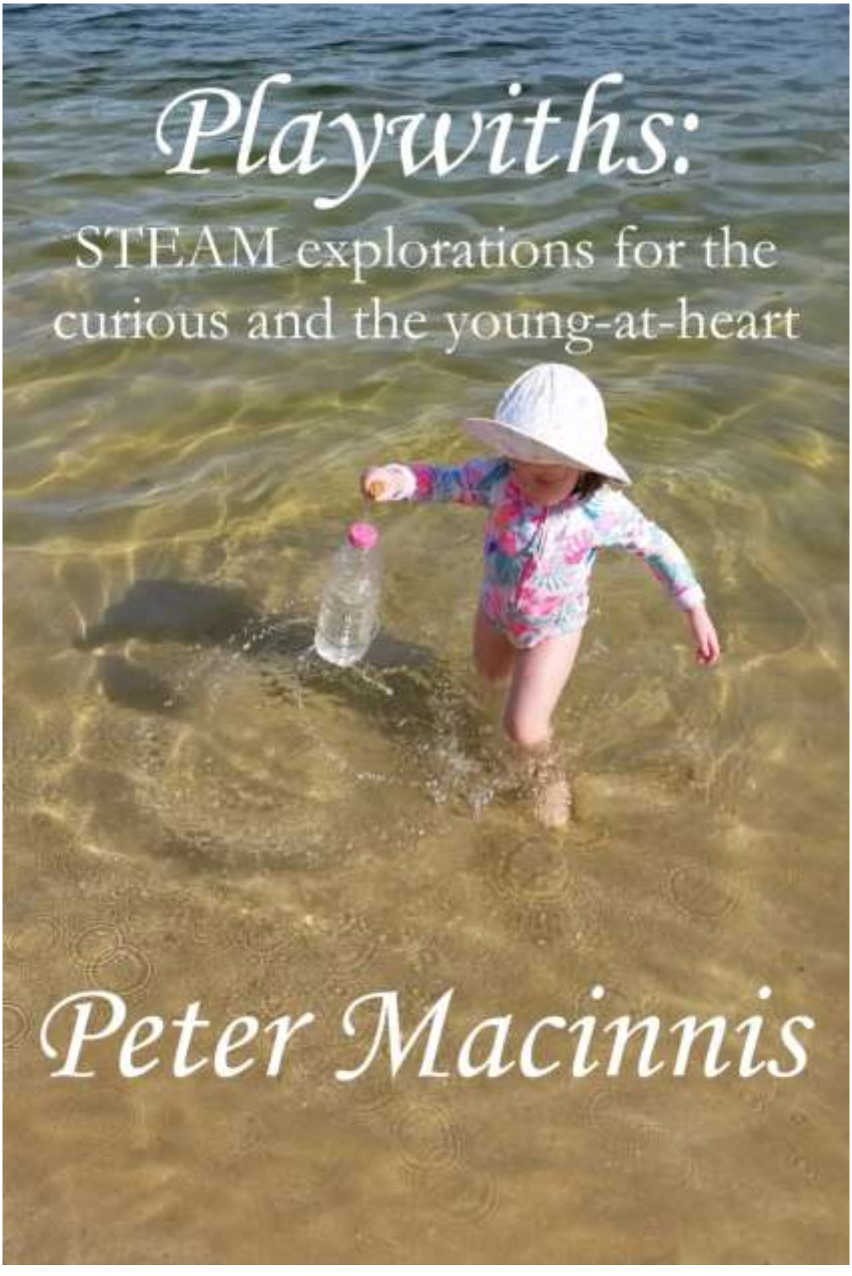

Playwiths:
STEAM explorations for the
curious and the young-at-heart
Peter Macinnis

Playwiths:

STEAM explorations for the curious and the young-at-heart

Please stop and read!

This is the cheap and nasty free version that you probably reached from http://members.ozemail.com.au/~macinnis/writing/playwithsbook.htm

This version (only) has lo-res graphics to save bandwidth, and I get zilch for it, while you get a degraded copy. You can share this version with the whiny message, but how about doing the right thing? Go to the clickable link above and buy one, please? Assuming you can afford it, that is.

A companion volume, *Looking at Small Things: a guide for naturalists*, available free if you go to this link:

http://members.ozemail.com.au/~macinnis/writing/smallthings.htm

Exactly the same deal on copyright, free copies and so on applies there, but *Small Things* is about looking at small things, animal, vegetable and mineral.

Playwiths:

STEAM explorations for the curious and the young-at-heart

The first man of science was he who looked into a thing, not to learn whether it furnished him with food, or shelter, or weapons, or tools, armaments or playwiths, but who sought to know it for the gratification of knowing…
Samuel Taylor Coleridge, (1772 – 1834), *Anima Poetae.*

This is the lower-resolution free PDF version: to chip in a small pittance by way of thanks, see the previous page.

petermacinnis@ozemail.com.au

Peter Macinnis

Publication data

Author: Macinnis P. (Peter) (1944 –).

Title: *Playwiths*.

Version: 4, 14 April 2020. *(Now complete!)*

http://members.ozemail.com.au/~macinnis/writing/Playwiths lo-res PDF version.pdf

(e-book edition): https://www.amazon.com/dp/B086BRJCMT

(print version): https://www.amazon.com/dp/B086BK29MB

Notes: Written as an e-book. Contains illustrations and navigation links.

Target audience: curious minds from pre-teens to mid-90s.

Subjects: STEAM: Science, Technology, Engineering, Arts, Mathematics.

Blurb

This is a practical introduction to the art of curiosity across Science, Technology, Engineering, Arts and Mathematics, or STEAM to the *cognoscenti*. The book aims to nurture curiosity, wisdom and joy in learning. There are no po-faced lists of "facts" to be learned.

No prior knowledge is required of readers, but the author's prior knowledge is clear: each and every one of the 300+ activities and explorations described here has been used by the author many times before. In a time of COVID-19-driven school closures, this is a tool for all instant and involuntary home-schoolers.

Peter Macinnis is an Australian writer for both adults and children. He is of advanced middle age, and he has won many awards from the Children's Book Council of Australia, the West Australian Premier's Literary Awards, the Wilderness Society, The Educational Publishing Awards Australia (EPAA) and the Royal Zoological Society of New South Wales, among others. The full list of these awards is at http://members.ozemail.com.au/~macinnis/writing/awards.htm.

Trained as a biologist, he cares about natural history, social history and the stories behind things, and is now well-regarded as a writer of Australian history. He used to talk on ABC Radio National, he sometimes teaches adults how to do extreme research and data handling, and thoroughly enjoys being the visiting scientist at his local K-6 school.

Thanks

This book is dedicated to my best friend, Christine, who like me, cares about sharing science and related matters. She has been my wife for more than 50 years. Of our three children, two are scientists, the other has a scientific mind: they grew up chewing on things like this.

I wrote this for people of any age who think outside the box (like Schrödinger's other cat), including Brianna, Alastair, Izzy and Pippa. They are our grandchildren, and played a part in this work, especially Brianna.

It began with a web site called *Science Playwiths*. This version owes a great deal to the 4 million-plus people who, between 1995 and now, visited the site, interjecting, correcting, commenting and suggesting, sometimes demanding that I add new pages. It's been a wonderful ride, one that reminds me of a comment about collaboration:

> …if computer art has a future as an art form in its own right, it is to be found in the dynamic, the animated, the interactive. It should look not towards Rembrandt, but towards Verdi's 'Aïda'. Not just the classical 'Aïda', but an 'Aïda' with the audience singing along and scrambling onto the backs of the elephants on stage. Chaos? No. Total theatre.
>
> — Philip J. Davis and Reuben Hersh, *Descartes' Dream*, Penguin, 1990, p. 53.

That said, I would never shaped, revised and remade it into this form if an unnamed Illawarra Year 6 boy hadn't suggested it, when we met at a luncheon for writers and literate youngsters at Fairy Meadow in 2018.

Of course, as I explain at the end, neither the site nor the book, would ever have happened if Julius Sumner Miller had not granted me a much longer interview than he had promised, in early 1963.

It seems that it takes a village to make a book.

$\sqrt{-1}\ 2^3\ \Sigma\ \pi$

Foreword

In my youth, we scientific types routinely solved problems that involved a steel girder of negligible mass, suspended at its centre of gravity by a silken thread, and before we were too far advanced, we heard our first physics joke.

It was about the three scientists who were trying to pick the winner of Australia's premier horse race, the Melbourne Cup, which is held each November. The first, a mathematician, gathered a wealth of data on weather, rainfall, wind, pollen counts and other possible influences, and three years in a row, failed dismally to pick a winner.

At the end of those three years, the geneticist had just finished drafting a plan for a breeding program that should, in five generations, produce a winner, but the physicist had got it right, three times in a row. The others asked the physicist how it was done. She reached into her pocket, pulled out an envelope and turned it over. Then she drew a circle on the back. "Consider," she said, "a spherical horse running in a vacuum…"

This book is suitable for all young people born after 1930, but some of the material needs greater maturity. When anything seems too hard, think "Hmmm, spherical horses!", jump over it, and come back to it later.

There is one mystery running through this book, which is explained at the end of the Afterword. You can look there, but then you will have lost the joy of discovery.

So, can you crack the code below?

$$\sqrt{-1}\ 2^3\ \Sigma\ \pi$$

Contents

$\sqrt{-1}\ 2^3\ \Sigma\ \pi$

Part 1: playing with things

> When we try to pick out anything by itself, we find it hitched to everything else in the universe.
> —John Muir, *My First Summer in the Sierra*, Boston: Houghton Mifflin, 1911, chapter 6.

When you start writing about a single thing, you find, as John Muir did, that everything else is connected, hitched together, but wonder is everywhere.

Wonder and curiosity make us human, but humans like us (*Homo sapiens*) evolved from the ape-like people we call hominids, whose emerging sense of curiosity and wonder must surely have slowly made them more human. The early ancestors, the ones who could 'read' tracks and signs were the ones that didn't starve: the others starved and didn't get to be ancestors. Modern fossil hunters use similar skills, reading bones to unravel the story of how we became human.

We call the hominids looking most like us *Homo* as well, but we call other, less-near-human pre-humans *Australopithecus*. Nobody knows why the changes began, but walking upright must have come first, because we have found a few fossil bones of *Australopithecus* specimens and the fossils tell scientists they walked on their hind legs.

Walking upright left their hands free to carry things including children, but once the hands no longer needed to be tough clumpy things that were used for knuckle-walking, slimmer hands weren't a liability. Thin hands were better adapted for holding and working with stuff, pursuing curiosity, making things, and their owners did better. Those changes happened by chance, probably driven by variations in the African climate, but once the changes happened, the path to people like us was open.

An Oldowan chopper, an early stone tool.

Tools to fit the new slim hands came next, and around two million years ago, *Homo habilis*, the first of our genus, applied the curiosity we would later call **science**. They started breaking rocks, clearly came up with methods and rules

for making good pieces, and **technology** emerged. Whenever tool-making first happened, that technology made our ancestors more human.

Fire came next, going on the evidence of old hearths with charcoal in them: these hearths and associated fossils of *Homo erectus* go back about 600,000 years. Managing fire probably involved both **science** and **technology**, but knowing how to keep a fire going was important. With fire, old people were more valuable, because while the fit adults went out for food, the old could look after the fire and the very young, training the youngsters, feeding their curiosity—the most human art of them all.

Engineering probably began when people started making shelters to keep out the weather, enemies and wild animals. There would be no civilisation without engineers making buildings and walls; bridges and roads; dams and channels for irrigation; ships and machines of many kinds.

The **Arts**, including music, painting, carving, dancing and storytelling, probably had to wait for language to develop, maybe 100,000 years ago. At night, communities sat around fires, telling stories in many ways and making things like clothes and tools, while the young watched and listened, taking it all in, and as language grew, asking questions.

This is how human culture was preserved and made to grow. About 30,000 years ago, *Homo sapiens* people in Europe were making flutes out of bone and carving figures from soft stone, or making them from clay.

The 'Venus of Willendorf' or 'Willendorf Woman' is in the Natural History Museum in Vienna. It is carved from oolitic limestone. It is typical of the other 'Venus' figures.

Around then, an Australian drew in charcoal on a rock fragment found recently in the Narwala Gabarnmang rock shelter in Arnhem Land. Modern humans were on the loose, all over the world.

Mathematics became essential once there were towns, cities and rulers who needed to know the value of π, which is about 3.14159. This is the number you get when you divide the distance around a circle by the distance across it.

The Old Testament tells us King Solomon built a temple at Jerusalem, with a circular tank 10 cubits across, and 30 cubits around. To Solomon's people, the value of π was just 3. The Hebrews were semi-nomadic herders and grain-growers, producing for local consumption, so this approximate value was good enough, although we can be quite sure the builders of Solomon's temple knew that this "good enough" was a bit off the beam.

Just nearby, in Pharaoh's Egypt, the correct value of π was a serious matter. Farmers paid tribute (taxes in the form of part of their crop) to Pharaoh's officials. The grain or other produce had to be measured in containers of different shapes and sizes, so Pharaoh took mathematics seriously. *Find me a reliable value for the ratio of the circumference to the diameter*, he must have said, *or you may end up a cubit shorter than you are now — and I'm not fussy which end it comes from!*

I would like to see a public examination in mathematics based on that principle. The people required to take it first would be those who complain about falling educational standards. If they fail, we shorten them, and once the complaints stop, we can drop the test.


At Alta, in Northern Norway, 6000 years ago, people carved petroglyphs like these, but was the picture on the left a way of recording somebody's count of reindeer? The right-hand picture seems to show that these early Norwegians had started to use fences to manage their herds, which means they probably counted them.

STEAM matters!

$\sqrt{-1}\ 2^3\ \Sigma\ \pi$

1. Science around the house

Back to the Contents

These are quickies to play with. Not a lot of pictures: just follow the words.

Which egg is which?

You have two eggs in your refrigerator. One of them has been hard-boiled, while the other egg is raw. How can you tell which egg is which?

Put one of the eggs on a dinner plate, and spin it fast. Then stop it, let it go, and watch what happens. Then do the same with the other egg, stopping it as it is spinning fast, and letting it go again.

Strange matter

Mix one and a half cups of cornflour with one cup of water in a bowl. Slowly dip your finger into the gooey mixture; then try slapping it hard with your hand or a heavy spoon. What happens? Why?

Then try letting some of the goo flow across a piece of rubber sheet cut from an old rubber glove. Stretch the rubber slowly, then stretch it fast, and notice what happens each time.

Get a pair of scissors, and pour some of the mix from a spoon. Can you snip the stream with the scissors? (Think: would I ask you this if you couldn't do it, somehow?)

Pile driver

Fill a plastic jar with rice and carefully jab a blunt knife into the rice five or ten times. The rice will settle a bit, so add more rice. Continue until no more rice can be added. Then quickly jab the knife into the rice and lift. What happens? Why?

Can you work out why this item is called "Pile driver"?

Plant-based pH indicators

Chemists measure acidity on something they call the pH scale, and an indicator changes colour as the pH changes. Take a few leaves from a red cabbage. Chop the cabbage roughly, pour hot/boiling water over it, and leave it for ten minutes. This gives an acid/base indicator that reacts to dishwasher 'detergent' and lots of other household chemicals.

Many flowers will make indicators, so will some felt pen dyes. In the mid-1970s, I had a yellow face tissue go blue on me when I used it to mop up dilute ammonia solution. There's a great opening there, but they don't make coloured tissues any more, but that yellow dye is probably out there, somewhere.

Black tea is another good choice and so are rhubarb and beetroot. Use lemon juice or vinegar as the acid, carb. soda or dishwasher solid/liquid (usually containing perborate or other nasties, with a pH of 10-11) for the base. The dishwasher detergents are dangerous if misused.

Natural dyes

Many natural dyes can be made from vegetables and flowers. Beetroot, red onion skin, carrot, rhubarb, spinach, many colourful flowers and berries, tea and coffee are just some of the things you can try. Many kinds of tree bark make good brown dyes.

You need to chop or grind whatever you are trying, bring it to the boil in an old saucepan, and simmer for half an hour or so, adding more water as some evaporates off, then dip a test square of cloth in it and leave it for fifteen minutes, before hanging it out to dry.

The effectiveness of dyes can be improved with a mordant. Add half a teaspoon of ordinary alum to about 500 mL (just under a pint) of water in a plastic container, and dissolve it. Then make up 500 mL of diluted household ammonia, and add it to the alum solution: this will produce a gel of aluminium hydroxide mordant, which clings to both the fibres and the dye.

There is a great deal of room for experimentation. Lichens can be used for some colours, an old blender can be used to do the grinding and chopping, and it may be that you can do some useful work with a microwave. Try fern stems and fern roots, and experiment with small amounts of vinegar or lemon juice (acid) or dilute ammonia (alkali) to change the colours, as most dyes work as "indicators".

Oak bark is a traditional European and American source, but what about the acorns, or the barks of gums and wattles, or other trees that grow where you live? In colonial Australia, leather workers used wattles as a source of "tanbark", from which tannins could be extracted to help tan leather.

You might also like to investigate other mordants, and try the dyes on different types of cloth: what works on wool may not work on cotton, and *vice versa*. A word of warning: aluminium saucepans and pots have a very thin layer of aluminium oxide that will bond tightly to some of these organic dyes. Use an old pot or pan, one that does not matter.

An ice lens

Take a round bowl, add a small amount of hot water, and then seal it with a piece of cling wrap across the top, raising one edge to let air escape if the plastic bulges up. As the air inside cools, the plastic will bulge inwards, making a nice mould for a plano-convex (flat/curved) lens of ice.

All you have to do is pour some boiled water that is now just warm onto the plastic, let it cool, add some more water, then put the bowl and the water in a freezer.

The plastic film is pushed in by air pressure as the air inside contracts (you can also just push the plastic down and seal it to get the same effect). Boiled

water has less dissolved air in it, so the ice is clear and freer of bubbles than ice from ordinary tap water.

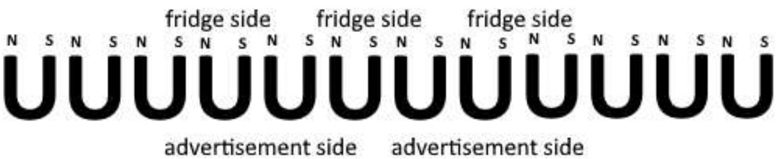
The rolling honey jar

A half-full tin or straight-sided round jar of honey or golden syrup, rolling down a gentle slope behaves in a most surprising way. Make sure the lid is firmly on, and that the tin or jar is only half-full, or less.

Refrigerator magnets

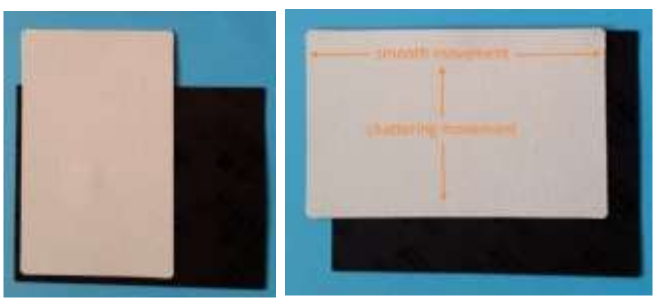
Have you ever tried sticking a fridge magnet onto a refrigerator with the black side out? If you haven't, try it, but it won't work. It seems as if the makers don't want you sticking the magnets so the advertising can't be seen.

The oddest thing is that two fridge magnets will always stick to each other because of the way they are made, with a series of magnetic strips, about 2mm apart:



A cross-section of the strips in a fridge magnet

If you pull two attracting fridge magnets across each other the right way, you will feel a sort of bumpy ride as attraction replaces repulsion and back again. Line them up, try pulling one across the other, and if you don't get the rattle effect, try moving one of them at 90º to the way you first moved, then turn one of them 90º and try different directions.



The arrangement on the left showed no effect, the right one 'rattled'.

If that doesn't work, replace one of the magnets. Some of the ones I tried failed to work, and I have no idea why, but I wondered if the 'stripes' might be in concentric circles. The most curious thing of all, until you think about the way the strips are made, is that when you have the magnets aligned, the chattering only works in one direction.

Making a weak magnet

Making a magnet.

Sewing pins and needles are often made of iron, which can be magnetised, but some of them are made of brass. You need a strong bar magnet to magnetise a pin, and it will help you choose suitable pins, or needles. Just dip the magnet in the pin dish, and use some of the ones that stick to the magnet.

All you need do is to stroke a pin or needle about 20 times, always using the same end of the magnet, and always going in the same direction. Why does this work? The official answer is **magnetic domains**: look this phrase up.

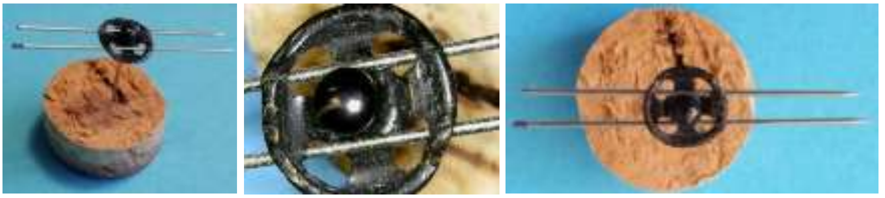
Making a small compass

What you need to make a compass.

You will need a press-stud, three steel pins and a piece of cork, as well as a bar magnet to magnetise two of the pins. A pair of pliers may be useful before you are finished, and you need a sharp knife and a cutting board to slice the cork. Check the pins with a magnet before you start, to avoid brass pins.

Take the bottom half of the press-stud, which has four holes around it, normally used for sewing it onto clothing. Using the pliers, and bending the stud as little as possible, push a pin through two of the holes. Then push a second pin through the other two holes.

Next, stroke the pins, twenty or thirty times with the same end of the bar magnet, always starting at the pointy end and going to the pinhead end (or go the other way, if you don't like following instructions!).



The finished compass

Now the pins will be magnetised. Push the third pin up through the cork slice, and balance the press-stud on the tip of the pin. Move the pins so the whole arrangement is balanced, and it should turn, so one end faces north, and the other end faces south.

The press-stud dome only makes a very small contact with the pin tip, giving an almost frictionless support. With gravitational forces balanced, the remaining force is the force of the earth's magnetic field, and this lines the compass up.

The sticking-up pin could be dangerous. Put the compass somewhere safe!

The lost explorers

There is an old physics joke about an American who had a valuable Tait brand compass that he took to Australia, but in the outback, he found that his compass jammed. In the end, some local children rescued him and took him back to a cattle station and safety. He complained to a stockman that his compass had jammed, and the stockman asked to see the instrument. "Ah," he said. "You brought a Tait's compass with you. We have a saying here, that he who has a Tait's is lost."

There is a serious point here: the Earth's magnetic field isn't level, so a perfectly balanced and unmagnetised compass needle dips once it has been magnetised. The earth's magnetic field dips away from the horizontal as you move away from the equator and this pulls one end downwards. The needle has to be filed and lightened at the lower end to balance this pull.

The problem is that the dip in the north is reversed in the south, so a compass made in England or America is lightened at the wrong end and will dip twice over, both from the magnetic force, and also from gravity. That means there is every chance that an English or North American compass will jam against the glass in the southern hemisphere, and give a false reading.

Richard Cunningham was never seen again after he wandered away from Major Mitchell's party near the headwaters of the Bogan River in 1835, possibly because his compass jammed. This may also have happened to 18-year-old Henry Bryan in South Australia when he was separated from Governor Gawler's party in 1839, not far from the Murray River.

Henry was carrying an English compass, and he was probably dehydrated. If he had not been delirious, he might have understood the problem, and tilted his compass to get an accurate reading. Whatever happened, Bryan's body was never found.

A 19th century dip circle.

Your challenge: find out what a dip circle is, and make one. A good one looks like the picture above, but William Gilbert, the first scientist to study magnets had one, and so did Edmond Halley (of Halley's Comet fame). Theirs must have been simpler…

A kitchen compass

This compass requires a cork, a sharp knife, a board, a steel pin, a magnet, a glass and some water. This method is often described on poorly researched websites, and as most of them describe it, *the method does not work*, but this one does.

The surface of water in a glass is always curved. Here, the meniscus bulges up.

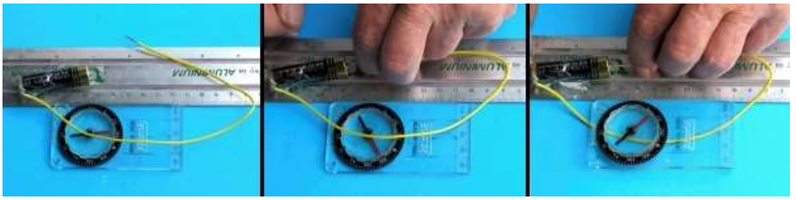
There is a fix which you won't understand until you read chapter 9. Briefly, when you have a partly-filled glass of water with a bit of cork floating on it, the water near the sides of the glass is higher, which makes the outside edge of the surface curve upwards. As a result, the cork drifts across and sticks to the side, but if you over-fill the glass, you get a bulging-up surface, and when you float a cork disc on this surface, it will stay at the highest point, in the middle. The physics behind this movement is simple and beautiful. Play with it!

Magnetise the pin by stroking it with the magnet, always moving the same end of the magnet the same way along the pin. Cut a disc of cork, fill (and then over-fill) the glass with water, and sit the disc of cork on the water. Put the magnetised pin on the cork, and your compass is ready to go, though it isn't very portable…

What Oersted found

Hans Christian Oersted (1777 – 1851) (Danes write his name 'Ørsted'), gave his name to the unit of magnetic field strength, the oersted. He also made up the word 'electromagnetic', so you shouldn't be surprised to learn that he discovered the magnetic effect of an electric current.

He connected a battery with a wire that carried electricity over a magnetic compass, and saw that the compass needle moved. If he reversed the current, the needle moved the other way, but if he ran the wire *under* the compass, this also reversed the needle's movement.



A home version of Oersted's experiment

You can see how it worked in the photo above, and as this is simple enough for the reader to try, let me note that the entire apparatus is one compass, one AA cell, a length of insulated wire and some sticky tape. The aluminium ruler is optional, which would have pleased Oersted (I'm deliberately not saying why!). I bared one end of the wire, taped it to one end of the dry cell (this was sloppy but good enough) and I bared the other end of the wire.

I taped the dry cell to the ruler, taped the compass to the ruler to stabilise it, and that was it. As you can see, the current from a single dry cell was enough to bring about a noticeable swing. Incidentally, if you reverse the wire (and as a result, the current), the swing reverses. Play with it!

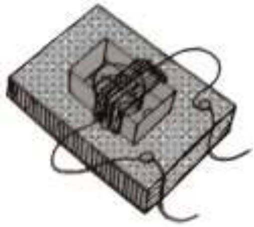
A quarter of a century later Oersted's discovery was essential to the working of the telegraph lines that had started to link the world. In his 1846 *Introductory Lecture to the Course on Natural Philosophy,* William Thomson (who later became Lord Kelvin), commented on what Oersted saw:

> Oersted would never have made his great discovery of the action of galvanic currents on magnets had he stopped in his researches to consider in what manner they could possibly be turned to practical account; and so we would not now be able to boast of the wonders done by the electric telegraphs. Indeed, no great law in Natural Philosophy has ever been discovered for its practical implications, but the instances are innumerable of investigations apparently quite useless in this narrow sense of the word which have led to the most valuable results.

So curiosity is *good*!

Measuring electricity

This is a simple gadget to detect electricity when it flows.



Wind insulated wire around a matchbox tray, and slip a compass into the tray.

The last time I made this, I used a cardboard matchbox tray, but matches are less common now. You can make a similar tray from light cardboard, or use some sort of plastic box.

You will need a piece of fine enamelled copper wire about 4 metres long, and a simple compass. Put the compass in the tray, coil the wire gently around the tray, always going in the same direction, and put it on a table, with the compass needle parallel to the coils of wire. Use sandpaper or a kitchen knife to get the enamel insulation off the ends of the wire. You need bare wire!

Nobody anticipated electronic communication, hacking and such: back in those days, spying used far simpler methods, but that's in the next chapter. First, here are some hints, clues, and even a few answers.

$\sqrt{-1}\ 2^3\ \Sigma\ \pi$

Notes for this chapter

Which egg is which?

The difference you see is due to momentum: think about what a liquid can do inside an egg shell that a solid cannot do. If you try this, you may be able to relate this to why we feel giddy after spinning around—look up <**semi-circular canals**> to find out more.

Now here is a puzzle I don't have an answer for: maybe you can find one: two cans of drink sit on the shelf in the refrigerator. You know that your mischievous friend has just shaken one of them, very hard. How can you tell which is which, before you open it?

(I would take the left-hand one, tell the friend I was choosing that one, point it at the friend, and go to open it—if the friend ducks, I would put that one down and take the other can, and repeat the experiment, but this time, I would open it, anyhow :-) This is well and good, but how can you tell if the friend isn't there? I don't know.

Strange matter

In science-speak, corn flour in water is thixotropic. Some clays and lahar, the earth that liquefies in a volcanic eruption, are also thixotropic. Lahars can be large, fast and deadly killers, so do not play with lahars.

The molecules in the starch are very large compared with molecules of water or other ordinary molecules. When you slap the surface quickly, they get tangled in each other, and this stops them splattering. In this way, the mixture behaves more like a solid.

If you move them slowly, or let them flow, the molecules can slip past each other, and so the starch behaves like a liquid. We call it a non-Newtonian fluid, and scientists speak of thixotropic and antithixotropic, so now you have the search words you need to learn more. You can also use custard powder (which is mainly corn starch) for this experiment, but watch out, because the custard leaves yellow stains if you spill it on anything.

The chemist in me says you should check to see if this yellow colour is an indicator for acids and alkalis. No, I don't know the answer…

The most important phrases in science: "*That's odd…*" and "*I wonder if…*"

Pile driver

The rice gets more and more packed down by repeated stabs from the knife until the rice is so compact that it presses against the blade of the knife with enough sideways force to overcome the pull of gravity on the jar.

$$\sqrt{-1}\ 2^3\ \Sigma\ \pi$$

The honey jar

Don't forget: the jar or can must be only half-full. The explanation: honey and golden syrup are viscous fluids: the particles hang together and only move slowly. As the jar rolls, the surface of the fluid rises at the back and slows the container down. As the fluid slides back to level, the jar or tin rolls again.

A tin of golden syrup (or treacle) is more mysterious, because you can't see what is happening. A glass honey jar makes it easier to understand and explain. The experiment doesn't work if the honey has 'candied' or crystallised. You can soften it with 30 to 60 seconds in a medium microwave. ***You must remove any metal lid*** to avoid sparking, so set the open jar upright.

Refrigerator magnets

Fridge magnets: https://engineerdog.com/2015/03/12/why-do-refrigerator-magnets-only-stick-on-one-side/. (Last accessed October 2019.) If you don't want advertising on your fridge, use a fingernail to peel off a corner of the printed message.

Think of the stripes as bunches of horseshoe magnets lined up beside each other. A friend tells me that if you have a lot of iron filings, you can cover a fridge magnet with iron filings, and see the stripes. I didn't have time to get any iron filings, but I know that garden soil often has lots of magnetic particles in it.

Make a discovery: wrap a handkerchief (or cling wrap) around a bar magnet, and pass it through some dry soil. If anything sticks to the magnet, unwrap the magnet carefully and collect the particles, taking care not to let them stick to the magnet. The fragments will, of course, make a mess of the fridge magnet when you sprinkle the filings or fragments on it. Use an old magnet!

Note: If you want more detail about refrigerator magnets, the terms to use are <**Halbach array**> and <**one-sided flux distributions**>. And by the way, the first Halbach array was designed for use in focusing the beams in particle accelerators. That's neat!

Compasses

The easiest compass needs just a bar magnet and some string. Use this mock-up for reference.

Copy this model, using cotton not rope, and a bar magnet instead of timber, to make a compass.

$\sqrt{-1}\ 2^3\ \Sigma\ \pi$

A kitchen compass

As you stroke the pins, always in the same direction, some of the random magnetic domains in the pin are flipped over, making the whole of the pin a weak magnet.

When you add more water to the glass, surface tension pulls all of the water molecules together, forming a sort of "skin", and the cork will always float up to the highest point, thus letting as much dense water as possible flow down to the lowest point, making a more stable arrangement. Surface tension is a serious matter for living things, as you can read in chapter 9.

Getting insulated wire

You can buy insulated copper wire at some electronics stores (I use Jaycar) and Bunnings sell 'bell wire' by the metre. I get most of my wire by cannibalising (pulling apart and scavenging) old electrical gear.

Old electrical motors are a good source of wire, but get some adult help.

About Oersted and aluminium

You will need to dig: it won't be hard!

Measuring electricity

The best wire to use here is 0.5mm enamelled copper wire. To make an electrical contact, you need to strip off the enamel, and emery paper is best for this. Get a small scrap of emery paper, lay the end of the wire on a piece of scrap wood, and slide the emery paper along the last centimetre or so, the roll the wire over and repeat.

When a current goes through the wire, it makes a small magnetic field, which should be able to make the compass needle twitch.

The small magnetic field pushes the needle away from where it has lined up with the earth's magnetic field (which is actually quite weak). The more turns of wire you have, and the thicker the wire, the more effect you will see, but if the wire is too thick, and there are too many turns, you may not be able to see the compass at all!

$\sqrt{-1}\ 2^3\ \Sigma\ \pi$

2. Science for spies

Alphonse de Neuville's 1880 painting *The Spy* shows a French soldier, in civilian clothes. The time is the Franco-Prussian War, and he has been captured by Prussians as he tried to get into Metz, which the Prussians were besieging. He was probably a messenger, but as he is not in uniform, he is likely to be shot as a spy. Will they find secret messages? Will he be shot? Over to you!

Back to the Contents

Sharing a cake fairly

Spies often need to share the proceeds of their crimes, so let's begin there. If a cake is to be shared between two people, one person cuts the cake in two, the other person chooses who gets which half. How would you do it with more than two people? There *is* a way!

Using invisible ink

You will need one of these: a pipe cleaner, a toothpick, or a small paint brush to use as your 'pen', or you can try making a quill pen. Steel pens were never used for invisible ink writing, because they left fine scratches on the paper that could be seen in a slanting light. Use your 'pen' to write a message on a piece of paper. Do not use too much 'ink', or the paper will wrinkle, drawing attention to the secret writing.

Invisible ink from milk

You need a small bowl and a small amount of milk. Use your chosen 'pen' to write a message and let it dry completely. The person who gets your message must heat the paper so the message reappears. This can be done by ironing or holding the paper above an old-fashioned (incandescent) 100-watt light bulb or a radiator, but watch out for burns! When milk is heated, it turns brown before the paper does, and the invisible message appears.

Invisible ink from a lemon

You need a small bowl, some lemon juice (or a lemon, a knife, a board and a squeezer), and one of the 'pens' mentioned above. You can write with lemon juice in the same way as with milk and read it after it is dry by heating it. You can also read it by spraying the paper lightly with red cabbage water. Use a plant misting bottle to spray on the red cabbage water.

With heating, the writing appears gradually because heat causes a chemical change in the lemon juice. The juice chars at a lower temperature than paper, so the writing appears faint and brown. Red cabbage water is an indicator for acids and bases. Since lemon juice is an acid, the red cabbage water interacts with the dried lemon juice and turns a different colour, so the secret message reappears.

Making red cabbage water solution:

a. Carefully chop part of a large red cabbage into small pieces on a board with a kitchen knife.

b. Simmer the cabbage pieces in hot water until it turns into a deep shade of purple.

c. Allow the water to cool, and refrigerate it when not in use.

Be careful with the red cabbage solution, because it can stain your clothes. Be sensible around sharp knives and boiling water.

Invisible ink from vinegar

You will need a small bowl, some vinegar, and a suitable writing instrument.

Write your message in vinegar and use red cabbage juice to read the message, as in the previous method. Vinegar is also an acid.

Invisible ink from starch

You need 5 mL (1 teaspoon) of corn starch in 60 mL (¼ cup) of water, and some way of heating the starch solution gently: half a minute in a microwave is about right.

Stir the starch and let it cool. Write your message on paper and let it dry.

To read it again, wipe the surface of the paper with a sponge that has been wetted in iodine and water. The iodine mixture should be 10 drops of standard iodine solution in 60 mL (¼ cup) of water. The message will show up dark purple on a light purple background.

Safety tip: Iodine can be used on cuts to kill germs because it is poisonous to living things. Drinking or eating iodine will make you sick. Wear gloves and wash up carefully afterwards. The dry corn starch message has a lot of starch. The iodine reacts with starch, and turns dark purple.

Note: Some types of paper may contain starch as a filler, which may stop you reading the message. This is a good way to discover the value of thinking ahead—and there is also a project idea here. Newspaper should be starch-free and work well.

Invisible ink from baking soda

You need baking soda, sodium bicarbonate or sodium hydrogen carbonate (same thing, three names), water and grape juice concentrate.

Mix about 60 mL (¼ cup) of baking soda and 60 mL (¼ cup) of water. Write with this mixture on paper, using a brush. Let it dry completely. To read the secret message, paint grape juice concentrate across the paper from top to bottom with a paint brush or a sponge.

Does it work with regular grape juice?

Tip: Grape juice stains things. Be careful not to spill it.

The acid grape juice interacts with the alkaline baking soda to produce a different colour making the secret message appear. Perhaps you can explore a few other fruit juices, to see if any of those work.

I haven't tried this one, but I think you will need to avoid flooding the page with grape juice, as that may wash the message away, so use a damp brush, or spray it with a misting bottle.

Invisible ink from lemon juice, honey and glycerine

I appear to have found this on the web: it was in my notes, but I don't think I wrote it, so I make no claim to it. Also, I have not tried it yet. You are on your own, Secret Agent!

You need lemon juice, runny honey and glycerine. My notes say the mix should be about 4:4:1 lemon : glycerine : honey. Glycerine can be bought at any pharmacy, and it is safe enough—but as a rule, never drink anything in the lab. Mix well and store in the refrigerator.

1. Dip a cotton swab or a brush into the ink and use it to write the secret message on a piece of paper.

2. Allow the message to dry completely.

3. To read the invisible ink, spray the message with the red cabbage water solution.

Substitution ciphers

These replace one letter with another. The simplest form is said to date from the time of Julius Caesar, and it involves replacing each letter by another letter, perhaps three along in the alphabet. The computer in the film *2001: A Space Odyssey* is called HAL, and some people think *this* was a substitution cipher for IBM. Think about it…

The trick to solving these ciphers is to do a quick count of frequencies for the different letters. That means longer passages are easier to decode, because e, r, s and t will all be common.

If you find three consecutive letters in the coded text (like J, K and L) that are turn up more than once, they are likely to be r, s and t. Try making two slips of paper like this:

Now all you have to do is slide these past each other (I have an offset of 3 in the second picture above). Once the equivalent letters match up, you can read the message off.

A code-making spreadsheet

I used a spreadsheet to generate the substitution cipher messages below. Here, I will give you just a few hints, but the rest will be up to you.

Cell A1 is the offset, the number of characters to shift. For example, if I have 5, an A will become F, B will become G and so on. Then in the rest of column A, I type the letters of the sentence to be coded, leaving out the spaces. That means your sentence becomes a column of letters, starting in A2.

I use all lower-case letters. There is an operator in spreadsheets called CODE that converts letters to numbers: A is 65, a is 97, Z is 90, z is 122. I enter this formula in cell B2: **=CODE(A2)**. Now I need to increase all of these values, so in cell C2 I put the formula **=B2+A$1**. *(The $ is a special trick that means when we copy this formula in other cells later, we will keep looking at cell A1—this is called* ***absolute addressing****. Don't worry about it, just do it!)*

	A	B	C	D	E
1	3				
2	t	=CODE(A2)	=B2+A$1	=IF(C2<123,C2,(C2-26))	=CHAR(D2)
3	h	=CODE(A3)	=B3+A$1	=IF(C3<123,C3,(C3-26))	=CHAR(D3)
4	e	=CODE(A4)	=B4+A$1	=IF(C4<123,C4,(C4-26))	=CHAR(D4)

	A	B	C	D	E
1	3				
2	t	116	119	119	w
3	h	104	107	107	k
4	e	101	104	104	h

	A	B	C	D	E
1	11				
2	t	116	127	101	e
3	h	104	115	115	s
4	e	101	112	112	p

Three views of the same spreadsheet, the first showing the codes, the other two with different offsets in A1.

The problem: some of the numbers will be too high, because we have gone beyond the range of the alphabet. All of my numbers need to be between 97 and 122. So now, I add a new formula in cell D2: **=IF(C2<123,C2,(C2-26))**. Once again, don't worry about this too much: it is just a handy bit of formula that turns numbers ***outside*** the range back into numbers ***inside*** the range. And now, we are ready to convert the number back to a letter.

In cell E2, we add the formula **=CHAR(D2)**. Now we are ready to copy cells B2 to E2 down as far as we need. Highlight those cells, then drag down to, say, row 100 and use the command **FILL DOWN** to copy those formulas. Now if you type a sentence, starting A2 and working down, the code will appear in column E.

	A	B	C	D	E
1	23				
2	s	115	138	112	p
3	i	105	128	102	f
4	m	109	132	106	j
5	p	112	135	109	m
6	l	108	131	105	i
7	e	101	124	98	b
8	e	101	124	98	b
9	x	120	143	117	u
10	a	97	120	120	x
11	m	109	132	106	j
12	p	112	135	109	m
13	l	108	131	105	i
14	e	101	124	98	b

A sample of the input and output.

(I actually get a bit more complicated, using the **=CONCATENATE** command to pull all of the letters into a single string, but I will leave that for you to play with.)

Challenge: can you use this information to create a spreadsheet that will decode such a cipher? If you are really cunning, you can enter the message in column A of this new design, and scan the 26 columns starting at E, to spot the one that makes sense. Remember that there are always simple solutions and answers in technology and engineering, and sometimes in mathematics. There are definitely areas where we can do science with everyday stuff.

Code challenge

Here is a common sentence that used to be typed by typists when they were learning to type. It is hard to analyse the frequencies, because most of the letters of the alphabet are used.

gurdh vpxoe bjasb kwhzc rqbir egury mlqbt

Here is another sentence often used by typists.

abjvf gurgv zrsbe nyytb bqzra gbpbz rgbgu rnvqb sgurc negl

Beating the frequency counts

As a teen, I had a problem with a relative reading my diary, so I devised a code that was easy to write, because I paired what I classed as 'similar' letters and swapped them. For example, A became O and O became A and so on. Here is the full set of the pairs: AO BP CK DT EI FV GX HJ LR MN QW SZ UY.

The result looks very like a foreign language:

Djez ez o zenbri igonbri, or to make it harder, ***Djeze zozen briig onbri***.

To muddy the waters, I would sometimes throw in blocks of random letters or meaningless Morse code. Can you find a better way to confuse nosy family members?

$$\sqrt{-1}\ 2^3\ \Sigma\ \pi$$

Notes for this chapter

Sharing a cake fairly

When three or more people share a cake, the first person cuts a slice. If somebody thinks it is too large, they can take a piece off the slice, but then it becomes *their* slice.

Then the next person takes a share, and so on.

Invisible inks

You can buy a misting bottle for anything from $2 upwards, but I use the ones that come with window cleaners, bathroom cleaners and stain removers. You just need to rinse and wash them very well.

More about traditional codes

Try https://www.cia.gov/news-information/blog/2016/cias-oldest-classified-docs.html. Yes, that's right: the CIA. (Last accessed October 2019.)

Frequency counts

If you want to know about letter frequencies in English, see http://pi.math.cornell.edu/~mec/2003-2004/cryptography/subs/frequencies.html (Last accessed October 2019.) I was amused to see that the eleven most common letters (in order) are etaoinshrdlu. To find out more, see https://hci.stanford.edu/winograd/shrdlu/name.html (Last accessed October 2019.)

$\sqrt{-1}\ 2^3\ \Sigma\ \pi$

3. Using forces

Children are never too young to discover something.
(And I'm never too old to not use a favourite once more!)

Back to the Contents

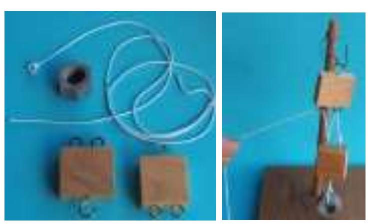
A block off the old chip

From the oldest sailing ships to modern dinghies and yachts, people have used blocks and tackles to pull sails tighter, and to raise heavy loads. A "block" is what sailors call a pulley, or a set of pulleys, mounted like the 19th century engraving on the left below, but the diagram version on the right is easier to work and plan with.

Pulley arrangements help us lift heavy loads.

In theory, the diagram on the right above shows a system that will lift a load six times the weight of a person hanging from the **effort** rope. We can calculate this ratio by looking at the number of strings (or ropes) supporting the load. The official way of describing this is to say the system has a mechanical advantage of six.

You can use simple blocks from scraps of wood like this with screw eyes and hooks to make simple weight-lifting systems. You can get screw eyes and hooks at hardware stores, and screw them into the wood by hand, if you make a small starter hole with a gimlet, a nail, or best of all, a drill.



I used blind cord to get clearer pictures, but a finer thread is better!

In reality, the lower block weighs something, so the real mechanical advantage is a tiny bit less. Welcome to the world of 'fairy physics': in physics fairyland, horses are spherical and steel girders have negligible mass, but don't worry about it.

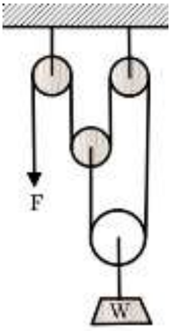
The idea is to fit a thread like cotton or dental floss to link two of the blocks, as you can see in the picture on the right, above. Try making two blocks like this, set them up, and then test them to see how many standard masses you can lift with a single standard mass. There is more friction here than in a block and tackle with pulleys, but it still works fairly well.

With this arrangement, if you pull the outside line down one metre, the mass you are lifting will only go up 25 centimetres, because there are four strings supporting the lower block, and each one shortens by 25 cm.

We can lift about four times as much weight as we are pulling with, but only *about* four times as much.

$\sqrt{-1}\ 2^3\ \Sigma\ \pi$

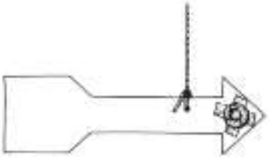
A curious tackle



A puzzle.

I am still working on a possible intuitive solution to this, based on the idea that the supporting ropes are all getting shorter to the same extent (or do they?) as the weight rises. Quickly now: what is the velocity ratio of this rig?

A cardboard wind vane



This is my favourite, and it's in two other books of mine.

The picture above shows you how to make a wind vane. Cut an arrow from a manila cardboard folder and sticky-tape a washer (or a coin) to the front end. Then find the balance point by sticking a pin in until you get it right, and tie on a piece of cotton. When you hang this, it points to the direction the wind is coming from, but if you walk around with it in front of you, it will always point in the direction you are going. Small children (like me!) love this.

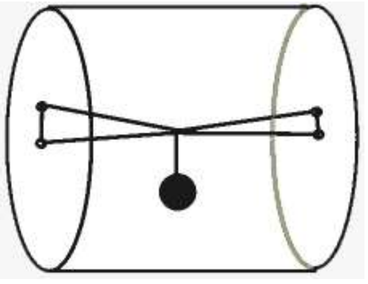
Convection snake

Cut a piece of paper into a 6 cm diameter spiral. It doesn't need to be too neat. I drew a guideline, and only followed it roughly.

Cut a piece of thread 15 cm long and tape one end of the piece of thread to the centre of the paper spiral.

Light the stove on low gas, and ask an adult to hold the paper spiral by the thread about 30 cm above the flame. (Caution: Do not allow the paper to catch fire.) What happens?

The comeback tin



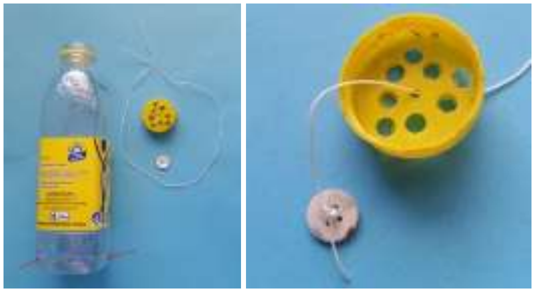
The weight in the tin winds up the elastic and makes the tin 'come back'.

This old favourite needs a large coffee tin, a drill, a length of elastic, cotton thread or string, and a small weight. Drill two holes in the lid of the tin, about 50 mm apart, and two matching holes in the base of the tin. Thread the elastic through the base holes, then through the holes in the lid, and tie the ends. Then tie the two sides of the elastic together with the string, and use the string to tie the weight tightly to the elastic.

Put the lid on the tin, and roll the tin away from you. This should "wind up" the elastic, causing the can to roll back again. The effect can be quite mystifying to those seeing it for the first time.

Hero was here

When I originally learned this trick, it used a paper milk carton. This version is much better (and messier, so try it outside!). You need a one-litre plastic milk bottle, a drill and drill bits, somewhere safe to use the drill (ask a tame adult!), a button, some fine thread a bucket of water, and somewhere safe outside the house to use it.



These pictures show you how to make this gadget

Drill the lid as shown (with a *small* hole in the exact centre), and attach the string and button through a small hole in the exact centre.

At the bottom of the bottle, drill a 2 mm hole on the left side of each face. When the water squirts out, Newton's Third Law says that every action has an equal and opposite reaction. Water shoots out the holes, and in effect, pushes back on the bottle with equal (but off-centre) force.

I tried filling the bottle from a tap while blocking the holes, but my holes were too large, so I sank the bottle in a bucket, then got somebody to lift it out, at which point the bottle span like crazy, causing wet feet. I gave it to my granddaughters to play with.

The results are pleasing to all ages from 2 upwards.

Find out more about Hero of Alexandria (also known to us as Heron of Alexandria) was, and work out what he has to do with a spinning milk bottle.

Hint: this is Hero's *aeolipile.*

Never shoot an elephant from a skateboard

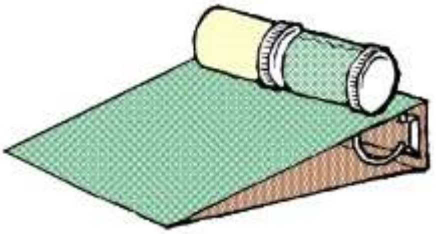
Kids! Don't try this at home, as elephants damage your parents' flower beds when they fall over, and your parents will get mad, (and the elephant will be none too pleased, either!).

Umm, sorry. The point of the heading is that an elephant has an immensely strong skull, so an elephant gun has to fire a huge lead slug that will crash through and damage its brain.

This is bad for the elephant, but to see what this leads to for the shooter, you will need some sort of a platform on rollers or castors, sitting on a hard, smooth floor, a heavy weight to throw, someone to catch the weight, elbow and knee guards, and a good sense of balance. When you fire an elephant gun, the force that sends a heavy lead slug in one direction also pushes the gun and also the shooter in an opposite direction. If you stand on your platform and throw a brick or a shot, there will be a backwards force on you in the same way.

The biological uses of this can be found if you are diving and you see a cuttlefish or squid. If you try to get too close, the squid will suddenly fly off at high speed, having just pumped a whole load of water in the opposite direction.

Racing jars



The racing jars.

Take two identical clear-glass jars, leave one empty, and fill one with water. Put the lids on both jars and tighten the lids. Put a large three-ring binder down on a level floor, and start the jars from the top of the "ramp" that the binder forms. Let them go and watch what happens. Which one gets to the bottom of the ramp first? Which one rolls the furthest?

The balancing hammer

The hammer can slip and fall, so have carpet or a mat underneath—and watch out for your toes!

Slip a rubber band over a wooden or metal ruler. Then following the picture put the band over the handle of a hammer resting at the end of its rubber grip. The hammer handle should rest against the other end of the ruler. Place the ruler's end on the table with the head of the hammer in, under the edge of a table and gently let go. Can you explain what happens?

The pendulum

Making a simple pendulum is easy. Just attach a weight to a bit of string, set it swinging, and that's it. Making a *good* simple pendulum is a bit harder. You need to take some care, mainly in getting a firm, non-slipping grip on the top of the string, but when you do, if your maths skills are up to it, a good watch and a few minutes can establish the truth of this mathematical statement:

$$T = 2\pi\sqrt{\frac{l}{g}}$$

Depending on how your local mathematics curriculum is organised, you may need some help with the mathematics: ask around about 'square root' and 'pi'.

That simple equation sums up all you need to know about a pendulum. The value l is the length in metres, and g is the acceleration due to gravity, which is usually about 9.8 metres per second per second, (or 9.8 ms^{-2} in physics). Don't worry too much about the ms^{-2} right now: you can read more in the notes at the end. Just take note of the *about*, because the variation in g in different parts of the world led to a string of interesting enquiries about the shape of the world (which is an oblate spheroid).

A good pendulum needs strong cord and a compact mass like a builder's plumb bob, which can be bought from a hardware store, or borrowed from a local DIYer (that's a do-it-yourselfer).

Resonant pendula

You will need two supports that will hold up a horizontal slack string (kitchen chairs are good supports), several lengths of string, and two heavy masses like large nuts.

Resonant pendula: work out what the name means!

Tie the masses to the loose horizontal line with identical lengths of string. Set one pendulum swinging, and watch what happens after a few swings. Next, remove one mass, add a longer string, and try it again. Is there a transfer of movement when the lengths are different? When the masses are different? When there are several masses hanging on the one system?

Energy is transferred from one pendulum to the other, and then back again, if the strings are the same length. I have never tried this, but I have been told that a pendulum should influence one a quarter of its length (*i.e.*, with half the period), but there should not be the chance to "return the compliment". Play with it!

The torsion pendulum

When you start any pendulum swinging, it keeps going because it either has a restoring force acting on it, or it has momentum. Ignore the momentum, and concentrate on the restoring force, which pulls my granddaughters on a swing down from the high point, and slows them as they approach the next high point. At the lowest point, there is no restoring force, but at the top, the restoring force is at a maximum.

Take a short length of solid wood and tie a string around it, so the beam dangles horizontally. Hang it from a hook in a doorway, and nudge it so it starts to turn. You have just made a torsion pendulum, which will turn one way until all the motion energy is stored in the twisted string. Ever so gently, the beam comes to a halt, and then it unwinds as the stored energy is returned to the wood.

Back and forth, like a swinging pendulum, it repeats this over and over, controlled by a restoring force which varies over time. The force is proportional to its displacement, the beam's distance from the rest point.

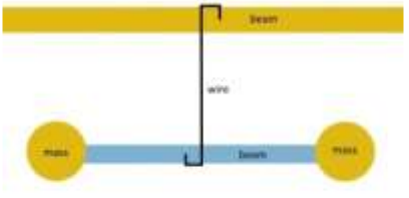
Because physicists are cunning, they can use this type of pendulum to weigh the world, and to measure the tiny forces of attraction and repulsion experienced by magnets and small electrical charges.

This is because the same restoring-force rule applies to a torsion pendulum: double the displacement and you double the restoring force. If the beam is very heavy, it will swing very slowly, but the restoring force will always be proportional to the displacement. If you use magnets or an electric charge to repel or attract a pendulum away from its rest point by 200 mm, you can calculate how big the force is.

You will need some wire, two tables or chairs, a length of 3" x 2" timber (that is, 75 x 50 mm), about two metres long, and a metre length of 2" x 1" (41 x19 mm DAR) dressed timber. You will also need a drill and drill bit, pliers or wire cutters, and a couple of heavy weights.

Piano wire is the best, and hardware stores sometimes sell piano wire but it might be hard to get. I have sometimes used bicycle wheel spokes for short lengths. You can even get fencing wire or baling wire to work, so long as the pendulum does not swing too far from side to side. You may want a couple of clamps to hold the whole rig on the tables: be sure to use scrap timber (and/or cloth) to protect the tables or chairs from the jaws of the clamps, or *somebody* will get angry!

Drill two holes close together (look at the picture on the next page) through the larger piece of timber, and cut off about 800 mm of the wire. Push some of the wire through one hole, use pliers to bend a right angle in it, and then another, so that you can ram the short end into the second hole (the idea is to have the wire attached to the beam in such a way that the wire can't slip.)



A torsion pendulum.

The torsion pendulum has a constant period, regardless of the starting displacement. Try varying things, and see how long the period is. (The period of a pendulum is defined as one full cycle from stop, through turn to stop, through turn back to stop again).

Extra reading for the enthusiast

Do your own digging, but three names stand out. Charles-Augustin de Coulomb developed the theory so he could carry out experiments on electrical charge in the 1820s. Some time earlier, John Michell planned to use the torsion

pendulum in an experiment that would weigh the earth, but he died in 1793 and in the end, his experiment was done by Henry Cavendish.

Coulomb explained that a very thin wire, which delivers a very weak restoring force, would allow even small forces to be measured. And he said the beautiful part is that you can use simple mathematics to calculate the very tiny restoring force associated with a deflection of just a few degrees.

And for older readers: when you read *Brave New World*, you will understand what image I had in my mind as I wrote this. Yes, even STEM people read literature!

$\sqrt{-1}\ 2^3\ \Sigma\ \pi$

Notes for this chapter

You could do a great deal worse than looking at the books of Henry Petroski, starting with those listed in the references. Then move on to Landels, but most of all, try things out! See also Lancelot Hogben, *Columbus, the Cannon Ball and the Common Pump*. For falling things, see my *The Speed of Nearly Everything*.

Pulleys

Engineers talk about *mechanical advantage*, calculated by dividing the weight that is moved by the weight needed to move it. They also talk about the *velocity ratio*, which compares the speeds of the load and effort. In an ideal world, with frictionless pulleys, the MA and the VR would be the same, but in reality, they never are.

That curious tackle

Trying to work this one out hurt my brain, so I made a stand with scrap timber, and measured the rise and fall.

In this shot, the base is just a flat board with dowel-sized holes, so the whole stand pulls apart.

So I now know the answer, but I'm not telling. Science is just like that.

Wind vane

The balance point for weight is towards the front of the arrow, because of the washer (or coin) taped to the front. The balance point of the arrow's area for the wind to push against is further back, so the tail will always swing away from the wind, and the arrow will point into the wind. Why is it in the chapter on forces? Play with that…

The convection snake

The energy from the gas flame heats the air above it. Warm air is less dense than cool air, so as the air heats up, it rises up from the stove. Cool air moves in to replace the warmer, lighter air. This "convection current" causes the spiral to twirl.

The comeback tin

The rolling tin stores energy in the elastic, because the weight always hangs down as the tin rolls in one direction. You can try making a second one in a clear plastic container, to show how it works.

Hero of Alexandria

A turbine relies on the energy of the moving liquid being converted into rotational energy. Hero understood this principle, but he probably never used his turbine to power anything, though he was very good with hydraulics (look that word up). By the way, 1 mm holes last longer but 4 mm holes are more fun, and the bottle refills faster. You can also try different sizes of hole. This gadget is fun at the beach.

Never shoot an elephant from a skateboard

One of the odder facts about gravity: inside a hollow sphere in free fall, the gravitational pull *anywhere* inside the hollow space is zero. If you ever become trapped in a situation like that, make sure you are carrying a spanner to throw in the opposite direction to the way you want to go.

Racing jars

I used a board, 40 cm x 20 cm, raised one centimetre at the top end: always be ready to try other ways!

This is complex physics. At first, the water-filled jar moves down the ramp faster than the empty one. This is because its weight is evenly distributed throughout its volume. The empty jar's weight is all in the glass outside so it doesn't roll quite as fast. Theory says that when they are on the flat surface, the greater weight of the full jar causes friction between the jar and the floor as well as friction between the water and the inside of the jar. The full jar is supposed to slow down, allowing the lighter, empty jar to move ahead, but that isn't what I see!

Play with this: try jars packed with rice or sand…

The balancing hammer

All objects have a centre of gravity that acts as if all the weight of the object has been balanced there. The centre of gravity of the ruler is in the middle, but the hammer's head moves the centre of gravity of the system to under the table's edge, which keeps the collection of items from falling.

Pendulum and acceleration

First, a note about acceleration: suppose your car is travelling at 72 km/h, which is 20 metres per second. We can also write this as 20 m/s (or if you know enough mathematics, 20 ms^{-1}). If you reach a motorway and accelerate in 10 seconds to 108 km/h, or 30 m/s, then in each of those 10 seconds, you

increase your speed by one metre per second, every second. Physicists say your acceleration is one metre per second each second, which means one metre per second per second, or 1 ms^{-2}.

With a value of *g* (the acceleration due to gravity) of 9.8 ms^{-2}, a falling object increases its velocity by 9.8 ms^{-1}, each second. Got it? If not, don't worry. Still, one of the problems I played with as a schoolboy was, "if you jumped from the Empire State Building, would you penetrate the roadway or splatter?"

Floors	Metres	m/s	km/h	secs
1	3	7.7	27.6	0.8
2	6	10.8	39.0	1.1
3	9	13.3	47.8	1.4
4	12	15.3	55.2	1.6
5	15	17.1	61.7	1.7
10	30	24.2	87.3	2.5
15	45	29.7	106.9	3.0
20	60	34.3	123.5	3.5
30	90	42.0	151.2	4.3
40	120	48.5	174.6	4.9
50	150	54.2	195.2	5.5
60	180	59.4	213.8	6.1
70	210	64.2	231.0	6.5
80	240	68.6	246.9	7.0
90	270	72.7	261.9	7.4
100	300	76.7	276.1	7.8
110	330	80.4	289.5	8.2
120	360	84.0	302.4	8.6
130	390	87.4	314.7	8.9
140	420	90.7	326.6	9.3
150	450	93.9	338.1	9.6

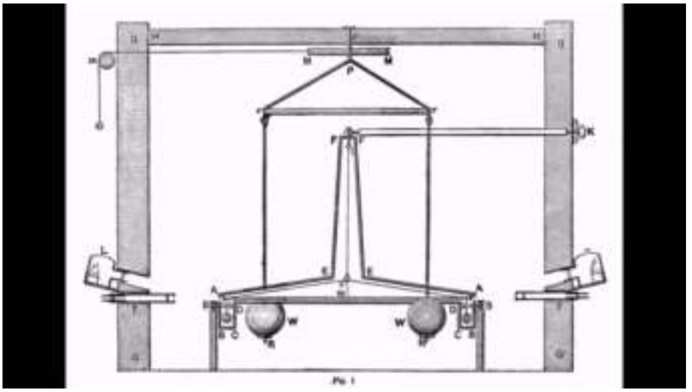
A table of theoretical speeds, generated in a spreadsheet.

Lacking sufficient data, my friends and I agreed on the compromise that you would splatter as you went through (well, we *were* schoolboys *and* physics students). The velocity v is given from $\mathbf{v^2 = 2as}$, where a is the acceleration due to gravity and s is the distance in metres. We *should* use $\mathbf{v^2 = u^2 + 2as}$, but we assume that u, the initial velocity, is zero, so the simpler formula works.

The elapsed time is calculated from $\mathbf{v = u + at}$, but once again, u is zero, so we fiddle $\mathbf{v = at}$ to $\mathbf{t = v/a}$, and use this to get the time.

Now look up *terminal velocity* to work out why this table is wrong.

The torsion pendulum



The torsion pendulum John Michell designed and Henry Cavendish used (indirectly) to weigh the earth.

Here is how Cavendish described it:

> The apparatus is very simple; it consists of a wooden arm, 6 feet long, made so as to unite great strength with little weight. This arm is suspended in an horizontal position, by a slender wire 40 inches long, and to each extremity is hung a leaden ball, about 2 inches in diameter; and the whole is inclosed in a narrow wooden case, to defend it from the wind.

Note 1: when you get a quotation this long, a web search on any ten words of it will usually get you the whole context. I just found this quote with "to each extremity is hung a leaden ball, about 2 inches in diameter".

Note 2: In the late 1990s, a torsion pendulum was used to prove the existence of something called the Casimir effect. You will have to hunt this one up for yourself. There will always be enough terms to help readers do an intelligent search.

$\sqrt{-1}\ 2^3\ \Sigma\ \pi$

4. Sound and hearing

These are definitely "don't try this at home" items!

The musical instrument above left, being played by Honoré Baudre, probably in the 1870s, is called a lithophone, a flint piano, or a silex. The other one is known as the "cat piano", and it is (I hope!) only a joke. This 19th century engraving shows seven cats, but the original description from the 1590s said there were ten cats, which yowled when a hammer came down on their tails. Note that the keyboard is two and a half octaves, so it would need thirty tuned cats.

Back to the Contents

A bell spoon

Use a slip knot to attach a metal spoon to the midpoint of a 60 cm string. Wrap the ends of the string around your index fingers and rest the fingers in your ears. Rock your body so the spoon taps against the side of a table. You will be surprised by what you hear.

The materials you need and the slip-not, before it is tightened.

With a bit of imagination, you may be able to relate this to a toy, often used by children, and involving two empty tins and a single piece of string (*a definition which rules out a pair of stilts*). When the metal spoon taps against the table, it sends a vibration up the string, through your fingers, and into your ears. Your eardrums pick up the vibrations and send them to your brain where they are translated into sound.

Sound travels in almost anything, but why is it much clearer here? Simply, the sound travelling along a solid bounces back into the solid each time it reaches the surface. The string acts like a tunnel, guiding the sound waves along and keeping them together, instead of spreading out, so nearly all of the sound gets to your ears.

If your ear is blocked in some way, sounds may not reach the ear drum, so you cannot hear them. If the small bones in your ear are jammed, the sound will not reach the auditory (hearing) nerve. And even if the sounds get that far, the nerve that carries sound to the brain may not work. These differences can be important, especially if your name happened to be Beethoven.

The deaf composer could 'listen' to the piano as he played it, by holding a stick between his teeth, and pushing the other end against the piano. The sound vibrations travelled along the stick, through Beethoven's teeth, into the bones of his skull, and so to his cochlea, where he heard them faintly, enough for him to keep composing, even after he was deaf. Whatever caused his deafness, we can tell from this that Beethoven had no problems with his auditory nerves.

$\sqrt{-1}\ 2^3\ \Sigma\ \pi$

Of Bells and bels

To scientists, sound is *a longitudinal wave that travels through a medium*, usually air. Sound also travels through liquids like water and solids like rock, wood and steel. The volume (loudness) of sound is measured using the decibel (dB) scale, which honours Alexander Graham Bell who invented a telephone.

The decibel is the unit of measurement of sound intensity. It is defined as one-tenth of a bel, either a decibel or dB. Bell was in fact more interested in the needs of the deaf than in making a telephone.

Sound engineers say the quality of a sound or tone is a combination of several things, including the waveforms in the note and the harmonics that are involved. Each explanation brings in more terms that need to be defined, so let's pause to consider Bell.

All the history books tell us that Alexander Graham Bell invented the telephone, but it need not have been so. On the very same day on which Bell's patent claim was lodged, ("for telegraphy"), Elisha Gray lodged a caveat, a limited claim. It was pure luck that Bell's attorney lodged first, without consulting Bell, just a few hours ahead of Gray.

The Bell family made a big fuss about their interest in the scientific study of speech. They must have thought this would help distinguish the young electrical amateur, Bell, from the established electrical inventor, Gray, if there were any court cases later on.

Alexander's father, Melville Bell had developed a method of representing speech with symbols, known as "visible speech". Playwright George Bernard Shaw was a friend of Melville's brother, and we can see something of Melville in Shaw's character Henry Higgins, especially in the opening scenes of *Pygmalion* (and also in *My Fair Lady*) where Higgins is shown in London's Covent Garden, writing down the speech of London Cockneys in his own notation. Melville Bell is also mentioned by name in Shaw's preface to the play.

Using his father's visible speech notation, the young Bell succeeded in squeezing human-like sounds from a Skye terrier while shaping its mouth with his hands, and he decided to try making an artificial "talking figure". If you have a dog that groans when squeezed, and which doesn't bite when its mouth is manipulated, maybe you can make a talking dog as well.

After that, Melville and Alexander visited the (now) elderly Sir Charles Wheatstone, who had made a talking device when he was 19, and asked to see his invention. Wheatstone obliged, and this planted the telephone idea in the young Bell's mind. This is how science grows.

Sound in a theatre

Acoustics is the study of how sound is produced, spread as waves and detected, and also the absorption and reflection of sound, especially in public places. It includes the study of how electrical signals are converted into mechanical signals, as in loudspeakers, and the reverse, as in microphones.

This Greek theatre was built at Taormina in Sicily in the 3rd century BCE. When this shot was taken, it was being set up for a concert, because the acoustics are still excellent.

Practical acoustics began in around 500 BC, when outdoor Greek theatres had open vases carefully placed around them to enhance sound levels by resonance. Modern theatres are designed, as far as possible, to avoid 'dead spots' where sounds reflected from different surfaces interfere with each other. Another major concern is to make an empty auditorium that mimics the acoustic effects of a full auditorium, meaning an empty seat needs to have much the same properties of absorption and reflection as a person sitting in that seat.

The acrylic donuts over the orchestra in the Joan Sutherland Theatre (the concert hall) of the Sydney Opera House from 1972 to 2020.

The donuts were to produce a 'sweeter' sound, but the Opera House people got upset if you called them donuts, and they called them "clouds", but whatever they are called, they were being removed as this book went to press.

Good hearing

Humans can hear sounds as low as about 15 vibrations per second, a tone we call 15 hertz or 15 Hz. Teenagers can hear tones as high as 20 kHz, 20 kilohertz, or 20,000 hertz, but after your teens, your hearing slowly gets worse, as you stop hearing the highest tones.

By the time you are thirty, you will only be able to hear 15 kHz, or even less, if you have been exposed to a lot of very loud music. By the time you are sixty, you will hear little above 10 kHz, and by the age of seventy, your upper limit will be about 6 kHz, not much more than the highest note on a piano. Bats and porpoises can *make* noises as high as 120 kHz, and they can *hear* 150 kHz. Dogs can hear tones as high as 50 kHz.

$\sqrt{-1}\ 2^3\ \Sigma\ \pi$

Low frequency sound

A French scientist, Marin Mersenne, was interested in sound frequencies. If you pluck a stretched string and watch it, all you will see is a blur, how could you possibly count the vibrations? The answer is simple if you know that longer plucked strings give lower frequencies. Double the length of any string and you halve the frequency.

Big may not always be beautiful, but it is attention-getting. Mersenne's 'plucked strings' were a hemp rope more than 30 metres long, and a brass wire 43 metres long. With that sort of length, the vibrations were slow enough that he could see each individual wave. By varying the length and the tension on these giant strings, Mersenne was able to find a formula that tied the frequency of a string to the length, the tension, and the mass of one metre of any wire or string.

He could now predict what the frequency of a stretched wire would be, even if the frequency happened to be too high to count. In this way, Mersenne found that the frequency of an organ pipe was 150 Hz, by tuning a wire to match the pipe, and then calculating the frequency of the wire. Mersenne wrote up his work with this dramatic introduction: "A deaf man may tune a lute, a viol or a spinet and other stringed instruments… if he knows the length and the mass of the strings."

That's all you get on this one. Why should I do all the work? Play with it!

Ultrasonic sound

Ultrasound is any sound with a frequency greater than 20 kHz. Depending on the frequency, some animals can hear some ultrasonic tones, and we use ultrasound in medicine because some very high frequency sounds are reflected back to different extents by different materials, such as some of the tissues in the human body. Medical ultrasound is usually in the range 3 to 10 megahertz.

This provides a way of getting safe and undamaging images of internal structures, which can deliver clear views of foetuses, but ultrasound is also used in engineering for things like detecting cracks in railway lines. The ultrasound pulses are produced by high-frequency **transducers** using the **piezoelectric effect**. (Now you have the technical words, you can look them up.)

To make ultrasound, get some lengths of 2 cm steel rod, ranging from 30 cm down to about 5 cm, a cathode ray oscilloscope (or CRO), a microphone, an amplifier, and some string. (Why do I think you might have some trouble doing this one at home? No matter—push somebody hard enough, and you may be able to borrow the gear.)

The longest bar will ring at an audible frequency when struck, but the shortest piece will vibrate at about 30 kHz. This ringing will be inaudible, but the microphone and CRO will reveal that the ringing is still there, even though we cannot hear it.

Shorter objects vibrate at a higher frequency. The effect will depend on the steel selected, so do some experimenting before you try this. It will help if you strike each piece of steel in its centre with a small rubber or wooden mallet.

Natural frequency

There is a popular myth that sopranos can hit high C and shatter wine glasses, but that only happens with a very special wine glass made of lead crystal, one with tiny weaknesses in it, and when tapped, it has to ring with a tone that a singer can reproduce. That tone is called the glass's natural frequency, and that tone *might* be able to shatter the glass.

If a note of that frequency is sounded, the object will begin to vibrate in sympathy with it, leading to the stories we hear of sopranos shattering chandeliers, and also of soldiers causing bridges to collapse when they marched over them in step. The simple analogy is of a child on a swing, given a series of small pushes that increase the amplitude of its oscillation.

A friend once came across some undergraduate engineers hitting a power pole with a hammer, trying to find its natural frequency, so they could shatter the pole. She gently explained to them that most of the energy of each blow would be absorbed by the soil that the pole was standing in, just as a wine glass in a hand won't shatter, because the hand absorbs the energy.

Neither will a pole in the ground, and we say the vibrations are damped. In reality, most objects are damped by their surroundings, so energy levels never increase far enough. The total energy in a system quickly reaches a limiting value, one that stays the same, regardless of how often it is hit.

Exploring pitch

A 19th century way of exploring pitch. All you need is a small gear wheel of some sort, and a piece of card to hold against the teeth of the wheel as it turns, so the card clicks each time a tooth of the gear slips past.

If you have a gear wheel with 30 teeth, making two rotations a second, there will be 60 clicks per second, and that will give you a *sort of* 60 Hz tone. The tone will not be completely pure, as the card itself produces a click that has its own frequency, but the effect will still be audible.

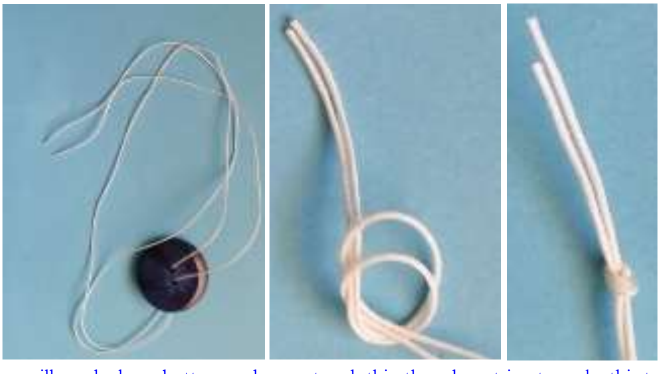
Beats

When there are two sound waves of very similar but different frequency, they will 'beat'. At certain times, the two waves are in the same phase, so that they add to each other. When they are in opposite phase, they cancel each other out. The number of beats per second is equal to the frequency difference of the two sources.

One common use of beats is in tuning guitar strings. First, the lowest pitched string is set to a reference tone from a tuning fork, a pitch pipe, or something similar. The other strings may then be tuned, one after another, by clamping off the lower pitched string of a pair at the fifth fret (or the fourth, in one case), and controlling the tension of the higher pitched string, until no beats can be detected, then using the newly tuned string as the lower of the next pair of strings.

A less common version of acoustic beating can be found in older (World War II) vintage multiple-engined aircraft, where the engines can occasionally be heard beating.

A buzz button



You will need a large button, and some tough thin thread or string to make this toy.

Put the two ends of the string through two holes in the button (if it is a four-hole button, use diagonally opposite holes), and tie the two ends of the string securely. Loop two fingers of each hand through the string, with the button in between your hands, and flip the button to make it turn once or twice.

By alternately pulling and releasing the string, the button will start to rotate, producing a characteristic roaring noise. Harder pulling produces faster rotation, and a higher tone. The two main things to remember: the button is spinning slightly irregularly, and these irregularities come at regular intervals (are you still with me?). Play with it!

The bullroarer

You can make a bullroarer with some string, a hand drill, a 30 cm ruler, and a place with enough room to swing the bullroarer. Drill a small hole in one end of the ruler, insert the string in the hole, tie a knot, and then swing it around your head.

This works better with a small fishing swivel in the string, close to the ruler. Bullroarers seem to have been common in most cultures around the world, and they were used by Indigenous Australians for ceremonial purposes.

The bullroarer spins around as you swing it, producing a compression as part of the wood swings forwards, and a rarefaction as it swings back—at least, that's my story until I can find something more satisfactory. I asked some friends about this, many years ago.

I wrote, "I have just added in the bullroarer, but I lack a good all-round explanation of the aerodynamics of the bullroarer's action. Why does it spin, and why does that spinning make a sound? Can anybody help?" Then I added, "In case you have never used one, drill a hole near the end of a 30 cm ruler, or similar piece of thin wood, insert ~1.5 metres of string, tie off, and swing it around."

Sally Edwards (Curiosity Company) offered this "I kept thinking the ruler must be moving back and forth about its long axis and the rhythmic movement might be giving the noise its distinctly "roaring" quality. Water wheels certainly create a roaring noise but I am not sure how. A roar seems to me to be a "shaky" kind of noise—one where changes in sound are regular, almost as if the vibrations themselves were vibrating. This fits to some degree at least with the different effects that you get with different sized pieces of wood (bigger surface area = lower frequency and higher amplitude) but I haven't tested to isolate changes in length, width or overall surface area."

The best Sally had found in her researches was a non-explanation like "the ruler makes the air vibrate and creates a roaring noise". She summed up what we had so far: "The bullroarer rotates, and as it rotates, it roars. What aerodynamic effect makes it rotate, and is the direction determinate? Why does

the turning make a roar, and is the frequency determinate? This is silly: somebody must know."

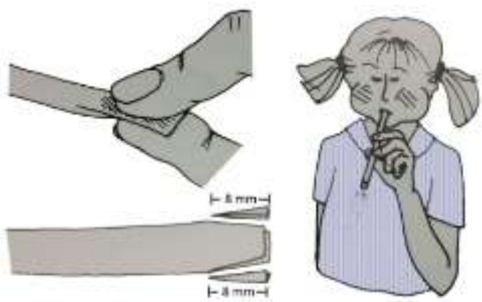
I commented: "This is getting serious. Somebody HAS to know. I want to know, Sally wants to know …" Glen Moore (then at the Wollongong Science Centre) came to the rescue, but I'm going to hide his comments in the notes.

One-tube Pan pipe

When you blow across the top of a closed tube, it makes a note, rather like a Pan pipe, which is not surprising, since the Pan pipes are a set of closed tubes.

If you blow across the top of a drinking straw when the other end is in a liquid, you can get different notes, depending on how much of the straw is under the surface of the liquid, since this controls the length of the open part of the tube. That's all—you do the rest! The note a pipe plays is determined by its length, so if you experiment carefully, you may even be able to work out the lengths for a tuned set of Pan pipes, made from bamboo.

Whistle blower



How to make a reed pipe.

This is an easy way to make a reed pipe, using a plastic drinking straw. First, flatten the end of the straw by pinching it between your fingers. Then cut off the corners of the flattened end, put that part in your mouth *past* your lips and begin to blow. If your lips are touching the flattened part, they will damp the vibrations.

If there is no sound, you may need to blow a bit harder or a bit more gently, or you may need to flatten the reed part out more by pulling it gently between your teeth. You can experiment with cutting small parts off the other end of the straw while you are blowing it, or cutting holes in the straw to play a tune, or you may be able to work out ways of joining five or six straws together, to make a very low note.

Echoes and echo effects

You will need two long cardboard tubes, a sound source like a piece of paper to crackle, a piece of cloth, and flat sheets of board, cardboard, metal, and glass. Lay one tube on a table and place the second tube at an angle to it, making a 'V', then put the sound source at the top of one arm, and your ear at the top of the other. Listen for any sound.

Then put a board at the base of the 'V' to act as a reflector. The compression waves of sound bounce off the flat surface, and like a ball on the ground, they bounce off at about the same angle as they approached (we call these angles the angle of incidence and the angle of reflection).

What is the best (and worst) reflector? Experiment with different reflector materials, and try the effect of covering the reflector with cloth. What sorts of surfaces reflect sound best? (Hint: noisy restaurants always seem to have tiled floors.)

Locating sound

How do we tell where a sound comes from? Do our brains recognize that one ear hears the sound a fraction earlier, because that ear is closer to the source? Or do our brains notice one ear hears the noise slightly louder, again because that ear is closer to the noise. The most popular theory says we can judge which ear hears the noise first, but the evidence is a bit weak. We are also able to locate sound in an up-down way, and neither explanation helps us very much there.

You will need a large piece (eight metres or more) of corrugated hose, of the sort used on swimming-pool cleaners, and a small screwdriver. Mark the centre of the length of hose, as accurately as possible, and get someone to sit with the two ends of the hose to his/her ears. The rest of the hose should be behind the subject, so it cannot be seen. Scratch or tap the hose gently with the screwdriver, and see whether the person can locate the sound as coming from either the left of the central mark, or from the right.

By doing a large number of trials, identify that part of the pipe where people never make mistakes, sometimes make mistakes, and where they often make mistakes, if you can. This experiment seems to suggest to me that we use the timing more than the strength of the sounds. Can you test this by sticking a handkerchief down one side? Make sure you can get it out again!

Sound-locating gadgets

This 19th century gadget may be an army officer trying to locate distant cannon, but it may also be a ship's captain trying to locate a foghorn. From his clothing, I think the man is a mariner, but I am no expert.

Not that it matters: the challenge here is to make something like this, and see if you can make it work. You will need two large funnels, each linked by plastic tubing to your ears, and you will need some sort of support for the whole system, as well as maybe a compass in front, so the user can directly read off the bearing to the sound source.

The idea is that two separated points for sound collection will give better separation and definition, a bit like a hammerhead shark having its eyes on the ends of extensions of its head, to give it more powerful stereo vision. I can't say that I'm entirely convinced, and I haven't tried this, but I hope people will be able to let me know how they get on, and how effective your gadget is.

The Doppler Effect

I live on a main road that has many emergency vehicles going along it. The sound of a wailing siren, dropping in speed as it passes us is something I take for granted. Early in the 19th century, as railways became more common and faster, people discovered the changing pitch of a level crossing bell, as heard from a passing train.

Those not rich enough to travel on the trains were still able to notice how the pitch of a train whistle altered as the train swept by. In 1845, Christopher Buys-Ballet put some trumpeters on a train and people were able to study the change more scientifically. If you don't have a trumpet, buy a small piezo buzzer from an electronics store, two pieces of wire, about 1.5 metres long, and a battery to match the buzzer (usually 1.5 volts). You will also need some gaffer tape.

Solder (or tape) the two wires to the piezo buzzer, attach the other ends to the battery, and wrap the buzzer in tape. Go outside, away from things that might break, hold the battery end and swing the buzzer around your head. You won't hear it in the centre, but the frequency shift between "approach" and "recede" is quite audible to anybody watching you from a safe distance.

The origin of the stethoscope

René Laënnec is said to have found a problem in listening to the heart action of a patient delicately described in most accounts as “a plump and shy young woman”. He solved the problem by connecting his ear to her chest with a paper tube, and was surprised to find that the heart sounds were then louder and clearer than when heard by an ear in contact with flesh. He soon replaced his paper tube with a wooden tube 30 cm long, the first real stethoscope.

The modern stethoscope has two bells that are connected to the earpieces via a flexible hollow tube. The bells can be selected by turning a valve that allows sound from only one of the bells to enter the tubing at a time. The open bell is used to listen to lower frequency (e.g. heart) sounds and the closed bell is used to listen to higher frequency (e.g. breathing sounds).

Notes for this chapter

Try to find Sir James Jeans' *Science & Music*. It is listed in the references at the end.

Curious music: https://www.youtube.com/watch?v=46w99bZ3W_M&index=4&list=RDkUO6ulYS-XM. Last accessed October 2019.

If you want a cathode ray oscilloscope on your smart phone, try searching the web with this string: **<CRO apps audio>.**

A bell spoon

Try holding the string in your teeth: the noise is nowhere near as impressive.

Low frequency sounds

The frequency n of a stretched string is inversely proportional to the length, and it is directly proportional to the square root of (the tension divided by the (mass per unit length)).

So you can halve the frequency if you do any one of:

- double the length;
- reduce the tension by 75%; or
- quadruple the mass per unit length (meaning double the diameter).

Glen Moore's account of the bullroarer

Bullroarers require some reasonably advanced physics to understand them but here are some things to try. If we consider the motion of a falling body such as a ruler (an approximation to a bullroarer shape) there are some interesting effects. Try cutting a small piece of paper approximately 50mm by 15mm and throw it into the air.

When it falls it undergoes a surprising motion. It will rotate about its long axis like a paddle wheel and also follow a spiralling path as it falls. The motion will not be exactly the same each time, because it depends on the way in which it is thrown. The reason for this is that a body is stable for rotations about two of what are called its major axes, through its centre of mass).

The unstable rotation is about the axis with the intermediate moment of inertia. For a ruler the stable motions are about the axis perpendicular to its plane (like a helicopter blade) and the one about its longest axis (like a paddlewheel).

The bullroarer has the added complication that it is a 'driven' motion (not free fall) and there is substantial air friction but the ideas are the same. When you swing the bullroarer around it acts much like the falling paper, taking on

the paddlewheel motion and producing lots of noise as it moves through the air…

Whistle blower extras

Sound is a set of regular compressions and decompressions (which are sometimes called *rarefactions*). When you blow down the pipe, pressure makes the two halves of the reed close up, then they bounce apart, then they close again, and so on. Each opening sees another compression race down the pipe, while each closing of the pipe causes another rarefaction as the pressure suddenly drops. There is more to it, but that might just get you started on a project.

And if you make a slit along one side of a straw for about 1 cm, you can slip that end inside a second straw to make a longer 'straw' with a deeper note. People seem to find something very funny about the noise you get from about four straws joined together…

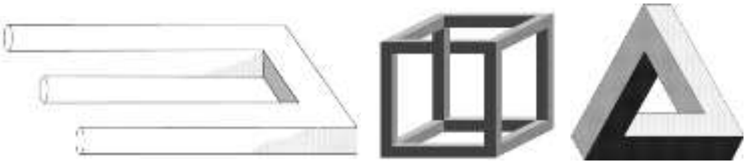
Locating sound: getting the handkerchief out

The easy way is to tie a string onto the handkerchief, but you only want it in there loosely, so unless you rammed it into the tube, it should shake out. If it won't fall out, you can always drop a broomstick in from the far end, and shake it on down

The Doppler buzzer

Sound is made of pressure waves and non-pressure waves (usually called rarefactions or decompressions). The frequency of a sound that we hear depends on how quickly the successive compressions reach you. If the buzzer is moving towards you, each successive wave comes from a bit closer, and so the compressions reach you more often, and the tone sounds higher. When the buzzer is swinging away from you, each successive compression has further to travel, and so the tone sounds lower.

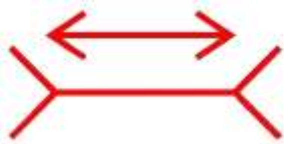
5. Tricking our eyes



Everything is not what it seems…

Back to the Contents

The arrows and the arrow heads



A simple optical illusion.

This is a simple illusion that can be used as the basis for a science project. The two horizontal lines that you see here are the same length, but one appears longer than the other.

If you set up one of these as a static drawing, the second arrow can be made as a slide, so you can get people to try to match the two lines.

You can get people to slide the lower arrow in and out until they feel that the two lines are of equal length. Generally, they will push the lower arrow in until the lower line is shorter: record the values for each subject, and maybe a few other variables like their sex and their age, and calculate a mean and standard deviation for each sub-group

How many prongs?

This well-known illusion can look like two prongs, or like three.

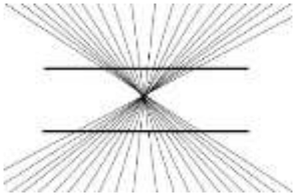
As a basis for a science project, you could ask people to say how many prongs there are, and see how long it takes them to realise that there is a contradiction.

I once passed this drawing over to the workshop of the lab where I was working, explaining that we wanted one of these in steel, exactly as shown, for a seed planting experiment. They sent the drawing back, saying there was a delay in getting the left-handed hammers they needed.

For this book, I added some extra shading to make the "two" side look more convincing: what effect would it have if you took that shading away? The other factor that could affect this illusion is its length. Maybe you could study how long it takes people to notice something is wrong with different lengths of the same illusion? As in all tests of this sort, it is important to get some good advice on statistical significance, and how you measure statistical significance.

$\sqrt{-1}\ 2^3\ \Sigma\ \pi$

How straight is that?



The two horizontal lines are completely straight, as you will see if you redraw this diagram for yourself, yet they look to be curved.

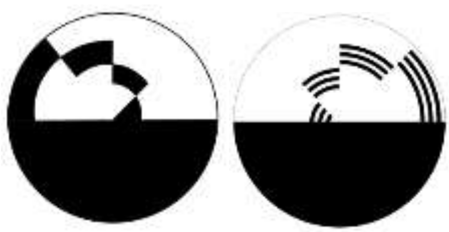
I have been playing with the idea of one of these, made with black wire, where people can bend the thicker horizontal wires until the "lines" look straight, but I have yet to work out how to measure the bending easily.

Maybe the answer is to have a wheel with a dial and a thread that pulls on the wire? It's your project…

Colour out of nothing

When toymaker Charles Benham invented his Benham discs, more than a hundred years ago, he put these sorts of pattern on the upper surface of a toy top, which may give you a hint about how to spin it.

These small and simple devices will make you wonder just what colour really is. When you spin one, your eyes will often perceive colour. They say spinning the disc in the opposite direction can reverse some of the colours, and there are other interesting effects to find as well.



Two of Benham's discs.

Use a pair of compasses and heavy paper to make discs like this, about 10 cm across. You can mount the disc on cardboard, fit a small bolt through the exact centre, and spin the disc in a drill (get adult advice on using a variable drill).

The first report of the disc was a brief and anonymous note in the British science journal *Nature* in 1894. It described the disc as a black semi-circle, with a white half divided in four, and with black arcs on it. As the disc turns, it said, people see different colours from the different black arcs. Soon after Benham said that if you shine a bright sodium flame on the disc, you will see a very clear blue, and a very clear red, but other people said they could not see this at all.

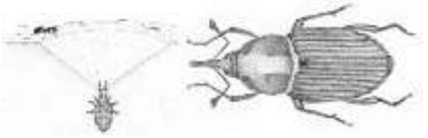
The "official" explanation now says we have three kinds of light receptor in our eyes, in the same way there are three kinds of phosphor in a colour TV. Speaking crudely, these light receptors, the cone cells, are all sensitive to just one of red, green and blue.

According to the theory, you need all three kinds of cone in the retina of your eye to see colours normally. Somehow, the cones that pick up one of the colours (red, for example) must react differently to flashing lights of a particular frequency.

So with different size black bits on the disc, we get different frequency effects, and our eyes are stimulated to "see" different colours. That's what the theory says, but nothing seems to explain the alleged effects of sodium light.

Some reports said different rotation speeds were needed for different people to see the same effects. Explore this claim, and see what you can discover. There are other patterns for Benham discs, some of them are better, some worse. Do some web research, then can you invent a better design?

Getting grey from black and white dots

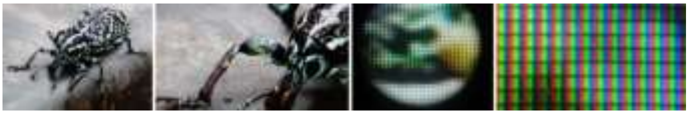


Drawing is all about lines, correct? If you look at the drawing above, there aren't many lines, there, except for the ant. And how about the weevil on the right?

Look as closely as you like at the weevil, because I drew it, and it was entirely done with fine dots, in a technique called stippling. Most of the printed pictures you look at are made of dots.

Screens and pixels

Let's stay with weevils for a bit. Here are four pictures of the Botany Bay Diamond Weevil, a specimen of which was taken to England in H. M. B. *Endeavour* in 1770. The four shots are successively higher magnifications of the same picture. (I took them for another book.)



Four views of the same picture at different magnifications.

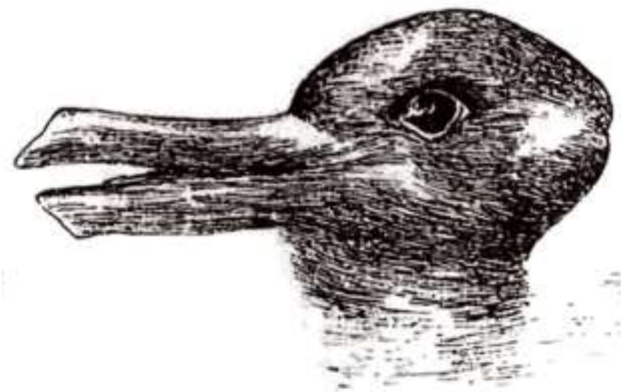
The screens of a tablet, a MacBook and a television.

If you have a hand lens or a clip-on microscope, examine your TV, your computer screen, a tablet and a smart phone, and you will see something like the images above. If you don't have a range of screens to look at, try printed pictures and see what you can detect, because books also fool our eyes.

This is from a biology book that was in reach as I wrote this page. I have shown in the first two where the next one came from.

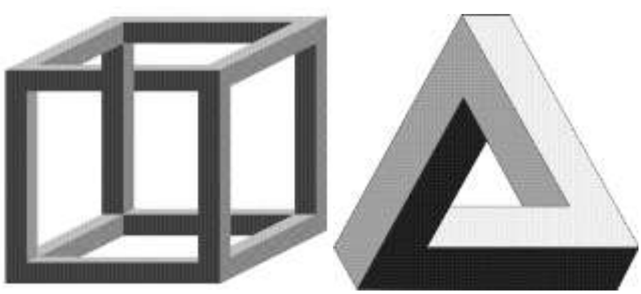
More illusions

Here are a few examples of the old standards that are all over the internet. The first two are from 19th century German sources: a duck or a rabbit on the left and on the right, an old woman or a young one?



Duck or rabbit; and maid or crone?

Next: an impossible cube and an impossible triangle: can you find their creators' names?



Notes for this chapter

You really should look into the works of M. C. Escher. Older readers can try Douglas Hofstadter's *Gödel Escher Bach: an Eternal Golden Braid* which will teach you a lot about computers and systems. Now I warned you there would be some art in here: go and look up *pointillism*, and look at the work of Georges Seurat and Paul Signac. Try pointillism yourself, although stippling, done with an Artline 0.3 mm fine-point is easier. My weevil was done with a 0.3 mm Rotring pen.

The arrows and the arrow heads

It may also be worthwhile asking whether people have seen this illusion before or not. You might find it worthwhile seeing what effect it has if you change the angle of the arrow head, keeping everything else constant.

To make the measurement easier, if set the test apparatus up on an upright board, and observe from behind it as people arrange the arrow, sliding it along a slot. Then you can put a scale of some sort on the back, so you can read the length off without having to get out a ruler or measuring tape.

Most importantly, if you are going to try this sort of thing, you will need some expert advice on how to do the statistical analysis. You will usually find differences in the means and standard deviations for groups, but you need to apply tests of significance, to see if the differences are likely to be just chance variations or not. Find an expert!

A note about statistics

At one stage in my working life, colleagues used to come to see me for help with "crunching their numbers". A statistic is a number that gives you a quick summary, and often they only had the summary numbers, and the original data had been tossed out. Whatever you do, never, ever, ever throw away any of the data, until well after all of the analysis and discussion is finished!

Benham discs

In the 1890s, if you wanted to see Benham's discs, you would look for the designs on a children's toy, known, predictably, as 'Benham's top'.

> An 'Artificial Spectrum Top', devised by Mr. C. E. Benham, and sold by Messrs Newton and Co., furnishes an interesting phenomenon to students of physiological optics. The top consists of a disc, one half of which is black, while the other half has twelve concentric circles drawn upon it. Each arc subtends an angle of forty-five degrees. In the first quadrant there are three such concentric arcs, in the next three more, and so on; the only difference being that the arcs are parts of circles of which the radii increase in arithmetic progression. Each quadrant thus contains a group of arcs differing in length from those of the other quadrants. The curious point is that when this disc is revolved, the impression of different colours is produced upon the retina.
> —*Nature*, 51 (1309), November 29, 1894, 113–114.

There is a further illusion (involving the full moon) described in chapter 8. Everything is connected!

Name that illusion

Most of the time, two or three words will find your answer. I knew we were looking at a Necker cube and a Penrose triangle, but I confirmed this with these two searches: <cube illusion> and <triangle illusion>. (Note that when a **search string** is surrounded by angle brackets, you leave the brackets out.)

$\sqrt{-1}\ 2^3\ \Sigma\ \pi$

6. Sight and light

In the 19th century, photography moved rapidly from a technology to an art.

Back to the Contents

Light adaptation

When you walk out of a brightly lit building at night, it takes a while before you can see what is around you. This happens as the pupils of our eyes open wide in the dark, to let more light in. We say that our eyes adapt to the dark.

The five named stars of the Southern Cross and the Pointers, which help us find the Cross.

How long does it take your eyes to grow dark-adapted? Use a standard star as your measure (in the southern hemisphere, try Epsilon in the Southern Cross), and see how long it takes for you to be able to see it after looking at a candle flame, a wood fire, and an electric light, keeping all other conditions the same.

Our eyes slowly get more used to the dark, but you will get different results on the night of a full moon, in a city, or just after sunset. *Epsilon crucis*, the smallest star in the Southern Cross, is the extra star in the Southern Cross on the Australian flag, which is not on the New Zealand flag, and which is now hard to see in light-polluted Australian city skies.

Measuring light

Joseph Wright of Derby, 'A Philosopher Giving a Lecture at the Orrery', a *chiaroscuro* painting. A lantern plays the part of the sun.

This leads to two really neat *kids-you-can-make-this-at-home* gadgets. First, though, we need some background. The Dark Ages really *were* dark ages, but the unlit ages went on longer than the Dark Ages. It seems hard to imagine now, but the normal 18th century night, even in a rich household, was like this *chiaroscuro* painting.

So how do you get a really bright light source? Tallow and wax candles are a start, but they would hardly be bright enough for what we expect today. Until the early nineteenth century, when electric arcs were used, there were no lights

as bright as daylight. Even in 1846, when the Paris Opera was lit by arc lamps, the power came from Robert Bunsen's electric cells that quickly lost their power. (Remember Bunsen: he comes up again, soon.)

Before 1880, bright lighting was all about finding efficient oil lamps. Efficiency is important, and if you want a lot of light in your house, and you are burning hydrocarbons, especially large molecule hydrocarbons, you need a big clean flame, free of smoke, and that means getting enough oxygen into the flame. This brings us to Aimé Argand, who invented a lamp in 1782.

The Argand burner design can work with either oil or gas. In oil Argand lamps, the fuel is burned on a hollow cylindrical wick, with air being introduced inside the wick, to give a large area of contact between the air and the fuel. The gas Argand lamp used a cylindrical flame, but there was no wick. In the hollow cylindrical flame, all of the fuel is burnt in a nice bright flame, and there is no messy smoke or soot. The flames of the Argand lamps were so bright that some were rated as high as 1200 candlepower.

Lighting mattered because 19th century industrialists were tying up so much money in machinery that it made good sense to work a second shift at night. Then they got twice the return, just for providing wages, fuel for the steam engines, and a bit of oil for the efficient Argand lamps.

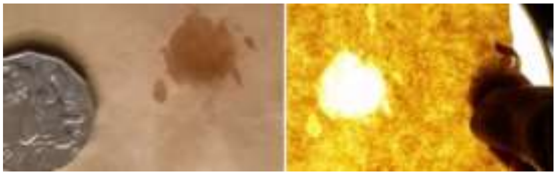
These days, we are used to bright lights, and the Argand lamp seems unimpressive, but in its day (which lasted for about a hundred years), it had a remarkable social effect. Later forms were fitted with governors to even out pressure variations, and these sold in huge numbers. Eventually though, the Argand lamp reached the end of its life.

Cheap mineral oil was available as a fuel, and gas burners with incandescent mantles would soon enter the market. Even so, some of the early mantle lamps used Argand burners, but it was a desperate last effort. All over the world, the Argand lamps were going out, because people could accurately compare rival light sources and choose the best.

And that brings us back to Bunsen…

The Bunsen grease-spot photometer

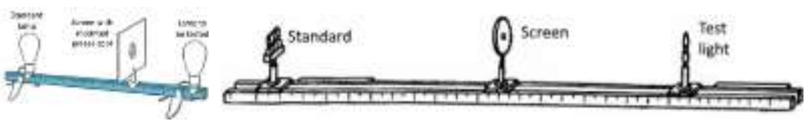
Artificial light was important, and there was money to be made if you could compare the brightness of different sources. Brown paper is less common than it used to be once, but if you have used it much, you will know that the paper shows grease marks really well:



Depending on where the light is, the grease shows up as dark or light.

I was lucky in my first science teacher, Andy ('Penguin') Watson. He had explored Antarctica in the early 20th century, returned to become a high school principal, and after he retired, he came back as a 'retread', to teach what he loved, which was science.

His teachers would have got their training in Queen Victoria's time, when the notion of using string and sealing wax to make equipment was common. Back then, the crazy inventions of Heath Robinson, Rube Goldberg and Storm P (chapter 8) didn't seem so crazy. Now you can see, perhaps, why I learned at school about the invention Robert Bunsen wasn't famous for, though unlike the Bunsen burner, Robert Bunsen really *did* invent the photometer that carries his name, and 'Penguin' knew all about it.



Two versions from old textbooks (and amended) of the Bunsen grease-spot photometer.

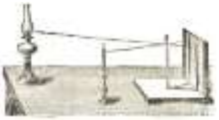
The photometer compares the intensities of two light sources. It is just a piece of brown paper with a greasy spot on it. When the light on the far side is brighter than the near-side light, the grease spot looks lighter than the surrounding paper. When the light on the far side is weaker, the spot appears dark, but if the two light sources are balanced, the spot disappears.

The photometer is easy to make: just use ordinary brown paper or even the white 'butcher's paper' that comes around your fish and chips, while butter, margarine or olive oil can also make the grease spot. If you do not know what the inverse square law is, now would be a good time to look into it: see the notes for this chapter.

No jokes about greased lightning, though, because even I would not sink to that level. You can use this photometer to calibrate the sun's brightness in the early morning or the late afternoon. You might even use it to test when official daylight starts: in the 18th century Royal Navy, daylight was by tradition the time during which you could "see a grey goose at a mile".

Islamic tradition identifies dawn during Ramadan, the month of fasting, by an imam holding two threads at arm's length, one black and one white, to see if they can be distinguished by the available natural light. Could a "standard candle" and a Bunsen photometer be used to assess the change from night to day in a similar way?

The Rumford shadow photometer



The Rumford photometer uses a more subjective comparison of shadows, cast by two lights onto a screen.

Once again, you need to keep in mind the inverse square law and do a bit of calculation before you can find a simple comparison of the power of two lights.

A photometer like Rumford's could be used to compare the strengths of candles and dips made from oil of different quality, or to assess the effect of reflectors, placed behind a flame to increase its apparent brightness.

Play with it!

The speed of light

The speed of light in a vacuum is called *c*, and it is measured in metres per second. The metre is now defined as the distance travelled by light in a vacuum in 1/299792458 of a second, so the speed of light in a vacuum will never change again from 299792.458 km/s. If we ever get a different result, we will change the length of the metre, to keep *c* constant.

There used to be a lot more variation in the stated value because measurement methods were crude. The first estimate of *c* came from Hero of Alexandria in the first century AD (we met his turbine in chapter 3). He thought we see objects because light rays travel from our eyes to the object, then bounce off them, and back to our eyes. This wrong belief gave him **WA#1** or Wrong Answer Number One.

Hero said that as soon as we open our eyes, we see distant objects, even the stars, which may be regarded as infinitely far away. Since we see these things as soon as we open our eyes, the visual rays from our eyes must travel at infinite speed, all the way to the star, and then back again.

About 400 years ago, Galileo Galilei also thought the speed of light was infinite, but Galileo's method was wrong. He tried to measure the speed of light by having people on to distant hills flash lamps at each other. The time taken for light to travel between the hills was about one forty-thousandth of a second, so the speed of light seemed to the experimenters to be infinite. This was **WA#2**.

Christiaan Huygens came up with a guesstimate of around 35 million kilometres a second, which was under today's value by an order of magnitude (**WA#3**).

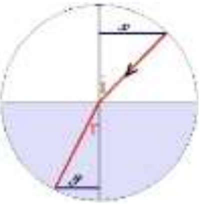
Ole Rømer looked at the regular slowing-down and speeding-up of the eclipses (properly, occultations) of the moons of Jupiter and realized that the

variation depended on the relative positions of our planet and Jupiter. We orbit the sun at a distance of around 150 million kilometres, so in the course of half a year or so, when we are on the opposite side of the Sun, we can be 300 million kilometres further away from Jupiter, about a thousand light seconds from our closest approach.

Rømer had to estimate the size of Earth's orbit, and so came up with an estimate for *c* of 227 million kilometres a second. This, **WA#4**, was about 25% below today's accepted value, but for the past hundred years or so, since really effective ways of measuring the speed of light were found, the measured speed has not really changed much at all.

Of course, we all know the speed of light is always the same, don't we? Wrong—and the variable speed of light explains lots of things, from rainbows to lenses to red sunsets.

Refraction and refractive index



This diagram shows a light 'ray' going from a less dense medium to a denser one, and the refractive index is given by x/y.

If you don't know what a sine is, you may prefer to skip this section.

Whenever light passes through transparent materials, it slows down. The weird thing is that when the light passes out of that material, the speed changes back up again. We call this change *refraction*, and the speed change sets a measure called the *refractive index*.

Just trust me for now that this index is equal to the ratio of the speed of light in a vacuum to the speed of light in the material, and it can be measured in a number of ways. The classic measure is to map a single 'ray' of light as it passes into material, with the refractive index being the ratio of the sine of the angle of incidence to the sine of the angle of refraction. (Of course, there's no such thing as a 'light ray', but because it makes thinking and calculation easier, we pretend that there is—remember the spherical horse?)

Every sort of wave can be bent, which is what refraction is all about. Light rays refract when they pass through a medium of different density, as when light travels from air into glass. When light passes into a region of increased density like this, it bends towards the normal, a line perpendicular to the surface where the light enters the other material. When light passes into a region of reduced density, it bends away from the normal.

Refraction happens to all forms of wave, even ocean waves, sound waves and earthquake vibrations, as well as light and radio waves, just so long as the waves are moving from a medium of one density to a different medium. In the case of sound, the dense damp air over calm water at night makes sound "travel over the water" by bending down the sound that would otherwise radiate upwards, while earthquake P waves can be significantly refracted as they pass through rock boundaries.

Estimating the refractive index of water

The apparent depth of water is reduced by refraction in the same way that light is bent. If you can get a deep glass container such as a large measuring cylinder, a fish tank or a long vase, and drop a coin into it, you will be able to estimate the refractive index of water.

Estimating the refractive index of water.

Set up the equipment like this, and then look down into the water while you move your hand down until you think your finger (outside the container) is level with the coin inside the container.

If you measure the real depth and the apparent depth, the refractive index is just the real depth divided by the apparent depth. You can see the effect, even with a water glass, but it's harder to get an accurate measure. A deeper container gives a better estimate.

Why the sky is blue

This is all about dispersion, which is what we call the separation of white light into its different elements (the colours or wave lengths). Dispersion happens because the refractive index of a material such as glass, dust or water is different for different wavelengths, so different colours are refracted through different angles. The *why* is Deep Physics, so we will dodge around it.

A colloidal suspension contains huge numbers of very tiny particles that are too large to be called dissolved, but too small to be seen by any ordinary microscope. When a beam of light shines through a colloidal suspension, you can see the beam because some of the light is scattered sideways by the particles. You can test this by shining a light through a mixture of milk and

water. To explain what happens, we need to know something about the nature of waves, and about the wave nature of light.

To a physicist, light is made of waves, if that's convenient. If not, then light is made up of little particles called photons. And if that won't do either, then light is made up of little particles made up of waves called wavicles. Or light is made of green cheese, if that helps to explain what is going on. Is that clear now? If it isn't, don't worry: just lie back and think "spherical horses".

For the purposes of this discussion, light is made of waves of different wave-lengths. When these light waves pass through milky water, they bounce around all over the place, but something strange happens. The blue end of the spectrum is scattered, and the red end of the spectrum is allowed to pass, at least comparatively speaking.

When a beam of white light shines through milky water, a person standing to one side will see a blueish beam glowing in the milky water, but somebody viewing the beam end-on will see a reddish beam coming at them. This variable scattering is called the Tyndall Effect, which causes the sky to be blue, and sunsets to be red.

When the sun shines through the atmosphere at dawn and at dusk, red light tunnels through to us, but the blue light is scattered in all directions: up into space, down to the Earth, all over the place.

This, say the physicists, happens because *the efficiency of the scattering of the light is inversely proportional to the fourth power of the wave-length*. In simple terms, if you halve the wave-length, you get a sixteen-fold increase in the efficiency with which the light is scattered.

When it is dusk here, it is noon somewhere else. People close to midday are directly underneath the sun's rays that reach us, and they see the blue light that is missing from our sunset, coming from all over their sky. At the same time, we see the sun's white light, minus the blue part, so the sun appears red, and now you know why the sky is blue.

Diffraction

Any old used CD or CD-ROM can show you refraction.

A diffraction grating produces a spectrum, and the grating is made up of very fine parallel lines. Any CD contains a spiral track that works like many fine, parallel lines. This CD was placed on a sheet of black cardboard, under a desk lamp. Any CD with data on it will work: you need to look at the CD on an angle, and what you are seeing is an interference effect, but that's enough.

Out of sight

The coin is there in both glasses: why can't we see it in the glass on the right?

Place a coin on a black piece of paper. Put a clear glass filled with water on top of the coin. Can you see the coin? Where is the best place to see it? Now look from the side. Can you see the coin without looking straight down through the water glass?

Why it is hard to spear fish

A safer spear that is easier to find in a kitchen.

When you put a pencil, a wooden spoon or some other straight object into a glass like this, you will see this sort of bending. Refraction must have been known from the very first time somebody tried to spear a fish in water, aiming at an angle. To see why this must be so, put a coin in a deep pan, cover it with five centimetres of water, and approaching at an angle of 45°.

Then try to poke the centre of the coin with a pencil. The result, every time, will be that you miss the 'fish', because it is not where you think it is. If you want to hit a fish, you have to have your spear partly in the water, and aim the part of the spear which is in the same medium as your target, a bit of physics known to every society that fishes with a spear from boats or the land.

In the interests of the fish, I won't say any more, but it comes down to the problem that you are aiming a spear that is in the air at a fish that is in the water. Take it from there.

Cylindrical lenses

A lens that once held Vegemite.

You will need a long clear cylindrical glass jar with a water-tight lid, or you can use a Perspex or glass rod. Fill the jar with water and seal it: use the jar both upright and sideways to look at things and people. It is best to avoid air bubbles, which you can do by filling jars under water in a bucket.

Underwater spectacles

Suppose you have a magnifying glass, and you want to look at a fish. Would it help to put the magnifying glass under water, close to the fish?

The power of a lens comes mainly from the difference between the refractive index of the lens material and the refractive index of the surroundings. Air has a refractive index of about 1, water is about 1.33, and glass is about 1.5, so work it out.

When I first wrote this up in the 1990s, I said, "the answer annoys me, because as I get older, I see less and less when I go snorkelling, and I recently had the bright idea of attaching an old pair of spectacles to the outside of my mask."

A few moments thinking showed me that I would not get the result I wanted. Can you work out how I could have got the necessary help? (Hint: *pince-nez*.)

In fact, since I wrote that, I have had cataract surgery and I now have mid-distance lenses, which are good enough for underwater work.

Notes for this chapter

See, in particular, Carl B. Boyer's *The Rainbow*.

On the day that I completed the second draft of this book, a friend sent me a link to a *Guardian* article on how cities are shaping evolution, partly by the ways light influences animals : https://www.theguardian.com/cities/2018/jul/23/darwin-comes-to-town-how-cities-are-creating-new-species (Last see, October 2019, the article is based on edited excerpts from *Darwin Comes to Town* by Menno Schilthuizen, published by Quercus.)

Measuring light

The word *chiaroscuro* comes from two Italian words, *chiaro*, meaning light and *oscuro*, meaning dark. It refers to the dramatic effects painters can get from contrasting light and dark.

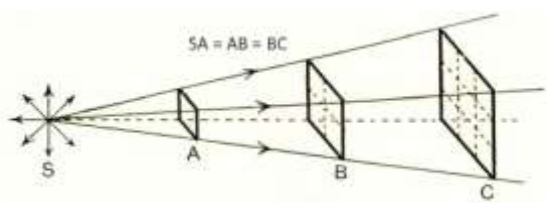
Sealing wax: when a colleague found some red sticks of wax in the stationery cupboard, he thought they were crayons, but they had a square cross-section and they didn't mark paper very well. He knew I was interested in old things so asked me if I knew what they were for. He was very lucky, because my father used to use sealing wax, and I recognised it. There are probably only a handful of Australians who have used it for its proper purpose.

Sealing wax is a hard type of wax that can be melted to seal things like important documents, or things that need to be very secure. If you look on the web, you can find places where you can buy sealing wax, and you can get ideas for amusing art activities. Be warned: you will be using flames and hot wax that burns the skin. Suggested age: 15+!

Light adaptation

Under city conditions, you may have some trouble seeing *epsilon*, the smallest star in the Southern Cross. You can certainly see it on a moonless night in country areas.

Photometers and the inverse square law



No, I won't explain this diagram. Work it out.

Here is a simple law of physics that explains how certain forces or intensities differ with distance. The force of gravity is affected by this law, and so too is

the intensity of light from a point source. It is usually credited to Sir Isaac Newton, although Robert Hooke felt he also deserved a share of the credit.

In its simplest form, the law states that the strength of a force or a radiation is reduced to one quarter of what it was if you double the distance, or to one ninth, if you triple the distance. In other words, given the intensity at one unit of length from the source, then at x units, the intensity will be $1/x^2$. Of course, if the distance is halved, the force or intensity will be quadrupled.

There is one small caution that needs to be sounded here. In the case of the earth's gravitational force, the starting place is the *centre of the earth*, as the force of gravity from a spherical body acts like an extremely dense mass, located at the centre of the sphere. So a spacecraft which lifts up to one earth radius (around 6400 km) above sea level will experience one quarter of the gravitational pull that we feel on the earth's surface at sea level.

And who invented the Bunsen burner? Peter Desaga perfected Michael Faraday's design. Robert Bunsen just made the design popular.

Refraction and refractive index

Eventually, you will meet with Snell's Law, which tells you how to calculate the refractive index. For those under 16, that's all you need to know: skip to the fifth paragraph, after the asterisk. If you are over that age, the refractive index (r.i.) is the ratio of the sines of the incident and refracted angles.

One of the curious effects of refraction is total internal reflection, which will happen where the simple mathematics of Snell's Law of refraction predicts that the refracted angle will be greater than 90°. As light inside a diamond approaches a surface, if the angle is great enough, the light will not pass out of the diamond, but will be reflected around the diamond.

The art of diamond cutting is all about enhancing the effect by ensuring that as much light as possible is totally internally reflected, often many times, before being transmitted back through the front of the diamond. The "fire" of a diamond comes from this total internal reflection, while the colours in a diamond come from the variations in refraction for different wave lengths of light.

Because it has a very high refractive index (2.47), diamond shows the effect more than any other natural substance, but even water can show total internal reflection, and a rainbow is caused by the same thing taking place in very fine water droplets.

$$\sqrt{-1}\ 2^3\ \Sigma\ \pi$$

OK, we got a bit technical back there, didn't we? The refractive index of a clear substance is a number that tells you how much the substance slows down light or bends light. The easiest way to measure this is to look at the angle of a light

ray coming to a surface (the incident ray), and the angle of that same ray after it passes through the surface (the refracted ray).

These angles are measured against a perpendicular line to the surface, right where the ray hits, but there does not seem to be any relationship between the two angles, until we look at a mathematical measure called the sine of each angle. Ethanol has a refractive index of 1.36, turpentine is 1.47, Crown glass is 1.53, and flint glass is 1.67. Let's leave it there.

Why the sky is blue

I made a light beam by sticking a piece of aluminium foil with a pinhole in it on the end of a torch. I got a tighter beam by putting a plasticine cylinder around the front of the torch, attaching the aluminium foil to the far end. Play with this. (Laser pointers will also work, but these need adult supervision.)

By the way, if you are looking for the "seven colours of the rainbow", forget it! There are really millions of colours in the rainbow, and our belief that there are seven colours is just a cultural interpretation. Aristotle apparently said there were just three colours, date-red, green and yellow. His later followers ("the Aristotelians") saw four colours (unspecified so far as I can discover), matching the four elements, qualities, humours and seasons. Abu Ali al-Husain ibn Abdallah ibn Sina (known to us as Avicenna) went for three, but once again I cannot track down what the colours were.

Some mediaeval scholars said there were three colours ("to honour the Trinity"), but Roger Bacon favoured five for the simple reason that he saw five, and once again they are not named: my bet is that he counted red, orange, yellow, green and blue as his five. Theodoric of Freiberg was faced with a religious claim for three colours in the 1300s when he wondered, if humans do not have three teeth or three eyes, why should the rainbow have three colours? No, said Theodoric, the number is four: red, yellow, green and purple. Theodoric also noted that there were many examples that always showed the same colours in the same order. (He is also called Dietrich in German or Thierry in French.)

Now about the fourth power scattering: red is 700 nanometres, violet is 400. If we calculate $(400/700)^4$, we get 0.107, which tells us deep violet is scattered 9 times as much as deep red.

Diffraction

The CD's thin shiny spiral track works like a grating. Light shining on the lines it is diffracted in all directions, but the light from neighbouring lines interferes constructively when the sine of the angle$=\lambda/d$. As the angle changes, so does the colour, and if you are clever enough, you can measure the angle of diffraction of different colours and work out the spacing of the lines on the CD—but I'm not saying how.

Why it is hard to spear fish

The problem is that the spear is in the air, while the fish are in the water. If the fish were also in the air, you would have no problems. If you were underwater, using a spear gun, there would be no problems. Think about it, knowing that there are hints here for you to find, and you may work out what you have to do to hit your fish every time.

Cylindrical lenses

A glass jar and a clear water bottle both work, if they are full. Try looking at things close up to the lens and things further away, and you will find a point at which the right-way-up image flips over, and appears upside down. Is this related to the diameter of the "lens" you are using?

$$\sqrt{-1}\ 2^3\ \Sigma\ \pi$$

7. Matter

Solid, liquid and gas, the three states of matter in Mt Yasur, an active volcano in Vanuatu.

Back to the Contents

Universal solvent

Why is a universal solvent impossible? How could you keep a universal solvent in a container? By definition, the universal solvent dissolves everything, including any containers you may wish to store it in.

Perhaps you could snap-freeze it, or store it as two components that do not react with their containers, and just mix the components that form the universal solvent when you need some. Don't pour the universal solvent down the drain when you are finished, though!

Universal solvent again

Having shown that a universal solvent is impossible, how could you keep some in a glass bottle? A friend tells me you can store universal solvent in a glass jar, as long as you have already added enough powdered glass to saturate the solvent with glass. If you need to get the universal solvent to work on glass, you would need to use the iron-saturated stuff that you keep in an iron vat instead. Play with this!

All good mixers

Herbicides, we are assured are applied selectively, only to their targets, and pollutants are only found in limited areas. When people say this, they are relying on your ignorance of entropy, the natural cussedness of matter. One of the most basic laws of nature is that everything spreads.

To see this happening, you need a deep glass container like a measuring cylinder or a long glass vase, a piece of fairly stiff glass or plastic tubing, taped to a small funnel, and some colour, either dye, or food colouring, or old-fashioned fountain-pen ink.

Fill the container almost to the top with water, put the tube in, and leave the container in a place where it will be safe for a week or two, to let random currents stop. Then pour your coloured material into the funnel and down the tube, so it gently reaches the bottom of the container.

Pour some fresh water down the tube to wash the last of the colour away and then take the tube out, again gently. You should now have a layer of colour at the bottom of the container, but over the next few weeks, random movement of the atoms and molecules will cause the coloured zone to expand and get lighter as the dye spreads in a process called diffusion.

Diffusion happens because of random events. Imagine you have an island, divided by a fence into a paddock full of rabbits (A), and another paddock (B) with no rabbits. The rabbits cannot get off the island, but there are gaps in the fence. This is my thought experiment, so I have blindfolded all of the rabbits, and they are wandering around at random, bumping into each other, tripping

over carrots, banging into fence posts and whatever else blindfolded rabbits may do. I also go in regularly to blindfold any new rabbits.

Look, don't argue. These are *my* imaginary rabbits, so I can do what I like in my thought experiment—even put them in 200 litre drums and blow Rugby whistles at them, so pipe down and pay attention! Now that I have your attention again, what is the probability of rabbits wandering *into* paddock A? The answer: none at all, because there are no rabbits in paddock B, yet.

The probability of rabbits wandering *out* into paddock B is higher. After a while, there will be about the same number of rabbits in each paddock, and now the flow of rabbits from A to B is about the same as from B to A. In real life, the rabbits would keep spreading wider and wider. We say that diffusion is always from areas of high concentration to areas of low concentration.

Play with this.

Julius Caesar's last breath

On the Ides of March, 44 BCE, Julius Caesar took his last breath, expired and expired. Between then and now, the air molecules he breathed out in his last breath have spread and mixed in the atmosphere. One estimate I have seen suggests that on average, every breath we take contains 1.3 molecules from Caesar's last breath. Play with this.

Soak some spuds

Liquids can also diffuse. Slice a small potato lengthwise into flat slices. Place some of the pieces in one dish and the rest in a second one. Fill both dishes with water. Add two tablespoons of salt to one of the dishes, stir it, and label it "salt water." Let the two samples soak for 15 minutes.

Pick up and compare the slices from the two dishes. Is there a difference in firmness? Why?

Getting magnetic sand and soil

There are often magnetic particles in sand and soil. If you rub a bar magnet through dry sand or soil, the magnet may never be the same again. So don't do it! That is, don't do it until you have wrapped the magnet in thin cloth or cling-wrap. Even then, unwrap the magnet carefully.

Perpetual motion 'inventors' always say that with bigger or better magnets, their plan could work, but I don't see this method as the future of large-scale iron ore mining. Do you?

$\sqrt{-1}\ 2^3\ \Sigma\ \pi$

Distillation

The earliest known piece of chemical equipment is a 3600 BCE distillation apparatus for separating perfume ingredients, and the earliest chemical directions were written by a woman around 2000 BCE, and they tell how to make perfume.

The process involves separating a liquid from a solid or another liquid. The liquid to be separated is first turned into vapour, often by the use of heat. The vapour is then moved to a different and cooler place, where it condenses back into a liquid.

A lot of gold was 'saved' in the 19th century, using mercury to pick up tiny bits of gold dust. Later, workers distilled the mercury off to use it again. At Thames in New Zealand, they have a complete mercury still, but they don't use it, as the process is dangerous.

Distillation relies on differences in boiling points in two substances. The vapour that is driven off will be richer in one component than the original mixture, or in some cases, contain just one of them. In the eastern goldfields of Western Australia, the land is arid. Indigenous people lived there in small numbers, knowing where granite basins would catch and hold water or direct it to areas where it soaked into the ground, so it could later be obtained by digging wells.

With the arrival of large numbers of white people on the goldfields in the 1890s, the careful balance was destroyed. A working horse, under hot conditions, may need up to 70 litres of water a day. Even in the arid zone, there was plenty of salt water, and fresh water can be distilled from salt water, but that needed fuel. Getting fuel was hard work, so fresh water cost a shilling or even two shillings a gallon (4.5 litres). That meant a man with one horse needed half an ounce of gold a week, just to keep the two of them in water.

Because boiling liquids can cause scalding, and this book may well be in the hands of young people, I usually suggest a tamer distillation method. This one can be used on wild beaches or in inland deserts, so long as there are plants or wet sand around; you can dig a hole; there is sunshine; if you have a plastic sheet and a bucket or other container.

Just dig a pit in a sunny place, put the bucket in there, surround the bucket with freshly cut plant material, cover the pit with plastic and weigh the edges down with stones or sand, and put a pebble in the middle of the plastic, over the bucket.

Distillation on a desert island.

Safety: This is a pit, and that means it is a bit like an animal trap. How will you make it safe for animals, younger brothers and sisters and so on? Young readers, talk to an adult.

This is a standard survival technique for getting water, which works just as well with a pit filled with salt water, because the sun's heat makes water evaporate, then it condenses on the plastic, runs down to the lowest point and drips off. By putting a pebble on the plastic sheet, you make sure the lowest point is over the bucket.

Fresh water from salt, the cold way

Fresh water is a looming problem for the world. Most of the world's fresh water is locked up in polar ice caps or as ground water, so the easy way to get more fresh water is to take it from sea water. The obvious way to get the fresh water is to distil it off, but there are other ways. For one, you need a plastic dish (like an ice cream container), a freezer, and a cloth.

All you need to do is put your salt water in the plastic dish in the freezer, and wait until an icy slush forms. As ice crystals form, there is no room in the crystal structure for sodium ions or chloride ions, so the salt is excluded, and the remaining water becomes saturated brine.

At this time, you need to scoop off the ice slush, which will still have a coating of brine. If you squeeze the slush in a cloth, you will get most of the brine to come off, leaving something close to pure ice. If you melt this ice into a fresh container and repeat the process a second or even a third time, you can get remarkably fresh water.

It works, but it needs too much energy to be practical.

$\sqrt{-1}\ 2^3\ \Sigma\ \pi$

Notes for this chapter

Look at Peter Mason, *Blood and Iron* and Henry Petroski, *Remaking the World.*

All good mixers

Most weeks, I use a herbicide, very selectively, in a sensitive ecosystem, and it doesn't spread, because it breaks down quite rapidly. It is squirted onto the target plants, and we do no "carpet-bombing".

Now about the oil drums and Rugby whistles: somebody did that once, while testing to see if stressed rabbits survive longer. The subject under study was the effects of stress on mortality in feral rabbits in Australia. There was reason to suspect that some fluctuating populations might be driven to vary by deaths that arose as a result of stress caused by living in a dense population. The experimenters needed stressed bunnies.

> The rabbits were subjected to stress in the form of intense cold in a deep freeze running at -15° to -12°C, or in the form of noise made by a referee's whistle attached to a powerful two-stage vacuum pump. The whistle and the rabbits were housed in a closed 44-gallon drum.

And that was why the rabbits were exposed to cold and whistles. Sadly, nothing came of it. Sometimes, you need a bit of luck on your side: it was not, so far as I can tell, meant to imply that Rugby players are bunnies.

Source: Griffiths, M. E., J. H. Calaby and D. L. McIntosh, 'The Stress Syndrome in the Rabbit', C.S.I.R.O. *Wildlife Research*, **5(2**), 1960, 134–149.

Potato slices

Through osmosis (which is related to diffusion), water moves from areas of low salt concentrations to areas of high salt concentrations. Adding salt to the water creates a higher salt concentration in the dish than in the potato, but the salt water has a lower concentration of water molecules in each millilitre. The result is that on average, the water in a potato that is soaking in salt water migrates out, leaving behind a limp spud.

People often make celery and strips of carrot go crisp by soaking them in fresh water. Guess what happens if you soak these vegetables in salt water…

$\sqrt{-1}\ 2^3\ \Sigma\ \pi$

8. Making things


A gold stamper from *Scientific American*, 1859, and a monitor (hydraulicking hose nozzle) from Oriental Claims goldfield near Omeo, Victoria.

In the middle of the 19th century, gold rushes in California and Australia funded science and industrial technology, and finding gold was all about separating large amount of rock and soil from tiny amounts of gold. Stampers were used to smash up gold-bearing quartz and hoses collapsed cliffs and hills so the mud could be 'washed'. No part of our past is separated from any other part.

Back to the Contents

Women worked as blacksmiths in the 19th century.

The world has changed: 19th century science and technology could be easily understood by lay people, who often made their own equipment, based on what they saw or read. Most Australians who have heard of Mark Twain know him only as the author of *Tom Sawyer* and *Huckleberry Finn*. Just a few Australians have read his 1897 book *Following the Equator*, describing Twain's time in Australia, but his *A Connecticut Yankee in King Arthur's Court* is almost completely forgotten here.

The story is about a 19th century American, time-travelling, and knowing how to make handy stuff like revolvers and ammunition in Dark Ages Britain. Could you go back in time and make any of the devices in your modern home, except maybe the clothes line?

We have lost something, but we can get it back, if we try. Let's start here:

A Notice to Young Readers and Older Readers Whose Education is Sadly Lacking.

If you haven't heard of Heath Robinson, Rube Goldberg and Robert Storm Petersen (or Storm P), you have missed some serious fun. Robinson was British, Goldberg was American, Storm P was Danish, and they all invented curious mechanical devices—or at least they drew them.

The styles are all slightly different, as you can discover by searching for their work on the web.

From left to right, Heath Robinson's pancake machine, Rube Goldberg's self-operating napkin and Storm P's door alarm.

Here, I show you how make rather practical things, starting with topology, the branch of mathematics that says a donut is equivalent to a coffee cup.

Topology is also involved in the four-colour map problem. This has now been proven, but the proof will never fit in the margins of any book.

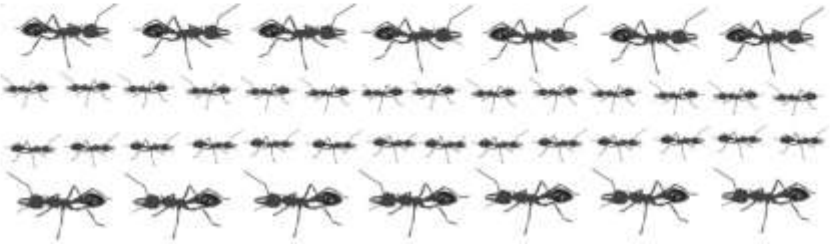
Topology also tells us that when you put a four-legged stool on an uneven floor, you won't have to turn it more than 90º to get it steady, and it studies Klein bottles and a paper structure that only has one side, one surface. Let's go there, first.

Möbius strips

A Möbius strip.

Cut a 5 cm strip lengthwise from paper (an old newspaper will do). Holding the strip out straight, give one end a half twist (180º) and glue or tape the two ends together. Your piece of paper is now a Möbius strip. When you twisted your strip, the inside and the outside became one continuous surface. There is also only one edge.

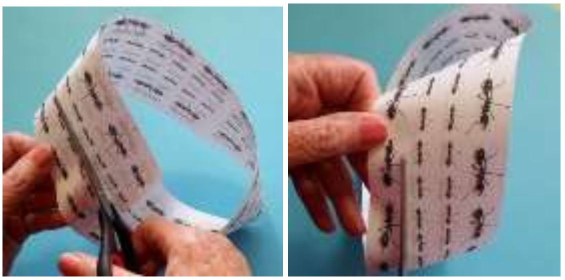
Take a pen and carefully draw a line along the centre of a new uncut strip. Where do you end up? Is the line drawn on the inside or outside of the paper? Now cut the strip along the line you drew. How many pieces do you get? It may help if you use the picture below to make an ant-covered Möbius strip: there is a link in the notes to a PDF that you can download and print.



Photocopy this if you wish.

You can use the PDF, or blow the above image up on a photocopier, so the chain of ants is 23 cm long then join two copies, as shown below, and do back-to-back photocopies. You need to experiment to get the ants on opposite sides of the page, going in opposite directions. I had a bit of trouble following my own instructions, so here's a step-by-step set of photos:

(1) PDF on-screen; (2) printed out; (3) cut up; (4) trimmed; (5) joined; and (6) a finished Möbius strip.



Cutting the Möbius strip in two different places.

Next, take the photocopied or printed sheets and cut two strips, 23 cm x 7 cm, and join them, so all the ants are in columns, and make a Möbius strip which you can cut, either straight down the centre (see left), or off to one side, as shown in the right-hand picture.

Try this again. But this time, give the paper a full twist. Then try one and a half twists, and see what happens. Last of all, see what you can discover about **Klein bottles**.

The art of the sundial

Time is what prevents everything from happening at once.
—John Archibald Wheeler, *American Journal of Physics*, 1978, **46**, 323.

A sundial is a way of showing the passage of time by the shadow cast on a graduated scale by a *gnomon* (a solid object of some sort, such as a rod or a triangular plate attached to the dial). As the planet turns, the sun appears to move across the sky, and shadows move.

A sundial can be accurate, within limits caused by the fuzziness of the shadow, variations in day length, and the annual 'equation of time' which must be explained. As we look at it from here on earth, the sun sometimes runs "fast", and sometimes it runs "slow". Around November 2 each year, the sundial is 16 minutes fast, but by February 12, it will be 14 minutes slow. If you ever visit a really accurate sundial, you will be advised to make a correction for this oddity.

This sundial on the Schürstabhaus in Nuremberg in Germany is often described as "ancient", but it is probably more correct to say it is "of ancient design".

The variation happens because our planet's orbit is an ellipse, not a circle. If you really want to know more than this matter, look up Kepler's Laws of planetary motion. Look at the second of his laws.

SUN DIALS,

For any five miles of the Territory.

THE undersigned begs to direct the attention of Gentlemen residing or having Stations in the Interior, to his calculated Sun Dials, which are kept on hand for any five miles in the Colony, and which also are computed to particular local order.

The above will be found of incalculable utility up the country, where no other means of maintaining a correct knowledge of time exists.

R. CLINT

George street,
opposite the Bank of Australasia

The advertisement above comes from an 1837 Sydney newspaper. It shows how early settlers could keep their clocks right.

People (especially "Gentlemen", meaning rich people) who owned a clock or a watch used the sundial to set it, but why did the sundial need to be adjusted? There was no radio, no telegraph, and no internet, so if you wanted to keep the same time as the main or capital town there was a problem. By definition, noon is when the Sun is at its highest point in the sky, so it is always noon somewhere in the world, with a noon line sweeping along through one degree of longitude every four minutes. Logically, you should be setting your clock forward or back by a minute for each 20 kilometres or so going east or west!

The sundial had to point north, though magnetic north wouldn't really be good enough.

To make life easier, we have split the world into time zones, usually 15 degrees across, where everybody keeps the same “official time”. If you are trying to set up a very accurate sundial, you need to make allowance for your position east or west of the official time longitude in your time zone.

Time is a very hard thing to explain, but measuring time is a lot easier. We know that people have been measuring time with sundials for at least 4000 years, and some people may have been measuring, estimating and recording time for something more like 40,000 years.

You need a pencil, a ruler, a square piece of board, a compass and some woodworking tools. Draw diagonals on the board, mark its centre, and drill a hole for the pencil. Set the pencil in the hole, and poke a piece of paper over the pencil. Rule a line along one edge of the paper and take the sundial outside.

Use the compass to set up the sundial with the line pointing north-south. Carefully mark where the shadow of the tip of the pencil falls, and write in the time. Repeat this a number of times during the day, and record what you see. Did the shadow move equal distances each hour?

A better sundial

An old Danish sundial.

This design is based on this one seen at Den Gamle By (that means ‘The Old Town’) in Denmark. I have no background information on this item, but as Den Gamle By is a ‘living museum’, I suspect that it is an old design. Metalworking requires special tools and expensive materials, so I chose a cheaper design, using strips cut from a manila folder to make a ring, about 12 cm across and 6 cm high:

Making the ring.

All I needed was a folder, a ruler, scissors, sticky tape, a paper punch and string. I’m tired, so *you* work out the rest from the pictures…

Completing the sundial.

Making astronomical instruments

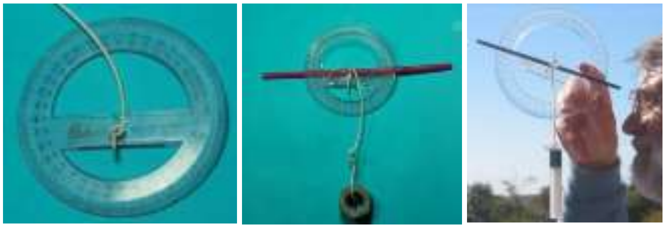
In the time before telescopes, all astronomers made their own observatories, and some of the best were in China, India and the Middle East: look up <**observatories history**> on the web, and you will find that there were seven major observatories older than this one below.

A Renaissance observatory at Uraniborg in Denmark.

Instruments were mainly designed to measure the distances between bodies in the sky, with all measurements written down as angles, and the old astronomers had to make do with that. You can measure some angles with a clinometer made from a protractor, a drinking straw and a weight on a string. You will also need sticky tape (and the string should be thinner than shown in the next few pictures).

Starting the clinometer.

The first thing to do is to drill a hole for the string, and then cut a small notch, because you want the string to hang from the very centre of the protractor. The next three pictures show you what to do.

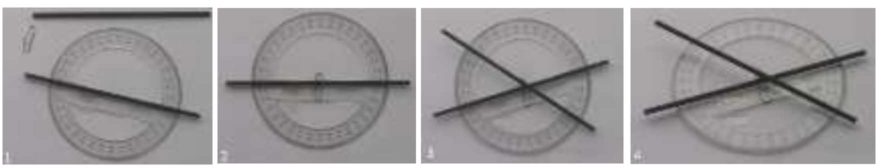


Note: *never* look at the sun, as I appear to be doing! (*I wasn't.*)

This actually came out of my design for a theodolite, which can measure angles between two objects like buildings, mountains or trees, any two things that you can see. A real theodolite uses accurate optics and a very fine scale, but we are going for a simple version, where we sight two landmarks through straws, and measure the angle between the straws.

The error is likely to be several degrees, but the principle is the same. (A slim drinking straw shows a field of view just twice the diameter of the moon, so it is about 1° across. A fat straw shows a field about 2° across.)

Tape one of the straws to the protractor but the other one has to be able to move. After a few failures, I sticky-taped a bent paper-clip beneath the protractor so the poke-out bit was at the dead centre of the protractor. Then I made two holes in the turning straw with a kitchen knife, and threaded it on and looked through: I could see past the wire.



The steps in making a theodolite.

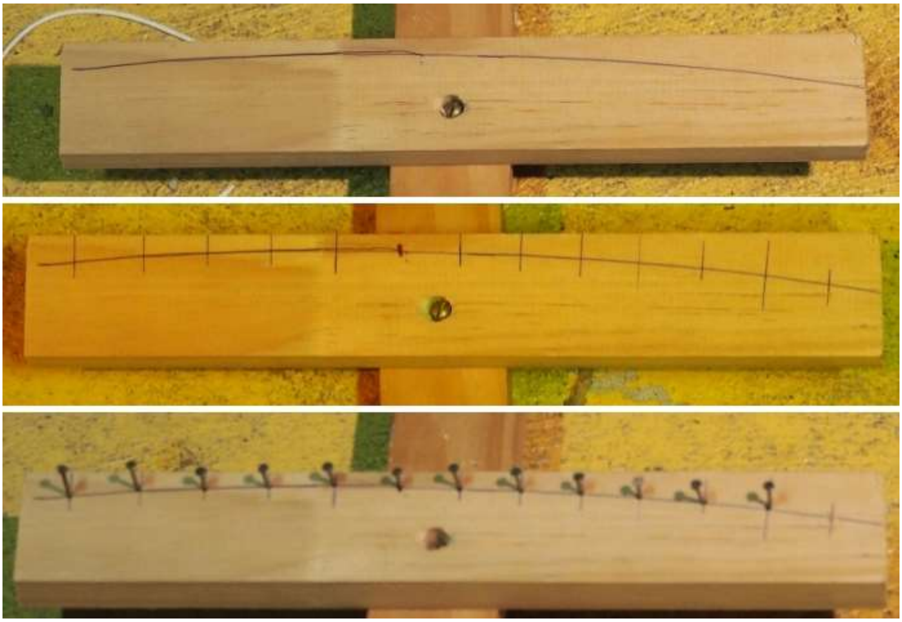
Hint: When you are using this, it may help to have the protractor and bottom straw attached to a stand. Otherwise, set it down on something at eye height, so you can line up the fixed straw first, and then line up the moving straw. For serious work, a cross stave was what the old astronomers used when they wanted to measure angles.

A model cross stave

The parts of the cross stave: the long piece is 2.1 metres, the cross bar is 500 mm. The string is to be used to draw part of a circle on the cross-piece.

You will need timber, nails, tape measure, plus quite a lot of ingenuity. I used a brass thread and wingnut to attach the two pieces of my model, so I also needed a drill.

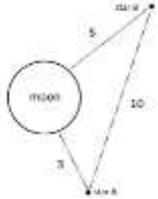
To make the cross-bar, you hammer small nails into a piece of wood, 35 mm apart. This piece of wood is then mounted on a second piece of wood at least 2 metres long. At a distance of two metres, each nail is just one degree away from its neighbours (*you* do the sums, using 2πr for the diameter).



The steps to take in making a cross stave. Notice how the nails are in an arc, not a straight line.

Use your cross-stave to make a map of a few of the main stars in the sky.

The moon takes about 30 days to go once around the earth, which means that it appears to shift across the sky by about 12° from one night to the next, which means that it moves about half a degree across the night sky in a single hour. The moon *subtends* (covers) an angle of half a degree, as we see it from earth, which means that it moves one moon-width across the sky each hour.



Each record needs to have the three sides of the triangle. Why? (**Note**: this is deliberately not to scale!)

Use your cross-stave to map and measure this movement, looking at the brightest stars within three to five degrees of the moon. Make sure you record

your results carefully every hour for several hours. The best way would be to take the measurements as quickly as possible, and enter them onto a sketch that you prepared five minutes before the sighting time.

There is a limit to the accuracy you can get with the cross-stave. Can you improve your results by getting further away from it, and using binoculars? Satisfy yourself first that the binoculars do not change the apparent angle, then use a piece of string 11.46 metres long, and see how well you can map things. At 11.46 metres, one degree will require marks 20 cm apart. Can you estimate angles to the nearest minute?

Note: to get really serious, you may need to use a flagpole with the halyard (rope) attached near the centre of the beam, and you will need to make it more rigid somehow: the magic word is *truss*. Or maybe *girder*… (This is how they did astronomy before 1600.)

Try taking photographs of the rising moon, from the same position, over a period of several hours. Once the moon is above the horizon, take shots where the moon is 5º, 10º, 15º, 20º and 25º higher than the original moonrise shot. Does the "inflated moon" illusion work in photographs as well as it does in real life? If you don't know this illusion, the moon always *looks* bigger, just after it rises.

(You will notice that I have left you room to add your own "frills" to the experimental design: discuss your plans with a reliable adviser before you go ahead, to make sure you have thought of all the variables.)

Afterthought: can you find a way of making the nail heads glow, maybe with LEDs, so you can tell them apart? I think that red LEDs would be best (you work out why) and I suggest that you think about having two LEDs every fifth marker (again, you work out why).

Making a stone blade

I make basalt blades for fun, using basalt cobbles that I collect from a South Coast beach in New South Wales, Australia. You will need to amend these details to suit your stone, which is why there are few pictures here.

NOTE: While you are banging rocks together, wear thick gardening gloves, and you (and anybody watching) *must* wear safety goggles and ear protection, because chips fly off and rock-banging is noisy.

The best basalt for the task is fine-grained, which seems to mean that it will always have fine bubble marks on the outside: I presume the lava cooled fast and that meant being close to the surface, and that meant low pressure, which allowed bubbles to expand.

The coarser rock on the left is coarser is my anvil rock. The one in the middle appeared have been split before. Far right: a blade that could cut leather and paper, and also chop softwood.

The best stones have diagonal planes of weakness through them. Take a larger stone in your left hand (if you are right handed), hold the blade stone in your right hand as though you are going to skim it across water, and bang it down sharply on the anvil stone.

If your stone is a good one, it may still take a dozen or more blows before it shears. Small pieces may fly off, so I repeat: gloves, ear protection and safety goggles are a good idea— and stay away from other people!

This makes a crude sharp edge, which you can work further, if you wish: a common Australian Indigenous tool for improving edges is a kangaroo tooth, or you can grind the edge on a piece of sandstone. Be warned: the fresh edges will cut flesh quite easily!

Once you have tried this, and especially if you have succeeded, you will know that anybody who looks down on "Stone Age people" as ignorant savages is talking through his or her hat.

An atomiser

This is just about as simple as it looks.

Cut a drinking straw almost through, like this, about three quarters of the way along. Put the short end into a glass of water and blow from the other end.

Then sit down and write me a rude letter asking why I didn't warn you to do this outside!

$\sqrt{-1}\ 2^3\ \Sigma\ \pi$

Model planes

In these photos, I used Christmas wrapping paper for some of these, so you can tell one side from the other, but just use a sheet of A4 printer paper to make real planes.

There are lots of books on paper planes, and plenty of web sites, so these are just a few ideas to set you going. As a general rule, thicker paper is better than flimsy stuff, and none of the Christmas paper planes really flew.

The paper dart

You probably already know this model. Fold the paper in half, fold two corners to the centre line, fold the corners in again, then fold out the wings, and throw. Most dart makers add a few flaps for good luck: that's up to you.

Follow the steps!

A solid glider

This is another well-known design. Fold a corner right across, open the fold and fold the other corner over. If you look at the fourth picture, you will see why you do the fold in the third picture. Now you have a flap on each side to fold up on itself.

Follow the steps!

A cut-out bird

This needs a printed sheet, a rubber band, two pairs of scissors and some sticky tape. Here is where you can get a PDF of the design sheet: http://members.ozemail.com.au/~macinnis/scifun/paper_plane.pdf

Follow the steps!

Fold the sheet down the centre line so that when you cut out one half, the other half matches it. I used the big scissors to trim the sheet, and the fine scissors to make the finer cuts.

The finished product.

The trick with cutting narrow inlets is to make several cuts, so there are no tears in the paper. Then carefully fit the wings in as shown here. You will need to tape a rubber band into the nose, before you bend the tail out, then throw it gently. It will fly in a surprising way. Can you do anything about this? Do you care, so long as it flies?

The engineers' special

How simple can you get? There is a better version in the notes!

In the 1960s, engineering students at Sydney University often tried to launch paper gliders from the back of the Wallace Theatre, aiming to land them on the stage at the front. This meant a design that was very stable in flight, with a shallow *angle of descent*, and somebody came up with the design above.

This illustration, using Christmas paper, is useless for flying, but it shows you how to make the glider: roll one end up, flatten it, and fold up a flap on each side. To launch it, just let it go: if the design is right, it will glide away.

You need to experiment to get your design just right, balancing weights in the rolled section with maximising the flat 'wing'. It works better if you put a fold in the middle to give a *dihedral* shape (look it up, or read the notes below!).

A simple balsa glider

This first one uses a balsa stick, 10 mm square, and balsa sheet about 2 mm thick, from which you cut off a strip, 25 mm wide. You will need an old box or a board to cut on, a steel rule, a very sharp box-cutter knife, and if you are under about 14 (or older and inexperienced), the advice of a wise helper. Seriously, I once cut myself down to the bone with one of those knives. It took a long time to heal.

The parts are best cut with box cutter *on heavy cardboard on an old table with adult supervision*!

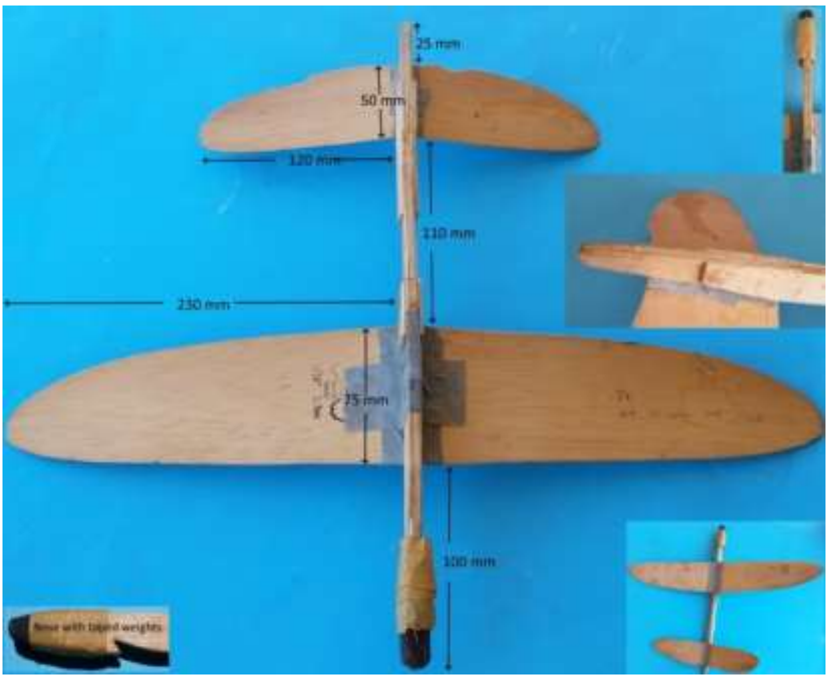
You will also need a handsaw (not a power saw!). I have a neat gadget that holds part of a hacksaw blade, but you can also use a coping saw or a fretsaw with a coping saw blade. This is to make the two slots at right angles on one end of the stick. Balsa wood is very weak, so cut *gently*. The first time you try it, you will probably break the balsa, so to avoid wastage, cut the two slots at one end first, and when you have those, cut the other end of the stick.

Cut very gently, with the balsa sitting mainly on an old piece of timber that doesn't matter. If you break the balsa, clean up the end with the box-cutter, and start again. When you have two good slots, cut a 150 mm length, using the box cutter. The wing and the tail pieces can be cut from a 25 mm strip cut from the larger sheet, using the box cutter. (I use a steel rule to cut balsa sheet, and I cut *slowly*.)

The wing is attached with a rubber band, add the tail pieces and put a drawing pin in the nose for weight, and tape it in place securely for safety (drawing pins *hurt*!). I once made 20 of these in an afternoon, just before a seventh birthday party, and each guest got one to take away. I also had spare bits, because balsa aircraft break!

Making a model like this, you need to be in your teens, and able to take it when the plane breaks.

The simple gliders (the first design) are just thrown, but the larger Camel glider was launched from a stretched-out set of rubber bands (usually called a 'catapult'). This advanced model is more suitable for teenaged hands (or younger hands with adult help) to make, and it is 35 years since I built one of these, so you get notes and a picture, not instructions. You will need to invent a bit for yourself.



All you need to know.

The Camel glider

Materials and stuff: You will need 2mm and 4 mm balsa sheet, cloth, PVA (wood) glue, cutting tools and fine and coarse sandpaper, plus somewhere to work where you can make sawdust, spill glue and out of the wind so you can leave the partly made bits while the glue sets. You will need pins to hold the bits together as the glue sets, and you will need bricks or wood blocks to hold the pieces.

I worked from a design that I think called this the Swallow, but I made my own variations, so I will call it the Camel, as in "a camel is a horse designed by a committee", or maybe after the Sopwith Camel.

We will start with the fuselage, the long and tapered stick that the wings and tail attach to. My fuselage was about 20 mm deep at the widest point (see lower left) and 8 mm at the rear. Just make it look nice: to get greater strength, I cut two strips of 2mm sheet, and then I made a set of cross-grain strips, out of 4 mm sheet, to the fuselage is three-ply.

This meant that I could glue all the bits together, and then sand off the poking out bits of the middle layer. I put one strip on plastic sheet, smothered it in glue, laid the up-down strips in place, covered them with more glue, and laid the second strip on before putting plastic and then several bricks on it and left them overnight. Peeling off the plastic, I sanded the fuselage, and cut the launching notch near the nose with a fret saw.

The next step is to make the wings and the tail pieces, where I just made a pleasing curve, not unlike the elliptical wings of the World War II Spitfire, but there is a big difference between the wings and the tail. This poor old warrior aircraft has flow many missions, and look at the damage on tail and wings.

The tail is a single 2 mm sheet, but the wings are two-ply, with 2 mm side-to-side grain underneath and fore-and-aft 2mm cross-ply on top. This gave me more thickness to shape with sandpaper into an *aerofoil* (look the word up!) profile. The curving of the wings, thick at the front, tapering at the back, was shaped with sandpaper.

Next I joined the wings with a hinge of cloth that would let them take up a dihedral shape, which makes the glider stable in flight. I glued cloth all around, and worked the pieces so the wings slipped apart and could form the angle you can see. Then it was time for the most dangerous part, cutting two gentle V grooves on the fuselage to take the wings and the tail. I wore a thick gardening glove on my left hand (I am right-handed) and I always cut away from me, never towards me.

Then it was a matter of using lots of glue and a few sewing pins driven through into the fuselage to join the parts, and then resting the craft so the fuselage was touching the bench, and the wings (or the tail: I did the tail later, after the wings were set) were just touching two wood blocks. Once the glue is dry, try a few gentle thrown flights on a playing field, and add weights to the nose so it glides well. Tape the weights in place.

In the 1980s, we could buy aeroplane rubber at hobby shops, but I think it may no longer be sold. You can launch your glider in a large open space if you link 40 or 50 rubber bands together, and tie on a piece of blind cord at the front: that goes into the notch. My catapult sometimes got tangled in the notch,

so I added a piece of cloth, which slowed the catapult down as the plane flew off. I used a large bolt as the anchor point, driving it into the ground.

While the plane is light, it can hurt anybody it hits, and excited toddlers who chase it may accidentally tread on it. You need a large area, free of people, pets and football posts, and make your first few flights gentle ones. Get used to the idea that there will be breakages!

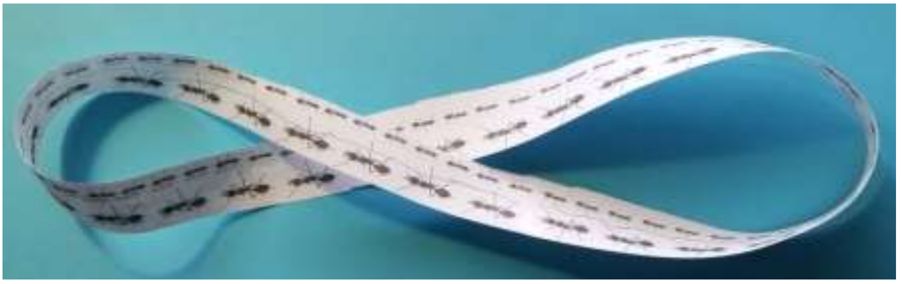
Notes for this chapter

Henry Petroski, *Remaking the World*, and Heath Robinson: *Bill the Minder*: https://www.gutenberg.org/files/33570/33570-h/33570-h.htm Last seen October 2019

Möbius strips

The link to the PDF to make the strip is http://members.ozemail.com.au/~macinnis/writing/Mobius%20ants.pdf

The pictures below show what you get when you cut the strip. The first picture shows that a cut down the middle gives a single loop, but there is a surprising result when you test for Möbiusness (my own word). The test is simple: draw a pen line along one side until you get back to the start: If the paper is still a Möbius strip, the line will be on both sides, but in the first picture, that doesn't happen:



A Möbius strip

Now in the second picture, there are two interlinked loops. I cut off the big ants, and something odd happened: the little ants are isolated on a Möbius strip, but the big ants are on a non-Möbius strip.

Another Möbius strip, but this one has been cut

Balsa wood

You can buy balsa wood at hobby shops, and my local Bunnings store sells balsa, near the paint section. The models you see here were made for my children 30 years ago.

Reverse engineering challenge

Can you make all these?

Here are six paper planes I made for my grandson. At the top middle you can see a variant on the "engineers' special", and the other ones are all fairly common designs. Reverse engineering is what happens when you see a model that works, and you make your own version of it that works in a similar way. When these fly, they all have a shallow dihedral (I *told* you to look it up!).

So: can you reverse engineer these models, from just the photograph? We are already is in the notes, so there are no notes to help you.

Sundials

The catch in using a magnetic compass? Look up <**magnetic declination**>.

A portable sundial for use in the Northern hemisphere. (I can see that at a glance, but how did I do it??)

"Clockwise" is a term derived from the direction the shadow of the gnomon takes on a sundial in the northern hemisphere, where sundials were first

developed. If the southern hemisphere made corrected clocks, with the hands going in the correct direction for southern sundials, then highs would be "clockwise" in both hemispheres. The correct pre-clock term for "counter-clockwise", incidentally, is "widdershins", while the pre-clock term for "clockwise" is "deasil".

Just for fun, a friend sent me that steam-punkish portable sundial and compass, modelled on an old-fashioned fob-watch. Nisaba sent it to me for fun, so why not share it? There are a few design faults, if you look very closely…

Kepler's Laws:

1 Each planet travels in an elliptical orbit with the Sun at one focus.

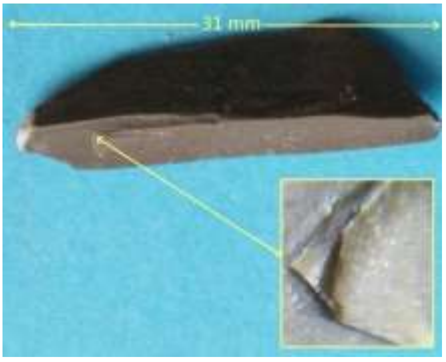
2 For a given planet orbit, the vector to the Sun sweeps equal areas in equal times.

3 For any two planets, the squares of the periods are proportional to the cubes of the distances from the Sun.

Making a stone blade

I will not reveal my source of stone, but it is only just in the Sydney Basin. Some of the best tools I have seen were made not from basalt but from quartzite. In June 2019, I got a useful blade from a piece of quartzite picked up on a mountain near Chefchaouen in Morocco.

This picture shows you what to look for with a hand lens: this is clearly a rock that will break into sharp fragments.

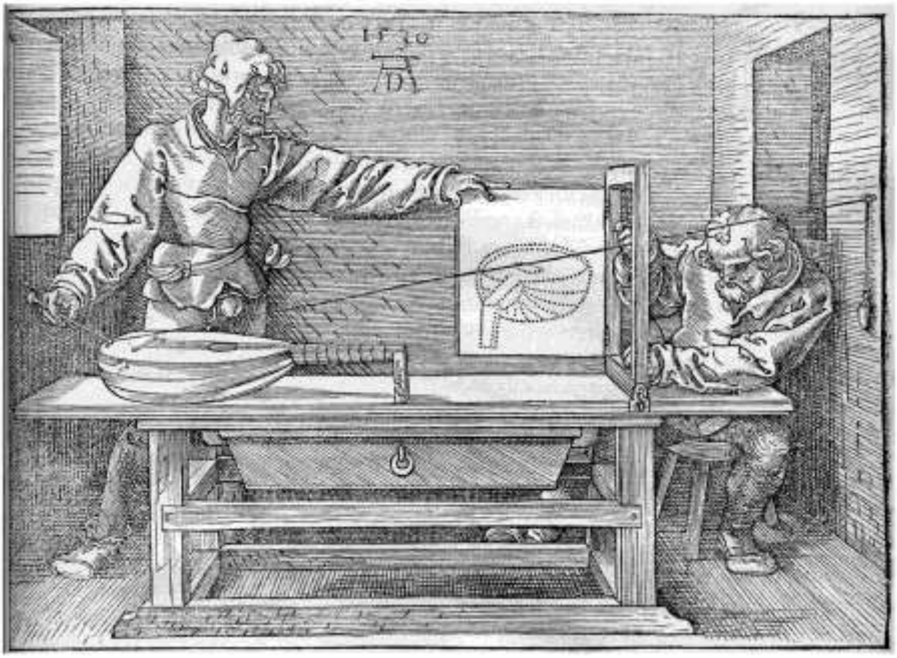


A small fragment of quartzite, picked up on a mountain track in Morocco.

There could be an interesting project in studying different stones in your locality as tool-making material, *but you must wear goggles*, because eyes hit by sharp rock don't grow back.

In Europe, of course, they use (and used) flint and obsidian for this sort of work, but those stones seem to be hard to find in Australia. What can you find out about silcrete?

$\sqrt{-1}\ 2^3\ \Sigma\ \pi$



Geometry comes to the aid of art. Albrecht Dürer was a German artist and engraver who will turn up later in this book.

He understood how to use mathematical precision to get the perspective of his drawings *just right*.

9. Not exactly floating

Going to sea could be less than fun. This is Théodore Géricault's *The Raft of the Medusa*, an 1816 painting showing the aftermath of a shipwreck. Find out the story for yourself!

Back to the Contents

Without science, technology, engineering, arts and mathematics, there would be no humans, just some smart apes. You can't have one without the others, because they all emerge from our human curiosity and they feed our curiosity—and one of the things that excited the wonder and curiosity of my granddaughters, before they were two, was bubbles.

As a mid-20th century child of old-fashioned parents, I learned a lot from *Pears' Encyclopaedia*, a compendium that was the Wikipedia of its day. This sturdy volume was prepared under the name of the makers of Pears' soap, one of whose advertising marks was Sir John Millais' portrait of his grandson, Willie James. The boy later became Admiral Sir William Milbourne James, GCB, and he had an agile and clever mind, but even as an admiral, his nickname was the painting's title: *Bubbles*.

Sir John Millais, a portrait of his grandson, later called *Bubbles*.

Compare Willie James, if you will, with my own granddaughters, below:

Two admirers of bubbles. This book is written for people like them, parents like theirs, and grandparents like me.

Bubbles bring joy, delight, wonder and curiosity, though some of the bubbles that follow have fairly unusual shapes.

First: a bubble mix recipe

I got this from a friend, who said to mix these ingredients very thoroughly:

- Three parts concentrated detergent ('Morning Fresh' or 'Dawn' work well);
- Seven parts warm water;
- One part sugar or glycerol (it helps the bubbles to last longer).

My friend added these notes:

- Bubble mix keeps well in an airtight container;
- It works better if it is at least two weeks old, and it lasts for years;
- Hard water isn't very good for making a bubble mixture;
- Don't let the mix soak into furniture or the carpet, so use it outside;
- If you ignored that, vinegar can help clean it up.

Odd-shaped bubbles

The first thing you need to do is to make some gadgets to shape some unusual bubbles, and that involves the tricks of the wire-bending trade that you will see in the pictures that follow. Note that these are suggestions, not rules. Play with any and all ideas that you find in this book:

- At the ends of each piece of wire, there is a turned-over bit that I use for joining wires;
- When I have a plan needing a number of pieces of the same length, I wind the wire around a ruler;
- If I want round shapes, I use a broom handle or a small cylinder to make neat circles;
- I join wires by wrapping them around each other and then crimping them with pliers.

Now let's try a cube, two pyramids and a helix. To make the photos as clear as possible, I used 2 mm aluminium wire, sold as bonsai wire, but you get better bubbles with thin, cheap galvanised tie wire, which is easier to find and cheaper.

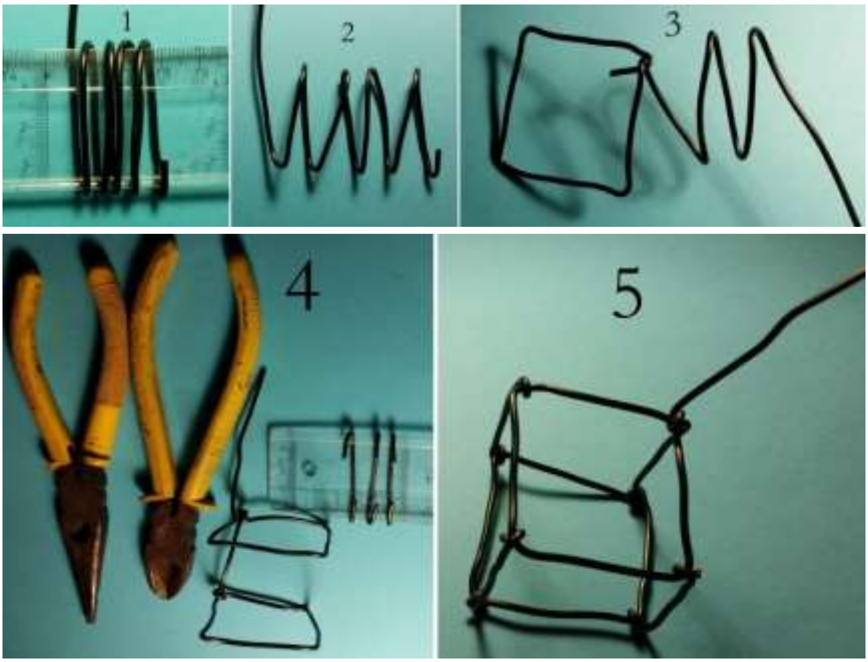
1. The cube

What is the natural shape of a bubble? To find out, you need some detergent or soap, a piece of soft wire, a pair of pliers, a pair of wire cutters and a dish. From these, you will gain an unexpected answer.

Safety note: It is possible to cut off short sharp bits of wire with wire cutters, but watch out: the cut-off bits often fly around, making a danger for eyes, and also for small children and pets. Safety goggles are essential for you and any helpers, and watch where the bits go. Clean them up!

Follow the diagrams below to make a cube with a wire handle (a bit like a Cubist frying pan). Sink this into the soap solution, pull it out, and check the shape of the bubble formed.

To make the frame, I used a ruler to measure out a number of similar lengths, as shown in picture 1. I also needed the pliers and cutters shown in picture 4. There are eight lengths of 3.5 cm, then a longer piece that makes a handle, all in one single length. Then as shown in picture 4, there are three more 3.5 cm pieces, each with short bent ends for crimping.



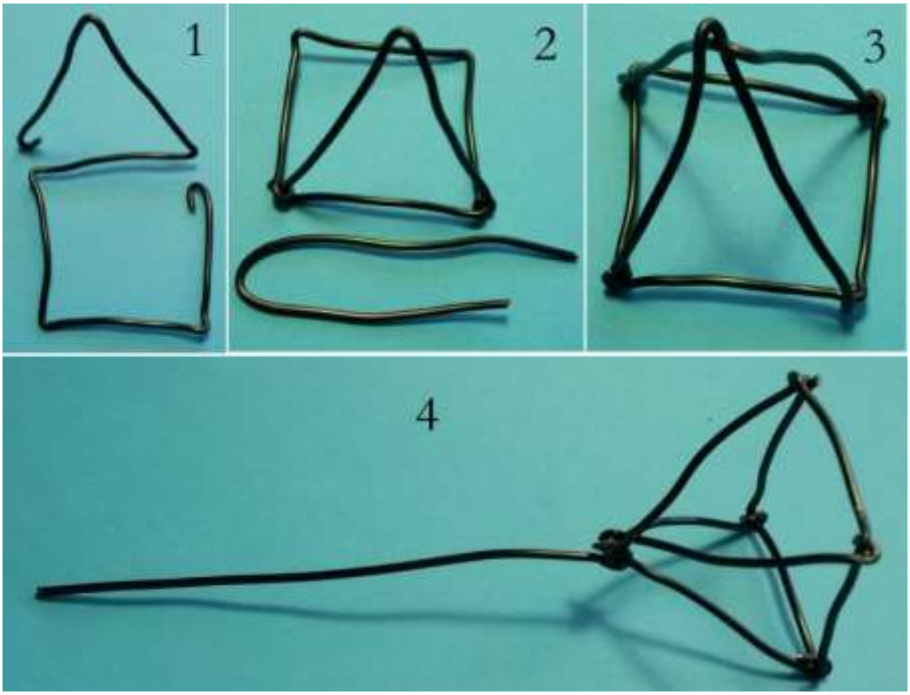
Bubble frames, including a wire cube with 3.5 cm sides, and a wire handle.

2. A square pyramid

This has the same shape as the Egyptian pyramids (but smaller): a square base, 3.5 cm on a side, and four triangular sides. I made the sides of the triangles about 5 cm long, but 6 cm would have been better.

Notice that there are just two pieces of wire in the construction of the pyramid, and notice also the allowances made for crimping on the ends.

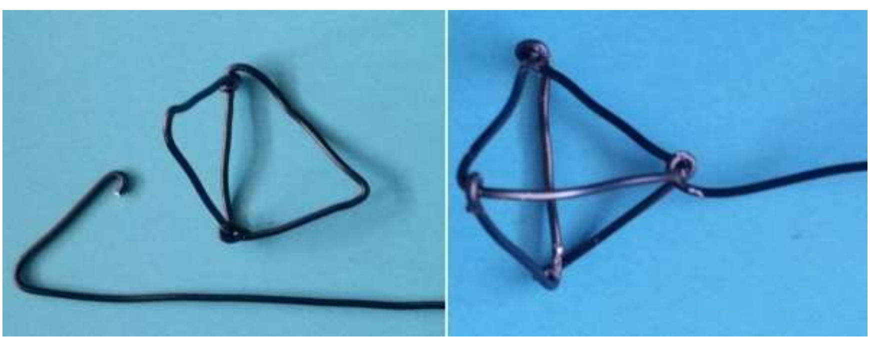
To finish off, I cut a separate long piece of wire to make the handle, using it to crimp together the apex (top) of the pyramid.



A square pyramid

3. A triangular pyramid or tetrahedron

This one is easy to make, because the construction takes just two pieces of wire, using the same methods as before. Play with it!



A triangular pyramid and handle from two pieces of wire.

4. The helix

Use any convenient cylinder to wind the helix and bend the very end into a short U shape that you will later crimp down to make a tight join. The crimping is done with the pliers.

The main thing is that you now have a closed loop that can hold a bubble.

Making a helical bubble.

Stretch the helix out, and cut the wire to leave a straight 'tail', about 20 cm long. This passes back through the middle of the helix, and the other end crimps onto it.

When you lift the helix out of the bubble solution, a bubble will be formed, joining the spiral to the central strand. But helical bubbles or spiral bubbles?

To be precise, the shape you will see is a helix, and you have made a helical film that is really a single-sided bubble, if you like. The 19th century engraving below probably explains it more easily than words, and it also tells us this isn't new science. The image comes from my Dover edition of C. V. Boys' classic book, *Soap Bubbles*, first published in 1890.

From C.V. Boys, page 49.

If you stop and think about it, the helical bubble is no more surprising than the flat bubble you get in a circle of wire. Once again, the effect of surface tension (we'll come to what that is, later) is to make the surface area as small as possible, stretched between the boundaries. Since the outer wire is a helix, the bubble must be spiral as well.

Did you get shapes like these?

Before we look at the shapes of bubbles, I want to look at some other round things, like balloons, lead shot and rain. The basic question: why are so many things roundish?

Balloons filled with helium may float upwards in the air, but air-filled balloons compress the air inside, and when you add in the weight of the balloon, the whole thing weighs more than the same volume of uncompressed air. Those balloons don't float, and as we will see later, bubbles are also filled with slightly compressed air. Bubbles don't float, either, though they are easily caught by breezes.

Fine balls of lead form when molten lead is poured through a copper sieve, at the top of a high tower called a shot tower. As the droplets fall, they change their shape, almost magically, into spheres, and they harden, at least on the outside, before they land in a cooling water bath. Nobody would suggest that lead shot floats, but as it is forming, lead shot falls more slowly than a larger lump of lead, because of air resistance. Remember the spherical shape…

Explaining surface tension

The shape change to spherical is driven by the hidden subject of this chapter, a force that scientists call surface tension, and that is what links the shot, bubbles and rain drops, which are also fairly spherical. For a while, rain drops are held aloft by updrafts in the cloud, eventually, they fall from the cloud and plummet down. They aren't teardrop-shaped, and they aren't spherical, but they are like flattened spheres.

Raindrops on a waxed marble table.

And when the rain drops land on a waxed marble table, they are also somewhat spherical, or at least hamburger-bun-shaped. All of the subjects here tend to be spherical, and the reason is the same: surface tension.

Balloons are a bit different, because their shape is determined by the shape of their membrane, but there are parallels with bubbles. All the other spheres are shaped by surface tension.

To explore this effect, we need to look at something that seems to float, but doesn't *really* float, either. You can see the surface tension effect with a glass of water and two paperclips:

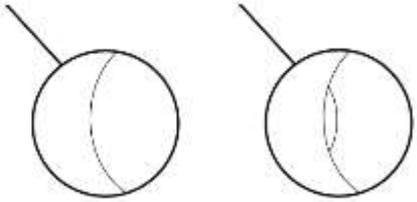
Bend one paper clip into an L shape. Use this clip to lay another paperclip gently on the top of the water. The surface of the water bends under the weight of the paperclip like stretched rubber, but doesn't let the clip through.

The 'floating' paperclip trick.

If the clip doesn't 'float', lift the paperclip out, dry it and rub a tiny bit of grease on the paperclip, and then try again. If you look closely at the reflections coming off the water in the third photo, you can see how the water surface is bent.

To push the water surface out of shape you must use force. If the paperclip can't exert enough force, it can't stretch the surface enough to let the paperclip slip through. One drop of detergent in the water though, and the magic goes!

Bubbles and string



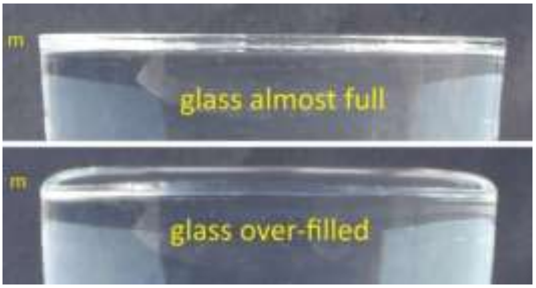
Wire loop and cotton thread.

Use the illustrations above as your models to see an unusual side to bubbles. Make a loop of wire about 5 cm across, and add a handle to it, so you can dip the loop into soap solution. Then tie a piece of cotton so it divides the circle roughly in two, while remaining a little bit slack. Build a second one, but this time, make a section of the thread double, as you can see in the picture on the right, above.

When you take the first wire loop out of the soap solution, notice how the thread can move around freely in the soap film. Then burst the film on one side of the thread, and notice what happens next. See if you can work out what has caused this effect.

When you have dipped the loop on the right into the soap solution and pulled it out, burst the soap film between the two threads, and try to explain what you see.

The meniscus



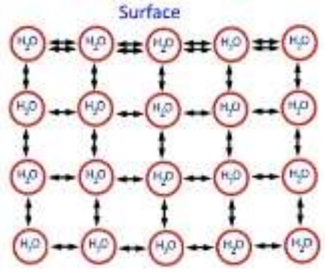
Two forms of the meniscus, marked m in each picture.

You met the meniscus effect, though not by name, if you made the kitchen compass in chapter 1. Surface tension also causes the shape of the surface of water in a glass, but you have to work out the rest for yourself, given that the surface is called a meniscus, it has to do with how the water wets the glass, and the meniscus behaves oddly when you add a drop of detergent.

Remember the title of this book, and play with it!

Explaining surface tension

"Surface tension" is how physicists describe the way a set of atoms or molecules attract each other. Because their particles are all pulling together, some complicated mathematics shows that when the material is liquid, the pulling forces make the material take a shape with the smallest surface areas, and that shape is a sphere.



Surface tension exists because water molecules attract each other.

If you want to make the biggest paddock with the smallest fence, you need a circular paddock. If you need to split a farm into many paddocks, there are better answers, but there is a legend that Queen Dido of Carthage knew about circles being good, almost 3000 years back.

After her brother Pygmalion killed her husband, she fled to the land of King Hiarbas, and asked him for as much land as could be enclosed by a single ox hide. Hiarbas fell for her apparently modest request, but rather than laying the ox hide on the ground, she cut it into thin strips, tied them end to end, and then laid the long strip out in a circle. This gave her an area large enough to found a small country on.

It took mathematicians until 1879 to prove what the writer of Queen Dido's legend knew by instinct or experience. That is, that circles enclose the biggest area for a given perimeter, just as spheres enclose the biggest volume for a given surface area.

Bubbles, shot and rain drops go naturally to spherical, and all because of surface tension. Where the water ends and the air begins, the attractive forces are to the sides and down into the drop. There is no force pulling outwards, and this makes the surface of the water act like a skin.

Some spiders and also insects called water striders rely on surface tension to stay 'walking' on water, like the paperclip. On the other hand, animals that are below the water have trouble reaching through to the air above the water.

On the left, mosquito wrigglers, from an engraving in C. V. Boys' book, on the right, some of my pets.

Mosquito larvae, usually called wrigglers, get around this challenge by having a breathing tube or siphon that is hydrophobic, meaning it repels water, so it pops through to the air. If it is threatened, the wriggler breaks free of the surface tension with a fast wriggle, hence its name.

Now just a note about bubbles and compression: the bubble's skin is held outwards by the air pushing from inside, but at the same time, the skin pulls in, so the air pressure inside is slightly greater than it is outside. Measuring that pressure is a challenge: play with it!

Oil spill problems

If you take an ordinary feather and push it into clean water, you will see a silvery film over the feather where a layer of air has been held, trapped against the feather by the bird's preening oil that it makes and spreads over the feather. This is clearest in the flight feathers of water birds.

If you spill a small amount of cooking oil onto the surface of the water, and push the feather in again, you will see some changes. Now there will be no silvery layer, because the cooking oil has mixed in with the bird's natural oils. In nature, when a bird is caught in an oil spill, this is what causes the feathers to clog together, cutting down on insulation, and often killing the bird with cold.

So do what the rescuers do: clean the feather with detergent and try again.

Whoops! No silver film! Why is that? There *is* a way to fix it.

Cast your pepper upon the waters

Fill a dish with water. Sprinkle pepper all over the top of the water. Put several drops of detergent into the centre of the dish.

What happens to the pepper?

Is the same thing happening over the whole surface of the water, or is it just in the middle?


All you need to see the pepper on the water.

A dish mop and surface tension

You will need a fluffy dish mop or a paintbrush, and a small container of water.

Notice that the brush or mop, which is fluffy when dry, is held together when it is wet. Look at it first in its dry form, and then when it is all wet and clingy. Can you see what problems this would cause for a fish (with feathery gills that spread out in water) if it wanted to go onto the land? Or would there be different problems for seals, otters and other water-mammals?

How does this relate to what your hair looks like, after a bath or a swim? I'm not telling. Nor do I plan to explain why toothbrushes and scrubbing brushes don't do this.

Float my boat, sink my boat

My granddaughters placed a toy boat in a bucket of water, and then loaded it with sand until it sank. My question: just as the boat sank, did the water level in the bucket rise, fall, or stay the same?

$\sqrt{-1}\ 2^3\ \Sigma\ \pi$

Notes for this chapter

In this clip, Julius Sumner Miller (he gets a mention in the dedication and again in the afterword) talks about bubbles:
https://www.youtube.com/watch?v=A5NwktsURpY (Last seen, October 2019.)

Cubic bubbles

The bubble surface squeezes in so as to give the maximum volume for a give surface area. If there are other constraints, like bits of wire that the bubbles stick to, this can vary the shape of the bubble. With large and multiple bubbles, there are lots of competing forces, but they quickly reach a balance.

Bubbles and string

The film of soap solution is elastic, pulling in all directions. When there is film on both sides of the thread, there is no lopsided pull on the thread, but as soon as you burst one part of the film, the remaining film pulls only in one direction.

About that 'floating' paperclip

The surface of the water bends around the weight of the paperclip like stretched rubber. This is because water has surface tension. The paperclip is not really *floating*.

In summary, surface tension is just the name we give to an effect caused by particles attracting each other. All of the water molecules attract each other, and this means water drops get pulled into a round shape. To increase the surface area, you have to do work on it, so unless the paperclip can exert enough force,

it won't be able to stretch the water surface enough to let the paperclip slip through.

Dido's oxhide

In reality, Dido would have used the leather strips to carve out a semi-circle on a sea coast. I suspect, and think I can prove, that this is an even better solution than a circle. Can you prove it, using the formulas for the area and circumference of a circle?

Oil spill problems

The detergent that takes away the polluting oil also takes off the natural oils, so the rescued bird cannot survive without help. This is why rescuers have to keep the birds they have saved until they have preened their feathers back into a naturally oily state.

Challenge: Can you make up an oil mix and use it to "preen" a washed flight feather back into shape again? If you are going to do this, you will need to try and find out what real preening oils are made of. Well, it *is* a challenge…

A dish mop and surface tension

The threads of the damp mop or brush are held together because surface tension in the water pulls the water together, so as to reduce the surface volume. Gills in water are fine, because they float free in the water but on land, they are useless because the filaments cling together, and so all land animals need lungs. Aquatic mammals need water-proof coats, or they get cold when they come out of the water.

Each problem comes from the way water molecules attract each other strongly. When you have a drop of water, it acts as though it has a skin, because the water molecules inside are all pulling on the outside ones, and the water around the mop fluff (or brush bristles) pulls all the threads together.

Float my boat, sink my boat

Your only hint: Archimedes and displacement.

$\sqrt{-1}\ 2^3\ \Sigma\ \pi$

10. Rocks and bits

Folded strata, Cascade Mountain, Banff, British Columbia.

Mud and mud cracks

Saharan mud.

Mud is an ongoing frustration for me. Hell hath no fury quite like that of an author whose fond belief has gone unsubstantiated, though the fury of Australian tourists, caught in sticky mud near the Sahara (above) must be a close second.

Still, we Australians know about dry mud. No TV news broadcast about drought would be complete without images of cracked and dried mud from the bottom of a farm dam, drained by drought. My writing is largely powered by temporary obsessions, and one of my themes relates to the way things break up, from cracking paint to basalt flows that form columnar jointing—and drying mud.

New Zealand mud, Waiheke Island.

This is cracked mud from Waiheke Island in New Zealand, but I could have chosen from a range of shots taken in places as far away as the Sahara. As you can see if you look, the cracks are all the same…

It occurred to me to suggest that readers grow their own cracked mud, but it seems the process is far from easy. Full of enthusiasm, I collected dried mud chips from cracked mud on waste ground, clearly the right material to use, but that was where the frustration began.

Mud chips, collected from a dried puddle, reconstituted mud.

After four or five days, there were visible cracks there, as you can see below, but the pattern was wrong. I decided to try again. I broke up the dried mud and reduced it to powder, but as my trusty white dish was originally manufactured as a baking dish, I decided to save time, and put the dish in the oven.

The results of my cracked-mud growing were poor.

I kept the temperature down to just under 100ºC, so the mud wouldn't boil and bubble, but while there were visible cracks, the result was still disappointing. If I knew more about how cracking is caused, I might have had better luck, but science is like that, and the devil is in the details. Perhaps the area was too small, probably the mud needed to be deeper. Over to you, but just in case you are wondering, mud cracks have nothing to do with crystals.

The oven-dried mud pie was just as bad.

About crystals

Look at the patterns in the balls in the gumball machine below. If you put identical marbles on a gently sloping flat tray, they will roll to the lower edge, and pack neatly together in the same way.

Hexagonal packing even happens in a gumball machine.

Spheres naturally fall into triangles, which form hexagons, with six spheres surrounding each sphere. Wherever you look, order is natural, at least in solids made of identical particles.

Crystals form because atoms are real, identical objects that pack neatly. Crystals form regular shapes, so they must be made of identical tiny units. Crystals get flat edges because wandering particles are more likely to stick to a gap that is filled on two or three sides. Once they stick in place, they are less likely to be knocked off again (unlike the corners and stick-out bits), so the gaps in crystals are filled in first, and the crystals develop flat sides.

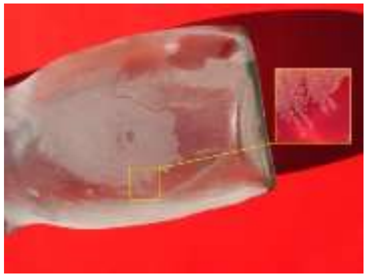
Water crystals

Frost on a car windscreen, Canberra in winter.

Higher-latitude Americans and northern Europeans know all about ice crystals, because they see snow every year, but few Australians live in alpine conditions.

With just a camera, a coffee jar, a damp cloth, a microwave and a freezer, you can make imitation snow crystals. Put a few drops of water in the jar, put the lid on but leave it loose (think about why!) and give the jar 20 seconds on high in the microwave to warm the water inside, then put a lid on it tightly, and leave the jar in the freezer overnight.

Next day, there will be tiny ice crystals inside the jar, where the water vapour has frozen on the glass. The crystals won't last long, so unless you live in a cold climate, you need help and a foam box with ice bricks to carry them to a bright spot to photograph them. The crystals look like this:



Water crystals.

Water vapour from the air condenses on the outside of the jar as soon as it comes out of the freezer, so you need a damp cloth to wipe the glass dry.

Sugar crystals

A sugar molecule contains 12 carbon atoms, 22 hydrogen atoms and 11 oxygen atoms (or as chemists say, sucrose is $C_{12}H_{22}O_{11}$). If you make some sugar syrup (a concentrated solution), and leave it for a few days on a dish in the open, crystals will form.

More sugar dissolves in warm water, so you need access to the kitchen, a bowl, some hot water (60ºC, which is not too hot to touch), two spoons, a glass bowl, a glass dish and some sugar. Put the water into the bowl, add sugar with a dry spoon, and use the second spoon to stir it until the sugar is all dissolved. Use the dry spoon to add more sugar, and keep going until no more sugar will dissolve. You have just made syrup.

Then carefully pour some of the syrup into the dish, leaving the last solid crystals in the bowl, and put it somewhere safe (from pets, careless adults and curious smaller children) for a few days.

Sugar crystals. Why don't shop-bought crystals (last shot) look like the first two that I grew?

You should get solid crystals like the first two. Use a magnifying glass to compare the crystals you have made with the crystals in the sugar container. They *should* look the same, but they probably won't. I *think* I know why, but maybe I don't.

Borax crystals

You will find borax in the supermarket, in the laundry products aisle. When you buy it, you will see that it is not labelled as a poison, though it has a label saying 'Keep out of reach of children'. While borax is not *extremely* poisonous, 5 or 6 grams of it could kill a baby, and the powder or a solution could burn your eyes, so be careful handling it. Common sense is all you need, and the crystals are pretty and easy to grow.

You only need a small amount of borax, about as much as would cover a $2 coin with 2 mm of the powder (use an old teaspoon and wash it afterwards). You also need a small dish (I used a Petri dish) and some hot water. I also used an old plate and a microwave oven. Put the borax in the Petri dish, add some hot water, and stir the borax in.

If the borax all dissolves, add a little bit more borax, and when no more will dissolve, add some extra water and stir it all in. You don't need to be precise here, because if the borax solution isn't saturated, it will become saturated as water evaporates. After a couple of days, crystals start to grow (or after an hour, if you leave the dish in the sun on a sheet of black paper).

These are all from the same Petri dish of borax crystals, with different camera devices.

Naphthalene crystals

Ready to start, and after one day in the sun.

You need a pack of mothballs from the supermarket, a clean jar with a tight lid, a warm or sunny place to leave the jar, and two weeks or more.

Naphthalene is flammable when heated, but in a sealed container like this, it is safe enough. The solid naphthalene sublimes, which means it changes to a

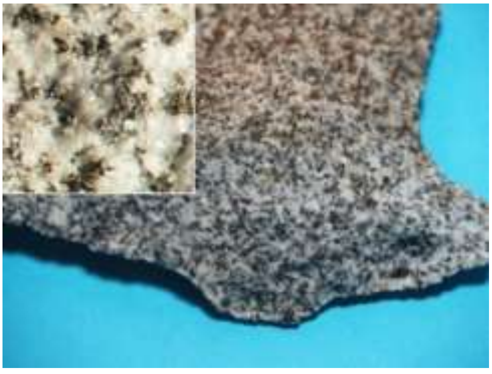
vapour without melting, and later, it condenses on a cooler part of the jar, away from the sunlight. You will see results after the first day, but really nice crystals can take as much as a month. This works well on a north-facing window-sill, but mine was just left on a north-facing deck, and it worked just fine.

Put the mothballs in the jar, tighten the lid, and leave it in a safe sunny place, away from wind, pets and stray animals including younger children. As the packaging says, naphthalene is a household poison: don't touch, smell or taste it—and keep the lid on! It is safe enough, in sensible hands: just be careful. Don't dispose of it, because it lasts for years.


A closer view of the jar (left) after 11 days, and a close-up, using a clip-on microscope on a phone.

Granite crystals

The word 'granite' means different things to different people. To a poet, any hard rock is granite, and a stone mason calls any rock with visible crystals granite, but geologists divide those big-crystal rocks up into granite, granodiorite, diorite, gabbro and others (and the poet's granite and what the mason calls granite may not even be granite at all!).




A granite hand specimen with a blown-up inset, and a small portion of a huge granite sculpture in Vigeland Park, Oslo, Norway.

Granite cools slowly enough for big mineral crystals to form, far below the earth's surface, and it only shows up on the surface when it is uncovered by weathering and erosion. Basalt is a rock that cools very fast, so any crystals that form are too tiny to see.

Salty sand or sandy salt?

You will need some samples of sand, taken from different parts of a surf beach: near the water's edge, and right up to the very back of the beach. Collect the sand when there has been no rain for a week or two, so salt spray has had a chance to "salt" the upper levels. Use standard coffee jars or something else, so you get the same quantity of sand.

You will also need access to a sensitive balance—how you find your way to one of these is up to you. If you cannot get a balance, you will need to modify this, and make eyeball estimates of the salt from each sample. Dry and weigh your samples of sand, then wash and filter the sand carefully to dissolve out any salt, dry the sand again, and weigh it to find out how much salt you have washed out. As a check, crystallise the salt and weigh it.

In theory, sand near the sea should be more salty, but is this the case? Because salt dissolves in water, you should be able to flush most of the salt out of the sand with two or three washings. When this water evaporates, the salt will be left behind in the water container.

The sources of error: some sand samples may be more tightly packed than others, which is why it is a good idea to weigh the samples if you can. Where does the salt come from? Think about the spray that comes off the ocean waves. Do you see why you were told to pick a surf beach?

If you heat the sand at 105 degrees C, organic matter in the sand is not affected. You could also try dissolving out any shell grit with hydrochloric acid, and then heating in an oven to 300º C to get rid of any organic matter in the sand. Think carefully about the order in which you do these tests, and get some safety advice from an adult. Strongly heated wet sand can form steam pockets that 'explode'.

Sand dune plants only grow so far down towards the sea. Is this because of salt in the sand? Do you have enough information to go and find out? With a bit of practice, you can estimate the amount of salt in a sample by drying out the filtered wash from a known volume of dried sand on a dark plate, and comparing the results. Weighing is best, but make sure all the samples are equally dry.

Beaches and waves

Look at a beach, and the waves coming in on an identical curve. Which one shapes (or shaped) the other? There are no answers on this one, but the question may carry a hint about my thoughts on the matter. The key word is refraction, mentioned in chapter 6.

$\sqrt{-1}\ 2^3\ \Sigma\ \pi$

The angle of rest

A simple gadget that explores the steepest slope formed by dry sand.

Particles of matter will develop a maximum slope that depends on local gravity, the attractive forces between the particles, their shapes, friction, and maybe a few other bits and pieces. This is the **angle of rest** (or the **angle of repose**).

Sand dunes and sand banks are controlled by this angle. So what is the angle for sand? Put some clean dry sand in a cylindrical glass jar with a lid. You will get the best results if the jar is about half full. After you have put a lid on the jar, tip it on its side and roll it along a table. You will notice the way in which the sand builds up to the angle of initial yield, then avalanches down the slope, and settles out at the angle of rest. (The pliers stop the jar rolling back.)

How are the sand dunes near where you live? Are they healthy? Are they stable? What angle does the sand lie at? How much water is available in the dunes at different places? What lives there, what is changing about the life forms in the area, and what are their prospects? What tracks can you find in the sand?

A wind-blown advancing dune in the Sahara.

You will need to make a number of visits at different times of day, and in different weather conditions. Try taking photographs from the same spot at regular intervals. If you are going to do this, choose a stable fixed point, like a walkway, just outside a fenced area, and centre all of your shots on distant landmarks, so that as far as possible you are taking equivalent shots each time.

A less healthy dune on the New South Wales coast.

There is probably an interesting science project for somebody here, collecting sand from various places, and carefully measuring the angles of initial yield and rest for each sample, and the difference between these, which is called the angle of dilatation. Typical published values for this measure are around 8 to 13 degrees. You would probably need to link this to the shape of the sand grains, and maybe the amount of salt, organic matter or shell grit in the sand.

You begin with the sand surface horizontal, with the jar on a sheet of blank paper on a table. Roll the jar several times to mix the sand well, and return it to the horizontal position. Mark where the jar touches the sheet of blank paper, and then roll the jar very slowly, until you see a single grain tumble down the slope. Mark the point where the jar touches the paper, and keep slowly turning the jar, and the rest of the sand will tumble down to the angle of rest.

For older mathemagicians: to get the angle of rest, measure the distance between two marks, divide that by the circumference, and multiply that by 360 to get the angle in degrees.

Continue rolling until there is a second avalanche, a third, and so on, marking the paper each time. The distances between the marks along the paper will then tell their own story. The angle of rest effect is also important to animals: read the section on ant lions in the next chapter to see why. Now here are three things to play with:

- The textbook definition of angle of rest refers to sand and stuff (usually just sand) pouring out of a funnel onto a flat surface. Obviously, if the surface has a slope greater than the angle of rest, this would make quite a difference. But does it make any difference to the angle of rest when the surface is at a small angle to the horizontal?
- What is the angle of rest of rice grains? Wheat? Macaroni of different shapes?
- Sand dunes are not just piles of sand, and they aren't deserts. They are living ecosystems, where there are many tough plants that shelter many more animals than you may imagine. Sometimes the angle of the sand slope on a mature dune may be greater than the angle of rest for pure sand, because the dune is held up and held together by plant roots.

Cross bedding

You know how they say, "don't leave home without it"? Well, to see this, you *will* need to leave home, because cross bedding is only found in the outdoors, and it is the result of the angle of rest acting, many years ago.

A lesson in geological showmanship: I got my young audience interested when I sat on an outcrop of cross bedded sandstone and said, "I'm sitting on a 200 million-year-old fossil." Of course, they wanted to know why and how I knew this, and I had them in the palm of my hand.

Cross bedding in a cutting in Hickson Road. The horizontal bed below tells us these are not tilted strata.

I produced my Vegemite jar angle of rest measurer (you can see it a few pages back), and explained that my seat was a fossil sand bank. Because we were all in Sydney, where the dominant feature is Triassic Hawkesbury sandstone, I knew the approximate age. The end result was that they started to see the cross bedding that was visible in their school grounds.

The cross bedding is set up when sand is pushed sideways, like the Sahara dune, a few pages back. That dune was pushed along by wind, but most cross bedding is formed by the pushing of water. As sand reaches the front of a sand bank, and tumbles down the slope, the sand starts to pile up at the bottom, and a new thin layer forms. Once this layer reaches the top, a new layer starts to form, on top of and in front of the last one.

Cross bedding in a cliff at Malabar, Sydney (inset: close-up), and in a road cutting at Fairlight, Sydney.

Some cross bedding lasts a long time. This picture below shows quartzite, seen in Norway. Quartzite is a metamorphic rock, formed when sandstone is buried under huge amounts of other rock, heated and squashed—yet the cross bedding still persists. That takes a long time!

Once you know what you are looking for, cross bedding can turn up anywhere. Always look for horizontal beds, above and below.

Cross bedding in quartzite, Norway.

Tilted and folded beds like these, seen on Mt Pilatus in Switzerland do *not* show cross bedding.

Science is like that: just when you think you have it all worked out, something changes. Then again, many animals seem to have their own environments worked out.

Notes for this chapter

See *The Secrets of Sand* by Gary Greenberg, Carol Kiely and Kate Clover, and because I wrote it, I know you will find a lot of good material in my *Australian Backyard Earth Scientist.*

Mud and mud cracks

Mud cracks sometimes take a while.

I left my mud dish out, where it was rained on and dried out, and a month later, it was developing cracks. Slowly. Can you do better?

Some crystal thoughts

The study of crystals is either crystallography, or gullibility if you have some theory that crystals have some magical power to cure illness. Crystals do indeed have an amazing healing property, but only for the sick wallets of crystal sellers, and crystals have also been used to resuscitate dying bank balances.

The tagline "A diamond is forever…" was coined by Frances Gerety, for a de Beers' advertisements in 1947, but diamonds are just hard crystals, and way back in 1772, chemist Antoine Lavoisier showed that a diamond would burn, if he heated it enough. In case you want to try this, Lavoisier sealed his diamond in a glass container and used a strong lens to focus the sun's heat on his target.

The angle of rest measurer

You need well-washed sand that has been thoroughly dried. If you use a microwave to dry it, do 30-second bursts on medium. If you start out two minutes on high, exploding pockets of steam will send sand everywhere. I know this from experience…

In 1959, a Dutch geologist called Phillip H. Kuenen calculated that all through the long geological past, each second, the number of quartz grains on the planet increased by one billion

11. Living things

I live in Australia, so this chapter is about Australian plants and animals. If you are outside Australia, look around for something similar, where you live!

An Australian 'Praying mantis'.

Back to the Contents

The humidity jar

Most small animals die if they dry out. To keep them alive, you need a container with a supply of hidden water that the animals can't drown in, but which still keeps them moist. You could put a piece of flywire on a jar with a wet tissue on top of that, before you screw the lid down, but a jar with a plaster base is easy to see things in.

These humidity jars are good for keeping snails, spiders, slugs, springtails and slaters alive, because they stop the animals drying out without making them wet. You can carry live animals in these jars and a large one can be used to 'relax' dead spiders or insects so you can photograph them:

Dead huntsmen occasionally show up in my garage, and if they are fairly fresh, they can be placed in a humidity jar, which softens them so they can be posed and held in place with pins as they dry again. Here, you see the pinning and the result.

You need a place where you can safely make a bit of mess, and you need to get some old newspaper, Plaster of Paris, a spoon, water, and some wide-mouthed screw-top jars. I mainly use glass 400-gram Vegemite jars, but 400-gram plastic peanut butter jars are safer. You can buy plaster of Paris at a hardware store. Once you open the plastic packet, put the rest in sealed and labelled jars.

Materials and the first step: adding plaster to water in the jar. Notice the spillage.

Spread the newspaper to catch any spillage. Then put one centimetre of water in a jar, and add several spoons of plaster powder. Let the wet plaster settle to a flat surface, with some extra water on top. Tap the jar to make the plaster spread out, and to get rid of air bubbles, then leave it. The plaster sets in about 20 minutes, but wait an hour to be on the safe side, before you pour off the extra water, and wipe any splashes of plaster from inside the glass with a tissue.

Finishing off your humidity jar.

Always dampen the plaster with 'aged' water, tap-water that has been left in an open container for a few days to get rid of any chlorine. Leave it for a few minutes, pour off the water, and wash it out with more aged water, wipe the jar and plaster dry with a tissue or paper towel. People who keep very small orb-weaver (web-making) spiders often poke a branched twig into the wet plaster to make a place for the spider to hang a web.

Humidity jars are good for many animals. Keep the plaster moist by removing the animal to a new jar each week, washing out the old one and mopping it almost dry with a tissue, a paper towel or newspaper.

Breeding mosquitoes

A mosquito breeding bottle with *two* rubber bands holding a piece of fly-wire in place.

You will need some large soft drink bottles, small sticks or twigs, some pond water, a commercial "complete fertiliser", like Zest or Thrive, and it would be nice to have microscopes, slides and cover slips. Get some pond water or water from an old bucket, water that has a greenish look about it, dilute it with tap water, and add in a small amount of the complete fertiliser. Use this water to fill the bottle(s) about half full. Put a branching stick bottom-first into each bottle: once it is pushed down, it will spring out and provide many places for adult mosquitoes to rest.

Put the bottles in a bright sunny place for about a week. At the end of this time, there will be a good supply of living stuff in the bottles, so it is time to

collect some mosquito wrigglers, and add some to each bottle, then put a piece of gauze or fine material over the top and fix it in place with two rubber bands. Take a careful look at the wrigglers at least once a day, and watch how they grow and change.

Mosquito larvae are filter feeders—I don't know whether the tumbler stage (pupa) eats or not, but maybe you can design a neat experiment with distilled water to find out. According to my reference books, the adult females will not lay eggs without feeding on blood. This is not my experience: try it, and see if you get a second generation of wrigglers, as I always seemed to do.

Right, an anopheline wriggler, parallel to the surface, left, a culicine wriggler, hanging from the surface.

Keeping pill bugs

For the last two years, I have had a small combination isopod-home-and-compost-heap sitting on my desk. This began as a test of an idea for my school students (if you came in part-way through this book, I am a 'visiting scientist' in a local primary school). I wanted an easy way to set up individual pill-bug farms, and I worked with groups of three or four students to get their farms started. Let's begin with my deluxe version, based on a clear polystyrene box that Ferrero Rocher chocolates come in.

A desktop compost heap which has now been running for two years.

For large-scale production in the school, we used thin plastic 'takeaway food' containers, and did the following, using sand from the school's sandpit, and part of my home garden compost heap. Still, the clear chocolate box is better.

I take the box out to add extra leaves and sometimes a bit of water, but I often get the eggs or grubs of tiny flies called fungus gnats, and they can be a pest. Now you can work out why, most of the time, I leave the lid on when the box is inside.

A look inside: I used a dissecting needle to move the leaves aside to expose a resident. Inset: a clearer view

Instructions given to my students:

- Put about 6 to 10 mm of sand in the bottom and spread it out;
- Add just enough water to make the sand go dark (and note the colour difference);
- Get Peter to add some rotting litter (it may have germs, so he wears gloves);
- Using a brush and a tube, catch eight pill-bugs from the leaf litter from his garden;
- Add them to the container;
- Add some clean dead leaves for the pill bugs to eat;
- Put the lid on, and add a sticky label with your group's names.

We also made five air holes in the lid with a needle. Those cheap containers split easily, but we drove all our holes through the label, which prevented splitting. After that, the students just needed to add water if the sand looked dry, and add leaves when the supply had dropped.

And that is how I invented the desktop compost heap. I have had one on my desk since then, and it is still doing well. At the time of writing, there is also a resident leech that has been parked there until I have time to photograph it. The pillbugs don't seem to mind, and the leech emerges from the leaves to wave hungrily at me, each evening.

Catching leeches

Some animals are smart, though polite people call the clever ones sagacious. Well, leeches are devoid of any sagacity, so they are easy to catch. They live on

blood, and use a heat sense to find mammals. You can use that to attract leeches into a jar. They seem to detect heat through the glass, and creep in.

Catching a loose leech on the desk. This method also works in the field.

The hand in these shots is that of my wife the leech magnet, who is quite calm about leeches. I am fortunate that she is such a brilliant leech attractor, so even on high, dry, sandstone ridges, if we stand still for a minute, one or two lean and hungry leeches will appear, looping along like 'inch-worms', hurrying to reach her shoe, hoping to reach her ankle. They rarely do.

We just hold an open jar in their path, and they rush in. Then, when we get home and need to photograph them, she puts her hand where it needs to be, to bring them into the camera's range, but she keeps her hand just out of reach. I often put animals I am photographing on a dry platform in a large dish of water, which is how I discovered that land leeches can swim. I learned, so I win, by seeing something new!

Science is like that.

Ant lions

On Cape York, ant lions dig their pits in the open, at least in the dry season. Note the boot print for scale.

I began playing with ant lions in 1952, and they are still my favourite animals, because they dig such neat holes, like this.

The ant lion sits in a pit in the sand, waiting for food to tumble in. (Yes, this was also in chapter 5.)

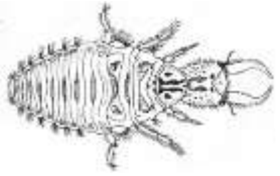
To keep ant lions, you will need some sandy soil in a flat tray, a plastic cup and a supply of ants. They live in sandy soil, under rock overhangs, beneath the eaves of houses, or under houses that are on piers, and similar sandy areas. Get some dry sand or sandy soil, put it in a flat tray, about 6 cm deep, and then hunt your ant lions. Look for small conical holes, about 1 to 3 cm across, in sandy soil in dry places.

Use the plastic cup to scoop up an entire conical nest, taking 2 or 3 cm of sand from underneath, and dump the whole lot into a bucket. Do this a few times, and take your sand back to the tray. Spread the collected sand out, and wait for a while: soon you will see the ant lions start to dig new holes.

A white dish has all sorts of uses. Here, it's a holiday home for ant lions.

Let them go without food for a day or two, and then make up some sort of an ant trap (a test tube with a small amount of treacly sugar solution or "Vegemite" works well). Leave the trap near an ant nest. When there are a few ants inside, pick the tube up, and seal it, then take it to the ant lion tray. The tray will be looking like a lunar landscape, with little pits where the ant lions are. Release a couple of ants in the middle, and watch what happens.

Ant lions are the larval stages of beautiful lacewings, and adults and larvae all prey on small insects. Mostly the larvae eat ants, but I have also seen one eat a small weevil.



The larva of a lacewing, which we call an ant lion.

The ant lion has a large head, with a big pair of nippers. It burrows into loose dry sandy soil and then throws sand out with flicks of its head, making a small conical pit. Then it sits at the bottom of the pit, waiting for something to fall in.

The dry sand is at the angle of rest for sand (see chapter 10), around 30 degrees. If anything blunders over the edge, it and a small amount of sand, tumble to the bottom of the pit where the JAWS are waiting. If the ant escapes,

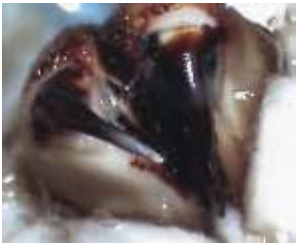
the sides of the pit fall down, carrying the ant back again, and all the while, the ant lion is tossing more sand up out of the pit. Some of that rolls down, pushing the ant back to the bottom. Soon the ant is seized, and pulled under the surface, where the ant lion slurps out its body juices.

Photographing spiders

Wolf spider, the frontispiece from Keith McKeown's *Australian Spiders*.

I got interested in spiders in 1958 when I read Keith McKeown's *Australian Spiders*. The frontispiece (above) showed a spider, face-on. I took one look and saw a resemblance to my Latin teacher. Any life form that could mimic Latin teachers had to be special, I decided.

I have been a fan of spiders ever since, and I address pests who come to my door and pushy sales people and scammers in Latin phrases, to confuse them. It also celebrates my Latin teacher who, it turns out, was an incredibly good actor.



Redback spiders (left) are scarier than Latin teachers, so leave them alone. Trapdoor spiders (right) are probably not too bad, but pictures like these are only safe to take if you have had some training (or if the spider is dead, like this one.).

A St Andrew's Cross spider.

If you are Australian the St Andrew's Cross Spiders are interesting. They insist on putting a diagonal cross (a saltire) in their web, and then they put two legs along each line. Why do they do it? The best guess I have seen is that they do it to make themselves look larger to potential predators. They are an easy-to-see target, so they make what hunters see look frightening. Are there similar spiders where you live?

Over the years, I have come up with some wrinkles to make photographing spiders easier. The jumping spider below lived up to its name and kept springing away, so I put it in a glass salad bowl, with blue card in the bottom. Then I just had to wait until it got tired of leaping.

A jumping spider: there are at least a dozen species in my small garden.

I used to wonder how orb-weavers avoided getting caught in their sticky vertical webs, but as the side-shot on the right below shows, the webs are NOT vertical. The web is blurry because most of it is out of the focal plane, but you can see the angle.

Later, I decided to try seeing the web better, and started working with card sheets. As you can see from the first two shots above, not all cards are equal: the black card made the web much more visible.

Orb weavers' webs with water on them.

Other tricks that are worth trying include catching webs with raindrops on them, or using flash in the dark. Note that (aside from a mild trauma from the flash {maybe}) for the spider, these do no harm to animals). The two shots on the left have raindrops on them, the others are different.

Some photographers use a misting bottle on a web, but on a foggy morning, just as the sun starts to shine through, you can get shots like these two on the right. (Just as I was finishing this book, I was watering plants in a nursery where I work as a volunteer, and I set the hose to 'mist', and got some excellent shots of webs for my next book.)

When spiders moult, you can recover their cast-off exoskeletons (shells, if you like), and if you have a microscope, or even a magnifying glass, you can get some amazing shots. On the right, the light is coming from below this huntsman. It is shining through, giving the eyes an eerie look.

The 'face' of a huntsman spider, and how to spotlight for spiders after dark.

At night, you can spotlight live spiders and examine them. Above right, that's my ever-helpful wife posing with a strong light near her ear. Walk out in the garden at night, look for glowing eyes in the grass and then move in on them.

Until the electric torch was invented, the spiders did well, but shine a light at them, and the eyes with *tapeta* (tapetums, if you like), reflect back a green light. Some spiders that live mainly in dark places have 'nocturnal eyes', which look pearly white. Most spiders have diurnal eyes, which appear dark, but when you shine a light on them, the reflections are easy to see.

You need a decent patch of lawn without too much light, but you can also spotlight spiders on bushes. You need a bright tight-beam torch, held close to your ear, so you can look along the beam for the reflections from their eyes.

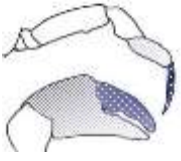
You can find even the tiniest spiders this way, though it's not a good idea to pick unidentified spiders up by hand! You will need a spotlight torch, and a jar and a card. I have also located Cape York spiders at night with a 'Petzl' head torch: these use LEDs for light and strap onto the forehead, leaving your hands free. Mind you, just photographing a spider in its web can also be fun:

Austracantha minax from North Head, Sydney on the left, and *Nephila* sp. from the Daintree River in the centre. There is a story that goes with the right-hand spider.

The third spider is called *Backobourkia*. I just threw it in here, because the name is marvellous. If you are Australian, can you see that? Because I have worked with taxonomists, I think I know how it got its name, but I found it on Sydney's North Head (where I work), *not* at the Back of Bourke.

$\sqrt{-1}\ 2^3\ \Sigma\ \pi$

Exoskeletons and how they work



This diagram shows a crab's leg and claw. It has colour coding for the last two segments of the leg. Look at it and you will see how a claw forms when the second-last segment grows outward.

The arthropods are the animals with jointed legs and no backbones: the insects, the crustaceans, the spiders and so on. You will probably find it easiest to work

on a dead crab or another of the lobster-crayfish group, because they are larger, and the "shells" are stiffer and easier to handle. Also, they have "nippers".

Stop and ask yourself how a nipper *might* work, and then examine one to see how it really *does* work, and if you can, look at the ends of the legs of a prawn (shrimp) and see if these are all the same.

Scorpions are poisonous, but pseudoscorpions aren't, though both types have nippers on long arms. Pseudoscorpions are found in leaf litter, and they do NOT have a stinging tail. Find out about them, learn how to catch some, and examine them with a lens to see how their nippers work.

You may be able to get bits of lobster shells from a restaurant, but the most interesting parts will have been broken by diners, and they will be crawling with pathogens. Wash them carefully before you start.

This book is supposed to be all about you being creative, so go and find out how the arthropods manage to grow a larger shell inside the smaller one, as they are moulting their way out of it.

Aside from that, make up your own enquiries, looking at structures in various groups. How do spiders grip things? Do all species use the same legs or palps?

Helixes and spirals

One of these things, not like the other… Look at these two screws: they might look identical at first, but look carefully, and you will see that one of them looks wrong.

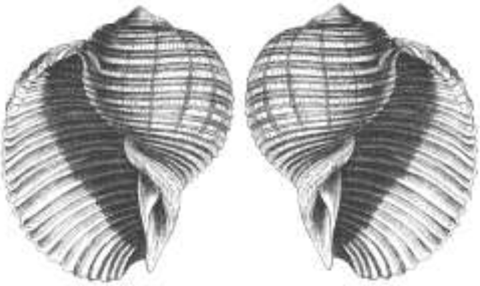
Can you spot the difference?

The two images above show the same wood screw, but the lower picture has been digitally reversed, so it now has a left-hand thread. You would have to turn the screwdriver the 'wrong' way to drive that screw into the wood.

Now here are two snails where I have pulled the same digital reversing trick, using public domain art. Most snails, but not all, have a spiral shell. Slugs have no visible shell, and the shell of a mature limpet is a flattened cone, like an

upside-down wok. Actually, most 'spiral' shells are helical, not spiral, but let's stay with the common name.

Spiral shells are also left-handed (left, below) or right-handed (right, below), just like creeping plants, which I will get to next. Some snails come as left-handed spirals only, some are right-handed spirals only, and a few are both.



Again, can you spot the difference?

To identify the 'handedness' of a shell, hold the shell, top up, so you are looking into the entrance hole. If the entrance hole is on the right, the shell is right-handed, but if it is on the left, the shell is left-handed. The other way is to imagine an ant walking up the spiral: if it's on the front and going to the right, that's a right-handed shell.

Thirty years ago, I examined several thousand Pacific shells, and several hundred Indonesian shells in museums and books. They were all right-handed, as were all the shells on display at the Australian Museum, and the Australian and New Zealand shells in several reference books. Even the Museum's fossil shells were all right-handed.

I gave up, but one day I was checking an aquarium tank at home. The snails I kept there to clean the glass all had left-handed shells. I suspect that this particular snail is an import from overseas, but there's a research thesis in there…

Rainforests have lots of lianas, vines which seem to dangle from branches 10 or 20 metres above the ground. These lianas have climbed up some of the hopeful young trees, long since dead and rotted, transferred to other trees and kept on climbing, until they were high enough to twine around the lowest branches of mature trees.

The creepers have a clear and obvious reason for twining, and they can be either left-handed or right-handed. The point of twining is to get some of the plant's leaves up high enough to get a share of the sunlight, and hang on.

The rarer left hand climber on the left and a right hander on the right.

A recent walk through rain forest at Dorrigo revealed that right-handed creepers are more common than left-handed ones, and I later found that in 2008, ecologist Professor Angela Moles from UNSW published a major study showing that around the world, 92% of twining plants are right-handed.

This applies north and south of the equator, so we can rule out any influence from the way the sun seems to move in the sky, and we can even rule out the Coriolis forces that determine the spin direction of cyclones.

Comedians Michael Flanders and Donald Swann wrote and performed a song called *Misalliance*, about a love affair between the right-handed honeysuckle and the left-handed bindweed. A web search on <**Flanders Swann Misalliance**> will turn up several versions.

Listen to their song, then wander out into the bush and look for twining creepers. Check to see which handedness is more common where you live, and see if any species can twine both ways, maybe even on different stems of the same plant.

Inside a spiral shell

This enquiry uses acid and a power drill: younger readers *must* get adult help. In nature, endocasts form when a shell or a skull fills with mud before being buried. Later, ground water may dissolve the shell or bone, just leaving the internal cast. This is a slow process, but I found a way to speed it up by filling a shell with plaster, and "dissolving" the shell with acid (the plaster does not react with acid, but the shell reacts and does not dissolve).

Endocasts of a garden snail shell (left) and a sea snail shell (right).

Work on several large sheets of newspaper, or use a large plastic bowl as your workspace. Wear rubber gloves and goggles, and remember that acid spills are

best treated with lots of water, so keep water handy, and work in a place where you can splash water around if you need to. You also need a file, a drill with a fine (no more than 2 mm) bit, some snail shells or seashells, an old yoghurt container, water, and an old teaspoon. You can buy hydrochloric acid and plaster of Paris at a hardware store.

Scratch the shell top with the corner of a flat file, so the drill can get a grip. Then put on a gardening glove so you can hold a shell and drill a small hole in the top to let the air escape when you stuff the shell with wet plaster through the main opening. You need to be very gentle with thin snail shells.

Mix the plaster and water carefully in a container until it is about as thick as cream. Keep adding water or plaster until it seems about right. Push the wet plaster into the opening of the shell until a small 'worm' of wet plaster starts to ooze out the drill hole.

Wipe the 'worm' away with a damp tissue and leave the plaster to set (about 30 minutes will do). Tip or wash any leftover plaster into a hole in the garden or into a container to go in the bin, not down the drain!

When the plaster sets, put the shells in a plastic container and add some dilute (about 1 part in 10) acid. When the shell reacts with the acid, there may be bubbles and foam, so don't fill the beaker more than halfway, and sit the container in a large plastic bowl.

With weak acid, you may need to wash out the container and add more dilute acid on the second and third day. Put everything in a safe place (think about pets, children, unaware adults, wind gusts, and think about what the acid will spill onto if the container tips over).

Wear rubber gloves when you take the plaster out, once all the shell has gone. What you do now with your trophy is up to you. I cleaned mine with an old toothbrush.

$\sqrt{-1}\ 2^3\ \Sigma\ \pi$

Tracks

Out of doors, tracks are easy to find, if you look in the right place. Water-washed mud is good, and damp, water-washed sand is even better. Working out what made the tracks can be harder, but if you can see a bird hopping or walking on a beach, you can get a photo of it, and its track, and you are on your way to making up an album. As a rule, I prefer not to identify snakes like the one that made the track below, though…

The track left by an unknown snake.

Macropods (wallabies and kangaroos are easy, and you will often find their tracks in the soft sand at the side of a fire trail: the first two in the next set are from Ku-Ring Gai Chase in Sydney, the third is from Wilpena in South Australia. Can you see how a 32 mm-across coin for scale helps?

Macropod (kangaroo and wallaby relatives) tracks.

The next three are a bit different. The dingo paw print on the left below was taken before I switched from a 20-cent piece to 50 cents. The middle shot is a characteristic scat from a wombat, and the last is a totally unknown small hopping mammal, near Marree in South Australia.

Other animal signs.

Over to you, wherever you live!

Notes for this chapter

Read *Adventures in the leech trade*:
https://oldblockwriter.blogspot.com/2013/02/adventures-in-leech-trade.html
(Last viewed October 2019.)

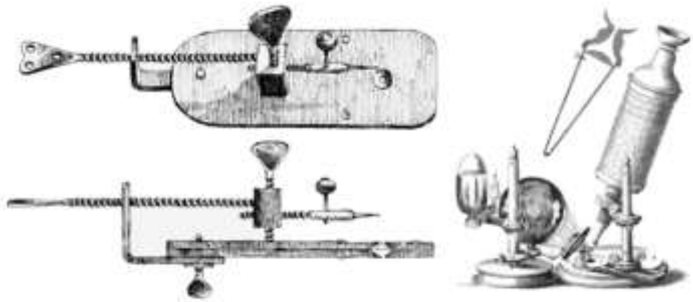
More about *Backobourkia*

As I said, I know taxonomists, and the hardest part of their work is finding a name that hasn't been used before. Some of the more unusual names that I know about are a flower called *Coopernookia*, and fossils called *Thingodonta* and *Montypythonoides*. Weird names like those are memorable, so people know they haven't been used. I have a theory about *Backobourkia*. Do you?

(Afternote): You can find that theory here:
https://oldblockwriter.blogspot.com/2019/12/the-naming-of-things.html

$\sqrt{-1}\ 2^3\ \Sigma\ \pi$

12. Microscopy



Two microscopes from the 1600s. On the left, Anton van Leeuwenhoek, and on the right, Robert Hooke.

I recently wrote a whole book on microscopy, so there are just a few ideas here, things where the reader can use a technique in other ways.

[Moth and butterfly scales]

[Spider web]

[Stomates]

Back to the [Contents]

Moth and butterfly scales

A scale from the wing of a dead moth.

Butterfly wings are interesting, because, strange as it may sound, they have no pigments. The moths and butterflies are called the Lepidoptera, which means "scale wing", because their wings are covered in very fine scales, and in the case of the butterflies, these scales produce the effect of colour because of the way they catch, reflect and split the light.

Making a wet mount (slide) of moth scales.

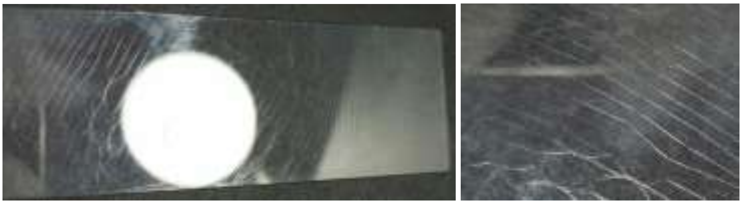
It's too technical for this book, but hints about how the wings get their colour will be found in chapter 6. For now, just look at the scales. Dead moths, collected on windowsills or out of light fittings will give you all the material you need, and you can use scissors to clip away part of the wing of a dead butterfly, caught in a spider web: there's no food for the spider in a dried-out wing.

Even though you will probably want the higher magnification of a monocular microscope, you will probably need to use reflected light to see any detail, so think about using a bright reading lamp as your light source. Here's how to make a slide, and that's all you get:

$$\sqrt{-1}\; 2^3\; \Sigma\; \pi$$

Spider web

It occurred to me that web would be interesting, and indeed it is, with a serious microscope. If you don't have one, you can look at some things with a hand lens or a clip-on as well. To get my sample, I went out with a microscope slide, and collected a small part of a spider's sticky web:

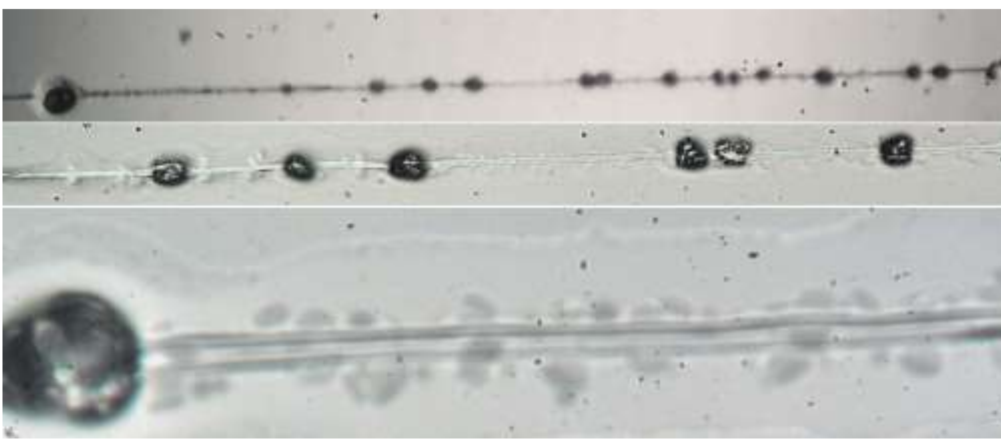


(Left) I needed a strong light to make the web show up on the slide, which explains the white circle. (Right) a cropped portion of that shot.

Now do you remember the St Andrew's Cross spider in chapter 11? I decided to take a closer look at the saltire (which is what Scots call that 'cross'), and these pictures tell the story:

The steps in examining the saltire of a St Andrew's Cross spider

The sticky parts of a web demand special attention, but that *really* needs a good microscope.



Those blobs on the thread are the 'glue' that catches a spider's prey. One of these days, when I stop writing, I will take the time to try to get better shots. Beat me to it!

Now let's look at taking a 'peel'. Perhaps you can think of other surfaces like sandstone or nailfiles, where peels might be interesting art sources.

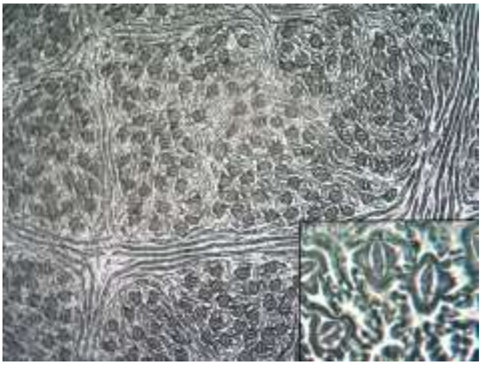
Stomates

The leaves of plants have to breathe, and they do so through tiny pores that are called either *stomata*, or stomates. These holes let carbon dioxide in and oxygen out. They also let water vapour escape, so to avoid drying out, plants need to control their stomates, which are very tiny, about 0.05 mm ($^1/_{20}$ mm) across. That means you won't see them with the unaided eye: you need either a very good hand lens, or better still, a microscope.

The easy way to view stomates is by taking a special cast of the surface. Using a small amount of clear nail polish, paint a thin strip, roughly 1 cm wide and 3 cm long (the size isn't really important) on the leaf's lower surface.

Preparing a 'peel' of an ivy leaf.

Leave this to dry for about 10 minutes, and then lay a strip of clear sticky tape over the nail polish. When you lift the tape off, the nail polish will come with it, and there will be a perfect cast of the leaf surface on the lower side. When you attach the tape to a glass slide (as shown above), you are ready to go.



A peel from the lower surface of a bay leaf, at x100 and x400 (inset).

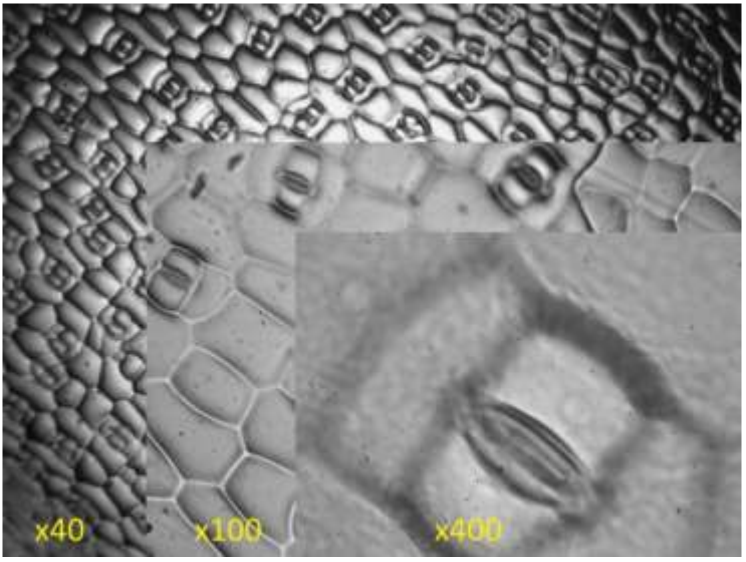
To show you what you can see with a professional level microscope, the shot of a peel from a bay leaf above was taken at x100, though the lower right inset is

at x400. Once you see this, the lower magnification views will make sense. Each stomate looks like two really thick lips.

A literature search told me the best plant for this exercise is *Tradescantia pallida*, a garden favourite with purple leaves, one that grows easily from cuttings. To help you find it, it's the plant below.

This is the plant you want.

And when you use that, here is what you will see:



Now here are the *Tradescantia* stomates at three magnifications, and all of that from a bottle of nail polish!

$\sqrt{-1}\ 2^3\ \Sigma\ \pi$

Notes for this chapter

See my new book, *Looking at Small Things*. I may yet sell that to a publisher, but even if I do, look at https://www.gomicro.co/wp-content/uploads/2019/05/Teaching-notes-1.pdf (last seen October 2019) to get lots of good ideas for free.

13. Getting artistic

Now imagine the artistic fun you can have with a microscope gadget that feeds pictures to a device or a computer!

The Two Cultures

Strange circles

Köchel numbers

Art from broken glass

Art with leaves

Art and ideas

Entertainment

Back to the Contents

The Two Cultures

In very early 1959, I argued with a pompous headmaster who had a Master of Arts degree, because I wanted to continue my studies in Latin, and also study physics. He rejected my request with a crushing dismissal: "Boys who do physics *do not* **do** *Latin*." That was how I became the victim of something neither of us would have heard of back then, the notion that learned society was made up of "two cultures", the Arts culture and the Science culture.

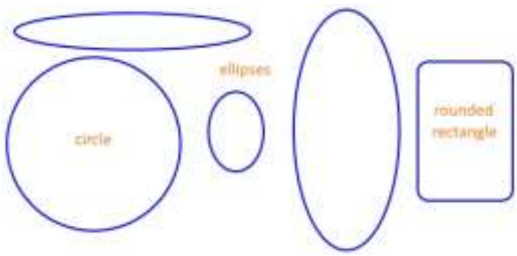
The divided cultures had been around for a century or more, but the name "two cultures" was only proposed in 1958 by C. P. Snow, a physicist who wrote fine novels, making him a member of both cultures. Snow said that, as the Arts people saw it, the "Arts Culture" contained all the witty, urbane and articulate people.

The "Science Culture" was, according to the Arts people, made up of scruffy men (and just a few equally scruffy women back then) who were incredibly clever about extremely difficult things, but who were absolutely useless when it came to dealing with people. Scientists were stolid and uncreative manipulators of objects, lacking in personal skills.

The scientists were often absent-minded, we were told, where the Arts culture people were clear-thinking. Leave us to do the ruling, puffed the Arts people. The scientists and engineers let this go, but in their turn, they puffed that the Real Work should be left to them.

According to this divisive pair of stereotypes, creativity is only found in the Arts people, and practicality lies only with the Science people. Fuelled by these notions, the two camps are encouraged to regard each other with a less than friendly contempt. My regard for people who accept that view is far less polite. To survive and do well, it helps to have a foot in each camp. To work in STEM, you badly need the art of debate, the ability to write clearly, sketch neatly, take photos and more. You need STEAM.

Strange circles



Non-standard round shapes.

Once upon a time, astronomers were certain that all the moving bodies in space travelled in circles, "because circles are perfect". In many ways, modern science

began when Johannes Kepler saw that the orbits of planets were ellipses. Or maybe science emerged when Isaac Newton proved that the orbits had to be that shape, because of the way gravity worked. Whichever way it happened, those odd squashed circles called ellipses were involved.

A 19th century engraving of a Gatling gun: notice the shape of the wheels.

To me, ellipses are important, because in perspective, circles look like ellipses, but I am no artist, and I need help to get my ellipses right. When I am drawing on paper, I use plastic templates to draw my ellipses, but with a simple graphics program like Paint.Net, I can draw ellipses of any shape and size.

If you want to work on shading and stippling geometric shapes, use a colour printer to print out pale sky-blue ellipse outlines. Make just enough fine black points on the paper to show the outline, then photocopy it: pale blue (often called "dropout blue") usually fails to show in a photocopy, and away you go.

We will meet Piet Hein again in chapters 15 and 20 of this book, but now we need to look briefly at his superellipses, which were adopted as a suitable shape for rounding-off a space in the centre of Stockholm, rather more nicely than the rounded rectangle above. If you look online for <Sergelstorg>, you can see the result in maps and aerial photos of Stockholm. By an odd chance, Hein came up with his solution in 1959, the year in which I encountered the two cultures, and C. P. Snow published a book about his them. Surely, if anybody ever showed how the Two Cultures notion breaks down, it must be Hein. And now, we need to venture into mathematics of a **Heavy Kind**.

There is a whole family of curves with the formula $\left(^{x}/_{a}\right)^{n} + \left(^{y}/_{b}\right)^{n} = 1$, and as a group, they are called Lamé curves, after Gabriel Lamé, who discovered them. If n is between 0 and 1, the figure is a four-pointed star. If n= 1, it is a parallelogram, and for n between 1 and 2, it is a rounded-off rhombus. If n=2, we get an ellipse or a circle (depending on the values of and b), and above that, we get squircles, or superellipses.

Sergelstorg has n=2.5, and a/b=1.2. Over to you, but look around on the internet for 3D supereggs and ellipsoids…

$\sqrt{-1}\ 2^3\ \Sigma\ \pi$

Köchel numbers

Music is important in all cultures, but STEM people can find more in music. The *Köchel-Verzeichnis* or *Köchelverzeichnis* is a careful listing, in order of composition, of all the works of Wolfgang Amadeus Mozart. This list was put together by an Austrian musicologist, Ludwig Alois Friedrich Ritter von Köchel. (Just in case you need to know, Ritter is a title, a bit like the English 'Sir' for a knight.)

K. 626 is the Köchel number of Mozart's last composition, the *Requiem*, composed in 1791. After the age of 10 (in 1766), Mozart churned out a fairly uniform number of works each year until he died, which means that you can estimate his age at writing from the number given a work in Köchel's listing. Just take the K number, divide by 25, and add that to 1766 to get the approximate year of composition.

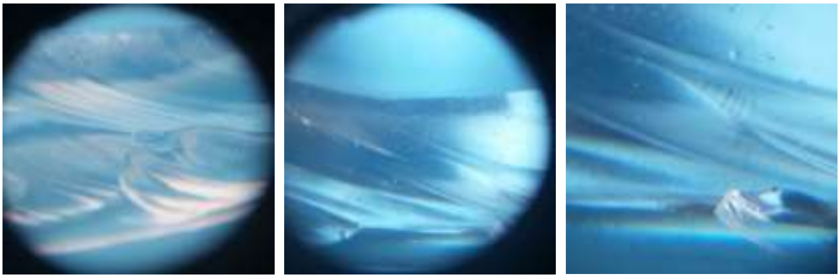
You can test the formula out with K. 165, *Exsultate Jubilate*, composed early 1773, K. 525, *Eine Kleine Nachtmusik* (1787), K. 551, the *Jupiter Symphony* (1788), K. 620, *The Magic Flute* (1791). Remember that it is only approximate: the formula tells us incorrectly that *Exsultate Jubilate* was composed in mid-1772. You don't know these works? Find them on YouTube! Mozart rules!

Art from broken glass

Speaking technically, glasses are liquids: they have no crystals in their makeup, so they have a very odd way of breaking. Like obsidian, a volcanic glass, they show conchoidal fracture. It looks like this picture below, where the circular field is about 9 mm across.

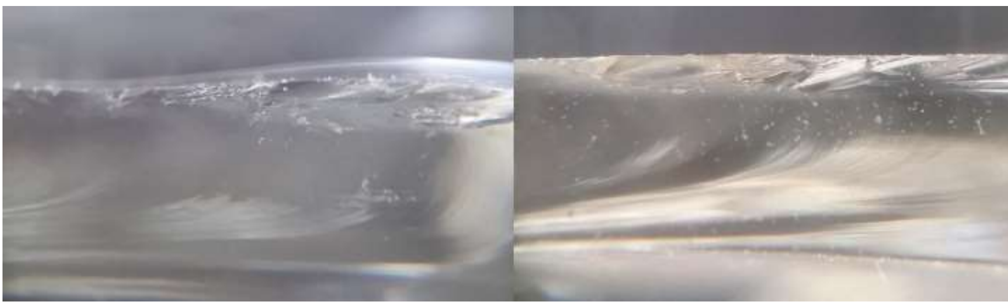
Conchoidal fractures in glass.

To make art from conchoidally fractured glass, you need some sort of a magnifier, and you will need some pieces of broken glass. I collect most of my specimens while walking around the local beach, mainly hunting plastic, but also picking up broken glass. The best samples are the thick glass from a bottle's base. **Safety note**: I have tough old hands, but even I wear gloves to handle broken glass!



More conchoidal fractures.

Take some images of broken glass like this, and make abstract art from it. The trick lies in choosing the right background. I used blue cardboard for the shots above, and black cardboard for the ones below. I think that what you need is a cartoon of a surfer…



Can you make art from something like this?

$\sqrt{-1}\ 2^3\ \Sigma\ \pi$

Art with leaves

You will need paper, sticky tape, a pair of scissors, access to a scanner and a computer. Go outside and collect a set of leaves from different types of tree. Take them back inside.

Dry the leaves if they are damp. Use small amounts of sticky tape to attach the leaves to a sheet of white paper, and scan the shapes. Use software to clip, rotate, reverse, shrink or colour the shapes

Save the image, and use software to add labels to the outlines of the different leaves, if you wish. Change the colour to black, using the available software.

Here are some ideas to take further:

- Investigate ways of making more artistic arrangements of leaves on sheets of paper.
- Print out your three best works and display them.

- On the practical side, can you put the plant names on silhouettes in white print?
- Create a small file from your leaf images which is tileable (look that word up), and use it as a background on a web page.

Don't feel limited by this: change the subject to butterfly wings, road kill or anything else that takes your fancy. Maybe not roadkill, it might attract flies or mess up the scanner, but feel free to take the ideas and bend them. In chapter 11, I explained how to keep pill bugs: look at their container, and you will find lots of interesting leaves, stripped down to mere skeletons.

The rest of this chapter is a set of thinking topics, any four of which, combined the right way, might give rise to an interesting novel.

Art and ideas

- What are the relationships between new ideas and change?
- Where do new ideas come from? How come? So what?
- What is a "good idea"?
- What do you think are some of the most important human ideas of this century? Where did they come from? Why? How?
- Who do you think has the most important things to say today? To whom? How? Why?
- Which of humanity's ideas would we be better off forgetting? How do you decide?
- What are the dumbest and most dangerous ideas that are "popular" today? Why do you think so? Where did these ideas come from? Why are they popular?
- If you had an important idea that you wanted to let everyone (in the world) know about, how might you go about letting them know?
- How do you tell when a good or live idea becomes a bad or dead idea?
- Where does knowledge come from?

Entertainment

- If you set out to invent a new sport that people would really enjoy playing, what features would it have?
- If you set out to make some existing sport into a megabucks crowd-pleaser, what existing sport would you use, and how would you change it to make it more popular and better-paying?
- If you were establishing a new pop group/fast food business/fashion clothing outlet, what features would it have?
- People go to the theatre and the movies to see realistic stories. In real life, people do not suddenly start singing to each other. So why are musicals and operas so popular?

- If you were an alien, judging earth by what you see on TV, how would you describe Earthlings? Why?
- Will some of today's soapies become classics that schoolchildren a hundred years from now will have to study at school?
- Why do people watch so much sport on TV?
- What is worth knowing? How do you decide?
- Why are some nuclei more stable?
- Why do unstable nuclei emit alpha particles and not protons?
- How did life arise?
- Is there life on other planets?
- How do we measure the universe?
- How do we measure the age of the universe?
- How do we measure the age of rocks?
- Why does gravity pull and not push?
- What would happen if gravity pushed instead of pulled?
- Why does toast go brown?
- What is the nature of creativity, and how can we foster it?
- What is the nature of tolerance, and how can we encourage it?
- What is the nature of intelligence, and how can we nurture it?
- What will humans be like in fifty thousand years' time?
- What should the history of science study?
- **You**: "I reckon we could pose more interesting questions than these. Let's write half a dozen and send them off to this bloke. His e-mail address can be found, if we look hard enough."
  Me: "Yes, please…"

$\sqrt{-1}\ 2^3\ \Sigma\ \pi$

Notes for this chapter

The Two Cultures

Can you develop an "Arts Quotient" test, and a similar "Science Quotient" test? The idea is to find questions for which an Arts person is far more likely to answer "yes" (or correctly) than a science person, and *vice versa*.

Assign a score of 1 for a correct answer to questions like the names of the authors of famous works of literature, or for an affirmative to "Have you attended a live theatre performance in the last twelve months?", and draw on some of your more arts-oriented friends for further ideas. (The aim is to get a stereotype of the "typical Arts type".)

Then chase your scientific friends, and get ideas for a "Science Quotient": maybe things like knowing the second law of thermodynamics, listening to science podcasts, knowing the value of π to five decimal places, things like that. Test both sets and choose the most effective items, then slim the list down to about eight questions for each set.

Now you are ready to go out into the highways and by-ways, scoring each person on the two measures, and plotting the results on a grid (x-axis the arts score, y-axis the science score). What you do with the results after that is up to you.

Köchel numbers

How to pronounce *Köchel*: near enough for now, it rhymes with *circle*. If you are looking it up, <Kochel> usually works just as well.

Getting artistic

Regarding a new sport, would you try to make a healthy sport, or a spectator sport with lots of large people hacking lumps out of each other, just made for television?

$\sqrt{-1}\ 2^3\ \Sigma\ \pi$

Part 2: playing with ideas and numbers

There is a joy in exploring ideas and puzzles which can all be solved, if you tackle them the right way. This half of the book is mostly about puzzles and numbers, so it's mostly logic, mathematics and computing.

When I was introduced to the next puzzle in 1980, it was described as "a Russian aptitude test for youngsters wanting to study architecture".

Can you make this without any adhesives, from one piece of card?

The student was handed a piece of white cardboard, 13 cm by 8 cm, a pair of scissors, and the drawing above. The task was to make the same thing in three dimensions, without using glue or sticky tape. I solved the puzzle quickly, *but only because I knew there had to be a solution*.

When you work it out, make one from sheet metal.

That night, I took a sheet of copper, a pair of tin-snips, and a steel straight edge, and made the object seen above, which has sat on my desk, ever since.

ABCB
ADEF +

GFFF
AHJA -

AGKD
D x

FKFD
J ÷

GKCG

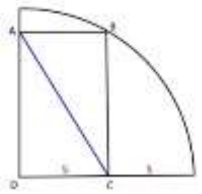
Can you solve these coded sums? Each letter represents the same digit, each time.

If you can solve that puzzle yourself, you will probably get the puzzle above as well. It is a set of sums, coded so each number is replaced by a letter. I think I

was 11 or 12 when I solved it because I knew it had to be solvable. Remember that, because it is the magic key. There is no sense in asking people to solve a problem that has no answer. Asking a question where *you don't know the answer* is different. I do that all the time, *but I always say when I don't know*!

Always start by knowing there has to be a way to solve a puzzle. Look at the addition at the top of the sum set above, and realise what the value of B is. Go down two sums to the multiplication and realise that D can only be zero, one, five or six, then rule out two of those right away. That's all the help you get, for now.

The mystery diagonal



What is the value of AC?

You have 30 seconds: what is the length of the blue diagonal, AC? This is one of those questions where the time limit tells you there must be an easy answer.

Full of germs

A bacterium divides in two, every 20 minutes. At exactly noon on January 29, one bacterium is dropped into a culture vessel, and at exactly noon on January 30, the vessel is found to be completely full. At what time was the vessel half full? As you will see when you work out the answer (or peek at the notes), you need an agile mind. There *has* to be an answer…

Can you match this?

Here are some very old puzzles that use match sticks to do mathematics with Roman numerals. As we will see later, an Italian mathematician called Fibonacci did not think using Roman numerals was a good idea, but I think he would have solved these challenges, anyhow.

You need to have some skill in both mathematics *and* Roman numerals. Remember, as always, that there has to be a solution (or maybe more than one solution). You can move one, and one match only to make a true equation. The first question has at least three solutions:

A puzzle in Roman numerals.

Here are the answers:

For the rest of these puzzles, though, there are no answers given, until you turn to the chapter notes.

2. 

3. 

The next one calls for a close approximation, and that's a hint!

4. 

The last one is more mathematical: convert this to a value of one by moving one match.

5. 

It's all about thinking logically, and that's where we go in the next chapter.

$\sqrt{-1}\ 2^3\ \Sigma\ \pi$

Notes for this chapter

The architecture aptitude test

This note doesn't tell you how to pass the test, but it should help. The version below was cut out of scrap cardboard, printed on one side only. Can you see the solution now?

That coded sum

```
 DBCA
+DBEA
-----
EACDA
```

A simple example of a coded sum.

Let's begin first with the simple puzzle above. If A+A = A in the first (right) column, then A = 0. If two four-digit numbers give a five-digit sum, E = 1. From the fourth (left) column, D+D = 10, so D = 5. From the second column, D= C+1, so C = 4, and from the third column, B = 2. So if we know a bit about numbers, these puzzles suddenly become a lot less tricky.

Now let's look at the first part of the big sum. If you had x + y = x, what is the value of y? Look at the right-hand column below, and you will know that B is zero.

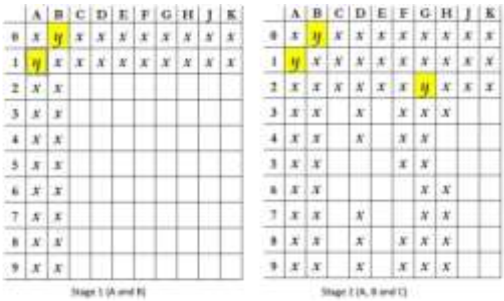
```
ABCB
ADEF +
----
GFFF
```

Starting the main puzzle.

In the hundreds column, B + D = F, but how can that be? Obviously there was a 'carry' from the tens column, so F is one more than D. All three rows have four numbers, so A has to be 1, 2, 3 or 4. I thought I would leave you to take it from there, but in the editing, I solved the puzzle again, and it was hard, so I decided to give you a bit more help:

This table shows how to start tackling it. In any row and column a *y* (for 'yes') means all the rest of that column or row is *x*, meaning 'no'. The table below records my progress to the point where B is zero, A is 1, G is 2, F= D+1 and H=F-2=D-1. The rest is *really* up to you. If you can't get there, set it aside.

With codes and cryptic crosswords, you need to either own the right sort of mind, or grow the right sort of mind by practice. Let the puzzle marinate.



This is how I tackle problems like this.

The mystery diagonal

Look at the *other* diagonal, the one running from D to B, the one that isn't shown. It is a radius of the circle, the two diagonals of a rectangle are the same length, and oh, look, there's a radius there, which is 2 x 5 units long. Easy!

Full of germs

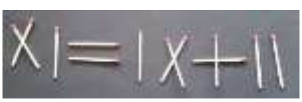
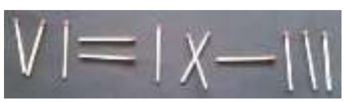
Anybody who knows (and worries) about human populations knows the answer to this. If the population doubles every 20 minutes, the vessel was half full at 11:40 pm on January 30.

See? It's all a matter of thinking outside the box, both you and Schrödinger's other cat.

Can you match this?

Here are the answers I know: there may be others.

2: 

3:  

4:  (For the next two, all is fair in love, war, and mathematical puzzles)

5:  (If you missed it, the square root of 1 is 1.)

14. Some first puzzles

Whatever you do in life, you will need to be able to solve puzzles. Start your training here.

Back to the Contents

The wolf, the goat and the cabbage

This simple puzzle occurs in many forms. They all involve a situation where a carnivore, a herbivore and some plant material must be carried across a river in a small boat.

Always start with "there has to be an answer: what is it, or how could it begin?"

Here is the puzzle: a girl has to get a hen, a fox and a basket of grain over a river in a small boat that can only carry one item at a time.

First, she takes the hen across, leaving the fox with the grain.

Next, she takes the grain across, and brings the hen back.

Next, she takes the fox across and leaves it with the grain.

Last, she brings the hen across. Easy!

The explorers' short walk

Two explorers saw a bear trying to get into their supply dump. Knowing the dump was bear-proof, they left, hoping the bear would go away. They walked one kilometre south, one kilometre east, and one kilometre north. They were then back at the supply dump and the bear was still there, so one of them shot it. What colour was the bear?

This is an old one: remember there is *always enough information to reach an answer*. No hints: use your search engine. Or play with it.

The puzzle of the lost pets

This is a simpler version of *The puzzle of the performers* (which is at the end of this chapter). Who owned what, and where was it lost?

1. Three pets, including a budgerigar and a wombat have been lost.
2. The pet lost in the garden is owned by Alastair.
3. Brianna does not own a wombat.
4. Callum's pet was lost in the bush.
5. The kiwi was not lost in the bush or in the park.

The hole through the sphere

This looks much harder, until you are shown the easy answer.

A cylindrical hole, 6 cm long is drilled through the centre of a steel sphere. What is the volume of steel left? Yes, *there is an answer*: try to get it first, then check the notes for a lesson in cunning.

The Prisoner's Dilemma

This is the name given to an interesting puzzle in game theory. The outline was originally created by Melvin Dresher and Merrill Flood of the RAND Corporation, and Albert W. Tucker gave it its name.

Two prisoners are each given exactly the same information: there is enough evidence against each of them to get them both sentenced to a gaol term. If one is prepared to give evidence against the other, then that prisoner will get off free, while the other prisoner serves five years. On the other hand, if each provides evidence against the other, each will be convicted and serve four years. The dilemma is that each prisoner knows the other prisoner has the same information, and will act in some way: so what is the best choice to make?

The problem has a number of practical applications: a child immunised against a certain disease may run a small risk (let us say one chance in a million) of dying because of a complication caused by the immunisation. On the other hand, if only half of the population are immunised against the disease, one child in fifty will certainly die in an epidemic. If 95% of the population are immunised, an epidemic will not take place, as the disease will be eliminated.

To many people, the selfish choice is best: avoid immunisation, and let others to take the risks for you, but if nobody is immunised, then those who are without immunity run a much greater chance of dying. Other applications are found in economics, evolutionary biology, and even in military planning.

What use are paradoxes?

Imagine a ball, thrown into the air, just as it reaches the highest point. One moment it is going up, the next, it is going down. If you take smaller and smaller fractions of time, there must be a point where the ball is neither going up nor down. Of course, if you measure accurately enough, there is no such moment: the ball is always either rising or falling, and its speed is changing. So how can we ever calculate how fast it is going, or how long it will take to get from A to B, and what are the mathematics of limits? How can we find the mathematics to describe the path of a cricket ball?

In the late 1600s, Isaac Newton and Wilhelm Leibniz invented the branch of mathematics called calculus, but that was too late for the Greeks, who said

there had to be a way of dealing with limits like that, but the mathematics of very small things made no sense to them, without calculus.

The old Greeks had a way of testing puzzles by reasoning, and if they got a contradictory result or a nonsense result, they called this a paradox, and knew there was a problem. Sometimes they deliberately set up a paradox to test something, like the one known as *Achilles and the tortoise*, or *Zeno's paradox*.

Invented by Zeno of Elea, nearly 2500 years ago, one version says Achilles runs 10 times as fast as the tortoise, but he gives the tortoise a 10-metre lead. At the start, Achilles sprints 10 metres, but tortoise has travelled another metre, and when Achilles travels that metre, the tortoise has gone a tenth of a metre, and so on. Zeno said Achilles can never catch the tortoise.

He wanted to prove that something is impossible, even though we can see it happening, from which it follows that since we can see the impossible happening, our senses must be faulty. In other words, his paradoxes were designed to make people think harder.

Later, Aristotle argued against Zeno's assumption that space and time were infinitely divisible. This argument made another Greek called Democritus suggest that matter was not infinitely divisible. That gave him the idea of atoms, and all because Zeno believed the senses could not be trusted. Even though Zeno had *proved* that Achilles could *never* catch the tortoise, we know that in real life, he *can*!

Practical people knew the tortoise was toast, and a few of them might even have had a feeling that the tortoise would be passed at 11.111111... metres, but they had no system of mathematics to deal with the sums, so maybe they didn't. Anyhow, the realm of fairy-tale mathematics, and treacherous tiny segments of time attracted the interest of scientists in the 17th century. They needed to deal with these ideas, and they did—but there were other paradoxes as well.

Self-reference paradoxes

Street sign, Athens.

I am easily amused, so when I saw *Odos Epimenidou* (Epimenides Street) in the old quarter of Athens, I laughed out loud. Epimenides of Crete is credited with one of the first self-reference paradoxes when he said, "All Cretans are liars", meaning by implication that this statement (made by a Cretan) was necessarily untrue. But if it is untrue, then not all statements made by Cretans are liars, and so on… Stop reading now, before your brain starts hurting.

There is a more complex form of this paradox, consisting of two sentences. “The next sentence is false” and “The previous sentence is true”. And try this one: *there are two erors in this sentence.*

No, really, stop, before your brain hurts. You don’t need the next four paragraphs. Jump over them!

Some words describe themselves. “Short” is a short word, but “long” is not a long word, “English” is an English word, but “German” is not a German word, and so on.

Bertrand Russell sent a paradox to mathematician Gottlob Frege in 1902, and it runs something like this: some sets, such as the set of all insects, are not members of themselves. Other sets, such as the set of all non-insects, being not insects, are members of themselves. If we call the set of all sets that are not members of themselves R, we have a problem. If R is a member of itself, then by definition it must not be a member of itself.

Or, if R is not a member of itself, then by definition it must be a member of itself, and either way, something is up! His letter about the paradox reached Frege as he awaited the appearance of the second volume of a two-volume treatise on mathematics. He added a note at the end of the second volume:

> A scientist can hardly meet with anything more undesirable than to have the foundation give way just as the work is finished. In this position I was put by a letter from Mr Bertrand Russell just as the work was nearly through the press.

Well, I warned you to stop…

A posy of paradoxes

Still reading? A student lawyer is trained by an older lawyer who says, “You must pay me for your tuition after you win your first case”. Several years go by, and the young lawyer has yet to win a case. The teacher sues the student, saying, “If I win my case, you must pay me, but if I lose, you have won your first case and must pay me.” “Not so fast”, says the young lawyer. “If I lose the case, I have yet to win a case and need not pay you. But if I win, then by the court’s judgement, I do not have to pay you.” Does the student lawyer have to pay?

$\sqrt{-1}\ 2^3\ \Sigma\ \pi$

Paradoxes can be useful ways of extending our knowledge, or at least ways of finding the right questions to ask. Fermi’s conjecture, also known as Fermi’s paradox, was offered by Enrico Fermi, a nuclear physicist. In simple terms, it asks, if the Galaxy is filled with intelligent and technological civilizations, why haven’t they come to visit us yet?

There are several possible answers to this question (good taste on the ETs’ part, distance, or a recognition that contact with a superior civilisation is

damaging to the more primitive one), but as we only have the vaguest idea what the right conditions for life and intelligence in our Galaxy may be, this paradox probably has no ready answer.

Paradoxes are also useful as a form of the mathematical proof called *reductio ad absurdum*, an argument that reduces an idea to an absurd or contradictory conclusion, hence showing that an initial assumption must be wrong. This shows up well in the so-called grandfather paradox of relativity. Imagine that your grandfather has just built a time machine, which you then use to go back in time, to give your grandfather the plans, so he can later build the time machine.

You reach him at a time when he has yet to meet your grandmother, he refuses to believe you, and during an argument, he steps out into a road, and is run over and killed by a passing car. He has now died before he met your grandmother, and because one of your parents cannot exist, you do not exist, and the time machine does not exist, so you cannot be there in any case.

Physicists use this sort of thing to support their belief in the *causality principle*. Others say the fact that we have never met time travellers proves that there will never be any, but this is probably one of the most useless paradox types. Maxwell's demon is better: this is a paradoxical being that was dreamed up by James Clerk Maxwell.

Gas molecules have a statistical distribution of energy (heat, if you like), with some hotter than average and some cooler than average. Maxwell proposed the notion of a small demon, able to see gas molecules coming, assess their energy, and divert them into one of two containers, providing one container of hot gas and one of cool gas. Then, by allowing heat to flow from one to the other, perpetual motion could be achieved.

Since physicists are convinced that perpetual motion is impossible, either the scientists had accepted a false claim, or there was some flaw in Maxwell's reasoning. In the end, the answer turned out to be (in simple terms) that the energy needed to examine and sort the gas molecules would be greater than any energy that could be extracted from the system.

Cats and logic

In the dedication and elsewhere, I have mentioned Schrödinger's other cat (which never existed), but let's turn now from Maxwell's demon to the second-most interesting beast in the menagerie of physics, Schrödinger's cat. The original Schrödinger's cat never existed either, but it was (and is) quite real (as a paradox).

Suppose we place a cat in a sealed container, along with some lethal device, like a gun or a cyanide capsule. We then set up a system in which some quantum event, when it happens, will trigger the gun or the capsule, killing the

cat. Further, we plan things so there is a 50% chance the cat will die. The survival of the cat is to depend on whether or not a particular radioactive nucleus decays.

Schrödinger's cat was a delightful paradox. In the ordinary world, we can tell when the cat dies by watching it. Here, we try to determine the time of death by writing down the equations describing the quantum process. Then we need only calculate the time at which the decay occurred that burst the capsule, revealing whether the cat is alive or dead.

Alas, the equations will yield a minimum of two solutions. One solution says the cat is happy, alive and kicking, the other says the cat has kicked the bucket. This is clearly an unsatisfactory state of affairs, and not just for the unfortunate cat.

Albert Einstein felt strongly that the world should not be prey to random events that could not be determined in advance, and he seized on the Schrödinger's cat paradox to support his belief. Leave out the cat altogether, if you must, the paradox says we cannot say with certainty whether a particular atom will decay or not. Having the cat there just makes it all easier to think about, unless you're a cat-lover, and find it all unthinkable.

Schrödinger's cat has had a number of lives. John Gribbin wrote a book on quantum physics called *In Search of Schrödinger's Cat*, and Robert Anton Wilson wrote two delightfully anarchic and tricksy science fiction novels with the cat in the title, and that is several more books than Maxwell's demon can claim. John Wheeler later resolved the paradox and, dare I say it, put Schrödinger's cat down, but let's leave the cat out there a bit longer. It might stop Maxwell's demon from getting lonely.

The Spanish barber and the crocodile

A barber in Spain is asked how business is doing. "Not badly," says the barber. "I shave everybody in the village who does not shave himself." The problem: who shaves the barber?

A crocodile seizes a child, but promises to let the child go, if the father guesses correctly whether he will do so or not. If the father guesses that the crocodile will not return the child, what should an honest crocodile do?

Self-replicating machines

The idea of self-replicating machines dates back to John von Neumann in the 1940s, with his Universal Computer and Universal Constructor. The Universal Computer could compute anything it was instructed to compute, while the Universal Constructor could build anything it was instructed to build. Some people have suggested that space could be explored by such machines,

programmed to find new matter in new solar systems, make more machines, and send them on to even newer solar systems.

The idea was that the Universal Computer held a program that directed the behaviour of the Universal Constructor. The Universal Constructor, in turn, would be used to manufacture both another Universal Computer and another Universal Constructor. Once finished, the newly manufactured Universal Computer was programmed by copying the program contained in the original Universal Computer, and program execution would then begin.

Some people have argued that the idea must be impossible, or by now the whole universe would have been converted to von Neumann machines based on originals created by earlier and more advanced civilizations. Others have argued that no species intelligent enough to make such a machine would set it loose on the future. Maybe they should look at how many governments are responding to climate change?

There the argument stands, although it sometimes turns up in a version of Fermi's paradox ("if there are intelligent life forms in space, why haven't they reached us?") in the form that if there were intelligent life forms anywhere, their von Neumann machines should have reached us. Perhaps the alien von Neumann machines are waiting for humans to become sufficiently civilized.

Curiously, the logical basis of reproduction in living cells is almost the same as that of von Neumann's machine. Part of his machines correspond to DNA, another part corresponds to the ribosomes, while another part does the job of certain enzymes. So in time, perhaps we will see a convergence of nanotechnology, wetware and artificial life forms, and perhaps when the von Neumann machines *do* reach us from the Andromeda galaxy, we may be unable to distinguish them from life as we know it.

Still, if we can design and build one such system, the manufacturing costs for more such systems and the products they make (assuming they can make copies of themselves in some reasonably inexpensive environment) would be very low. And we can be fairly sure that nobody will be sending von Neumann machines into space. Instead, we may be injecting them into our bloodstreams, but should we fear the nanorobots? You decide…

The puzzle of the performers

Alastair, Brianna, Callum, Duncan, and Ernie were the top five finishers in a school's talent contest, taking, in no particular order, 1st, 2nd, 3rd, 4th, and 5th places. The children came from, in no particular order, 1st, 2nd, 3rd, 4th, and 5th grades, and they all performed *Pachelbel's Canon*, but they all did it in different ways. They either sang, tap-danced, hummed, yodelled, or whistled.

None of the numbers in the order of finish were exactly the same as the grade numbers.

Callum finished higher than Alastair but below the singer, Duncan and the tap-dancer, but those last three people are not necessarily in any particular order.

Ernie finished behind Brianna but ahead of Duncan.

The singer was in 3rd grade and the tap dancer was in 1st grade.

The child that was the hummer deserved to finish in fifth place and did finish there.

The yodeller was in 4th grade.

Based on the clues, match names with order of finish, grades, and performances. Your task: to try and work out who came where.

$\sqrt{-1}\ 2^3\ \Sigma\ \pi$

The paradox of science

Scientists will tell you that no part of science is ever fully proven, and yet scientists always rely on science as if it is all facts. What is going on? In mathematics, lots of things are called "fully proven", and that's why I want to turn there now.

Mathematics is more than sums

> Mathematics is the queen of the sciences …
> —Karl Gauss, quoted in *Gauss zum Gedächtniss* (1856) by Wolfgang Sartorius von Waltershausen.

The mathematics I did as a boy always seemed to be about men who cut wood with saws with 1729 teeth per perch, saws that were 25.6 inches long, and operating at 173 furlongs per fortnight with each tooth producing one scruple of sawdust per millisecond. From this, we had to calculate the number of Florentine bushels of sawdust that 3.27 men could produce in 8 hours, 11 minutes and 54 seconds.

Mathematics teaching is better now, but it is sometimes still hard to see how mathematics is fun. Trust me: it *can* be! It would be boring with Karl Gauss' teacher though, unless Karl Gauss was in the class to make it interesting.

Karl Friedrich Gauss (1777 – 1855) was later a famous mathematician. There is a legend that when he was a boy, he had a lazy teacher who told his class to write all of the integers from 1 to 100 and add them, assuming this would give him an hour of relaxation. Gauss' hand went up immediately. The answer, he said, was 5050, which the teacher knew was correct, as he had laboriously calculated it himself, many years earlier.

Angry that the boy must have been told the answer by a previous student, the teacher challenged Gauss to prove his result by showing how he had arrived at this value. The boy explained that the two outside numbers, 1 and 100, make

101, as do 2 and 99, 3 and 98, and so on. In all, there are 50 pairs, all summing to 101. Then, 100 x 50 is 5000, add 50, and there is your answer.

The puzzle of the hens

Try your wits on this one: a poultry farmer knows that a hen and a half can lay an egg and a half in a day and a half. How many hens does she need to produce one dozen eggs in six days?

This is a classic example of a puzzle, where you know there has to be an answer. I got it by intuition in about five seconds, but the easy way is to use a table. Try to work out the method first, but there is more on using tables to solve problems in the notes.

An ordered number

What is special about the number 8549176320? Well, if you look at it the right way, every number is special. Think about special numbers: set them down in order, starting with 1, and work up through them. In the end, you must come to a number which isn't special, and we can call that 'the smallest non-special number', but that means *it has to be special*, doesn't it? It follows that all numbers are special.

The main thing about 8549176320 is that it contains all the single number integers, and the numbers are in alphabetical order. If you divide it by five, you get another number with all ten digits in it, 1709835264. Is there a name for numbers like this? I have no idea… Make a name up!

Patterns in numbers

This section is inserted here for a reason, and that is that *some* of the patterns mentioned here will pop up later on. Some of the others won't, but they are still fun.

- **The 11-times table**: Multiples of 11 up to 9 x 11 are easy, because you just write the first number twice, and 10 x 11 is easy, but can you see a pattern in 121, 132, 143, 154, 165…? There is a pattern there, when you add the outside digits, but how high does it go?

1	1 x 9 =	1 x 9 = 0	1 x 9 = 0	1 x 9 = 09
2	2 x 9 =	2 x 9 = 1	2 x 9 = 1	2 x 9 = 18
3	3 x 9 =	3 x 9 = 2	3 x 9 = 2	3 x 9 = 27
4	4 x 9 =	4 x 9 = 3	4 x 9 = 3	4 x 9 = 36
5	5 x 9 =	5 x 9 = 4	5 x 9 = 4	5 x 9 = 45
6	6 x 9 =	6 x 9 = 5	6 x 9 = 5	6 x 9 = 54
7	7 x 9 =	7 x 9 = 6	7 x 9 = 6	7 x 9 = 63
8	8 x 9 =	8 x 9 = 7	8 x 9 = 72	8 x 9 = 72
9	9 x 9 =	9 x 9 = 8	9 x 9 = 81	9 x 9 = 81
10	10 x 9 =	10 x 9 = 9	10 x 9 = 90	10 x 9 = 90

Building up a 9 times table.

- **The 9-times table**: The table above has five columns which show in five steps how to create the nine times table, knowing nothing more than the order of the digits.
  Look at the columns and spot the pattern. In the fourth column, look at the bottom three lines.
- **The endings of square numbers**: When you multiply a number by itself, that is a square. The first few squares are 1, 4, 9, 16, 25, 26, 49, 64… Are there some digits that are never found at the end of a square number? Why?
- **The endings of cubic numbers**. Cubic numbers (or cubes (a^3) are all created by multiplying a number by itself to get a square, and then again to get a cube. 1^3 is 1, 2^3 is 8, 3^3 is 27 and so on. There is a pattern in the last digit of the cubic numbers. Use a calculator and pen and paper if you need to, but find the pattern.
- **Powers of 5**: These have a very simple pattern in their last digit. By the time you get to 5^4 or 625, you should have seen it.
- **Powers of 3**: The first few are 3, 9, 27, 81, 243… Continue the series and find the pattern.
- **The number of digits in powers of 2**: As a small child, I used to put myself to sleep by calculating this series in my head: 2, 4, 8, 16, 32, 64, 128, 256, 512, 1024, 2048, 4096… I recall noticing that there were three with one digit, three with two digits, three with three digits. I thought I had something, but I got to 8192, and knew I was wrong, but *is* there a pattern? I have no idea.

91 x 1 = 91
91 x 2 = 182
91 x 3 = 273
91 x 4 = 364
91 x 5 = 455
91 x 6 = 546
91 x 7 = 637
91 x 8 = 728
91 x 9 = 819

Looking at a 91 times table.

- Now here's another curious times-table, involving 91, a number that you should remember, because it will turn up in two other chapters. Read down the three columns in the products, and you will see an odd pattern developing. Can you find the other interesting things about 91, before they are explained in chapter 16 and chapter 18?

$\sqrt{-1}\ 2^3\ \Sigma\ \pi$

Fast calculators

In *The Maths Gene*, Keith Devlin describes seeing a man demonstrate finding the square roots of six-digit numbers. Before starting, the performer asked that the air conditioning in the room be turned off, and while he and the audience waited for that to be done, he explained that the important thing was to hear the numbers, and the hum might interfere with that.

Georg von Neumann, one of the pioneers of computing, also had amazing calculating skills, and a number of stories exist about him. Von Neumann could also read any book once, and afterwards, recall each word of it.

Just as a good musician can look at a musical score and 'hear' what is on the page, so some calculators can feel, see or hear the answer to a complex sum. An American, Zerah Colburn, asked to square 4395, hesitated for a moment, but when the question was repeated, he offered the correct answer, explaining that he did not like multiplying four-digit numbers together, but he had squared 293, then multiplied the result by 15, twice over. The number 4395 is, as we all know, the product of 15 times 293.

Sometimes, mathematicians find numbers familiar, because they have a specific meaning for them. Ordinary Britons, Americans and Australians would all recognise at least one of 1745, 1776 and 1788, but how would you respond to 1729? As we will see shortly, Srinivasa Ramanujan regarded that last number as an old friend…

Some of the lightning calculators are unfairly called idiot savants, people who just have the single skill of calculation. The idiot savant label is a cruel one, because these people are by no means idiots, except by contrast with their mathematical skills, but others have or had that number skill along with superior performance in other areas.

Like von Neumann, A. C. Aitken, a professor of mathematics at Edinburgh, performed amazing tricks. He could recite the first 1000 digits of π from memory, and confronted with the number 1961, he broke it down into the following: 37 x 53, or $44^2 + 5^2$, or even $40^2 + 19^2$. Wim Klein, another calculating wizard, is quoted as saying that for some people, 3844 this was just the digits 3-8-4-4, but he would react with "G'day, 62 squared".

On the other hand, more people will see 4900 and say "G'day, 70 squared.", but a smaller group will say "G'day, $1^2 + 2^2 + 3^2 + 4^2 \dots +23^2 + 24^2$". A number of people, knowing this, have tried to 'tile' a 70 x 70 board with those 24 squares. *This hasn't been done, so far.*

Back to the number whizzes: pocket calculators and computers have not done away with the mathematical prodigies, though they are less likely to find steady work on the stage. All the same, in 2005, a French student, Alexis Lemaire, used memorised tables to calculate the 13th root of a 200-digit

number, in his head. In less than 9 minutes from when he was given the number, he provided the 16-digit answer, which was 2,391,481,494,636,373.

As Fermat would say, there is insufficient space in the margin of this book to write it down.

The case of the mulgawood Mercury

Other stage acts involving numbers rely on the performer's ability to rapidly recall strings of numbers. Amateurs may rely on a mnemonic like "To express e, remember to memorize a sentence to simplify this". To find the value of e, count the letters in each word to retrieve 2.7182818284… Personally, I just know that many numbers, but then my phone number is made up of the first four digits of √2 and the first six digits of e.

Professional stage performers often rely on a method developed by Pierre Hérigone in 1634. It begins with learning by heart a table of consonants like this, until it is automatic to link each consonant with its specified value:

Digit	Consonants	Reminder to help you remember
1	T or D	T has one downstroke
2	N	N has two downstrokes
3	M	M looks like a 3 rotated 90° counter-clockwise
4	R	R is the fourth letter in FOUR
5	L	L is 50 in Roman numerals
6	J, soft G, SH, CH	J looks like a 6 reversed
7	K, hard G, hard C	K can be made from two 7s
8	F, V or PH	A lower-case script f has two loops, like 8
9	P, B	P looks like 9 when reversed
0	Z, S or soft C	Z is the initial of Zero

The trick is to make an association or image to recall, using these consonants to find words that use them and no others. To take a simple example, oxygen has an atomic weight of 16, so **D**a**SH** or **T**ou**CH** would be suitable reminders. Somebody who **D**a**SH**es needs a **T**ou**CH** of oxygen, and there's a mnemonic.

The element indium (which chemists order in very large bottles, so they can play carboys and indiums) has the atomic number 49, which gives us either the combination R-B- or R-P- so we cast around: rubber, robber, rope, rupee, and we have it: the **R**u**P**ee is the Indian unit of currency, which links neatly to indium. (So does the Indian **R**o**P**e trick!)

The experts will often take shortcuts, so the square root of 6 is recalled without the leading 2 (people using tricks like this know that the value has to start with two, so the standard mnemonic is **R**a**R**e **B**ee, where you recall that

the standard honeycomb is made up of sets of hexagons. The value is 2.449. In the same, 1729 could be coded as **T**al**K**i**N**g **B**ee.

$\sqrt{-1}\ 2^3\ \Sigma\ \pi$

Numerology involves introducing "magic" into numbers, but this wastes time, because numbers have their own magic! Still, numerologists are always finding new things. In Psalm 46 in the King James Bible, the 46th word is 'shake', while counting backwards, the word 46 from the end is 'spear'. And in 1610, when the new translation was first printed, William Shakespeare was 46 years old!

If you think that means anything at all, you would be very **R**a**SH**, but if you **T**ou**CH** your **T**oe**S**, you will be able to remember the year in a flash. If you get confused and **T**ou**CH** your **N**ose, you will have the decimal part of the square root of 10 (3.162), so apply this trick with care.

Mercury boils at 357°C, **MLK** or **MLG**, so you might picture the Greek god **M**ercury **L**ic**K**ing up **M**i**LK**, or buzzing around on his winged sandals with a bottle of **M**i**LK**, but in 1950s Australia, tacky *objets d'art* were carved from the wood of *Acacia aneura*, or to give it its Australian name, mulga. For me, the value 357 will always live in a rendition of the lively god in dark brown **M**u**LG**awood.

Magic that isn't

$$\begin{array}{r} 927 \\ 729- \\ \hline 198 \\ 891+ \\ \hline 1089 \end{array}$$

Refer to this sum when you read this section.

Find a book, and look at the 10th word on page 89 of a book. Produce the book and announce that you can read minds. Write down the word, and seal it in an envelope, seal it and give it, and the book to a member of the audience to hold.

Ask three people to give you three different numbers, and write them on a white board. Underneath, reverse the number, then take the smaller from the larger. We are now up to line 3: reverse that, and add the two numbers: the answer will always be 1089. Now ask the person with the book to open the envelope and read out the word, and then give you the tenth word on page 89.

If the two don't match, they have miscounted. Just say "I have memorised that book, so please count through the words again!"

A square quicky

What square is the product of four consecutive odd integers? This one is hard, so look at the notes. It does need some algebra.

Doing squares

As an undergraduate in the days before calculators and personal computers, I had to do a lot of pencil and paper number-crunching, and a lot of that involved correlations which required squaring numbers. It took time to calculate 1.4^2, but because I knew 14^2 was 196, I knew the answer was 1.96.

Because I am good at being Smart Lazy, I memorised all of the two-digit squares up to 25, but after that, it was too hard. Then I realised there was a pattern in the squares of numbers from 10 to 99, and all I needed was the first 25 squares, and I could get to 50^2, without any effort. Later, I worked out how to extend it further.

Write out the squares from 10 to 50, and see if you can see a pattern, centring on 25^2. There's more in the notes, but be warned: it isn't easy!

$\sqrt{-1}\ 2^3\ \Sigma\ \pi$

Lightning cube roots

A stage act can be based on a very small amount of memorisation and a lot of trickery. Suppose I tell you I can supply the cube roots of every integer cube between 1 million and 8 million.

I give you a calculator, inviting you to enter a 3-digit number, less than 200, and read off the result after multiplying it by itself twice. You might choose to enter the value 173, which would give you the value 5,177,717 for 173 x 173 x 173. When you read this out from the calculator, I would immediately tell you that the number you entered first was 173.

This does not involve memorising all the cubes up to 200^3. That would also be possible, but it is unnecessary. You only need to memorise the cubes up to 20, because adding three zeroes will give you the cubes of all of the multiples of 10 up to 200. You can extend this further if you wish, but for this discussion, that is enough. My lower limit of 1 million means I can concentrate on 3-digit numbers, but again, the trick can be extended. I start with a table of cubes, where I only need an approximate value.

Here are the ten values I need to know:

number	100	110	120	130	140	150	160	170	180	190	200
cubed (millions)	1	1.3	1.7	2.1	2.7	3.3	4	4.9	5.8	6.8	8

There is a curious feature about the last digit of a perfect cube and how it relates to the cube root, the number we began with:

number ends in	0	1	2	3	4	5	6	7	8	9

cube ends in	0	1	8	7	4	5	6	3	2	9

Now you have my secret: when you say "five million, one hundred…" I know we are between 170 and 180. Then I listen for the last digit of the cube (7), so I know the last number of the cube root is 3. QED, as Mr. Euclid might have said (if he spoke Latin): the answer is 173.

Notes for this chapter

In the references section, start with the works of Ian Stewart and Martin Gardner. Then go to Boris Kordemsky's *The Moscow Puzzles*.

The wolf, the goat and the cabbage

The key to this sort of problem is to ask: which pair (or pairs) are safe together?

The puzzle of the lost pets

For convenience, I will repeat the statements here:

1. Three pets, including a kiwi, a budgerigar and a wombat have been lost.
2. The pet lost in the garden is owned by Alastair.
3. Brianna does not own a wombat.
4. Callum's pet was lost in the bush.
5. The kiwi was not lost in the bush or in the park.

I needed to draw up a table, and start filling it in: numbers indicate the statement used.

Owners	Alastair	Brianna	Callum
Pets			
Places			

By item 2, Alastair's pet was lost in the garden.

By item 5, the kiwi was lost in the garden.

By item 3, Brianna does not own the wombat so Callum does, and Callum's pet was lost in the bush. Here is the partly completed table:

Owners	Alastair	Brianna	Callum
Pets	kiwi (5)		wombat (3)
Places	garden (2)		bush (4)

So Brianna's budgerigar was lost in the park. Finished!

The hole thorough the sphere

Learn from this: if there is *enough* information, even though you don't know the diameter of the hole, so clearly, that doesn't matter. The result will be the same, even if the hole has a radius of zero. So the answer is $^4/_3 \times \pi \times 3 \times 3 \times 3$, or 36π cm^3. Learn from this!

What use are paradoxes?

The French diet paradox is a good example: it is named for the lower incidence of heart disease in France, and it was a problem for many heart researchers, because French people eat high-calorie, high-fat foods but remain healthy. Then a 1999 study of diet and drinking patterns published in the *American Journal of Clinical Nutrition* revealed that people who drink wine often choose

foods that are healthier for the heart. So the studies showing wine-drinkers to have lower incidence of ischaemic heart disease may be attributable not only to the wine itself, but also to their other dietary choices.

The study used a random sample of 48,763 Danish men and women who were questioned about their drinking and eating habits. For the purposes of this study, a "healthy diet" was defined by high intake of fruit, vegetables, salad, and fish; reduced intake of saturated fat; and the use of olive oil in cooking. On that basis, moderate wine drinkers (1 to 3 glasses per day) consumed the most heart-healthy diet.

Self-reference paradoxes

It will be hard going, but the best source on this topic is Douglas Hofstadter's brilliant *Gödel, Escher Bach: an Eternal Golden Braid.* Harvester Press, 1979. Best read when you are at least 16.

The Spanish barber

My solution is that the barber might have been a woman. Note that this paradox comes from a time when my solution would have been unthinkable—unless one thought outside the box.

This is the only sort of box suitable for thinking inside of.

The puzzle of the performers

The main thing with puzzles like this is to set them out well. I drew up a table with headings that said "Place, Grade, Name, Performance". Now straight away, you know that the grade for place 1 can't be 1, and so on. The names I code as ABCDE, and the acts can be coded as HSTWY. So you write these codes into each of the spaces, and then you start crossing-out. The main thing to remember is that once you have a cell in the table filled in, you can cross off that choice for all of the other cells in that column. Here is the table after I applied two statements: you work out which ones, and carry on from there.

Place	1	2	3	4	5
Grade	2345	1345	1245	1235	1234
Name	ABC	ABCE	ABCDE	ACDE	ACD
Performance	HSTWY	HSTWY	HSTWY	HSTWY	HSTWY

The puzzle of the hens

Problems of this sort always fall apart when you draw up a table. Here's an example:

situation	hens	eggs	days
1.5 hens, 1.5 eggs, 1.5 days	1.5	1.5	1.5
Twice as many hens means twice as many eggs in the same number of days.	3	3	1.5
Doubling the number of days doubles the number of eggs from the same number of hens.	3	6	3
Now double the days to get the required dozen eggs (and the answer!).	3	12	6

Time travel paradoxes

Speaking of time travel, I like to play with the notion that the whole universe is full of time travellers, but that we cannot detect them. Nonetheless, they are there, and in fact they are the "missing dark matter". This is irrefutable, which is not the same as saying it is true.

Science is *not* like that.

Gauss' sum

Teachers and intelligent readers with curious minds, please note: as a science teacher, taking a maths class at short notice one time, I told my Year 9 students this story about Gauss, but I refused to say how Gauss did it. How often do you see Year 9 people pursuing a teacher doing playground duty at recess, to ask about maths?

Patterns in numbers

As you will soon realise, pattern finding is the sort of thing you can do anywhere, but as I mentioned, my practice of doing powers of 2 at a very young age meant I never had a problem going to sleep, but I later went far beyond that, up past 2^{20}.

These days, if I need to take my mind off a worry like the dentist operating on my mouth, I calculate the cube root of 17 in my head by trial and error. I never get very far, because I am slow.

Fast calculators

For this section, I drew on a chapter on lightning calculators in Martin Gardner's *Mathematical Carnival.*

Magic that isn't

I have a proof of sorts, but the margin of the page is too narrow. These facts may be interesting:

$1089=33^2=65^2-56^2=99x11=999+90$;

9801=1089x9, and the only other number whose reversal is a multiple of itself is 2178 (=1089x2).

Mainly, I think the three numbers that you start with *must* be different.

My phone number

If you work out my phone number, you are free to ring me. But if you want me to talk, you need to read *The game of 1729* (next chapter), and be able to tell me a sum that uses the square root symbol, and returns a value of 9. Start by wondering where the square root can go.

A square quicky.

This result was published in *Mathematics Magazine* 38, January 1965, 60. David L. Silverman said that we had $n(n + 2)(n + 4)(n + 6) = m^2$, which simplifies as $(n^2 + 6n +4)^2 = m^2 + 16$. Only 0 and 9 are squares of the form $a^2 – 16$, and since m^2 is odd, the square we are looking for must be 9, but how do we get four numbers which multiply to give just 9? Easy: 9 = (-3)(-1)(1)(3) is the answer. It is a moment's work to prove that (-5)(-3)(-1)(1)(3)(5) is also a square. There's the start of a pattern there…

Doing squares

To save you some effort, I used a spreadsheet to generate the following table. The patterns you are looking for work around the three coloured cells, which are 25^2, 50^2, and 75^2. You will need enough algebra to be able to expand $(x – y)^2$ to $(x^2 - 2xy + y^2)$. If you don't know what that means, either wait a while, or ask somebody who is older than about 14, and good at maths.

range	squares									
1-10	1	4	9	16	25	36	49	64	81	100
11-20	121	144	169	196	225	256	289	324	361	400
21-30	441	484	529	576	625	676	729	784	841	900
31-40	961	1024	1089	1156	1225	1296	1369	1444	1521	1600
41-50	1681	1764	1849	1936	2025	2116	2209	2304	2401	2500
51-60	2601	2704	2809	2916	3025	3136	3249	3364	3481	3600
61-70	3721	3844	3969	4096	4225	4356	4489	4624	4761	4900
71-80	5041	5184	5329	5476	5625	5776	5929	6084	6241	6400
81-90	6561	6724	6889	7056	7225	7396	7569	7744	7921	8100
91-100	8281	8464	8649	8836	9025	9216	9409	9604	9801	10000

A table of squares, from 1^2 to 100^2.

First, my method: to calculate 34^2, the number of hundreds is (34–25), or 900. To that, I add the square of (50-34), 16^2, or 256, so the value of 34^2 is 900+256=1156.

Why is this so? Well 34 is 50-16, and if we square that, we have

$$
\begin{aligned}
(50 - 16) \times (50 - 16) &= 50^2 - (50\times16) - (50\times16) + 16^2. \\
&= 50^2 - (100\times16) + 16^2 \\
&= 2500 - 1600 + 16^2
\end{aligned}
$$

In a similar way, $53^2 = (53 - 25) \times 100 + (53 - 50)^2 = 2800 + 9 = 2809$

I have put together a truly remarkable proof of this method, which this margin is too small to contain. Can you extend the method beyond 100?

$\sqrt{-1}\ 2^3\ \Sigma\ \pi$

Lightning cube roots

Note added in 2019: I thought I had invented this method, but I have just found that somebody called Wallace Lee beat me to it. Mathematics is like that!

Extra reading

See what you can find out about these:

- Olbers' paradox: why is the sky dark?
- Buridan's Ass.
- Hempel's ravens.
- Curry's paradox.
- The sorites paradox.
- The chainstore paradox.
- The potato paradox.

15. Some spatial puzzles

Sam Lloyd's famous sliding block puzzle. Look it up! *

Back to the Contents

* Image by en:User:Booyabazooka - http://en.wikipedia.org/wiki/Image:15-puzzle.svg, Public Domain, https://commons.wikimedia.org/w/index.php?curid=1059593

The crossed house puzzle

Your task looks simple: draw the diagram below by putting your pencil down on the paper, and drawing a single continuous line. You are not allowed to draw over any of the lines.

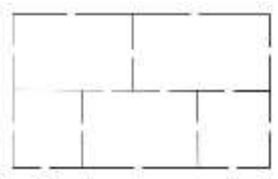
There *is* a solution, and in time, you will see a pattern!

You can solve this with a lot of difficult trial and error, or you can be mathematically clever, and work out a basic principle that applies to problems like this one and the next two as well. That's a hint!

The question you have to ask yourself is this: "how many times do I enter or leave from one of the key points?" There is something very special about the points with odd numbers of starting and finishing points. The rest is up to you, but the problem does have a solution.

The prisoner and the cells

A prisoner in a rather strange prison (with even stranger guards!) was told that if he could find a way to walk through all of the doors of all of the cells, once and once only, he would be allowed to go free. The diagram below shows how the cell doors were arranged.

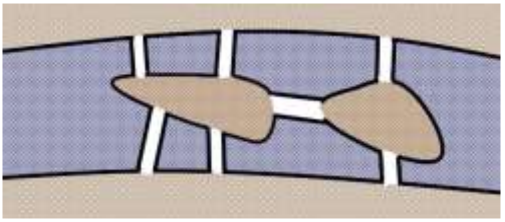


The prisoner's puzzle.

Analyse the problem and see whether it is possible, and if it is, work out the solution. If it is not possible, prove it. Well, if you had any sense, you would have done the crossed house problem first. And that's a hint. If you draw this figure on a torus in such a way that the hole of the torus is inside the middle cell at the bottom, it might be a bit easier—and that's another hint.

The Königsberg bridge problem

In the city that was once called Königsberg, there were two islands in the river, linked to each other and to the shore by bridges as you can see in the diagram. The river is blue and the bridges are white. The problem for the citizens of Königsberg was this: was there any way of walking around the city and crossing each of the bridges once and once only?



A map of ancient Königsberg, with two islands in the river, and seven bridges.

Well, if you had any sense, you would have done the prisoner and the cells problem first. And that's the last hint, for now. Now a research question: were/are there islands and bridges like this in Königsberg?

Once around the moon

Your lunar exploration vehicle has fuel tanks that will carry it one third of the way around the moon, and it can carry twelve spare fuel containers, enough to take it another third of the way around the moon. This means that a full fuel load will let you travel one third of the way around the moon and back, or two thirds of the way around the moon before you run out of fuel.

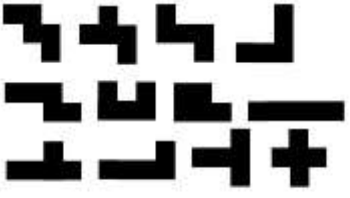
You can top up the fuel tanks at any time: what is the smallest number of fuel containers (starting with the tank empty) that you will need to travel once around the moon? And when you have solved that, can you come up with an answer for a situation where twelve fuel containers only carry you a quarter of the way around the moon?

A lunar bird puzzle

A bird is fitted with a lightweight oxygen tank, so it can breathe on the moon, where the gravity is $^1/_6$ of that on Earth. Will its flying speed be the same, faster or slower than on Earth?

Pentominos

Below, you can see the Pentominos (the last I heard. the name was a registered trade mark of Solomon Golomb). There are twelve of them, and they are each made up of five squares. You can lay them down either side up, and you can use them to make a variety of larger shapes.



Solomon Golomb's Pentominos.

First, get some cardboard or light board of some sort, and make up a set, using the patterns you see here. Once you have done that, see if you can arrange them into a square, 8 x 8, with a small empty square, 2 x 2, in the middle somewhere.

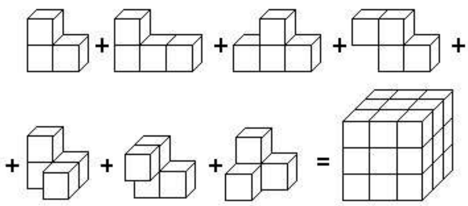
Then try to see if you can arrange all of the Pentominos to make a 6 x 10 rectangle, then a 5 x 12, a 4 x 15 and a 3 x 20 rectangle. Golomb has published at least one book on the subject—try your local library to see if you can track it down. You can also make a 5 x 13 rectangle that leaves a hole in the shape of one of the Pentominos, while other challenges include making scaled-up versions of some of the Pentominos, using nine of the other pieces to make a model three times as long and three times as wide.

Another interesting challenge is the "double double" where you make the same shape with two Pentominos, make a second copy with two more Pentominos, and then make a double-sized model with the remaining eight Pentominos.

Why not make a set to use at home?

The Soma shapes

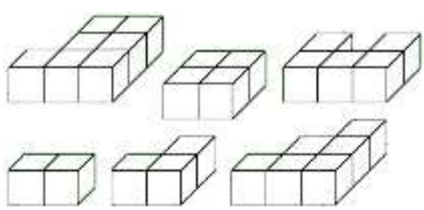
The Soma shapes are as shown below: they were the invention of Piet Hein, who pops up in other places in this book. There are six shapes made of four cubes, and one shape made of three cubes.



Piet Hein's Soma shapes.

Use cardboard to make a set of templates that can be folded and glued into the shapes, or make a set from wooden blocks, or sew them from cloth and stuff them like cushions (this works if the basic cube is about 20 cm or more on a side), and then see if you can solve the puzzle.

The diabolic cube



The diabolic cube shapes.

This 19th century puzzle requires you to take the pieces you see here, and assemble them into a cube. Just make them up in the same way that you would make up the Soma pieces, and then get to work to fit them together. What could be easier?

$\sqrt{-1}\ 2^3\ \Sigma\ \pi$

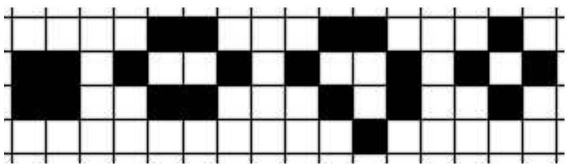
John Conway’s Game of Life

In October 1970, fans of recreational mathematics encountered The Game of Life in *Scientific American*. In those days, before personal computing, we either had programmable calculators or we used pen and paper to amuse ourselves. The calculators couldn’t do Life for us, so it was done on paper. A few, a very few, were able to play it on university computers, but I was a paper player.

All you needed was a grid with some coloured in squares, and a set of rules for generating a new set. A cell that was filled in was live, one that was empty was dead. In the next generation:

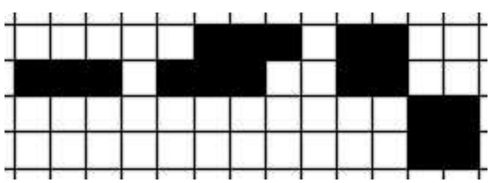
> any live cell with fewer than two live neighbours died;
> any live cell with two or three live neighbours lived on;
> any live cell with more than three live neighbours died;
> any dead cell with exactly three live neighbours became live.

The simplest starters or seeds were called Still Lifes, because they never altered



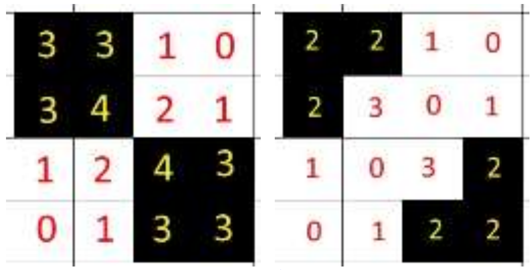
Four still life forms: block, beehive, loaf and tub

Some seeds alternated between two types, and these were called Oscillators. To find out why they get their name, you will need to take up pencil and paper, or look up <“game of life” oscillators> Here are some oscillator seeds, named blinker, toad and beacon:



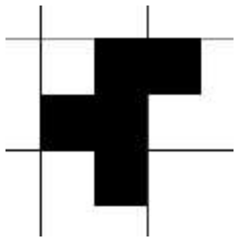
From left to right, blinker, toad and beacon.

To see how you analyse these shapes, here are marked-up versions of the two stages of the beacon:



Beacon stage 1 and Beacon stage 2

This is one to research for yourself, because there isn't room for any more here, except to note that this shape, known as the r-pentomino, is a methuselah. In mid-April 2020, Conway succumbed to the pandemic sweeping the world.


The r-pentomino.

Notes for this chapter

In the references section, start with the works of Ian Stewart and Martin Gardner. For Pentominos, see also Derrick Niederman's *Number Freak*.

Spatial puzzles

The first three problems all have a common theme: entries and re-entries to certain points. If a cell in the second problem has an odd number of doors, you must either start inside it, or you must end in it, but not both. In the Königsberg bridges problem, each island has an odd number of entry and exit points, as does each bank. There is no solution to the second and third problems.

If you look back at the ways I bent the wires in chapter 9, I faced similar problems. Everything is connected!

To find out about Königsberg reality, look for maps of Königsberg online.

Once around the moon

Six fuel containers carry you one-sixth of the way around the moon. With a full load of fuel, you can travel out one sixth of the way, dump twelve containers, and return. On your second trip, refill your tanks, refuel at the first dump, and drive out to one-third of the way, dump twelve containers, return to the staging point, refuel with the remaining six containers, and return to the base camp.

Then load up with a full load of fuel, and travel around the moon in the opposite direction, arriving at the one-third dump, just as you use up all your fuel.

The bird on the moon

There is no air on the moon, so the bird can't fly.

The diabolic cube

I saw this in a particularly cute version at the Edinburgh Festival of Science in 1993. The pieces were made from cushion material and stuffed, and as I watched, two 8 or 9-year-old children battled the pieces into place. So there you have it: the puzzle can be solved: all you have to do is work out where to start.

Odd mathematics

https://www.iflscience.com/editors-blog/how-an-impossible-crystal-has-shed-new-light-on-a-milliondollar-math-problem/ (Last seen, October 2019.)

16. Numbers, magic, statistics

This engraving contains a magic square, and the centre cells at the bottom remind us that this work was created in 1514. You can see the magic square more easily on the next page.

Back to the Contents

In this chapter, the early items are easy, while on average, the later ones are harder, but we start with a hard thought that you can ignore:

The value of the sum of the tenth powers of the first thousand positive integers was calculated by Jakob Bernoulli, who said he did so (using a short-cut of his own discovery) in less than ten minutes. His answer was 91,409,924,241,424,243,424,241,924,242,500.

Why would he bother and how did he do it? (I don't know!)

Magic Squares

1	8	6
9	4	2
5	3	7

16	3	2	13
5	10	11	8
9	6	7	12
4	15	14	1

Two magic squares, one of which you saw, just now.

A magic square is one in which all of the rows and all of the columns add up to the same number. In truly excellent magic squares, the diagonals sum to the same value, like the example on the right, above. There's more about this one at the very end of the chapter, because it appeared in an engraving by Dürer.

It is possible to make much larger magic squares. The 3 x 3 example is not very elegant: can you do better, and produce one with those numbers and with diagonals summing to the same value?

52	61	4	13	20	29	36	45
14	3	62	51	46	35	30	19
53	60	5	12	21	28	37	44
11	6	59	54	43	38	27	22
55	58	7	10	23	26	39	42
9	8	57	56	41	40	25	24
50	63	2	15	18	31	34	47
16	1	64	49	48	33	32	17

An 8 x 8 magic square.

Benjamin Franklin created the 8 x 8 square above. Each row adds to 260, and stopping halfway along each row makes 130. Going diagonally up four, across one, and down four also adds to 260 (that is, 9 + 58 + 59 + 12 + 21 + 38 + 39 + 24 = 260). As well, the four corners and the four middle numbers add to 260, and the sum of the numbers in any four-box square is 130.

Any four numbers lying diametrically equidistant from the centre also add to 130: try this with the four corner numbers (52, 45, 17 and 16) or with the four centre numbers (54, 43, 23 and 10). If you examine the patterns and balances in his solution, maybe you can work out how he did it.

- Design a 4 x 4 magic square, different from the example shown above.
- Design a 3x3 magic square with a 5 in the middle, leaving out 3 and 7, but using 10 and 0 instead. (It can be done!) That is, you use 0, 1, 2, 4, 5, 6, 8, 9 and 10. These add up to 45, which tells you that your target sum is 15, and that's all the help you get!
- Is it possible to construct a magic square of any sort, using only prime numbers? I suspect that it is not possible, but you may be able to prove me wrong—or you may be able to prove me right. I really don't know the answer.

The height of a building

This is a 19th century problem: use a barometer to measure the height of a building. This picture shows a mercury-filled Fortin barometer, 800 millimetres high, weighing just under 10 kg, like barometers were, even in the 1950s.

The modern problem: to come up with a *creative* way of using the barometer to do it. Be imaginative, and play with it!

The standard ("guess what I'm thinking") answer is to use the atmospheric pressure at the bottom and the top, and from this, calculate the actual height of the building. Can you come up with a better answer?

There are hints for this problem…

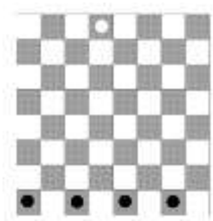
A mercury barometer, constructed in 1788.

Perfect numbers

The number 6 is the first perfect number. These are numbers that are the sum of their factors (in this case, 1+2+3=6). The next perfect number is 28 (1+2+4+7+14=28). To be precise, the perfect numbers are the sum or their proper positive divisors, but "factors" will do.

The next two perfect numbers, and the only other ones known in ancient Greece were 496 and 8128. One problem, which I believe still has to be solved, is to find an odd number which is also a perfect number. This doesn't have much to do with anything, but there are a few things in this chapter which look like that at first. Keep watching!

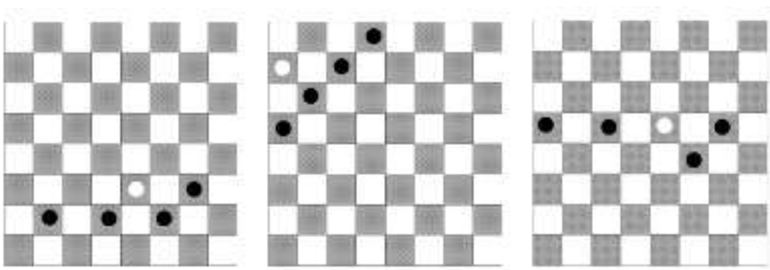
The rajah and the sepoys



The start of a game.

This is a simple version of a chess variant called **the maharajah and the sepoys**, where black has a full set of chess pieces and white has only a king, but the king can move as either a queen or as a knight on each move. It is, in the language of gaming, a solved game, which black can always win, although white can win against an inexperienced opponent.

This simpler version is played with four black pawns and one white pawn, placed as shown. Each piece moves one square diagonally, but the white pawn can go backwards or forwards, while black can only move forwards. The aim is for white to get past the black line, while black wins if the white pawn can be surrounded and stopped from moving.



From the left, a game under way, five moves in; next, a win for black imminent; last, a win for white.

Knight's Tours

You will need a ruler, pencil, rubber and paper. A knight's tour is a closed trip around a board with squares like a chess board, visiting each square once and once only. Each "jump" is a "knight's move" in chess: one square forwards, backwards or sideways, and one square diagonally. A proper knight's tour visits every square on the board once and once only.

The best way to work out a knight's tour is to draw up a small grid, and write in the numbers, counting from 1, on the squares that you visit. Here is an example, using a 3 x 3 grid, which cannot be solved completely, as there is no way you can get to (or from) the centre square.

7	2	5
4		8
1	6	3

An impossible knight's tour puzzle.

Problem 1: Find the smallest size grid that can fit in a knight's tour, even if the tour is not closed (which is where you end up a single knight's move away from the starting point). It will be no larger than 6 x 4.

Problem 2: Find the smallest grid that can fit in a closed knight's tour (see task 1 for a definition). (This can be done in 8 x 8, but may be able to be done on a smaller grid.)

Problem 3: Find a solution for a standard chess board (8 x 8)

Problem 4: Can you find a complete 8 x 8 knight's tour that is also a magic square? Leonhard Euler designed the 8 x 8 "knight's tour" magic square that appears in the notes. If you are a chess player and understand this, try it for yourself. If you need help, ask for it and then try it. (Hint: do four in each of three quadrants, and eight in the fourth quadrant before doing four in the third, second and first quadrants, and then repeat to complete.)

The main trick is to realise that a chess knight alternates between black squares and white squares. That makes getting in and out of corners a bit of a challenge. There is a fair amount of literature around: look for **recreational mathematics** or **mathematical games**. Apart from that, you're on your own. Good luck!

$\sqrt{-1}\ 2^3\ \Sigma\ \pi$

Curious measures

The value 65536 is the ratio between the smallest and the largest of the traditional English measures for liquid. Even before Leibniz proposed a binary

system of counting (we come to this in chapter 17), the English were using binary in a practical way.

They began with a measure called the mouthful, about 15 millilitres or half a fluid ounce. Two mouthfuls made a jigger or handful. Two handfuls made a jack, or jackpot, and two jackpots made a gill, or jill. When King Charles I needed more money, he placed a tax on the jackpot, and reduced its size, so there would be more of them. By its definition as two jackpots, the gill was also reduced in size, much to the annoyance of the common people.

The pail was another measure, about the size of a gill. Given that King Charles wore a crown, until he was beheaded a few years later, you may now be able to read the old rhyme about Jack and Jill with more understanding. Keep in mind, though, that the gill is eight mouthfuls.

Continuing, two gills made a cup, and there were two cups to a pint. Two pints made a quart, and two quarts filled a pottle, and we find this pair of measures in *Henry IV part 2*, V, iii:

> SHALLOW. By the mass, you'll crack a quart together—ha! Will you not, Master Bardolph?
>
> BARDOLPH. Yea, sir, in a pottle-pot.

The pottle, then, is 128 mouthfuls. Twice a pottle was a gallon, while the double gallon was also called a peck, the double peck was a half bushel, and obviously two half bushels made a bushel, which was eight gallons, or about 35 litres. Two bushels filled a cask, and two casks made a barrel or chaldron. Doubling the barrel gave us a hogshead, but that is hardly enough to drown a man in, as Shakespeare knew.

Still, it was enough to lose oneself in, according to Prince Hal, the future Henry V. In *Henry IV, Part 1*, the roistering young prince is asked where he has been, and he answers, "With three or four loggerheads amongst three or fourscore hogsheads."

Just to help you keep count, the hogshead is 16,384 mouthfuls. Back to drowning a man, though: in Act I, scene iv of *Richard III*, the First Murderer, as he stabs the Duke of Clarence, says:

> Take that, and that. If all this will not do,
> I'll drown you in the malmsey-butt within.

The butt was also called a double hogshead or a pipe, but in Shakespeare's play *The Tempest*, Trincalo lands on Prospero's island after clinging to a butt of sack. This sack was a strong wine. There was one more step in the barrel range, the tun, which is close to a ton or tonne in weight. When sailors in the Royal Navy had to heave tuns and butts full of water around in ships, this helped to make ruptures the most common injury in the peacetime British navy.

Of course, to older computer-savvy readers, the number 65536 has another significance. Aside from being the 16th power of 2, it is also the real numerical value of the 64 kilobytes which were all that we primitive folk could fit in (or afford) in the early 1980s for our computers.

A note about coincidences

One estimate of the size of the *entire* universe puts its radius at 3 x 10^{23} times larger than the size of the *observable* universe. That is almost exactly half the value of Avogadro's number, which every good chemist knows to be 6.022 x 10^{23}. So what?

The speed of light in terafurlongs per fortnight is 1.803, close enough for government work to the metric equivalent of a fathom, showing that any measured value can be given almost any number by a cunning choice of units. Any reasoning based on the coincidence of two values needs to be questioned closely to see if the coincidence is just, well, a coincidence—or the work of somebody using peculiar units to get a result.

For example, the number of islands in the Hawaiian island chain is 137, and the ratio 1/137, often referred to as alpha, is the fine structure constant in physics. This value represents the probability that an electron will emit or absorb a photon. It is the square of the charge of the electron divided by the speed of light times Planck's constant, and it is just a number: there are no dimensions or units involved at all.

The significance of alpha was first spelled out in 1915 by a physicist named Arnold Sommerfeld—at the time, measurement errors made the value closer to 136—and physics ever since has been littered with efforts to explain the number.

The most famous attempt was that of Sir Arthur Eddington, a prominent astronomer who believed that such constants could be used to produce a theory of the universe. He built a huge 16-dimensional equation full of these constants and claimed that alpha could be calculated from the number of terms: $(16^2 - 16)/2 + 16$, or 136.

Unfortunately, experiments quickly showed that alpha was really closer to 137. Eddington was not dismayed. He said he had forgotten to add one more factor, alpha itself, and made the value 137. For this, *Punch* magazine dubbed him Sir Arthur Adding-One.

Eddington was not deterred. Proudly he proclaimed that the firmament contains exactly (137 - 1) x 2^{256} protons. In 1938, he declared:

> I believe there are 15 747 724 136 275 002 577 605 653 961 181 555 468 044 717 914 527 116 709 366 231 425 076 185 631 031 296 protons in the universe and the same number of electrons.

Of course, he may have been right; I have not yet been able to count them all, and it's hard enough trying to find the value of 2^{256}. If that seems a bit hard, consider an oddity that was given to me by my granddaughter while I was editing this book in New Zealand. It goes like this:

A run of five

Brianna mentioned to me one night that 1+2+3+4+5 sums to 15, while 2+3+4+5+6 sums to 20. Any set of five consecutive numbers, she told me, would sum to a multiple of five.

Sometimes, a number coincidence comes about because it is a mathematical law. I decided to see if I could prove it, and so Brianna met algebra. "Call the first number n," I said. "That gives us n + n+1 + n+2 + n+3 + n+4, which is five lots of n, added to 1+2+3+4, which is 10." Because she was new to algebra, we had to work through a few examples so she could be satisfied that the sum would always be 5 x n + 5 x 2, or as I wrote it, 5(n+2), which had to be divisible by 5.

The next morning, she told me that with runs of three, the sum was always divisible by three, and I replied that 2+4+6+8+10 and 1+3+5+7+9 both gave sums that were divisible by five. Later in the day, she threw 1+4+7+10+13 at me, but you have to be quick to beat a mathemagician. There is a general pattern that I had found: the rule works for runs of seven, nine, eleven and thirteen numbers.

I think I'm right. Please check it for yourself. Does it extend to other odd numbers, as I suspect?

The number 91

This is our second look at this figure, the number of naturally occurring elements which exist on our planet. The last of these elements is uranium (element 92), but technetium, element 61, is never found in nature.

A case could be made for saying that there are just 88 naturally occurring elements, given that another three are incredibly rare. Three more elements are so rare that they might as well not be present. Promethium is formed in small amounts in the fission of uranium and two others decay so rapidly as to be vanishingly rare, with less than 600 grams of each in the entire earth's crust.

At any given time, there will only be about 30 grams of astatine in the earth's crust, formed by alpha decay of the other rare element, francium. This forms from the radioactive decay of actinium, and its most stable isotope has a half-life of only 22 minutes, so francium is effectively non-existent outside nuclear research facilities.

Incidentally, $91 = 1^2 + 2^2 + 3^2 + 4^2 + 5^2 + 6^2$. If you were so minded, you could probably build a good swindle on this number, but watch out: the mathematicians are watching!

Randomness and fraud

I once broke a serious fraud by pretending to be an idiot (it wasn't hard, my boss told me later), so the crooks gave me the pay sheets I needed. I expected to use Benford's law to catch them out, but putting the data into a spreadsheet, I found all the proof I needed in a pie chart, which showed a pattern that was a complete giveaway.

In 1938, Frank Benford showed that in long lists of data, more of the numbers will begin with 1 than any other number: about 30% start with 1, 20% with 2, 14% with 3, and 10% begin with a 4. Barely 5% start with a 9. When tax cheats or people swindling on their expenses make up numbers, they will hand in a more even distribution, and tax collectors know this.

Even random words show patterns: in 1949, G. K. Zipf was looking at the frequency of occurrence of words in ordinary text, where the most common word is given a rank of one, the next word a rank of two. The lower the ranking, the higher the frequency of that word.

Zipf found that the frequency of occurrence (f) is equal to the reciprocal of the product of its rank (r) and the logarithm of the number of words in the language (W). Mathematically (and this is hard),

$$f = 1/(r \times \log(W))$$

Zipf's law was later tested out on James Joyce's *Ulysses*, which has some 30,000 word types among its million words, and also on a large sampling from American newspapers, with 43 989 words of text, and some 6000 different words actually used. It worked well in each case.

To be a successful fraud, you need to know some mathematics, and to be a successful fraud catcher, you need to know even more mathematics.

The magic triangle

Take a triangle, write the numbers 1, 2 and 3 on the vertices, and add the numbers 4 to 9 (two on each side), so each side adds to 17.

What are the chances?

Able has two children, at least one of whom is a girl. Baker also has two children, and the older one is a girl. What is the probability that Able has two girls? How about Baker?

The hitchhiker's probability story

A hitchhiker was grateful to be given a lift on a deserted road, and told the driver several cars had passed him by. "You took a risk," he said. "How do you know I'm not a serial killer?"

The driver smiled. "The odds of two serial killers in the same car must be vanishingly small."

Once in a thousand years

Consider the number of years between events described as "once in a thousand years", such as floods. To the layperson, this immediately raises the question: how can the authorities access data, covering several thousand years? The answer is that they can't, but they have what is usually referred to as the Poisson distribution to fall back on, and to understand that, we need to consider an old tale of Prussian cavalrymen who were kicked in the head by their horses.

Just in case you know any French, the Poisson distribution has nothing to do with handing out fishes. It was developed by (and named after) Siméon-Denis Poisson. It describes the probability of clusters in random events, given nothing more than the average occurrence of such events. Poisson died in 1840, before the Prussians were kicked. Ladislaus Bortkiewicz published a book in 1898 in which he tried out the distribution of head kicks in each of the 14 corps of Prussian cavalry over a 20-year period, to see if it matched Poisson's predictions.

Basically, the Poisson distribution works like this: given a sample average (or better, a population average), you can predict the probability of clusters of, say, breast cancer cases in a workplace, the number of calls to a call centre in a given minute, power failures on a grid, some types of traffic accident, the number of typographical errors on a page and the failure of light bulbs. And given some flood data for a few inundations, the Poisson distribution can predict about how often there would be a flood of a certain level.

Let us consider the Prussian data: there were several cases where a significant number of kicks had happened, and many more where no kicks had happened, so Bortkiewicz got hold of the data for 200 corps-years. In 109 cases, there were no injuries, but there were 65 instances of one injury, 22 cases of two, three cases of three head-kicks and one unfortunate corps, in one year, had four instances, a total of 122 cases. That meant the probability of a case in any given corps in any given year was about 6/10, or if you want precision, 0.61.

Bortkiewicz triumphantly showed that the known distribution was an almost perfect fit to the theoretical prediction. After that, people everywhere took up Poisson's idea enthusiastically.

This story was popular, because most of the world liked the idea of Prussian cavalry being kicked in the head, but the main point was to say that there would be variation, and a high "score" did not necessarily imply carelessness or anything else. Ask anybody who has done some basic statistics, and they will all know about the Prussian head-kicks. It's the example that is always mentioned.

What is less-mentioned is that you can calculate the flood height that, based on prior data, would happen once in a thousand years. This figure would be approximate, and the estimates would be refined after each flood, and they would be slightly invalidated if the risk is increasing rather than steady, but it's better than nothing if you need a predictor.

I actually began looking into this issue, revisiting it after several decades, because somebody was questioning the science behind climate change and global warming, and as a throw-away line, poked fun at councils in Australia which have maps showing the limits of one-in-a-thousand-year floods. How, the idiot asked, could anybody know what has happened in the past?

Those who know my historical interests will not be surprised to learn that I point to 1859 as the year when scientists in unrelated disciplines began to be unable to understand one another. The public had started to feel lost around science a few years earlier, but after the 1860s, a great deal of science was either *counter-intuitive* or it relied on obscure methods. One way and another, science all got progressively more complicated.

Counter-intuitive science is in some ways the worst source of dissent and confusion, but if we know that mathematicians have a clever wrinkle that lets them estimate what a one-in-a-thousand-year flood would be like, we can accept that. Science that flies in the face of uninformed 'common sense', science that causes fears to arise, these are the sorts of science that cause trouble.

Even if the ancient Greeks knew that the world was a sphere, peasant minds were happy to say that the world they saw was clearly flat. In the same way, other equally simple and fearful peasant-quality minds attack the idea of evolution, misrepresenting what evolution is, even as they deny it. Climate is another case: the modern peasants who watch the weather on TV thinks they understand climate, which is a very different kettle of poissons.

$\sqrt{-1}\ 2^3\ \Sigma\ \pi$

Notes for this chapter

In the references section, start with the works of Falkener (on magic squares) and Ian Stewart and Martin Gardner.

That first tricky 3 x 3 magic square

Here is one where both the diagonals add to 15.

4	9	2
3	5	7
8	1	6

Magic squares

- Look at the pattern formed by the 1, 2 and 3 in the 3 x 3 example, and at the pattern formed by the 7, 8 and 9. This should tell you something.
- The 4 x 4 example was included in a picture by Albrecht Dürer in a year that is hidden in the magic square. See if you can use the web to find out when it was completed. The name of the picture is *Melencolia*.
- If you count rotations and reflections as one, there are 880 different 4 x 4 magic squares.

The height of a building

The *interesting* answers I have heard include, in no particular order:

- giving the barometer to the building manager in exchange for the information you need;
- dropping the barometer from the top of the building and timing its fall (rather environmentally undesirable);
- using the barometer as the weight of a pendulum that almost touches the ground, so you can dangle it on a string and time the period of the pendulum;
- lowering the same pendulum, pulling it back up and measuring the string;
- measuring the shadows of the pendulum and the building and using the shadow ratio to get the height ratio;
- using the 800 mm barometer as a yardstick, working your way up the fire stairs, marking off 800 mm rises as you go.

$\sqrt{-1}\ 2^3\ \Sigma\ \pi$

The rajah and the sepoys

In my experience, I think black can always win, but I know of no proof of this. The game can go either way when played by young players: black needs to keep the line as level as possible, always advancing when white withdraws, unless this leaves an opening. The game is excellent training for those under the age of nine who are about to begin playing chess. I know I have a book somewhere which documents this game, but it seems to be entirely unknown under this name on the internet.

Magic squares and knight's tours

And now for something completely different:

1	48	31	50	33	16	63	18
30	51	46	3	62	19	14	35
47	2	49	32	15	34	17	64
52	29	4	45	20	61	36	13
5	44	25	56	9	40	21	60
28	53	8	41	24	57	12	37
43	6	55	26	39	10	59	22
54	27	42	7	58	23	38	11

This is a combination knight's tour and magic square, developed by Leonhard Euler.

On this magic square, if you go from number to number in sequence, each step is a chess knight's move on the board. You have to wonder how he did it…

The magic triangle

I found two solutions, thinking this way:

The answer requires sides adding to 14 (between 1 and 2), 13 (between 1 and 3) and 12 (between 2 and 3). These add to 39, the total of the range 4 to 9, and there are six numbers, so we are seeking pairs giving those sums:

12: could be 4+8 or 5+7; 13: could be 4+9, 5+8 or 6+7; 14: could be 5+9 or 6+8.

If we choose 4+8 for 12, we must use 6+7 on 13, leaving 5+9 for 14: **solution 1**.

If we choose 5+7 for 12, we must use 4+9 for 13, leaving 6+8 for 14: **solution 2**.

We can never use 5+8 for 13, because that rules out both possibilities for 12 (and also, both possibilities for 14).

Runs of numbers

Start with trial and error on a few runs, but all the methods you need are in the text. My present position is (in formal language) that any odd number (n) of integers in arithmetic progression will yield a sum divisible by n. Look up the terms and play with it.

The number 91

Now look at Bernoulli's product in the box at the start of this chapter. It is ~91 million million million million, but that has to be just another coincidence.

This number bobs up for a third time in the next chapter. Is that a coincidence, or what?

Randomness and fraud

Most of my fraud cases remain confidential, but these two have been published. Each involved a lot of number-crunching, so I give them a *** difficulty rating.

http://members.ozemail.com.au/~macinnis/ockhams/fraudo.htm (Last seen, March 2020.)

https://oldblockwriter.blogspot.com/2014/08/the-selling-of-plato.html (Last seen, March 2020.)

The probability of two girls

Able's two children could have been (in age order), girl-girl, girl-boy, or boy-girl, so the odds are $^1/_3$ that he has two girls. Baker's children must be either girl-boy or girl-girl, making the odds $^1/_2$. If you like this sort of thing, discover the Monty Hall problem.

Me and 1859

The year 1859 was a magic year in science, and I wrote a whole book about it: *Mr Darwin's Incredible Shrinking World*, available in libraries and as an e-book.

$\sqrt{-1}\ 2^3\ \Sigma\ \pi$

17. Strategy games

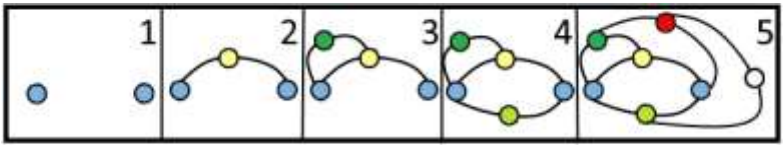
Woodcut from Jacobus de Cessolis' *The Game and Playe of the Chesse*, William Caxton, c.1483.

Back to the Contents

The game of Sprouts

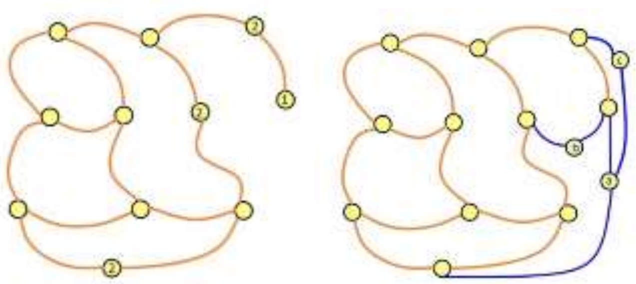
This gets its name from the appearance of a finished game. It begins with just a small set of points drawn on a sheet of paper. You may like to start with a two or three-point game, then work up through four and five-point games.

The first player draws a line between two dots, and then adds a new dot, somewhere along the line. The next player then does the same, and the game continues until one player can't move. Consider this completed two-dot game: the player making the white dot in frame 5 is the winner.



How the game of Sprouts develops.

Get the idea?



A more complicated game.

No point can have more than ***three*** lines beginning and/or ending at that point (though a line may begin and end at the same single point), and no line may cross over another. The first diagram above shows a partly-completed game, where the unlabelled dots are used up, and the dots with only one or two lines are labelled to show how many lines have come in at this point.

Those three dots labelled 2 can have one more line beginning or ending there, and the dot labelled 1 can have two more lines to or from it. Remember that each extra line, while it closes down two existing nodes or attachment points, creates one new node. The right-hand diagram above shows how that game ended after three more dots were added, in order, a, b and c. There is no way to join b and c.

There is a lot of information available on the internet about Sprouts. Use a suitable search engine to find out more, or better still, play it yourself, and prove what the winning strategies are (if any). Names to look for: John Horton Conway, Michael Paterson. They invented the game on 21 February 1967.

There can be no more than 3n-1 moves in a game that starts with n points, and it has been proved that there must be at least 2n moves in any game. The one and two-point games are trivial, but games with three or four points allow plenty of room for practice before you go on to larger and more complex games.

There is a proof that the first player wins the three, four and five-point games, while the second player will always win the six-point game, *provided both players always play logically*. That little phrase is very popular with mathematicians who study games…

A curious series

6, 15, 24, 33, 42, 51, 60…

What is this?

I'm not telling, even if you ask me six or seven times. Keep reading, and you may get it…

Adding and subtraction games

The game called **race to 100** is easy, but to win every time, you need to know what to do. The idea is to start at zero, and take it in turns to add in a number between 1 and 10, where the player to reach 100 is a winner. There is a way for you to win, every time, and that is for one of your turns to reach a total of 89. Then, whatever your opponent adds in, he or she won't have reached 100, but you will be able to do so on your next turn.

But to get *there*, you need to reach 78: whatever number your opponent adds, you add a number to bring you to 89. Before that, you need to get to 67, 56, 45, 34, 23, and 12. As soon as you get to any of those numbers, you have a guaranteed win. You can change the rules to make a different target, or you can change what may be added, but the principle stays the same.

All you have to do, as starter, is to add in 1: your opponent's addition will bring the total to a number between 2 and 11, you add enough to make 12, and then go on to win.

Now let's try a subtraction game: you begin with 40 bottle tops, or cherry pips or pebbles, and players remove between two and five pebbles. The player taking the last item is the winner. As you may have guessed, this game also has a winning strategy. If you leave 7 pebbles, your opponent has to take between two and five, leaving you with no more than five pebbles to take, giving you a win!

The key numbers before that are 14, 21, 28 and 35, so if you play first, take five, and then make sure that your opponent's and your subtractions add to

seven. Playing against somebody who understands the game, the second player can never win.

There is another subtraction game called Nim that I decided to leave out, but you can look it up, if you wish. If you want to learn how to win in the Game of Nim, you need to know about counting in other bases, and I will explain that now.

All Your Base Are Belong to Us!

You have to be old to remember when this phrase became a popular meme, at a time when memes were probably not yet invented. It was, people said, the worst example of translation in a shoot-'em-up game ever. It was a Japanese Sega Genesis game, but the bases meant in that phrase were military bases. The name has nothing much to do with what follows, but I always wanted to use 'All Your Base Are Belong to Us!' as a heading.

In chemistry, bases are the opposite of acids, and DNA (deoxyribonucleic acid), our genetic material, is made up of four bases, but we can ignore those bases as well. When we count from one to nine, the next number is ten, which is written 10, and to mathematicians, that means one lot of the counting base (ten), and no digits. In the same way, 729 means seven lots of a hundred (10^2), two lots of ten, and nine digits, and 1984 means one lot of 10^3, nine lots of 10^2, eight lots of 10 and four units.

The thing is, we don't *have* to count in tens and hundreds, and that brings us to a pre-computer shoot-'em-up war between two mathematicians, Wilhelm Leibniz and Isaac Newton, who both claimed to have invented a complicated mathematical tool called calculus. Luckily for the people around them, they used words, not bullets.

On the left, a 1966 West German 30 pfennig postage stamp showing Leibniz, and a 1957 French 18 franc stamp of Newton, who was on the back of an English pound note, but never on a British stamp, it seems.

The squabble began at the end of the 1600s, when Newton said he had started working on calculus in 1666, and Leibniz had seen a manuscript of Newton's in 1676, which may have given him some help.

Leibniz said he started work on calculus in 1674, and published his first paper on it in 1684, while Newton did not publish until 1693. With no clear evidence, it seems fair to assume that the two geniuses had the same idea independently, because the world was ready for the calculus.

They say Wilhelm Leibniz taught himself Latin when he was eight, and by fourteen, he could read Greek as well. We may as well believe this as not: these legends of precocity in the scientific greats are as tenacious as any urban myth. It matters little if he taught himself to swear in Swahili while hanging upside down like a bat at the age of four: what really counts is what he did later on.

In his lifetime, Leibniz introduced the use of the dot to indicate multiplication, popularized the decimal point, the equals sign, the colon for division and ratio (example, when we talk about a gear ratio of 11:4), and the use of numerical superscripts for exponents (like x^2 and x^3) in algebra. We also owe the long sigma (for summation) in calculus and the way we use the letter d in differential calculus (as in dy/dx) is his as well. Leibniz also designed a calculating machine.

Later, Leibniz was librarian to the court of Hanover, but when the Elector of Hanover went from there to England to take up his new throne as King George I in 1714, Leibniz was left behind in Germany, probably because of his disputes with Newton.

Whatever the reason, he stayed in Hanover, and died a couple of years later, leaving a 'sleeper' in the form of a letter to the French Academy of Sciences, written in 1701, in which he outlined the binary system used by all modern computers.

> I enclose an attempt to devise a numerical system that may prove to be entirely new. Briefly, here is what it is...By using a binary system based on the number 2 instead of the decimal system based on the number 10, I am able to write all of the numbers in terms of 0 and 1. I have done this not for mere practical reasons, but rather to allow new discoveries to be made...This system can lead to new information that would be difficult to obtain in any other way...

Here's how a counting sequence in binary (base 2) runs 1, 10, 11, 100, 101, 110, 111, 1000, 1001, 1010, 1011, 1100, 1101, 1110, 1111, 10000…

Other bases

A counting sequence in 'hex' (base 16) runs 1, 2, 3, 4, 5, 6, 7, 8, 9, A, B, C, D, E, F, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 1A, 1B, 1C, 1D, 1E, 1F, 20, 21…FF (which is 255 in decimal). The next number is 100 (meaning 256 in decimal). Get the idea?

In mathematics, the base number for a counting system is the turnover point for counting to start again. In the usual decimal system, the base is 10, while in binary mathematics, the base is 2, in octal it is 8, and in hexadecimal, it is 16. Any number larger than 1 can be used as a counting base. A few historians of computing may know about octal numbers, based on 8, because computer output in the early days of computing was sometimes given by three lights, counting from 0 to 7.

People who know their number systems really well are probably the only ones familiar with duodecimal numbers based on 12. In this system, the numbers are 1, 2, 3, 4, 5, 6, 7, 8, 9, A, B, 10, where ‘10’ means one complete set of twelve and no units. This system has sometimes been urged by the technically competent, because a 12-piece set can be divided in more ways than a 10-piece set.

Interestingly, most chocolate biscuits come in packets with a prime number of pieces, which makes sharing difficult: perhaps the manufacturers hope we will buy a second packet? (Or even a third?)

Duodecimal may make sense to technicians today, but why would the Romans bother to work with twelfths? In part, it seems, for the same reason: the Romans found it convenient to divide things that way, because then you could share evenly between two, three, four or six people. They even had a special word for a twelfth part, *uncia*, which gave us our words for both inch and ounce.

Twelve is a number which has proven convenient in times gone by, because a dozen objects make up a 4x3 arrangement which is easy to check with the eye. And now, no pun intended, you have the basic stuff you need to understand how we analyse the art of winning at Nim, but it’s complicated, so it’s not here.

Instead, here’s a simple puzzle: why do humans use base 10? It’s because we have pentadactyl limbs, but I won’t tell you what is or why. Look it up!

$\sqrt{-1}\ 2^3\ \Sigma\ \pi$

Two coin puzzles

A moving-coin puzzle. You have to reverse the triangle.

This first one *looks* quite simple. You need ten coins, close-packed and arranged in an inverted (upside down) triangle, as shown above. Move some coins, leaving each moved coin touching two others, reversing the triangle.

Most people can change the array to the one on the right by moving five coins. I am told that it is possible to do it in four moves, but I can’t see it. I don’t care: I can do it with just three moves. Can you find the trick?

Look at the coins. I chose a selection of different coins that will help you work out what went where, but I’m not telling you the order of the moves. Still, there is more than one order that works.

Another moving-coin puzzle. Change the layout.

For this second (and harder) puzzle, you need six coins, arranged in a rhombus, exactly as shown on the left above. The challenge is to move three coins, no more and no less, one at a time, to look like the picture above. In each case, when a coin comes to rest, it has to be touching *two* other coins. Yes, there are hints, both here and at the end of the chapter. Some of the hints here are not very obvious.

Notes for this chapter

In the references section, start with the works of Ian Stewart and Martin Gardner.

All Your Base Are Belong to Us!

A note for younger readers: In *The Hitchhiker's Guide to the Galaxy*, Douglas Adams described the search for the answer to life, the universe and everything. In the story, the answer turns out to be "42".

That meant the searchers needed to find out what the Question was, and when this turned out to be (more or less) "what's the product of 6x9?", that told the searchers that there must have been a programming error. In fact a few subtle minds (well, one that I know of (me, actually)) saw immediately that there was another solution, which is that the computer, named Deep Thought, may have been working in base-13 notation. Think it through: 42 in base 13 means four lots of 13, plus two.

If you don't get it, forget it. Move along…

That curious series

I repeat: I'm not telling, even if you ask me six or seven times. It's pretty basic… No, make that *really* basic.

Two coin puzzles

First, this shot, part-way through being solved, explains the inverted pyramid puzzle. Keep an eye on the sources and values of the coins, because this information gives you hints.

Speaking of inverted pyramids, you may care to seek out a poem by Stephen Vincent Benét, called *The Innovator (A Pharaoh Speaks)*. Read it, just for amusement.

For the second puzzle, looking at the coins will give you a bit of a clue, but here's a step-by-step. Keep an eye on the different coins!

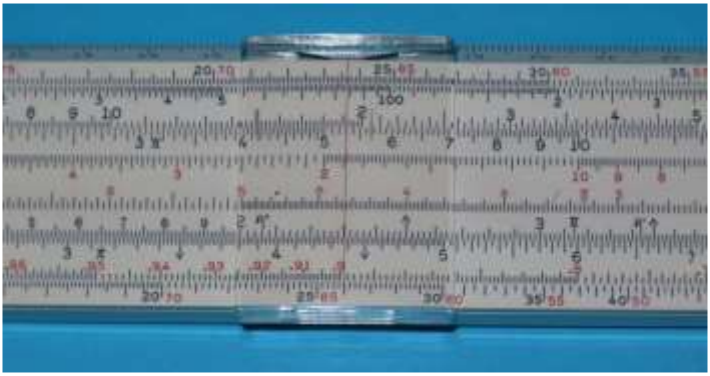
   

If you are using this as a challenge to somebody else, look at the picture below. You can really mess with their minds by showing them how to do it, then setting the coins up as shown below (a mirror image of the first step when you did it).

The mean way to set up the coins for somebody else.

$\sqrt{-1}\ 2^3\ \Sigma\ \pi$

18. Serious number play



I am old enough to have used one of these slide rules, at school and at university. I never used Napier's Bones though, but they are described in loving detail on the web.

Back to the Contents

The next two items will get you ready for *The game of 1729*. Younger readers may prefer to skip this chapter, but if you see that brush-off as a challenge (I would have!), read on!

Two consecutive numbers quickies

Can you use the numbers 9 to 1, in that order, to write a sum which has the answer 99?

Can you use the numbers 1 to 7, in that order, to get a sum which has the answer 100?

Using four numbers

Can you write a sum that returns different values, using four of the same number? For example:

(2x2) / (2x2) = 1 (or 22/22 = 1);

5/5 + 5/5 – 2;

$(2^2 +2)/2 = 3$;

$(2^2/2) + 2 = 4$;

(5 x 5 + 5)/5 = 6;

(2/.2) x 2/.2) =100 (or $(x/0.x) \times (x/0.x) = 100$, where x is any single-digit integer;

(5+5) x (5+5) = 100;

99 + 9/9 = 100

The game of 1729

The number 1729 is special for a number of reasons. One is that it is usually said to be the first number that is the sum of two cubes in two different ways. Can you find the two distinct solutions to the equation $x^3 + y^3 = 1729$? Srinivasa Ramanujan was a self-taught Indian mathematician, and he sent a bundle of his most interesting results to Godfrey Hardy in Cambridge. The work Ramanujan had done in India was so astounding that Hardy arranged for Ramanujan to travel to Cambridge to work with him.

They say two other mathematicians received Ramanujan's material first, but they sent it back without comment. Hardy decided an unknown mathematician of genius was more likely than a fraud of the genius needed for a clever fraud, and assumed that Ramanujan was genuine.

Ramanujan died at the age of 33 from tuberculosis, after a long illness. On one occasion, Hardy visited his sick colleague, and while making conversation, Hardy mentioned the number of his taxicab, his favourite form of transport. It

had, said Hardy, a rather dull number, 1729. Ramanujan disagreed. "Oh no, Hardy, it is a very interesting number. It is the first number that is the sum of two cubes in two different ways!" Ramanujan was referring here to the fact that 1729 is the sum of one cubed and twelve cubed, and also the sum of nine cubed and ten cubed.

The two mathematicians then went on to discuss the fourth powers equivalent, but that has no part here. There *is* a solution, by the way, with 133 and 134 being the numbers on one side: the rest I leave to you.

1729 is one of a special group of numbers called Carmichael numbers, which are important in number theory, but we will ignore them for now. Hardy was probably trying to find out if Ramanujan had discovered Carmichael numbers in his intuitive way, but he got a surprising answer.

The number 1729 is an unusual Carmichael number, because its three factors (7, 13 and 19) are in arithmetic progression: we have known since the mid-1990s that there is an infinite number of Carmichael numbers, but is there an infinite number of them with factors in AP? Probably…

An oddity that struck me while I was editing this chapter: *there is a smaller number* that is the sum of two cubes in two different ways. That number is 91, and while 1729 = 7 x 13 x 19, 91 = 7 x 13. We will meet 91 in other places here, but 91 = $4^3 + 3^3 = 6^3 + (-5)^3$.

	A	B	C	D	E	F	G
1	no.	square	diff(1)	diff(2)	diff(3)	diff(4)	diff(5)
2	0	0	NA	NA	NA	NA	NA
3	1	1	1	NA	NA	NA	NA
4	2	4	3	4	NA	NA	NA
5	3	9	5	8	9	NA	NA
6	4	16	7	12	15	16	NA
7	5	25	9	16	21	24	25
8	6	36	11	20	27	32	35
9	7	49	13	24	33	40	45
10	8	64	15	28	39	48	55
11	9	81	17	32	45	56	65
12	10	100	19	36	51	64	75
13	11	121	21	40	57	72	85
14	12	144	23	44	63	80	95
15	13	169	25	48	69	88	105
16	14	196	27	52	75	96	115
17	15	225	29	56	81	104	125
18	16	256	31	60	87	112	135
19	17	289	33	64	93	120	145
20	18	324	35	68	99	128	155
21	19	361	37	72	105	136	165
22	20	400	39	76	111	144	175
23	21	441	41	80	117	152	185
24	22	484	43	84	123	160	195
25	23	529	45	88	129	168	205

Differences between squares: see the text below

Now here is something added very late, and it began with the pattern in square numbers: 1-0=1; 4-1=3; 9-4=5; 16-9=7… I wondered if there were other patterns, and created the spreadsheet above.

In this scheme, diff(1) means the differences between successive squares, while diff(2) means squares that are two apart, and so on across the spreadsheet. (NA means 'not applicable'.)

Looking at the values, there are some curious and very obvious patterns that set me thinking: what would happen if I did the same sort of thing with cubes?

	A	B	C	D	E	F	G
1	no.	cube	diff(1)	diff(2)	diff(3)	diff(4)	diff(5)
2	0	=A2*A2*A2	NA	NA	NA	NA	NA
3	1	=A3*A3*A3	=B3-B2	NA	NA	NA	NA
4	2	=A4*A4*A4	=B4-B3	=B4-B2	NA	NA	NA
5	3	=A5*A5*A5	=B5-B4	=B5-B3	=B5-B2	NA	NA
6	4	=A6*A6*A6	=B6-B5	=B6-B4	=B6-B3	=B6-B2	NA
7	5	=A7*A7*A7	=B7-B6	=B7-B5	=B7-B4	=B7-B3	=B7-B2
8	6	=A8*A8*A8	=B8-B7	=B8-B6	=B8-B5	=B8-B4	=B8-B3
9	7	=A9*A9*A9	=B9-B8	=B9-B7	=B9-B6	=B9-B5	=B9-B4
10	8	=A10*A10*A10	=B10-B9	=B10-B8	=B10-B7	=B10-B6	=B10-B5

The spreadsheet showing the codes

This table has some cells coloured: this colouring is used on the values table as well. Watch for those cells in the next table! Now we can look at the actual values:

	A	B	C	D	E	F	G
1	no.	cube	diff(1)	diff(2)	diff(3)	diff(4)	diff(5)
2	0	0	NA	NA	NA	NA	NA
3	1	1	1	NA	NA	NA	NA
4	2	8	7	8	NA	NA	NA
5	3	27	19	26	27	NA	NA
6	4	64	37	56	63	64	NA
7	5	125	61	98	117	124	125
8	6	216	91	152	189	208	215
9	7	343	127	218	279	316	335
10	8	512	169	296	387	448	485
11	9	729	217	386	513	604	665
12	10	1000	271	488	657	784	875
13	11	1331	331	602	819	988	1115
14	12	1728	397	728	999	1216	1385
15	13	2197	469	866	1197	1468	1685
16	14	2744	547	1016	1413	1744	2015
17	15	3375	631	1178	1647	2044	2375
18	16	4096	721	1352	1899	2368	2765
19	17	4913	817	1538	2169	2716	3185
20	18	5832	919	1736	2457	3088	3635
21	19	6859	1027	1946	2763	3484	4115
22	20	8000	1141	2168	3087	3904	4625

The spreadsheet with values, rather than codes.

The things that made me pay attention were the three yellow cells. These results were interesting, maybe even Interesting. The blue cells, though, are all either the sums or differences between two cubes: have I missed any?

117 = 5^3-2^3;

217 = 6^3+1^3;

513 = 8^3+1^3;

728 = 9^3-1^3 (but see below);

$999 = 10^3 - 1^3$;

$1027 = 10^3 + 3^3$;

$1736 = 12^3 + 2^3$.

I had rather hoped to find 1729 showing up in the list, but it wasn't there.

I did, however, find that $6^3+8^3=9^3+(-1)^3=12^3+(-10)^3=728$! I note that 728 is 1001 less than 1729, and the factors of 1001 are 7x11x13.

When you have finished playing with this, move back to the main part of the game of 1729, the challenge part.

$\sqrt{-1}\ 2^3\ \Sigma\ \pi$

The 1729 challenge:

There are many ways that you can manipulate a group of numbers to obtain give different values. Your task is to find solutions using the numbers 1, 7, 2 and 9 in that order, once only, combined by any mathematical symbols such as exponentiation, square roots, multiplication, addition, subtraction and division, with as many brackets as you like. You can even use factorial notation (5! = 5 x 4 x 3 x 2 x 1) or any other notation, but no other numbers.

For example, $1 = 1^{729} = -17 + (2\text{x}9) = 1 - 7 - 2 + 9$ etc.;

or $6 = 17 – 2 – 9$;

or $7 = -1 + 72/9$;

or $8 = (1 \text{ x } 72)/9$;

or $9 = 1 + 72/9$;

or $10 = 1^{72} + 9 = 17 + 2 – 9$;

or $12 = -17 + 29$;

or $30 = 1^7 + 29$;

or $36 = 1 \text{ x } 7 + 29$;

or $46 = 17 + 29$.

When I posted this on the web site that was the beginning of this book, I had lots of help from Klaus Marx and Frank Schnell, then at Robert Bosch Gmbh in Germany, who helped me find solutions for every integer up to 50. Frank was still at Bosch in 2018, but Klaus had retired to Northern Italy, not that far from where Leonardo Pisano Bigollo was born. Like me, they still play with number things, so watch out for them around the traps. But who was Leonardo Pisano Bigollo?

Fibonacci's serious rabbits

The early 1200s were very much the Middle Ages, but even then, steps were being taken that would lead, in time, to the Renaissance. Most of those steps involved trade, which led to new goods being introduced to new places, and along with them, new ideas.

Very few people have heard of Leonardo Pisano Bigollo by that name, but a lot more know a bit about him under the name Fibonacci. He was the son of a merchant who carried the nickname 'Bonaccio' which you can take to mean either 'good-natured' or 'simple', according to taste. I prefer to believe that Bonaccio, like his son, was far from simple.

Anyhow, the father ran an Italian trading post in what is now Algeria, and he produced a very bright son, who joined him there in the late 1100s, where the boy learned the Arabic (or Hindu) system of writing numbers. Leonardo knew a good thing when he saw it, and so he travelled around the Mediterranean, studying with various Arab scholars. Then he published his *Liber Abaci* in 1202. Literally 'the book of the abacus', this work introduced the new counting system in terms that tradesmen and academics could both understand, and young Leo gave practical examples.

It was by no means the first book to mention Hindu-Arabic notation, but it took off. This must have been due, at least in part, to the practical examples, like one in which he examined the way rabbits breed like, well, rabbits. Everybody knew how fast rabbit populations grew, but what was the mathematics of it?

He assumed that rabbits take a month to mature, then breed and produce two young, a male and a female, after one more month, and that rabbits live for 12 months. From that, he wondered how many rabbits there would be at the end of this time, starting with just two new-born rabbits. At the end of the first month, the rabbits mate, and there is still just one pair. At the end of the second month, the doe gives birth and there are two pairs. The parents mate again, and at the end of the third month, there is a third pair.

The first of the new young and the parents both mate and produce young at the end of the month. Now there are five pairs, three ready to breed, and two immature. At the end of the next month, there are eight pairs, and so on. The total number of rabbit pairs, taking the start as Month 0 increases like this:

Month	0	1	2	3	4	5	6	7	8	9	10	11	12
Rabbits	1	1	2	3	5	8	13	21	34	55	89	144	233

The rabbity origin of the series.

The point of this small puzzle was for young Leo to show how much easier and quicker it was to add 89 and 144 than to add LXXXIX and CXLIV, the same numbers in Roman numerals.

At a Greek restaurant in Palm Cove in Queensland, I photographed this tiled table, to the puzzlement of a waiter. I have added numbers that may help you to work out why I was delighted. There are no other hints on this, but read on.

The new numbers caught on with the mob. It did no harm that there is a somewhat mystic number, ϕ (phi), known as the Golden Ratio or Golden Mean, defined by the simple equation $\phi - 1 = 1/\phi$.

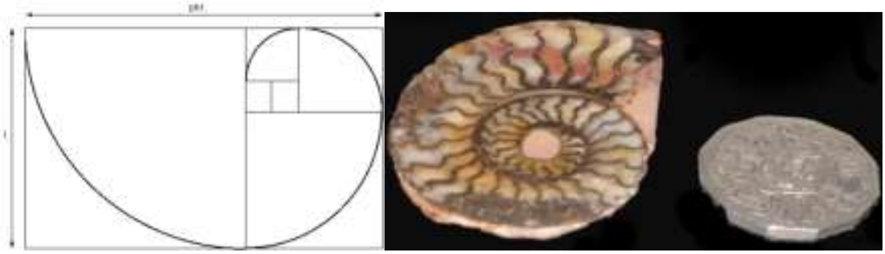
This value turns up in art, in Greek architecture, even in the proportions of normal sheets of paper, and when you divide any term in the Fibonacci series by the previous one, you obtain values that get closer and closer to ϕ, about 1.618. That *really* impressed people.

After he died, Leonardo came to be known as Bonacci's boy, *filius Bonacci* in mediaeval Italian, or Fibonacci for short, and that is why the extended sequence of numbers is known today as the Fibonacci series. Of course, if you wanted a continuing series, you needed to assume that the rabbits were immortal, but given his other assumptions about the rabbits, what was wrong with that?

Though maybe we should celebrate Leonardo, the Golden Mean and his randy, speedy, rabbits by calling it the Phibonacci series, a comment that I will now explain.

Fibonacci and ϕ

The Fibonacci series has some very interesting properties that you can track down with a web search. This will deal with just a few of them. For example, the ratio of any two successive terms gets closer and closer to phi, the "Golden Mean". Then again, the numbers of seed whorls in a sunflower counting clockwise and counter-clockwise, will always be two successive Fibonacci terms, if you count up through complete turns.



Start with a rectangle ϕ x 1 and draw squares like the ones here. Their sizes are in the Fibonacci series, and quarter-circles in the squares make a beautiful spiral. (Right) an ammonite fossil from Morocco. Nature got there first!

Or if you count the leaves going up a stem, then as you go, you will slowly rotate around the stem, after you have made as many turns as one of the Fibonacci numbers, the leaves you have counted will sum to another Fibonacci number. Why? Do a web search!

- Some of the numbers in the Fibonacci sequence above are composite (divisible by other numbers), and some of them are prime. Is there any deep pattern that determines what a particular Fibonacci number is divisible by, if anything?
- What is the maximum number of Fibonacci numbers you will need to add together to reach any integer? Is this always a maximum? How would you prove it? (For example, 6 = 1 + 5, 7 = 1 + 1 + 5, and so on).

Squares and Fibonacci numbers

The square of any Fibonacci number above 1 can be expressed as the product of its neighbour Fibonacci numbers, plus or minus 1: is there a hidden pattern here?

$2^2 = 1 \times 3 + 1$
$3^2 = 2 \times 5 - 1$

$5^2 = 3 \times 8 + 1$
$8^2 = 5 \times 13 - 1$
$13^2 = 8 \times 21 + 1$

Other ways of getting a value for Φ

Here is a formula that returns a value of phi:

$$\Phi = \frac{5+\sqrt{5}}{5-\sqrt{5}}$$

Get your calculator and try it out, then if you can, open a spreadsheet program.

First, these two clips from screenshots show you how to write the code for the Fibonacci series.

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	1	1	=+A1+B1	=+B1+C1	=+C1+D1	=+D1+E1	=+E1+F1	=+F1+G1	=+G1+H1	=+H1+I1	=+I1+J1	=+J1+K1	=+K1+L1

The spreadsheet codes for the Fibonacci series.

To save yourself time, type the code into cell C1, then use the mouse to highlight cells to the right. Once they are highlighted, holding down the Control key and tapping R is the same as **Edit – Fill – Right.** The main thing is that this is what you see:

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	1	1	2	3	5	8	13	21	34	55	89	144	233

The spreadsheet results for the Fibonacci series.

Then I added this code in row B:

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	1	1	=+A1+B1	=+B1+C1	=+C1+D1	=+D1+E1	=+E1+F1	=+F1+G1	=+G1+H1	=+H1+I1	=+I1+J1	=+J1+K1	=+K1+L1
2		=A1/B1	=B1/C1	=C1/D1	=D1/E1	=E1/F1	=F1/G1	=G1/H1	=H1/I1	=I1/J1	=J1/K1	=K1/L1	=L1/M1

Going from Fibonacci to phi.

And I got this result:

A	B	C	D	E	F	G	H	I	J	K	L	M
1	1	2	3	5	8	13	21	34	55	89	144	233
	1	0.5	0.66666667	0.6	0.625	0.61538462	0.61904762	0.61764706	0.61818182	0.61797753	0.61805556	0.61802575

Going from Fibonacci to phi.

A friend mentioned in passing that the value of Φ to three decimal places is 1.618, and that you could generate a "pseudo-Fibonacci series", beginning with the number 16 and 18, and that this series would also settle in to a close approximation to the Golden Mean. I tested this with a spreadsheet, and you can as well. Here is the code (and remember to use **Control-R**!)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
1	16	18	=A1+B1	=B1+C1	=C1+D1	=D1+E1	=E1+F1	=F1+G1	=G1+H1	=H1+I1	=I1+J1	=J1+K1	=K1+L1	=L1+M1	=M1+N1	=N1+O1	=O1+P1	=P1+Q1
2		=B1/A1	=C1/B1	=D1/C1	=E1/D1	=F1/E1	=G1/F1	=H1/G1	=I1/H1	=J1/I1	=K1/J1	=L1/K1	=M1/L1	=N1/M1	=O1/N1	=P1/O1	=Q1/P1	=R1/Q1

Going from phi to Fibonacci.

Here is the result:

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
1	16	18	34	52	86	138	224	362	586	948	1534	2482	4016	6498	10514	17012	27526	44538
2		1.125	1.888889	1.529412	1.653846	1.604651	1.623188	1.616071	1.618785	1.617747	1.618143	1.617992	1.61805	1.618028	1.618036	1.618033	1.618034	1.618034

Going from phi to Fibonacci.

Anybody writing a book called *Playwiths* is going to play with things, so I tried copying the two rows and inserting my favourite number and the name of my favourite novel as start points. Here is what I got: There is something mysterious going on here: I can smell a pattern!

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
1	16	18	34	52	86	138	224	362	586	948	1534	2482	4016	6498	10514	17012	27526	44538
2		1.125	1.8888889	1.5294118	1.6538462	1.6046512	1.6231884	1.6160714	1.6187845	1.6177474	[illegible]	[illegible]	1.61805	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3																		
4	17	29	46	75	121	196	317	513	830	1343	2173	3516	5689	9205	14894	24099	38993	63092
5		1.7059	1.5862069	1.6304348	1.6133333	1.6198347	1.6173469	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6																		
7	19	84	103	187	290	477	767	1244	2011	3255	5266	8521	13787	22308	36095	58403	94498	152901
8		4.421	1.2261905	1.815534	1.5508021	1.6448276	1.6079665	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Going from 1729 or 1984 to phi.

Speaking of patterns, Joseph Lagrange tested the last digit of successive Fibonacci terms, and found that after sixty terms, the pattern of last digits repeated. Logically, the last two terms in the set have to be one and zero, but here is the actual pattern:

1, 1, 2, 3, 5, 8, 3, 1, 4, 5, 9, 4, 3, 7, 0, 7, 7, 4, 1, 5, 6, 1, 7, 8, 5, 3, 8, 1, 9, 0, 9, 9, 8, 7, 5, 2, 7, 9, 6, 5, 1, 6, 7, 3, 0, 3, 3, 6, 9, 5, 4, 9, 3, 2, 5, 7, 2, 9, 1, 0,

1, 1, 2, 3, 5, 8, 3, 1, 4, 5, 9…

Finding this may seem hard, because the 60th term in the series is more than 1.5 trillion, but you can do it easily with a spreadsheet, using this small snippet below as a model. The code just takes the sum, and if it is more than 9, it takes 10 off it, but otherwise, it just provides the sum.

How to get the last digits of the Fibonacci series.

Lucas numbers

The Lucas sequence runs 1, 3, 4, 7, 11, 18, 29, 47, 76, 123, 199… Apart from the first two numbers, can you prove that there is no number common to both the Lucas and the Fibonacci series. (I can't!)

Q numbers

Q numbers run 1, 1, 2, 3, 3, 4, 5, ***5***, ***6***, 6, 6, 8, 8, 8, 10, 9, 10, ***x…***

To find the next number (shown here by "x"), count back the number of places from the x position shown by the two numbers before the "x". This will bring you back ten places to the bold italic 5 in the series, and nine places to the bold italic 6. Adding these together will give you 11, the next term in the series.

That's all you get: make up your own problem. Can you write spreadsheet code to generate the first thousand Q numbers? Can you find any patterns?

Still here? What about trying to work out if the series always gets bigger, or whether it gets back to zero at some point? What about trying a Q series with two other starting numbers?

Biggest number

$$2^{2^{2^{2}}} = 65536$$

Now which is the biggest of 2^{222}, 22^{22}, and 222^{2}? Is there a quick way of finding out?

An easy sequence

10, 4, 7, 12… Find the next number: it is either 5, 10, 15 or 20. There are no hints.

Can you crack all of these?

There is an old saying that any fool can ask a question so hard that nobody can answer it. The following puzzles start out easy, but the later ones are ***brutally hard***. See how many you can get.

In each set of three, you are given two examples to begin with. Each example has two working numbers, outside the brackets, and these numbers must be used in some mathematical way to reach the target number which appears inside the brackets. In each set, the two examples and the puzzle use the same rule.

You have to work out how the puzzle maker reached the target, so you can fill in the blanks in the puzzle, but let's begin with the examples for a really simple one: 3 [8] 5; 4 [11] 7.

Can you see a pattern there? How would you get 8 by writing a sum that involves 3 and 5? Come up with an idea, and test it on the second. Can the same sum use 4 and 7 to get 11?

If we call the outside numbers a and b, and we call the bracketed number c, it looks as though we have c = a + b. So if the puzzle is 12 [.] 28, the answer has to be 40.

You can use brackets, you can use a and b more than once, you can us +, -, x and / (for division), you can use square roots but not cube roots (because where would you get the three from?), and you *can't* use a^2, but you *can* use a x a. You can also use factorial notation.

In this system, 5! (we call it five factorial) is 5 x 4 x 3 x 2 x 1=120. In general terms, n! = n x (n-1) x (n-2) … x 3 x 2 x 1. Your puzzle setter might have chosen to use double factorials, multifactorials, primorials and other fancy sets, but didn't. His granddaughter said he should use them, but he found them too hard to understand.

One word of warning: there is an obvious solution to 5 [20] 100, but it isn't the only answer, and that is why you need to test your solution to the first puzzle out against the second example. And one hint: look at the values for a and b, and see what they all have in common.

The puzzles:

5 [20] 100; 8 [120] 15; 9 [.] 11

4 [4] 8; 3[16] 19; 12 [.] 16

2 [7] 5; 9 [25] 16 ; 7 [.] 18

33 [11] 3; 49 [7] 7; 16 [.] 8

3 [10] 1; 4 [20] 4; 9 [.] 19

4 [25] 3; 1[50] 7; 5 [.] 5

13 [49] 6; 7[36] 1; 9 [.] 5

4 [2] 8; 6 [3] 12; 10 [.] 5

4 [6] 3; 9 [21] 7; 25 [.] 8

5 [19] 3; 7 [45] 2; 8 [.] 14

4 [28] 8; 8 [72] 10; 5[.] 9

11 [33] 14; 6 [18] 9; 12 [.] 8

5 [20] 100; 800 [80] 6; 3 [.] 2

5 [20] 6; 6 [6] 120; 4 [.] 6

5 [12] 3; 8 [42] 6; 9 [.] 5

16 [20] 25; 64 [56] 49; 100 [.] 81)

64 [2] 3; 40,000 [80] 5; 256 [.] 3

144 [2] 36; 900 [3] 100; 256 [.] 16

49 [16] 81; 144 [27] 225; 169 [.] 196

64 [20] 144; 49 [24] 289; 121 [.] 400

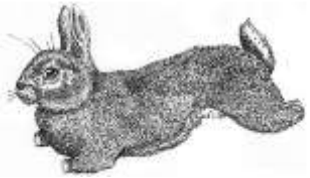
The art of estimation

All tools can have surprising uses, and I once used a plumb bob to make my electricity supplier replace the power/light pole outside my house. I phoned them to report that the pole was in danger of falling and causing injury, but they ignored me. The second time I called, I told the person answering that the pole was 5.05º out of plumb, and that I was monitoring it, expecting the angle to increase.

The offending light pole and my high-tech equipment.

The operator was clearly suspicious of my claimed level of accuracy (as I would be, in the same position), and wanted to know how I measured it. “A plumb bob pinned, 1500 millimetres up the pole was 132 millimetres out at the base. That’s a sine of 0.088, and there’s my angle,” I said.

The lesson: like tools, numbers also have surprising uses, and one of the best tricks is when you get to use numbers as a cattle prod—and common folk are alarmed by even simple science. The pole was replaced a week later, which was what I had estimated.



A *very* unlucky rabbit.

To a mathematician or physicist, the notion of an immortal rabbit is quite acceptable for calculation purposes. As a school student, my English teacher encouraged me to psychoanalyse Macbeth, even when I protested that Freud hadn't been invented when Shakespeare was writing. Ever a historically-minded cuss, I argued that it would be more relevant to look at the political situation in London, with a Scot (James I) sitting on the throne. Exasperated, he exhorted the class to ignore me, and engage instead in the willing suspension of disbelief.

In the same way, a spherical horse or spherical cow can be a useful starting point to explore ideas, to get a first approximation that can be extended. That brings us to the claim about the bumblebee that was shown not to be able to fly: this is often trotted out as evidence that scientists are thick, but there is a little more to the story than that.

In 1934, a French entomologist called Antoine Magnan tried to apply an engineer's equation to bumblebees, and showed how, according to that equation, designed for aircraft that did not flap their wings, the bee could not generate enough lift to take off.

There is a great deal of folklore wrapped around this "event" and who actually was involved, but it appears that the equation was worked out by André Saint-Lagué. While the incident is often dressed up as "a scientist proving that bumblebees can't fly", all that Magnan really showed was that the equation was inadequate to describe the flight of the bumblebee.

He had shown that you can't apply *that* particular equation to bumblebees, rather than proving that spherical bumblebees can't fly, even if real ones can, flapping their wings at 130 times a second, moving happily along at 3 metres/sec, 11 km/h. Like Zeno's paradox, Magnan's calculation merely showed that there was a faulty assumption in there somewhere. This minor paradox showed that the mathematical model was flawed.

Safely out of the English classroom and into the lab, we heard of the marvels that could be done with simple apparatus. The muzzle velocity of a bullet could be measured with just a block of wood, a piece of string, a protractor and a measuring tape.

Our physics teacher, as equally at home with fiction as our English teacher, explained how, in the days of gunpowder and muzzle-loading firearms, slight variations in the ingredients or their amounts and proportions, could make a lot of difference. In the 17th and 18th centuries, Britain and France were always at war, and better gunpowder could make all the difference between winning and losing. The very best saltpetre, an essential part of gunpowder, came from India.

The most obvious measure of powder quality was the speed at which a cannon ball or musket ball left the barrel of the gun, or in physics-speak, the muzzle velocity. The idea was quite simple. You suspended a large block of wood and fired a bullet at it from close range.

The bullet lodged in the block, and all the energy of the bullet was transferred to the block, which would swing like a pendulum. Then the researcher only had to measure the swing angle and calculate the height the block reached.

This gadget even has a name: it is the ballistic pendulum, and it was invented by Benjamin Robins in 1742. From the swing, or so we were told, it is an elementary calculation to estimate the energy and hence the velocity of the bullet. Unfortunately, this explanation ignores the 800-pound spherical horse that is rolling around the room. (OK, it *could* have been a spherical elephant, but that's a different joke.)

Some of the energy would go into deforming the bullet and the wood, some would be wasted as friction, and to do any calculations, we would have to assume that the bullet stopped instantaneously (which is about as likely as a girder with negligible mass).

Of course, if you were simply trying to compare different grades of gunpowder, rather than measuring the muzzle velocities, the losses will be similar in each case, and they can be ignored. Whichever powder produces the biggest swing is the best, if everything else is kept constant, and in fairy physics (which is, you will recall, the name that engineers give to this sort of thinking), that *always* applies.

Robins' ballistic pendulum would have shown that Indian saltpetre made the best gunpowder. He died in India in 1751, supervising the construction of forts, and a few years later, the British drove the French out of India, getting all that excellent saltpetre for their own use. (History is one of the Arts, but chemistry has to be understood as well.)

And you need to keep an open mind. When you enquire about fast animals, more often than not, you will read that the fastest animal of all is the deer botfly. This is credited with an amazing 1287 km/hr, though if you convert this to miles per hour, that comes out as a round 800 mph, a figure that smells a

little bit of fudged science—and rightly so, because round numbers are *always* suspicious.

A 1927 article in the *Journal of the New York Entomological Society*, written by an entomologist called Charles Henry Tyler Townsend reported a speed like that. Townsend said these flies passed in a blur, and so must have been travelling very fast. On that 'scientific' basis and no other, he credited the flies with a nice round 400 yards per second.

In 1938, when Irving Langmuir, a Nobel laureate in chemistry tested the assumptions. He found that the air pressure on the fly at that speed would be more than half an atmosphere, enough to crush it. The energy needed to maintain the flight would be 370 watts, half a horsepower. Aside from anything else, the fly would use up its own weight in fuel every second.

Langmuir had been hit by these flies, and while it hurt, a fly of that weight, going at 1300 km/hr would have left a significant hole in him, rather like that of a soft bullet, and the fly would have been mashed inside the wound. Instead, the fly bounced off. He used solder to make a pellet, the size of a fly, 1 cm long and 0.5 cm wide, and tied it to a string.

He whirled the pellet around his head. Knowing the length of the string and how many circuits it made each second, he calculated the speed, and found that at 13 mph, it was a blur. At 26 mph, it was barely visible; at 43 mph, an observer could not tell which way it was going; and at 64 mph, it was invisible. He said Townsend's blur came from a fly travelling at 25 mph (40 km/hr).

Langmuir's results were published in *Science* and reported in *Time* magazine, but legends are tough things, even when they are debunked by Nobel Prize winners. So even today, the same old values keep emerging from the woodwork.

Speeding arrows

Estimation, unlike history, is a part of mathematics, and it is an important one, if you are relying on a calculator, where a slip of the finger can move the decimal point. Estimation is also useful when you don't have complete and reliable data. For example, until about 1600, most military firepower, aside from the odd cannon, used to batter walls from a distance, came from bows and arrows. In reality, up until the mid-1800s, it would have made more sense to keep on using archers, because a skilled bowman could fire more shots faster, doing greater harm at the end of their range, than a soldier could do, equipped with a rifle or a musket.

The key point is that an archer had to be skilled, and those who used longbows had to be strong. On the other hand, the skill and strength needed to fire a crossbow were low, like those needed to discharge a firearm. Crossbows were less rapid than longbows, but more damaging than muskets.

In October 1415, the small English army of King Henry V, some 6000 men, was faced at Agincourt with an army of 50,000 Frenchmen. The difference was not as great as you might think, because 5000 of the Englishmen were skilled archers. The French army was mainly composed of cavalry, and facing a rain of arrows, the French cavalry turned back into the French infantry, causing confusion that is bad for winning battles.

A good archer could fire off ten arrows a minute, each of them leaving the bow at 60 m/s (more than 200 km/h), and arriving a few seconds later, still carrying three quarters of that speed. All of these are estimates, of course, but we know that in 1590, Sir Roger Williams complained that only 10% of archers could do harm "12 or 14 score off", which is at 240 to 280 yards, or 220 to 260 metres. Even at Waterloo in 1815, muskets had a range of less than 100 metres.

Much of the armour used at Agincourt was thin metal, perhaps 1 mm thick, and tests have shown that arrows would go through 1 mm steel. Some armour was up to 4 mm thick, and that would have withstood arrows, but not crossbow bolts.

The crossbow has the advantage that it can be loaded in advance, and used when necessary. More importantly, it fires a heavy bolt with real killing power, and no real training is needed to use one, because the operation is intuitive: point, steady the bow and shoot. After a ranging shot or two, most operators can be accurate enough to be dangerous.

The crossbow bolt would have been slower at first, but later ones are credited with ranges of a quarter of a mile (400 metres) and more. Allowing for air resistance, the bolts must have reached at least 75 m/s, close to 300 km/h. The rate of fire of the crossbow was comparable with that of a trained musket user, with less chance of a misfire, making the changeover to firearms (when it happened) a bit odd, because arrows were still better. Perhaps the people in charge believed Zeno's Paradox?

That same argument can also be applied with appropriate changes to an arrow approaching a target, but Zeno also said that if we divide the time into tiny enough segments, in each of them, the arrow is not moving. Either way, it will never reach the target. Remember the bumblebee!

Another case of estimation

I was once asked (never mind *why*) to calculate the mass of a cork ball, two metres in diameter. Getting the volume is easy: $^4/_3 \times \pi r^3$ or 4.189 cubic metres, but how much does a cubic metre of cork weigh? There are two ways to find out: one is to look it up, the other is to estimate it, by looking at a cork in water.

Estimating the density of cork.

I decided that 20% of the cork in the photo above was submerged, giving a density of 0.2, while the reference books give a value of 0.24. My estimated mass was 838 kg, while the official answer is just over 1000 kg.

Whatever: under each answer, a 2-metre cork ball was a bad idea in a children's playground! Oops, I gave the *why* away, but my calculations saved somebody's job.

Goldbach's conjecture

This unproven suspicion of mathematics suggests that every even number larger than 2 can be expressed as the sum of two prime numbers (4 = 3 + 1, 6 = 5 + 1, 8 = 7 + 1 = 5 + 3 etc.).

Your task is to explore the pattern of even numbers that can be "Goldbached" in more than one way. Don't ask me what the answer is, because I have no idea where it might lead.

Another interesting conjecture, this time concerning odd numbers, was put forward in the mid-19th century by French mathematician, Alphonse de Polignac. He argued that "every odd number can be expressed as the sum of a power of 2 and a prime". In presenting this notion, de Polignac implied that he had tested this against all odd numbers up to three million.

While most odd numbers can be constructed by adding a prime to a power of two, 127, which is also a Mersenne prime, fails the test. All of the possible constructions of this number (2 + 125, 4 + 123, 8 + 119, 16 + 111, 32 + 95 and 64 + 63) involve adding an odd number that is a composite to a power of two.

Can you find the next number that fails de Polignac's conjecture? It's time to start fiddling with spreadsheets.

Notes for this chapter

See Jerome S. Meyer, *Fun with Mathematics* for Fibonacci numbers.

Try this link: *Phi the Golden Key*: this is amazing art and mathematics. https://www.facebook.com/JamieJanoverMusic/videos/10153215452583907

For more mathematics puzzles http://www.cut-the-knot.com/

Two consecutive numbers quickies

9+8+7+6+5+43 +21 =99; 9+8+7+65+4+3+2+1=99 and 98-7+6+5-4+3-2x1=99 (I thought this last one up while reviewing this).

(1/2 + 3x4) x 56/7 = 100, but this is one I thought of during editing, and I don't think it was my original solution.

The game of 1729 (a)

First, a spreadsheet hint: to get the codes to appear in Excel, hold down Control, and select the top left key on your keyboard (the grave symbol, `, which appears under tilde, ~).

Until I take the original Playwiths web pages down, you can find most of the other answers there.

To track things down from hints, you need *Google fu*. I got the answer to the fourth power riddle by searching on this string: <**133 134 "fourth power" ramanujan**> and looking around.

Something I came up with during editing: can you come up with a 1, 7, 2, 9 sum that returns the value 91? I can get to 82, but that's all…

I'm not saying how I did it, but of the first 2000 integers, 150 of them can be expressed as the sum (or difference) of two cubes. I will admit to using both a spreadsheet and a word processor with a SORT function.

Curiosity of no importance: 729 is 9^3, and it is also the sum of three cubes: $1^3 + 6^3 + 8^3$, but as $6^3 = 3^3 + 4^3 + 5^3$, 729 is also the sum of five cubes: $1^3 + 3^3 + 4^3 + 5^3 + 8^3$.

The game of 1729 (b)

There are 20,138,200 Carmichael numbers between 1 and 10^{21}, and the first seven are:

561 (5 x 13 x 17); **1105** (5 x 13 x 17); **1729** (7 x 13 x 19); **2465** (5 x 17 x 29); **2821** (7 x 13 x 31); **6601** (7 x 23 x 41); and **8911** (7 x 19 x 67).

In the early days on the internet, while discussing Carmichael numbers, I noted that two in this sample (1729 and 2465) had factors in arithmetical progression. These were briefly dubbed Macinnis numbers, but they were uninteresting, so we forgot about them.

One of my students threw 1105 at me, asking what I thought of it. I replied that it was a Carmichael number, but he thought it was better described as the product of the first three primes of the form $4n+1$.

I should have known that he was laying a trap for me. “It’s perhaps more to the point that it is the sum of two squares in three different ways,” I said.

He fired back much too quickly. “Four ways, actually!”

I constructed this spreadsheet, and saw that he was correct:

	A	B	C	D
1	1	=A1*A1	=1105-B1	=SQRT(C1)
2	2	=A2*A2	=1105-B2	=SQRT(C2)

Fibonacci and other numbers

The pattern I saw was in the alternation of plus and minus, but does it continue? Prove it.

Other ways of getting a value for Φ

It was late at night when I wrote that the calculation must have been hard for Lagrange to do, but as my head hit the pillow, I realised that maybe he didn’t need to do the additions at all. Here is the end of the pattern, and the start of the next sequence in bold blue:

9, 3, 2, 5, 7, 2, 9, 1, 0, **1, 1, 2, 3, 5, 8.**

My way to find the whole series is to know that 1, 0 must be the last two, and working back before that, the previous number must be 9, and 2 had to come before that, and so on!

I got up the next morning, and I can deduce the whole sequence, running backwards, but I rather think that if Lagrange ever heard of spreadsheets, he would have killed for even Visicalc or Lotus 123. (If you are less than 50, you will probably need to look those up.)

The brutally hard problems

Here, you will find the whole question repeated, but with the answer in place.

5 [20] 100; 8 [120] 15; 9 [99] 11. c= a x b

4 [4] 8; 3[16] 19; 12 [4] 16. c= b - a

2 [7] 5; 9 [25] 16 ; 7 [25] 18. c= b + a

33 [11] 3; 49 [7] 7; 16 [2] 8. c= a / b

3 [10] 1; 4 [20] 4; 9 [100] 19. c= (a x a) + b

4 [25] 3; 1[50] 7; 5 [50] 5. c= (a x a) + (b x b)

13 [49] 6; 7[36] 1; 9 [16] 5.   c= (a – b) x (a – b)

4 [2] 8; 6 [3] 12; 10 [20] 5.   c= (a x a)/b

4 [6] 3; 9 [21] 7; 25 [40] 8.   c= sqrt(a) x b

5 [19] 3; 7 [45] 2; 8 [50] 14.   c= (a x a) – (b + b)

4 [28] 8; 8 [72] 10; 5[40] 9.   c= (a x b) - a

11 [33] 14; 6 [18] 9; 12 [48] 8.   c= a x (b – a)

5 [20] 100; 800 [80] 6; 3 [4] 2.   c= a! - b

5 [20] 6; 6 [6] 120; 4 [4] 6.   c= a! / b

5 [12] 3; 8 [42] 6; 9 [40] 5.   c= (a x b) -b

16 [20] 25; 64 [56] 49; 100 [90] 81.   c= (sqrt a) x (sqrt b)

64 [2] 3; 40,000 [80] 5; 256 [10] 3.   c= (sqrt a) – b!

144 [2] 36; 900 [3] 100; 256 [4] 16.   c= (sqrt a) / (sqrt b)

49 [16] 81; 144 [27] 225; 169 [1] 196.   c= - (sqrt a) + (sqrt b)

64 [20] 144; 49 [24] 289; 121 [31] 400.   c= (sqrt a) + (sqrt b)

Estimation

When one is engaged in fraud investigation, one fertile method is to do some rough estimating, because these will often show up fraud. If an operation averages eight sick days per worker each year, you can make certain assumptions. If after allowing for seasonal colds and the like, the averages or the frequencies don't fit the estimates, a closer look is recommended.

Round numbers

There is a legend that the surveyors who measured the height of Mount Everest found that the numbers they had gave a value of exactly 29,000 feet, but they decided that nobody would accept that, so they gave the value as 29,002 feet (8,839.8 m), fearing that the calculated value of 8,839.2 m would be dismissed as a rounded estimate. This remains a conjecture that most scientists would like to be true.

Goldbach's conjecture

Yes, I didn't explain what a Mersenne prime was. Science writers are like that. Look these numbers up!

This is completely useless but fun: the formula $n^2 - 79n + 1601$ generates a long string of prime numbers. Can you work out when it breaks down? It may be easier to tackle the related prime-generating formula $n^2 + n + 41$, which breaks down in half the time. That's a hint…

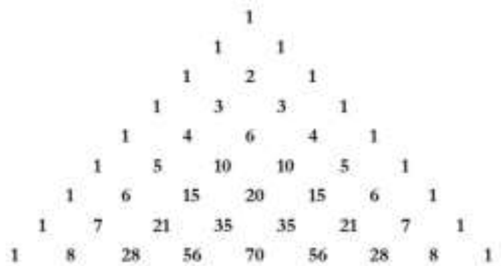
19. Using technology on numbers

Charles Babbage's Difference Engine, a forerunner of the modern computer. Lots of people have heard of Charles, but his son Herschel Babbage, a meticulous Australian explorer is hardly known. Everything is connected!

Back to the Contents

Pascal's marvellous triangle

Blaise Pascal pioneered probability theory, but he is most famous for Pascal's triangle, seen here: examine it to see how each row is generated from the one above, then draw up as many rows as possible on a single A4 sheet of paper. This example shows you how to tackle it.

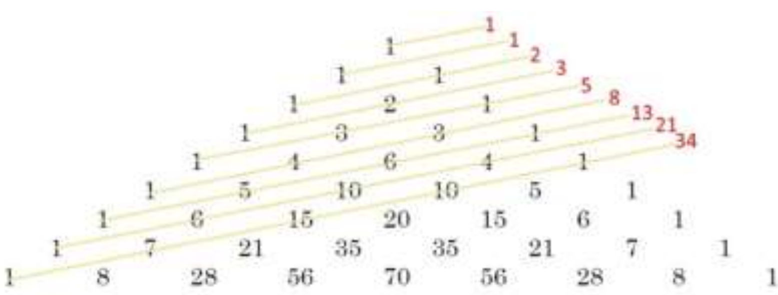


Pascal's triangle.

Or if you prefer, create it on a spreadsheet and print it out. Put the value 1 in cell K1, then type **=A1+C1** in cell B2 and copy it all over the sheet. This puts a lot of unnecessary zeroes in there: there are ways to get rid of them, but you need to find them. Play with it!

Pascal's triangle has blocks of numbers that are all divisible by the same number. It is possible to write a computer program to plot these into a diagram: try the numbers divisible by three first, and then 5, and move up to larger numbers later.

By the way, if you draw a slanting diagonal through the 1 at the left of the fifth row, then through the leftmost 3 in the fourth row, and the 1 on the right of the third row, the total of the numbers is 5. Now if you do the parallel diagonals above and below and add the numbers on each diagonal, you will discover a wonderful thing. Look at a few of them, and it will hit you: do those numbers ring a bell?



Fibonacci hiding in Pascal's triangle.

Amicable numbers

The number 220 is the smaller number in the first pair of amicable numbers. The other number in the pair is 284. The proper divisors of 220 (1, 2, 4, 5, 10, 11, 20, 22, 44, 55 and 110) sum to 284, while the proper divisors of 284 (1, 2, 4, 71 and 142) sum to 220. Up until 1946, there were 390 known pairs of amicable numbers, but by 2007, there were almost 12 million known pairs. The number reached 1,224,546,836, according the **Amicable pairs list** (https://sech.me/ap/ (last seen December 2019), which is available on the internet. It will be higher, by the time you read this…science is like that, and so is mathematics.

π from a spreadsheet

There are quite a few series that converge on a value of π, or some function of π. Here's one:

$$(\pi^4)/96 = 1/1^4 + 1/3^4 + 1/5^4 + 1/7^4 + 1/9^4 + \ldots$$

These instructions will help you to create a spreadsheet that will get to π to about five decimal places in about 250 rows.

Begin with the value **1** in cell A2

Now from the home tab, select **FILL SERIES (step 2)** to get the numbers 3, 5, 7 … 199 in the cells down to A101. Column A is now ready.

Now enter this formula in B2 : **=1/(A2*A2*A2*A2)**

And put this in C2: **=C1 + B2** (this will give us a running total of column B, up to that row).

Then put this in D2: **=SQRT(SQRT(C2*96))** to get your first estimate of the value of π.

Now you can highlight cells B2, C2 and D2, and then highlight down to row 250, and use **FILL DOWN** from the Home tab to copy the formula down into those rows as well, and extend column A down to row 250 (*think about this!*).

Check the answers that you get in cells D246 and D247, after you have extended the spreadsheet down to row 250. The value you should be aiming at is 3.141 592 653 589 793 238 462… but getting there will take a while longer…☺

If anything does not work, check the values in column A, which has to contain only the consecutive odd numbers. Then work your way across, checking each of the formulas in the instructions, until you spot the mistake you made. The formulas given here worked (many years ago) in MS Works and

they still work in MS Excel (2010 version), but they have not been tested on other or more recent spreadsheets.

	A	B	C	D
1				
2	1	=1/(A2*A2*A2*	=C1 + B2	=SQRT(SQRT(C2*96))
3	3	=1/(A3*A3*A3*	=C2 + B3	=SQRT(SQRT(C3*96))
4	5	=1/(A4*A4*A4*	=C3 + B4	=SQRT(SQRT(C4*96))
5	7	=1/(A5*A5*A5*	=C4 + B5	=SQRT(SQRT(C5*96))
6	9	=1/(A6*A6*A6*	=C5 + B6	=SQRT(SQRT(C6*96))
7	11	=1/(A7*A7*A7*	=C6 + B7	=SQRT(SQRT(C7*96))
8	13	=1/(A8*A8*A8*	=C7 + B8	=SQRT(SQRT(C8*96))
9	15	=1/(A9*A9*A9*	=C8 + B9	=SQRT(SQRT(C9*96))

	A	B	C	D
1				
2	1	1	1	3.13016916
3	3	0.0123	1.012345679	3.139785789
4	5	0.0016	1.013945679	3.141025632
5	7	0.0004	1.014362172	3.141348138
6	9	0.0002	1.014514588	3.141466133
7	11	7E-05	1.014582889	3.141519007
8	13	4E-05	1.014617902	3.14154611
9	15	2E-05	1.014637655	3.1415614

Here is what you will see: code on the left, output on the right.

The sieve of Eratosthenes

This is an ancient method (or algorithm) for finding prime numbers in a range. Write down all of the integers between 1 and n, then go through and cross out every second number starting at 4, every third number starting at 6, every fifth number from 10 on, seventh number beginning with 14 and so on. Some numbers will be crossed out more than once, but that doesn't matter.

You end up with a sequence like this, where the bold numbers are the ones crossed out:

1 2 3 **~~4~~** 5 **~~6~~** 7 **~~8 9 10~~** 11 **~~12~~** 13 **~~14 15 16~~** 17 **~~18~~** 19 **~~20 21 22~~** 23 **~~24 25 26 27 28~~** 29 **~~30~~** 31 **~~32 33 34 35 36~~** 37…

Runs of composites

The aim here is to explore the natural sequence of integers for runs of consecutive integers that are composite, meaning they have factors. Two examples are series like 8, 9, 10, or 24, 25, 26, 27, 28. (Look at the example above: the crossed-out bold bunches are runs of composites.)

I started using a spreadsheet to help me search for runs longer than five composites, but for a while, the best I found was seven in a row: is there any link between the central number in the first example of any run of a particular size? Note that there will always BE a central number, as the totals will always be odd. Can you prove this? I can…

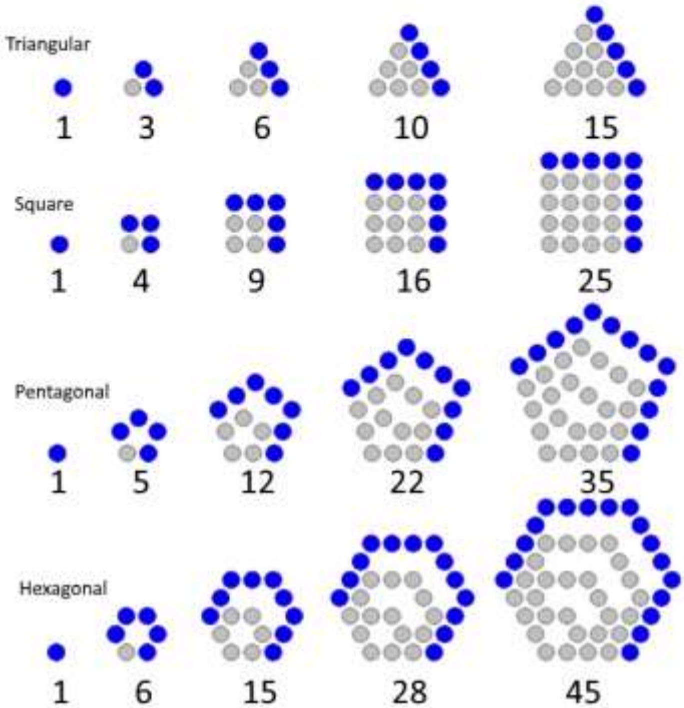
In October 2002, I found a run of 33 consecutive composite numbers, all of them less than 10,000. I used a spreadsheet to do it, and here are a couple of helpful hints.

- Note that I used the **=IF** function quite a bit…
- To test if a number x is exactly divisible by another number n, you use the form x/n=INT(x/n). I have some kludgy spreadsheet solutions, but no really good ones…

Play with it!

Polygonal numbers background

This is hard, but sort-of fun. Polygonal numbers are generated by drawing patterns like those seen in the figure below.



Polygonal numbers, graphically represented.

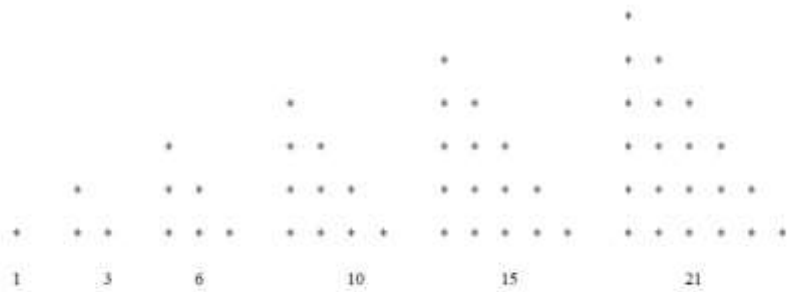
Notice how the added dots at each stage are shown in blue. The numbers 1, 3, 6, 10 and 15 are the first five triangular numbers, and so on.

- Aside from the trivial cases of 0 and 1, there is another number under 500 that is both triangular and pentagonal, and there is another one under 50,000: are there any others? Can a computer be set the task of looking for these?
- There are three numbers under 2 billion that are at once triangular, pentagonal and hexagonal. Can you find them?
- There is at least one number under 1000 that is both square and heptagonal: are there any others?
- There is an obvious link between triangular numbers and hexagonal numbers. Do any other sets of polygonal numbers have a relationship like this?
- The triangular numbers appear in Pascal's triangle. Do any of the other sets appear there? Why or why not?
- Think up some others yourself by deducing the formula for a set.

Triangular numbers

This story (which quickly gets harder) has its beginnings with me playing with the triangular numbers, 1, 3, 6, 10, 15, 21… that are generated by 1, 1+2, 1+2+3, 1+2+3+4, 1+2+3+4+5, 1+2+3+4+5+6…

They are called triangular numbers because you can make them up into neat triangles like this:



Triangular numbers.

There are several really cute things about these numbers that were known, back in the days of Diophantus, an Ancient Greek who liked playing with big numbers.

Every perfect square is the sum of two consecutive triangular numbers, as you can see if you plot the square numbers as asterisks or dots like the diagram above. With a bit of effort, you can use a similar method to prove that every odd perfect square is of the form 8T + 1, where T is a triangular number.

It occurred to me that the 8^{th} term in the series of the numbers in the series was 36, which is a perfect square, and then I wondered if there are any other numbers in the series that are perfect squares, and if so, how you could generate them.

It was late at night, I mistakenly calculated the value of T(15) as 121 (it is actually 120), and so it looked worth trying, but I went to sleep before I found any more.

Next day, I realised my error, and since I suspected that there would not be many numbers fitting the pattern, I created a spreadsheet that would generate them, knowing that term number T in the series is given by

T(n) = n * (n + 1) / 2, which means that term 11, for example, is 11 * 12/2 = 66

$\sqrt{-1}\ 2^3\ \Sigma\ \pi$

About the Spreadsheet

Like Lagrange when he was doing the last digits of the Fibonacci series (chapter 18), I think Diophantus would have killed for even a simple spreadsheet program. Here is my spreadsheet solution to test for numbers that fit:

A1 is the starting number of the terms to be explored

A2 =A1 + 1

B1 =(A1*A1+A1)/2

C1 =IF(SQRT(B1)=INT(SQRT(B1)),1,"")

B2 and C2 are filled down from B1 and C1.

	A	B	C
1		=(A1*A1+A1)/2	=IF(SQRT(B1)=INT(SQRT(B1)),1,"")
2	=A1 + 1	=(A2*A2+A2)/2	=IF(SQRT(B2)=INT(SQRT(B2)),1,"")
3	=A2 + 1	=(A3*A3+A3)/2	=IF(SQRT(B3)=INT(SQRT(B3)),1,"")
4	=A3 + 1	=(A4*A4+A4)/2	=IF(SQRT(B4)=INT(SQRT(B4)),1,"")
5	=A4 + 1	=(A5*A5+A5)/2	=IF(SQRT(B5)=INT(SQRT(B5)),1,"")
6	=A5 + 1	=(A6*A6+A6)/2	=IF(SQRT(B6)=INT(SQRT(B6)),1,"")
7	=A6 + 1	=(A7*A7+A7)/2	=IF(SQRT(B7)=INT(SQRT(B7)),1,"")
8	=A7 + 1	=(A8*A8+A8)/2	=IF(SQRT(B8)=INT(SQRT(B8)),1,"")
9	=A8 + 1	=(A9*A9+A9)/2	=IF(SQRT(B9)=INT(SQRT(B9)),1,"")

	A	B	C
1		0	1
2	1	1	1
3	2	3	
4	3	6	
5	4	10	
6	5	15	
7	6	21	
8	7	28	
9	8	36	1

Here is what you will see: code on the left, output on the right. The 1 in column C marks a perfect square.

I then fill down columns A, B and C to row 50000, and insert the value 1 in cell A1 to test the first fifty thousand terms. To get the next 50,000 terms, I type 50001 in cell A1, and so one.

A “hit” is indicated by the value 1 appearing in column C in the same line as the hit.

I found it a nuisance searching for the hits, so I created 20 cells in column D to help me find them:

D1 =sum(c1:c2500)

D2 =sum(c2501:c5000)

and so on to D20—this told me roughly where the hits were.

Then to eyeball for ANY hits in a block (they get fewer and fewer) I created E1 =sum(d1:d20), then all I had to do was insert my starting values 50001, 100001, 150001 etc. in A1 and trawl through the terms, zeroing in on a specific 2500 rows to search for the hit when one was indicated in cell E1 and column D. Once I learned to calculate the approximate value, I could jump almost to the correct row, but that calculation is jumping ahead of the story.

$\sqrt{-1}\ 2^3\ \Sigma\ \pi$

The Results

What I had now was a curious pattern, where the terms that were perfect squares went like this:

n	n can be stated as	Value of T(n)	square root of T(n)
0	0	0	0
1	1^2	1	1
8	2 * 2^2	36	6
49	7^2	1225	35
288	2 * 12^2	41616	204
1681	41^2	1413721	1189
9800	2 * 70^2	48024900	6930
57 121	239^2	1631432881	40391
332 928	2 * 408^2	55420693056	235416
1 940 449	1393^2	1882672131025	1372105
11 309 768	2 * 2378^2	63955431761796	7997214
65 918 161	8119^2	2172602007770040	46611179
384 199 200	2 * 13860^2	73804512832419600	271669860
2 239 277 041	47321^2	2507180834294500000	1583407981
13 051 463 048	2 * 80782^2	85170343853180500000	9228778026

The Mysterious Constant

About this time, I started to see some patterns. I found that these term numbers appear to be in a geometric progression with the ratios of two successive term numbers converging. Leaving out the first couple of terms of the converging series, I found these ratios between the key numbers:

5.87755102040816, 5.83680555555556, 5.82986317668055, 5.82867346938776, 5.82846938954150, 5.82843437620146, 5.82842836889813, 5.82842733820888, 5.82842716137060, 5.82842713102994, 5.82842712582431 and 5.82842712536459.

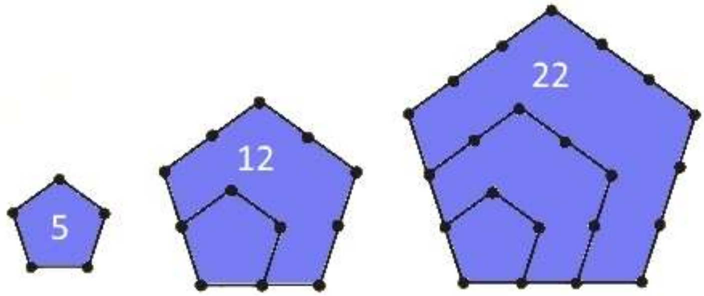
There is (or was) more online. It's complicated, so I have left it out of this book, but the constant was explained by Ben Morphett as $(3+2\sqrt{2})$, the solution to the quadratic equation $x^2 - 6x + 1 = 0$. I warned you this was hard!

$\sqrt{-1}\ 2^3\ \Sigma\ \pi$

Pentagonal numbers

These numbers are generated as shown in the diagram below, and there is also a general formula which generates the whole set. Can you find it?

The numbers in the series are 1, 5, 12, 22, 35, 51, 70…



How to generate pentagonal numbers without maths.

Interestingly, the first factor in the general formula for triangular, square, pentagonal, hexagonal, heptagonal, octagonal numbers and so on is always 1/2n, and the second factor shows a fascinating pattern, which I leave you to discover when you work out the other formulae.

$\sqrt{-1}\ 2^3\ \Sigma\ \pi$

Notes for this chapter

In the references section, start with the works of Ian Stewart and Martin Gardner. Then move on to Albert Beiler's *Recreations in the Theory of Numbers*. For counter-intuitive science, see Lewis Wolpert's *The Unnatural Nature of Science*.

Pascal's marvellous triangle

When you colour in the numbers divisible by a certain factor, you get something called a Sierpinski triangle. Those who can wrestle Python, here's a hint!

π from a spreadsheet

Here, without explanation, are two other convergent series that close in on π.

$\pi^2/_6=1/1^2+1/2^2+1/3^2+1/4^2+1/5^2+\ldots$

$\pi/4=1-{}^1/_3+{}^1/_5-{}^1/_7+{}^1/_9\ldots$

There are more of these: use <**infinite series pi**> as your web search string.

Runs of composites

Because even numbers are always composites, and odd numbers are only sometimes composite, each string of composites will start and end with an even number. This means that every string will have an odd number of members. The numbers 8 to 10, 24 to 28 and 90 to 96 represent some of the strings that can be found with ease. For larger sequences, it is possible to construct a spreadsheet that will test for primeness, set flags for all composite numbers, and display longer sequences. Sadly, the margins of this book are too narrow for me to set the method out fully.

One way of generating a string of guaranteed composites is to take the series n! + (2, 3 … n). That is a tricky bit of notation. 5! = 5x4x3x2x1, and one string of composites will be 122, 123, 124, 125, but that is part of a larger string: that sequence is a guaranteed set, that's all. You do the rest.

Side note: n!-1 is often (but not always) prime, and the primes get rarer, once n exceeds 40.

$\sqrt{-1}\ 2^3\ \Sigma\ \pi$

20. Can we trust statistics?

Show this engraving to your tame adult, and he or she will probably guess know that this is "The Lady with the Lamp", Florence Nightingale, who turned nursing a profession. Tame adults are unlikely to know that the engraving was by James-Charles Armytage, and they are very unlikely to know what Florence Nightingale did for statistics, which she used to argue for reforms in nursing. To rally public support for nursing reforms, she wrote a pamphlet called *Mortality in the British Army*, and this was the first use of pictorial charts to present data.

She invented all those diagrams in the financial pages, with wheat bags, or oil barrels or human figures lined up like so many paper dolls. She hammered away again in 1858 in her *Report on the Crimea*:

> It is not denied that a large part of the British force perished from causes not the unavoidable or necessary results of war...(10,053 men, or sixty percent per annum, perished in seven months, from disease alone, upon an average strength of 28,939. This mortality exceeds that of the Great Plague)...The question arises, must what has here occurred occur again?

In 1858, Nightingale was elected to the newly formed Statistical Society and turned her attention to hospital statistics on disease and mortality. Now read on…

Back to the Contents

This chapter began as two radio talks delivered on the ABC, almost thirty years ago. My friend Peter Chubb asked me if I had addressed these issues, and I said that I hadn't, but that I had provided a link to the text of the talk. Two nights later, I decided to add it, the next night, I rewrote it.

There is enough information here to let readers try my exercise in Evil Statistics out for themselves.

$\sqrt{-1}\ 2^3\ \Sigma\ \pi$

Boris, Don and Scotty went fishing, and caught ten fish. Four weighed 1 kg, two were 2 kg, two were three kg, one was 6 kg, and one was 10 kg. They reported that the average was 1 kg, 2 kg and 3 kg, and all were telling a sort of truth. Boris reported the *mode*, the most common mass, Don reported the *median*, the masses of the middle two fish, Scotty reported the *mean*, adding all the masses and dividing by ten. Each value was true, each was different.

It all sounds a bit like "Lies, damned lies, and statistics", but who first said that? The popular myth is that it was Mr. Disraeli, the well-known politician, but many quite reputable and reliable reference books blame author Mark Twain.

It turns out that it was first published by Twain all right, but Twain attributed the line to Disraeli, and you won't find the story in any earlier publication than Twain's autobiography. In short, Mark Twain made the whole thing up! Disraeli never spoke those words: Twain invented them all, but he wanted the joke to have a greater force, and so gave the credit to an English politician.

Twain wasn't only well-known for his admiration of a good "Stretcher" (of the truth, that is), he even lied when he was talking about lies, and his name wasn't even Mark Twain, but Samuel Clemens! Now would you buy a used statistic from this man?

Last century, when Disraeli is supposed to have made the remark, statistics were just numbers about the State. The state of the State, all summed up in a few simple numbers, you might say.

Now governments being what they are, or were, there was more than a slight tendency in the nineteenth century to twist things just a little, to bend the figures a bit, to bump up the birth rate, or smooth out the death rate, to fudge here, to massage there, to adjust for the number you first thought of, to add a small conjecture or maybe to slip in the odd hypothetical inference.

It was all too easy to tell a few small extravagances about one's armaments capacity, or to spread the occasional minor numerical inexactitude about whatever it was rival nations wanted to know about, and people did just that. Even today, when somebody speaks of average income, if you don't smell fish, at least remember them, and ask if that's the mean, the median or the mode.

When I was young, I smoked cigarettes, but the cost and the health risks convinced me, so I stopped, back in 1971. Smokers think we reformed smokers are tiresome people who keep on at them, trying to get them to stop as well.

The non-smokers say those who still puff smoke are the tiresome people, who can't see the carcinoma for the smoke clouds, who deny any possibility of any link between smoking and anything. Like the tobacco pushers, the smokers dismiss the figures contemptuously as “only statistics”. The really tiresome smoker will even say a few unkind things about the statisticians who are behind the figures. Or about the statisticians who lie behind the figures.

By the end of the 19th century, statistics were no longer the mere playthings of statesmen, they were way to clump large groups of related facts into convenient chunks. If you can see how the statistics were arrived at, perhaps you can trust them.

At one stage in my career, I led a gang of people who gathered statistics and messed about with numbers, but we preferred to be called ‘number-crunchers’. People say a statistician is “somebody who's rather good around figures, but who lacks the personality to be an accountant”.

They speak of the statistician who drowned in a lake with an average depth of 15 cm. We are told that a statistician collects data and draws confusions, or draws mathematically precise lines from an unwarranted assumption to a foregone conclusion. They say “X uses statistics much as a drunkard uses a lamp-post: rather more for support than for illumination”.

Crusty old conservatives give us a bad name, pointing out that tests reveal that half our nation's school leavers to be below average, which is true, but it is equally true that the vast majority of Australians have more than the average number of legs. All you need is one Australian amputee!

If somebody does a Little Jack Horner with a pie that's absolutely bristling with statistical items and they produce just one statistical plum, I won't be impressed at all: the plum's rather more likely to be a lemon, anyhow. The statistics have to be plausible and significant. Later, I will show you a statistical link between podiatrists and public telephones: this is obviously nonsense, and we will ignore it. There is no logical reason for either to influence the other.

Still, unless there is a plausible reason why X might cause Y, it's all very interesting, and I'll keep a look-out, just in case a plausible reason pops up later, but I won't rush to any conclusion. Not just yet, I won't.

First, I will check on the likelihood of a chance link, something we call statistical significance. After all, if somebody claims to be able to tell butter from margarine, you wouldn't be too convinced by a single successful demonstration, would you? Well, perhaps you might be convinced: certain advertising agencies think so, anyway.

If you tossed a coin five times, you wouldn't think it meant much if you got three heads and two tails, unless you were using a double-headed coin, maybe. If somebody guessed right three, or even four, times out of five, on a fifty-fifty bet, you might still want more proof.

You should, you know, for there's a fair probability it was still just a fluke, a higher probability than most people think. There's about one chance in six of correctly guessing four out of five fifty-fifty events. Here is a table showing the probabilities of getting zero to five correct from five tosses:

zero right	one right	two right	three right	four right	five right
1/32	5/32	10/32	10/32	5/32	1/32

The clever reader may notice a resemblance to Pascal's triangle here! Now back to the butter/margarine study. Getting one right out of one is a fifty-fifty chance, while getting two right out of two is a twenty five per cent chance, still a bit too easy, maybe. So you ought to say "No, that's still not enough. I want to see you do it again!".

Statistical tests work in much the same way. They keep on asking for more proof until there's less than one chance in twenty of any result being just a chance fluctuation. The thing to remember is this: if you toss a coin often enough, sooner or later you'll get a run of five of a kind.

As a group, scientists have agreed to be impressed by anything rarer than a one in twenty chance, quite impressed by something better than one in a hundred, and generally they're over the moon about anything which gets up to the one in a thousand level. That's really strong medicine when you get something that significant.

Did you spot the wool being pulled down over your eyes, did you notice how the speed of the word deceives the eye, the ear, the brain and various other senses? Did you feel the deceptive stiletto, slipping between your ribs? We test statistics to see how "significant" they are, and now, hey presto, I'm asserting that they really are significant. A bit of semantic jiggery-pokery, in fact.

That's almost as bad as the skullduggery people get up to when they're bad-mouthing statistics. Even though something may be statistically significant, that's a long way away from the thing really being scientifically significant, or significant as a cause, or significant as anything else, for that matter.

Statistics make good servants but bad masters. We need to keep them in their places, but we oughtn't to refuse to use statistics, for they can serve us well. Now you are ready to object when I assert that all the podiatrists in New South Wales seem to be turning into public telephone boxes in South Australia, and it all began with Florence Nightingale. Most people think of her as the

founder of modern nursing, but as part of that she created ways to use statistics to pinpoint facts.

After her name was made famous, directing nursing in the Crimean war, she returned to London in 1857, and started to look at statistics, and the way they were used. She wrote a pamphlet called “Mortality in the British Army”, and the very next year, she was elected to the newly formed Statistical Society.

She looked at deaths in hospitals, and demanded that they keep their figures in the same way. The Statistical Congress of 1860 had, as its principal topic, her scheme for uniform hospital statistics. It isn’t enough to say Hospital X loses more patients than Hospital Y does, so therefore Hospital X is doing the wrong thing.

We need to look at the patients at the two hospitals, and make allowances for other possible causes. We have to study the things, the variables, which change together. Statistics, remember, are convenient ways of wrapping a large amount of information up into a small volume. A sort of short-hand condensation of an unwieldy mess of bits and pieces.

And one of the handiest of these short-hand describers is the correlation coefficient, a measure of how two variables change at the same time, the one with the other. Now here I'll have to get technical for a moment. You can calculate a correlation coefficient for any two variables, things like number of cigarettes smoked, and probability of getting cancer.

The correlation coefficient is a simple number which can suggest how closely related two sets of measurements really are. It works like this: if the variables match perfectly, rising and falling in perfect step, the correlation coefficient comes in with a value of one. But if there's a perfect mismatch, where the more you smoke, the smaller your chance of surviving, then you get a value of minus one.

With no match at all, no relationship, you get a value somewhere around zero. But consider this: if you have a whole lot of golf balls bouncing around together on a concrete floor, quite randomly, some of them will move together, just by chance.

There’s no cause, nothing in it at all, just a chance matching up. And random variables can match up in the same way, just by chance. And sometimes, that matching-up may have no meaning at all. This is why we have tests of significance. We calculate the probability of getting a given correlation by chance, and we only accept the fairly improbable values, the ones that are unlikely to be caused by mere chance.

We aren’t on safe ground yet, because all sorts of wildly improbable things do happen by chance. Winning the lottery is improbable, though the lotteries people won't like me saying that. But though it's highly improbable, it happens

every day, to somebody. With enough tries, even the most improbable things happen.

So here's why you should look around for some plausible link between the variables, some reason why one of the variables might cause the other. But even then, the lack of a link proves very little either way. There may be an independent linking variable.

Suppose smoking was a habit which most beer drinkers had, suppose most beer drinkers ate beer nuts, and just suppose that some beer nuts were infected with a fungus which produces aflatoxins that cause slow cancers which can, some years later, cause secondary lung cancers.

In this case, we'd get a correlation between smoking and lung cancer which still didn't mean smoking actually caused lung cancer. And that's the sort of grim hope which keeps those drug pushers, the tobacco czars going, anyhow. It also keeps the smokers puffing away at their cancer sticks.

It shouldn't, of course, for people have thrown huge stacks of variables into computers before this. The only answer which keeps coming out is a direct and incontrovertible link between smoking and cancer. The logic is there, when you consider the cigarette smoke, and how the amount of smoking correlates with the incidence of cancer. It's an open and shut case.

I'm convinced, and I hope you are too. Still, just to tantalise the smokers, I'd like to tell you about some of the improbable things I got out of the computer in the 1980s. These aren't really what you might call damned lies, and they are only marginally describable as statistics, but they show you what can happen if you let the computer out for a run without a tight lead.

Now anybody who's been around statistics for any time at all knows the folk-lore of the trade, the old faithful standbys, like the price of rum in Havana being highly correlated with the salaries of Presbyterian ministers in Massachusetts, and the Dutch (or sometimes it's Danish) family size which correlates very well with the number of storks' nests on the roof.

More kids in the house, more storks on the roof. Funny, isn't it? Not really. We just haven't sorted through all of the factors yet. The Presbyterian rum example is the result of correlating two variables which have increased with inflation over many years.

You could probably do the same with the cost of meat and the average salary of a vegetarian, but that wouldn't prove anything much either. In the case of the storks on the roof, large families have larger houses, and larger houses in cold climates usually have more chimneys, and chimneys are what storks nest on. So naturally enough, larger families have more storks on the roof. With this information, the observed effect is easy to explain, isn't it?

There are others, though, where the explanation is less easy. Did you know, for example, that Hungarian coal gas production correlates very highly with Albanian phosphate usage? Or that South African paperboard production matches the value of Chilean exports, almost exactly?

Or did you know the number of iron ingots shipped annually from Pennsylvania to California between 1900 and 1970 correlates almost perfectly with the number of registered prostitutes in Buenos Aires in the same period? No, I thought you mightn't.

These examples are probably just a few more cases of two items with similar natural growth, linked in some way to the world economy, or else they must be simple coincidences. There are some cases, though, where, no matter how you try to explain it, there doesn't seem to be any conceivable causal link. Not a direct one, anyhow.

There might be indirect causes linking two things, like my hypothetical beer nuts. These cases are worth exploring, if only as sources of ideas for further investigation, or as cures for insomnia. It beats the hell out of calculating the cube root of 17 to three decimal places in the wee small hours, my own favourite go-to-sleep trick.

Now let's see if I can frighten you off listening to the radio, that insomniac's stand-by. Many years ago, in a now-forgotten source, I read that there was a very high correlation between the number of wireless receiver licences in Britain, and the number of admissions to British mental institutions.

At the time, I noted this with a wan smile, and turned to the next taxing calculation exercise, for in those far-off days, all correlation coefficients had to be laboriously hand-calculated. It really was a long time ago when I read about this effect.

It struck me, just recently, that radio stations pump a lot of energy into the atmosphere. In America, the average five-year-old lives in a house which, over the child's life to the age of five, has received enough radio energy to lift the family car a kilometre into the air. That's a lot of energy.

Suppose, just suppose, that all this radiation caused some kind of brain damage in some people. Not all of them necessarily, just a susceptible few. Then, as you get more licences for wireless receivers in Britain, so the BBC builds more transmitters and more powerful transmitters, and more people will be affected. And so it is my sad duty to ask you all: are the electronic media really out to rot your brains? Will cable TV save us all?

Presented in this form, it's a contrived and, I hope, unconvincing argument. Aside from anything else, any physicist can tell you that the radiation used for radio transmission is the wrong wave-length and lacks the energy needed to

change any cells. My purpose in citing these examples is to show you how statistics can be misused to spread alarm and despondency. But why bother?

Well, just a few years ago, problems like this were rare. As I mentioned, calculating just one correlation coefficient was hard yakka in the bad old days. Calculating the several hundred correlation coefficients you would need to get one really improbable lulu was virtually impossible, so fear and alarm seldom arose.

That was before the day of the personal computer and the hand calculator. Now you can churn out the correlation coefficients faster than you can cram the figures in, with absolutely no cerebral process being involved.

As never before, we need to be warned to approach statistics with, not a grain, but a shovelful, of salt. The statistic which can be generated without cerebration is likely also to be considered without cerebration.

And that brings me, slowly but inexorably to the strange matter of the podiatrists, the public telephones, and the births.

Seated one night at the keyboard, I was weary and ill at ease. I had lost one of those essential connectors which link the parts of one's computer. Then I found the lost cord, connected up my computer, and fed it a huge dose of random data.

I found twenty ridiculously and obviously unrelated things, so there were one hundred and ninety correlation coefficients to sift through. That seemed about right for what I was trying to do.

When I was done, I switched on the printer, and sat back to wait for the computer to churn out the results of its labours. The first few lines of print-out gave me no comfort, then I got a good one, then nothing again, then a real beauty, and so it went: here are my cunningly selected results. I have simply used, for honest reasons, the methods of the crooks and con-men.

	Tasmanian birth rate	SA public phones	NSW podiatrist registrations
Tasmanian birth rate	1	+0.94	-0.96
SA public phones	+0.94	1	-0.98
NSW podiatrist registrations	-0.96	-0.98	1

Well of course the podiatrists and phones part is easy. Quite clearly, New South Wales podiatrists are moving to South Australia and metamorphosing into public phone boxes. Or maybe they're going to Tasmania to have their babies, or maybe Tasmanians can only fall pregnant in South Australian public phone booths.

Or maybe codswallop grows in computers which are treated unkindly. Figures can't lie, but liars can figure. I would trust statistics any day, so long as I can find out where they came from, and I'd even trust statisticians, so long as I knew they knew their own limitations. Most of the professional ones do know their limitations: it's the amateurs who are dangerous.

I'd even use statistics to choose the safest hospital to go to, if I had to go. But I'd still rather not go to hospital in the first place. After all, statistics show clearly that more people die in the average hospital than in the average home.

$\sqrt{-1}\ 2^3\ \Sigma\ \pi$

Notes for this chapter

For many years, I was an occasional essayist on STEM areas on ABC Radio National: try this one on statistics for size: http://members.ozemail.com.au/~macinnis/ockhams/stats.htm. Now you know where this chapter came from.

If you want more of the same, see http://members.ozemail.com.au/~macinnis/ockhams/ocklist.htm (both last accessed, October 2019).

21. Pros and versus, prose and verses

The author at work.

Back to the Contents

Who says there's no room for verse or whimsy in science?

> Miss Robinson and R. McCance
> Have made a notable advance
> On dealing with tyrosinase,
> And the queer laws which it obeys.
> Aided by Anderson and others
> Our saccharologist Carruthers
> Attacked the problem of rotation
> Of glucose during activation.
> —J.B.S. Haldane, *Report to the Secretary of the Sir William Dunn Institute for the Year 1924-25.*

> Cuspidors made out of platinum
> Would buckle and bend if you sat in 'em.
>   You can make them of rhodium
>   But never of sodium
> Because then they'd explode if you spat in 'em.
> — attributed to Sir John Cornforth, Australian-born chemistry Nobel laureate.

Wise people say you *can't* teach poetry, but most practising writers know you *can* teach verse-making. As one of Australia's better 20th century poets taught me, if you want to rhyme platitude and attitude, always use the more common word (attitude) second. Do it the other way, and the rhyme seems forced. This chapter is all about creating rhymes that appear unforced.

Science limericks on a rainy day

Under an alias, I sometimes contribute to OEDILF, the *Oxford English Dictionary in Limerick Form*, and it amused me to see that OEDILF had chosen to refer contributors (including me) to a page on the website that was the original of this book. They cited it, because too many people think five lines, with an AABBA rhyming scheme will do to make a limerick. There's more to it.

There are five lines, with lines 1, 2 and 5 rhyming, and lines 3 and 4 rhyming, but elegant limericks use different words at the line ends. To be acceptable, limericks also need the right rhythm, or metre, shown by capitals for the stressed syllables below, while on the right, you can see an old favourite: notice how we can sneak in the odd syllable, or leave one out, at the ends. Look at lines 4 and 5:

d-DAH-dah d-DAH-dah d-DAH (dah)	There WAS a young FELlow named WHEELing,
d-DAH-dah d-DAH-dah d-DAH (dah)	Who RODE on a TRAIN bound for EALing.
d-DAH-dah d-DAH	It SAID on the DOOR:
d-DAH-dah d-DAH	'Please don't SPIT on the FLOOR.'
d-DAH-dah d-DAH-dah d-DAH (dah)	So he CAREfully SPAT on the CEILing.

As a rule, the best limerick writers begin with the last line, or the last two lines. For example, I came up with this next one, after seeing the letters OLE on a

car's number-plate. I thought of the shout of the Spanish crowd at a bull fight, jumped to Café Olé, and that gave me the last line:

A Spanish soprano called Fay
Always sang in a *can belto* way
In the *Coffee Cantata*
When she was a starter,
The people cried *Café Olé!*

That all came to me during a walk of 200 metres, from when I passed the car, to when I reached the bus stop I was headed for. Then I just had to tweak it. The moral is: always keep your eyes skinned, as limericks can come from anywhere.

As a first exercise, I invite you to write some limericks, given a few lines to work with. In five lines, you will introduce somebody, explain where they are or what they are doing (second line), explain what happened to the person or thing in line three, what the reaction was in line four, and finish the whole thing off in line five.

Now you are ready to begin, with this hint: when you are writing short pieces (essays, stories, speeches, limericks or jokes), it is always easiest to start knowing the ending. Once you know where you plan to land, all you have to do is set things up so that you get there. The best place to start is with a zinger of a line 5.

Fifth lines:

And made cider inside her inside (that's an old one);

The President slithered away;

A Norse of a different colour;

The people cried "Cafe au lait" (Olé) (used above but can you do better?);

(There aren't many fifth lines, because when I get a good one, I generally use it).

Third and fourth lines

It is usually better to have a good word play in mind for the fifth line, or a good idea about your third and fourth lines. Here are some couplets:

Though she feared they had germs,
She ate all the worms

His large flock of wrens
That he passed off as hens

They found the canary
Was rather too hairy

As the camels walked in,
They started to grin,

If the horse had a chance
It would normally dance

She said "Thanks very much,
But I cannot speak Dutch,

$$\sqrt{-1}\; 2^3\; \Sigma\; \pi$$

Third lines

As the rainforests fell;

For the rest of his life;

The Impressionist school;

As her feet turned to lead;

As the keyboard went green.

First lines (with some rhyme ideas):

There was a young man from Palm Beach (reach, beseech, teach, leech, leach, peach, preach);

A kangaroo hunter named Fred;

There was a young girl from Dee Why;

There was a young lady called Smith (myth, pith, kith, with (?)).

Other ideas for limericks:

Dig into a textbook, and look through the index for some interesting words. Visit your library, and see if you can find a *rhyming dictionary*—it lists words by their rhymes.

Clerihews

Clerihews are a simple verse form invented by Edmund Bentley (whose middle name was Clerihew). These are amusing "potted biographies" of people. They do not need to have a rhythm (a metre, if you are pedantic), but they must have a rhyme, and they must say something about the person involved who has to be historical. Here is an example:

George the Third
Ought never to have occurred.
One can only wonder
At so grotesque a blunder.

Limericks must have a perfect metre and astounding rhymes, but clerihews don't have to scan. The aim is to be historically correct in an odd sort of way, and to get a dreadful, weird rhyme. Here are two more examples:

Sir Christopher Wren
Said: "I am going to dine with some men.
If anybody calls,
Say I'm designing St Paul's."

Sir Humphry Davy
Abominated gravy.
He lived in the odium
Of having discovered sodium

Now it is time for you to try your hand. Here are some names to get started on. Most should be accessible to most people, and some are drawn from areas other than science, so feel free to pick and choose. These people will all be found, somewhere on the internet.

Julius Caesar	Mary Anning	Louis Pasteur	Stephen Hawking
Dame Nellie Melba	Sir Isaac Newton	Marie Curie	Enrico Fermi
Catherine the Great	Pablo Picasso	Nebuchadnezzar	Agatha Christie
Annie Jump Cannon	Burke and Wills	Kiri Te Kanawa	Jakob Bernoulli

Here's just one of my attempts:

Burke and Wills
Were paying their bills,
When somebody said
Why bother? You're dead!

Remember that you will need to investigate each of these people before you write your clerihew, and find out what they did, or do.

Just look at the examples, then do some researching before you start scribbling. Historical accuracy is never important, but historical relevance always matters. Try these starters:

Louis Pasteur
Was a him, not a her,

Marie Curie
Got into a fury

Jakob Bernoulli
Was often unruly

Pablo Picasso
Sang a rumbling basso

Florence Nightingale
Always read her nightly mail

Ernest Hemingway
Went out the lemming way

Charles Babbage
Hated cabbage

Alexander Graham Bell,
Completely lost his sense of smell

Mary Anning
Took up gold panning

Agatha Christie
Had eyes that went misty

Samuel Morse
Was a vegan of course

Edward John Eyre
Started losing his hair

Verse using sayings

I like constructing versicles that have a well-known line sneaking in at the end. The trick is to begin with the final line.

The Dark Knight
The knight rode up, in squeaking armour,
Fury writ upon his brow
And strange to say, he rode a lama—
A thief had nicked his favourite cow.

A knight whose thing was riding cattle?
I hear you ask, in rising fear.
Why yes, he did, even in battle—
His horse he'd sold to pay for beer.

His helm was sable, like his rage
And black was all the gear he wore
Save on his arm an off-white gage
But black was the stubble on his jaw.

He slapped his shield upon the bar,
His shield with the motto "*Ebon semper*"
He made it clear, both near and far
He had a really nasty temper.

He kicked the spittoon over twice
And gave the crowd a dreadful fright
And then they saw, as in a trice:
It was a dark and stormy knight.

Kids and lambs
I recall, one winter's day,
Our mothers led us out to play
And we took off our hats and coats
And romped among the sheep and goats.

Our mothers had gone out to paint
The scene, but one fell in a faint.
The other mothers brought her round,
And that was when we children found

She thought it made us all look cheap
To frolic with the goats and sheep.
She wanted us, midst rocks and greenery
To form part of the painters' scenery.

When faced with such artistic needs,
Obedient youngsters mould their deeds.
We children gave our solemn word
That we'd be scene but never herd.

The next comes from a question I was asked once in Luang Prabang in Laos.

My frypan is a handy size
For cooking food and swatting flies
So if you want things cooked in fat
I'll say "Would you like flies with that?

To write amusing verse, you have to be an opportunist! Then again, a lot of science began with somebody seeing something odd, and grabbing the opportunity.

Verse about the seasons

There are very few simple verses about the seasons as we encounter them in Australia. I am working on a set myself, at the moment, so I know it can be done. I am not about to reveal those here, but I am prepared to challenge you to do better, without seeing what I have done.

Work on a plan of 4 to 12 lines in verses of 4 or 6 lines, using rhyming schemes like abab, cdcd etc., or maybe aabccb etc. Pay VERY careful attention to where the stresses come, and see how much scientific background and Australian natural history you can slip in.

The main thing to recall is that finding rhymes for the seasons can be extremely hard, so work on finding other words that are easier to rhyme, something like:

> The trouble with summer: it's hot;
> The trouble with winter: it's not.

OK, not one of my best, but you get the idea. Pay some attention to the punctuation—you would be amazed how much information you can give to the reader with the right punctuation marks.

$\sqrt{-1}\ 2^3\ \Sigma\ \pi$

Master Class: Piet Hein's grooks

Elsewhere, you have met the soma cube and a superellipse that were invented by Piet Hein (1905 – 1996), a Danish inventor, scientist, mathematician, philosopher, designer, author, and poet.

He specialised in short verses that made people think, like these:

> **ATOMYRIADES**
> Nature, it seems, is the popular name
> for milliards and milliards and milliards
> of particles playing their infinite game
> of billiards and billiards and billiards.

> **OMNISCIENCE**
> Knowing what
> thou knowest not
> is in a sense
> omniscience.

Look him up, and then try your hand at a few grooks of your own.

$\sqrt{-1}\ 2^3\ \Sigma\ \pi$

STEAM verses

Science

There was a young lady named Bright,
Who travelled much faster than light.
  She started one day
  In a relative way,
And returned on the previous night.
— Anon. and trad.

I think that I shall never see
A poem lovely as a tree
— Joyce Kilmer (1886-1918) *Trees*

Great fleas have little fleas upon their backs to bite 'em,
And little fleas have lesser fleas and so ad infinitum.
And the great fleas themselves, in turn, have greater fleas to go on;
While those again have greater still, and greater still, and so on.
— Augustus de Morgan (1806 - 1871)

Water is H_2O, hydrogen two parts, oxygen one,
but there is also a third thing, that makes it water
and nobody knows what that is.
— D. H. Lawrence (1885 - 1930), *Pansies*, 'The Third Thing'.

Twinkle, twinkle little star,
I don't wonder what you are,
For by spectroscopic ken
I know that you are hydrogen.
— Anon

Technology

We tell these tales, which are strictly true,
Just by way of convincing you
How very little, since things was made,
Anything alters in anyone's trade.
— Rudyard Kipling (1865 - 1936), *A Truthful Song*.

I heard him then, for I had just
  Completed my design
To keep the Menai bridge from rust
  By boiling it in wine.
— Lewis Carroll (Charles Lutwidge Dodgson) (1932 - 1898), *Through the Looking-Glass*, chapter VIII.

Gold is for the mistress — silver for the maid —
Copper for the craftsman cunning at his trade.
'Good!' said the Baron, sitting in his hall,
'But Iron — Cold Iron — is master of them all.'
— Rudyard Kipling (1865 - 1936) *Cold Iron*.

$\sqrt{-1}\ 2^3\ \Sigma\ \pi$

Engineering

They shut the path through the woods
Seventy years ago.
Weather and rain have undone it again,
And now you would never know
There was once a path through the woods.
— Rudyard Kipling (1865 - 1936), *The Way through the Woods*.

Arts

There once was a brainy baboon,
Who always breathed down a bassoon,
        For he said, 'It appears
        That in billions of years
I shall certainly hit on a tune'.
— Sir Arthur Eddington (1882 - 1944), *New Pathways in Science*.

Mathematics

There was a young man from Trinity
Who solved the square root of infinity.
  While counting the digits,
  He was seized by the fidgets,
Dropped science, and took up divinity.
— Anon.

The platypus egg
Has a single leg
On which it stands
To save its hands
— Duncan Bain (1944 -), 'The platypus egg' in *Self-reverenced Sentiences* (n.p.). (used by permission)

Medicine

He prayeth best who loveth best
All things great and small.
The *Streptococcus* is the test
I love him least of all.
—Hilaire Belloc (see the notes regarding the author)

$\sqrt{-1}\ 2^3\ \Sigma\ \pi$

Clear communication in science

How unclear can you get? I once wrote this as a deliberate example of bad communications: “Is it not untrue that Ebenezer did not write a book on knot-tying?”

Then there’s the one I wrote as a test piece for speech-recognition software: “I threw a stare at a bear hair”, or was it “eye through a stair at a bare hare”? It was something like that, anyhow.

One way to cause confusion is to build up an expectation in the listener, like this: psychologists call it **response set**.

Speaker: *Today, we’re looking at related words:*

- *What comes out of a chimney? <wait for the answer,* ***smoke****>;*
- *What’s another name for Coca-Cola? <wait for the answer,* ***Coke****>;*
- *What’s another name for a funny story? <wait for the answer,* ***joke****>;*
- *What’s another name for a prod with a finger? <wait for the answer,* ***poke****>;*
- *What’s another name for the white of an egg?*

You probably got caught: what’s the white of an egg called? Are you sure?

It can happen with numbers as well:

- By how much is 40 greater than 32?
- By how much is 32 less than 40?
- By what percentage is 40 greater than 32?
- By what percentage is 32 less than 40?

The answers should be 8, 8, 25%, 20%, but a lot of people will answer the fourth question with “25%”. A good communicator doesn’t fall for that trap, and a good communicator doesn’t deliberately set out to trap readers or listeners. But to make yourself more aware of the effect, can you create any confusing questions or statements of your own?

Humour

- A pun is a play on words. Why do most people groan when they hear a pun, even a brilliant pun? (I don’t know: I’m contrapuntal!)
- Who makes up the new jokes? Why?
- Think of three very funny jokes. What do they have in common? Can you use this knowledge to make up new jokes?
- Who makes up urban myths? Why? Can you make up a convincing urban myth? Analyse a number of them to see what makes them tick.
- Tall tales are very much a pioneer and/or rural tradition. Most of them started in the oral tradition. Why?
- Why is it funny when a slapstick comedian falls over and gets hurt?

- Why are some terrible things funny? Why do we laugh at cartoon violence, when a character is squashed flat, then blown up by a bomb?
- Why do we laugh when we are tickled?

Symbols

- How many symbol systems do humans have? How come? So what?
- Where do symbols come from?
- Why do symbols change?
- What are some good symbols? What are some bad symbols? What makes them good or bad?
- What bad symbols do we have that we'd be better off without?
- What good symbols could we use that we do not have?

Concerning symbols, flags are symbols, so are national anthems, logos, uniforms, old school ties, words, designer clothes, hairstyles and other fashions. Language is a potent symbol if you live in a place like Quebec or Wales.

Language

- Where do words come from?
- How would you explain "red" to somebody who is blind?
- What makes a language a language? Vervet monkeys have a vocabulary of about fifteen words (see Jared Diamond, "*Rise of the Third Ape*" for more)—is that a language or a symbol system?
- What other "languages" do humans have, besides those consisting of words?
- How might human survival activities be different from what they are if we did not have language?
- If you were making up a new universal world human language (like Esperanto), what grammar rules would the language follow? Where would the words come from?
- What does human language permit us to develop (as survival strategies) that animals cannot develop?
- We know what people mean by "bad language", but what language is really bad? How can "good" be distinguished from "evil"?
- Some languages (including English) have two forms for nouns: singular (just one person or thing) and plural (more than one). In some languages, there are three forms: one, two and many. This is commonly misinterpreted as meaning that these people count "1-2-many" which is wrong, but back to the point: how would this sort of structure develop? What would be its advantages?

Suppose I (as a vervet) said the vervet version of "leopard water". How could you (as another vervet) tell if that meant I was saying:

- there's a leopard over there by the water;
- the leopards come when it rains;
- it's raining leopards at the moment; or
- let's go over and pee on that leopard?

The second vervet would have no idea which meaning was correct. Language usually relies on something more than words to get a message over: part of the answer is "context", and the other part is something ending in the letter x (the word is mentioned, four paragraphs down. On counting systems, this sort of structure goes all through the languages of Micronesia, so there are three ways of saying good morning when you enter a room, depending on how many people you find there.

Another interesting structure is having two forms of 'we', which can be found in the Austronesian languages of Indonesia and Papua New Guinea. One form is "inclusive"—it includes the person addressed, and the second is exclusive: the person addressed is not part of the 'we'. Consider this: "Brianna, ***we*** have no food: let's ask Alastair for some. Hey, Alastair, ***we*** have no food, will you give *us* some?"

This structure was so strongly embedded that when the people of New Guinea developed Pidgin English, using words from English, German, and even Chinese, they kept two forms of 'we': *yumi* and *mipela*. I leave it to you to guess which is which :-) Just a note: never make the mistake some people fall into: Pidgin is *not* "broken English". It is a full language with rules of grammar and syntax, and when English words are used, they often have a different meaning that confuses beginners.

Good, bad and meaning

- How can you tell "good guys" from "bad guys"?
- What does "meaning" mean?
- When you hear, read or observe something, how do you know what it means?
- Where does meaning "come from"?
- What would happen, what difference would it make, what would humans not be able to do, if they had no number (mathematical) languages?
- Mathematicians, scientists, statisticians and juries all have different ideas about what is "proof" of something. Which form of "proof" is the most useful? Why?

What are some ways to go about getting to know what is worth knowing? Which of those ways are the most useful? Why?

Sentences and their rules

They say never begin a sentence with a conjunction (and & but), and we are told never to end a sentence with a preposition. And yet there are 12860 sentences in the King James version of the Bible which my word processor reports as beginning with the word 'and'. There are also 1560 sentences that start with 'but', which rather makes a hole in the 'rule' about never starting a sentence with a conjunction!

The other "rule" that gets up my nose is the squawk that amateurs emit when they see a sentence ending in a preposition. The translators of the King James Bible, generally considered the finest writers of clear English, notched up the following scores: 9 overs, 1 under, 68 ups, 39 downs, while 'to' ends four sentences, and 'for' ends two sentences. There are 9 sentences ending in 'by', 2 ending in 'with' and 2 ending in 'from', even though it is something we should not put up with!

Shakespeare, that other favourite of the pedants, had quite a few sentences ending in prepositions. The endings are 'over' (6), 'under' (2), 'up' (79), 'down' (77), 'to' (45), 'for' (45), 'by' (38), 'with' (21) and 'from' (2). Well, so much for pedantry.

What a pity I haven't yet worked out a quick way to search large slabs of text for split infinitives!

$\sqrt{-1}\ 2^3\ \Sigma\ \pi$

Notes for this chapter

More limerick ideas

Keep in mind that the sorts of skill used in planning a limerick are very like those you use in some games.

Try thinking of a word that is hard to rhyme, and make it a challenge. Many years ago Chester (Phillip Graham), wrote something very like this:

> There was a young fellow from Babylon,
> Invented a board to play Scrabble on.
> They were wonderful boards,
> Applauded at Lord's,
> And now they have caught with the rabble on.

And this is a limerick, if you say it the right way:

$$\frac{(12 + 144 + 20) + (3 \,.\, \sqrt{4})}{7} + 5 \,.\, 11 = 9^2 + 0$$

Verse about STEAM

For background on who really wrote the medical verse at the end, see https://oldblockwriter.blogspot.com/2012/03/mr-belloc-has-been-done-disservice.html)

$$\sqrt{-1}\ 2^3\ \Sigma\ \pi$$

22. Language and understanding

This is an indoor chapter for stick-in-the-muds who don't want to get stuck in the real mud, some wet weekend. In this piece, names and technical words are there so you can search for more information.

Warning: this is the last chapter, because it isn't easy, but the good news: there's no examination! There's also nothing to make here, nothing to watch, nothing to find, just stuff to ponder on—unless you decide to make your own discoveries, which is what I hope for. Let's begin by thinking about us, the humans.

There are many ways to define human beings. One that I learned as a boy came, I think, from Samuel Johnson, and it went like this: "Man is the only animal that cooks his own food". These days, we might dress that up in slightly less gender-specific language, but the meaning is clear.

Sadly, "cooks own food" won't work any more, because earlier this century, a bonobo chimpanzee called Kanzi learned how to light a fire and cook food over it, after seeing humans doing so. Search the internet on Kanzi and fire, and you will even see this clever ape lighting a fire and toasting marshmallows!

But how did we humans learn the cooking trick? Charles Lamb offered us a nice little fable in his *A Dissertation Upon Roast Pig*. He told how a Chinese boy accidentally burned the family hut down, raked out a charred pig, and having burnt his hands and sucked them, discovered the marvellous taste of roast pig.

Remember, this is a fable, and there is no reflection on Chinese people. I imagine Lamb chose China because it was far away and little known. Though we have a huge list of major inventions that have come our way from China, this was a *Just So* story.

Slowly, Lamb said, the practice spread, and people cooked the only way they knew, which was to put pigs in a building and incinerate them. Only later, did they invent the spit and other modes of cooking, he said. Cooking *might* have been started like that, but the odds are against it. When we are dealing with old history, we know that something of that sort must once have happened, but most probably it came in the aftermath of a wildfire of some sort.

We can but speculate—and we must be cautious not to embrace such legends with too much enthusiasm, because even 65,000 years ago, possibly 300,000 years ago, our ancestors had brains just like ours, and would have seen that there was no need to burn a whole house down. That aside, the Chinese had a complex culture at a time when Charles Lamb's ancestors still painted their bottoms blue with woad!

Still, Kanzi only learned to cook after seeing humans doing so, which leaves us a possible definition: that we are the only animals to independently invent cooking. It is, to be honest, a flimsy, thin and threadbare sort of definition.

Taking another tack, humans seem to be the only animals capable of assessing definitions. Will that do?

I actually prefer the idea we are the only animals to communicate, but that's a definition, and we need to assess it carefully. Humans certainly communicate, but each morning, I hear noisy miners calling. These are small birds, but among the largest of the honey-eater tribe and they sit in trees outside my house, calling a warning to each other when a larger predator bird appears, cruising and looking for a juicy fledgling for breakfast. They also squabble over food.

Noisy miners are tough little beasts, and quick to mob any raptor or corvid, any predatory bird that cruises by, a little too close to their nest, looking longingly at the miners' chicks. What I hear before dawn isn't language, but a fairly uniform call, with a single meaning.


Noisy miner (left) and magpie facing off over food scraps.

Perhaps we should say only humans have a large vocabulary, but at last report Kanzi the bonobo had a vocabulary of about 250 words, and can link these to symbols called lexigrams. Kanzi also makes and uses stone tools

So perhaps it's better to assert that humans are the only animals with syntax, rules for putting words together to convey a meaning. In *The Rise of the Third Ape*, Jared Diamond says that vervet monkeys have a vocabulary of about fifteen words, but is that collection a language or a symbol system? Suppose I (as a vervet) said the vervet version of "leopard … water". How could you (as another vervet) tell if I meant:

* there's a leopard over there by the water;

* the leopards come when it rains;

* it's raining leopards at the moment; or

* let's all go over and pee on that leopard?

If you were another vervet, you would have little idea which meaning was correct, at least until you looked around. Language usually relies on something more than words to get a message over: part of the answer is "context", and the other part is syntax. Recent research (Esther Clarke in 2015) identified some structure in gibbon 'hoo' calls: the call that warns of raptors in the area is

shorter and lower in frequency. This has to be deliberate, she says, because raptors have poor low-frequency hearing.

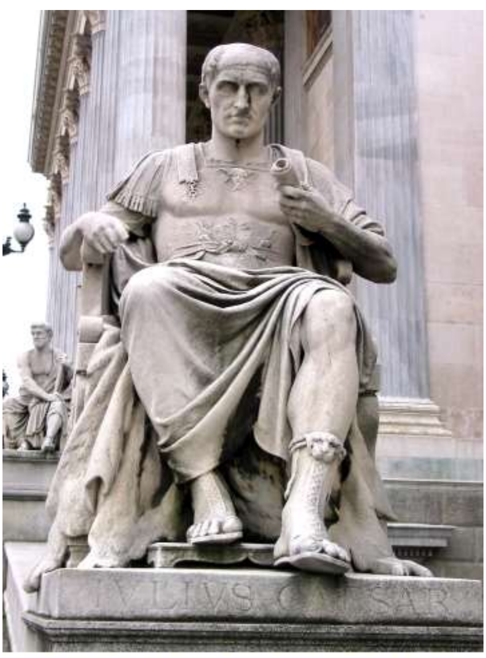
Other workers have been interpreting chimpanzee gestures (Catherine Hobaiter, 2014); and Lucy King found a possible elephant word for "human". These are words, though, and that is far from being a language. Every human language has syntax, a grammar system, meaning a reasonably firm set of rules that make it possible for the listener to understand the speaker.

In English, we mainly look at word order to catch the speaker's drift, though in poetic language, we may have to think for a bit, but we can still manage it. Order lets us recognise the meaning in "I see you", but most of us would take "you see I" to be an inverted form of "I see you", with the same meaning. Most of us have encountered inverted English in the *Star Wars* movies when we listen to Yoda, and we can even understand Yoda.

If I were to say "your mother wears army boots", that is clear enough and rude enough. Even the Yoda-ish "army boots your mother wears" makes sense—after a bit of thought. If I said "army boots wears your mother", that order is a more confusing, but we find some help, thanks to our habit of inflecting verbs, but now I need to explain ***inflection***.

In the case of *to wear*, for example, we change the endings to make a meaning clearer. The form *wears* tells us the subject, the thing or person doing the wearing, is singular. Compare "army boot wears your mother" and "army boots wear your mother", and you will see the information we can extract from a bit of simple inflection.

The rules of grammar that a tribe or a nation uses were never invented by a clever thinker. The rules grew and evolved, and it is probable that the *wear/wears* distinction has been preserved by the convenience of knowing if there is one subject or more than one involved in the action.



Statue of Julius Caesar wearing caligae, Vienna.

In Latin, the rules for word order are much less rigid. The Latin equivalent of "your mother wears army boots" is *mater tua caligas gerit*, which translates literally as "mother, your, army boots, wears". In Latin, an army boot is a *caliga*, and two of them are *caligae*.

But why *caligas*? Anybody who has learned Latin at some stage

knows that the language is madly inflected, and that every Latin noun, each Latin adjective and all Latin verbs have many different endings—and every ending brings its own special shade to the meaning.

A taste of Latin

When we learn Latin, we study it as a dead language, and that means we have to learn the forms off by heart, reciting them in sleepy classrooms, but the Romans never had to do that: they just picked them up. As part of the boring dusty background, the nouns aren't inflected, they are *declined*, and each of the lists is called a *declension*. Live with it, and be glad that I didn't explain that Latin verbs are *conjugated*, and the *amo*, *amas*, *amat* bit which is all most people know, is part of the *first conjugation*.

The first declension of nouns, taking *mensa* (table) as the example, runs like this: *mensa, mensa, mensam, mensae, mensae, mensa*. Those are the six singular forms, and there are also six plural forms: *mensae, mensae, mensas, mensarum, mensis, mensis*. The rule applies to other similar words like femina (woman): *femina, femina, feminam, feminae, feminae, femina*; and *feminae, feminae, feminas, feminarum, feminis, feminis*. Or *causa* (cause), which runs *causa, causa, causam, causae, causae, causa*; *causae, causae, causas, causarum, causis, causis*. Look at the table about a table (or tables) on the right.

Case	singular and plural Latin	singular and plural English
nominative	mensa, mensae	the table(s) (subject)
vocative	mensa, mensae	O, table(s)!
accusative	mensam, mensas	the table(s) (object)
genitive	mensae, mensarum	of the table(s)
dative	mensae, mensis	to or for the table(s)
ablative	mensa, mensis	by, with or from the table(s)

A table of the Latin forms of table.

The six cases (forms of nouns) are nominative (the actor or doer, the subject of the verb), vocative (something addressed—rare), accusative (object of the verb, thing acted on), genitive (possessive), dative (to, or for) and ablative (by, with, or from).

(Just for the record, countless generations of Latin students have sniggered, because *causas* is pronounced "cow's arse". Luckily, I am too polite to have ever noticed this.

There's actually a bit more to Latin grammar, but that's complicated enough. And talking of complication, notice how some endings recur. This is one of the reasons why Latin has always been so hard to puzzle out for foreign beginners. It didn't matter to the Romans, because they grew up with it, and what they heard all made sense, in context, in their prepared minds.

Back to your mother and army boots for a moment, the word order in Latin matters less because there are clues to the meanings, buried in the endings of

each of the four words. That said, it is good form in Latin to put the verb at the end, and it is normal to put any adjective or possessive pronoun after the noun.

Mater is declined according to a different but equally fixed set of rules. Still, to any Latin user, it is clear that the mother (in the nominative case), is the person doing what the verb will later describe. The word *tua* means your, and it is singular and feminine: even possessive pronouns and adjectives get changed to match the nouns they go with. So we know that the "your" refers to the mother. The word *caligas* means army boots (plural), in the accusative or object form: they are being worn.

Finally, we come to the verb: up to this point in the sentence, we know your mother does something to the army boots, but is she eating them, painting them, making them, washing them or cooking them? The verb *gerit* is third person singular, in the present tense, making it clearer that it is a single person who is wearing the boots and that it is happening right now.

So now you know how to insult any ancient Roman you happen to run into. You also have the first step of my personal program to confuse phone pests like telemarketers and scammers with random Latin phrases. Trust me, it works like a dream. It also works against street sellers in foreign countries who assail you with offers of their wares or services. Just remember to smile nicely, and by the third phrase, they are backing away. *It's a language Jim, but not as we know it…*

Clearly, nobody could have invented a language system like that: it just grew over time, and one of the things that make us human is the way very small humans can acquire these complex rules and use them to make their wants known at a very early age.

Language was invented once, or maybe more than once, and each language has been being reinvented, over and over again, ever since. Language changes, it always has, and always will, and older people will always be outraged at the new ways of talking. Here is William Caxton's Preface to *Eneydos*, a book that was published in 1490. This is Middle English, but it is deliberately not translated, so see what you make of it, and remember that science is like that, sometimes!

> And certaynly our langage now used varyeth ferre from that whiche was used and spoken whan I was borne. In so moche that in my dayes happened that certayn marchauntes were in a shippe in tamyes, for to have sayled over the sea into zelande. And for lacke of wynde, thei taryed atte forlond, and wente to lande for to refreshe them. And one of theym named sheffelde, a mercer, cam into a hows and axed for mete and specyally he axyd after eggys. And the goode wyf answerde, that she coude speke no frenshe. And the marchaunt was angry, for he also coulde speke no frenshe, but wolde have hadde egges, and she understode hym not. And thenne at laste a nother sayd that he wolde have eyren. Then the good wyf sayd that she understod hym wel. Loo, what shode a man in thyse dayes now wryte, egges or eyren. Certaynly, it is harde to playse every man, by cause of dyversite and chaunge of language.

OK, that was mean, so here's a quick summary: merchants were in a ship in the Thames, planning to sail to Zealand in the Netherlands. There was no wind, and they were becalmed at Foreland. A mercer named Sheffield went to a

house to ask for meat and eggs. The woman he asked thought he was speaking French, and didn't know what "eggs" were. Another man asked for *eyren*, and she produced some eggs.

That brings us to the matter of *loan words*, terms that have come to us from another language. If I sit on the *veranda* of a *restaurant*, drinking a *capuccino*, that involves a Hindi varaṇḍā, a French restaurant and an Italian name for a kind of coffee. Sit down at breakfast and have a *pow-wow* over the *muesli* and as you sip on your *orange* juice, does anybody still speak *dinkum* English? As a Canadian writer, James Nicoll put it:

> We don't just borrow words; on occasion, English has pursued other languages down alleyways to beat them unconscious and rifle their pockets for new vocabulary.

No bonobo comes close to matching our level of linguistic invention and theft, but there are probably other definitions of humanity. Mr Tchaikovsky gave us the *Waltz of the Flowers*, and Mr Disney took Tchaikovsky's *Dance of the Reed Flutes* and set hippos dancing to it in *Fantasia*, but in real life, only humans move in time to the music. We tap our feet, we sway our bodies, we respond as no other animal does. At least, that is the case right now: the thing about science is that our cherished beliefs often go west.

> …the great tragedy of science—the slaying of a beautiful hypothesis by an ugly fact…
> —T. H. Huxley, *Presidential address to the British Association* in September, 1870.

The best definition for People Like Us, *modern humans*, seems to be that they are creatures given to innovation, experimentation, and fashion. People studying Cro-Magnon sites in Europe can look at the artefacts found there and determine a date for a site quite reliably, just by looking at the styles that are left behind. Some of these finds were small musical instruments, so the musical side of humanity has been around for quite a while.

The jury is still out on the question of dance, though I suspect that dance may be even older. Clearly, Europe's modern humans, some 35,000 years ago, the ones who replaced the Neandertalers, were able to talk and share ideas, they were able and willing to trade and share, so once a new fashion emerged, it spread rapidly over long distances.

It's a curious sort of fashion-consciousness that we see in modern humans, coupled with conservatism among the older members of the tribe, community or nation. I imagine our ancestors sitting around the fire at night, arguing, story-telling, instructing and enjoying the warmth. The evidence is that humans were using fire before they made the jump to being modern.

Fire, tools and becoming human

Even if Kanzi the bonobo can make a fire, he has to be given matches (or a lighter). Only humans can make a fire with nothing more than what they find around them, and they learned how to do this, possibly 1.5 million years ago,

and or maybe only half a million years ago, but at some stage, they learned to make fire when they needed to, and they probably started keeping fires going, not long after that.

Pre-industrial humans usually maintained their fire by using a few surviving burning coals or embers to restart a fire in the morning. Without embers, and before matches, fires were started by friction, using a bow and drill system (or the hands) to spin a hard wooden shaft in soft dry wood and make it hot enough to burn. In parts of Southeast Asia (Indochina, Burma, Malaysia, Indonesia), a fire piston is sometimes used. This is a cylinder made from bamboo, hardwood or horn, with dry tinder in the bottom, and it is greased with fat.

The Diesel engine works on the principle that when a cylinder is compressed, it gets hot enough to make any fuel in the cylinder ignite. The user of the fire piston drives the piston into the cylinder, which compresses the air inside, again making it hot. This produces enough heat to set the tinder alight. In other parts of the world, a flint and steel can be used to make a spark that will light tinder, just as electric sparks can light a gas jet.

Fire cooked food, and that provided better nutrition, as well as killing parasites in the meat and destroying the harmful toxins in some plant foods. Fire also drove the change to a society where the elderly and/or women with small children stayed near the hearth to maintain the fire. That meant human groups might settle in one place for longer periods of time.

So what group of humans first tamed fire? Most students of pre-human history, the people who study our ancestors, can be divided into lumpers, who try to assign new finds to existing species, even if they look rather different. Others are splitters, who claim every new find as a new species, even when they are very like an existing species. The truth probably lies in the middle, and if I choose now to leave out *Homo rudolfensis*, *H. heidelbergensis*, *H. ergaster* and quite a few others in my story, that is only because I am keeping a complex story simple.

I am neither a lumper nor a splitter, though I have worked with both kinds. There is no clear right or wrong shared by the lumpers and the splitters, no common ground. The evidence they gather is hard to collect, but once it is in, it has to be interpreted, and most people see what they expect or want to see. What follows leans to the lumper direction, but only to make a clearer story.

For simplicity, I will consider early humans to be *Homo habilis* (probably 2.4 – 1.6 mya or million years ago), *Homo erectus* (probably 1.2 – 0.5 mya, maybe 1.8 mya to 25,000 years ago) and *Homo sapiens* (modern humans, people who could think and talk as we do). This last group may have been here for 300,000 years, but they have certainly been around for at least 60,000 years. The fine points are open to question, but the pattern is clear.

All dates are open to challenge and revision as new material is found, or as existing material is tested in new ways. On my simple view, the first human-like beings were, so far as we know, *H. habilis*. They had small brains and ape-like bodies, but they walked upright, somewhere near the Olduvai Gorge, and their remains are associated with tools made in a style called Oldowan, after the gorge.

In chapter 8, you can see a picture of my right hand holding a basalt chopper that I made. In early 1993, I handed a good plastic cast, a copy, of an ancient Oldowan stone chopper, to a visitor to my workplace, commenting about how well it fitted the hand, just like my chopper. My visitor was left-handed, and she said both objects felt wrong to her. Over the next week, a survey of left-handers and right-handers convinced me that the Oldowan tool and my chopper were in fact better for right-handers.

Now this is where interpretation comes in. We *might* have said, "Aha! *H. habilis* was right-handed, and made tools to fit", but we did not. Sometimes, interesting patterns happen by chance, and whole theories have been based on flimsier evidence than that, but you can't really call such claims science!

Still, I would stake a fair amount of money on the view that some 2 million years ago, a right-handed almost-human, quite possibly *H. habilis*, used that particular tool, in the Olduvai Gorge. I know that I have kept my own chopper for more than thirty years, because I am right-handed and it fits my right hand.

Homo erectus made fancier tools in a style we call Acheulean, and sometimes their remains and tools seem to be associated with ashes, charcoal, or other signs of fire. Just as the apparently right-handed tools might have been a chance thing, so might the traces of fire. Maybe dry leaves collected in a cave, and a wildfire set them alight, perhaps a burned bone came from an animal that was trapped in a fire.

There is better evidence when you go looking for it. Two dig sites at Koobi Fora in Africa have reddened sediments. This is a colour change that happens between 200°C and 400°C, and the sites are 1.5 million years old. The Cave of Hearths in South Africa has burned deposits that are 200,000 to 700,000 years old, while a site at Gesher Benot Ya'aqov in Israel seems to have been the home of fire-using humans, 690,000 to 790,000 years ago.

In Australia, where the plants and animals were unsuitable for agriculture, the Aboriginal people used *firestick farming*. Ecosystems were maintained by small and regular fires, which renewed the vegetation, and ensured that standing fuel did not build up to levels that would sustain wildfires. In parts of the western United States, the Native Americans also used fire as a management tool.

Fire helped us dry foods to store them, to cook foods that would otherwise be inedible, and we used fire to make pottery, metals and glass. Fire provided

light at night, so that people could sit around and tell stories. Fire also provided some protection against wild animals.

Without fire, we would not be human, so the human story must reach back, at least to the time when we learned to use fire. Forget the cooking aspect: I would count “fire-using” as a passable working definition of ‘human’.

Inventing writing

There were a few conditions that would need to be met before writing caught on. As a rule, nomads would not wish to make or carry around records, especially when they were written on heavy clay tablets. So people probably needed something to write on, something to write with, and a useful place where the written records could be kept. Inscribed stones might appear, but unless there were other uses, the whole writing thing might be a bit of a non-event.

The Sumerians explained the invention of writing with a sort of fairy tale about a messenger who was so tired when he reached the court of a distant ruler that he could not deliver his message from the king of Uruk. Hearing this, the Sumerian king took a piece of clay, flattened it, and wrote a message on it. That story has a few sizable holes in it. How would the person receiving the message know what the symbols meant? Then again, what can we expect in a tale about events that happened so long ago, especially when it was probably not written down when it happened?

Hieroglyphs look like this.

The Egyptians said the god Thoth (the scribe and historian of the gods) invented hieroglyphs; the Sumerians either credited the unnamed king who wrote to the king of Uruk—or the god Enlil. The Assyrians and Babylonians said the god Nabu was the inventor, while the Mayans said they owed their writing system to the supreme deity Itzamna who was a shaman, a sorcerer, and creator of the world.

More plausibly, Chinese tradition says writing was invented by a sage called Ts’ang Chieh, a minister to the legendary Huang Ti (the Yellow Emperor).

Some writing used characters to represent syllables, other writing systems used a symbol just to mean a letter-sound (as we do in English), while still others used a symbol to mean a word or idea, as happens in Chinese.

These word/idea symbols are called ideograms or logograms (meaning each symbol is an idea), and they can mean the same thing in different languages, rather

A quick puzzle: can you "read" these signs?

like numbers, or the signs in airports or the numeral 5. Just to confuse things, some of those airport signs are also called pictograms, because they are pictures of what they represent.

Then again, Egyptian hieroglyphs are a mixture of alphabetic characters and ideograms, with a few extra symbols to clarify the meaning. Few writing systems were designed from scratch: they just grew, a bit like English spelling!

The Sumerians lived in what is now southern Iraq. Ignoring the myth quoted above, their writing probably started with marks on clay that Sumerian accountants used around 3300 or 3200 BCE to record numbers of livestock and stores of grain, the sorts of records societies need, once they start farming. Over about 500 years, the symbols became more abstract, allowing ideas to be written down as well.

Egyptian hieroglyphs (literally, the word means 'priestly writing') are unlike Sumerian cuneiform. They probably developed separately, but maybe the Egyptians got the basic idea of marks to represent language from other people. The Harappan script from the Indus valley in what is now Pakistan and western India, seems to be another independent growth, though nobody has learned to read it yet. The civilisation which established it collapsed in about 1900 BCE, so the script did not develop further.

The oldest alphabets that we know about seem to have emerged in Egypt around 1800 BCE. They were developed by people speaking a Semitic language, and the writing only covered consonants. These variants later gave rise to several other systems: a Proto-Canaanite alphabet at around 1400 BCE and a South Arabian alphabet, some 200 years later. There were others, but we will stay with those examples.

The Phoenicians adopted the Proto-Canaanite alphabet which later became both Aramaic and Greek, then through Greek, it inspired other alphabets used in Anatolia and Italy, and so gave us the Latin alphabet, which became our modern alphabet. Aramaic may have inspired some Indian scripts, and certainly became the Hebrew and Arabic scripts. Greek and Latin inspired Norse runes and also the Gothic and Cyrillic alphabets.

Now the way was open for poetry, love letters, literature, history, philosophy, mathematics, tax records, recipes, technical information, weather and astronomical records, religious teachings and more to be written down and passed from one generation to another, without the need for story-teller, whose main role had been to memorise everything, but records could be lost as well. In Geoffrey Chaucer's *Summoner's Tale*, we hear of a friar who would beg for food:

> A peyre of tables al of yvory,
> And a poyntel polysshed fetisly,

And wroot the names alwey, as he stood,
Of alle folk that yaf him any good.

But once he was out of their sight,

He planed away the names everichon
That he biforn had written in his tables

The tables the friar used were small enough to carry around. In fact, they were wax-coated ivory tablets, on which he inscribed notes with a carefully pointed stylus (the poyntel), but then as soon as he was out of sight, with a quick wipe, he flattened the surface, ready to start a new sucker list on what the Romans would have called a *tabula rasa*, a clean table.

Death of a writing system

Writing systems aren't only invented: they can also fall by the wayside, as Harappan did. When civilisations decay, so do their forms of writing, scholars of ancient cultures have concluded. The ancient writing systems are connected to the ruling classes and religions of the societies they are used to depict.

All writing systems require a good deal of investment by the owner society, if the system is to survive, with a strong commitment to training young scribes. Usually the early systems fulfilled multiple functions, like the administrative dealings of the government, and religious matters. When those functions became limited, or when the religious basis for using a writing system failed, another script replaced it.

Many scripts died out when a powerful, centrally organised entity, like the Roman or the Spanish empire, took over. The new rulers consider the old script to be an undesirable link with the past, a possible rallying point for rebels. The old script is declared obnoxious and worthy of suppression. Both Aramaic and Greek in Mesopotamia, Greek in Egypt, Spanish among the Mayans, all displaced the languages and high cultures that people were losing interest in—or were forced to lose interest in.

In early Christian times in Egypt, the new regime mutilated pictorial decorations in temples, but left the writing alone, presumably because literacy in that writing system had been extinguished when the previous ruling elite was wiped out. Mayan glyphs were also generally spared in temples, but a Spanish bishop, Diego de Landa, infamously burned most Mayan texts in the 1500s.

Our modern alphabet does not appear doomed to the fate of the ancient scripts. It is simply too common around the world, and used by all classes. As a result, it is likely to be more successful than ancient writing systems linked to elites and specific religions. Perhaps there is a general warning here for elites of all sorts.

Reviving a writing system


The Rosetta Stone

Just occasionally, we can get lucky, but most ancient systems are only 'cracked' by intensive work. Carved in 196 BCE, the Rosetta stone was acquired in 1799 by French soldiers fighting in the Napoleonic Wars in Egypt. The inscriptions all said the same thing, but in Greek, in Egyptian demotic script, and in hieroglyphics. In other words, for the first time, the mysterious hieroglyphics could be compared with a translation.

The stone's content is fairly boring, a list of taxes repealed by Ptolemy V, but having the same text in three languages made it very exciting. When the French were defeated, the stone was handed over to the British, and placed on display at the British Museum in 1802.

The Rosetta stone was described by its original French finders as '*une pierre de granite noir*', a stone of black granite, but this was not a geologist's granite. This term 'black granite', conferred in less geologically rigorous times, was applied 200 years ago by Egyptologists to a dark, fine-grained stone from Aswan. The British have always called the stone basalt, since they gained possession of it during the Napoleonic wars. Neither description is correct.

Cleaning and a careful examination in the early 21st century showed the stone was probably sourced from Ptolemaic quarries to the south of Aswan. Probably nobody cared much what the stone was, as the important question was the text, not the material it was inscribed on.

From a technical point of view, it is neither a basalt nor a granite, but a fine-grained granodiorite, perhaps modified by "metamorphic and/or metasomatic processes" (think of that as heating). For most purposes, we can think of it as a granodiorite, which has quartz and plagioclase, but it also contains biotite and hornblende, and it is typically darker than granite. All the same, it is hard to see how it could be mistaken for basalt, but the secret to the issue lies in the reference to recent cleaning.

The confusion arose because the stone has been covered for many years with black carnauba wax, finger grease, dirt and remnants of printer's ink, used to obtain contact-prints of the inscriptions, with white paint in the incised lettering to make it stand out. There was none of the rock visible.

When the stone was being cleaned in 1998, it became apparent that the stone was not basalt at all. Work based on petrographic examination and analysis of a fragment from the Rosetta stone showed conclusively that it is a granodiorite. To be precise, the Rosetta stone is granodiorite that has probably

been exposed to some extra heating. It is not basalt, but it should not be taken for granite, either.

The wisest fools

There is a proverb that says a little knowledge is a dangerous thing, but for some people, a tiny amount of knowledge is a dangerous overload. Problems only arise in using the imagination when people overstep the mark, using their limited to erect giant schemes.

In 1647, a French-born British druggist, Theophilus Garencières, accused sugar of being the cause of *Tabes Anglica*, later known as consumption, though we now call it tuberculosis. As a measure of his abilities, the same author used the prophecies of Nostradamus to show that King Charles II would have a son. Sadly for both prophets' reputations, Charles died childless.

Garencières called sugar "not only injurious to the lungs in its temperament and composition, but also in its entire property". One of his supporters, Dr Thomas Willis, quoted Garencières favourably, adding the opinion that sugar was also responsible for scurvy. In France, Philippe Hecquet called sugar an essentially treacherous substance, a poison that used pleasure as a lure.

In fact, the theme of sugar as a sinister lure continues right up to the present day, but it isn't always seen that way. In the late 19th century, many physicians in France and Germany were loud in their praise of the health-giving properties of sugar. This changed again in the twentieth century, and stays negative to this day, with web sites warning solemnly of dangers, like this example:

> Carbon dioxide, which is another toxin, is then used to remove the lime (and according to my studies, not all is removed).

I could (but won't) offer a source for that, but you can track it down if you must: just be aware that many people have re-posted this bizarre claim without questioning it. The notion of remnant lime in the sugar is at odds with the 1980s mantra that sugar was "pure, white and deadly", to quote John Yudkin, while another author said sugar was "… as chemically pure as the morphine or the heroin a chemist has on the laboratory shelves."

This is like saying "Vlad the impaler had two legs and was evil: you have two legs so you must be evil". These people don't blind their readers with science: they don't know any. Rather, they blind them with words. They thought this purity in white sugar conferred all sorts of magical powers, and apparently even the hint of potential purity at some future date can work its evil harm, for another author who remains nameless argued that sugar caused madness at a time when it was far from pure:

> In the Dark Ages, troubled souls were rarely locked up for going off their rocker. Such confinement began in the Age of Enlightenment, after sugar made the transition from apothecary's prescription to candymaker's confection.

This sort of argument is known among logicians as *post hoc, ergo propter hoc*, a Latin tag that means 'after that, so caused by that'. On this principle, if I die after drawing breath, I died of a surfeit of air, if I die on exhaling, I died because I failed to hold my breath. In short, this sort of "logic" turns a chance correlation into a major issue. It is as invalid as it would be for me to say I lost weight, my headaches stopped, and I felt better after avoiding sweets, while neglecting to mention that I also gave up alcohol and drugs and stopped head-butting walls.

The best way to protect us from the flood of nonsense on the internet, is to use good statistics well, and to realise that statistics offer us generalities, distilled from a horde of individual cases. This requires a degree of sophistication which I can recall not possessing as an undergraduate when the concept of half-life eluded me for a while. But first, a digression:

Take 200 dice and scatter them across a table. Remove every die that comes up with a single dot. Then count the remainder and gather them up, scatter them, remove the ones, and so on. The number of dice remaining will drop, and a spreadsheet simulation gave me these numbers: 200, 168, 140, 118, 99, 81, 65, 54, 48…

The half-life of an unstable (radioactive) isotope is the time that will be taken for half of a sample of atoms to decay. In the case of the dice, the half-life of a die is about four throws, so after four throws. We are down to 99, and after four more, we have reached 48, about a quarter of the original number.

With atoms, a long half-life indicates that there is a low probability that any specified atom will decay in a period of time, while a short half-life means a higher probability of decay. It took me quite a while to come to grips with that when I was young, so I will explain.

Nobody can predict which atoms in a sample will decay, and nobody can predict when a particular atom will decay, but given sufficiently large numbers of atoms, we can make statements of great certainty about the probabilities attached to those very large numbers of atoms, just as one of the founders of statistics, Adolphe Quételet, knew was the case with criminals.

> The constancy with which the same crimes repeat themselves every year with the same frequency and provoke the same punishment in the same ratios, is one of the most curious facts … We can tell beforehand how many will stain their hands with the blood of their fellow-creatures, how many will be forgers, how many poisoners, almost as one can foretell the number of births and deaths.
> —Adolphe Quételet, (1796 – 1874, attrib.), on French crime statistics.

As an undergraduate, half-life made no sense to me, because it is counter-intuitive, so I questioned the notion. Had I been better informed, when my lecturer patiently explained how the half-life came from a statistical view of probability, I might have reminded him of Lord Rutherford's dictum: "If your experiment needs statistics, you ought to have done a better experiment".

Had my lecturer been on top of his work, he would have answered me by saying that this same Rutherford later sat in on Horace Lamb's lectures on mathematical statistics to improve his statistical analysis of the alpha particle deflections. In the right hands, statistics do no harm.

Epidemiologists are medically trained but they rely on a heady mix of knowledge, information, statistics and logic. If children living on a river get bad diarrhoea, if all the cases are in towns near the river, and if the outbreaks seem to spread down-river, this would give you a hint that there might be something wrong with the river water. Investigation might prove this suspicion wrong: it might be a disease-bearing mosquito that was being spread down the river, or something else. At least you could start testing some hypotheses.

Sometimes, though, it is worth falling back on words and polemic, because you know the cause, but you are pursuing a Cause, the greater public awareness of something. In 1897, Robert Sherard published *The White Slaves of England* to make the public aware of the ills caused in the murderous white lead trade.

Spring, he wrote, never came to Widnes and St Helens, the principal places for alkali works, because the belching foul gases had killed every tree and blade of grass for miles around. Farmers complained so often of crops ruined by fumes that the factory owners found it cheaper to buy up the land affected by their fumes than to pay for the damage. Trees cannot live in this wasteland, Sherard said, "… but men must, and do."

Sherard was well aware of how the statistics were being misused. He knew the evidence against chlorine was hidden and hard to find. A doctor who treated the St Helens workers told Sherard the alkali trade was an unhealthy one, even though the statistics failed to show it. "The chemical yard only kills a man three parts out of four, leaving the workhouse to do the rest."

Dr O'Keefe, doctor to the Mersey Chemical Works Club for some 31 years conceded that sulphuretted hydrogen (H_2S) was "… a terribly poisonous gas, and but one of several which in these alkali works shorten life." The doctor was willing to look on the bright side. "There is this, however, to be said in its favour, that if it poisons men, it poisons microbes also, and its effect is to minimise contagion by fever. We have but three patients at present in the fever hospital."

Sherard pulled out all the stops. He told how the men joked about 'Roger', as they called chlorine, laughing about cats and donkeys dying of chlorine. It seems they had little else to laugh about, because they knew what was being done to them. One of the men explained to Sherard how easy it was to manipulate the statistics. "It's like this. You get gas. We run to the office for the brandy bottle and say, 'so-and-so's got gas.' Brandy is served out. You go home and die. Doctor says you died of faint, and the proof is that brandy was needed to revive you."

Ancient manuscripts and wisdom

Before 1650 or 1700, the education of a young man was a mixture of the old and the very old. They learned mathematics, exactly as Euclid had laid it down, with maybe a bit more besides, they learned Latin and Greek, they learned grammar, rhetoric and logic, and that was about it. Young women were barred from open education for a variety of bizarre reasons, but a few of them were taught those things at home.

If you wanted to know about the natural world, Aristotle gave a sound Greek view, and Pliny the Elder gave people the Roman view. Pliny jumped to conclusions on many things, as you can see in the translation below. This translation was written about four hundred years ago, so the language is a bit strange, but so long as you know *chirurgery* is an old word for *surgery*, you should be able to follow it. The "veins" which the text mentions are the optic nerves which run from the eye to the brain.

> Many right skilful masters in chirurgery, and the best learned anatomists, are of the opinion that the veins of the eyes reach to the brain. For mine own part, I would rather think that they pass into the stomach. This is certain, I never knew a man's eye plucked out of his head, but he fell to vomiting … and the stomach cast up all within it.

The older the source, the more respectable it was, but when I shared this quotation with my son, after he had eye surgery, he was not amused. Before printing became common, old books could be lost in fires. Before printing, the copy in one library might be the only copy in the world—and fire wasn't the only threat. In *The Story of Maps*, Lloyd Brown tells of a fishmonger who worked near the British Museum. This man found that parchment and limp vellum, even though spoiled by ancient ink or paint, was better than oiled paper for wrapping fish. Thanks to his thefts, many rare manuscripts went west.

Because copies were so rare, rather than walking hundreds of leagues to check, people often wrote down what they recalled. Around 470 BCE, an Athenian named Anaxagoras (*c.* 500 – 428 BCE) said the Sun, Moon and stars were all made of the same material as the Earth, and that the Sun is just a hot glowing rock. He was later charged with "impiety", which is easier to understand once you know that the Greeks believed the Moon and the Sun were gods. Depending on which author you consult, either Anaxagoras escaped or he was banished.

At other times, it seems that later authors slipped their own ideas into genuine works, or giving Ptolemy or somebody else's name to their own ideas. This was not fraud, just the normal practice in those days, when 'authorship' was not seen in quite the same way. Over time, as books were copied out, thanks to copyists' errors and additions, the 'work' of an author could change remarkably. In most cases, we only possess one line of descent, so this process of decay is hidden from view, but occasionally, we can track the changes down.

Printing began in the 1450s, but for half a century, some copies were still made by hand, so there are 58 pre-1500 copies of Geoffrey Chaucer's *Wife of Bath's Prologue* still in libraries today—and they all contain copyist's errors. I came across Christopher Howe's study in 1998: it involved biologists working out the "family relationships", just as they would with the genes in chloroplasts, and now they know which manuscript is closest to the "ancestor", meaning Chaucer's original. Because my own undergraduate and postgraduate worked used similar techniques in other fields, I read on.

Usually, the copyists' errors were real words, as when *moon* became *moan*, or *beside* became *bedside*, and once made, they were passed on down. When copy A has all of the errors found in copy B, plus *one new error*, we can assume that copy B is older, and that copy A might have been made from B, or from a reliable copy of B. Over time, a family tree builds up. The analysis identified 11 copies that seem to have no close relatives. The unique pattern of changes and errors suggest that these may have been made directly from Chaucer's lost original, or from early copies of the original.

After serious printing took over, there were many fewer "mutations", but more importantly, any work of scholarly interest could be reproduced, hundreds of times over, so books could escape and spread, carrying ideas away, faster than they could be banned. And the simple idea of printing was also free to travel, so people elsewhere could print works, either in Latin or in the local language.

Suddenly, science bobbed up in the early 17th century, all over Europe. The Italians, Germans, Danes, French, English and Dutch, all began to explore scientific topics, and to tell each other what they were doing. By 1700, there were natural philosophers all over the place, and many of them were communicating in their own languages, rather than in Latin.

Quickly, their scientific ideas spread into the more general population, and soon there was a whole new world for scholars to explore. They might still read Aristotle and Pliny, but now they did so with a smug chortle, for they had learned to find things out for themselves. Scholarship was no longer limited to quoting, without question, the pronouncements of long-dead opinionated scribblers.

Everybody who wanted could investigate the natural laws which decided how things happened: linen drapers, spectacle makers, people from all walks of life, anybody could make equipment, and discover new things. You did not go to university to learn science: you learned to read and write first, and then you dabbled, talked to other scientists, and dabbled some more. You learned science by working at it, because while science could be learned, it could rarely be taught.

The first investigators did not specialise in any branch of science. They believed they were simply seeking out the set of unchangeable Laws of Nature, laid down by a Creator. That God, they thought, had left the laws for humans to discover, all intertwined. When the laws were sorted out, they would be seen in the end to be beautifully unified.

This view of God as a riddler, a celestial maker of cryptic puzzles and riddles, lasted (for some of them) into the later part of the 19th century. In a way, it worked, because this approach to science as a giant riddle gave us all of the triumphant practical successes of the Industrial Revolution. Scientists think a great deal of any idea which provides results, and they worked hard at laying bare the secrets of science.

Working at science meant you had to know how to do a whole range of things with your hands, practical things that were not part of the normal training of an Arts degree (though they should be!). These practical enquirers after God's Truth worked and investigated, shared their ideas, and built on their own and other people's mistakes. Yet while they experimented and observed, the natural philosophers were still part of the same general cultural tradition. They were just humanists with rather specialised hobbies.

For a while after that, up until 1750 or 1800, a few wealthy women had an equal chance with the men, and a number of girls were able to involve themselves in science, but it did not last, for now science became serious. Mainly, people started to realise that they could use these laws of science as a basis to build better steam engines, better pumps so mines could go deeper, and it led to more accurate telescopes, and all sorts of marvellous and valuable things.

Before long, people were making money from science and engineering, and these became professions that you got yourself trained in, as part of your education. You had to be a very determined woman indeed, if you still wanted to make your way in science and engineering, between 1800 and about 1920, unless you were willing to stick to something "ladylike", such as preparing delicate illustrations of flowers. Women scientists and engineers were about, but they were rare.

About 200 years ago, scientists and natural philosophers began specialising still further, making new branches of science. The skills of the chemist were now different from those of a biologist, and a physicist had different needs from those of the first geologists, who were just starting to appear on the scene.

By the middle of the 19th century, a collective name was needed for all these different kinds of investigators, and that was when William Whewell suggested the name "scientist". Then after the middle of the 19th century, the sciences began to divide up into specialist areas inside their own disciplines. Now a

chemist had to be either an organic chemist or an inorganic chemist, and even those fine divisions began to split.

Finally, the sciences began to criss-cross in the twentieth century, as biochemistry, geophysics and physical chemistry brought the skills of specialties into other areas, where they were desperately needed.

Challenge starters

These playwiths mainly involve poking around in libraries, or these days, banging around on the web and then using your imagination. These are just starter ideas: begin here, but follow your curiosity. These are playwiths that may lack any correct answer.

1. *Roast Pig*: Discover and read Charles Lamb's essays from the web. Make up your own version explaining the discovery of the car, the computer or knitting (or your own choice).
2. *Sign language*: A full signing system like Auslan really *is* a language, because it has syntax, so it is more than "leopard … water". Find out about Kanzi's language, and how he learned it.
3. *Vervet language*: To change "leopard … water" into a language, what would you add? Signs? Extra words? Something else?
4. *Inventing languages A*: Find out about the histories of artificial languages like Esperanto, Ido, Interlingua, Volapük and Brithenig. Can you find out how to say "my hovercraft is full of eels" in any of them?
5. *Inventing languages B*: Find out about how and why people invented fictional languages like Klingon, Wenedyk and Quenya (Elvish). Can you find out how to say "my hovercraft is full of eels" in any of them?
6. *Inventing languages C*: Find out about Creole languages like Tok Pisin, Bislama and Kriol. Can you find any songs in Kriol? (Hint: try *Waltzing Matilda*.)
7. *Creoles*: Creole languages aren't just broken English: they have their own syntax. Austronesian languages (look them up) have two forms of *we*: inclusive and exclusive. *Inclusive we* means the listener is part of 'we'; *exclusive we* means the listen is not included. Consider these two sentences: "We have no food, let's ask Lee for some." "Lee, we have no food, can we have some?" Your task: what words are the two forms of *we* in Tok Pisin? What else can you discover?
8. *Loan words A*: Make a list of unexpected loan words in English and see where they came from. Start with alcohol, bandicoot, cockroach and dollar.
9. *Loan words B*: Find out about trading languages like Swahili, 'Bazaar Malay', Bahasa Indonesia, Police Motu and *lingua franca*. Make a list of words that are common to more than one of them. (Try *book*, *world*

and *milk* for starters, and yes, I've been there before you, but I think there will be more to find.)

10. *Colours of the world*: Limiting yourself to white, black, red, yellow, blue, orange, green and purple, discover the words for those colours in at least a dozen languages and see what you can learn.
11. *Days of the week A*: All over the world (I think) a week has seven days. (Is this so in the high Arctic?) That aside, collect the names of days of the week in a variety of languages and see what you can learn.
12. *Days of the week B*: The Akan people of Ghana name their children for the day on which they were born. Ghana's first president, Kwame Nkrumah, was born on a Saturday, and Saturday is Kwame (though Saturday girls are called Amma). Can you find a better bit of linguistic trivia?
13. *Days of the week C*: Who was Kofi Annan, and what day of the week was he born on?
14. *Mater tua caligas gerit*: Can you use the internet to come up with the Latin for "your father wears a silly hat"? Finding the words will be easy. Getting the inflections right will be a bit harder.
15. *Seminarium rithimus (Latin for nursery rhymes)*: Over 60 years ago, a certain Latin teacher (mentioned in chapter 11) despaired of teaching 40 boys the intricacies of Ovid's poetry, last period on a hot Friday afternoon, so she taught us nursery rhymes, in Latin. See what you can find, using these shreds: <*Mariae fuit agnulus*>; <*Bála-lániger!*> or <*Ba-la ovis*>; < *Puer Parvus Caeruleus*>.
16. *Middle English*: search out some other examples of Middle English, and see how much sense you can make of them. (Hint: Malory's *Le Morte d'Arthur* is easier than Chaucer.)
17. *Making fire*: There are many ways of getting fire, like "Döbereiner's Lamp"; using a lens to focus the sun's rays; "rubbing two sticks together"; using an electrical spark from a battery or using a flint and steel. See what you can learn, and find which one you can make work.
18. *Matches and Lucifers*: If you prefer searching the web, see what you can learn about matches, safety matches and vestas. Going sideways, find out about "phossy jaw".
19. *Inventing writing*: Invent a new and more sensible alphabet.
20. *The Pardoner's table*: Find a version of this story (use a short bit of text from the quotation to find it). See if you can make sense of the Middle English, then search out a *parallel text*, which offers Middle and Modern English versions, side by side.
21. *How to wake up dead writing*: There have been other books on Linear B, but I liked *The Riddle of the Labyrinth* by Margalit Fox. Get ready for the next challenge by reading this book.

22. *Dead writing systems*: Find some samples of Harappan script (also called Indus script). Draw up a plan to unravel it. What information would you need, what training and what equipment?
23. *Investigations A*: You can find bits of Sherard's *The White Slaves of England* online. See if you can find a full copy in a library and look into it.
24. *Investigations B*: In the Victorian era, a number of writers set out to show the horrors of being poor in the cities in the 19th century. Charles Dickens did so in his novels, but in different ways, so did Blanchard Jerrold who worked with French artist Gustave Doré, Danish-American photographer Jacob Riis in New York and Henry Mayhew in London. Who else was there?
25. *Half-lives*: Go to your computer, open up your spreadsheet program, learn to generate random numbers, and run the dice simulation.
26. *Pliny's Natural History*: To find this work, you may need to know that Pliny was known in his day as Gaius Plinius Secundus, and he called his work *Naturalis Historia*. Find a version in English, dip into this and find five weird things to share. (I used Philemon Holland's translation.)
27. *Statistics A*: Consider: what are the odds of Smith beating Jones if Smith has won 19 of the 25 tennis matches they have played together? Would you change your mind if you learned that Jones had lost the first nineteen, and then won the last six matches?
28. *Statistics B*: One of my heroes, J. B. S. Haldane, a mathematician and evolutionary biologist once wrote "I'd lay down my life for two brothers or eight cousins". Was this mathematical geneticist's view of altruism right or wrong?
29. *Haldane again*: A bit of Haldane's verse appears in chapter 21, but he wrote a much longer piece (*Cancer's a funny thing*) when he developed rectal carcinoma. Find this on the web, and write your own celebration of Covid-19, rabies or SARS.
30. *Women scientists*: Lots of people have heard of Mary Anning, Annie Jump Cannon and Marie Curie, but what do you know about Lise Meitner, Eunice Foote, Maria Goeppert Mayer, Mary Lyon, Margaret Burbidge, Mary Somerville, Irène Joliot-Curie, Sophie Germain, Hypatia, Ada Lovelace, Margaret Sanger or Cecilia Payne-Gaposchkin? Yes, I left out other well-known cases, but these are the lesser-knowns that my oldest granddaughter has yet to tell me about.

So you want to work in STEM?

Being a scientist (or working in any STEM area) involves a lot of thinking, and then a lot of persuading. This part is different, and it pulls no punches. Read as much as you need, or as much as you can stand. This section is really for older readers, but nobody is too young to look around at the ideas here.

The thinking behind science

- A lot of science is *counter-intuitive*: it goes against what "common-sense" would expect. The world looks flat, but science says it is not, and the Sun and Moon seem to go around us. Why do people still accept science when it contradicts what they would normally expect?
- Is there a point at which scientists will have to stop asking questions? If so, why should they stop?
- Will science ever come to an end?
- Has science already ended?
- Suppose you realise that a new Dark Ages is about to descend, and you want to write down a small set of key scientific ideas to preserve, ready for discovery at the end of the Dark Ages, to get science going again. You can engrave 1000 words on a special sheet of material. What facts, what ideas and what principles would you place on the sheet?
- What would be the effect if a spaceship landed, and the aliens in it estimate that they are 400 years ahead of us. What would happen if they offered us all their scientific knowledge? Would it be good or bad? Why?
- How does that handout of alien science differ from writing stuff down for the new scientists to read at the end of the next Dark Ages?
- If you had a billion dollars to spend on scientific research, what would you spend it on? Why? How would you spread the money out over different parts? Would your answer be different if you had a hundred billion dollars?
- People care about some death causes that affect very few, like AIDS and 'mad cow disease', but nobody cares about the big killers like malaria, or heart disease, caused by eating fat sane cow meat. Why?

This is just to play with. Take one before bed each night, and play with it. There are no answers offered here, because there are no right answers—but there can be *better* answers.

Economics vs ecology

- Economists talk about commodity value, how much you can sell something for, and amenity value, how useful (in dollar terms)

something is, but they say very little about ethical or moral value. Who or what are the big losers from this limitation to economics?

- Old trees and grandparents are both often seen as unproductive, and you can't taste the egg in a cake, but old trees hold ecosystems together; grandparents hold societies together; and the egg holds a cake together. Is there a case for factoring in the background value of things? Maybe we should call this "future value", a sort of investment in a future for our species and our world?
- How much wealth is too much wealth? Should we take money away from rich nations and people, to give to poor nations and people?
- Who in our society gets paid too much, and who is not paid enough? Why? How do you judge a question like that?

Concerning wealth, you may like to think of wealth in terms of people's health, well-being and life expectancy, or in terms of quality of life, or in terms of their energy usage.

We First World people live at 7 kilowatts. Every second, 7 kilojoules of energy must be used to maintain our lifestyles. Would we be less wealthy, using less power to produce the same goods and services?

If you plan to be a STEM person, you will only be half a person if you neglect the arts. If you avoid museums and art galleries, you will be hollow; if you neglect poetry and well-constructed novels and plays, you hollows will be empty; if you ignore music you deserve to be slowly done to death by howling off-key banshees using socks full of sea urchins.

STEAM matters!

Notes for this chapter

Recommended reading: Ben Goldacre, *I think you'll find it's a bit more complicated than that*. London: Fourth Estate, 2014; Gary Greenberg, Carol Kiely and Kate Clover, *The Secrets of Sand*; Jacob Bronowski, *The Ascent of Man*; Martin Gardner, *Fads & Fallacies in the Name of Science*; Peter Mason, *Blood and Iron*; Brian L. Silver, *The Ascent of Science*; Morris H. Shamos (ed.), *Great Experiments in Physics*; Sir J. Arthur Thomson, *Riddles of Science*; Sir George Thomson, *The Foreseeable Future*.

Recommended listening: This book was constructed with the calming help of Alfven, Bach, Beethoven, Bernstein, Brahms, Britten, Chopin, Delius, Dvorak, Elgar, Faure, Glazunov, Glinka, Grieg, Handel, Holst, Ippolitov-Ivanov, Joplin, Kabalevsky, Lassu, Liszt, Mahler, Mussorgsky, Nikolai, Orff, Palestrina, Quilter, Rutter, Saint-Saens, Satie, Sculthorpe, Sibelius, Stravinsky, Tchaikovsky, Verdi, Wagner, Warlock, Williams and Xenakis, among others.

References and sources

All of these books contributed in some way to this book. The star code: *** means hard, you can work the rest out. Most of these relate to maths and engineering: the science and technology come mainly from the author's experience.

Barrow, John D., *Pi in the Sky*. Oxford: Oxford University Press, 1992. **

Beiler, Albert H., *Recreations in the Theory of Numbers*. New York: Dover, 1966.

Bell, E. T., *The Development of Mathematics*, New York: McGraw-Hill, 1945. ***

Berlinski, David, *A Tour of the Calculus*. London: William Heinemann, 1996. **

Biro, George and Jim Leavesley, *How Isaac Newton Lost His Marbles*. Sydney: Harper Collins, 1999.

Boorstin, Daniel, *The Discoverers*. London: J. M. Dent, 1984. *

Boyer, Carl B., *The Rainbow*. Princeton: Princeton University Press, 1987. **

Boyer, Carl B. (rev. Uta Merzbach), *A History of Mathematics*. New York: John Wiley and Sons, 1991. ***

Bronowski, Jacob, *The Origins of Knowledge and Imagination*. New Haven: Yale University Press, 1979. ***

Bronowski, J., *The Ascent of Man*. London: BBC, 1973. *

Bronowski, J., *A Sense of the Future*. Cambridge: MIT Press 1977. **

Bronowski, J., and Bruce Mazlish, *The Western Intellectual Tradition*. New York: Harper and Row, 1960. ***

Burke, James, *The Pinball Effect*. Boston: Back Bay, 1996. *

Cohen, Jack and Ian Stewart, *The Collapse of Chaos*. London: Penguin, 1995. **

Cook, Theodore Andrea, *The Curves of Life*. New York: Dover, 1979. *

Dampier, Sir William Cecil, *A History of Science*. Cambridge: The University Press, 1942. **

Davis, Philip J. and Reuben Hersh, *The Mathematical Experience*. London: Penguin, 1981. *

Davis, Philip J. and Reuben Hersh, *Descartes' Dream*. London: Penguin, 1986. **

Devlin, Keith, *The Maths Gene*. London: Weidenfeld and Nicolson, 2000. *

Dewdney, A. K., *200% of Nothing*. New York: John Wiley and Sons, 1993. *

Eastaway, Rob and Jeremy Wyndham, *Why do Buses come in Threes?* London: Robson, 1989.

Falkener, Edward, *Games Ancient and Oriental and How to Play Them*. New York: Dover, 1961.

Feather, Norman, *Mass Length and Time*. Ringwood: Pelican, 1963. **

Gamow, George, *Mr Tompkins in Paperback*. Cambridge: Canto, 1993. *

Gardner, Martin, *Fads & Fallacies in the Name of Science*. New York: Dover, 1952. *

Gardner, Martin, *Science, Good, Bad and Bogus*. New York: Prometheus, 1989. **

Gardner, Martin, *The Ambidextrous Universe*. London: Penguin, 1991. **

Gardner, Martin, *Mathematical Carnival*. London: George Allen and Unwin, 1976. *

Gardner, Martin, *More Mathematical Puzzles and Diversions*. London: Penguin, 1961.

Gardner, Martin, *Mathematical Puzzles and Diversions*. London: Penguin, 1965.

Gardner, Martin, *Order and Surprise*. Buffalo: Prometheus, 1983. **

Goldacre, Ben, *I think you'll find it's a bit more complicated than that*. London: Fourth Estate, 2014.

Gullberg, Jan, *Mathematics: From the Birth of Numbers*. New York: W. W. Norton. 1997. *

Gimpel, Jean, *The Medieval Machine*. London: Futura, 1979. *

Greenberg, Gary, Carol Kiely and Kate Clover, *The Secrets of Sand*. Minneapolis: Voyager, 2015.

Gribbin, Jean, *In Search of Schrödinger's Cat*. London: Corgi, 1984. **

Hirshfeld, Alan W., *Parallax*. New York: Henry Holt, 2001. **

Hofstadter, Douglas, *Gödel, Escher Bach*. Hassocks, Sussex: Harvester Press, 1979. ***

Hofstadter, Douglas, *Metamagical Themas*. London: Penguin, 1986. **

Hogben, Lancelot, *The Vocabulary of Science*. London: Heinemann, 1969.

Hogben, Lancelot, *Maps, Mirrors and Mechanics*. London: Heinemann, 1973. *

Hogben, Lancelot, *Columbus, the Cannon Ball and the Common Pump*. London: Heinemann, 1974. *

Hore, Julia, *The Pursuit of Wonder*. Melbourne: Miegunyah Press, 2005. *

Ingram, Jay, *The Barmaid's Brain*. London: Aurum Press, 1999.

Jeans, Sir James, *Science & Music*. New York: Dover, 1968.

Kline, Morris, *Mathematics in Western Culture*. London: Penguin, 1990. *

Kordemsky, Boris A., *The Moscow Puzzles*. Ringwood: Penguin, 1972.

Landels, J. G., *Engineering in the Ancient World*. London: Constable, 1998. *

Lukács, C. and Tarján, E., *Mathematical Games*. London: Pan, 1969.

Macinnis, Peter, *The Speed of Nearly Everything*. Sydney: Murdoch Books, 2008. *

Macinnis, Peter, *Australian Backyard Earth Scientist*. Canberra: National Library of Australia, 2019.

Marvin, Carolyn, *When Old Technologies Were New*. Oxford University Press, 1988. *

Mason, Peter, *Blood and Iron*. Ringwood: Penguin, 1984. *

Meninger, Karl, *Calculator's Cunning*. New York: Basic Books, 1961.

Merton, Robert K., *On the Shoulders of Giants*. New York: Harbinger, 1965. **

Meyer, Jerome S., *Fun With Mathematics*. New York: World Publishing, 1952.

Neugebauer, O., *The Exact Sciences in Antiquity*. New York: Dover, 1969. **

Niederman, Derrick, *Number Freak*. Sydney: Harper Collins/ABC, 2009.

Northrop, Eugene P., *Riddles in Mathematics*. London: Pelican, 1961. *

Olmert, Michael, *Milton's Teeth and Ovid's Umbrella*. New York: Touchstone, 1996. *

Paulos, John Allen: *A Mathematician Reads the Newspaper*. New York: Basic Books, 1995. *

Pearson, Karl, *A Grammar of Science*. London: J. M. Dent and Sons, 1937. ***

Penrose, Roger, *The Emperor's New Mind*. London: Vintage, 1990. ***

Perutz, Max, *Is Science Necessary?* Oxford: Oxford University Press, 1991. **

Petroski, Henry, *The Pencil: A History of Design and Circumstance*. New York: Knopf, 1992.

Petroski, Henry, *Remaking the World*. New York: Knopf, 1997.

Petroski, Henry, *Invention by Design*. Harvard: Harvard University Press, 1997.

Pólya, G., *How to Solve It*. London: Penguin, 1990.

Rolt, L. T. C., *Brunel*. London: Methuen, 1965.

Russell, Bertrand, *History of Western Philosophy*. London: George Allen and Unwin, 1961. ***

Salem, Lionel, Frédéric Testard and Coralie Salem, *The Most Beautiful Mathematical Formulas*. New York: John Wiley and Sons, 1992. **

Sawyer, W. W., *Prelude to Mathematics*. London: Pelican, 1955. *

Sawyer, W. W., *Mathematician's Delight*. London: Pelican, 1963. *

Schuh, Fred, *The Master Book of Mathematical Recreations*. New York: Dover, 1968.

Shamos, Morris H. (ed.), *Great Experiments in Physics*. New York: Dover, 1959. *

Shapin, Steven, *The Scientific Revolution*. Chicago: University of Chicago Press, 1996. *

Silver, Brian L., *The Ascent of Science*. Oxford University Press, 1998. *

Singer, Charles, *A Short History of Scientific Ideas*. Oxford: Oxford University Press, 1959. ***

Singh, Simon, *The Code Book*. London: Fourth Estate, 1999.

Stewart, Ian, *The Magical Maze*. London: Phoenix, 1997.

Stewart, Ian, *Game, Set and Math*. London: Penguin, 1989.

Stewart, Ian and Martin Golubitsky, *Fearful Symmetry*, London: Penguin 1993. **

Stewart, Ian, *Does God Play Dice*? London: Penguin 1990. *

Stewart, Ian, *From Here to Infinity*. Oxford: Oxford University Press, 1996.

Stewart, Ian, *Professor Stewart's Cabinet of Mathematical Curiosities*. London: Profile Books, 2008.

Stewart, Ian, *Professor Stewart's Casebook of Mathematical Mysteries*. London: Profile Books, 2014.

Stewart, Ian, *Another Fine Math You've Got Me Into*. New York: W. H. Freeman, 1992.

Thomson, Sir J. Arthur, *Riddles of Science*. New York: Hart, 1958. *

Thomson, Sir George, *The Foreseeable Future*. London: Readers' Union, 1957. **

Trigg, Charles W., *Mathematical Quickies*. New York: McGraw-Hill, 1967.

Watson, Fred, *Stargazer*. Sydney: Allen and Unwin, 2004. *

Wells, David, *The Penguin Dictionary of Curious and Interesting Numbers*. London: Penguin, 1987.

Wells, David, *The Penguin Dictionary of Curious and Interesting Puzzles*. London: Penguin, 1992.

Williams, Robyn, *A Promise of Miracles*. Ringwood: Penguin, 1993. **

Wolpert, Lewis, *The Unnatural Nature of Science*. London: Faber and Faber, 1992. **

Worth, Martin, *Sweat and Inspiration*. Thrupp: Sutton, 1999. *

About the author

This was obtained from an unusually unreliable source.

I took seven years to get a Bachelor of Science, because I was intent on getting an education. I then became a secondary science teacher before being hijacked into the Department of Education's administration, where I completed a Master's degree in statistical jiggery-pokery (you don't want the details).

Unwilling to seek a cushy haven among the Refugees from the Classroom in Head Office, I behaved outrageously: calling out the parasites, making decisions and questioning stupid policies. I also became a regular contributor to ABC Radio National's science programs. This unusual creativity alarmed my superordinates (I never called them superiors) who pushed me up to Principal Education Officer, and told me I now had to behave myself.

Dismayed by this prospect, I ran away to join a circus called the Powerhouse Museum, setting up their education division before being headhunted to work in IT and fraud detection. Then I became an educator at the Australian Museum before a lustrum back in the classroom again, before being headhunted to work as a science writer. Since 2005, I have been a full-time writer, winning many awards for my writing for children.

Throughout the years, from 1971 onwards, I wrote books in various areas, was an early adopter of the internet and served with K12Net and other groups, introducing pioneer IT teachers to the intricacies of the web. During this time, *Playwiths* had its start as a platform for teacher training.

I am a grandfather who plays the role of 'visiting scientist' in his local primary school. My hobbies include chattering to persistent salespeople in a combination of Latin and Gibberish (the native language of Gibraltar), walking up small mountains slowly, and sitting on top of small mountains, wondering how to get down again. I also create curiously spurious 75-word or less *curricula vitae*, which are apparently watercraft, not at all unlike the Delphic coracle.

.

Afterword: my sense of wonder

This is all true: this guarantee does not cover the previous page.

In 1962, I was an aspiring journalist on the University of Sydney student newspaper, *honi soit*. The editor, later a famous political correspondent, had decided to interview the TV sensation, Julius Sumner Miller, a physics professor from California, whose simple (and wickedly unexplained) demonstrations of physics had entranced Australians that year. The editor asked me to come along, as I was enrolled in the science faculty.

He didn't know I had just decided to transfer to the Arts faculty, but I said nothing, and we went along to Sydney airport with a (then) novel portable tape recorder. "I can give you two minutes," Miller said, but when the tape ran out, 20 minutes later, he was still going, and I had resolved to be an Arts student who cared about amazing things, a student with a sense of wonder.

Three years later, with my plans to become a pre- and post-Islamic mediaeval Javanese historian shredded by outside events, I took up botany (as one does), and the rest is history, just not of the pre- and post-Islamic mediaeval Javanese kind. I later became a science teacher who enjoyed wonder, and I always had some curious rig or other on the front bench, which I refused to discuss in class, dismissing it merely as something I was trying out.

The mystery might be a home-made eucalyptus oil extractor; a Masonite and plastic bag hovercraft powered by a vacuum cleaner; a square wave generator; a pill-bug farm or a gas discharge tube. Another day, it might be a long cardboard tube that boomed when placed over a Meker burner; bent-wire bubble-makers; a water-driven sediment separator; a Berlese funnel or a Baermann funnel (for nematode worms); a dead sparrow being boiled down for its bones in a one litre beaker; yabbies in a tank, or leeches.

I did my best educating through my sideshows. A self-selected gang of students stayed behind, demanding details—and getting them, then they started suggesting improvements. In my world, education involves all of teaching, wisdom, knowledge, learning, culture, training, understanding and erudition, but above all we must foster enthusiasm, wonder and curiosity.

And that explains this book, but what explains $\sqrt{-1}\ 2^3\ \Sigma\ \pi$?

Easy: I ate some pie. Think about it…

By the same author

About 15 of my print works are still available, either in hard copy or as e-books, issued by several of the print publishers I have used in the past. You can keep up on the latest news from this link: http://members.ozemail.com.au/~macinnis/writing/index.htm

In recent times, I have written a series of quirky books, mainly about specialist areas of history, niche books for small specialist markets, and these have (mostly) been self-published under the series title *Not Your Usual…*

There is, however, one title that is, even for me, distinctly unusual. *Sheep May Safely Craze*, is a comedy/fantasy/mystery, published both as a Kindle e-book, and also as an Amazon paperback. You can learn more about it here: https://www.amazon.com/dp/B077R7FC45, where you can find, among others, this review:

> If you're a fan of word-play, sly humor, obscure literary references, and whimsy, this book is for you. It should be on the shelf next to Douglas Adams' works. And it helps if you're a collector of trivia and miscellany.

If you like my willingness to amuse, as seen here, give it a look: you will never be the same again.