightly before the actual change. When you see the solution start to go cloudy, you know that the colour change is imminent. Be sure to practice this trick in the lab a few times so you can perfect your timing before trying it with an audience.





THE MYSTERIOUS CHANGING BEVERAGE TRICK

EFFECT:

A bottle containing a disgusting green liquid becomes different beverages as it poured from one container to another.

DESCRIPTION:

A conical flask (or beaker) contains a green liquid. When it is poured into the first empty flask the liquid will change to a light red colour; becoming rosé wine. As this light red beverage is poured into the second empty flask it will switch to a blue colour, becoming blackberry juice.

HOW IT WORKS:

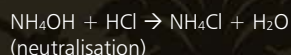
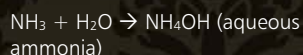
The initial flask contains normal tap water and universal indicator. Because tap water is pretty much neutral, the indicator will be in its neutral colour, in our case: green. The first empty flask actually contains a tiny volume of a concentrated acidic solution that will turn the solution acidic and so the universal indicator becomes red in colour. The final flask has a small volume of a concentrated basic solution that will turn the whole solution basic and so the universal indicator switches to be blue in the presence of a base.

CHEMICAL INFO:

For the acidic solution we used a small amount dilute of hydrochloric acid.

For the basic solution in the second flask, we used a small volume of 10% aqueous ammonia i.e. ammonium hydroxide (note that this and especially more concentrated solutions have a pungent smell, so keep your audience at a distance).

As we poured the acidic solution into the second beaker containing ammonia, it had to initially neutralise the base before the solution could turn basic. Here is the equation of the ammonia neutralising an acid:

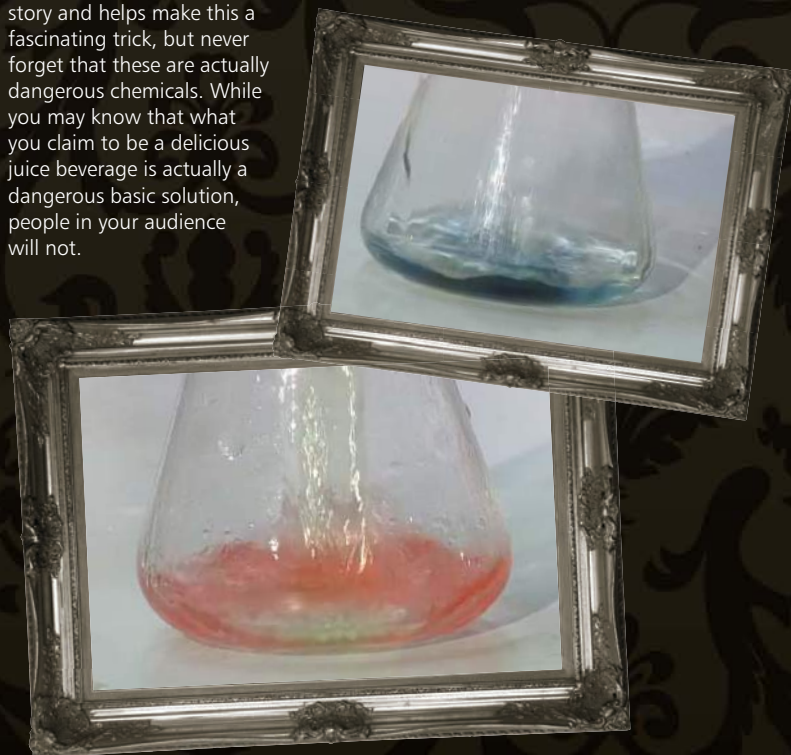


HINTS AND TIPS:

WARNING: The idea of a mysterious changing beverage is a good story and helps make this a fascinating trick, but never forget that these are actually dangerous chemicals. While you may know that what you claim to be a delicious juice beverage is actually a dangerous basic solution, people in your audience will not.

Do not leave the solutions unattended, or in the hands of a spectator, in case they try to drink them!

Dilute hydrochloric acid and aqueous ammonia solutions are corrosive so handle with care and less skilled illusioner operators should consider wearing gloves.





THE AMAZING FALLING-CARD-IN-SPACE TRICK

EFFECT:

In space a card falls, while a hammer floats.

DESCRIPTION:

Onboard the International Space Station, where everything floats in microgravity, a card and a hammer are released at the same time, and the card magically falls.

HOW IT WORKS:

This is how different magic in space looks. Filmed aboard the International Space Station by Illusioneering team member Richard Garriott, the trick adds a new space-age twist to the classic physics experiment by medieval Italian scientist Galileo Galilei. Galileo is said to have dropped a ten-pound weight and a one-pound weight from the leaning tower of Pisa and showed that they both hit the ground at the same time. Galileo was experimenting to confirm that ancient Greek philosopher Aristotle, who said that a ten-pound weight would fall ten times faster than the one-pound weight, was wrong.

Today we have a useful theory of gravity, through the work of Galileo, Newton and others, that tells us objects of the same mass fall under gravity with the same acceleration. Even if there is very little gravity to speak of, for example the microgravity on the near earth orbiting International Space Station, with about one tenth of the gravity on Earth, two objects of different mass, the card and the hammer, should behave the same, so with Richard's recreation there must be a trick!

So why does the card fall and the hammer float? The magicians' code of secrecy still applies in near Earth orbit so we here at Illusioneering aren't telling; can you work it out for yourself? Newton says we need a force to make an object move, so if it's not gravity or even the lack of gravity that makes the card fall what could it be? What do you think?

HINTS AND TIPS:

Take your maths, science and engineering seriously and perhaps one day you too will make it, or help others, into space, to float on a 'magic carpet' (that one is easy, just float) or create the next amazing magic tricks that work in space.

FASCINATING FACT

Because of a series of local wars the Leaning Tower of Pisa, the bell tower for Pisa cathedral, took around 170 years to complete. The tower began to lean even before it was half built; the foundations sank into the soil, tipping the building. To make up for this the later stages were built with a backwards bend to try and compensate for the leaning, the engineers built upper floors with one side taller than the other. Even with this heroic medieval attempt to fight the laws of gravity, eventually the battle looked like it would be lost and the ever increasing tilt would become tragic, until modern day engineers and mathematicians predicted that removing soil from one side of the foundations would encourage the tower to tip back

and stabilise itself, and it did! This story provides a wonderfully sideward view of the world where amazing modern engineering and mathematical magic helps to preserve marvelous medieval masonry.

USEFUL WEB LINK

Classroom physics and mathematical activities based around the leaning tower are available at www.upd8.org.uk/activity/304/Leaning-tower.html





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Heron's (or sometimes known as Hero's) horse was an amazing bit of ancient engineering masquerading as impossible magic. The statue of the horse would be used to prove the 'power of the gods'. A sword could be passed right through the horse's neck, and not only did the head remain in place but the horse would continue to be able to drink from a bowl of water. The secret was in some cunning internal engineering, with clever revolving cog wheels and sneaky ratchets. To discover the inner workings go to www.illusionengineering.org.

Picture by David Rowyn from Richard Garriott's private collection of magical artefacts



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The online learning videos and PDF resources for the Illusioneering project (www.illusioneering.org) and this booklet were developed with funding from the UK HESem project and supported by the Faculty of Science and Engineering, Queen Mary, University of London. Peter McOwan appears courtesy of the cs4fn project (www.cs4fn.org).

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