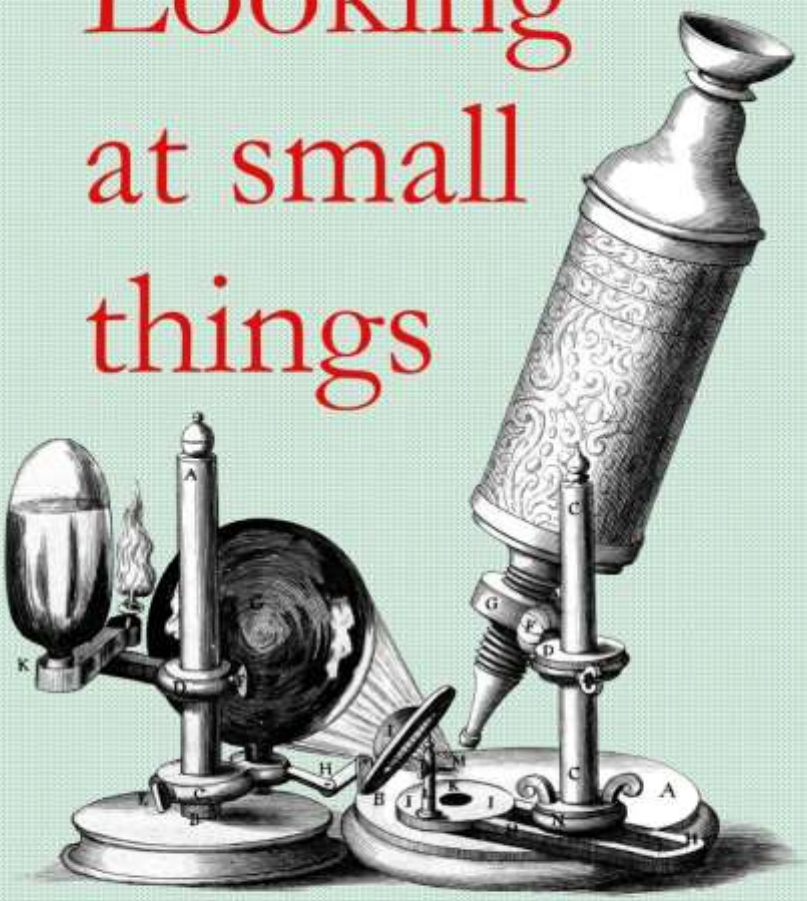
Looking at small things



Peter Macinnis

Looking at Small Things:

a guide for naturalists

Please stop and read!

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

What you can do with the images and text:

A companion volume, Playwiths:STEAM explorations for the curious and the young-at-heart, is available free if you go to this link:

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Exactly the same deal on copyright, free copies and so on applies there, but Playwiths is more general, dealing with all the branches of STEAM.

Looking at small things:

a guide for naturalists

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

By Peter Macinnis

From left to right: *Drosera spatulata* leaf; Piha sand (NZ); filamentous green algae; phasmid head; borax crystals; *Bidens pilosa* seed; leech; ice crystals.

Publication data

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Notes: Contains illustrations. This is a rapid-response, fill-the-lockdown-gap sort of book, and may have a few minor layout problems. There's enough here to keep readers sane!

Target audience: Curious minds from 9 to 90; tinkerers and gadgeteers, people exploring their world from a safe home base.

Subjects: Science; biology; microscopy; minerals; materials; technology; natural history.

Cover illustration: Robert Hooke's microscope from *Micrographia*.

Dedication

This book was written

- to engage the curiosity of solo 7-year-olds such as I once was;
- to answer the questions of curious 17-year-olds such as I once was;
- to provide the answers that elude hard-pressed 27-year-old teachers such as I once was;
- to offer ideas wanted by happy and engaged 37-year-old parents such as I once was;
- to provoke the imagination of 47-year-old museum educators such as I once was;
- to draw outside 57-year-old compulsive writers such as I once was and still am;
- to inspire 67-year-old grandfathers such as I once was and still am; and
- to enliven the life of 77-year-olds such as I soon will be.

As such, it is dedicated to Christine who introduced me to swamp ecology, and our children, always willing to poke around in the wilderness, to round up bones, to track things, to poke things, to admire things, to examine things. It is also dedicated to my many students who, over the years, invaded my lab with specimens, demanding access to microscopes and reference books; or came in, wanting to know why I was boiling up a dead sparrow; or why I was covering a tray in cling-wrap.

It is dedicated also to my more recent students at Manly Vale Public School, to whom I am Peter the Visiting Scientist; to my grandchildren; and to the anonymous young audience member who came up at the end of a museum lecture on bones to say "Thanks, Mate!"

And it is dedicated also to Jared, who got excited at the thought of being shown carnivorous plants in the school grounds. Tricked by my accent, he thought he heard me say "cannabis plants", but he still enjoyed feeding cheese to the sundews, which usually trap and eat insects.

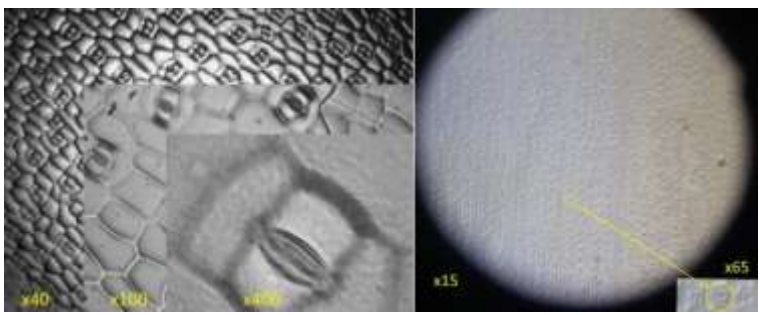
Foreword

If you like small things, anything that fits in or on your hand, this book is for you—if you have an independent mind. This is no colour-by-the-numbers book, but you will find ideas, advice, hints, suggestions, and provocative questions. This book does tell you where to find specimens, how to look after them, and tells you what's fun to look for (and at) when you find one.

I am a teacher by training, a naturalist by preference, and a writer just because. I wrote this book for readers of all ages, especially young ones. People know me best as a writer for children, but I also write serious books for an adult audience. The underlying truth is that all of my books are written for people who are curious. Curiosity is typically something children have, but adults are welcome to join in.

Some of the things in this book involve complicated ideas or tools that may be a little too dangerous or hard for youngsters. Then again, at times, the fetching of specimens may be a task better left to the young, agile and supple. As I say, this book is written for children between 9 and 90.

You can magnify things using cameras with a zoom lens; or you can use hand lenses; clip-on magnifiers on phones and tablets; and traditional microscopes, all of them under $500. The cost and sophistication may vary—but I try always to offer a choice of devices.



For example, the picture on the left above shows three views of stomates on a leaf, as seen through a microscope. On the right is what you see with my phone and a clip-on, looking at the same

slide. The x15 view is well within the reach of a hand lens. So which equipment should you choose?

It's horses for courses. I use all of them, because in any level below what our unaided eyes can see, there are hidden wonders, and there are new wonders as you drill down. Wonder is what science grows on, and continuing wonder is the food that sustains a love of science. Wonder is where new worlds begin, for all of us, so come with me into this book, and explore. I have mainly used material local to my home in Sydney, but as a rule, you can find something similar, close to where you live, all over Australia and even overseas. I have tried hard to make it that way…

From left: ant's head; satin; huntsman; normal fault in shale; rotifer; naphthalene crystals; sutures in a skull; a 10-cent coin.

Contents

These headings are all hot links.

1 Embiggenment and smallification

At one kilometre away, a large house looks tiny, taking up less than one degree on the horizon. A grouse, 30 metres away, looks the same size. So does a mouse, seen from a distance of 6 metres or so, and I imagine that from 7 centimetres, a louse would fill the same angle. The catch is that if our eyes were only 7 cm away from it, many of us would have trouble seeing the louse in focus.

We can focus our eyes because each eye has a squishy lens that the eye muscles squeeze until you see a sharp image on the retina at the back of the eyeball. Move up really close to the house, grouse, mouse or louse, and the image blurs, because the lens in your eye can't squish enough. When that happens, we need another lens to help.

The standard Sherlock Holmes image from the movies (above, left) shows the wrong way to use a magnifying glass. The correct way (right) has different relative positions for the eye and the lens, and as well, the thing being examined is moved closer. When you use a lens, it is as though your eye is hovering just above the grouse feather or whatever, but still able to bring the image into sharp focus. My mate Warren Bonnett, once the extraordinary owner of Embiggen Books in Melbourne, and an earlier shop of the same name in Noosaville told me that we have *The Simpsons* to thank for 'embiggen'.

I have no idea where 'smallify' and 'smallification' came from, but they seem to be a decade old. Lenses can also smallify things: if you use binoculars and telescopes in reverse, things look tiny. I used to teach physics, meaning I *could* explain that, but it's complicated, so I won't. Look it up! Still, there's usually precious little need for smallification.

We might smallify a blue whale, so we could take it all in, but we don't, because we curious apes are quite good at seeing the bits of something large, and stitching the bits together in our minds. We need embiggeners like microscopes, even simple ones, much more often, but occasionally, it's hard to see the big picture.

Here are some embiggeners:

From left: hand-lens, 'Go Micro' clip-on, USB micro-camera, binocular (dissecting) microscope, monocular microscope.

I recommend that beginners start with either a hand lens or a clip-on. The cost is so low that almost anybody can play, and that gets you started. Later, you can move up to microscopes. Young people (and most older people) don't know where to find interesting material, or how to catch things or how to handle what they catch, so this is a field biologist's guide, delivering the necessary what, where and how, with a lot of why, and a dash of who and when.

It's a book that shows you ways to get more out of your microscope, and ways to put more things under your lens. Now let's look at something every house has: dust. My photos of dust in the

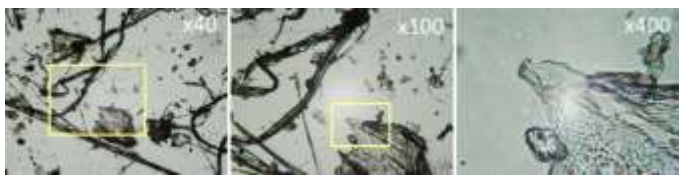
next few pages were taken with a monocular microscope, but you can do interesting stuff with cheap gear.

A closer look at dust

Any dust collection will contain all sorts of surprises. With a good microscope, you may be able to identify a few pollen grains as well (and we will come back to pollen in chapter 11).

You will need sticky tape and a microscope slide. If you don't have any glass microscope slides, pieces of the clear polystyrene cases that come with CDs will do just as well, and so will flat pieces of clear plastic chocolate boxes, but slides are better.

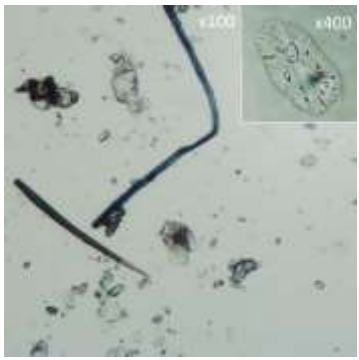
Look for dust under beds, on outside or inside windowsills, on floors and carpets, even sitting on the tops of books. For my example shots, I sampled my lounge room floor, my desk (which is rarely dusted), and a Venetian blind.



Dust from my desk, seen through a monocular microscope at three magnifications.

You can collect dust from anywhere, by pressing a piece of sticky tape onto the dusty surface to collect a sample of the material you

found there. Stick the tape down onto the slide, and you're ready to look at the dust, but expect a few mysteries…



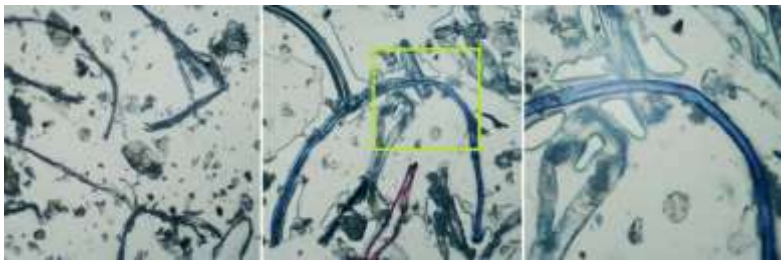
Above, you can see dust particles from my lounge room. Floor dust may include fibres from clothes, food scraps, bits of tiny dead animals that have fallen apart, mineral grains, flakes of human skin and hair, fragments of paper, pollen grains and tiny bits of rotted leaves.

The dust may have been picked up by the wind and whirled around, mixed with fragments of food and soot particles. As you zoom in, so you begin to see new and enchanting details that were hidden at lower magnifications. You will only find what is hidden there if you search! Here is some dusty cobweb.

When you look closely at things, any sign of order, any regular pattern like the helical strands of fine web or a series of branches usually means that a living thing is involved. Patterns like this are

the sorts of signs a spacecraft, flying past a planet, would seek out, when they scan for extra-terrestrial life.

Computer monitor screens attract dust, as I noticed, one sunny winter Sunday morning. I used sticky tape to sample it, and then made an odd discovery: blue fibres! Below, there are two shots at x40 to the left. The rightmost one is at x100.



With a bit of experimentation, I discovered that the blue colour was a trick of the light, and that it came from slanting sunlight shining on the slide at an angle, because when I blocked the sunlight with my hand, the blue disappeared. I have a theory about what caused it, but I'm not sure, and I'm not saying!

Things to look out for in dust:

- Flakes of skin or hair, food scraps;
- Tiny dead mites or their fragments;
- Mineral dust; threads from clothes;
- Spider web, bits of plants: just keep looking!

But does 'x40' or 'x100' really mean what it says? Let's look at the word 'magnification' more carefully.

Magnification and scale

Microscopists talk about resolution, not magnification, but I will start with magnification, to avoid getting bogged down. The next four pictures show the same millimetre scale at four levels of magnification, but remember that as I write this, I am looking at the images on a screen where each A4 page is three times as wide as A4: if you read this on your phone or in print, things may be smaller. In other words, be careful what you believe!

The first two pictures below were taken with the Open Camera app on my Android tablet, held steady, about 50 mm away, the first at normal setting, and the second one at maximum digital zoom.

Length shown: 57 mm

Length shown: 13.2 mm

The next two were taken with a Go Micro attached to my tablet, first with no digital zoom, and then at maximum digital zoom.

Length shown: 9 mm

Length shown: 3.3 mm

On my screen, each image is 300 mm wide, and the ranges are as shown beside each shot. *On my big screen*, I see magnifications of about x5, x23, x33 and x91 — but the magnification you see will be different. Notice how the pictures get less sharp as we magnify more. This is an example of how you trade off magnification and clarity. With other screens, the magnification is determined by how and where you are viewing the image.

Now here's another way to estimate the magnification: I took two shots with a USB camera using the same magnification each time: one shows ~4.3 mm of a scale, while the other one shows some carpet fluff. You do the sums!

A magnification case study

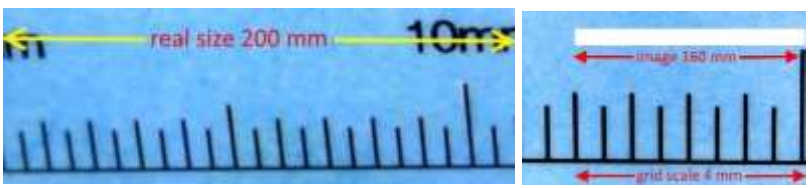
This is my review of a neat little toy that I came across while writing this book. I went into some technicalities which I think are sufficiently explained, but they aren't essential to readers here. I have my reservations about this gadget as a tool, but I recommend it as an informative toy for youngsters.

Mine seems to have no brand, but it is a camera, sold by various suppliers as a "digital microscope", and it comes with a USB cable.

It cost about $26 on eBay, and uses **amcap.exe** (for Windows). On my MacBook, I just use Photo Booth to capture the images.

The camera looks like this: the USB lead delivers the power to light up the LEDs. The right-hand shot shows the cicada shell that was being taken in the middle shot. As you can see, the pictures are sharp and clear, but the gadget comes with deceptive labelling:

On the carton, there are magnifications as high as x1600, while this one is only claimed to be x1000, and on the gadget, we are told we can change between x40 and x1000. This is all rubbish! I decided to test this, using the handy scale that came with the gadget, and here are the two extremes that I could obtain.



A few technicalities here: the camera only delivers 640 x 480 pixels, and the images are reported to be at 96 dpi (dots per inch), which means the images ought to be about 170 x 128 mm, but setting my

simple software program to "actual size", I get an image that is 200 x 150 mm on the screen. This is near enough, and it means that the images above show magnifications of x18 and x40, near enough.

Of course, if I put that image on a huge screen, the magnification would be more, but things get blurry, as the simulation on the next page shows:

Still, this "digital microscope" is a cheap, simple and interesting place to begin.

About lenses

As I explained at the start of this chapter, there is a right way and a wrong way to use a lens. The real Sherlock Holmes would have known this, but the actors who played him don't. For the best results, you need to hold the lens close to your eye, and move the object towards you until you see it in clear focus. With the lens near your eye, you will find there is a small flat zone where everything is in focus.

Photographers call this area the **focal plane**. It is flat and lies at the exact distance of best focus. Anything above or below this level will be out of focus and blurred. When you hold the lens close to your eye, the things you are looking at appear less distorted if they are in the focal plane.

Any hand lens will help, but the best sort is the two-lens variety, lower left in the pictures above. In the rightmost picture, look at the size of the image where the lenses overlap. Each lens magnifies, and together, they give around x20 (meaning a magnification of 20 times).

For field work, you need a folding hand lens, or jeweller's **loupe**. You can buy these at natural history shops, camera shops and telescope shops. A web search on **<jeweller loupe site:.au>** will find people selling reliable loupes from about $10 or $15 upwards. For about $30, you can get a lens advertised as x30 and x60: I have one of those, and it seems good, but you don't quite get the claimed magnification. You never do, with cheap optical gadgets.

The main benefit from these new lenses is the light. The shots on the right were taken with a similar power clip-on.

Get to know your hand lens before you start examining living things. Look at your fingertips, cloth, wood, newspaper, stones, leaves and anything else that is in reach. Then look at some leaves and flowers, any insects you can find, and some soil. Once you have mastered the hand lens, why not examine some sand, close up? Microscopes are usually better, but we will get to them later.

I recommend that you make your start by looking at some dry sand, with either a hand lens or a clip-on, because all you need is sand, a Petri dish and coloured paper or cardboard for contrast. Newsagents and stationery shops sell sheets of manila cardboard for school students to mount projects on, but this cardboard is very useful when you are looking at small things: look at the pictures in this book, and you will soon spot that I use either black or sky-blue cardboard. Now it's time to consider the equipment you need to find interesting things.

Catching animals

Using a paintbrush

No naturalist should be without a choice of small artist's paintbrushes, (often called camel hair brushes). You must never use tweezers or forceps to handle small animals, because the effect of tweezers on them will be a bit like a *Tyrannosaurus rex* picking you up in its mouth! The picture above shows me rolling a pill bug onto a Petri dish. On the other hand, you can persuade most small animals to climb onto the bristles of a brush if you press the brush down in front of them and chase them on with a second brush. A damp brush will stick to very small animals, letting you pick them up.

Using a jar and a card

You can chase small-to-medium insects and spiders into a jar, using a brush, or a stick. You need a jar with a lid, small paintbrush and a piece of thin cardboard. You can trap bigger insects and spiders by putting a large upside-down jar over them. Let the animal settle, and then slip a piece of cardboard partway under the jar. Move the jar sideways to chase your quarry further onto the cardboard, moving the jar as the animal moves.

Once the whole of the mouth of the jar is on the cardboard, pick up the jar and cardboard as one and tip the jar over. Tap the cardboard until your catch falls to the bottom of the jar, then quickly put a lid on. If you are at all nervous about spiders, practise on beetles or pill bugs first. You can catch some flying insects like bees by lowering a wide-mouthed bottle over them as they feed on a flower, so they fly up into the bottle. Often, though, a pooter is easier.

Making a pooter

A pooter (or inhalator) lets you pick up small animals gently. It has a *tube* to carry your catch into a *clear container* that is easy to open and shut, a *second tube* that you suck in on, and a *filter cloth* to stop dust and animals going into the second tube. When I was young, pooters were made from a glass jar and glass tubing, which was dangerous.

Every idea can be improved, and some primary school teachers suggested the model below to me during an inservice course I was running in about 1992. This new design used a clear film canister and plastic tube. It is much safer, but hardly anybody uses clear film canisters any more.

Obviously, I needed a new design, but that took me a while. Remember: you need a clear container that can be opened easily, two tubes, and a filter, which stops the insects going down your throat. There are probably lots of better designs out there, and remember: all ideas can be improved…

My newest design uses a small (300 mL) plastic bottle with a lid that clips or screws on, about 30 cm of 3 mm (inside diameter) clear plastic tubing from a hardware or aquarium store, some sticky tape and a piece of fine cotton cloth, like a piece of an old clean handkerchief.

Here are the parts of my current design, ready to put together, and being assembled.

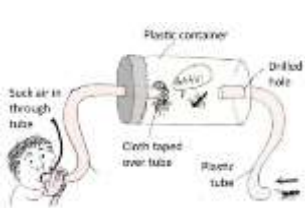
You will also need scissors, a drill with a drill bit slightly smaller than the plastic tubing, and somewhere like a work bench, where it is safe to use a drill. Strip off the labels on the bottle, dry the inside, take off the lid, and you are ready. Turn the lid upside down on a piece of scrap wood, hold it with pliers and drill two holes in the top.

I use a 5 mm drill bit—start with a small hole and enlarge it slowly, or test various drills on a bottle cap you don't need. Remember the **Law of Holes**: *you can make a small hole larger, but you can't make a large hole smaller*. Still, if the hole in the lid *is* too large, wrap a bit of sticky tape around the plastic tubing.

Cut and push a 4 cm length of tubing through one hole and push a longer (~30 cm) piece through the other hole. Sticky-tape a piece of cloth (about 3 cm x 3 cm) over the *inside* end of the long tube, and fit the cap on the container. Point the smaller tube at an insect, and suck air in through the longer tube. I recommend reading the next section, and then practising on picking up small scraps of paper, first.

Using a pooter

Once you can pick up paper scraps with the pooter, go out and practice catching small insects and spiders. Here's a picture from my one-time colleague, Carrie Bengston, used with permission, and a picture of me, capturing aphids with the new design.



Never pooter up ants or stinkbugs! When they are annoyed, ants release formic acid, and the fumes go through the filter. The acid can hurt your throat, and it is dangerous stuff to breathe. If you need to catch ants, a portable vacuum cleaner is a good bet, but I will outline a better method later.

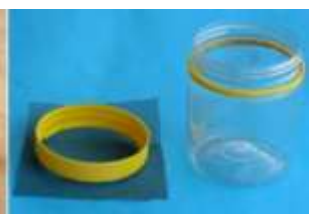
I will leave you to *think* about pootering stinkbugs…*don't do it!*

Making a sieve jar

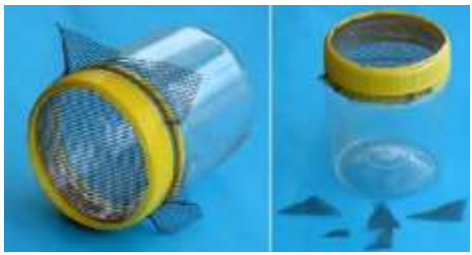
This one has many uses. I *think* I got the inspiration for the sieve jar while watching a scientist friend collecting tardigrades. I saw from her equipment that I could make a handy sieve from a 450-gram cylindrical jar with a lid made of soft plastic. Vegemite and plastic peanut butter jars are ideal for this.

Watch out: Fingers are always at risk from hammers and chisels, and inexperienced users, especially those under 12, need adult help. Furniture is at risk from carelessly used tools, and young users are better off using peanut butter jars, which are made of plastic. You will need the jar, some plastic flywire, scissors, a wood chisel and hammer, a backing board to work on, and a workbench or table that can take the occasional scratch. Get the flywire from a hardware store or from somebody who is replacing screens, and beg or borrow the chisel and hammer.

The backing board is any old piece of scrap timber. It stops you marking the workbench or table, so the board should be at least 200 x 200 x 20 mm. To make my sieve, I took the soft plastic lid from a jar, set it upside down on my piece of board sitting on a newspaper, and used a hammer and a small (10 to 15 mm) chisel to make a set of cuts that let me remove the flat top, leaving just an open ring.



Then I took a square of flywire and fitted it to the jar, as shown in the pictures below, then trimmed the corners of the gauze, half-filled the jar with leaf litter, and shook it gently over a white dish, watching to see what dropped out, pootering my finds up so I could examine them.



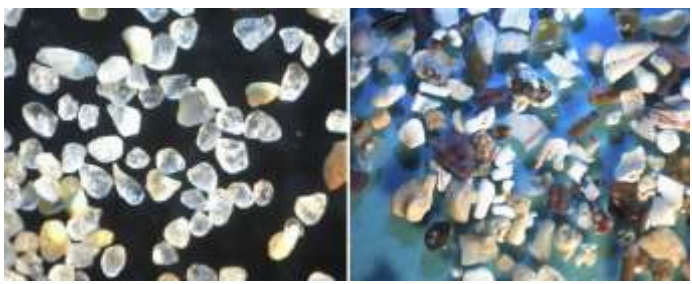
Most beach sand has just a few interesting shells, along with a lot of small sand grains, but I will come back to them in a moment. I hope my readers will find new uses for the sieve jar, just as I have done in the past ten years.

In science, ideas are shared, but there is no law saying you have to use the ideas exactly as you found them. Ideas are our servants, not our masters. I used a similar sieve design in making a simple Berlese funnel (described in chapter 5, which has lots more catching tricks) to find small animals, but let's look at how sieves can help sort pieces of broken shell from sand. There is just one warning: small hands and slippery wet jars near rocks: can you see the problem? *Use plastic jars!*

Discovering things

Finding shell fragments

When I was three years old, some beach sand squeaked when I walked on it. At the time, I wanted to dig for a squeaking burrowing animal, but serious digging offered no evidence. Recently, it happened again, so I took a sample and developed a more scientific hunch. The squeaky grains appear to be mainly quartz, but it would take more study to answer this question.



I looked at the squeaky sand (left above) under a microscope, and saw small, uniform grains. I then got some non-squeaking sand (right) and found quite a lot of shell grit, tiny broken-up fragments of shell. There are similar fragments in these two shots of Coller's Beach sand, taken with a fairly good microscope, using reflected light, at x20 and x40.

Look for minerals in the left-hand shot above. It *appears* to be mostly quartz, but is it? I think there are at least three minerals there, but there may be more. The right-hand sample has shell fragments as well as several minerals. Go to a number of different beaches, and sample in different places on each beach. The sand at the top of the beach has usually been wind-blown, so the grains will be smaller, while down on the shore at the wave line, you may (or may not) find many more shell fragments.

Over to you, though I'm not sure that a hand lens will be enough! To make any useful discovery, you probably need to look at the size of the grains of sand, the shape of the grains and the colour, which tells you something about the minerals involved.

I keep coming back to sand, because sand grains have many stories to tell, sand is easy to get, and sand doesn't run away, or die and go smelly. More to the point, when you look closely, sand is amazingly variable. Wherever you look, there are interesting things to see and discover, but sometimes you need to get the conditions just right for seeing.

Once you have a sieve jar, collecting shell bits is easy, but choosing the best beach is harder. Ideally, the sand grains will be fine enough to pass through the sieve, leaving you with a collection of shell bits to work through. The trick is to fill the jar ¾ full of sand, rinse off the sand around the rim, screw the lid down, and then shake the sieve vigorously in water, to wash the small sand grains out. I always put my other hand under the jar, so I know when sand stops falling out, then I tip or wash my catch into a second jar. I have a toolbox that carries six labelled jars and the sieve jar.

I take this kit out with me, along with a notebook so I can record where the jars were filled. The most expensive item was the $2 plastic toolbox: apparatus and equipment don't *need* to be complicated!

To find hidden treasures, spread a thin layer of grit in a white dish, and let it dry in the sun before pushing the pieces around. You can use a small paintbrush, but I prefer to use forceps (tweezers), so when something good comes up, I can pick it up and drop it into a Petri dish. In the picture below, there is too much material, but it was wet, so I just took the shot. Notice the white dish, the forceps and the Petri dish. The jar on the left is what I carried my catch home in.

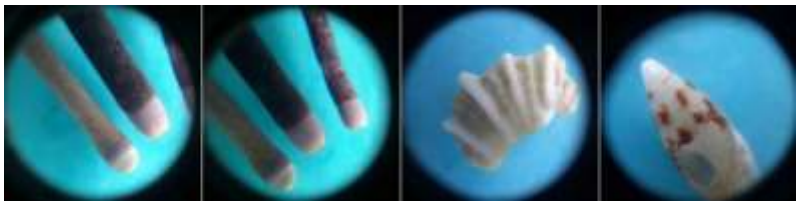
My standard white dish is also good for sorting. The interesting bits go into the Petri dish for closer inspection.

Now all we need is an embiggener!

Shells and their details are well within the reach of a clip-on, or even a hand lens, so sand-sieving is one of those activities that can be adapted in many ways.

Looking at shell fragments

The following is a picture essay. Above, you can see some of the original subjects, sitting in a plastic Petri dish, waiting to be taken with a camera. First, here are some of them as seen with a clip-on: the pictures below represent an area of about 9mm x 9 mm. From that, you can work out the magnification as you see it.



Two sea urchin spines, an unknown shell, possibly a false limpet and (right) an unknown snail.

A limpet and a piece of bottle glass, a snail killed by a predator that drills a hole in it, and a piece of another shell.

A couple of notes: the identification as glass is confirmed by the stripy fracture pattern, called a conchoidal [pronounced con-coydle] fracture. There is more about conchoidal fractures in chapter 12. The drilled shell is an oyster-borer, also called a mulberry shell or *Morula*. One of its own species may have killed this one, but we have no indication of how the one on the right died.

Look out for these:

- The edges of broken shells can give you an insight into how shells are built up;
- The holes in shells can often tell you how the owners died;
- The outsides of shells probably tell you something about how they avoid being eaten.

Looking at sand

Now let's look at some sand grains. To study sand, you only need a pinch, like this picture. The coins in many of my pictures are there as a scale. Every grain of sand has a history. The average sand grain takes many hundreds of millions of years to lose 10% of its weight

by rubbing, but it slowly becomes rounded. Even so, a sand grain moving on the bottom of a river loses 10 million molecules each time it rolls over.

We won't run out of sand though, no matter how much the grains wear away. In 1959, a geologist calculated that all through the long geological past, each second, the number of quartz grains on the planet increased by 1,000 million! Look at what you have. Sand is made up of light-coloured rock fragments, right? Not really: take a look, even under a hand lens, and you will start to see differences.

Look out for these:

- Look to see if the grains are angular or rounded;
- Squeaky sand (an obsession of mine since 1947!);
- Look to see how many different kinds of grain there are;
- Look to see how much the sand grains are uniform in size.

Dune science

There can be interesting small things on and near sand dunes. Here, you can see me looking for spiders in the Sahara: I didn't find any spiders, but I found a toad!

Sand dunes are not just piles of sand: they are living ecosystems, where the many tough plants shelter many animals. Sometimes the angle of the sand slope on a mature dune may be greater than the angle of rest for pure sand (we'll come to this later), because the dune is held up and together by plant roots. Dunes are *not necessarily* deserts!

How healthy are the sand dunes near you? Are they stable? How does the sand vary from place to place? What angle does the sand lie at? How much water is available at different places in the dunes?

What lives there, how are the life forms in the area changing, and what are their prospects? What tracks can you find in the sand?

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 fixed point, like a post on a walkway fence, zoom either right in or right out and centre all of your shots on distant landmarks, so you take comparable shots each time.

2 Simple discoveries

How screens work

All the screens we use rely on dots called pixels to make images. This unusual-looking but common Australian beetle below is a weevil. One of this species was collected in 1770, making it the first insect specimen taken by European scientists in Australia.

These all show parts of the same picture of a weevil, the Botany Bay Diamond Weevil, *Chrysolopus spectabilis*, at four magnifications.

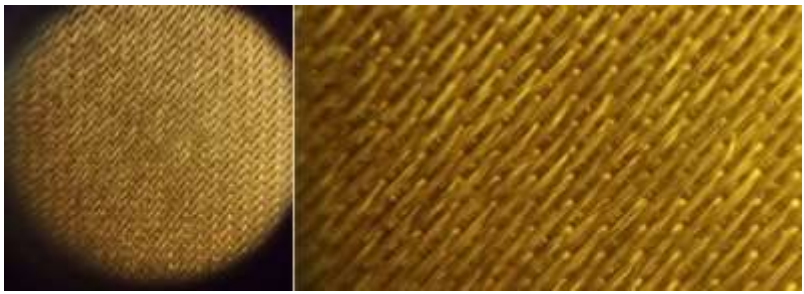
Be gentle with your screens. You will need a number of devices: tablets, phones, computer screens and TVs and either a hand lens or a clip-on. Use an arrangement like the one shown below.

The screens on the right are (left to right) a Samsung tablet, a MacBook Air and a Samsung TV.

After the close-up, take a shot of the screen from further back: the displays are all different, and unless you have a way of labelling the shots as they are taken, you will lose your way. The middle shot on the right obviously goes with the MacBook shot on the left.

A closer look at cloth

When people get their first hand lens, they examine their hands, fingerprints and fingernails, and then they look at their hair. With clip-ons, the first time they set their device down on their lap while they move something, they see the detail in cloth.

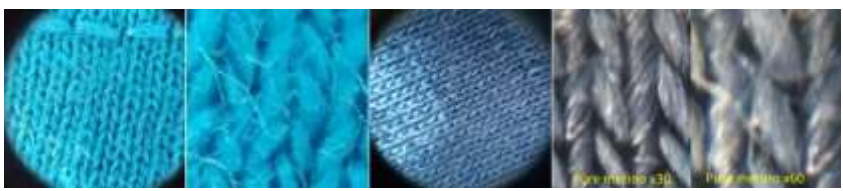


Two views of one piece of cloth, probably satin.

You will need some different types of clothes (or a ragbag of clean scrap material), and an embiggener. Shirts and blouses are usually woven cloth, t-shirts are typically knitted, and I know little more than that. There are some interesting images to be gathered, though. What you do from there is up to you. Discover something!

Three other cloth samples, but how many types of fibre can you see?

Now look at the fibres in cloth samples, to see if they can both be distinguished in the fabric, or not. Here are two shots of cotton polyester at x15 and x60, then three of pure merino, at x15, then at x30 and x60. This exploration began when I wondered if you could see the different fibres in composite cloth like cotton polyester cloth. I *think* I can!



But can you tell merino from cotton polyester without labelling or a microscope? I don't think I can!

Money and its details

This is one of the fun ones, but I suppose I *would* say that, because I was once an amateur numismatist, working in the Commonwealth Treasury Department, and used to answer all the odd public enquiries about money and other things. You will need a range of coins of different ages.

The best fun comes with pre-decimal coins (earlier than 1966), so ask your grandparents if they have any. There are fine details hidden away, like the abbreviated Latin details around the sovereign's head, but there are also mint marks and designers' initials.

Some Australian coins from 1951 have PL on them, so they were minted in London (nobody knows why, but "it is traditional").

GEORGIVS VI D G BR OMN REX F D IND IMP is an abbreviation of the Latin "*Georgius sextus, dei gratia britanniae omnis rex, et indiae imperator*", which means "George VI by the Grace of God, King of all the British territories, Defender of the Faith, Emperor of India".

Pennies and halfpennies have KG near the kangaroo, but it doesn't mean *KanGaroo*, it reminds us that George Kruger Grey designed it (and also the shilling coin, which later became 10 cents.

Bertram MacKennal did the head of King George V, so there is a BM under the king's neck. Herbert Paget (HP) did the same for King George VI.

I can't recall who did Queen Elizabeth II, but there have been four or five versions of her image, I think. Most of the decimal coins were designed by Stuart Devlin (SD), and if you look at coins minted during World Wars I and II, you will find many foreign mint marks like S (San Francisco), D (Denver), and I (for India), meaning the British mint in Calcutta.

Above, you can see an old florin (two shillings, which became the 20 cents), minted in San Francisco (S over the date 1943), and the designer's initials on the Australian 10 cent coin, between the lyrebird's tail and foot. Of course, if you can't find any of those older coins, there are still plenty of other surprises, like gashes, scratches and other marks. Until the early 20th century, the British £1 coin known as the sovereign was always called 'gold', but it was

really 22 karat gold, an alloy (mixture) of $^{11}/_{12}$ gold and $^{1}/_{12}$ copper, because pure gold is too soft and wears away too quickly.

Even with the added copper, the Royal Mint estimated that sovereigns would lose 0.25% of their mass each year, just from rubbing against other coins in pockets and purses.

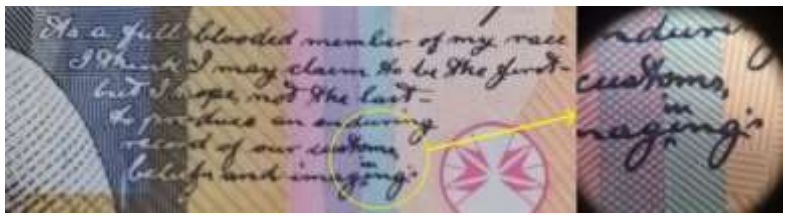
Now look at this image above: do you recognise it? I came across it, and even though it was a shot I had taken with the Go Micro device, I had to check where it came from.

Let the hunt begin! Clearly, there are many more puzzles like the ones suggested here for you to set your family! And then there are the bank notes, even foreign ones. Here are three images taken with from the new Australian $5 note: would you recognise any of them? The third one might be a give-away, but the other two aren't that easy.

Here are five bits of the new Australian $10 note: once again, the last one is the give-away.

I couldn't find any interesting things on the $20 note, but did you know there is an error in the old $50 note? That's the lower note in the picture below.

The engraving for the note shows an actual manuscript, written by David Unaipon, and faithfully reproduces his correction of an error (and correction) that he had made in his manuscript.



The fine detail that you see in bank notes is one of the ways that the authorities can check for forgeries.

Look out for these:

- The fine details in notes and coins, designed to make counterfeiting harder;
- Signs of wear, like scratches in the money;
- Curious mint and designer marks.

Exploring feathers

Just a note of warning: wild feathers may carry **zoonoses**, animal-borne diseases. I have never had any problems from collecting feathers, but it's a good idea to play safe and use clean feathers. A leaky Doona or an old split parka with down filling provides safe feathers. This is a sick parrot with beak and feather disease. Beware!

You need a microscope slide or a 90 mm plastic Petri dish, but think about the problem of focal plane, which you met in chapter 1. Remember, the closer you get to something, the harder it is to focus on it, and when you use lenses, there is only a shallow level, the focal plane, where everything is clear.

Notice how parts of this ant are in clear focus, but other parts aren't. One solution is to reduce the aperture (the opening that light comes through), but that won't work with a hand lens or a clip-on.

With a microscope, you can 'rack up' or 'rack down' to see different levels. The focal plane issue is why microscopists use thin sections

and glass slides, but glass slides are fragile and dangerous in pre-teen hands.

I came up with a way of looking at feathers using a plastic Petri dish, sitting on a microscope slide. With the microscope slide underneath, the feather is squeezed flat between a very thin clear layer of plastic on top, and a hard slide under it, so the whole feather is in a single plane. The feather on the left in the shot below sits on top of the slide, and is squashed down by the Petri dish.

A piece of thick cardboard, 7 cm square, can replace the slide. The down plume on the left is a tangle, and you won't see much detail. Other feathers, like the one in the middle, are only partly downy. Make some discoveries!

The white speckling in the shot on the right is because my Petri dish was a bit grubby. To get the right-hand shot, I took my fluffiest feather, holding it in tweezers, and sliced off several threads. The ticklish part was getting the threads to let go of both the tweezers and the scissors at the same time, while I was holding my breath to stop them blowing away. (Do you see why some things are not easy for very young children?).

Look out for these:

- Look for the ways in which various parts of the feather differ;
- Look for the ways the parts line up;
- Look for signs of symmetry and its opposite, asymmetry;
- Flight feathers are asymmetrical, and the front, or leading, edge is narrower. This is how the palaeontologists who study *Archaeopteryx* knew the animal could fly: the clue is in the asymmetrical feathers.

- Totally off-topic, right-handed writers in the 18th century used quill pens made from flight feathers taken from the left wing of a goose (and *vice versa* for left-handers). Work out why!

Looking at ice crystals

Higher-latitude Americans and northern Europeans know about ice crystals, because they see snow every year, but few Australians live in alpine conditions. Unless you live in frosty Canberra where I took this shot, here is a way to make some imitation snow. You may have trouble seeing these crystals with a microscope, but hand lenses will work.

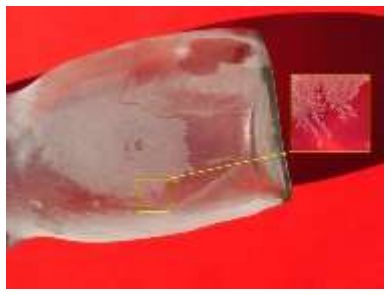
You need either a thin-walled glass flask with a stopper (this is better to see through, but easier to break) or a clean, empty jar with a lid. You also need a freezer and a damp dishcloth to wipe the outside of the jar or flask with. Be careful, because when you take them out, the glass containers will quickly become slippery, and there may be some pain in handling sub-freezing glass. Think about safety!

Just about all solids can freeze into a crystal form, but the ice you make from water in an ice tray in the fridge shows no real signs of crystal form. Frost, whether in a freezer that has been left open, or on a car on cold mornings, shows crystal shapes better. Ice crystals form when water vapour condenses on a cold surface, and immediately freezes. That is the principle we are relying on here.

I do this sort of messing-about for a living, and this idea began when I wanted a way to make water crystals to include in *Australian Backyard Earth Scientist* (National Library of Australia, 2019). First, I

tried leaving a jar with a few drops of water in it in the freezer. That didn't work, so I took a jar with a few drops of water in it.

Give the jar 20 seconds 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, you will see crystals inside the jar, because the water vapour inside the jar has frozen on the glass. Unless you live in a cold climate, the crystals won't last long, so you probably need a foam box with ice bricks to carry the jar to the microscope. Leave the jar lid tight, to stop warm air getting in, take the jar out into the sunlight, and photograph what you see.



Photographing these crystals will be hard, because water vapour from the air condenses on the outside of the jar as soon as it comes out of the freezer, and that stops you seeing the ice crystals inside. Use the damp cloth to wipe away the water drops. There is a further challenge with using a clip-on, a hand lens or a microscope: focusing through thick glass to see the ice crystals. This is why a thin-walled flask is better. But what about the microscope users: how can they get the jar under the microscope lens? I think that if you put a microscope slide in the jar and work *very quickly* when it comes out of the freezer, you *might* be lucky.

Look out for these:

- Look for hints of hexagonal crystals, of the sort that can be seen in fake Christmas 'snowflakes';
- If your freezer has 'frosted up', use a plastic pot scraper (*not* a knife!) to collect some crystals to study.

Out in the garden

When I was young, almost everybody had a garden, because people lived in houses with yards, or duplex flats that still had yards. Now more and more people live in high-rise, and that makes it harder to be a naturalist. If you live in a multi-storey, then you need to be creative.

When you are looking for plants to study, weeds on the street are fair game, and you will find quite a few weeds featured here. Because I am a Visiting Scientist at my local school, I sometimes need special leaves or flowers, I beg for things quite a bit. It's all about asking nicely! People usually agree to my courteous requests for a leaves and things, when I say I need it to look at under the microscope.

Getting soil can be a bit harder, and you should ask if you can have a pinch of soil before you take it, unless there is some waste ground. Remember that you only need a very small sample: a single leaf, or a sand or soil sample no larger than the tip of your thumb.

If there is a community garden near your home, you can ask there, or if there is a park, take a small glass jar along and talk to one of the gardeners, show them your jar, and ask if you can take a small sample of soil. If your high-rise block has gardens that are managed by gardeners, ask one of them to let you take a sample. As a rule, adults are keen to help people of all ages to learn.

Seedling roots

Unless you are used to weeding, you probably won't have really noticed roots in any detail. There are two easy ways to get some: the first is to pull a few small weeds out of the garden, making sure the 'weed' you choose isn't somebody's prize petunia! Weeds are free, but for obvious reasons, avoid Asthma Weed (Pellitory or *Parietaria judaica*) and plantain (*Plantago lanceolata*), which causes hay fever.

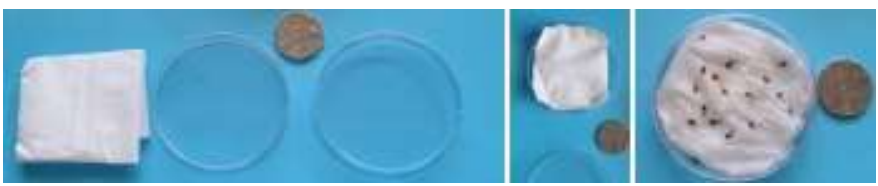
Once again, talk to a gardener, this time asking about the weeds in your local area. The safest seeds are radish and dandelion, but any crop seeds will do, if you lay them out on a damp tissue in a dish.

Avoid using perfumed tissues (if they still make them), because those with eucalyptus extract (at least) can delay germination for up to a week. (People looking for science project ideas, this is a hint!)

If your area has sheoaks (*Allocasuarina* sp.), leave some 'cones' on a saucer for a week, and you will have plenty of seeds. Put them on a damp tissue, wait another week, and the first shoots will begin to show. One week after planting the *Allocasuarina* sp. seed, a root was clearly visible. Two days later, a shoot was visible.

I used *Allocasuarina* in the photo above. You will get faster and better results with most weed seeds, but growing a young tree is more satisfying. Most wattle (*Acacia*) seeds are good, and you can try planting one or two out. I favour using (harmless) local weeds, because they are cheap and easy, but mainly because weed seeds have to be good at grabbing any opportunity to germinate.

Radish seeds germinate well on a damp tissue, and so do dandelion seeds and Cobbler's Pegs seeds. On my quick test, 2 out of 25 Cobbler's Pegs seeds had stems and roots in just three days, but the rest had failed to respond. Five days later, a week from planting, 23 of the 25 had sprouted. Be patient!



You can use old saucers, jar lids, Petri dishes or anything else that is a similar shape. A Petri dish is best because with the lid on, the paper stays moist longer. Put some paper towelling or paper tissue

on the saucer or dish (I fold a normal tissue in nine to fit a 60 mm Petri dish). Dampen the paper and add seeds, then set the dish away for a week or two and check it every day or so.

Once the seeds sprout, you need to remove the lid so they can push upwards, and keep the water supply up. Look for a root, and as the root develops, use forceps (tweezers) to lift one seedling onto black cardboard to photograph it. If you look closely enough, you may even see root hairs, but we will come back to those later: there is more about this in chapter 11.

Looking at dandelion seeds

You will need a container to hold the seeds, a face tissue, water, and a container to germinate the seeds in. Tweezers might also be useful. Look around the streets, because on waste ground, you should find some plants. The seed heads are best carried home in a sealed jar, so the seeds don't all blow away: use your lens or microscope to look at the plumes on the seed.

Pluck off two or three seeds. Throw them into the air, and watch them drift. What does that tell you about how the plant spreads from place to place? Then inside, in a room with the doors and windows closed, strip the rest of the seeds into a dish, and get rid of the stalk.

Notice how some of the plumes don't have a seed attached: did the seeds come off, or did those seeds fail to form? (I don't know the answer: *you* find out!). Then take ten seeds and put them on wet tissue in a dish. Just plant ten!

In the right-hand shot above, you can see what happens if you add too many seeds: a jungle! Look at your dish one week later to see how many of the seeds sprouted: that tells us why dandelions

are weeds. If you plant a few of these in small pots, and water them carefully, you should be able to grow them to the flowering stage, and if you watch them outside your window, you may be able to work out what pollinates them. You can also lift one plant a week, and look at its roots under the microscope. (No, I don't know what you will find: *you have to do some science*!)

Look out for these:

- Roots will start to form root hairs (we will look at root hairs in chapter 11);
- The first leaves out of a weed seedling may be different: they are called cotyledons;
- Plants like grasses have one cotyledon, and they are called monocotyledons;
- The other plants, the dicotyledons, have two cotyledons.

You want more plant stuff? That's in chapter 11, but to work there, you need to make a hay infusion now, because it's what chapter 11 starts with, and a good hay infusion takes time to grow.

Preparing a hay infusion

A hay infusion is a sort of cold vegetable soup, with all of the nutrients most pond life needs, both plant and animal forms. Just get an old saucepan and boil some grass in water, then let it stand in a bucket for a day or two. Or cover some grass or leaves with water, and put the container in a warm place, out of direct sunlight. The formal names for this sort of thing are 'algal culture' or 'hay infusion', but I prefer the blunter term: green slime, and that's how you will meet it, later on.

There might be disease-causing pathogens or cyanophytes (blue-green algae) in any water samples that you collect, so use gloves

and/or wash your hands thoroughly. I always take a plastic bag with me to wrap wet bottles in after I have taken a water sample, and I wash my hands after taking samples, using bottled 'hand-wash', and a rinse of fresh water. I recommend that you do the same.

I usually keep a few clear PET (soft drink) bottles, half-full of water and assorted slime samples that serve as sources. I leave these outside my study and use them to start new cultures, and I add small water samples from random pools and ponds to boost the variety in the containers. I *like* surprises!

I get water samples with a used washing-up liquid container, the sort that has a pop-up/pop-down lid. Once this is washed out thoroughly, I take it when I go walking. If I see some nice green water, I pop the lid open, squeeze some air from the bottle, turn it upside down, push the top under water and unsqueeze to take a sample. Sometimes I increase the animal catch by taking water from close to plants, rocks or the bottom. Then I bag the bottle and wash my hands.

You can also boost the culture by adding a few small slops of water from a pond or a slow stream, or some of the cloudy water from the bottom of a vase of dead flowers. Another booster: I usually toss in a small pinch of all-purpose fertiliser. Once you have done the preparation, you will need to wait a couple of weeks, after which this will contain lots of microscopic life. Hold a clear bottle up to the light and look for anything that seems to be moving independently.

Once you have done the preparation, you will need to wait a couple of weeks. So let's move on to other things, working the simplest way, using a hand lens to look at a few things.

While you are waiting

I know you want to get started, so here are a few things to try looking at with a low power lens. If you haven't already done so, look at:

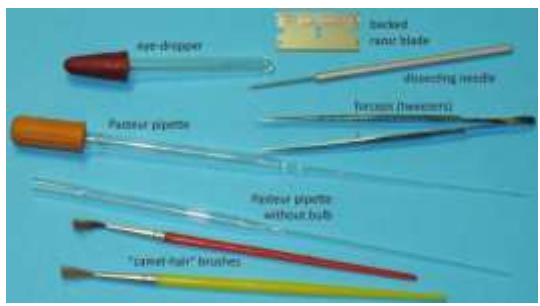
- your skin and nails;
- some pieces of stone;
- your hands and fingers;
- some old pieces of wood;
- some leaves that feel 'furry';
- your clothes and some cloth;
- the edge of a piece of torn newspaper
- hairs and bristles on insects and mammals;
- the fine detail in some birds' down and feathers.

Once you are comfortable with your embiggener, let's take a first look at microscopes.

3 Real microscopes

If it isn't raining, jump into chapter 4 and come back to this later. Otherwise, if it's raining, it's time to learn some tricks of the trade. Serious work needs a binocular (or dissecting) microscope (left in the photo) or a monocular microscope like the one on the right. The eyepieces deliver x10 magnification, the objectives on the binocular one give x2 and x4, and the monocular one has x4, x10 and x40 objectives.

Binocular microscopes are easy: put the thing you want to look at in a dish, get a strong light that shines into the dish, and go for it! There are times when it helps to have the dish lit from below, but most of the time, just sit your dish on a microscopy plate. My binocular microscope came with a plate that is black on one side and white on the other. You can also use black and white use tiles and paper.



Working with a monocular microscope is harder. You need the microscope, slides and preferably a few well slides, cover slips, fine forceps, at least one dissecting needle, and a fine camel hair brush. An eyedropper or a Pasteur pipette will help.

For some work, you may need some **entomological pins** to hold specimens in place. If your microscope does not have a light source, you will need that as well. Just about everything you look at will be in water, with a cover slip on top, something we call a wet mount. You will also need some Petri dishes to store specimens and study material. Here you can see my pet leech Gladys, safely contained.

Choosing a microscope

For serious work, you don't want a cheap toy with plastic lenses—you need good glass lenses. On the other hand, microscopes can be expensive, so it might be a good idea to start with a toy or a second-hand microscope. I bought two new microscopes when I started writing *Australian Backyard Naturalist* in 2011, to see how useful an average entry-level microscope would be for young people.

Monocular microscopes have one eyepiece and a higher magnification, and binocular ones have two eyepieces and a lower magnification, but they let you examine small things in 3D. You can also dissect things, which is why we often call this type a dissecting microscope. I bought my two from an Australian supplier.

The microscopes were made in China, and while the shop seems to have gone out of existence, Amazon offers similar products (and rather more cheaply!) My binocular microscope offered x20 (about the same as a good hand lens), and x40.

The x40 magnification shows up even the tiniest animals, because the microscope has one light above the stage and another under the stage, so I can look at things in a Petri dish and spot even tiny wriggling and swimming things. That one cost me $299, but you would get acceptable results now for around half of that. As a rule, you get more when you pay more, but read the reviews!

The monocular microscope has magnifications of x40, x100 and x400. It cost $199, but is probably not quite as useful to the amateur naturalist as the binocular one. It has an internal light beneath the stage and a small wheel with various size holes that can be used to control the amount of light. This replaces the iris diaphragm found on more expensive models.

> (The lightbulbs in my microscopes were hard to source. If you have a glass bulb with a pointed piece of metal at each end, those are called ***cabin bulbs***, and you can get them at shops that sell fiddly bits for yachts and cars, or you can get them online, using that name. Check the wattage and voltage ratings.)

Products at the low end seem to advertise that they deliver x200 magnification, which I doubt, but they retail for under $50, so I avoided them, except for the USB camera mentioned in chapter 1. As a rough guide, you will probably get junk below $150 or so, and magnification up to x400 on a monocular and x40 on a binocular microscope will be enough. I recommend getting one that has a built-in light, but this may need to be suited to Australian 240 volt power. Check this!

In about 2013, I also bought a different sort of USB camera ($450) which slips into the top of a proper microscope, replacing the objective (eyepiece). Some of the microscopic shots in this book were taken with it, but there are other USB microscopes around. Looking at recent offerings (April 2020), the price had come down a long way, and I bought a much better new one last year, for less than $100.

Probes and dissecting needles

You can make suitable probes from dowel stick, pins (not sewing needles!!) and epoxy resin. Just drill small holes in one end of a few 10 cm lengths of dowel. Mix up a small amount of epoxy resin on a bit of scrap cardboard with an old nail. Use the same nail to poke some epoxy resin down the hole and using pliers to hold the pin, coat its head with resin, then slip the pin into the hole, cover the

end of the dowel with more resin, and put it aside on old newspaper to set.

I sometimes use piano wire instead of a pin. I can sharpen one end on a grinding wheel and hammer the sharp end in. When the epoxy resin has set, I sharpen the blunt end on the wheel as well. Piano wire is often hard to get, but it is brilliant material for jobs like this, so search around. Sewing needles are dangerous to use in probes, because they snap and send bits flying when you use them with force. Grinding wheels can eat fingers: get advice and help before you use one!

Another solution is to get stainless steel wheel spokes from a bicycle shop: they sell for about 90 cents each.

Slides and thin sections

You have to use slides when you are using a traditional microscope. For things like pollen grains and sand under low power, two slides are better than an open dish, and that is safer than using a cover slip for beginners, but around age 12 or14, you will probably need to start using cover slips.

The idea behind using a slide is that you keep everything in the same focal plane, so the whole of your view can be in focus at the same time. Usually, there is water involved, which makes your slide a **wet mount**. Let's go there.

Making wet mounts

It is possible just to look at an uncovered drop of water on a slide, but you can see more through a flat surface, and that means using a cover slip of very thin glass to flatten the water out. You will almost certainly break a few cover slips and cut yourself at least once.

Wear safety goggles to protect your eyes, practise very hard at being gentle with the cover slips, and when the slips do break, get rid of *all* the broken pieces *very carefully*. The thing to note: to avoid getting air bubbles, there is only *one* correct way to put the cover slip on.

I got my adult biologist son to carry out a simulation with a 10 cm microscopy plate and a knitting needle. Because of the scale, he needed to steady the plate, but you don't need to hold the cover slip at all. (The reason is surface tension: look it up!)

Above, this is a simulation using a knitting needle and a round plate, about 10 cm across. The change of scale meant the operator had to hold the 'cover slip' steady to stop it slipping. Notice how the needle always touches the 'slide' and comes out gradually. Now let's look at the real thing:

Making wet mounts: the real thing, with a slide and a cover slip. The black side of the microscopy plate used earlier as a 'cover slip' is now being used as a background. Notice how the water flattens out in the last shot. You put the cover slip down so it touches the drop of water on one side, while holding the slip up with a dissecting needle on the other side.

Then you slowly pull the needle out, keeping the needle down at an angle of maybe 20°, so the cover slip comes slowly down on the drop, and the air underneath is pushed sideways. Before you put the slide on the microscope, use a tissue to remove any excess water from the slide.

Well slides

One of these slides solves several problems at the same time: if you are not using a cover slip, a drop of water evaporates quickly, but a well slide holds more water. If you have an organism that is 1 mm across, it will hold a cover slip up on one side, so you will be looking through a sloping surface.

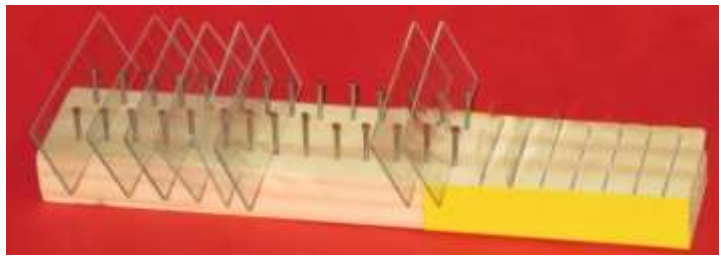
A well slide has a depression that the organism slips into, which saves it from being crushed. Well slides are quite expensive, but you can glue a thin washer to an ordinary slide to make something almost as effective. Use well slides to look at larger micro-animals, sand or soil.

Managing microscope slides

I wash and dry my microscope slides for re-use, and I needed somewhere to leave them to dry. I planned to sit them in saw-cuts in a piece of '2x1', but the saw I was using did not make wide enough cuts, so I used panel pins to hold the slides, and used the saw cuts that I had already made, to hold the cover slips. The pictures tell the story.

My slide and cover slip stand. I wash glassware in the plastic dish, blot it on paper towel, and leave it on the rack until needed.

Then because I use circular cover slips, when I moved my stand, the round cover slips rolled out. I took a piece of scrap plastic, cut two strips, and glued them along the side with Superglue. The other fix is to get square cover slips which are much better in young hands—or old hands.)



Another view of the stand with the sides added.

A simple microtome

You will only need this gadget if you have some microscope slides, and a way of viewing your slide over a light source. One way to beat the depth-of-field problem is to cut thin sections of things so all of the parts of your specimen are at the same level, just one cell thick.

You can do this using the sort of razor-blade that has a strong backing edge. These are very sharp and dangerous, so if you are young, get adult advice and safety goggles before you start. Thin sections can be mounted in water under a cover slip, and they will let you see cells, though unless you use stains (we'll come to those soon) you won't see much internal detail.

Before long, you will realise that your 'thin sections' are usually wedge-shaped, and you can see better detail at the thin side of the wedge. If you want a thin section that is even all over, you need a **microtome**. Professional microtomes are expensive, but there is a way to make one almost for about $2. All I needed was a razor blade and a matching half-inch Whitworth wing nut and bolt (some hardware is still sold in 'old' units).

For younger readers, ADULT SUPERVISION is essential for this one—risks include cuts and possibly broken blades hitting the eye. You will need a bolt with a wing nut to match, safety goggles, a safe

very sharp blade and an old cutting board. Note that the wing nut is on the bolt 'backwards'.

For your first attempt, cram a short piece of carrot (or celery) into the wing nut's threaded hole, then slip the bolt into the wing nut back-to-front, with the 'wings' at the end nearest the bolt. When you go to slice a section of carrot, you will see why the nut has to be this way around. Once the bolt has a grip on the nut, put on the safety goggles, get the cutting board and use the blade to trim off all the carrot that is sticking out of the nut.

As the bolt slowly moves into the nut, the carrot in the threaded hole is pushed out just as slowly on the other side, and if you slide a sharp blade across the flat surface of the wing nut, you will cut that tiny bit off, producing a thin section that can be mounted on a slide.

Now trim off any bits that are sticking out of the nut. Once that is done, you are ready to start sectioning. Turn the nut slightly, so a tiny amount is pushed out of the hole in the nut, and slice *carefully*. Then transfer the thin sections to water:

While you are beginning to learn how to cut sections, put the slices in a dish of water and repeat the operation until you master the method. Then throw away your first attempts and examine the good sections in a wet mount if you wish, but now you are ready to section difficult stuff like leaves. You will need some scrap

polystyrene foam to wrap around what you are sectioning. You can also use cork or a piece of carrot or potato for this, anything that grips tightly on the leaf or stem.

Professionals often use wax instead of foam, but ignore this. It is hard to make a water mount of a waxy section, because wax and water don't mix. Reference books recommend using very toxic chemicals to dissolve the wax, so polystyrene foam is safer than wax. Do some experimenting first: and remember that a piece of foam larger than the hole can always be squeezed and 'screwed' into the nut, once it is wrapped around the leaf or other object.

Put the wing nut on the bolt again, with about one full turn of the nut on the bolt, and then fill the empty portion of the nut with whatever you want to slice. If you really want to section a leaf in wax, prop the bolt upright in an old jar or can, poke the leaf in, and then drip candle wax in, until the leaf is surrounded with wax and leave it to set, but remember: this is *not recommended*.

Your view will still be a bit unclear, because most of the slices will be many cells thick, as you can see in my carrot thin section above. You need to learn to think about what you are seeing as you focus down. The thin edges of raggedy slices will always be the best parts to look at, and that is what I used here in this view of carrot tissue, cut with my microtome.

From Robert Hooke's representation of the 'cells' in cork, from his *Micrographia*.

Remember: practice makes perfect, but you don't always need a complete section in one piece! Why not try cutting two thin sections of cork, one hand-cut and one microtome-cut. Compare these with Robert Hooke's 1664 image of cork: he saw the holes as rooms in a monastery, and called them 'cells', which is where the name comes from.

Stains and the microscope

Stains are dyes, and dyes often cause problems. They can easily stain baths, basins, carpets, people and pets—among other things. More importantly, while pale and colourless chemicals can also be dangerous, you are usually wise to assume that coloured chemicals are *always* dangerous. Any chemical which attaches to a biological molecule inside a cell (as stains do) may also cause damage in the cells that are attacked. Treat all biological stains as dangerous, to be on the safe side.

That is why, knowing that some readers will be quite young, I have decided to say nothing much about stains, other than that they exist, and for serious science, you will need them. Most stains are one or more of irritants, poisons or suspected or known carcinogens (cancer-causing agents). If you need to use stains, research them well first, and discover the **Material Safety Data Sheet** or MSDS for short.

These sheets are easy to find on the web by searching on **<(*name of chemical*) MSDS>**. Some MSDS sheets are hard to understand, but the ones at **http://msds.chem.ox.ac.uk/** are reliable and clear. Try searching **<methyl cellulose MSDS>** and **<eosin MSDS>** for practice. (Eosin is often provided in microscopy kits, but even this may be a bad idea for young users.)

We are forever learning new things, and while methylene blue is regarded as safe now, even that may change. Read the MSDS first, before buying or using any stain! You also need to understand that an MSDS will spell out *all* the risks: read the MSDS sheets for table sugar (sucrose to chemists), water and table salt (sodium chloride), and you will see how complete and thorough the writers are!

A junk box wish list

Anybody who has read any of my three *Australian Backyard* books (see the reference list at the end) will know that I'm keen on using cheap equipment. That means you can make what you need, using materials that may be around your house. Anybody who has worked with me or been taught by me knows that I always have a well-filled junk box.

You can borrow from a tame adult, but clever gadgeteers soon start a junk box. Mine contains all of the things listed below, but remember that mine is a matured (like me!) junk box. So start collecting!

- Old wire coat hangers, copper wire, piano wire, light fencing wire, tie-wire, and pipe cleaners.
- PVA wood glue, 'Super-glue', contact adhesive, epoxy resin glue.
- Wood: mainly 41 x 19 DAR pine, but dowelling and scraps of wood are handy and so are a few pieces of 190 x 19 mm (8 x 1) board. An old broomstick can be handy.
- PET bottles with lids, especially large bottles, with the labels removed.
- Glass or plastic jars with large lids that seal to be watertight.
- Plaster of Paris, stored in a jar (you can buy it at the hardware shop in sealed plastic packs).
- Small clear plastic containers in which fruit and berries are sold in supermarkets, but treasure any clear polystyrene boxes (like chocolate boxes) that come into your house.
- Plastic flywire, old stockings or pantihose, an old handkerchief or a square of fine cotton or linen, and old curtain fabric (the white synthetic stuff that you can see through is good).
- Petri dishes are useful in so many ways that you would be wise to buy or beg some from somewhere. Each dish is made up of a base and a lid. They are named after their

inventor, Julius Richard Petri (pronounced 'Pea-tree'). Mind you, jar lids will do almost as well, in most cases.

- I usually carry a few small spice jars to catch or hold tiny animals, and I usually carry glass specimen tubes, 50 mm long x 10 mm diameter. These are fragile and not safe for youngsters.
- Brushes: old toothbrushes are useful to clean glassware and other stuff. Always grab any 'eyedroppers' that are about to be thrown out from ear drops and eye drops: they are perfect for water animals, but rinse them very well.
- You will also need a few tools like a saw, a drill, pliers and a hammer: especially if you are a younger reader, pay careful attention to the safety warnings. Talk to a tame adult!

Because I sometimes need to look a bit professional or can't make the thing I need, I occasionally buy equipment. I have been using one equipment firm for some years: Australian Entomological Supplies (www.entosupplies.com.au).

To indicate their prices, my most recent purchases include plastic Pasteur pipettes (30 cents each), 60 mm Petri dishes @ 55 cents each, 90 mm dishes @ 52.5 cents each (cheaper because they come in bigger packs), dropping bottles @ $6.20 and wash bottles @ $9.20. They also sell microscope slides, cover slips, hand lenses and forceps.

I recommend, as a minimum, a dozen Pasteur pipettes, 40 Petri dishes, and if you have a real microscope, you need at least one box of microscope slides, a box of square cover slips and probably two or three well slides.

I don't get commission or discount. I just like and support this very useful small business. There are probably others, just as good, but I have yet to find them.

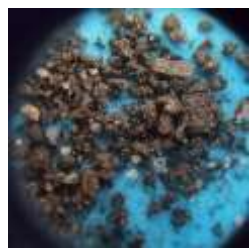
4 Non-living things

If you look at my other books, you will see that I trained as a biologist, but I care about earth science!

Sand and soil

All living things depend on each other. Tiny animals, bacteria and fungi help keep soil productive and fertile. Garden soil is more than 'dirt', it includes small rocks, sand, clay, air, dead and rotting pieces of plant and animal, and a very large number of live animals, fungi, bacteria, and the searching roots of plants. The living things in the soil all live by eating each other. Plants need the minerals released from dead stuff by bacteria and fungi. That is what the roots are searching for, along with water and oxygen.

Soil is much more than dirt, though this is easier to see in a sandy soil than in a clay soil. The soil in the jar shown below is about 50% sand. To try this for yourself, put some soil in a jar, add water, shake it vigorously, and then put it aside to settle. Any pebbles drop first, then the sand, then the mud, followed by the fine mud. Some of the plant material floats, and if you are lucky, some desperate soil animals will be clinging on to the floating bits.

Soil is worth exploring closely. If you have some well slides, mount a *tiny* bit of soil and look at it under the microscope, remembering that when you are preparing slides, *less is better*. Use just a tiny pinch of soil, well spread out in a Petri dish or on a slide, so you can see each bit.

Don't be surprised if you notice a few things moving around. Try comparing soils from different places. The shot on the right shows you what soil looks like under a clip-on at x15. Remember to

wash your hands after handling soil, because you never know where (or what) it's been!

Compare garden soil, which often has lots of extras added, with soil from a paddock or some rough ground. Many soils also have magnetic particles in them, mostly iron oxide. Wrap a strong magnet in cling wrap, and run it through some dry and powdered soil. The cling wrap saves you having to clean the small bits of iron and magnetite (a magnetic iron oxide) off. Just unwrap the magnet carefully when you are finished, and then examine the magnetic particles under magnification.

Over time, soils develop layers, forming a *soil profile*. There will usually be topsoil, subsoil and bedrock, but some soils are more complicated and have more levels. To see this layering, you need to dig a hole, about 60 cm square, with straight sides, and at least 60 cm deep, like the one on the left.

This sort of activity gets adults cranky, so ask for permission first! The layers you see as you dig down are called soil horizons, but they may be missing in garden beds and areas that have been landscaped. Or, there's a less destructive way, where you let ants do the work for you, bringing deep soil up to the surface.

You can estimate how much water a soil sample contains. Weigh some soil and dry it out at around 100° C for an hour or two in an oven, then weigh it again. Ordinary postal or kitchen scales will be good enough to calculate a rough percentage. The most important thing is to avoid high heat that might break down some of the sugars in dead plant material (the decay starts at 110° C, but the losses will be small until you hit 200° C). The standard for scientific drying is 105° C.

Limestone only breaks down at 900° C, so you'll have no worries there. If you heat the dried soil sample for several hours in an oven at 350° C, you will burn out most of the plant and animal matter, and you may be able to estimate the amount of humus and litter in the soil, but the results may not be all that accurate. It might also be a bit smelly, so talk to the tame adult in charge of the oven, first!

Look out for these:

- Grains of sand, maybe particles of clay;
- Tiny, live animals;
- Fragments of dead animals;
- Fragments of dead plants.

Dry soil

Rocks break down under the influence of water, air, heat and cold, the impacts from falling rocks or lightning blasts, the hooves of heavy animals or the wheels of vehicles. Earth scientists call these changes *weathering*, and we will look at weathering more closely later in this chapter. The rock fragments left behind after weathering fall down, or are washed to some low point, where the less stable minerals break down, mainly forming clay and some soluble chemicals that leach out. Waves and rivers play a role as well, but the end result is sand which gets washed away.

Soil is weathered rock, rotting leaves and twigs, dead animals, and living things, like small animals, fungal spores and bacteria. You won't see clay particles, but you can see sand grains, bits of rock, and *humus*, the Latin word for soil, which now means the soil parts that were once living. Dry soil is best to look at under the microscope, because you can crumble it.

The drying is easy: lay the soil out on a plate or saucer in a thin layer, break up any clumps with a spoon, give it 20 seconds on high in the microwave, and then increase the exposure by ten seconds each time. Heat the soil gradually because steam may form inside clumps, and some of these may pop if you give them too much heat all at once, and this makes a mess in the microwave.

After 60 seconds, there should be no water left, but crush the soil lumps with the back of a teaspoon. If the soil sticks to the spoon, give it another 90 seconds on high, then two minutes, and leave it to cool. It should now be extremely dry, and the time taken is less than you would need to clean the microwave. Finish the crushing and take a sprinkle with the spoon, remembering in all microscopy work, you need to look at the thinnest of thin layers. Look for the unexpected. Most great discoveries began when somebody said, "That's odd!"

The microwaving process means there will be very few things alive in there, though it is possible you will see a few bits and pieces of animals and rather more plant fragments.

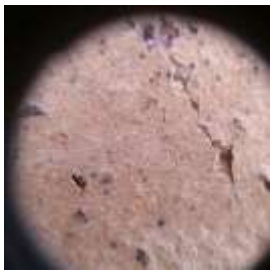
Looking at the mortar between bricks

You need a brick wall, ideally one where the bricklayers weren't too tidy. You also need either a device and a clip-on or a camera with a macro lens: you can't do this with a microscope. Choose a place where the bricks and the mortar contrast well. I found that it helped to have a small corner of a brick in the picture as well. You can see it here, at the very top of the shot above.

The 'pointing' (mortar) between bricks is four parts soft sand and one part cement, but you may have trouble getting the mortar in focus. With any sort of luck, the bricklayers will have left a few traces on the surface of the bricks. When I tried this, all I could see was sand grains. The ratios for sand and cement in mortar can vary, depending on its purpose. The numbers can be found on the web by searching on <**mortar mix ratio**>.

Now what about the bricks?

Looking at bricks and tiles



Once more, a microscope won't do. You need either a device and a Go Micro or a camera with a macro lens. You also need a brick wall (see above), or a loose brick and some roofing tiles. Half-bricks and broken tiles are a good idea: fragments are lighter and safer, and you can also look at the broken surfaces. You only need one or two bricks and tiles with different textures to be found. Be aware of different sorts of brick, terra cotta tiles, concrete tiles, slates and more.

Looking at sand again

I am an active volunteer bush regenerator, and I am their erosion obsessive, applying the traditional Australian solution to erosion gullies called "chuck a log in it". This involves disrupting and calming torrential flows that gouge out clay, sand and even pebbles. Water trickling instead of rushing down a gully loses its load of sediment, soaks in, and fails to carry any more sediment away.

As you can see, I mainly use rocks, not logs, but the principle is the same. The rocks in the developing gully above were later extended to fill the entire trench, and they are now all hidden by sand that has washed in. I have spent a fair amount of time comparing the sand at

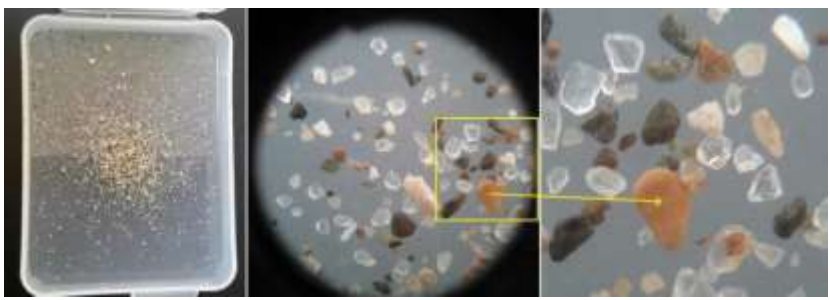
both ends of a few gullies, and not seen any differences, but the question is worth considering. Who knows? Your results may be different…

All sand may look the same, but as builders can tell you, there are many classes of sand. It's only when you get up close that you can see the variations in the minerals, particle size and particle shape. In short, sand is more than just sand. Spread the dry sand out thinly, and you can learn a great deal. The science lies in the details.

You only need a small sample of sand, and small empty jars from the spice rack are fine. If they have paper labels, you can write on them, and taking this amount of dry sand from a beach should not raise an eyebrow, but check for local regulations.

I also use zip-lock sandwich bags for sand samples. They are light and convenient, and you can write on them with a ballpoint pen. Sand from freshwater areas may have some biological or industrial contaminants. If wet sand is dried in a microwave, it will 'pop' and throw sand. It is better to sun-dry the sand in a shallow tray.

You will need some black cardboard (also blue, if you are looking at 'black sands') and a variety of sand samples. Some Petri dishes or jam jar lids would be handy. Here's what I found, while in New Zealand, playing with my grandchildren in early 2018. We spent most of our time at the beach, where there was a lot of sand, and we had a brand-new clip-on to play with.



Three views of the same sand sample.

Look out for these:

- Grains of different size;
- Grains of different colour and origin;
- Remnant bits of plants and animals.

Crystals

No ordinary microscope will ever show us atoms, but we can see the evidence of atoms, scientists say. They explain it like this: objects the same shape and size always form regular arrangements: snooker balls in a frame, or oranges in the fruit shop do this, and so do gobstoppers.

Notice how the gobstoppers in the circle have packed to make a neat hexagon. Atoms in a crystal behave the same way. Depending on the shape of the units, crystals may take up different shapes, but *crystallography* is a whole branch of science, and I want to keep things simple.

You will need slides, an eyedropper, some paper towelling, soluble material such as sugar and salt, and enough chemical knowledge to judge whether or not spilled solutions can damage your microscope. If you are in ANY doubt, assume that the solution is harmful. To be on the safe side, leave each slide inside a 90 mm Petri dish to protect the microscope.

The idea is simple: make a saturated solution of a salt (that's a solution with as much salt as the water can take up). When some of the water evaporates, crystals start to grow. The amount of the solid

you need depends on what you choose. With table salt, you need about 4 grams in 10 mL of water, with Epsom salts (magnesium sulfate), it's about 3.6 grams; ordinary sugar (sucrose) is about 21 grams; while a saturated borax (sodium borate) solution contains around 0.3 grams in 10 mL of water. If you don't have a balance, don't worry: any unsaturated solution will soon become saturated as it dries out.

Place a drop of your saturated solution on a slide, spread it across the slide, wipe the under-side of the slide on the paper towel to clean up any spillage, then put the slide carefully on the microscope stage, *without a cover slip*, and wait for it to dry. If you can, photograph the slide as the crystals develop. Many of the crystals will be long and needle-like because of the way drying happens: I leave it as a challenge to find a way of producing larger, more normal crystals under these conditions.

When you look at sugar and salt, they are both white crystals (unless your sugar is brown sugar). Our taste sense tells us salt and sugar are different, but can we *see* a difference? To find out, you will need small amounts of salt and white sugar at least, and if possible, 'coffee crystals' and rock salt, which have larger crystals, black cardboard, and an embiggener, preferably one that can be used with a camera.

Photograph the different specimens, make sure the pictures are correctly identified, and then examine the different shots. What differences can you see? Here is what I found:

One is salt, the other is sugar: those with a smattering of chemistry can tell which is which. Work it out!

Look out for these:

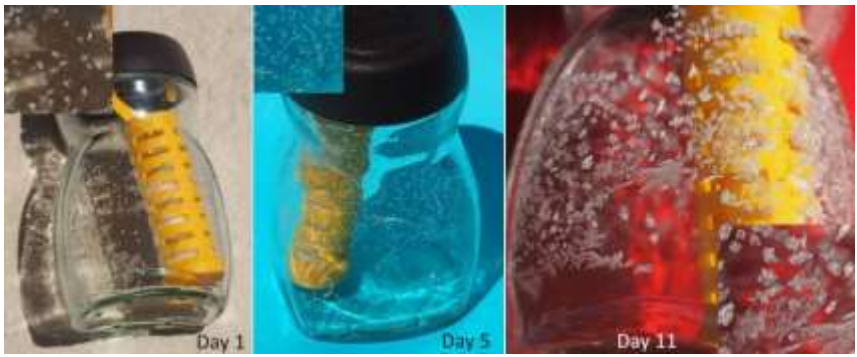
- Regular straight edges and angles;
- The same pattern repeating in different crystals;
- Irregular bits where two crystals have joined together.

Naphthalene crystals

Naphthalene is flammable when heated, but in a sealed container like a jar, it is safe enough. The solid naphthalene sublimes, which means that, left on a sunny windowsill, it changes to a vapour without melting, and later, it condenses on a cooler part of the jar, away from the sunlight.

Be careful: 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 talk to a tame adult and be careful. Don't dispose of it, because it lasts for years: see the 22-month shot, in the set of photos on the next page.

You need a pack of mothballs from the supermarket, a clean jar with a tight lid, a place to leave the jar, and two weeks or more. Just 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 young children. You will see results after the first day, but really nice crystals take as much as a month. This exercise works well on a north-facing windowsill, but mine was just left on a north-facing deck, and that worked just fine.



The same jar on days 1, 5 and 11. The insets show the crystals in greater detail.

A clip-on view of the crystals, taken after several months, and the jar, almost two years after it was started.

Borax crystals

Borax can be found 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 it is not *extremely* poisonous, 5 or 6 grams of borax could kill a baby. The powder or a solution also burns the eyes, so be careful handling it. Common sense and safety goggles are 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. You also need a small Petri dish, an old teaspoon 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

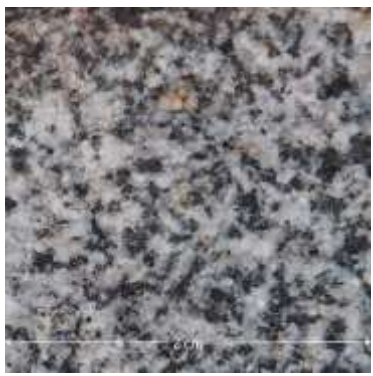
don't need to be precise here, because if the borax solution isn't saturated, it will become saturated as water evaporates. After a couple of days, crystals start to grow, or after an hour, if you leave the dish in the sun on a sheet of black paper (use paperweights!!).

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

Granite fragments

A chemist testing granite and pumice would say they were very similar, but pumice floats and granite sinks. Poets call any hard rock granite, stonemasons call any rock granite if it has crystals you can see, but geologists divide the big-crystal rocks up into granite, granodiorite, diorite, gabbro and others.

To geologists, the poet's granite and the mason's granite may not even be granite! All of the rocks with big crystals have one thing in common: they cooled very slowly, far beneath the surface of the planet, maybe 10 or 20 kilometres down. Down there, molten rock (called magma) cools slowly, so it has the time to form big crystals, ones we can see with the naked eye, meaning without any magnifiers.



As the label on the photo above indicates, this is a 2 cm x 2 cm square of granite. The easiest way to get bits of granite is to look for it as 'crushed granite': look this term up on the internet and you will find that there are people selling it near you, mainly for paving, landscaping or bonsai.

You may also be able to scrounge pieces of rock from a monumental mason (somebody who makes grave stones). You need fresh, unweathered surfaces, and that requires some care. The next picture comes from a 'hand specimen', about 8 cm from one side to the other.

It was found beside a road near Hartley, just across the Blue Mountains from Sydney. Above is my hand specimen before I bashed it: the inset shows the square at the centre bottom. I needed to break it, and that needed a hard, safe surface and protective goggles. I placed the rock in an old sock, on top of a brick in a plastic tub. Then I put on safety goggles and hit the rock, hard, with a hammer. I used the sock to catch most of the bits, so I could look at them later, and here they are, seen by reflected light.

It might be worth looking at any effects of polarised light here, though that sort of work is best done with thin sections of uniform

thickness. If you have access to high power magnification, why not try hitting a few other rocks?

Can you see crystals in basalt, for example? What can you see in limestone and sandstone? You may be tempted to bang rocks together to get fragments, but this is not a good idea: you may mash fingers or get fragments in your eyes. If you use a hammer on a rock, use safety goggles and a breathing mask, but don't try to smash up pumice, and don't try to grind it, either. ***Not ever!***

Look out for these:

- Crystal shapes;
- Different minerals.

Looking at pumice

Pumice floats in water. It is easy to make pumice dust by rubbing two blocks together, ***but this is very dangerous***! It occurred to me to try it, and I did my grinding outdoors with a breathing mask, but then I had my doubts about the safety of doing this. I looked it up, and found evidence in the medical literature of pneumoconiosis in Italian pumice stone workers: this is a serious lung disease. **DON'T TRY IT!!!**

You need pieces of pumice, which can be bought (expensively) from pharmacists or small lumps lie around at higher levels on many Australian beaches, and thereby hangs a tale. New Zealand's Kermadec Islands are uninhabited, except for a small station on Raoul Island. When a volcano erupted on a seamount (a mountain under the sea), 250 kilometres south-southwest of Raoul, in the middle of July 2012, it was a big eruption.

Still, nobody noticed that a submarine volcano on L'Havre Seamount was releasing pumice and ash, which forms when gas-rich molten rock is under huge pressure until it emerges from the volcano into comparatively low pressure. In water, it cools too quickly for the gas to escape, so the gas just expands and forms bubbles, making a rocky froth that floats on water.

Even though the pumice output was about the same mass as the world's annual coal production, we didn't even hear about the event until large amounts of pumice were washed up on beaches on the east coast of Australia in the summer of 2013–2014. In 2019, there were still small pieces of pumice on east coast beaches, above the tide mark.

Out in the ocean, tiny animals hatched from fertilised eggs, found the pumice and made a home. You can often find some of the animals, mainly gooseneck barnacles, on old footwear that is washed up on the shore, and also on pieces of driftwood.

On the left, tube-worms, centre, gooseneck barnacles, right, a close-up of the remains of a bryozoan, all on pumice.

Work over any pieces you find with a hand lens: you will probably find a few surprises. These days, traces of life are rare, but the porous nature of pumice makes it interesting as well, and next time there is an eruption, you will know what to look for. (Note: in April 2020, there's one on the way, they say, but it hasn't shown up yet!)

Look out for these:

- Pores in the pumice;
- Sand and other things caught in the pores;
- Traces of life growing on the pumice.

A few more rocks

Looking at sandstone

Sandstone is a sedimentary rock made mostly of small grains of silicon dioxide (quartz) sand. Sandstone isn't usually made from beach sand, but from sand washed down huge rivers.

You need some **hand specimens** of sandstone. Geologists give this name to any piece of rock that fits in the hand, but pebbles will do: the piece shown below is a biggish hand specimen: its largest dimension is ~8 cm. What you use to look at it will depend on the size (and height) of your sample. This fist-sized hand specimen of sandstone has a streak of darker mineral sands in it.

Hand specimens won't fit under any of my microscopes, but you can tackle them with any of a camera, a hand lens and a clip-on. I chose the specimen above because of that vein of darker minerals in it. The sandstone below contains quartz pebbles, evidence of a flood, long ago, a rushing current that could push larger pebbles than the usual. Even in the commonest rocks, there will always be variation, if you look hard enough.

Weathered sandstone

Over time, all rocks 'weather', which means they break down as air, water, heat and cold go to work on the minerals in the rocks. These effects are worth studying, but please don't break any bits of weathered rock off: admire the forms and leave them. Here, we see weathered sandstone, shaped by iron oxides that have been carried in by seeping water.

There is a very curious form of weathering, called honeycomb weathering, because it looks a bit like a honeycomb. There are a few theories about how it is formed: nobody is quite sure why it happens, but it does, all over the world.

On the left, we see honeycomb weathering in sandstone at Cape Banks, N.S.W. On the right, a specimen from Maroubra, N.S.W.

Sandstone and fossils

Fossils are rare in sandstone, because the grains are too large, but there can be interesting traces in the rock. On the left below, you can see what are probably wormholes, but what made the holes on

the right? These are worth more study! (We come back to fossils in chapter 12.)

You can rub two pieces of weathered sandstone together to get some sand grains. Do this outside, and wet the sandstone to reduce any dust. Wash the grains into a dish and then transfer them to a well slide. I repeat an earlier hint for rock collectors: I have often used stone yards as a source: they have broken bits and off-cuts that they otherwise need to pay to get rid of. It's worth asking!

Sandstone is effectively glued-together sand, the gluing being caused by long-term pressure and some heating. I am unaware of any research on the times, temperatures and pressures needed to form sandstone, but then I'm not a geologist. The Beatrix mine in South Africa goes 2.2 kilometres below the ground, and the temperature increases by about 29º C for each kilometre. At the bottom of the mine, the rock temperature is close to 100º C, the boiling point of water at the surface. The pressure in the rock is about 50 megapascals, which means about 0.5 tons per square centimetre.

About 10 kilometres below the bottom of the Beatrix mine, the rock pressure would be around 300 megapascals. Imagine an African bush elephant (the biggest type of elephant) wearing really fashionably pointy high heels, balancing on just one of those heels. The pressure under that heel would also be around 300 megapascals.

An elephant in high heels, you say? Look: I told you to imagine this. It's not as though I suggested a flea in gumboots or a fruit fly in fluffy slippers or something!

Looking at shale

All people have their faults, but I keep mine on my desk. *Boom tish*. This is a story, rather than an enquiry the reader might pursue, because you would need the correct material and access to a diamond saw, if you wanted to try this.

I found the specimen you see above while looking at the entrance of a tunnel, part of the disused Sandy Hollow railway in the Hunter Valley (NSW), where I picked up what I thought was a piece of mud-covered slate.

It was only when I got home and washed it that I realised that this mud-covered block was in fact varved shale, and then I noticed tiny geological faults in it. I started trying to cut a clean edge with a hacksaw, but it was difficult because the block kept rocking. In the end, a work colleague used a diamond saw to give me one nice flat surface. Anyhow, it's fun to see what we can do.

Typically, each varve pair represents one year (or one cycle) of deposition. Varved shales are often found downstream of a glacier, where there is a reduced flow in winter and a greater flow in summer. These are both x15.

The magical part, for me, was finding tiny faults in the rock, probably produced by local slumping, because none of the faults extends very far.

If you go to the site, I wouldn't trust the stability of the tunnel much, but the shale bed (from memory) is at head or shoulder height on each side of the tunnel, and my piece was outside the

tunnel, on the ground. I have no idea where else you would find this rock.

Look out for these:

- Bedding planes in the shale;
- Splitting, weaknesses and faults in the shale;
- Any signs of weathering in the shale.

5 Other ways to find or catch things

The sun is shining as I write this, so I will pretend that your rain has stopped as well, and take you outside to the places where there are living things waiting to be caught and examined. Last century, every specimen would have been killed, labelled and stored away, but that is now frowned on. Instead, we admire in place, or we take inside and admire, then we release our temporary guest.

For example, where people used to kill ants, you can attract them with a drop of honey or Vegemite, or a scrap of meat on a sheet of paper. When there are enough ants, pick up the sheet and shake a few of the ants into a jar, and when you have finished, let the ants go where you caught them. You can cool an ant down in a refrigerator (not a freezer!), so it moves more slowly.

Predators are all good at seeing movement, because moving things may be food. Prey animals have to be just as good at seeing movement, because any moving thing might be a hunter. Our ancestors were probably once both prey and predators, so we have inherited the same ability from the survivors, and that brings us to one of the gentlest methods. The best way to see life in a rock pool is to sit and watch, but exactly the same method works almost anywhere in nature. Sit still in a tree's shadow on a night with a full moon and you may see possums, bats, night birds and more.

Sometimes, the animals leave marks. The tracks seem a bit mysterious at first, like the marks I sometimes see on dry sandstone, or the related tracks I sometimes find in rock pools.

Above, on the left, these trails were made on sandstone by an unidentified snail browsing the algae on the surface of the wet rock. On the right, the trails in sand on the bottom of a rock pool were made by the black periwinkle, *Melanerita*.

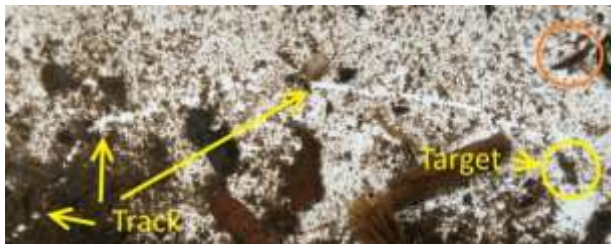
If you sit by a rock pool and don't move, shy animals will soon begin to dart around, but more importantly, you will notice the slow movement of snails like the periwinkle snails above. If you move your hand and throw a shadow over the pool, shy animals may rush into cover, but snails don't stop. They have tough shells, and nothing much can hurt them.

Using a white dish makes it easier to see moving animals. When you pick up some leaves or grass clippings, there may seem to be no life there at all. If you spread the material out on a white surface and wait, you will soon see small animals moving around cautiously, looking for somewhere to hide. White paper will do as well, but a white dish stops them escaping. Even a clean margarine tub works.

You will need some sort of probe (a water colour paint brush, a stick, a piece of wire, an old pen or pencil) to move the litter around. If you do this in strong sunlight or under a bright lamp, any animals you uncover or dislodge will scurry off to the nearest shelter, and you will see the movement.

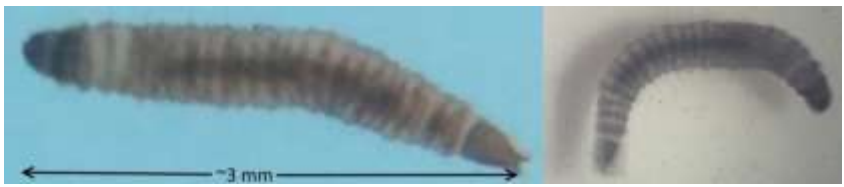
I use an old white enamel dish, the sort my grandmother once used for cooking. These are heavier than plastic dishes, and they are useful for many other things, but plastic ones are fine. You can also use the dish, with salt water in it, to shake off the small animals clinging to a piece of dried seaweed. Just put some seawater in it and swish some seaweed off a beach through the water to shake or wash loose the animals that were living in or on or under the seaweed.

If you rinse the dish out, you can tip in some muddy swamp water and wait to see what crawls across the bottom, leaving a trail. Usually these will be planarian worms (*alias* flatworms) or snails), but be ready for surprises. One day I went to a site where I hoped to find flatworms. I scooped up muddy water, and let it settle in a white dish. Below, you can see the track I saw.



There are three things to see here: (1) the target animal (a blob in the yellow circle), (2) the track from the lower left corner almost to the right side that gives it away, and (3) the mystery animal circled in orange, which I only noticed when I was marking up the photograph.

The mystery animal looks like a velvet worm, but this thing was living happily under water, and velvet worms don't do that. The target animal, the one that made the track is also a bit of a mystery, but it was an insect, and probably the larval stage of a midge: there were also mosquito wrigglers in the same sample. I picked the target up with a Pasteur pipette and transferred it, first to a Petri dish, and then to a well slide. Here is how it looked.



Notice the scale: on my screen, the animal is about 180 mm long, which would make the magnification x60, but as you see it, the animal will be smaller. Does this make the magnification less? Of course it does, and that is why a *relative* scale like this is better to use. As I said in chapter 1, "magnification" values are misleading! Then I transferred the slide to a binocular microscope with a camera fitted, and got the slightly better shot on the right.

As you can see, there's a bit more detail here, but the white dish was essential to finding it in the first place. You can use a white dish instead of an umbrella to shake insects and spiders off a bush, so you will be seeing my dish again and again.

Unexpected umbrellas

There are probably some old sheets around the house, maybe put away to use as drop sheets when the house needs painting. At a pinch, you could use white paper or even sheets of newspaper, but old bed sheets are the best. Otherwise, you need an umbrella, but let's talk about the sheets first. All you have to do is spread a smooth sheet out on the ground under a bush, then give the bush a good shake, and see what falls out. One form of this method is quite old, because an artist called John Lewin, who travelled to Australia in 1803 to paint insects, wrote a letter about using sheets.

You can also shake a bush over an upturned opened umbrella. Collect the fallen animals with a pooter. Then tap them to the bottom of the pooter, take off the lid, and shake them out into a jar or white dish. Plain black or white umbrellas work well—or even a black and white umbrella. Aside from an umbrella, you can find small animals on bushes and trees by looking carefully on the bark of the trunk, and on the backs of the leaves, but there are other ways to collect small animals.

A shelter board

Some of the most interesting backyard wildlife is the tiny shy stuff that only comes out after dark, animals that scuttle into cover at the first sign of movement. You can use this reaction by putting a board in a part of the garden with lots of fallen leaves.

You need a piece of timber board, about 15 or 20 cm square, with a hole in one corner, a piece of string or light rope, plus four pebbles. Sit the board on the pebbles, leaving just enough room for small things to squeeze in underneath, and leave it overnight. When

you lift the board, the animals all rush off, looking for cover, so you have to look quickly, or get to work with your pooter.

One important safety hint: spiders and centipedes may hide under the board, so drill a hole in a corner of the board and attach a string so you can lift the board and look under it safely. Otherwise, you can use a stick, a trowel or a screwdriver to raise the board. Just play safe!

Making a pit trap

To keep your specimens under the board until the next morning and to stop them running away, you need a clean small jar, buried up to its neck in the soil of a garden. The best place is somewhere that has lots of sticks and leaves on the ground, stuff that provides food and cover. This is just a shelter board trap with a jar under it to hold most of the prisoners.

Use a trowel to dig the hole, put the jar in carefully, and pack soil around the edges, trying to keep the soil out of the jar, though a bit of soil won't matter. Then put four pebbles around the jar, lay the board on them, and leave the trap overnight. The board keeps out the rain and big predators, while the gap lets small animals in to take shelter.

The next morning, look at them in the jar, examine or photograph them, and then let them go. As well as lizards, you may find insects, spiders, mites, slaters and pill bugs, maybe even some amphipods. If you don't know some of these, keep reading! If you want, you can add some food scraps for bait: in science, every idea can always be improved. Most animals will be attracted by the right bait, but only use small amounts of bait. Old bananas and rotting fruit work on fruit flies and quite a few other small animals, while a tiny piece of scrap meat will bring a different set of visitors.

You may also get *some* insects to come if there is a small light in the jar, though other small animals like to shelter from the light, and will avoid the trap. Play with this!

A simple trap

To make this, you need two large (1.25 litre) PET drink bottles and food scraps for bait. You need scissors for cutting the bottles and making holes in them, and a place where your traps can lie undisturbed for several days. (PET is polyethylene terephthalate, the clear plastic found in most soft drink bottles.) Here is what the trap looks like.

This design uses a PET bottle with a hole cut in the side, and the top of a second PET bottle poked into the hole (get adult help to make the first hole). There is a trick to getting the neck of the funnel piece through the hole in the side of the bottle, based on the **Law of Holes**: *you can make a small hole larger, but you can't make a large hole smaller.*

The starter hole in the bottle has to be made with either scissors with sharp points or a knife with a sharp point: this is best done by an adult! Use a small pair of scissors to cut a hole that is too small, and cut a series of radial snips, as shown in the picture above. Now, when you push the bottle neck into the hole, the small flaps push back, and the neck is gripped in the hole.

Add bait to the completed trap, and set it out somewhere away from interference from pets, possums and small children. Dream up your own bait, but I have had success with meat for blowflies, banana skin or a small amount of white wine for fruit fly (their other name is 'vinegar flies', and over a day or so, the wine will turn to vinegar).

Maybe you can find a way to put a light inside the bottle, through the side-hole, so you can make a light trap? Think about covering most of the bottle with aluminium foil, so the insects go to the funnel.

I have used the same trap design in the shallow waters of a swamp, using meat and bread baits, and had interesting results. I attached a string tied to a bush to stop the trap washing away or being carried off by animals, and I put some stones inside to make the trap sink. This is a partly-baked design that I leave for you to improve. I mainly caught small fish and some insect larvae with it, but see what *you* get. Try using other baits, or even try leaving a waterproof light in there, overnight.

And remember: Rule 1 of being a naturalist: the most interesting questions are your **own** questions!

Things hiding in the open

You need some trees, a pooter or better still, a portable vacuum cleaner like a 'Dust Buster' (you need to have a clean bag and shake what you collect into a white dish) and a hand lens. Bark is an excellent hiding place for flat huntsmen spiders and other interesting life forms. You can also search trees with a hand lens, and see what you can find. The fibrous bark on some gum trees is even better, but almost any tree has interesting things living on or in its bark.

You need to anticipate and understand that people will look at you oddly, if they see you running a battery-powered vacuum cleaner over a tree. In bush areas, they tend to hurry away, and in urban areas, it may cause road accidents. The author refuses to say how he knows this.

Using a sheet and a light at night

You can attract night insects with a light, though other small animals like to hide from the light during the day. Play with this! If you place a light on the ground, shining up onto a hanging white sheet (or a white wall), insects will be attracted to it, especially in the evening after rain.

They can be examined and left in position, or selected insects can be caught with jar and card, or pooter, but most of them should be released again, soon after. Think about safety with power cords or gas lamps. You will need a sheet or sheets and somewhere to hang it/them, or a wall, a light or lights, pooters or jars and cards, or photography gear. Try to look, rather than touch. Respect life.

A light trap

Have you ever noticed how outside electric lights get filled with insects? You can make an effective insect light trap with a funnel, a light with a shade, and a jar. You will need a plastic funnel, cardboard or paper, sticky tape, aluminium foil, a plate, a pencil, scissors and a torch. The shade and the funnel should not let light through. Look around for plastic funnels, and if necessary, tape aluminium foil to the outside, or paint the funnel black. (Please, if you are doing that, ask your tame adult about the best place to do the painting.)

The only way the insects can see the light is along a path that leads them to the top of the funnel, where they will fall down into the jar. You can adjust the gap between the shade and the funnel to keep out larger insects. Your funnel needs a wide spout, so every insect that gets through the gap can fall down into the container. Get advice from the tame adult about the safest place to set the trap up. Then follow the pictures.

A low voltage light trap, using a small torch.

Use the plate to cut a circle of cardboard, cut a sector out and fold it to make a conical shade with a hole in the middle, cover the cardboard and funnel in aluminium foil to make them light-proof, fit the torch, place a jar on a stand and put the trap out on a warm, still night after rain.

You need to check the jar regularly, and either study and release the animals. If you catch one or two larger animals, the smaller ones may be battered to pieces. Moths begin to lose scales from their wings as soon as they start fluttering against the sides of the jar.

As a general rule, don't leave the trap unattended.

Catching leaf litter animals

The easiest way to get a few animals out of leaf litter is to put a handful of leaf litter into a white dish, and search through it with a paintbrush, as described earlier. The second easiest way is to get some leaf litter in a sieve jar (chapter 1) and shake it over a white dish. Note that the usual warnings about potentially venomous animals and the need to wash hands apply here.

The quickest way of finding leaf litter animals uses a bucket of water. Just throw some leaf litter into a bucket of water, and use a pooter or a brush and a dish to collect the animals that come to the top. When you are finished, tip the bucket out on the leaf litter.

Any patch of leaf litter is like a tiny jungle, full of food, and full of bigger animals that will eat small ones if they can. Just as the jungle can flood, so can the leaf litter, and only the animals with an instinct to climb up out of the water will survive. Aside from floods, jungles and leaf litter can also suffer from drought. As it dries, animals need to burrow down in to deeper layers, or even into the soil, seeking a moister place, where they won't dry out.

The most efficient way of catching the really small animals is to rely on their drought survival instincts, but to do that, you need to make a proper piece of equipment that I call a drought machine, though scientists have a fancier name for it. They call it a Berlese funnel.

Making a Berlese funnel

A single square metre of leaf litter is home to thousands of small animals, and millions of bacteria and fungi. Most of the animals hide under leaves, so they are hard to spot. That is why we have to flush them out with a Berlese funnel. There are similar gadgets called Tullgren funnels and McFadyen extractors. They all chase leaf litter animals into the open.

I had no idea who Antonio Berlese was until just now, when I looked. Nor did I know anything about Swedish arachnologist, Albert Tullgren, though I started using one of these funnels just a few years after Tullgren died. I know almost nothing of Amyan McFadyen, though I was working in a lab that used the McFadyen version, soon after he published it, and he only died in 2015. Their stories matter less than the fact that their inventions work well.

This story isn't about them, but about ways to adapt designs. The traditional Berlese funnel was always made like the picture above. (A clock glass is a curved glass dish.) All of these gadgets work by having a funnel, a sieve and a gentle heat source to encourage the animals to move down to darker and damper places. There are probably more design variations than there are experimenters, so try my two versions, and then see if you can do better. Note that the light bulb needs to be an old-fashioned incandescent type that puts out heat, but not too much.

Safety matters: be aware of the risk of venomous animals and the need to wash your hands after handling leaf litter. Use a low wattage incandescent bulb, to avoid any risk of fire. Some years back, I set out to make a safer Berlese funnel, using a one-litre clear plastic milk bottle, flywire, plaster of Paris, cardboard, foil and sticky tape.

The bottle became both the funnel (the top) and the catcher (the base), with a layer of plaster in the base to make it more stable and give a flat surface with no crevices for animals to hide in. The

animals show up against the white plaster, and the damp plaster keeps the container humid, which is good for the animals.

I later added a cardboard sleeve to keep things dark at the base. The animals move away from both heat and light, and the cardboard sleeve covered most of the funnel, so the animals would move down into darkness. You can also use heavy paper, but make the sleeve loose enough to slip on and off, tape it together, and you are ready.

Then I wondered if the sieve area was too small, and came up with the design below. This needs a standard sieve jar, cardboard, scissors, sticky tape, a lamp with a 15W incandescent bulb and a 1.25 litre drink bottle. The pictures below tell the story.

Here are the steps to follow: make a funnel from the top half of a 1.25 litre soft drink bottle, and sit that in/on the bottle base, which acts as a catcher. For improved stability, put a layer of plaster in the base. Put leaf litter in the sieve jar, fit the lid on the jar and invert it over the funnel.

The model shown here used an old bedside lamp from the junk box for heat, so I made a timber stand for it from scrap craft wood (I needed just three screws). The whole rig is enclosed in a cardboard tube to make the lower parts of the jar darker. The pictures show you how to assemble it. In tests, it worked well with a 15-watt incandescent bulb, which is gentle enough to avoid any risk of fire.

You can never really predict what will come out. Sometimes, your catch will include animals that seem to be too large to have come through the mesh, but there they are. I think this is because leaf litter animals have to be good at getting through tight spaces in the leaf litter, so don't be too surprised if you find centipedes, just a few millimetres long, or fly larvae, or larval ticks, which only have six legs, or almost anything else that creeps or crawls or wriggles.

The only drawback is that you can't get water animals this way. As a rule, there will be plenty of pale, bouncing animals, about 1 mm long. These are springtails, and you will find more about them in chapter 8.

Catching small animals from a dam, river or lake

Here is an example of how discoveries are made in the outdoors. Some years ago, I tried a rough method of sampling the life in rushes that were growing in a dam. I tied a rope to a plastic bucket, threw it into the dam, then hauled the bucket in through the reeds and started looking for life in the water, as described below.

I had some clear plastic 2-litre juice bottles to carry samples away, and a funnel made from the top half of a smaller PET soft-drink bottle, and I poured in some water that had small shrimp in it, about 4 cm long. When I got home, I held one bottle up to the light to show my daughter the small shrimp, and we saw that the water was swarming with even tinier life forms: insects, crustaceans including water fleas, and even a couple of small and almost transparent fish.

I have been holding up bottles like this ever since, so try it! Add your sample to an empty bottle and wait for the sediment and currents to settle before looking at the bottle with the sun behind it or to one side. Look for fast flicks of movement, or slow and steady movement when the other suspended material is staying put. Don't be surprised if you get a few surprises!

Sieving and sorting fresh water

Get your fresh water with a bucket as in the same way, run each bucketful through a small kitchen sieve, and backwash the sieve into a dish or a bottle. (To save spillage when backwashing into a bottle, use a funnel made by cutting the top 12 cm from a 2-litre soft drink bottle.)

Or think about making a large-bore pooter with a larger chamber and a longer tube. I'm not going to tell you how, but you can avoid

sucking up swamp water by having a single-tube pooter, a tube fitted to a big and squashable bottle. Many of the things you are looking for are pale, so you can see them in a clear bottle, held up to the sun. Just don't look directly at the sun, OK?

Making a wash bottle

You can buy a proper laboratory wash bottle (hard to find but expensive) or you can make one. A wash bottle can squirt upwards to flush material out of upside-down sieves and containers. The easy way to get one is to take either a drink bottle or a detergent bottle with a 'pop-up' lid and use that, as is. You can use these to squirt upwards or downwards, but it's messy, and if you want a gentle and controllable water flow, you need a better wash bottle.

You need a soft plastic bottle (I use a one-litre milk bottle) with a screw-top lid, about 35 cm of 3 mm (internal diameter) plastic tubing, a drill with a bit about the same size as the tubing, some thin iron wire, some gaffer tape, and a safe place to use the drill.

The tubing has to reach the bottom of the bottle inside, and come part of the way down on the outside, as you can see from the picture below, so work out the length you need for your bottle. Choose a drill bit that makes a tight hole for your tubing: I use a 5 mm drill bit, but you need to test this for your tubing. Use an old cap and drill several test holes to choose the drill that gives a tight fit.

Then take the cap off the bottle, drill a single hole in it and feed the tubing through the hole until there is *enough tubing to reach the bottom of the bottle.* After you have fitted the cap onto the bottle, wind a piece of wire around the tubing so the tubing will take and hold whatever shape you give it. Then cover the sharp ends of the wire with gaffer

tape, add water to the bottle, and you are ready to go. You can also use a small amount of tape around the tubing to make a tighter fit where it goes through the cap: this trick also works for pooters.

The last shot shows the wash bottle, ready to use. Notice how the wire keeps the tube doubled over, and the tape covers the wire. The result is ugly, but it does the job!

So what does the wash bottle do? It washes things out of one container into another.

Making a water sampler

You can also adapt the wash bottle design to make a water sampler bottle. I will cover this briefly, and then leave you to experiment by yourself. You don't want the water coming out when you squeeze, so if you are holding the bottle right-way-up there should only be a short length of tube inside the bottle.

You can also use a long tube attached to a stick to draw up samples from deeper water, but remember to squeeze the bottle before you put the tube in the water, so bubbles don't chase off the wildlife or stir up the sediment too much.

With a bit of thought, you can probably use the same design for a simple one-tube pooter for catching ants. You need a fairly tight seal where the tube goes through the bottle cap, and I sometimes use epoxy resin glue to seal a tube in place. I advise you to get adult help to experiment with epoxy resin. Work outside, don't breathe the fumes, and try not to get it on your skin. Epoxy resin isn't *that* dangerous, but play safe!

Water insects

Many insects have juvenile stages that live in the water. To see them, you need a bucket and a rope, a kitchen sieve, a funnel, a white dish, assorted extra water containers, and a number of three-litre juice bottles. You also need a reasonably large body of water, preferably with reeds growing near the shore, and somewhere safe to stand above the water, like a rock or a jetty. To get specimens to photograph, you will need a Pasteur pipette and Petri dishes. I prefer to get a few animals into a dish to photograph them before returning everything to the water.

Making a sieve funnel

Where I live, the standard one-litre milk bottle is square and clear. You need one of those (carefully washed), some sharp and pointed scissors (or a sharp knife), a piece of board, a hammer, a wood chisel about 1.5 cm wide. You also need a small square of plastic fly wire, about 4 cm x 4 cm. I cut a bottle in half, separating top from bottom, then I turn the bottle top into a sieve, and I have a sieve funnel: play with it!

Sieving and sorting fresh water

This is easy to do. Get your fresh water with a bucket, run each bucketful through a sieve, and backwash the sieve into a dish or a bottle. (To save spillage when backwashing into a bottle, use a funnel made by cutting the top 12 cm from a 2-litre soft drink bottle,)

You can also use a better net (see **Making a plankton net for ponds**, chapter 10), and backwash that into a dish or bottle. Think about making a large-bore pooter with a larger chamber and a longer tube. I'm not going to tell you how, but you can avoid sucking up swamp water by having a single-tube pooter, fitted to a big and squashable bottle. Many of the things you are looking for are pale, but you can see them in a clear bottle, held up to the sun. Just don't look directly at the sun!

6 Keeping small animals

Don't be limited by my examples: these 'homes' are good for many other animals as well.

A humidity jar

I use jars with a plaster layer for snails, spiders, slugs, springtails and slaters. A large humidity jar can be used to 'relax' dead specimens (chapter 9), and you can carry live animals in them. To make them, you need a place where you can safely make a bit of mess, some old newspaper, Plaster of Paris, a spoon, water, and some wide-mouthed screw-top jars.

I mainly use glass 'Vegemite' jars, though plastic peanut butter jars are probably safer. So why do we need humidity jars? 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 or get soggy in, but which still keeps them moist. You can 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.

You can buy plaster in 1 kg sealed plastic bags from a hardware store. Once you open a bag, put the rest into jars with air-tight lids, because it slowly goes 'off'. Then spread out the newspaper to catch any spillage. Put about a centimetre of water in a jar, and add several spoons of plaster powder. The idea is to have the 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 any air bubbles), then leave it.

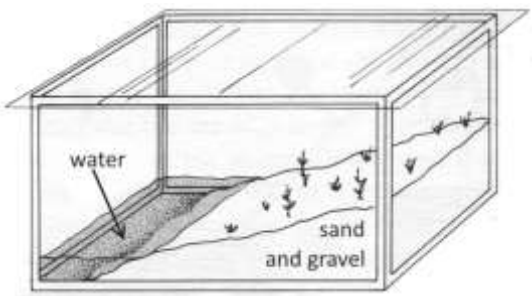
The plaster will set in about 20 minutes, but wait an hour to be on the safe side, before you pour off the extra water, and wipe any splashes of plaster from the glass with a damp tissue.

Before you use a jar to store animals, pour in some 'aged' water. This is tap-water that has stayed in an open container for a few days to get rid of any chlorine. Leave it for a few minutes, pour off the

water, wash it out with more aged water and wipe the jar and plaster dry with a tissue or paper towel.

Professional scientists use plaster mixed with powdered activated charcoal, but plain plaster does the job almost as well, and it is much easier to work with. People who keep very small orb-weaver (web-making) spiders often poke a branched twig into the wet plaster to make a place to hang a web.

Setting up a terrarium



You need an old fish tank that does not leak, gravel, washed sand, and some plants that do well in moist conditions. Use a daylight electric light (you can get them at aquarium shops) or place the tank on a windowsill near (but not in) sunlight. If you can't do that, choose shade plants.

Put a sloping layer of gravel in the tank, 2 cm deep at one end, with no gravel in the last 10 cm: this is where there will be a water pool. Then add sand over the gravel to make a 10° or 15° slope along the length of the tank (you can leave out the gravel, if the sand is coarse-grained). Pack the sand down as you add it and water it gently: the excess water will run down and pool at the low end. You can grow duckweed and algae in the water, and it will be a source of excellent green slime for microscopy.

Use small plants: mosses, *Selaginella*, weedy things, violets and small ferns, up and down the slope, and maintain the water level. Collect small samples of moss when you are out and about, dividing each piece into three parts when you get home. Place these on the

slope at different levels so they can thrive in the best environment. Add a few river pebbles as part of the dry surface to provide more niches. A small piece of granite is good in the water, because mosses and algae can grow up it. After that, just keep adding bits and pieces and rip out any plant that gets out of control.

You can water the system by leaving an upside-down soft drink bottle sitting on a rock at the lower end. This keeps the water level constant over a long period, which is very useful during holidays. If you will be away for a long time, you should cover the tank in cling wrap as well. A one-litre bottle is good for a fortnight in hot weather with a flywire cover.

Occasionally, spray water gently up and down the slope with a watering can to maintain a bit of variety, and to help the mosses and ferns that need free water to breed. You can also spray the surface with a wash bottle or misting bottle, sending water through the flywire to make 'rain'.

I always shape my flywire covers like the lid of a shoe box and then 'stitch' them into that form with a stapler—you just lift the lid off when you want to garden, adding some new bits of moss, fern or whatever. The flywire also keeps the spiders in and the mossies out.

An insect cage and water

You will need a cube-shaped wooden cage, about 30 to 40 cm on a side, with one glass wall and the rest made of flywire. Inside the cage, you will need a safe water source, a sugar food source, or a meat food source, where the eggs will be laid. You can keep almost any non-stinging insect in there, even flies!

You need a water source that the larvae will not drown in. Fill a small glass with water, put a paper towel piece over the top, and cover it with an upside-down saucer. Hold the three together and then quickly turn the set upside down. A small amount of water will seep out, and as the insects drink this, or it evaporates, more water will be released. The water in the saucer will never be deep enough to drown them. Scale this up or down, depending on needs.

Flies only carry disease when they have been in contact with food (dead bodies, dung etc.) which has dangerous germs on it. If you are careful, you can safely keep flies and breed them, but fruit flies are probably less upsetting to adults than bush flies or 'blowies', unless you live in a fruit-growing area. To get fly-proof access to the cage, you need to sew two sleeves of soft cloth to two holes in one side of the cage wire, with elasticised cuffs. These will let you reach into the cage without letting any flies out.

A good sugar food source is a bottle lid holding dry grains of raw sugar. Flies land on this and 'eat' the sugar, which should always be in the cage. Fruit flies will lay eggs on slices of banana and the larvae will grow there. You could try grapes or plums instead of banana.

Any meat should be small pieces of lean meat on a bottle lid, a saucer or a Petri dish. Add two small new pieces to the cage every second day: after a few days, the flies will start laying eggs on the meat. The meat may smell fairly bad, so you will need a safe animal-proof place out-of-doors to culture your maggots. Put each piece of meat in a test tube, and plug the tube with a tight roll of cotton wool. This gives the maggots the air they need, but stops them escaping. Damp down the cotton wool each day.

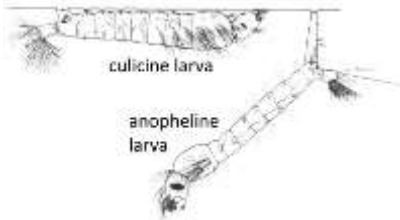
When the maggots look fully-grown, part-fill a large jar with sand. Unstopper the tubes, put them in the jar, and cover the jar with fine cloth or flywire, held in place by *two separate rubber bands*. Always use two fasteners, because rubber bands seem to break at the most inconvenient times!

The maggots climb out of the tubes and settle on the sand when they are ready to change into pupae. You can collect them from the sand, but if you use tweezers, be gentle, and it is better to sweep them into a jar or glass tube with a paint brush. When the adults emerge, put them back in the cage, or better still. Put the uncovered jar of pupae in the cage before they emerge.

Before you start, talk with a responsible adult about where to leave the cage, because most people will be grossed out if they know you are breeding flies. The same thought and planning may keep you out of trouble if you decide to breed mosquitoes (next

section). If you work on houseflies, don't handle the 'bad' meat, so use gloves and *wash your hands regularly.*

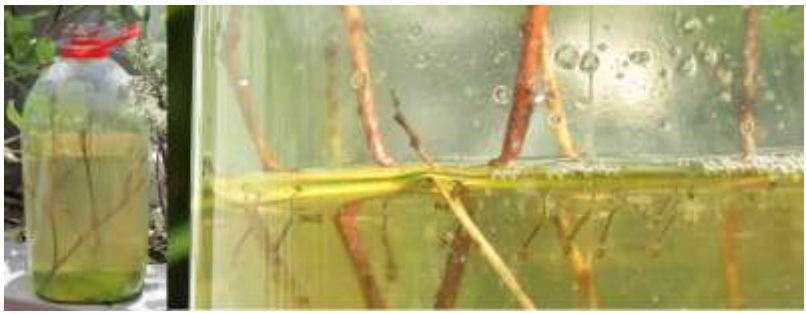
A mosquito jar



The world is home to about 3000 species of mosquito. The adults have a piercing proboscis for feeding on nectar or blood. The larvae live in water, often living suspended beneath the surface film. Some species transmit pathogens causing malaria, yellow fever, filariasis and Dengue fever. An expert once told me that the only visible difference between malaria-carrying mosquitoes and some related mosquitoes that don't carry malaria is found in unexpected markers like the hairs on their legs, so mosquitoes are worth studying.

There are two groups of mosquitoes: the **anopheline**, whose larvae hang horizontally in the water, and the **culicine**, whose wrigglers hang vertically. Both types spread myxomatosis in rabbits, but only some of the anopheline mosquitoes spread malaria. More people are killed in the world each year by diseases spread by mosquitoes than die from diseases spread by flies when they land on our food.

Nobody likes mosquitoes, so keep them in a sealed container. A PET plastic drink bottle is fine, but a large glass jar will do just as well. Seal the bottle or jar with a piece of material or flywire, held by *two* rubber bands around the bottle's neck (the second rubber band is in case one breaks). You also need to know somewhere to catch wrigglers in stagnant water. Note the flywire, held on by *two rubber bands*. Notice the water level, which is kept low enough to give the maximum water surface area for gas exchange.



You also need a branched twig for the adults to land on so they don't drown. It must be long enough to poke out of the water. Choose a dead piece with fine branches, about two thirds the height of the bottle. Push it down into the bottle, thick end first. Once it is inside, the branches will spring out again, providing plenty of landing places.

Mosquito larvae ('wrigglers') are filter feeders, sweeping up tiny living things from the water, so you need green water in their home. Fresh rainwater or creek water is the best start. Chlorinated tap water (most water supplies) should be boiled and allowed to cool before you half-fill the bottle. To make sure the water contains enough food, take some water from a drain, pond or swamp, put it in the bottle, and drop in a small amount of plant fertiliser to feed the tiny plants (algae) which will grow in the water.

Some wrigglers scrape food from the surface of dead leaves, so put a few old leaves in your bottle. If your wrigglers are not scraper feeders, the dead leaves will still help the algae. Cover the bottle and let it stand in a sunny place. Add a few wrigglers to each bottle, and then put the cover on. Observe the wrigglers at least once a day, and watch how they grow and change. See if you can photograph a wriggler moulting.

Mosquitoes are filter feeders as larvae — but looking around the web, nobody seems to know whether the tumbler stage (the pupa) eats or not. It is likely that they don't: maybe you can design a neat experiment with distilled water to find out (that's a hint!).

According to my reference books, the adult females that hatch will not lay eggs without a feed of blood, because they need the iron

they get from the blood. This may not be correct: try it, and see if you get a second generation of wrigglers, or do an experiment where you let some of the female mosquitoes feed on you.

Live wrigglers and tumblers can be mounted in a well slide, and chilled in the refrigerator to slow them down for microscopic examination, while allowing observation of movements of the gut, breathing tubes, and so on. Adult specimens can also be mounted, though this will kill them: can you tell males from females?

Take a series of photos to show the development of the mosquito from wriggler to tumbler to adult.

A word of advice to juveniles of all ages

I used to breed mosquitoes when I was 10 years old, and that was how I learned that adult humans of a certain type (the ones who don't know how to dream) have limited patience. To keep these strange people happy, you need to confine the mosquitoes to their home. That's what the flywire and rubber bands (or wire) are for. Wire is better for holding the flywire on, because rubber can perish.

Mosquito wrigglers are usually found in stagnant water, which *may* contain pathogens. Maintain careful standards of hygiene while collecting and handling them.

Look out for these:

- Compare the ways wrigglers and tumblers move through the water and 'hang' from the surface;
- Try to watch a tumbler changing into an adult;
- Using a well slide, can you see what a wriggler has been eating?

A compost heap for invertebrates

Birds will always come if they can get food. One of the best natural food supplies is a compost heap, but these are sprawling messes, so here is a neat design. You need four 1800 mm garden stakes, 3 metres of 1200 mm chicken wire, some iron wire and a few fencing staples. The size depends on the space available, and you can change it by increasing or reducing the amount of chicken wire. My specifications will take up a square, one metre on a side: talk to your tame adult.

The wire makes a fence that surrounds the compost, but sits 200 mm above ground level, so you can dig out compost from below. Lay the chicken wire out on the ground and put the stakes along the mesh, 750 mm apart, starting at one end. The flat tops of the stakes should be a couple of centimetres above the wire, so you can hammer them into the ground later. The pointed ends should be 500 mm from the lower edge.

Use a few pieces of wire to attach the stakes to the chicken wire, then turn the whole thing over on a hard surface and attach the chicken wire with fencing staples. Hammering fencing staples usually means hitting your fingers, so either get adult help or use iron wire to tie the chicken wire on instead. You can also try holding the staples in fine-nosed pliers as you hit them.

Then join the end flap to the stake at the other end, and drive the stakes about 30 cm into the ground in your chosen place, and begin adding lawn cuttings and non-woody garden waste. You can speed things up by laying a few handfuls of rotting leaves at the base and a few more, higher up. Now the wild Small Things have a place to live, shelter, feed on each other and be fed upon. Keep adding lawn clippings, leaves and other vegetation.

If you can't get the space to set up a heap like that, try to find a corner of the garden where you can build up a pile of leaves, and damp it down, every now and then.

And now it's time to consider the things you are most likely to look at: what we in our house call wee beasties, what scientists call the invertebrates, and you may call minibeasts, then we'll get to plants and other stuff.

Enough planning: let's biologise!

7 An introduction to invertebrates

Animals are divided into **vertebrates** that have a backbone and **invertebrates** that don't. The usual reason for giving a name to any group is so we can link animals or plants that have something in common. A fruit fly, a nematode, an oyster and a sea urchin have hardly anything common in their biology, yet we call them *all* invertebrates. We name invertebrates for something they *don't* have, which seems silly, but we are stuck with it.

Mind you, this chapter is devoted to the legless invertebrates, meaning *two* negatives, but there's a good reason for starting there: animals without legs move more slowly. Leaving that aside, common names change, and two centuries ago, spiders were called insects. Nowadays, we count the spiders' legs, and when we see eight, we class them as **arachnids**.

Then there are the **arthropods**, and that is a more useful name, because lobsters, flies and spiders all have a number of things in common, mainly their jointed legs. When we consider their evolution, it is likely that these animals all had a common ancestor at some stage. There is a problem, though: most biologists are uncertain about how to place other similar groups like the tardigrades and the velvet worms, which we will look at later.

We guess as best we can, and continue to look for the evidence. The good news for young naturalists is that there are still things to be discovered, and there will still be, if you decide to be a scientist in later life. We haven't even come close to running out of things to discover.

Before we begin though, here are a few hints on persuading living animals to keep still enough for you to look at them.

Dealing with fast animals

Slowing small water animals down

The three main ways of slowing water animals down are:

* to put in barriers, so the animal can move a lesser distance;

* to put the animal in a more viscous (sticky) solution; or
* to knock them out or kill them.

The most common barriers are bits and pieces of cotton wool or ground-up face tissues. This is not very effective with anything smaller than a mosquito wriggler, but it's better than nothing.

I have been using the same bottle of ®Gurr's Water Mounting Medium for 50 years, and it seems to be unavailable now, though it is still mentioned by (older?) professional scientists. Searching the web on <water mounting medium>, I found a good set of safe recipes by J. A. Kiernan from the University of Western Ontario. Apathy's gum syrup sounds like a good one to use.

A solution of 10 g of methyl cellulose in 90 mL water forms a syrup that will slow most animals down for microscopic examination, while allowing observation of movements of the gut, breathing tubes, and so on. You can buy methyl cellulose at hardware shops (as "mortar thickener"), and you may also get it at health food shops, where you will probably pay a lot more for it.

If you mount the animals in 70% alcohol, this will kill them, but a 1% solution of magnesium sulfate (often sold as 'Epsom salts') will just anaesthetise them. Note that 1% here means 1% by weight or one gram in 100 mL of water. Put a drop of this on the slide and then use a camel hair brush to add the animal. If you can't weigh the crystals, just add a level teaspoonful to 200 mL of water, and that will be close to right. Rinse the spoon, put a stopper or lid on the bottle, and label it carefully.

Slowing an animal down by breathing on it

I haven't been able to get much effect with this, but a clever friend tells me it works. The air we breathe out contains about 5% carbon dioxide, and my friend says this is enough to almost knock animals out for a short time. Give it a try…

Slowing an animal down by cooling it

This trick is useful in both macrophotography and microscopy. We say invertebrates are 'cold-blooded', which just means that their body temperature is much the same as their surroundings. We humans, on the other hand, have a body temperature which is

usually close to 37°C, and we call ourselves 'warm-blooded', even though, on very hot days, we are cold-blooded, compared with our surroundings.

Now the thing to remember is that most biochemistry works at a speed that depends on body temperature. Biologists talk about the Q10, which means the change in metabolic rate for a change of 10 degrees on the Celsius scale. Most living things have a Q10 of 2 or 3, which means that if you chill an animal from 37° C to 27° C, the metabolic rate will be halved or reduced to $^{1}/_{3}$, and so on.

Working with Q10 is more complicated than that, but cooling down an animal usually makes it move more slowly. If you have a well slide, you can look at a chilled copepod (a kind of crustacean), and you will see movement inside, but the movement will be slowed down. In the same way, when you get to looking at mosquito wrigglers, the innards will be easier to see in a cool mossie. And now, back to macroscopic shots.

Many years ago, back when Australian ravens were still called 'crows', I saw some feeding on the small banks of snow that last into high summer in the Snowy Mountains, around Mt Kosciuszko. At first, I thought the crows were swallowing the crystals of ice, but when I looked closely, they were eating grasshoppers that had landed on the ice bed, and chilled down to almost 0° C, so they could not move, leaving the crows with a range of semi-frozen snacks.

This sort of thing, I realised, would be great for photographing bull ants. Begin by catching a bull ant with a card and jar. Next, put the ant in the refrigerator (*not* the freezer, which will kill it!) for half an hour or so. After it has cooled down, put it on a saucer, floating in a large dish of ice water, and you may just get a shot like the one you will see here, one in my home, on ice, the other in the wild, without ice.

This cooling trick also works when you are looking at venomous spiders, though you need to be at least 18 before you try that. Unless you are in poor health, the bite of a redback probably won't kill you, but I hear that people who are bitten often wish they *were* dead.

When I work with animals like these, I wear thick gauntlets, I have fast reactions, I know how redbacks behave, I stay well out of reach—and my friends tell me that I am disposable, in any case. Still, cold slows all invertebrates down, giving me a better chance of avoiding a spider bite.

Remember that putting animals in the freezer will kill them, and I prefer not to kill specimens, but if you need to do so (as I did, recently, to test a hypothesis about the effects of preservatives on dead redback spiders in the 1860s), freezing is a good and painless way for them to go.

Mind you, when it comes to bull ants, as soon as they are dead, their nippers cross over, and this is how you can tell that my shots above were taken using live specimens. Before you start playing with bull ants, you need three things: first, you need to read this; second, you need to know how bull ants sting, because if you know that you know how to avoid being stung, as explained in chapter 8.

Lastly, if you are under 10, you need to talk to an adult, and you should get adult help. If you know what an epi-pen is, that may mean you need to avoid this project, because at least one Australian bull ant can cause anaphylactic shock. Just talk to somebody older and wiser, an *informed* tame adult.

Now, about those redbacks…

Using an 'island' in a tub

This moat trick applies mainly to camera work, but it is worth keeping at the back of your mind. For example, when I was keeping ant lions in my white dish on one occasion, the ants that I dropped into the food kept scrambling over the sides of the dish and escaping. When I sat the dish on a paver over a tub of water, the ants stayed on or around the dish, and they were eventually eaten by the ant lions. There is a picture of another moat setup in chapter 8.

You can use a block of wood, surrounded by water in a dish, or a brick surrounded by water, or it can be something sitting on a block like that. I used this, for example, when I was photographing dangerously venomous redback spiders that needed to be returned to the wild, later.

The paving brick is surrounded by a 'moat', but the redbacks release a silken thread that drifts in the wind, making a bridge that they will try to climb across. The fly swatter (in the shade on the left in the second shot) is not to kill the spider. It is there to break that link, quickly and safely. The spider comes from its resting place in a humidity jar, the gloves are for protection against bites, and the 50-cent coin is for scale.

A better way of cooling small animals

I developed a gadget while writing this book. I made the 'ice cell' by putting a 60 mm Petri dish inside a 90 mm Petri dish with some water. I weighed down the smaller dish with two 50-cent coins, and put it in the freezer. Once the water was frozen, I took the coins out and carefully added a chilled ant.

The ant in this picture came out of the refrigerator, and lay as if asleep, but later became slightly more active, allowing me to get some good shots. I sat the cell on a sheet of clear glass, over a piece of blue cardboard. This is very much a partly-baked idea: feel free to develop something else out of it!

Legless invertebrates

The insects, the spiders, and the crustaceans (prawns and lobsters), all have an outside 'shell' or exoskeleton which helps to protect the animal from attack, and gives the muscles something to work on. Snails have shells, and leeches and worms have complicated systems of tubes inside their bodies, tubes which can be pumped full of fluid, or emptied at need, and this is all they use for a skeleton.

Most of the legless invertebrates live in the soil. Most of them depend on larger animals, like dung beetles and earthworms that carry rotting material down into the soil. As they burrow around, these soil animals also let air in. Soil is usually moist, so the living things in the soil don't get too hot, too cold, or too dry. If the soil dries out, they just burrow deeper down. The soil is a great place to

live if you are a small animal, but it would be much more barren if there were no earthworms.

Grasslands usually contain about 2500 million arthropods (insects, spiders and other small animals with legs) in each hectare. There will also be 150 kg of amoebae, and about a million earthworms, weighing around 600 kg in this same hectare of pasture. In fertile pastures, the weight of bacteria in the soil can be greater than the weight of cows living on top of the same pasture. In your garden, there may be 4000 million bacteria in each gram of soil, along with a thousand nematode worms. In healthy forests, a litre of topsoil will often have more than 10,000 springtails and 1000 mites.

There is a continual cycle of the important minerals we call nutrients. Plants soon grab rare stuff like phosphorus, calcium and potassium that get into the soil when rocks break down. When leaves and twigs full of minerals fall down, they are 'eaten' by something that uses the nutrients, and eventually, the minerals are excreted into the soil, where they dissolve, and are taken up once again by the roots of plants. The soil of your garden is just as wonderful as any rainforest or coral reef, and it's just outside your door!

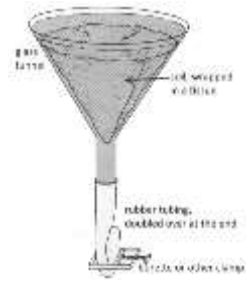
Nematode worms

Some nematodes are good and some are bad. In the mid-1980s, the damage done to agriculture by pest nematodes around the world was estimated at $30 billion a year. They are usually tiny, and most of them are too small to see without a microscope, but one nematode, the Guinea worm, is a human parasite, and almost a metre long, but they are the exceptions.

> I once persuaded a gullible (Arts graduate) headmaster to let me uproot a rose garden and replace it with Australian native plants by showing him the haul of nematodes I had collected from that garden bed. If the truth be known, the nematodes were harmless, but the rose thorns had injured several students, and I wanted the native plants for teaching purposes.

This is *not* what they mean by "blinding with science" but it will do.

Scientists have identified at least 10,000 nematode species, but there may be as many as 100,000—and they live everywhere. A hectare of good pasture may carry twenty billion nematodes, three nematodes for every living human, all in a single hectare! Some of them are very specialised, and one species only lives in German beer mats, and another, called *Turbatrix aceti*, can live in old vinegar.



Catching nematodes is surprisingly easy: you need a funnel, preferably transparent (think about making one from the top of a plastic bottle), a face tissue, a piece of tubing and a clamp. This is a **Baermann funnel**. In its classic form, this is a glass filter funnel with a 6 cm piece of opaque rubber tubing on it, doubled over at the end and clamped with a burette clamp. It looks like this:

Most commonly, the funnel is used for catching nematode worms, but other tiny animals can be collected in the same way, including tardigrades and copepod crustaceans. You pour water into the funnel until the tubing and the stem are full, lower some soil wrapped in a face tissue, into the funnel, and then gently cover the tissue with more water.

Over the next day or so, some of the animals in the soil will wriggle down through the tissue and take refuge in the dark inside the rubber tubing. When you open the clamp and let some of the water flow out into a dish, there should be some nematodes and other surprises in it.

Substitutions: You can replace the glass funnel with a clear plastic one, and plastic tubing, wrapped in gaffer tape or aluminium

foil to keep the light out. You can clamp the tubing with a large bulldog clip. You can also use a piece of cheesecloth instead of a tissue.

Most of the time, you need a good microscope to look at your catch. Even if you use good gear, don't be too disappointed if you see nothing, or just a mysterious wiggling blur. Here are three frames from a video of a nematode worm.

Earthworms

Earthworm casts, a Wardian case, and a legpull.

Earthworms have no arms, no legs, no eyes, and no shells to hide in, yet they survive and thrive. They are also important because they keep the soil fertile, as we have known since the late 1800s. Often, the only evidence that they are there comes from their 'casts' (above left), the soil that has passed through their gullets and been stripped of any food.

Around the world, there are some 6000 species of annelid, the technical name for the earthworm group. Australia has about 1000 native species and around 80 introduced species that must have come here in potted plants and Wardian cases (above centre). I don't think any of those worms were ever deliberately introduced in Australia, but when sheep farmers in New Zealand cleared the scrub for pastures, their new grass was disappointing.

Compared with similar land in Europe, the grass grew poorly. Then in the early 1940s, a farmer noticed the grass in a pasture near his orchard was well up to European standards. European earthworms, which were slowly replacing the native species, had invaded these richer fields. At some time in the past, these new worms had been accidentally introduced in the soil that came with plants in the early days of settlement in New Zealand.

Later research showed there was a mat of plant material lying on the surface of the soil, and the imported earthworms broke this down, producing a 30% increase in grass production. For some time now, New Zealand farmers have regularly introduced European earthworms into their pastures.

The size of Australian worms is variable, with the Giant Gippsland earthworm, *Megascolides australis,* taking the prize, at 3 metres long. Another worm from near Kyogle in N.S.W., *Digaster*, can be up to 1.5 metres long, but I have never seen a garden earthworm longer than about 15 cm.

The fanciful representation above on the right shows Australian "aborigenes" catching the Giant Gippsland Earthworm. It appeared in a German book in 1962, and in a US-published translation that came out in 1968. Either the author of the book had been hoodwinked, or he was joking.

Earthworms are made up of segments, as you can see by looking at them, and certain segments have special functions or contain special body parts (like hearts). They evolved from worms that lived in water, and they breathe through their skins, so they need no lungs, but they have five hearts, a brain and a nervous system, as well as an intestine.

They also have a very neat system of muscles that they use to change from long and skinny to short and stubby. When you catch a worm, rub a finger along it both ways and you will know how it moves along, without any legs at all: it has backwards-pointing bristles. See if you can get the same answer with a hand lens or a microscope. (You need to remember that earthworms wriggle wildly when you pick them up, and often escape, so do this over a container.)

You may need to watch for a while to see them, because the bristles, called setae, can be withdrawn or poked out. The setae, combined with the muscles, are all the worm needs to move around. They have a **hydrostatic skeleton**, a set of tubes that they can pump fluid into. While I was writing this book, I put two nice big juicy earthworms, about 12 cm long in a plastic box with sides 8 cm high. The worms were able to use their hydrostatic skeletons to rear up, then use their setae to hook the edge and climb out of the box and escape. Now you know why I have no photos of them!

Earthworms come to the surface after heavy rain, because they have to leave their burrows if they want to breathe. They can live in flower pots, and they eat most kinds of rotting leaves. You can also dig for earthworms, or you can water a lawn heavily, which waterlogs the soil.

You need to realise that earthworms dry out quickly, so keep them in a moist jar for a short while, and then let them go or put them in a worm farm. You can get big worm farms from hardware stores that are good for recycling vegetable scraps. If you want to save money, you will find all the designs you need to make either a <**wormery**> or a <**worm farm**> on the web.

Old books say you can catch worms by spreading 4 litres of 0.5% potassium permanganate solution on a square metre of lawn, and waiting for the worms to come up. It seems that waiting for rain is better. I suspected that this was bad for the worms, and I checked my reference books. Potassium permanganate is toxic to worms. Formalin, the other suggestion found in those old books, is just as toxic, and it also causes cancer in humans. *Never use either of these methods!*

Here are two better choices: household detergent and mustard! Buy your mustard as an emulsion, dilute it in water, and spread it on a newly mown lawn. This is quite safe for worms. The mustard also flushes out burrowing slugs, **enchytraeid** worms (potworms) and other underground beasties. Now, who'd like a tasty earthworm and mustard sandwich?

Look out for these:

- Look up <**earthworm setae**> on the web and then see if you can see or feel them;
- Count the segments on some earthworms: are they all the same? (Hint: use a photo!);
- What senses do earthworms have? Charles Darwin tested their hearing (or lack of hearing).

Flatworms

This land planarian (above) was feeding on a millipede on a brick wall. You will see this picture again, later. There is no easy way to find these, but over the years, I have often come upon them by chance, usually in leaf litter in my garden. Scientists call them planarians, but they are just very small flat worms. They are more common in fresh water than you may think, but they are hard to find until you know where to look and what to look for.

Land planarians can be up to 300 mm long. Those ones have a shovel-shaped head, and they travel on a layer of slime like a snail or a slug. The slime is amazing stuff, because it hardens, and if a land planarian goes over the edge of a drop, some species can lower themselves down on a thread of hardened slime, like a spider dropping on a web. The body gets longer when it is stretched by gravity as it dangles.

Land planarians eat earthworms so they can sometimes be a problem in worm farms (which means you may find them in a worm farm!), but they also eat a wide range of other garden 'meat', including slugs. I am told that if you leave a small piece of meat in

some leaf litter, inside some sort of cage to stop larger animals getting at it, you may attract a land planarian, though this has never worked for me.

The last reliable count, made in 1999, showed 822 species of terrestrial flatworm around the world. The greatest variety is seen in mainland Australia, Tasmania and New Zealand. But why are the flatworms flat? The answer is probably so they can breathe! With no lungs, blood or circulation, oxygen has to **diffuse**, to seep in through their skin to reach all of their cells, but the gas is all used up before it gets more than about 0.5 mm from the surface.

Look out for these:

- Look for the slime trail;
- Can you watch one feeding? (It's a bit disgusting!)

Catching aquatic flatworms

These are two public domain views of water planarians. I was unable to locate any live ones while I was writing this book, as there was a drought on. These ones are much cuter. In the wild, flatworms that live in water avoid the light, so you will usually find them attached to the under-side of stones or twigs, and they will often be in groups.

They typically have a pointed tail end and an arrow-shaped 'head' end, with two very primitive eyes, not much more than two light-sensitive patches. Most of the water ones are less than 10 mm long, but land planarians (for some odd reason, people don't call them 'land flatworms') are much longer:

Small freshwater flatworms can be found almost anywhere, when the conditions are good. In just a week, I once found them in four different sites in bushland, all in the swampy margins of slow-moving water, but I also used to find them in a seepage drain in a former home.

A spring at the back of our backyard fed this drain. It's a good idea to assume that there could be dangerous chemicals or bacteria in drains, and wear gloves while collecting there. Think about where the water has come from. My drain was *probably* safe enough (I think it was fed by a neighbour's leaky water pipes), but I took no chances!

To hunt them, go to any lake, swamp, pond, puddle or small stream, scoop up a cup of water and mud, and add it to a two-litre clear plastic bottle, or a flat white dish, and repeat. Put a couple of centimetres of water and mud into a white dish, and leave it to stand. If you later see tracks in the silt, you probably have either flatworms or tiny snails.

Using the pictures at the head of this section as a guide to their appearance, if there is extra water in the catching bottle, look for arrow-headed worms attached to (or climbing) the sides of the bottle. In either case, use a modified eyedropper or a pooter to pick up the worms, once the mud has settled out, and the worms have started moving. They will usually be slow-moving.

To gather flatworms up so you can move them to a clean tank, put a small piece of food on the floor of their tank, wrapped in cheesecloth. This will attract the flatworms, so tie a string to the parcel, remove them with as little water as possible and put them in another tank with clean aged water in it.

I find that it helps to clear a strip of mud from the centre of the dish, and lift them from there with a pooter, but if your water source is at all 'doubtful', a Pasteur pipette is much safer! Transfer them to a smaller dish, and then into a third dish, leaving most of the mud behind.

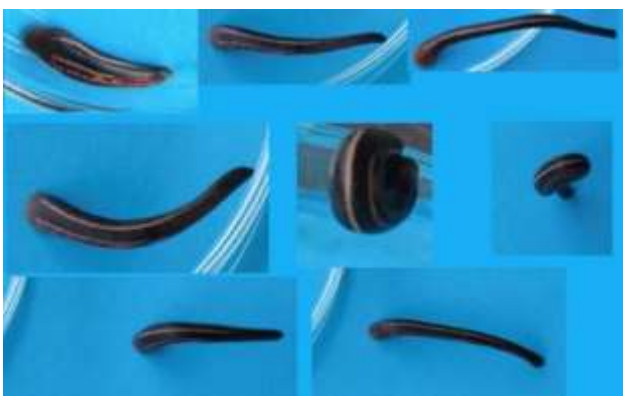
The traditional food for flatworms is small pieces of liver, but they also like a sliver of cheese dropped into the dish. Another answer is hard-boiled egg yolk or small pieces of beef. Flatworms will **regenerate** (grow back missing bits) if you chop them in halves through the middle with a sharp razor blade. It is also possible to split the 'head' lengthways between their primitive eyes, and produce a two-headed flatworm. This requires a sure hand, and it is unkind.

Flatworms are photonegative (light-avoiding) so keep them in opaque containers with covers. Change the water regularly. They rarely reproduce sexually in captivity, but do occasionally produce orange 'cocoons' that hatch out a month or so later. They also reproduce by fragmentation, even if nobody chops them up.

Leeches

If you go walking in the bush, you may discover one day that you are bleeding, and that the blood flow won't stop. This is probably a leech bite, after the leech has dropped off, but don't worry about the bleeding, because it will stop in time.

Below, you can see what an engorged (well-fed) leech looks like. Leeches live on blood, and have a chemical in their saliva to stop blood clotting, but continued bleeding washes out the anticoagulant, and also, with luck, any germs that may be in the wound. Of course, if the leech got into your shoe and you end up with a squelchy blood-filled sock, that can be upsetting.



The leech here was out loose on my desk. Playing with them is safe, if you know what you are doing. Leeches may *possibly* spread

diseases like hepatitis, so they aren't good playthings. Just admire them and walk away. If you get a leech bite, wash it in clean water, disinfect it, dry it and cover it, then get the wound checked. You must definitely seek help if you start to develop a fever.

The best way to identify a leech is to know how it moves, because nothing moves quite like a leech: look at the pictures above, and see how leeches move like the caterpillar called an inchworm or looper. Leeches are attracted by body heat, and this one is trying to detect prey.

They usually have their mouth end in the air, 'questing' for warm bodies. The first time my younger son saw them, at the age of about four, he called them "tails", which is an excellent name for them. I would have said that unless your garden is fairly damp, you probably don't have leeches, but in the last year, one of my students found a leech in leaf litter from my fairly dry garden.

In the past, leeches have supposedly cured many people. Well into the 1800s, doctors used leeches to drain blood from sick people. A few medicinal leeches are still used today, mainly to control bruising. Some leeches live on small invertebrates, others attack any sort of vertebrate to get blood, but the land leeches we notice most specialise on mammal blood, finding their prey by sensing body heat.

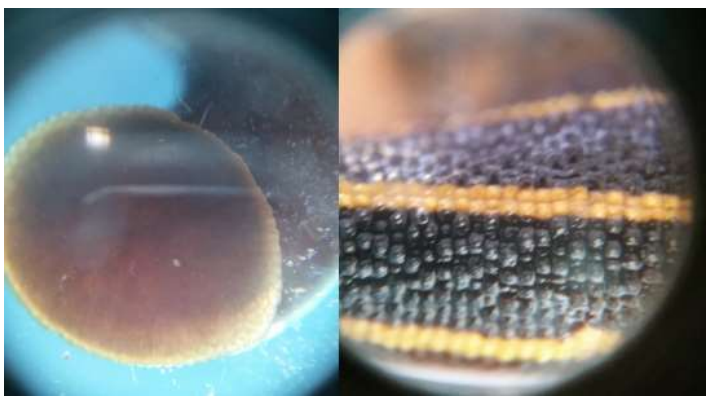
My wife and I are both experienced leech wranglers, and so long as you stay calm, there is no problem. If a leech begins to attach, it can easily be removed before it gets through the skin. Just wipe it off, or drag it off and drop it somewhere safe. Leeches can only move about three centimetres a second, so leech wranglers simply need to stay alert.

The art of leech wrangling

You can use their heat sense to attract leeches into a jar like this. They detect heat through the glass, and leeches aren't very clever. The hand in these shots belongs to my leech magnet wife.

I am lucky she is such a brilliant leech magnet, because even on high, dry, Hawkesbury 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 either move away, or if we need a specimen, we just hold an open jar in their path, and they rush in. Then, when we get home and need to photograph them, my leech magnet comes along and puts her hand where it needs to be, to draw them into the camera's range, but she keeps her hand out of reach. I often put animals I am photographing on a dry platform in a large dish of water, and that was how I discovered that land leeches can swim. I won, by seeing something new! These two shots were taken with a clip-on.



I occasionally blog about my leeches, and you can find those articles from this link:
https://oldblockwriter.blogspot.com.au/search?q=leeches

Look out for these:

- Count the number of segments, using a photo;
- Examine the suckers at each end;
- Can you see a mouth at the front end?

Molluscs

Snails and slugs

Snails, slugs and whelks make up the class **Gastropoda** (the gastropods) within the phylum **Mollusca**. The other main types of mollusc are the bivalve shellfish (like oysters) and the squids, but those are not gastropods.

A simple note about grouping and naming: I will ignore *domain* and *kingdom*, and start at the *phylum* level. Plants and animals are grouped into various phyla (that's the plural of phylum, and pronounced 'filer'). A few animal phyla are the **Mollusca**, the **Arthropoda** and the **Chordata**, which includes us. Below that, there are different *classes*, and examples include **Porifera** (sponges), **Insecta** (insects) and **Mammalia** (us).

Next, we have the *order*, and we humans are in the **Primates**. The largest order of insects is the **Coleoptera** (beetles), while the **Lepidoptera** (moths and butterflies) is also quite large. The next division puts things into different *families*. We humans are in the **Hominidae**, and beetle families include the **Curculionidae** (weevils) and the **Scarabaeidae** (scarabs).

The next levels down are *genus* and *species*, which usually come together, always in italics, with a capital on the genus. We are *Homo sapiens*, my favourite termite is *Coptotermes acinaciformis*, and a swamp wallaby is *Wallabia bicolor*. No species name can be given to more than one species, and whichever species was named first keeps the name (which is why the platypus had to be renamed *Ornithorhynchus*). We are called *Homo sapiens*, and no other animal can be called that. There are a number of trees called 'mountain ash', but there is only one *Eucalyptus regnans* (and note the italics: good biologists always use italics in genus and species names).

Of course, professional scientists make it much more complicated, talking about superfamilies, tribes, subtribes and more. We don't need to worry about those, but when you see something like *Acacia* sp., that means we are talking about a

wattle which belongs to the genus *Acacia*, but we don't know (or it doesn't matter) what species it is. Now back to the molluscs.

Snails can be found in the sea, in rivers and ponds, in gardens, around deep-sea hydrothermal vents and even in deserts. Some of them are incredibly rare and endangered: a scientist at the Australian Museum once told me about a snail species he had found which only lived on a single isolated fig tree in a desert somewhere in Australia. There are more than 60,000 known species of snail around the world, but think about that desert snail: how easy would it be to miss seeing the whole species? And how much longer do you think it will survive, if the fig tree dies?

Snails have shells to protect them from predators but slugs don't. (Actually, a few slugs do have a tiny internal shell, just a trace of one, an evolutionary leftover like the vestigial hind legs that you can see in the skeleton of some whales, if you look carefully enough.) The gastropods we call snails are the ones that usually have a visible coiled shell. Limpets are gastropods and have coiled shells when they are very young, but are they snails? Does it matter?

Common names like mushroom, toadstool, frog, toad, moth, butterfly, snail and worm aren't clearly defined. There may be technical differences (as there are between crocodiles and alligators), but there are more interesting things to about, until you are an adult specialist.

Catching snails

Snails are easy to catch: the name *gastropod* means stomach-foot, which refers to the foot they travel on. The holder of the snail land speed record is a snail called Archie, who was clocked in 1995 at 10 metres an hour, which means a single-minded snail could travel a kilometre in just over four days, 90 kilometres in a year, and go from Sydney to Perth in less than 40 years. Luckily, snails don't live that long, and they usually keep turning aside to chew on a tasty plant (or animal).

Many snails are plant-eaters, but some of them eat meat, even hunting and eating other molluscs. The largest snails are whelks that can be 600 mm long, while the smallest (and least known) are less

than a millimetre long. You don't need any real equipment to catch them, you just need an idea of where to look for snails.

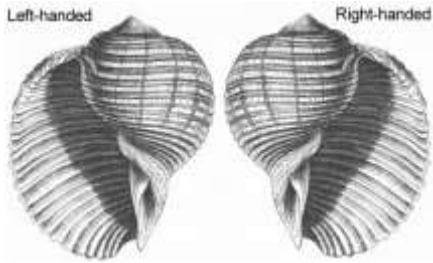
With a bit of knowledge, you can get the snails to help you find them. Water snails shelter under rocks or logs and land snails shelter under rocks or a board that is just clear of the ground. So you just have to look in the right place, but always think about what else might be under a rock or board before you turn it over!

You can also buy water snails at aquarium shops, or get them from somebody who keeps fish. These snails will eat algae, waterweed, or any other plant life that comes along. Keeping marine shellfish is more difficult—and smelly because they always die. Parents do not appreciate this!

Looking at snails

Even with a hand lens, there are things to see. Land snails have two sets of tentacles, and there are eyes on the tips of the longer pair, but sea snails have their eyes at the base of their tentacles. Most snails, when you look closely enough, have 'growth rings' (for want of a better term). Can you see a series of ridges on a snail's shell? Can you see more detail under the microscope?

A helix can twist two ways: right-handed and left-handed. An ant going up a right-handed helix standing on its end moves to the right, until it disappears around the back of the helix, while an ant going up a similar left-handed helix moves to the left as it crosses the front of the helix. Ordinary bolts and screws are right-handed, but gas fittings have left-handed threads. Snail shells also have two forms.



Some spiral snails come in left-handed spirals only, some come in right-handed spirals only, and a few come in both forms. The easy way to identify the 'handedness' of a shell is to hold the shell, top up, so that 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.

For a book that I wrote more than 30 years ago, I examined several thousand Pacific shells, and several hundred Indonesian shells. They were all right-handed, and so were all the Australian shells on display at the Australian Museum, and the shells of Australia and New Zealand that I examined in several reference books. Even the Australian Museum's fossil shells were all right-handed! I decided to give up my hunt for a left-handed shell.

Then one day I was cleaning out an aquarium tank. The small snails that I kept in the tank to clean the glass were all left-handed! I suspect the species is an import from overseas, but the lesson here is never to give up looking! So collect a range of snail and shellfish shells. Sort your shells into species, and into right-handed and left-handed forms (if any). What conclusions can you draw, and why?

I think there are three species of shell from the Margaret River area in the picture above. Do you agree?. While you are at it, look at your

snails, and see if you can find any differences within a species. If they are striped, do all of them have the same size stripes? If they have knobs on their shells, are all of them just as knobby, or are some of them smoother? Are they all the same colour?

Keeping snails

Snails are hermaphrodites, so when they mate, two snails swap sperm to fertilise each other and then two weeks later, both of them lay small white eggs which hatch out after another two weeks. Water snails attach their eggs to rocks or plants, so if you keep water snails in a clear container, you may be able to see the eggs on the side of the container. Look for a small piece of clear jelly with dots in it.

Snails use their shells for protection against predators, and also against drying out. When a garden snail egg hatches, the first thing it does is to eat its egg shell, and then it goes looking for plant material to eat. The cell walls of plants contain calcium compounds that snails use to build their shells. After a few days, the young snail emerges into the open, but it takes two weeks to develop the dark brown shell we know and recognise. The main parts of a snail are the shell, the mantle, the foot, two long tentacles or eye-stalks (they have eyes on their ends) and two short tentacles or 'feelers'. The foot produces slime to help the snail move along, and the mouth has a rasp called a radula.

Some marine whelks have a 'door' of shell material (called an *operculum*) that they use to seal off the shell from attackers, and to hold moisture. We will see opercula in a few pages. Snails have lungs, and breathe through a hole (the spiracle) near the shell's edge. If you watch a snail moving up a sheet of glass and look at it from

beneath, you can see the spiracle on your left (the snail's right-hand side).

To keep gastropods, you need a container that can be sealed to stop the snails escaping, with some sort with food plants in it. An old fish tank is ideal: you can cover it with fly-wire, held in place by a piece of elastic or a chain of rubber bands.

If you are using rubber bands, they will eventually break, so always have two separate chains of bands in place, and replace any broken chain. A very easy way to keep gastropods is to use a humidity jar. With a fish tank, the lid can be a sheet of glass or wood, or fitted flywire, or even a piece of cling-wrap, held by a rubber band. If you use the flywire, you need to keep the soil damp. Some snails may live in deserts, but most of them prefer damp moist soil. A piece of raw potato is a good source of moisture.

Put about 10 cm of soil or coarse sand in the bottom of an old fish tank, and dampen it. Most land snails eat lettuce leaves, which you can grow in yoghurt containers. You can buy the seeds at any garden or hardware store. Put three seeds in a new small pot every two or three days. As soon as the first plants are 5 cm high, bury the pots so they are flush with the soil, and add about five snails.

At six months, a garden snail is half-grown, with three full whorls (turns) to its shell. It keeps growing until it is an adult at one year. After that, it grows no larger, but its shell gets thicker until it starts to reproduce when it is two years old. Not everything in a shell is a snail, though. Hermit crabs will take over seashells, and sometimes a leaf-curling spider will use an empty snail shell as a home. This is a reason *not* to collect empty shells!

The best way to learn about snails is to watch them, to see how they behave.

Look out for these:

- When they are on glass, look for the mouth and radula;
- Also, while they are on glass, look for waves of motion in the foot;
- Look carefully at the eyes: my references say a snail's eye contains a lens.

Can you see it?

Keeping slugs

Slugs aren't very exciting for most people, but they are easy to keep. Like snails, they are good at escaping from enclosures, but they like the dark and damp, so try them in a jar with compost, or a humidity jar, and watch to see what they eat. Try potato, carrot, bean, lettuce: they like lettuce, but a mixed diet is probably better for them.

My happy slug.

The slug in this humidity jar lived happily on lettuce and carrot for four months while one of my books was being written. It was then released into the author's herb garden. It cheered loudly as it galloped away.

OK, I made some of that up—it only cheered quietly as it galloped away.

Look out for these:

- Can you see any trace of a shell?
- When they are on glass, look for the mouth and radula;
- Also, while they are on glass, look to see how they move;
- Look carefully at the eyes: if a snail's eye contains a lens, do slugs also have lenses?

Seashells are molluscs too

Two notes to begin with:

- Some of the content here appeared also at the very start of this book, but there is more detail here.

- Collecting shells, even dead shells, may be against the law on beaches that are parts of national parks or reserves. Collecting dead shells is usually OK on public beaches, *but* never take more than a few. When I need a population set or a collection of fragments for teaching, I always return them to the same beach, and when I need photos, I do them on the beach.

Finding shells and shell bits

As you walk along any beach, there will always be a few shells washing around in the wave zone. The shells are all that remains of the skeletons of what we call 'shellfish'. When waves hit them, the shells bang into each other and break. The smaller bits rub on sand grains, and slowly wear away, but you can usually identify the bits, if you look closely.

The stranded shells are on Barragoot beach, NSW. Further up the beach, there will be other tide-lines, and you can find some shell bits there as well, but the most interesting pieces of shell are usually buried in the sand. The easiest way to collect shell bits is with a sieve jar and a container to tip your catch into, using the method described in chapter 1. Later, you can rinse your shell bits in fresh water, dry them out in a white dish, and sort through them.

If you are searching for shell bits in wave zone sand, fill the jar ¾ full of sand, rinse off the sand around the rim, screw the lid on, and shake the sieve vigorously in the water. I put my other hand under the jar, so I can tell when sand stops falling out, then I tip or wash my catch into a second jar.

If you are searching dry sand at the top of the beach, don't rinse the jar: just shake it and let the dry sand fall out. If I ever do this, I make sure the shell bits from the wave zone go in one labelled jar,

and the ones from the top of the beach in another. Science grows from seeing differences and similarities.

Look out for these:

- The shells will include more than just sea snail shells: look carefully;
- The edges of broken shells can give you an insight into how shells are built up;
- The outsides of shells probably tell you something about how the owners avoid being eaten.

Finding the best fragments

In this next shot, my practised eye found a quartz pebble, a brown glass fragment, and a small brown and white conical snail, probably a volute, as well as fragments of dark blue or purplish shell, probably from a cunjevoi. What you see, of course, will depend mainly on where you were when you collected the material that you are looking at.

I can also see several more sea urchin spines, bits of limpet shells, and somewhere in there, I found (and then lost) a tiny fish vertebra, a backbone segment. If you know the shells of Australia's rocky shores, you will also see *Bembicium* and *Melanerita*, but who can tell what else is hidden under the sand's surface? Here is another

key to looking at the picture above—and your own finds. The shell I labelled 'limpet' may be a false limpet. Make a decision!

Seashells are readily available, and no animals need to be killed if you collect only cast-up shells, found on the beach. It should be against the law to collect live shellfish, as it is unethical.

And then there's the smell, and the risk of encountering cone shells, which are venomous. Note the shape: the cone shell below is from Vanuatu, but many of the Australian ones are quite beautiful, and just as deadly.

Along the NSW coast that I know best, there are several stripy zebra snails, like *Austrocochlea* and *Bembicium*, and limpets like *Cellana* and the false limpet, *Siphonaria*. Even young searchers will notice neat round holes in some of the shells and wonder about how the holes got there.

Now look at the holes: if they are small, neat and chamfered, the holes are the work of a family of snail-eating snails called the Naticidae, but if the hole is ragged and rough-sided, it is probably the work of an octopus. If you are lucky enough to find a drilled

cowrie shell, it will probably have a ragged hole, drilled by an octopus, close to the narrow opening in the shell.

If you look at a bivalve (that's a shellfish with two shells like the ones in the middle shot above), the ones with holes are usually all bored in the same place, near the muscle that keeps the two shells close together, but a few of them break the pattern. Scientists think the killer snails learn where to attack, because sometimes you can find shells with holes in random places.

In the rocky pools beside the sea, there are many snails with murderous tendencies. *Morula*, also called the oyster borer or mulberry shell, is one example, and there are others as well, like the burrowing sand snails and cart-rut shells. These amble up to their relatives, drill a hole in their shells, and slurp them out. No shellfish is safe, though, as you can see.

Seashells are well within the range of even a hand lens, so sand sieving is one of those activities that can go in many directions. For example, try examining the drilled holes: how neat are they at a microscopic scale? Once you have your shells to play with, the world is your oyster!

Opercula

As we saw in chapter 1, a number of snails have a 'door' to their shell, and scientists call one of these doors an *operculum*. (It is one *operculum*, two or more *opercula*, but don't worry about that too much.) When you find one, it means a snail has died.

I found these opercula while I was sieving sand. The smallest of them are about 3 mm across. Apparently, the operculum does more than keep predators out, because some intertidal marine snails have them, and seem to need an operculum to save them from drying out and dying.

The oyster shells from beaches are also interesting. This one has tubeworms (*Galeolaria* sp., centre shot) and small barnacles (right shot) growing on it. The close-ups were taken with a clip-on. The lesson here: always take a closer look, because there's always a story there, waiting to be read, every time you zoom in!

8 Invertebrates with six legs

The next three chapters look at the phylum Arthropoda, the arthropods, a name that means 'jointed legs'. This chapter covers the main six-legged insects, in alphabetical order; then we move all the way up through the arachnids to the invertebrates with many, many legs, the centipedes and millipedes.

A few insects grow through a series of similar stages called **instars**. Other insects begin as eggs, hatch to a **larva**, then develop to a **pupa** that becomes an adult and lays more eggs if it is female. Just to confuse things, each moult of a larva is also called an instar. Two examples where the young are similar to adults are cockroaches and grasshoppers. Remember that the sloughed-off skins of invertebrates can be collected and photographed: spider and crab 'skins' and cicada nymph shells are probably the easiest.

Ignoring the leg count for a moment, arthropod heads are remarkably variable, but they all occur at the same end of each animal, where the sense organs and the mouth are collected. It probably works better to have your sensors at their front end, so they can detect food (or things regarding *them* as food) in plenty of time. Look closely, and decide how many variations you can find in the eyes and the way the antennae are attached. Are the mouthparts all the same in this mantis, cricket and wasp?

For the most part, only dead insects will stay still long enough to be studied or photographed, and dead insects don't sting or bite. A supply of captive or dead insects is best, and you can get these by plundering spiders' webs and outside light fittings that are switched on at night. Above you can see the yield from a single light fitting (probably two years' worth of catch).

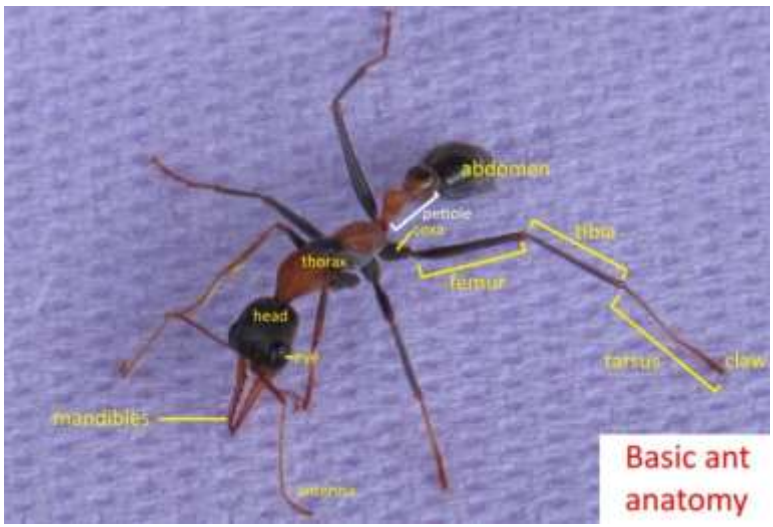
Look out for these:

- The 'shells' (**exoskeletons**) are made of a very tough material called chitin: can you find anything common in the appearances of the pieces?
- Look closely at how the joints work;
- Do all of these animals have antennae?
- What can you see of the eyes?

The common insects

Technical names are useful when you are doing internet searches. If you search on <**butterfly scales**>, for example you may end up with hits for 'Butterfly' brand kitchen scales, but <**Lepidoptera scales**> will get you closer to what you want (unless you really *did* want to buy kitchen scales!). Some parts of insects will be given their technical names, others won't. Unless you need the terms, ignore them. Over time, you will get used to them, and you will notice that most of the names of the orders of insects end in **–ptera**, which means 'wing'.

You'll pick up the rest as we go along. Before we start, though, here's a quick run-down on the main bits of an insect's body parts, using one of my cool (in several senses) bull ants as an example.



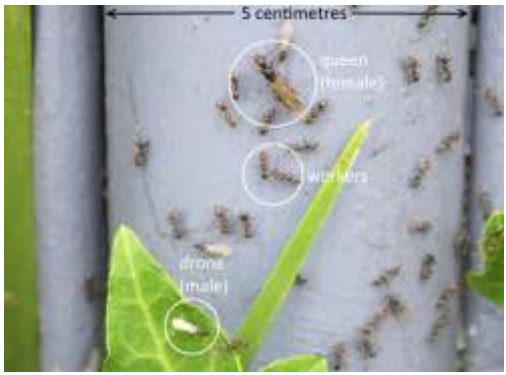
Insects all show variations on the same basic plan, though sometimes, parts are fused together: if the head and the thorax can't be distinguished, we call that a cephalothorax. You probably don't need to know that, or the names of the leg parts, unless you are trying to identify a species. The one thing not shown here is the ant's sting, which is at the end of the abdomen.

Ants

Ants belong to the order **Hymenoptera**, a name that means 'wedding wings', which reminds us that the family have wings only during mating. That certainly applies to the ants, but in Australia, a recent count found about 1275 species of ant, 176 sawfly species, about 10 000 wasps and 2000 bees, and all of those are in the Hymenoptera. Don't worry about it!

In the top row, two anthills near Kati Thanda (Lake Eyre) one from the Swan River and Purnululu (the Bungle Bungles) in the Kimberley, and in the second row, sites from the Margaret River and North Head (Sydney).

Notice the raised soil around each exit hole. Water barriers may not be needed in sandy soil, but in flat clay soil, they are essential. While anthills are largely just dumps of sand, hauled out as the ants make tunnels underground, they also serve, in some cases, to keep water from flooding down into the nest. As you can see from the pictures, the ants often bring soil and sand to the surface that is very unlike the material on the surface. Reach for your microscope, here's a ready project to try, but use a teaspoon to get the sand samples, so you don't get stung!



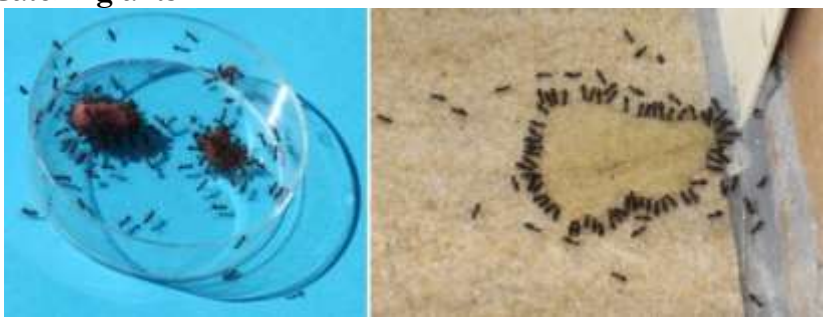
In summer time, you will sometimes see ordinary ants swarming around, usually on a warm **e**vening, and in among them, you will see some ants with wings. These are the males and the breeding females, setting off to establish new nests. The queen lands somewhere, usually with one or more males.

She mates with one, storing the sperm that she will use for the rest of her life. Most flying ants are eaten by other animals, but occasionally a queen survives. She loses her wings and finds somewhere to start a nest. She has to raise the first brood herself, but after that, the wingless worker ants, all sterile females, care for the larvae.

Ants vary in size from almost invisible, not much more than 1 mm long, to claimed lengths of up to 40 mm for bull ants, though 30 mm is more likely. Warm northern Australian climates, average 150 species of ant per hectare, while in cooler southern climates, there may be 75 different species in each hectare.

Remember that ant stings can be serious for some people. Make sure you know about **anaphylactic shock**, and whether or not you are at risk, before you start playing with ants. In the northern parts of Australia, green tree ants are interesting to watch, *but not good to annoy*.

Catching ants



These photos show ways to attract ants with two small fragments of steak (left) and honey (right). This was part of an attempt to photograph ant trails, a topic I will come to next.

I mainly need to catch ants to feed to ant lions, which we will look at next. Attract them with Vegemite, a bit of meat or a dab of honey on a weighted-down sheet of paper: most ants will go to at least one of these baits. Get a glass jar and sit it in a tub with 1 cm of water in the bottom of the tub to make a moat. This jar will be the ants' temporary home.

Next, put four stones on an A4 sheet of paper near an ant trail, and set your bait in the middle. When there are about 20 ants on the sheet of paper, use tweezers to remove the meat bait (but leave the honey or Vegemite), remove the rocks, pick up the paper and bend it into a U shape, then shake the ants down into the jar. If you need more ants, put the sheet out again.

Ant trails
In cartoons and movies, we see conga-lines of ants, following head-to-tail, but while photographing leafcutter ants in Peru, I could not see this pattern. Back in Australia, I tried all sorts of tricks to get a trail, and took almost 500 photos. I sometimes found a line of sorts, but it wasn't clear.

In the end, I got this more convincing trail on a kerb outside the Alice Springs cemetery. As near as I can see the cartoon ant trail only exists in our minds, in much the same way that the movement we see in the cartoon only exists in our minds, because movies are a series of still shots, one after another. Our eyes can be tricked in many ways.

Avoiding bullant stings
A bull ant stings by grabbing you with its nippers, but the sting is in the end of its tail (that's its abdomen to scientists). So when you feel the pinch of the nippers, you have about one second to get rid of it. Don't try to grab it, or it will probably sting your hand: hit it a glancing sideways blow that brushes it off, and then move safely away. It also helps if you know how to use a jar and a card (chapter 1), because that is the safest way to get a single ant into a jar. Once it is there, put the jar in the fridge with a warning label, and when it is cooled down, drop it onto a paper towel, floating on a piece of wood, floating in a bowl of iced water.

And now, you are ready to start photographing ants. If you can manage bull ants safely, the rest will be easy, but if you are under 12, you need to talk to an adult, and you get adult help. If you know what an epi-pen is, you may need to avoid his project, because at least one Australian bull ant can cause anaphylactic shock. Just talk to somebody older and wiser, first.

Photographing bull ants

The safest way of all to get a shot like the one on the right above: with a camera, standing and leaning over the bull ant. For closer shots, as I mentioned earlier, ice can be the photographer's friend. And as mentioned earlier, if you need to kill an ant to examine its parts in higher detail, a freezer is a quick and painless way to kill them, but I prefer to keep them alive and active. And once again, the nippers on dead bull ants cross over.

On the left, process and product in one shot: the water is icy cold, the ant is just out of the fridge, and it sits on a raft cut from the base of an old-style ice cream container, sitting on some pebbles. For ordinary ants that are alive, I think a clip-on works best, because you can move it quickly: just keep on taking shots until you get one that works, though most shots ill look like this:

These ants were about 7 to 10 mm long, and not very useful. Sometimes, you get lucky:

These shots may give the reader ideas for projects, looking at antennae, hairs on legs, joints on legs, sculpting on the mandibles or thorax, the eyes or any other body part. If you can catch a drone, a queen and a worker during a swarm, you have all the material you need for a comparative study.

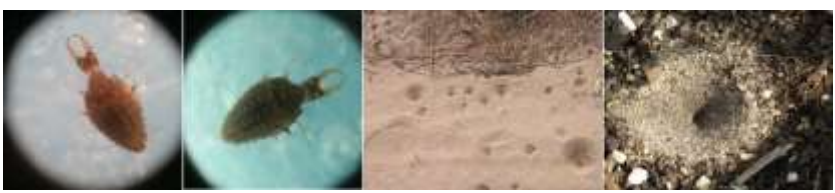
Look out for these:

- Look for variations in the antennae;
- Look for variations in the patterning on the thorax and/or abdomen;
- Look to see if you can spot the sting;
- Take a close look at the eyes: how do they compare, from species to species?

Ant lions

These are my favourites because they were the first insects I studied, and they make neat pits in sandy soil. They are the larvae of lacewings, *alias* **Myrmeleontidae** (Neuroptera). The name 'lacewings' describes their pretty wings quite well, but 'ant lion' is a good name for the larval stage. Instead of hunting like lions though, they dig pits in the sand and sit at the bottom, waiting for an ant to fall in.

I once saw one of these animals capture a small weevil, but usually, they eat ants. Whatever the prey is, once the unlucky animal reaches the bottom, the ant lion seizes it in its pincers and sucks it dry. In the end, it flicks the empty husk of the prey out of the pit. Ant lions are neat!

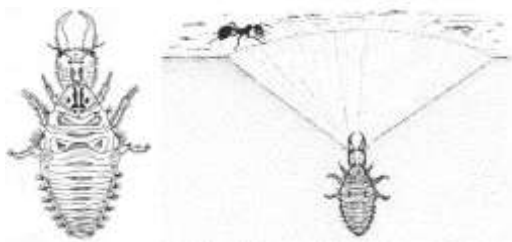


The first two views of an ant lion show the depth-of-field problem for photographers: you can't get multiple levels in focus. To find these curious creatures, look for a small conical pit, 1 to 3 cm across in dry sandy soil. Sometimes, you can even see ant lion pits,

completely out in the open in the dry season on Cape York, in the summer around Myall Lakes in NSW and in dry areas. All they need is dry sandy soil. The third and fourth shots above show multiple ant lion pits in sand near Weipa, on the Gulf of Carpentaria (note the footprint); and a single pit, in bush near Sydney.

A large ant lion can be 6 mm long, but a quarter of that length may be the nippers that it uses to seize its prey. It digs a pit by backing into the sand and moving in a circle, flicking sand out with its head. Recent research on fossils in amber suggests they have made pits for 100 million years.

Dry sand only piles up to a certain slope, called the **angle of rest**, and this is the slope of the sides of every pit. At this angle, the sand is unstable and ready to tumble down if a small animal walks near the edge. As soon as sand grains hit the bottom, the ant lion starts flicking sand up from the bottom of the pit. Some sand falls down again, knocking its prey down the slope, but if the ant lion flicks enough sand out from below, the whole slope begins to slide down, carrying the food animal down with it.



These drawings come from my long-out-of-print *Exploring the Environment* (Longman-Cheshire, 1986).

An ant lion homes

Here are two effective places to keep them: Ant lions won't escape from either of these, until they change to adults (when they can fly away). The white dish version is better for seeing and photography, but the moat (the water in the outer dish) is good for stopping the food getting away.

First, you have to catch some alive, and that means you need to know where to look for them. They like sandy soil, and they usually seem to prefer dry sand, so the best places to look are under buildings that sit up on piers, like demountable classrooms in a school, but they can also be found close to the trunks of large gum trees with sap that kills grass and under overhanging rocks.

Look at the pictures, then search for cone-shaped pits near your home. I have shown these pits to hundreds of people, and the very few who had seen them before all assumed the pits were made by raindrops. As you can see from the picture above, the ant lions are in the sand, a bit deeper than the bottom of the pit, but at any sign of danger, they will further down into the sand. If you want to keep some ant lion pets, find some of their pits in sandy soil, and leave them there.

Carefully *and gently,* sieve some sandy soil with a sieve jar, put the sand in an ice cream or similar container, and smooth the surface. You need about 5 cm of sand. Use a plastic cup to catch your ant lions. Scoop quickly and deep, digging about 2 cm below the base of the pit in one quick motion to make sure you get the ant lion. Put the sand *gently* into the sieve jar, close the lid, turn the jar upside down over a tray and *gently* swirl the jar to get the sand out.

It will play 'dead' when it is disturbed, so if you sieve the sand, the ant lion will be a shrivelled greyish thing in one corner. When you put a new ant lion into fresh sand, it will 'freeze' for a while, giving you a chance to photograph it on the sand. It will stay still for some time, and then suddenly start to burrow backwards into the sand.

Sometimes it may wait a day or two to make a complete pit, especially if it had a good feed just before you caught it. Once they start digging, the tray will be dotted with craters. You might fit about a dozen pits in one ice cream container, but no more, and half a dozen is better. Watch what happens when one ant lion throws sand out and it lands in another pit. With six ant lions around, any ant dropped into the container will be caught quite soon, once the lions are hungry.

Watching them feed is the best part. For that, you need a supply of ants: look back a few pages and you will see that I have described how to get the ants. Let them go without food for a day or two, and then catch some ants. Let a couple of ants go in the middle of the tray, and watch.

Ant lions only take live food, so you need to pick your ants up carefully (or avoid handling them altogether). One ant at a time is best, so you can observe the hunt in some detail. Don't over-feed the ant lions, or they may stop catching food.

This is macrophotography, rather than microscopy, but you may be able to photograph or video an ant lion detecting its prey, and catching it. Clean, washed and dried sand gives better contrast, and better shots. Work with lighting from one side of the container only. See if you can film the ants' exoskeletons being thrown out, and post that on the web.

Ant lions grow up into beautiful lacewings that destroy aphids which are garden pests, so keep feeding them until they develop into adults, or release the ant lions where you found them. (To study the adults, you would need a fly wire cover over the container, but do you need to?)

My ant lions have occasionally not liked my clean sand. Maybe the sand was too dry, but see what you can discover. Now I always keep a hole in one corner of the sand tray, and pour water in gently until the bottom 1 cm of a 5 cm layer of sand is damp. The ant lions seemed to be much happier with that. What sort of sand do they favour? Find out! However you look at them, ant lions are amusing!

Studying ant lions

Look out for these:

- Map the places where ant lions can be found;
- Compare the sizes of some pits with the sizes of the ant lions;
- Sieve the sand after a season of growing ant lions, and see how many exoskeletons you can find;
- Take a close look at the nippers of an ant lion: how well are they suited to catching live animals?

Aphids and cicadas (Homoptera)

Aphids feed by sucking the sap of plants. The larvae of ladybirds eat them, so do some lacewings, and they are 'farmed' by ants, which protect them. Cicadas tell us when summer has really arrived, which is probably why they appear earlier in the more northerly parts of Australia. Around the start of summer, nothing is more magical than watching an adult cicada emerging from the nymph stage.

The nymph is an ugly-looking beast: the front legs look more like talons for ripping flesh, but they only use the legs for digging tunnels. Juvenile cicadas are rarely seen, except when the nymph digs its way out and climbs up a tree, where the adult emerges. While the cases are easy to photograph, you will have more fun capturing a complete sequence of the adult emerging from the nymph case.

When an insect starts out as a larva (or a nymph), it has no wings. Logically, the larva, pupa or nymph can't have wings, because at the first moult, when the outer case or exoskeleton ('shell', if you prefer) is sloughed off, the wings would go as well. Instead, the wings remain inside, as mere buds. Before the adult emerges from the case of the pupa, the wings form inside as scrunched up membranes that are living.

As the adult emerges, fluid is pumped into the wings, under pressure, a bit like those modern tents that take a complex shape, thanks to a few rods that are slipped inside. We call the channels that the fluid is pumped into "veins", but they don't carry blood. The wings take their final shape and after they have dried, they keep it.

This wing-unfolding is the reason why you need large containers to raise butterflies, and why butterflies need perches where the new adult can hang, not touching the sides, while the wings harden.

Two cicadas, probably of the same species, and the wings of a different species, found dead and largely eaten by ants.

More about wings

We call the pattern the veins form *venation*, and you can look at this in all sorts of insects. You can get wings from all sorts of places: in late summer, look out for dead cicadas around the place: you can harvest a wing by carefully using forceps and a pair of scissors. You can also study swatted flies and mosquitoes, dead bees and dead insects taken from spiders' webs.

Speaking of webs, recently, while bushwalking, I found a curious pattern. It turned out to be an orb weaver's web that had been saturated with flying ants. I have to assume that the ants were too much work for the spider to kill given the food obtained, because the web had been abandoned. Take a look at the picture above, and see how the sticky threads are 'mapped' by trapped ants. There is more on spider web in chapter 9.

Look out for these:

- Are there standard patterns found in all the cicada venations?
- Wash the scales from a butterfly or moth wing: can you see any venation?
- Where insects have four wings, how do the front and rear venations compare?

Beetles

A beetle came into my house the other day. It rode in on a wattle flower I had collected to look at its pollen. The beetle was so small that I only saw it when I began removing stamens from the flower under the x20 magnification of my dissecting microscope. I should have seen it earlier, but I wasn't expecting beetles in the flowers. I should have expected them, because beetles are everywhere.

Scientists have named about half a million of them, and there are probably three times as many still to be collected, described and named. The beetles, or Coleoptera, are very successful, and they are about 40% of all the insects—and 30% of all known animals are beetles!

A famous evolutionary scientist, J. B. S. Haldane was once asked on a radio program what he thought the Creator must be like. Haldane thought—or pretended to think for a bit—and said, "He must have an inordinate fondness for beetles", referring to the huge number of known beetle species. There really are a *lot* of beetles.

Another famous 20th-century scientist, J. D. Bernal, was a physicist who was mainly interested in crystals, and in 1960, he commented in a lecture that "All that glisters may not be gold, but at least it contains free electrons." Bernal was a clever scientist, but he forgot the scarab beetles which have a metallic lustre without having any trace of metal or free electrons. Even the most golden beetles shine without being worth anything at the bank.

One of these gold scarab beetles, perhaps the best known in Australia, is the Christmas Beetle, *Anoplognathus*, like this dead one. This beetle is in the subfamily **Rutelinae**, a small (for beetles) subgroup of scarabs with about 2500 species throughout the world and 96 species recorded in Australia.

The thing you will notice when you examine a beetle closely is that the outside pair of wings are hard and tough. These covers (the elytra) are little use in flying, but they protect the delicate and gauzy flying wings that lie beneath. In Greek, a sheath is a *koleos*, so Coleoptera means 'sheath-winged'.

An African scarab called the Goliath Beetle seems to be the world's biggest, with larvae 15 cm long and weighing 100 g at their largest. The adults weigh about the same, but are more like 10 cm long. A beetle called *Nanosella fungi* is just 0.25 mm long and weighs 0.4 mg, but remember that three quarters of the world's beetles are undescribed.

There are probably no undiscovered giants, but there must be many tinier beetles still waiting for somebody to study them, and recognise them as different. With so many beetles, we shouldn't be surprised that beetles eat almost everything from leather (the dermestid beetles) to wood (like the deathwatch beetles) to dung.

The weevils are delightfully different beetles. They don't do anything much except to look weird, but quite a few of them have grubs that are crop pests. Their snout thing is called either a **proboscis** or a **rostrum**. When you see one of those, you know you are looking at a weevil—unless it has big ears, in which case it might be a small elephant. Run!

The very special weevil on the left was the first species ever collected in Australia, when James Cook and Joseph Banks visited Botany Bay in 1770. The Botany Bay Weevil, or *Chrysolopus spectabilis* is also called the diamond beetle, and it is found from Adelaide to near Townsville.

Weevils can be very tiny, like the one above, seen on a flannel flower: these flowers seem to attract a lot of insects. When you are looking at beetles, the interesting things are the antennae, the legs, the eyes and the protective elytra over their flying wings.

Two views of a longicorn ('long-horn') beetle with interesting (and very long) antennae.

Look out for these:

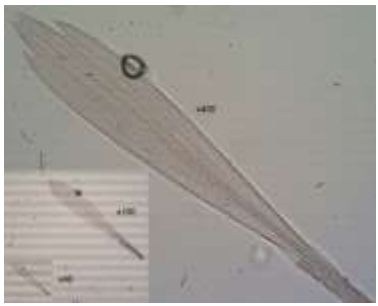
- How do the legs compare?
- How do the antennae compare?
- How do the eyes compare?

Butterflies and moths

Butterflies and moths have two pairs of wings. They start out as eggs that hatch into wingless caterpillars that later form wingless pupae in cocoons before they emerge as adults. The people who study them call them Lepidoptera, and scientists call those people lepidopterologists.

As in the Coleoptera, the **-ptera** part of the name comes from a Greek word meaning 'wing', and the **Lepido-** part of the name reminds us that moths and butterflies have wings covered in fine scales, which give the wings their colours. To study these scales, you need a microscope, but see what you can do with a hand lens, using the dead moths that are often trapped in light fittings.

The scales may have evolved as something that made the moths and butterflies an unpleasant mouthful for predators, but this is just my speculation: can you come up with a better idea? Could the scales be useful in flight? Many caterpillars taste bad, or have bristles that choke anything eating them. The caterpillars with good defences are usually brightly coloured, the colours acting as a warning.



The same moth wing scale at three magnifications. They can be viewed with a clip-on, and even with a hand lens. Butterfly wings have no colours in them—or at least there are no pigments. The scales on the wings produce the effect of colour because of the way they catch the light and bend it. If you want to look it up, the process is called **birefringence**. 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. That is to say, you will want a bright light above the stage, but to see scales, you need to mount them on a slide and use a light below the slide.

I still don't know where the colours come from, even though I scraped some scales off and made a wet mount of them. This is hard to do, because the scales repel water and slide out from under the cover slip. In the end, I took a dead moth, snipped a few pieces of its wing with fine scissors and dropped the pieces into a small specimen tube with a few drops of water and a drop of detergent.

Then I used the handle of a small paintbrush to treat the wing pieces roughly, before I fished out the main pieces of wing, using tweezers. Then I stirred the water up a bit and lifted a drop of it to make my slide. There were only a few scales on the slide, and some of those were broken, but there were enough whole scales to study. The scales seem to vary in any one moth, but I don't know whether each type makes a different colour. There's an interesting bit of research for somebody there!

Studying caterpillars

Assume that brightly coloured caterpillars are dangerous in some way, though some of them are bluffing: bright colours sometimes advertise that the caterpillar's diet has filled it with poison, but some

caterpillars just have the bright colours: play safe! Bristly caterpillars can often hurt us, but they don't warn us as clearly. Choose your caterpillar carefully. You are fairly safe with silkworms.

With a hand lens or a magnifying glass, you may be able to examine the mouthparts of a silkworm caterpillar and see how it eats a mulberry leaf. Loopers are also known as 'inchworms'. It's the same animal either way, and both names come from the way it moves along. Leeches move in much the same way, but they have a different shape and no legs.

I found this 2 cm long looper on my arm in a Dorrigo Plateau rain forest, so I encouraged it to climb off onto a railing and took these shots.

Some humane sources of moths and butterflies

There are usually a few dead moths inside light fittings, but there is a trick to getting a cover off and down in one piece, so if you don't know how to do it, get some help. If you get 'weevils' in the flour, keep them in a sealed jar and use the adults (usually, they are moths) as specimens – but only open the jar *outside*. Moths and butterflies are often caught in spider webs, but there is no food for a spider in the wings, so you can snip off part of a wing with a pair of scissors. The spider won't starve!

You can also photograph silkworms, but they are fragile beasts, and can easily be squashed by a lens pressed down on them too

enthusiastically. I have adopted a simple solution: angling the device at around 45° to the horizontal, and sliding it in gently towards the target, with an assistant watching from the side, to warn you when you get too close. Practise this on a 10-cent coin or a gumnut, first, with a helper watching out from the side, to warn you when you get too close.

Flies

I hate flies, especially the flies that tell me summer is here. One year, I was running workshops in Canberra, and I stopped about half-way from Sydney to get some water samples at Paddy's River. Walking back to my car, I nearly dropped everything because I needed two hands to carry the tray of samples, and there were flies all around me. Flies seem to be just plain bad, but if they didn't eat up dead carcasses and dung, things would soon smell dreadful. Maybe flies aren't all that bad, after all!

The world's smallest fly is a northern European midge, with a wingspan of just 1.4 mm and a length of 2 mm, but with a bite bad enough to frighten a rhino. One of the largest flies known is an endangered species called *Gyrostigma rhinocerontis* or the rhinoceros stomach botfly, which has a 7 cm wingspan. It is endangered because the African rhinoceros, the host for its **larvae**, is being hunted to extinction.

Those botfly larvae live inside rhinos; fruit fly larvae live in ripe fruit; mosquito larvae live in water and so do some midge larvae. Gall midge larvae burrow into plants and make the plant grow in strange ways, forming a gall that makes a home for it. Fly larvae can live almost anywhere.

A fly's other wings

All the flies have one pair of flying wings. They are grouped in an order called the **Diptera**, which means 'two wings'. They once had four wings, like all the other insects, but two of the wings have shrunk down to traces called **halteres**. Mosquitoes and midges are also flies, and like the other flies, they have halteres. We met this fly picture in chapter 1, but without the circle and the label:

Flies use their halteres for balance when they are flying around. If you examine a large fly with a hand lens, you should be able to see the halteres, just behind the wings, in the position where the hind wings used to be. The best flies for seeing the haltere with the naked eye are the crane-flies, also known as 'daddy-long-legs' or tipulids.

In case you are jumping around in this book and missed my discussion of this picture earlier, it is a 'cheat', because I used software to stitch together a whole bunch of pictures taken on different focal planes. The composite house fly image was stitched together from about eight different shots, all taken on low power. I held the fly in place by gluing it to cardboard and clamping the cardboard to the stage of the microscope. Slowly moving the objective lens, the bottom lens, down, taking a photo at each step requires both a steady hand and a good microscope, and I had both.

Then I selected the focused parts of different levels out and joined them with ImageJ that you can get from the (US) National Institutes of Health) at https://imagej.nih.gov/ij/plugins/. Sadly, the original pictures were later lost, so you will just have to take my word for it that ImageJ is brilliant — and free!

Look out for these:

- Do flies have antennae?
- Find the halteres on a few different flies: the tipulid flies ('daddy long-legs' flies) are easy;
- Can you see halteres on a mosquito? How about on a midge?

Mantises (Mantidae)

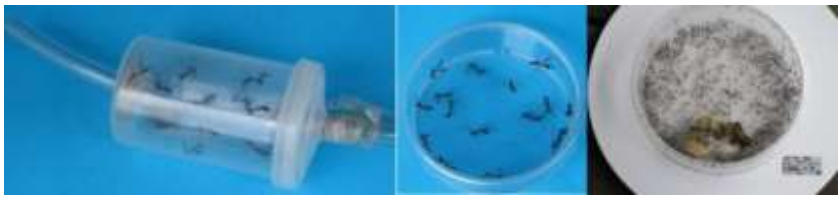
Watching a mantis feed is not a pretty sight, but nature is like that. If you have a populated terrarium tank, you can keep a mantis long enough to see it feed. I am not an expert on these beasts, so I will just offer this brief mention and leave the rest to you. If you find a dead one, their parts are fascinating. Look at the spikes on their front (catching) legs, their mandibles, their eyes and their antennae.

They are grouped in the family **Mantidae** in the order **Mantodea**. Some experts disagree on how they are classified, but that is the most usual way to group the 2300 known species. The largest mantises can be almost 20 cm long, and you can buy them in some pet shops. The longest I have seen in Sydney was about 12 cm long, the smallest were less than 5 mm—so keep your eyes skinned!

Their triangular heads with large compound eyes are the most obvious feature when you need to identify one. The 'praying mantis' is more of a 'preying mantis'. Those two legs that it holds up as if praying are actually used to seize the prey they eat. They eat almost anything smaller than they are, if it moves: mosquitoes and flies, wasps, moths and, even lizards and other mantises!

If you have a female in captivity and it lays eggs, she will eat her young if she is still there when they hatch. Worse, the young will eat each other, which might make you wonder what was going on in

these next two pictures, because at first glance, this looks like a really bad idea. The third one was me getting lucky.



One morning, a praying mantis had laid its eggs near my front door, and all these young mantises had hatched and settled on the screen door. I quickly pootered them up (left), and tipped them into a Petri dish (centre) for quick shots before I scattered them across my garden because mantises help control insect pests (and my granddaughter Brianna thinks they are brilliant). You don't really need a Petri dish, because for a lot of things, a jar lid will do just as well, but once you own some dishes, you will be amazed at how useful they are. I really needed the lid here.

That's also the case when a dead animal has fly eggs in it. I got into trouble once, when I was seven. I took a case moth to school for the nature cage, and flies started emerging, which fascinated me and upset my teacher. It nearly happened again recently when I put something dead to one side to look at and forgot it for 48 hours, during which time, many, many eggs hatched. Luckily, this time, it was in a Petri dish with a lid! For scale, the Petri dish is 6 cm from side to side. Imagine all of those tiny flies, loose inside the house! I was lucky the lid was on.

Look out for these:

- Compare the front legs and the hind legs;
- Are the antennae of all mantids the same?
- Can you keep mantids in a terrarium? What will they feed on? Try springtails (they're next!).

Springtails

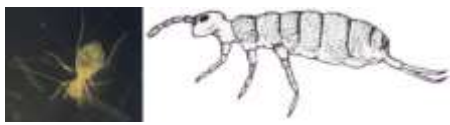
Technically, these are in the order **Collembola**. They are usually between 1 and 3 mm long, though some are less, and a few are up to 10 mm. If you have ever lifted a flowerpot and seen a lot of

small, pale jumping things, tinier than fleas, those were springtails. If you pour water on a pile of rotting leaves in the garden, you may see the same white springtails clambering up out of the water.

Once they climb onto something floating, they jump away. They have a strange prong at the rear, called a **furca**, which they use to throw themselves into the air. When they are in a dish under the microscope, they do the same thing, which is why they are hard to photograph while they are alive—unless they are floating on water.

Another way to see small life forms that burrow down is to put some leaf litter in a clear plastic box or a glass jar and put it down somewhere. Leave it for a few hours and then pick it up and look from underneath. I discovered this by accident while photographing a large bush cockroach in a plastic box of leaf litter.

Springtails are all over the world, from mountaintops to coral reefs, deserts and polar regions. There may be 6000 springtail species around the world and 2000 in Australia, but like other small animals, many of them have not been described or named so far. There are many families, but the two you will most often see are called the **Sminthuridae** and the **Entomobryidae**, which are also the best jumpers.



(Left, above) a sminthurid springtail, about 2 mm long, found on a hammer in my workshop! The entomobryids (right, above) are slimmer. Springtails eat dung, decaying plant matter and dead animals, a few of them prey on bacteria, protozoa, rotifers and nematodes, and one species attacks living plants.

Their main defence against being eaten is jumping, but some of them mimic other (dangerous) species, some have spines and others secrete nasty tasting fluids (No, I don't know how anybody discovered that). Don't eat them, although spiders do, and people who keep spiders use them as food.

To catch them, you need to remember that springtails hide under damp leaf litter and live in soil. You can catch them by plunging

some leaf litter into water to make the springtails float up, or with a Berlese funnel. In the wild, they eat fungi, and springtails can live on baker's yeast (not brewer's yeast!). Baker's yeast is sold in supermarkets for bread-making.

You can also try using a piece of lettuce leaf as food, either for them or the fungi that they eat. Don't worry about adding fungal spores, because there will be some on the animals you catch. You can keep springtails in humidity jars. If you want to study springtails, expose them to constant low light levels, or they will hide every time you try to look at them. If you are raising them to feed to small spiders (or pseudoscorpions), keep the yeast out of the spider jars.

See if you can work out the differences between the males and the females of the species you are studying. The mating practices of different species vary considerably, but not a lot is known about many species so you may even be making original discoveries. Make sure you share it with somebody, especially if you have good photographic or video proof.

Minor insects

The most interesting parts are their legs, eyes and antennae, but look around.

Bees

You can catch a bee without killing it, using a clear and dry one-litre plastic bottle with a fairly wide mouth. A clear one-litre milk bottle is the best, but long coffee jars also work. Make sure there is room for you to retreat if you need to get away, though the bee seems to have no idea that you are connected to its problems (paper wasps are smarter!). Wait for a bee to settle on a flower, move the bottle down gently over the bee and let it fly up into the bottle. Put the lid on the bottle, look at the bee, and let it go. Just turn the bottle upside down, remove the cap, put the bottle on the ground, right way up, and wait for the bee to climb or fly out. If it doesn't leave the bottle after a reasonable wait, try shaking it out, onto a bush.

Look out for these:

- Can you see pollen or the pollen brush on the hind leg?
- Can you find the antenna cleaner on the front leg?
- Can you see the sting at the rear?

Book lice

Book lice (Psocoptera) are also known as bark lice or bark flies. Until the invention of printing, and probably for a lot longer, there weren't many books around for book lice to live on, but there have always been plenty of trees. They sometimes attack paper, but only if it has already been damaged. They can also do a lot of harm to people's insect collections.

They are small, about 1.5 to 7 millimetres long, and you can catch them by holding an upside-down open umbrella against a tree and sweeping the bark with a wallpaper paste brush (or similar: have a look at these brushes in a hardware store and ask what their cheapest similar brush is). Use the flat on the outer bark and the edge to chase things out of crevices.

Earwigs (Dermaptera)

You may not realise it, but when you start looking between the plants that make up your lawn, there will be earwigs there, somewhere. You can always recognise them by the strong forceps (pincers) at the rear end of their bodies. They probably use these as a defence, but nobody is sure.

Look out for these:

- Are the antennae always the same?
- Can you see any differences between the front, mid and hind legs?
- Can you see an earwig using its pincers for anything?

True Bugs (Hemiptera)

To an entomologist (an insect expert), "bug" means something very different. Bugs are insects with mouthparts designed for sucking. These mouthparts will be hard to see clearly, even with a hand lens,

but try it. I always recognise them by the way their wings cross at the back.

Cockroaches (Blattodea)

Cockroaches frighten a lot of people, but most of these flat oval scavengers recycle dead material, so they are useful. Most people only know the few species that infest houses and drains, but there are more than 400 native cockroaches in Australia. They live in the bush and they are never pests in the house.

The bush cockroach above was about 40 mm long. It lived in captivity for three weeks, eating potato before I released it back where it came from. In the middle, its home, and on the right, how to turn a lunchbox into a cockroach kennel. Always use *two* sets of rubber bands, in case on breaks.

You can buy the Queensland giant burrowing or rhinoceros cockroach *Macropanesthia rhinoceros* in some pet shops. They live on gum leaves, and make marvellous pets. I have used these animals in public displays, and while I would understand people who ran away screaming, they don't.

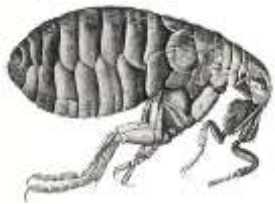
Enter the species name into your search engine, and then show your parents. You *need* to square this with them before you buy a rhinoceros cockroach! By the way, these cockroaches are listed in some record books as the heaviest of all the cockroaches, weighing in at 35 grams.

Look out for these:

- Can you find a cockroach without wings? This is called a nymph.
- Can you see the leathery forewings, called tegmina?

- Can you see the cerci, the two little hairs on the rear of a cockroach? These detect breezes or movement.

Fleas (Siphonaptera)



Do you remember this beast? You really should! Details of a flea, from Robert Hooke, *Micrographia*.

Fleas are insects that evolved from a winged ancestor, but their descendants lost their wings and developed a flattened form that helps them stay on their hosts and eat blood. This pays off in the long run, because they get to stay with the food. Many fleas are specialised and only live on a single species of animal. They move from host to host when two animals come into contact.

Look out for these:

- Look closely at the legs: what do you think each pair is used for?

Grasshoppers, plague locusts and crickets (Orthoptera)

Locusts are always a summer possibility. The signs will be everywhere, literally, when they are swarming. This group have nymphal stages that are very like the adults, except that they have no wings, but they all have strong hind legs which they use to jump. You can catch them with a sweep net (made of canvas, this is used to sweep through grass and low scrub.

In an outbreak, the Australian plague locust, *Chortoicetes terminifera*, will be everywhere, including on windscreens and in radiator grilles. Locusts are grasshoppers that form large and damaging swarms. While Australians often call cicadas 'locusts', cicadas are *not* plague locusts.

Watch out! There are sharp bits on broken grasshoppers, and live ones can inflict a painful bite if they are roughly handled, so gloves or tweezers are recommended. Depending on the vehicle, contact with the hot radiator is a possibility. Go carefully, and ask permission from vehicle owners first: they are unlikely to say no, but ask.

Look out for these:

- Can you work out how crickets make their noise?
- Look at several species: are there any common patterns in the spiky bits, across species?
- How many species of grasshopper can you find?

Stick insects (Phasmatodea)

We often call these animals phasmids, but specialists divide them into the leaf-like **Phylliidae** and the stick-like **Phasmatidae**. There are about 150 known species in Australia, and the biggest of them is 300 mm long (the container on the right is 600 mm wide). They all resemble plant parts, and even their eggs look like plant seeds!

Phasmids can be almost anywhere, but you may never see one in the wild, even if you are close to it. You can see them in pet shops, and I twice found one clinging to a plant on a second-floor balcony, after they fell from a nearby *Grevillea*. They eat young vegetation, but it's probably best to admire them and leave them in the wild—or examine dead ones.

I kept mine for a day or two, before I took it back to the tree it must have come from. Over the next week, I showed it to quite a few neighbourhood children, before we lost track of it.

Look out for these:

- Look at the spines on the body and legs: are the spines armour or camouflage, or both?
- Look at several species: are there any common patterns in the spiky bits, across species?
- Look at several species: are there any common patterns in the antennae, across species?
- How do the legs work?

Silverfish and bristletails (Thysanura)

You can often find silverfish at the back of bookshelves that have been undisturbed for a while. The form of the tail is probably the easiest way to recognise them. Silverfish have no wings, and their bodies are covered with fine scales that smear when you kill one. They eat books, so I always kill them. This is a silverfish, as Robert Hooke saw it, looking through his primitive microscope in about 1665.

Sawflies

The sawflies are different from other hymenopterans in a number of ways. The adults lack a pinched-in waist to their bodies, and sawfly larvae look like caterpillars in appearance and habit. When you look closely, you see that the 'grubs' have six or more pairs of prolegs on their abdomen, while caterpillars have five or fewer pairs, and the sawfly larvae have just two simple eyes while caterpillars have six.

Sawfly grubs curl up and 'vomit' smelly yellowish oil. They eat leaves (though some chew wood as well, and I have a badly-scarred deck chair that was left under a *Melaleuca* tree to prove it!). They may not be dangerous to handle, but I suggest that you play safe!

Termites

We think of termites as those nasty 'white ants' which chomp away at our homes, but in Botswana (Africa), scientists were puzzled in the late 1970s by 'fertile stripes' in the fields on some farms, long bands of rich soil which ran parallel to each other, about 50 metres apart. Research showed that the soil was improved by termite nests, sometimes running for kilometres along under the ground.

Termite nests, right one on a tree trunk, two others on the ground. The left one is about eight metres tall.

So Botswana's equivalent of earthworms are termites! In northern Australia, termites are the main grazers, and a basic food source for many species. When you break open a termite nest or trail, you will probably see both 'workers' and 'soldiers': these are suitable subjects for both hand lens and microscope.

You need access to a tree or stump that has live termite tunnels running from it. If you don't know what these tunnels look like, there are two extinct tunnels leading diagonally down, from right to left in the picture on the next page. They are about the same diameter as a pencil, and they can run down trees, or as in this case, across rock from one wood source to another.

Now what about ant bed? My other main hobby is writing about Australian history, and white settlers learned from the Indigenous people that crushed termite nest, wetted and flattened, made an excellent floor, in the days when concrete was hard to get. Why did the Indigenous people know this? Easy, they used to make sleeping platforms on the western plains, when shallow floods covered the plains.

Termites run up and down inside tunnels like the ones above, and when you break a tunnel by rubbing a stick across it, they come rushing out to repair it. With luck, there will be both workers and 'soldiers', which have bigger heads and large pincers.

Precautions: While soldier termites *might* bite people, they don't seem to do so. If the nest has been treated with arsenic oxide or another insecticide, they might be slightly poisonous if you touch them.

Look out for these:

- How different are workers and 'soldiers'?
- Look at the castes: are there any common patterns in the antennae or other body parts?
- Can you find any queens and drones? (Hint: watch out for signs of swarming.)

Wasps

These insects are best admired from a distance. They have two main ways of making visible nests: some of them use mud, others use 'paper'. There are also digger wasps, now usually called sand wasps. The close-up shots below were taken by a nervous photographer with only a rough idea of admiring from a distance. I had a hand-held camera, so join the dots!

Mud wasps are solitary and harmless, paper wasps make large nests with social groups, and they will sting painfully if they feel threatened. *Polistes humilis* is an Australian paper wasp, which preys on some pest caterpillars but there seems to be less information about some of the other introduced species of paper wasp. Spider wasps are also solitary and harmless (except to spiders).

Nikko Tinbergen did some fascinating studies on digger wasps in sand dunes in the Netherlands. He won a Nobel Prize for working out how wasps return to their nests. His brilliant experiments were simple, and you may be able to repeat them if you have the right sort of wasps. Use your favourite search engine and the search string **<Tinbergen wasps>** to learn more.

9 Invertebrates with eight legs

Spiders

Arachnophilia is an enthusiasm for spiders, arachnophobia is the fear of spiders. The words really mean the love and fear of arachnids, a group that also contains scorpions, ticks, mites and pseudoscorpions. Most arachnophobes are only frightened of spiders, and arachnophiliacs mostly like spiders more.

Spiders have eight legs, but sometimes this can be hard to see. Here are two views of a net-casting spider, *Deinopis* sp. It was about 80 mm from front right to back left. How many legs does the St Andrews Cross spider (below) have?

The largest spiders have a leg span of around 300 mm, but only a few are more than 120 mm across. Bigger spiders are too easy to see, either by prey animals who avoid them or predators who eat them. Above, a St Andrews Cross spider, *Argiope* sp. (That way of naming it means the genus is *Argiope*, but the writer isn't sure of the actual species.) We will meet *Deinopis* and *Argiope* again, because they both live around my house, and both hold their legs in pairs.

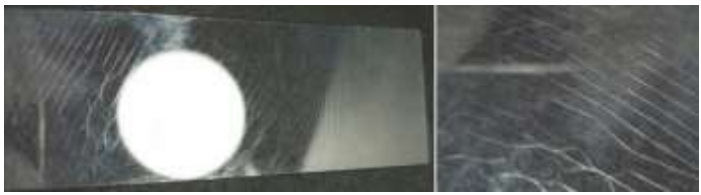
I discovered spiders in 1958, when I saw this picture of a wolf spider's face in Keith McKeown's *Australian Spiders*. I suppose the fact that I was reading that book says I was already interested, but the spider bore an uncanny resemblance to my Latin teacher. I decided that animals that can mimic Latin teachers are worthy of admiration, though I never told my Latin teacher about that.

People who hear of my interest in spiders have one question: how do spiders avoid getting stuck in their own webs? When they ask this, they mean 'orb weavers' when they say 'spiders'. There are two parts to that answer: orb weavers' webs aren't vertical. The picture above shows that the webs slope, and the spider hangs off the lower side. That's the first part.

The second part needs a microscope. Spider web is fascinating, if you have a serious microscope. That said, you can look at some things with a hand lens or a clip-on as well. Even for those, I went out with a microscope slide, and collected a small part of a leaf-curling spider's sticky web, after chasing it away.

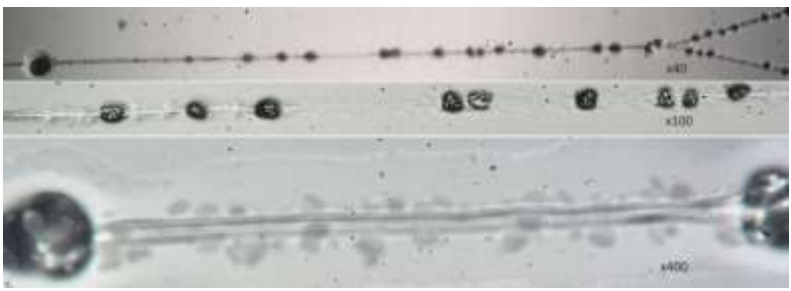
Some of the silk that spiders make, all of the web framework, isn't sticky, which is the other part of why spiders don't get caught in their web. The spiral of web that joins up the arms is different,

because it has droplets of sticky 'glue' along it, and this is what I want you to see.



I pushed the slide into the web, snipped off the threads and took the slide inside. I needed a bright lamp that reflected off the glass, to show the web. I cropped that for the close-up on the right. When I looked at this web under the clip-on, I could see hints of 'glue' and decided to look at it on a good monocular microscope. Note that these images were not taken through a cover slip.

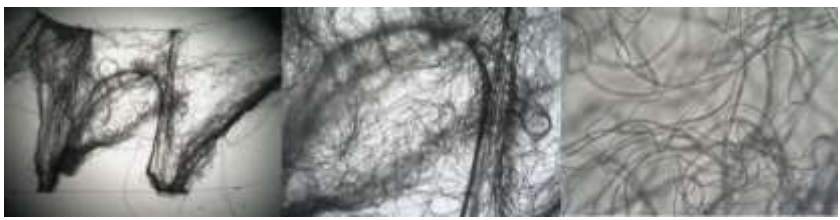
In this first image (above), taken with a clip-on, the sticky drops on the web don't show clearly, but in the next three images, taken with a microscope, they do. It is possible the photo is of a thicker, non-sticky strand. These next three shots, taken from nearby on the web, clearly show the sticky droplets:



While we're here, let's look once again at the St Andrew's Cross spider, which has a special web-spinning organ called a **cribellum** that produces extremely fine fibres. These are combed out by the spider's **calamistrum**, a set of leg bristles that make silk with a woolly texture, forming, in this case, what Scots people call a saltire.

This is how the 'cross' looked on the slide and under the lowest magnification with a clip-on. Being partly of Scottish extraction, I decided to take a closer look at the saltire. I chased away the *Argiope* that lives in my courtyard, captured one arm of the cross on a slide, and snipped away all of the web threads, all around the slide.

To do this, you need a stick to chase away the spider, a microscope slide or a piece of clear plastic, and small, sharp, scissors: if you don't have a slide, CD cases also work, but I used a slide, and got a good result. Once again, I used this as a dry mount, with no cover slip. I also looked at it with a hand lens. Higher magnifications were a bit disappointing, so I turned to my microscope again: note that these were all taken with back-lighting. Here are three shots of the same slide, at x40, x100 and x400.



The smallest spiders need a hand lens or microscope for you to see any real detail, but the body plan is always the same. They all have a head (technically, a **cephalothorax**), a number of eyes, two **chelicerae** (their 'fangs'), two palps which look like legs, eight walking legs attached to the cephalothorax, and an abdomen with **spinnerets**, used to produce webs of different sorts.

Almost all spiders are carnivorous. The one known exception, *Bagheera kiplingi*, lives in Mexico, where it mainly eats *Acacia* buds and nectar, along with the occasional ant larva. All other spiders eat only foods they have caught and killed by injecting saliva into their prey. The saliva turns the insides of the victim to a sort of soup that the spiders drink.

Over time, the saliva of some spiders' has evolved into a deadly venom that kills their prey as well, but there are still some puzzles. Funnelweb venom is most dangerous to primates like the apes, yet Australia's only primates, human beings, have only been here for the last 63,000 years or so!

It looks as if we humans are just unlucky.

A funnelweb bite may hurt a dog or cat, but it won't usually kill it. These days, deaths from funnelwebs and redback spiders are largely a thing of the past, but their bites will still hurt and make you very sick. There probably aren't any other deadly Australian spiders, but a few of them can hurt or cause harm. If spiders frighten you, or you don't know how to handle them, leave them alone!

Watching a spider catching a meal

To watch spiders feeding, you will need a flytrap, the simple trap made from two PET bottles, described in chapter 5. You will also need one or more orb weaver spiders, either in your garden or in a large container (in the garden is best).

First, catch your flies, then open the screw top on your trap, let a fly escape into a web, and watch how the spider approaches its prey, how it wraps the victim, and when and how it bites the captive. Then watch for some days to see when the spider eats its catch, and when (and how) it gets rid of the remains.

Ants are not good food for spiders (because ants fight back, I think), and beetles are too heavy, so flies are a good choice. Young crickets are excellent for larger spiders. Crickets are harder to catch, but you can buy live young crickets in aquarium shops.

Finding spiders by day

The easiest spiders to see are the orb weavers, the large spiders which make the biggest and most visible webs. On the ground and on the bushes, there will be tiny spiders out hunting for food, and they are easy to catch: just watch for sudden motion. Some tiny ones jump on their prey, cast nets to trap their victims, or dangle a length of web like a fishing line to catch flying insects. Other spiders walk on water or dive under the water, and some dig burrows under

the ground. There are even spiders which fly, spinning out a 'parachute' of web so they are carried up by the wind.

You will often find smaller spiders hiding on the under-sides of horizontal leaves. Just turn the leaves over and look, then shake them into a jar if you want to catch them for a closer look. You can also shake small spiders from a tree onto an opened upside-down umbrella.

Finding spiders at night

Spiders that hunt at night have eyes that reflect light, almost like mirrors. This is because some of their eyes have a reflective layer called the tapetum, and in all of their evolutionary history, that layer has been useful in helping them survive, because it improves their night vision.

Until the electric torch (a flashlight to Americans) 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 shine out.

It's probably not a good idea to pick unidentified spiders up by hand. You will need a bright tight-beam torch, and a jar and a card. You also need a patch of lawn without too much other light. You can also spot spiders on bushes.

Hold the torch 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. 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.

Spiders have different arrangements of their eyes, especially jumping spiders (**Salticidae**). Professional spider fanciers (**arachnologists**) can use the eyes to identify a spider's family in many cases. Investigate your local spiders. The most interesting spider eyes to look at are the eyes of the ones, which chase their food, because orb weavers make webs and depend more on touch to catch their prey animals. The crab spiders (**Thomisidae**) have two curved rows of four eyes. These spiders often lurk in flowers, waiting for insects to land.

Huntsman spider: how many eyes can you see? The second picture of a moulted shell may help.

Keeping spiders

Look through the methods below and make your own to-do list. To keep an orb weaver, you need a large enough space for her to make a web, and then you need to feed her. The cosmopolitan house spider (*Pholcus phalangioides*) which Australians call 'Daddy Long-Legs' will happily catch slaters on the ground, and pull them up into its web, so this spider can exist very comfortably in a slater tank, if you have one. The slaters may not be so happy, and I usually leave my spiders where they are, and visit them.

I keep very small spiders in humidity jars, because it causes less fuss from my family (and they *like* spiders). I give the spiders either a forked twig or a couple of toothpicks as a frame to make a web on. Feed them on springtails or other small leaf-litter animals that you can collect with a Berlese funnel.

Photographing spider webs

Dew or light rain on a web makes it show up for photography. Dew is better, because rain can damage cameras. These two pictures on the left show raindrops on webs, but they were taken after the rain had stopped.

The best time of all to photograph spiders' webs is as the sun breaks through a heavy fog. It's tricky, because you need to shoot almost into the sun, and I had to get a friend to hold my hat to shade the lens for the two right-hand shots above. From experience, you have about ten minutes to get the shots you want. I went out while the fog was heavy, and waited…

The other way to get good shots (and this is what professionals do) is to use a misting bottle, the sort that window cleaner comes in. I have tried this, and on a hot day, you have about one minute from when you squirt the web until it is dry again. Friends have lots of uses!

I think this is a spider that I know almost nothing about, a sheet web spider. If you want to look them up, they are family Stiphidiidae, and they are found in Australia and New Zealand, with one genus found in Papua. These webs were seen on a dewy morning on Cape York, Queensland. No spiders were visible, so there are no guarantees on this identification!

The faces of spiders

For more years than I care to recall, I have had a preserved female Sydney brown trapdoor spider, *Misgolas rapax*, on my desk: in the first shot, here, it has been taken from its container and laid out on top of a hand lens, to show the fangs and the eyes.

There are no dangers in working with preserved specimens (though collecting and preserving is frowned-upon these days). Cast-off exoskeletons like the huntsman are safe (for them and us), but if you are working with live spiders, you need to *know* that they are safe.

Sources for spiders: Seek and you will find! Most of mine are caught with a jar and card, examined and released back where they came from, but I photograph some of them where I find them, often getting somebody to hold coloured cardboard as an out-of-focus background.

Spiders in all their variety: trapdoor, jumping spider, netcasting spider, *Austracantha minax*.

Look out for these:

- Fangs and mouthparts;
- Any special bits on the legs (to see where to look, watch an orb weaver making its web);

- Unusual varieties of web;
- If you are looking at an orb weaver's web, can you see a tiny silver ball? This is a different species that steals food from the orb weaver;
- Can you find a tiny male (*not* a silver ball!) hiding in the web of an orb weaver?

Relaxing a dead insect or spider

I prefer not to kill animals, but I am happy to use things which have died naturally. Huntsman spiders are very hard to photograph, because they run around, and dried-out dead ones like the one above look all twisted and unnatural:

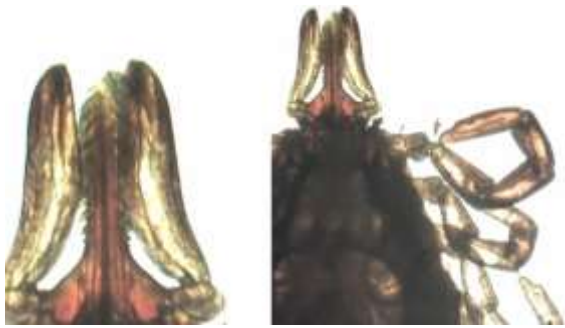
So when I found a dead one in an old bucket in the garage, I left it overnight in a humidity jar to soften it (the technical name for this is 'relaxing'), then put it on a piece of plastic foam and used long pins to hold it in place while it dried out, like this, Note that none of the pins goes *through* the spider.

(I like playing jokes on people overseas, and I sometimes persuade them that the huntsman spider gets its name because it throws spears. Guess which of these photos I use as proof!) Anyhow, the end result was the third shot.

Spider relatives

A word about ticks

Ticks are bloodsuckers, and they can also transmit diseases and mammalian meat allergy. Some people say there is no Lyme disease in Australia, other people say there is. Since the first group deny the Lyme disease claim because they cannot detect the bacterium *Borrelia burgdorferi* (which causes Lyme disease), careful people like your author say only that there appears to be **Lyme-like disease** in Australia.



A tick from my neck: note the barbs on the stylet.

There are some 70 species of tick in Australia: 16 of them may attack humans, and 95% of all the bites are from the Australian Paralysis Tick, *Ixodes holocyclus*, which is found east of the Great Dividing Range, wherever the bush is moist enough. The female lays several thousand eggs which come out as larvae, less than a millimetre across. While ticks are arachnids with eight legs, the larvae have just six, changing up to eight at the next stage, when they are nymphs.

Between 1912 and 1989, there were twenty fatalities, mainly children, but the last recorded death was in 1945. The tick often lodges behind the ear and causes unsteadiness, a loss of coordination, lethargy and paralysis: the pupils dilate and the victim gets a headache. These are the alarm signs to watch for. The tick needs to go, *but it has to go in the right way*, and the one pictured above was *not* treated properly. If you look closely at the top of the picture, you can see the stylet, the part that the tick drills in with, and you

can even see the barbs there. I acquired this specimen in 2009 while collecting lichens as part of the research for another book.

As was then standard practice, I treated it with methylated spirits, and when it failed to let go, I got my wife to pull it out with tweezers. It hurt! She put it in a dish, I looked at it under the microscope, and so discovered the barbs. What we had done was dangerous (to me), but we were unaware of it then, and I was lucky. Pay attention, please!

Most mammals (except humans) have a sugar molecule in their blood, called alpha galactose (often shortened to alpha gal or alpha-gal), and this sugar triggers an allergic reaction later, when sensitised people eat meat that contains alpha galactose. That includes beef, pork, lamb, kangaroo, goat and venison. If you are a meat eater who has been sensitised, you have to miss out on your favourite foods.

Because of those barbs, the tick's body is always squeezed as you pull it, and some of the fluid it has taken out can be injected back into the victim. The blood the tick got from its last meal, usually one of the non-human mammals contains alpha gal, so squeezing the tick with tweezers is a Bad Idea. When this foreign blood is injected into our blood, it sets us up for an allergic reaction to mammalian meats.

That is why medical advice is now summed up in a slogan: **Freeze, don't squeeze**. If you get a tick, your pharmacist will be able to sell you a freezer spray like the ones used to freeze off warts, or even, in 2020, specially prepared tick freezer systems. Freeze the tick, killing it, and *leave it there to drop off*. Do not pull it out or off. This is an important message to get out there.

A word about mites

Like ticks, mites are arachnids, and together, they form the Acarina. The most obvious difference between them and spiders is that there is no clearly visible narrow point between the **cephalothorax** (the head-and-body part) and the abdomen (the tail part). Ticks and mites have up to four simple eyes and usually have eight legs, though their juvenile forms only have six legs.

Mites are everywhere: all through your house, but the largest of them are only about as big as a full stop. Ticks are bigger, and a gorged sheep tick can be as much as a centimetre across. They live outside, mainly on bushes and grass. Mites eat almost everything, and some are active hunters. Ticks are said to be attracted by carbon dioxide and warm bodies (but some ticks prey on bluetongue lizards!): there might be an interesting project there. Just remember that they live on blood!

The easiest mites to find are the oribatid mites that live in leaf litter, which can be extracted with a Berlese funnel, and the mites found on tree bark that can be collected by scraping, pootering or applying a portable vacuum cleaner. Sometimes these are called beetle mites, but if you find a tiny 'beetle' with eight legs, it's an oribatid mite instead.

For example, this is an oribatid mite. The animal may look like a beetle, but count the numbered legs carefully: they have been numbered to help you. (Then note the dark circle that is an air bubble: this is a wet mount, and *having a bubble is bad technique*!) We should avoid bad technique, but that's life.

Mites are found in the soil in huge numbers, and there may be as many as several hundred thousand in a square metre. Around the world, there are probably 10,000 different species. Some mites eat fungi and dead animals, others prefer dead plant material, and some of them are even predators. They are important to healthy soil, because they recycle the minerals that plants need.

When you extract springtails from soil or leaf litter with a Berlese funnel, you will usually get some oribatid mites as well. The mites don't do tricks, they don't make good pets, they are just there, but

you need to know about them because you are sure to find them. *They dwell among us!*

A gross bit

This one is offered without any preliminary comment or apology other than the advice to read it at your own risk. I have never succeeded with this—but it sounds like seriously gross fun!

> You can get to know your own forehead mites the following way: stretch the skin tight with one hand, carefully scrape a spatula or butter knife over the skin in the opposite direction, squeezing out traces of oily material from the sebum glands. (Avoid using too sharp an object, such as a glass edge or sharpened knife.) Next scrape the extracted material off the spatula with a cover slip and lower the slip face down onto a drop of immersion oil previously placed on a glass slide. Then examine the material with an ordinary compound microscope. You will see the creatures that literally make your skin crawl.
> —Edward O. Wilson, *The Diversity of Life*, 177.

This drawing, taken from an 1896 German encyclopaedia, shows the forehead mite, *Demodex folliculorum*.

It *does* make your skin crawl, just reading it, doesn't it? You can buy immersion oil on the web.

Pointers for further internet digging: Karl Gustav Theodor Simon (1810–1857) discovered this mite (named *Demodex folliculorum*) in 1842. He became director of the department of skin diseases and syphilis at the Berlin Charité hospital in 1848. He visited England and France in 1850, but suffered "progressive paralysis" in 1853 and died four years later.

Scorpions

Scorpions are arachnids, but aside from the eight legs, they aren't much like spiders and ticks. They grab their prey with their pincers and then bring their tail over the top to sting. In case you are thinking of handling a scorpion, read this, from the journal of Peter Warburton, a minor South Australian explorer. Sahleh was an Afghan camel driver with him, and he was stung in late 1873.

> Sahleh's finger very bad indeed from the scorpions sting. The state of our blood allows no wound to heal of itself, and I have no medicine suitable to its case. If it continues to get worse, without any prospect of surgical aid, some one—not I—will have to chop his finger off with a tomahawk, or he will lose his arm and his life.

The sting of a scorpion is painful but not usually deadly, and Sahleh's problem may have been a secondary bacterial infection. There are 29 known Australian scorpion species, and they range from 2 to 12 cm in length. Unusually, they fluoresce under ultraviolet ('black light'), which makes it easy for professionals to hunt for them at night. It is wiser to leave this group to the professionals. (That's why you get a public domain woodcut above, and not a photo!)

Pseudoscorpions

One group you won't see unless you go looking for it is another of the arachnid clans, a pseudoscorpion. The biggest I have seen are about 5 mm long, and that includes their pincers. It doesn't include their tails, or their stings, because they don't have either. They get their name because their front end looks a bit like a scorpion, but that's as far as it goes.

(Left) the first good illustration of a pseudoscorpion, published by Robert Hooke in 1664, and a more modern illustration.

There are several ways to find pseudoscorpions: you can spread leaf litter out on a white dish and watch for movement, or use a coarse mesh Berlese funnel. They are often found under the bark of trees, and gum trees are good places to search. A few of them also ride on insects (mainly flies, beetles and wasps), but nobody seems to know if they are attacking these insects or just getting a ride.

At last count, there were 166 pseudoscorpion species living in Australia, so you should have no trouble finding some, though catching them is a bit harder. Pseudoscorpions are hard to keep as pets, but they will feed on springtails if you want to observe them.

Note: while I have often caught these over the years, I did not see *any* while writing this book, which is why you see only public domain images here. Keep trying!

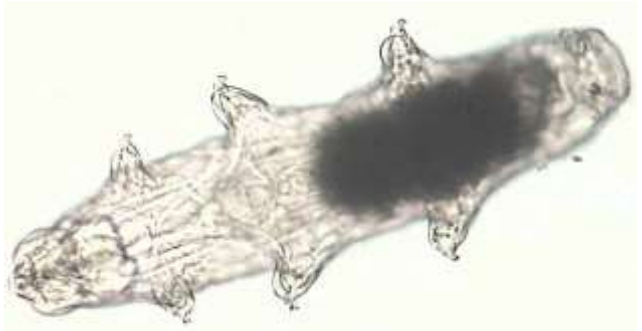
Look out for these:

- If you get some specimens look to see how the nippers work;
- Also look to see what they use nippers for.

Tardigrades

This one is *hard*, and I wouldn't have put it in here, but I wrote all this for *Australian Backyard Naturalist*, and the editor wisely said, "this is too hard". I am putting it here, but I suggest that you need to be about 15 before you try it, and it might be a very good idea to get a patient adult helper.

Tardigrades aren't easy to find: the biggest of them are 1 mm long, the smallest are only 0.4 mm (400 microns). That means you probably won't see them without a hand lens, and you certainly won't see any real detail without a microscope, but tardigrades are everywhere.



A tardigrade. The two hind (left side of photo) legs are tucked in underneath the tail.

Even under x20 with a dissecting microscope, tardigrades are small wriggly blobs, just visible enough to pick up with a brush or a needle, to transfer onto a well slide. Under a high-power microscope, you will be able to see that they have eight legs, each one usually ending in a claw, though the soil tardigrades are clawless. Sometimes, the two hind legs are curled up under the body, but after you have seen a few tardigrades, you will learn to recognise the curved claws on the legs. The individual shown here has two legs hidden.

The name 'tardigrade' means 'slow walker', but their common name is 'water bear'. Tardigrades turn up almost everywhere, from high mountains to deep in the sea, but the easiest ones to catch are the ones that live on or under the bark of trees or among lichens and mosses. You can also find them in leaf litter sometimes. Some tardigrades drink the juices from plants, but others are hunters, and experts can tell the hunters at a glance, because the hunters have a big **pharynx**. They eat mosses, fungi, protozoa, nematodes, rotifers and even other tardigrades.

Tardigrades are hard to classify, but they seem to be a sister group to the velvet worms (chapter 10). They have no respiratory organs, because they are just small enough to absorb the oxygen they need through their skins. They have a 'straight-through' digestive system, and under the microscope, you can usually see their digestive glands, but not much else.

One thing: tardigrades are tough! You can find them 6000 metres up mountains and 4000 metres down in the oceans, and on

the ground, all the way from the poles to the equator. They can survive being frozen below -200° C for several days, they thrive in boiling hot springs and they can even be heated to 151° C for several minutes. They can also live for a century without water, and for longish periods without oxygen, even in a vacuum, and they can survive huge doses of radiation.

People used to say that after a nuclear war, only cockroaches would be alive, but the tardigrades will do even better!

Catching tardigrades

Remember: what follows isn't easy!

Scratch some bark off a tree with the side of the blade of a paint scraper, or gather up some moss or leaf litter. You have probably just collected your first tardigrades. Leave this material to soak in water overnight to knock the tardigrades out.

Extracting tardigrades from bark scrapings. Sieve the damp bark in a coarse sieve. Wash it with a wash bottle and discard the large stuff in the sieve. Take the material that went through the sieve and run it through a cloth sieve to get rid of fine stuff.

The tardigrades and similar-sized fragments are on the cloth and can be washed into a jar. Run the water and bark through an ordinary kitchen sieve, and catch the water in a jug. The tardigrades will now be in the jug, but separated from the big bits of bark.

Leave the jug to stand for 30 to 60 minutes, and then strain the water through a 40-micron mesh. If this is hard to get, use a square of an old silk blouse or even a piece of linen. A piece of stocking or pantihose is too coarse, at around 400 microns, the size of a large tardigrade, but even that will catch some, if it is not stretched too tightly.

This second stage separates the tardigrades from the *really* small stuff in the water. Then you turn the sieve over and run some water the other way, to wash the tardigrades and anything about their size off the sieve and into a small amount of water. The best way to do this is with a wash bottle.

After that, you just need to search carefully through the remnants in a Petri dish, looking for what you can see moving around. To get the focus about right, and sprinkle a few sand grains in the dish to focus on, so you will be searching the right level, on the bottom.

Expect to find all sorts of surprises in there, along with the tardigrades, including large protozoa, nematodes and small mites at the very least. Leave the dish completely still and look for any movement in and under the bits of litter and sand grains. At first, you probably won't see the tiny wriggling shapes without a microscope, but once you know what to look for, a good hand lens may reveal some of the larger tardigrades.

A 'Dust Buster' or other portable vacuum cleaner can save you a lot of work. Fit one with a clean bag and use it to sample tree trunks, lichens and moss mats near waterfalls. You can use it to pick up mites, springtails, beetles, flies, bark flies (book lice) and small spiders. Ian Kinchin, who invented this method, said it was particularly useful on tardigrades.

You need to have a white dish or ice cream container, large enough to let you shake the vacuum cleaner bag into it, banging it with your hand to shake off any small passengers that are hanging on. Then tip the contents of the dish into a holding jar. In my attempts so far, I think I have used moss that was too dry, so I only got small numbers of mites from the moss.

Estimating the mesh size of cloth

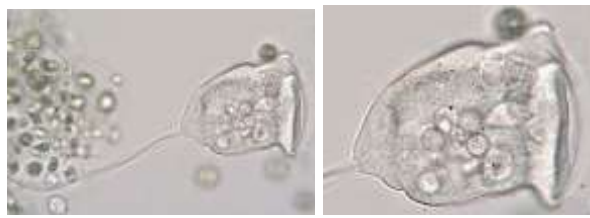
First, you need to look at a graduated scale of some sort under a microscope, so you can work out how large your field of view is. Using a plastic ruler as a scale, my monocular microscope covers 3.5 mm under low power (x40), and about 1.4 mm under medium power (x100). Under x400, my field is about 0.35 mm across, but I had to calculate that. If I remind you that 0.35 mm is 350 microns, you may be able to see how, looking at cloth under high power, I can estimate the size of its pores. I just count the number of holes across a field, and then estimate how much of the space is thread, and how much is hole.

Flushing rotifers from a moss mat

You will need a good light source, a Petri dish or a saucer, some moss and some water and/or 70% alcohol. I prefer using just water, so the animals live and I can release them later. The alcohol would kill them, and living animals are more interesting.

Damp moss mats are full of animals that are hard to see or find. If you slowly add water to a moss mat in a bowl, some of the animals will climb up into the dry. Adding 70% alcohol with an eyedropper has the same effect, but you need to watch out for fire, and avoid breathing the fumes. Remember that forceps are bad news for animals. You should use a paintbrush to pick up any animals you want to mount on a slide for closer examination, and always use well slides to avoid crushing the animals.

A moss mat like this one was on dry Sydney sandstone may not contain much life. Moss growing near a stream or a waterfall or even in a damp alley could be a better source. The 'possibles' in a moss mat include rotifers, also called 'wheel animals', a name that refers to their cilia, which beat continuously as a way of catching food, and look like spinning wheels. Rotifers are about 100 to 500 microns (0.1 to 0.5 mm) long, though a few are as large as 2 mm.



Under the microscope, rotifers are always moving, seeking food. Mostly, rotifers are found in fresh water, and the ones you will probably see are the ***sessile*** forms, the kind that grip onto something and stay there, but other rotifers are free-swimming, and some 'inchworm' their way around. Rotifers are also called 'wheel animals', a name that refers to their cilia, which beat continuously as a way of catching food, so that they look like spinning wheels. You could call them worms if you like, but 'worm' can mean almost anything.

Most of the land 'worms' are nematodes, but there are also leeches, flatworms and earthworms, once all classed as 'vermin' (which means worms). Indeed, if you go back a thousand years or so, even dragons and snakes were once regarded as 'worms'. The point is that rotifers are quite like worms in some ways. From their size, you might think that they are single-celled protozoa, but they have multiple cells, an alimentary canal with a **pharynx** (think of it as a mouth) and an anus. They mainly eat single-celled algae like *Chlorella*, *Euglena* and *Chlamydomonas*.

Rotifers have a very simple nervous system. In many species, males are rare. No males are known at all for any member of the family that includes the genus *Rotifer*, and they reproduce by producing eggs which have a full set of chromosomes. (This is specialised: look up **<bdelloid rotifer diploid egg>** if you want more information.)

To get some rotifers to study, collect some pond water and stand it on a windowsill in moderate light for a few days. The rotifers will collect near the top, where there is more oxygen, so you can pick them up with a Pasteur pipette or an eyedropper. You will also find some attached to filamentous algae and other bits and pieces in 'green slime'.

If you soak a piece of moss mat in water and then squeeze it out over a bowl, you will generally find both nematodes and rotifers. The method is supposed to produce tardigrades. I have never found tardigrades there so far, but I have washed out lots of rotifers! If you really want to see tardigrades and nematodes, you can also use a Baermann funnel, described earlier.

10 Invertebrates with many legs

Crustaceans

Crustacea is a **sub-phylum** in zoologist-speak. There are many classes of crustacean, and the group is really a bit of a ragbag for 'other arthropods'. Here, we find things as different as barnacles, crabs and lobsters, prawns, shrimp, krill, woodlice—and quite a lot more.

I will keep the technical names out of it as far as I can, except where I think the reader needs those terms to look them up. Unless you want to search for something, ignore those names! Who needs to know that the barnacles are called the Cirripedia?

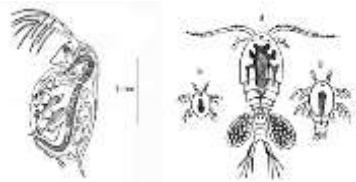
Crab bits

Poking around on beaches or among the rocks, you may find a crab's claw, leg or shell, but that doesn't always mean that a crab has died. Crabs and lobsters have an outside shell, and when they want to grow, they need to moult, losing their old shell and then growing a new, bigger shell. The proper name for this shell is **exoskeleton**, and the outsides of the legs, the pincers and the bodies are all made of a polymer called chitin, which is also found in insect exoskeletons—and in the cell walls of fungi.

Sometimes, there are amazing things to see, like the sculpting of spikes and knobs, and the way crab claws are formed, but we will start with the smallest crustaceans.

Water fleas

These animals are flea-sized, hence their common name, but when you look closely, they are actually crustaceans. The ones you are most likely to see are *Daphnia*, *Cypris* and *Cyclops*, but you never know your luck! They move differently, but you need at least a hand lens to see any details. Technically, they are all **branchiopods** (not to be confused with **brachiopods**!). *Daphnia* are in the sub-order **Cladocera**, the similar looking *Cypris* is in the **Ostracoda**, and *Cyclops* is in the **Copepoda**, so you may need to look up cladocerans, ostracods and copepods on the web.



The copepods are much less flea-like. Personally, I don't bother too much about the names, unless you want to look them up: just enjoy looking at them. Here you see a cladoceran *Daphnia* on the left, the copepod *Cyclops* on the right. These are almost impossible to photograph, but they make good pets,

Water fleas turn up in all sorts of places. Try scooping some water out of rushes with a bucket on a rope, and pouring it into clear bottles. As noted earlier, when you hold a bottle up to the light you should be able to see any small animals that are in the water. If you add some soda water to the container, this increases the carbon dioxide concentration and makes the animals move to the top of the bottle, which will let you pick them up more easily. Some of these will be water fleas.

The soda water trick was discovered by Jacques Loeb, a German-born physiologist who moved to America. He never explained how he made this discovery, but it must surely have been during a laboratory party, when somebody spilled or poured beer into a tank!

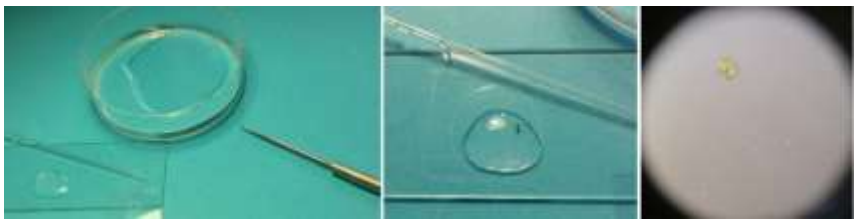
Culturing and examining water fleas

The culture methods described for hay infusions (chapter 2) are exactly what you need for tiny crustaceans, because they thrive wherever there is food. On the other hand, some professional biologists prefer to feed their *Daphnia* on small amounts of brewer's yeast, so the choice is yours.

The golden rule is to have several cultures of anything precious, and to feed them at different times. That way, if the yeast zombies take over, you will have other cultures to use, though often, if a 'dead' culture is left for a while, there will be eggs, spores or survivors that will bounce back.

To see them properly, you need a good microscope—but you can see them (*just!*) with the naked eye, and you can see them with a

clip-on, but you will need a well slide. I used a Pasteur pipette (a very long eyedropper) to move three cladocerans from a culture jar to a Petri dish, and then I moved two to the slide.



Next, I set to work to examine them, the aim being mainly to see what was visible, using different sorts of equipment. Not much there, is there? Just a green blob in the water drop, but it shows up with a clip-on.

Here, for comparison, is a front-lit image with a binocular microscope at x40, and a back-lit image of the same beastie, using a x40 monocular microscope. You can see a hint of legs at the top, and bristles around the middle, showing where the focal plane lay in this shot. Don't expect to see much more of water fleas with any home microscopy kit.

The best way to breed a lot of *Daphnia* quickly is to take some water from a murky green aquarium, making sure you don't pick up any filamentous algae. Add a small amount of hard-boiled egg yolk, mixed with water into a sort of soup, and stand back!

In stagnant water, *Daphnia* develop more haemoglobin, up to ten times as much as in water with plenty of oxygen, so the *Daphnia*

from stagnant water can be quite pink. See if you can make a series of photographs to record this.

What you need, though, is a way of catching them, and to explain the next heading, water fleas count as freshwater plankton.

Making a plankton net for ponds

Even a home-made plankton net can sample small animals swimming at or near the surface of the water or floating in that area. The main parts are a towing line to pull the net along, a swivel to stop the line kinking because the net spins while it is being pulled. You also need a stiff hoop to hold the net open, three lines attaching the hoop to the swivel, a very fine net, and a small glass bottle that closes the lower end of the net.

As you pull the net along, any animals trapped in the open mouth will be pushed down to the end, where they will be largely protected from damage by the still water in the glass bottle. You can buy nets like this for a high price, or you can make one very cheaply.

The towing line can be a fishing line: I have used a fishing rod to haul a net like this through the water while walking along a jetty, but you can tow one from a boat fitted with a 2-horsepower motor, or even rowed or paddled.

You can buy a swivel from any fishing equipment shop. The hoop can be a length of coat hanger wire, bent into a circle, the mesh can be the leg of a stocking, either stitched or stapled over the hoop, or even glued to the hoop with contact adhesive (wear gloves and work outdoors to avoid the fumes if you use this glue). If possible, fix the bottle to the net by attaching a metal or plastic screw lid at

the far end of the net, so you can change bottles regularly, just by unscrewing them. The lid will need a hole in it, but if you use a standard jar, you can have plenty of spare lids.

With a suitable net, you can explore the plankton types and densities over a time period: looking for daily patterns, or monthly patterns (some plankton may respond to the full moon, so samples taken regularly at 9 pm could be useful). Maybe there are patterns you can see as the seasons change. Nets like this can also be hauled through seaweed and waterweed to sample the small animals living on those plants. This is likely to damage the net, so use a cheap one.

You could also just explore the types of plankton found in one place, or compare different environments at more or less the same time of day, over a period of time, to see if any observed changes are correlated, and whether any observed differences are maintained over long periods. Aside from that, you have the tool, you have some ways of using it, so go for it, remembering that the most interesting questions are always your own questions!

Don't forget to take a white dish, though!

Look out for these:

- Watch out for the very tiny items, but be gentle with tadpoles and fish;
- If you sieve the water through a very fine mesh, you are more likely to see plankton.

Amphipod crustaceans

If you have ever lifted a flowerpot and seen a lot of pale jumping things, tinier than fleas, those were springtails. If they are bigger than fleas, assuming there are no midget kangaroos in your garden, most of the other jumpers will be very small relatives of the prawns. They are all amphipods.

Technically, we call these animals talitrids. When I am working with young folk who don't need to be technical, I call them *land prawns*. Other people call them landhoppers or sandhoppers. This magnificent image above was cropped from a Wikimedia Commons original by Waugsberg. It shows a beach talitrid from the Baltic Sea.

The beach ones are usually found under pieces of stranded seaweed. You will mostly find them in damp, thick leaf litter, and they are *very* hard to catch. I only know one effective way to trap them, using a jar to stop them jumping, then slipping a card in underneath.

They are about 5 mm long, and they leap all over the place, making them a real challenge to photograph, so to slow them down, put the jar in the fridge. The name amphipod means 'different legs', but the isopods have 14 legs that are almost the same, and we will consider them now.

Look out for these:

- Look at all of the legs: how many different kinds are there?
- How do amphipods jump?

Isopod crustaceans

These dead slaters are arranged to give a side view, a view from above and a view from beneath. The isopods have many common names: slaters, wood lice, sow bugs, pill bugs and roly-polies are just the best-known. They are crustaceans like prawns and lobsters, but the isopods have legs that are all the same, giving them their scientific name **Isopoda**, which actually means 'same feet' (or legs). If you can get one to stay still long enough, you will see that there are seven legs on each side.

Land isopods are mostly small, up to a centimetre long, but there is one marine species, *Bathynomus giganteus*, which can be up to 37 cm long, weighing 1.7 kg! There are also marine species that live on the shoreline around much of Australia. They are the colour, shape and size of cockroaches, and most people mistake them for cockroaches, but cockroaches could not survive the salty conditions on the edge of the sea.

The land isopods we know best are generally found in leaf litter, but the easiest way to find them is to pick up a few rocks or pots that are sitting on damp ground. Snails, scorpions, centipedes and spiders may also shelter there, so be careful! Most isopods are large enough to catch with a small jar and a brush, but they will also fall into pit traps. For the most part, they eat dead vegetation and rotten wood, which explains their 'wood louse' name.

A slater on the left, and a pill bug on the right.

Only one type (*Armadillidium* sp.) can roll up into a ball, so it's a 'pill bug', but not all isopods deserve that name. All of them have a protective casing, and like other arthropods that grow, they need to moult and form a new, larger shell. In the ones I have observed, the moult takes several days, starting at the back and working forward in stages.

Just a note in passing: I am curious about bizarre and quack medicine, and a few years back, researched the meaning of "a dose of millipedes". It turned out that the 'millipedes' were really pill bugs: the curious reader is referred to my *Not Your Usual Treatments* for Amazon Kindle (e-book or paperback on Amazon), or get the relevant part for free at this link: https://oldblockwriter.blogspot.com/2014/04/take-dose-of-millipedes.html.

Keeping slaters

The slater runs away and hides, but the pill bug (above) rolls itself up into a ball, like an armadillo or an echidna, making it easy to roll them into a container with a brush. There is no scale in these shots, but the largest of these animals are up to 1 cm long. I breed pill bugs in a container on my desk, and the smallest I have seen were about 1.5 mm long.

Most crustaceans live in the sea or fresh water, where they can get their oxygen from gills, but like spiders and scorpions, the isopods have book lungs. You will probably need a dead slater to see these lungs, because they are on the under-side of the animal, and they don't like lying on their backs.

Look for the pleopods, labelled P in the photo on the right, above: in aquatic species, these work as gills *and* as a means of propulsion. In males, the second (and sometimes the first) pleopods are used in the transfer of sperm.

These animals are still on my to-do list, so I can't actually say how to tell males from females, and there isn't a lot of information available. So there's your first project: take enough pictures, work out which is which, and publish your findings on the internet. Who knows? You may end up famous!

To keep one slater for observation, use either a humidity jar or a jar with damp paper or sand in the bottom, and a small slice of raw potato, which provides both food and moisture. To keep larger numbers, I prefer a tank or a tray of damp sand, covered with cling wrap when it is not being 'gardened'.

Put about 10 cm of sand in a glass or plastic tank or tray and dig a hole down almost to the bottom of the sand. Add water until you see a small pool remaining at the bottom of the hole. Scatter bird seed, wheat or grass seed over the sand, then rake the seed in a bit, add some dead leaves from the garden and put the tank in a well-lit place, out of direct sunlight.

Maintain the water depth, and after a week or so, trim the grass with a pair of scissors. Drop in a few slaters and seal the top of the

tank with cling-wrap to keep the moisture in. Soon you will have many slaters, provided you 'mow' the grass with scissors once a week. Slaters aren't good at climbing smooth surfaces, but they will try, so you should keep a lid on it: this also keeps the sand moist. In a jar, a damp tissue or a piece of potato will manage the humidity for you. Then there's the best way of all.

A desktop compost heap

For the last two years, I have had a small combination isopod home and compost heap sitting on my desk. This method began as a test of an idea for my school students (if you came in part-way through, I am a 'visiting scientist' in my local primary school).

I wanted an easy way to set up individual pill-bug farms, and I worked with groups of 3 and 4 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. For large-scale making in a 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.

Here are the instructions I gave my students (as I am not a teacher, we are on first-name terms):

- Put about 6 to 10 mm of sand in the bottom and spread it;
- Add just enough water to make the sand go dark (and note the difference in colour);
- Get Peter to add some rotting litter (it may have germs, and he's expendable);
- Using a brush and a tube, catch eight pill-bugs from the stuff Peter brought in;
- Add them to the container;

- Add some dead leaves that the teacher brought in;
- Put the lid on, and add a sticky label with group names.

We also made five holes in the lid with a needle. Those cheap containers split quite easily, but we drove all our holes through a sticky label, which prevented splitting. After that, the students just needed to add water if the sand looked dry, and add leaves when the food supply dropped. And that is how I invented the desktop compost heap. I have had one on my desk for the past two years, and it is still doing well.

Isopod investigation ideas

- Find out more about how crustaceans breathe, especially the isopod crustaceans. If you can find some land amphipods in your garden (they look like tiny jumping prawns), you may even be able to work out how they breathe, as well. This will tell you why crustaceans are usually found in damp places. Key words for web searches: **pleopods**, **lungs**.
- How many isopod species live in your area? How can you be certain they are different? How can you be certain you have found all the species?
- Isopods are good subjects for behaviour studies. You can test to see if they prefer to be in the light or the dark, and damp or dry, but you can also see if they prefer a dark or light background by drawing a chess-board pattern on some paper and putting it in the bottom of a tray. You need to seal the tray with cling wrap.
- You can also set up a sloping tray and see if they prefer to move up or down the slope, and by plotting their movements on grid paper, you can estimate how fast they move.
- Finally, can you discover anything about isopods' preferences for different foods?

Studying your food

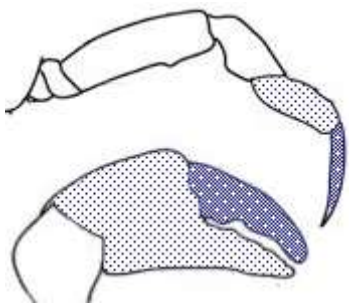
When you eat prawns, crab or lobster, there will be lots of bits left over. If have a tame adult to help, go for it! Boil the leftovers, pour out the 'soup' and tip the hard pieces into a fine mesh bag, like the ones oranges come in. Tie off the end of the bag, and leave it at the

end of the garden, under a plank, pinned down with several tent pegs. Leave ants to do the rest of the cleaning, and leave the bits out there until the smell fades away.

If you can't find a tame adult, look around on beaches and in rock pools, and you are sure to find some crab bits and pieces. There are safe ways to handle live crabs and lobsters, but these have to be taught, one-on-one. It is easier to use dead material, but that means washing your hands afterwards! Use crab, yabby or lobster shells, claws and legs, whatever you can find. The yabby claw on the left below was cleaned by ants.

Rock pools are a good source of crab remains, which won't always mean a crab dying, because crabs often moult, shedding their exoskeleton. Some pieces will be washed up on the shore, and as explained earlier, a seafood dinner can also be a useful source for some parts. This is one of those explorations where you can start almost anywhere, and go off in almost any direction. Discover how many pieces there are and how they join together.

Explore the lumps and markings. The crab carapace (about 3 cm across) shown above appears to be totally symmetrical, until you start to look at it very carefully: the symmetry is close but not perfect.



Discover how many pieces there are in each limb, and how they join together. Then look closely at how the claw forms: where humans use an opposable thumb to grip, crustaceans do it differently.

In the diagram above, the last two joints have been colour-coded, on a walking leg and on a clawed leg. The second-last joint has an outgrowth that the last joint can squeeze against. Compare that with how your finger and thumb work.

Look out for these:

- Joints in the legs;
- How claws operate.

Even more legs

Centipedes and millipedes

Centipedes and millipedes have different numbers of legs, both on total count, and also on each body segment. The main thing they have in common: neither has as many legs as their names suggest. Centipedes have two legs on each of between 15 and about 48 segments (so they never have a hundred legs). Millipedes have four legs on each of up to a hundred segments, so they never have a thousand legs.

Centipedes are carnivores with a venomous bite, but millipedes are vegetarians; centipedes are flat while millipedes are usually cylindrical; and only millipedes can roll themselves into a spiral. The easiest way to tell the difference is to count the number of legs on a single segment. Both can be found in leaf litter, or under logs and bark, but millipedes can also be found wandering on damp lawns.

Millipedes don't bite, but I was burnt by a millipede once, when I was handling it. I looked it up and read that they secrete hydrocyanic acid, which would be a good defence against predators. Over the years, I have cited this fact in classes and lectures.

Always check your facts, because when I was writing about a "dose of millipedes" for another book, I learned that this was only partly correct. They produce a mix of hydrocyanic acid, along with quinones, alkaloids, ketones, terpenes, esters and phenols.

The pirate Henry Morgan died after a dose of millipedes, and I started planning a new chapter—but it was the wrong millipedes for my purposes: Morgan was actually given a dose of dried and powdered pill bugs. So why were pill bugs called 'millipedes'? Here, it seems, is the answer: they curl up like the real millipedes:

It occurred to me to wonder what ate millipedes, and I found a part answer one morning, beside my letterbox, where a land planarian was feeding: this picture is also an earlier chapter, if it seems familiar.

Locomotion in millipedes

Handled carefully, millipedes are safe enough to work with, and one of their more fascinating aspects is the way they walk.

A long-legged species of millipede.

You will need a millipede, a light-coloured matte surface, and some way of stopping it walking away, and a camera or hand-lens. Study a millipede closely and see how it walks without tripping over its legs. Does the number of 'waves' of movement change when the animal is going faster or slower?

This type of millipede, with many more legs than the first one, is ideal for study. Notice how the asterisks on the picture mark 'compressions'.

There is a joke about the scientist who asked a centipede why it never tripped up, when it had all those legs. The centipede replied that it had no idea how it managed. Then it walked away wondering about this, and promptly fell over. So how *do* animals with that many legs never trip? Once you have explored this, you will know millipedes when you see them.

You can find millipedes on garden walls in the early morning, or in the leaf litter and mulch of any garden, all day long. They are often under fallen wood. Turn the leaf litter over with a stick, and when you see a running cylinder, use the card and jar trick.

Millipedes can also be found wandering on damp lawns. They are herbivores which are perfectly safe when they are in a container. I am old enough to have used overhead projectors, and these devices are wonderful for showing the movement of a millipede. You must interpose a water bath between the light source and the animal to save it from being burned, but as the likelihood of you having an overhead projector is remote, I won't elaborate on that.

Look out for these:

- Do centipedes show the same waves of motion?
- How do millipedes eat?

Velvet worms

Few people know these animals, but those who do usually call them **onychophorans**, a name that means 'claw-bearer'. That is their formal scientific name, but let's call them velvet worms. That name reminds us of the tiny lumps on their skin called **papillae**. They use these for feeling and smelling, but the papillae also make their skins water-repellent. They can see with simple-lensed eyes, at least well enough to hunt prey.

The first scientist to describe a velvet worm was the Reverend Lansdown Guilding. He mistook his first specimen for a slug in 1826, which is a bit odd, considering that this 'slug' has legs! In many ways, they look more like caterpillars with feelers or antennae, except that each leg ends in a claw, and there are *lots* of legs.

A photo of a slug and a 19th century engraving of a velvet worm for comparison.

Guilding just noticed the feelers, but the legs should have been a dead give-away that these things weren't slugs. All the same, unlike the six legs in an insect and eight in an arachnid, velvet worms usually have between 14 and 16 pairs, though some can have as many as 43 pairs of legs!

This would have disappointed one of my university teachers in the 1960s, who dreamed of the day when a scientist could sit at a computer, type <I HAVE AN ANIMAL> and get the response <HOW MANY LEGS DOES IT HAVE?> as a first step in identifying the animal. Maybe it could still work…

Velvet worms have been around for a very long time, probably 500 million years. They are sometimes described as a sort of missing link between the **arthropods** and the annelid worms (earthworms etc.), but these days, scientists think they are more closely related to the arthropods.

The animals have another common name, *Peripatus*, which is the genus name Guilding gave to the first species he found. It just means 'wanderer'. There are several hundred species known around the world, 74 of them in Australia, and they can be found in the wet tropics and the south-eastern and south-western corners of Australia, anywhere that you can find rotting logs and leaf litter that will support their food supply. Some of them are 100 mm long, but most of the Australian ones are about 20–40 mm. They are generally dark, though some of them have complicated patterns.

They are hungry carnivores which trap their prey by squirting them with sticky slime from a pair of modified legs. This stops the prey escaping, and the velvet worms then eat their food in much the same way that spiders do, by sucking up body parts that have been softened with their saliva. They also use a squirt of slime to discourage any predator that wants to eat them.

A velvet worm eats almost anything not too big, if it moves. Slaters, spiders and termites are all on the menu, though exotic pet suppliers recommend crickets. Dayton Stoner, an experienced hunter of these animals said in 1923 that the best place to look for them was in rotten and decayed wood. He found a few in the soil, but he said it was better to break up old logs. He warned that the

range of the slime threads was 10–15 cm, and that they spray it when they are picked up.

Stoner said the spray was harmless but annoying. Still, in a group that varies even in the number of legs they have, can you rely on all velvet worm sprays being harmless? Don't put your face too close, just in case! By the way, one school holidays, I had some young people searching leaf litter from Hyde Park in Sydney, and we found several velvet worms. An expert identified our animals as a Victorian species, and suggested that they had hitched a ride north in a potted plant.

Exploring arthropod legs

If you keep yabbies or crabs in captivity, you may be able to acquire some legs from their home, after they moult or die. Others may be studied on live animals. Orb weaver spiders often leave their old skeleton in a corner of their web. Crab legs can be found on beaches and in rock pools.

I use this chicken wire cage to clean up bones of dead mammals, but you can deal with crabs and lobsters in the same way. Here, it is wired to a tree to stop scavengers dragging it away. Insects can get in and eat the flesh, but it is a good idea to cover the cage with a heavy board: ravens pecked out most of the bandicoot remains that were stored in this cage.

With crab, lobster and prawn legs, I boil them and leave them in a container outside, a container that birds and mammals cannot enter, but ants can. Boil them again before you bring them inside.

11 Plants

Some of your garden's plants don't have flowers and don't form seeds. Botanists call these "the lower plants", but when you start looking, ferns, mosses, liverworts and lichens are just about everywhere that is damp enough. Lichens grow even in dry places, and so do some fungi. Biologists will tell you that lichens and fungi aren't really plants at all, but I have to fit them in somewhere, so here they are.

Fungi

The mushrooms and toadstools that we think of when we hear 'fungi' are just the aboveground part of large underground organisms made of tiny pale threads called hyphae. Mushrooms and toadstools are the fruiting bodies, the surface bits of the fungi that release spores aboveground so they can blow around. Any spores that reach somewhere damp start to grow, and if the new thread finds food, it continues growing.

The fungi break down dead stuff, mostly dead plant stuff, but some fungi can use dead animals as well. When they have taken enough food in, the fungus sends some threads to the surface, where they form fruiting bodies and release more spores.

A puffball (left) and two types of mushroom.

Fairy rings form when a fungus is living happily on the buried stump and roots of an old dead tree. Often you can't see the ex-tree, but the fungus can find the wood in the ground, and each year, it will form a series of fruiting bodies at the outside of its range.

The most obvious Australian fungi, mushrooms and toadstools, appear mostly between mid-autumn and midwinter, but some are around into late spring. Bracket fungi (above) are visible all the year around, usually on fallen logs or dead trees.

Hint: If you hunt around at nurseries and garden shops, you may be able to buy a 'mushroom farm' and grow your own mushrooms, which are safe to handle and eat.

Looking at mould on bread or oranges

A few fungi can kill you, and some moulds might infect humans, but sensible people are safe enough. Some caution is needed, not a lot. Handle moulds with care, wash your hands, and try not to breathe in when your nose is near the mould. There is certainly a great deal to see at the microscopic level.

The spores come from vertical flaps called 'the gills' which lie under the umbrella shape, and the rate of fall depends on the humidity, so getting a good print may take 2 hours or 24 hours. The main thing is to get the gills close to the paper: you can make a hole for the stalk to poke through, or you can cut the stalk off. Then put the mushroom down on paper for several days.

You will need to leave a bowl inverted over them to stop any wind blowing the spores around. Spray your prints with artist's fixative (see an art-supply shop or any artist who works with charcoal or any art teacher for advice on where to buy this). Can you identify different species by their spores? Can you tell mushrooms from toadstools by the colours and patterns? (I can't!)

Look out for these:

- Gills;
- Spores in patterns.

Lichens

Lichens offer us an example of symbiosis, because each lichen is made of three organisms, two fungi and an alga. Until 2016, people thought it was just one fungus and one alga, but this now seems to be wrong, though only specialists need to worry about the change in the details.

Lichens live in places where neither an alga nor a fungus could live by itself. If the two types are symbiotic, the alga makes food for them both and the fungi hold water to keep the alga alive, but some scientists think the relationship is different. They call it **helotism**, from a Greek word for 'slave', *helot*. In the helotism theory, the alga is a prisoner or slave of the fungus (or fungi), and people who favour this idea say that lichens are just fungi that have discovered agriculture.

There are three types of lichens: crustose lichens that form a flat crust on rocks, roof tiles and sometimes tree barks, foliose lichens which look more leafy, but which grow on rocks and some trees, and fruticose lichens, which grow mainly on soil and a few tree trunks.

From left to right, a crustose, a foliose and a fruticose lichen (wolfbane).

There are unusual yellow lichens on rocky shores close to the sea, all over the world. I have seen them from Scotland to Italy to Pacific islands and Australia). Some yellow lichens (like the one on the right above, seen in British Columbia) contain vulpinic acid. Called wolfbane, it delivers a poison that was once used to kill wolves, so don't eat yellow lichens (especially if you are a werewolf).

Smooth-barked gum trees have no lichens on them because those trees shed their bark each year, but there are more than 3500 lichen species in Australia and its territories. In the 1970s, some city lichens disappeared because air pollution killed them, but in many places, the lichens have come back. That, of course, raises the question: *where did the lichens return from*?

Some lichens spread by fragmentation, but for a lichen to reproduce, the fungus and the alga must disperse together. Some lichens produce *isidia*, which look like tiny complete lichens, others form *soredia*, or a cluster of algal cells wrapped in fungal filaments. Examine your lichens for cup shapes.

Two views of a crustose lichen (clip-on version on the right). The black cups are the soredia, mentioned above.

Look out for these:

- This is one of the times when a clip-on works well, because it is usually hard to collect and carry away samples: can you find any lichens growing on pebbles?

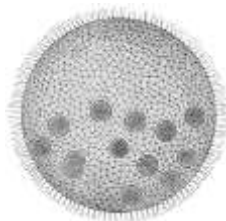
Green slime

Water plants at a glance

Before you start looking at samples of green slime, note that you need to use gloves and wash your hands.

This quick introduction will give you the names you need to seek more detail on the web. The simplest water plants are single cells that can convert sunlight and simple chemicals to food and energy. They form new individuals by dividing into two smaller cells that can grow before they also divide.

We will start with your hay infusion (chapter 2), which is the formal name for green slime. Most of what you see will just appear under your microscope as little green blobs, but even if they are small, they are important, because water animals depend on these for food, either directly or indirectly. You may find diatoms and green algae like *Euglena*, *Chlamydomonas* and *Chlorella*.



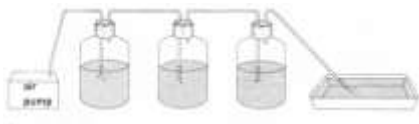
Then there are the more complicated forms that include a few cells linked together, and a beautiful colonial alga called *Volvox* (above), which has to be seen to be believed. Look it up on the web, and then look for it in your samples. It forms colonies (balls) of up to 50,000 cells, with new colonies forming inside.

One common way to collect larger algae used to be to strain large amounts of water through a fine handkerchief tied over a tap. If this still works (and I think it may not) it wastes water, but you could always try filtering stream or pond water in a similar way. Then there are long strings of cells, the filamentous algae, like *Spirogyra*, and in the algae, all the cells are the same. In the more

complicated plants, some cells specialise and do different things, and we come to those soon.

Algal culture tricks

You can culture free-floating and swimming algae in a series of bottles, connected by tubes, with an air pump bubbling through each in a series.



This scheme improves production: put each inlet tube (the bubbling ones) just under the water surface, to avoid too much strain on your air pump. You need clear bottles so light can get in to make the algae grow. You may see either a *Paramecium* or an *Amoeba* in your cultures. Find out what these are, and if you find some, watch how they react to light. If you have an air pump, you can culture freshwater invertebrates in a setup like this.

To keep things going, add small wild water samples into any bottle that seems uninhabited. A week later, I usually have a good crop of something or other, which I can sample to try to make pure cultures. If you have a fish tank, some of the most interesting stuff comes from the filter.

Most of what you see will be algae. I suggest that you look up the following on the web and become familiar with the appearance of *Spirogyra*, *Volvox*, *Scenedesmus*, *Nostoc* and *Chlamydomonas*. As you track those down, you will probably see other familiar algae as well. One thing you are sure to find is rotifers, which we met earlier.

Looking at green slime

This needs a microscope. Hand lenses and clip-ons won't do. You need microscope slides (and at least one well slide), cover slips, a dissecting needle to lower the cover slips down, a medium size camel hair brush, and an eyedropper or a Pasteur pipette (which is just a long eyedropper, made by somebody with bit of training in

chemistry). You saw this before in chapter 3, but here, again, is what you need:

Basic microscopy equipment. From the top: eyedropper, dissecting needle, forceps (tweezers), Pasteur pipettes (one spare without a bulb) and paintbrushes.

Get a *tiny* amount of green slime from a pond, put it in a drop of water on a slide and add a cover slip. When you look at your first slide, it will always be too dark to see anything. Make a second slide, and this time, use even *less* slime, and spread it out with two needles or two pairs of forceps.

Even then, some parts of the slime will be too thick, so move the slide until you are looking through a less populated part, and focus on it under low power. Then, if something looks interesting, put the interesting bit in the middle of the field of view, and move to a higher power. (This instruction will make sense once you know your way around your microscope.)

Most ponds and puddles will develop a collection of life over time, as spores blow in, or are carried in on water-birds, and you will normally take a good sample of this life, along with the slime, which is actually an assortment of algae. Most of the animals that you will see are too small for a hand lens, but within the visual range of a clip-on, though you will be lucky to catch them. They move too fast and zip out of your focal plane, but you can only try.

Take a small amount of slime, and spread it out with a brush. Stir this up a bit, and then take some of the material with an eyedropper and put it in a Petri dish. The image above shows moving dots, probably *Chlamydomonas*, while below, four frames from a video, probably show *Paramecium*. These were taken at x400 with a USB camera and a monocular microscope. Don't expect too much more than this!

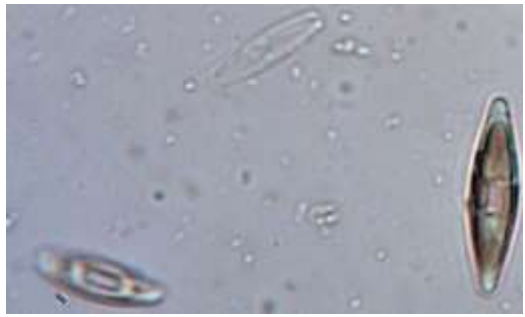
With a black background and a strong light, you should be able to see if there are any tiny animals in the water, with an unaided eye. If there are, use a Pasteur pipette to take a sample. If there are no visible animals, use a flat slide, as described in chapter 3, **Making a wet mount**: if you can see moving animals in the gunk with your naked eye, use a well slide.

When you switch to high power, you may see *Paramecium*, some nematode worms, or some of the other larger animals that live in green water. *Paramecium* is a single-celled animal with the common name 'slipper animal', because it is shaped a bit like a slipper. These are classed as **ciliates**, which means they move along by beating large numbers of short hairs called cilia.

The large ciliates feed on bacteria, yeasts and algae, all of which have smaller cells. *Paramecium* cells range in size from 50 μm to 350 μm, which means the largest ones will be visible with a hand lens, if you are lucky. I see them most often as large dark blurs that shoot

across my microscope's field of view, out of focus, when I am looking at something smaller, like diatoms.

(In case you don't know it, µm is the standard symbol for micrometre, which is one thousandth of a millimetre: 50 µm = 0.05 mm; 350 µm = 0.35 mm.)



Diatoms are single cells most of the time, but some of them form filaments, ribbons and even colonies. They have cell walls made of silica, and there are probably 100,000 different diatom species around the world. There are three diatoms in this picture, but two of them were on different levels and so more blurred than the one on the right. These were viewed at x400, so they are hard to see in simple microscopes, but you may get lucky!

Keep an eye out also for filamentous algae like *Spirogyra*. That one is easy to spot under the microscope because it has spiral **chloroplasts**. To identify your algae, you will need a dichotomous key to the green algae, or the filamentous green algae. To search on the web, it will probably be better to enter a search string using the technical name for the green algae: **<key freshwater chlorophyta>** or **<chlorophyta identification freshwater>**.

Two unidentified filamentous algae.

Filamentous algae are often called 'moss' or 'pond scum' when they attack fish ponds and tanks, where they often go out of control and end up dying to leave a decaying mass, riddled with bacteria which

use up all the oxygen in the water, killing the fish. These algae are actually long strings of algal cells.

Some of the most interesting filamentous algae can be found where water runs through channels in a rock. The cells in the filaments are too small to see with a hand lens, but you can see detail even under low power with a microscope.

Look out for these:

- Small, fast-moving blurs;
- Curious patterns in surfaces.

The more complicated algae

Evolutionary theory says the earliest life forms were single cells, then the next stage saw some of the cells strung together in long chains or threads of identical cells. At the next stage, the cells formed sheets, and maybe some of the cells had a special function, like hanging onto a rock. After that, we have plants and creatures like us, complicated three-dimensional things with hundreds of specialised cell types.

That's the theory, anyhow, and that means that filamentous algae are fairly simple, and they are easy to see if you tackle things the right way. The main thing to say here is that you need back-lighting, and that means a proper microscope. Then, if you are going to see anything much, go back and read about wet mounts (chapter 3), because you need the threads to be surrounded by water, and you need a flat surface to look through.

At the very least, you should be able to see traces of green. At higher magnifications, you should see the green blobs that are the chloroplasts, the parts of the cell that carry out photosynthesis, making the building materials that the cells need.

Looking at kelp

The kelps are brown algae that grow in deep water, but they are often washed up on beaches, where they provide a home and/or food for many small beach animals that will wash off when you

swish a frond in a dish of seawater. In times gone by, I would have added a splash of formalin, which made the beasties *jump* out, but now we know that formaldehyde (methanal to chemists) can cause cancers. ***You may see formalin recommended in old books, but don't use it!***

Seaweeds like kelp are often eaten as 'sea vegetables' in Korea, China, and Japan. They are also used to produce hydrocolloids such as alginate, agar, and carrageenan, but they have little direct interest that I know of for microscopists. See if you can prove me wrong! (Hint: start with agar.)

I think the one on the left is *Ecklonia*, but I'm not betting on it. The floats on the sand around it certainly aren't that genus!

The kelp seaweeds grow, attached to the sea floor at the end of long stalks, but the most interesting part is their attachment, which is called a holdfast. Those are worth consideration. Holdfasts look a bit like the roots on flowering plants, but the roots on higher plants do useful things like picking up water and minerals, or providing a home for bacteria that fix nitrogen. Like roots, the holdfasts help tie the plant in one place, but holdfasts don't do the other useful things.

All the same, holdfasts of the common Australian kelp, *Ecklonia radiata* do provide homes for polychaete worms, barnacles, and tubeworms, so the holdfasts, even on stranded seaweeds, are worth a closer look. Swish the holdfast in some clean seawater in a dish or bucket, and look carefully.

Hormosira banksii

Known also as Neptune's necklace, sea grapes, or bubbleweed, this brown alga is common in the mid-tide regions of shore rocks in Australia and New Zealand. Fragments like this one often wash up onto beaches, where they are stranded.

The beads have a slimy layer that helps the plant stay alive at low tide, when many other seaweeds will dry out and die off. The plant provides food for sea urchins, some crustaceans and even a few fish. Its reproduction is interesting, but a bit complicated: look up <**Hormosira reproduction**> for more information.

Two views of *Hormosira banksii*, showing the sexual organs (conceptacles) which (for advanced microscopists) produce sperm and ova, mainly between July and October.

Look out for these:

- The 'warts' on the surface are called conceptacles, and they are involved in reproduction in *Hormosira*.

Ferns

Ferns start out very small, but some of them, like the tree ferns, can grow quite large. Ferns show up in the fossil record about 350

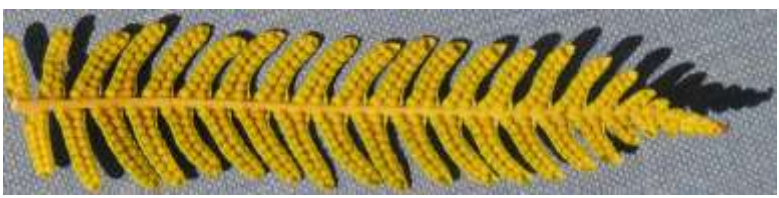
million years ago, but the fern families we know today are around 200–250 million years old. Because they have survived for a long time, many ferns have 'biologically active' chemicals, meaning some of them poisonous.

Nothing survives for that long without having defences! This water fern nardoo, growing at Mount Annan Botanic Gardens, N.S.W., has defences that probably killed the badly-prepared explorers, Burke and Wills.

Ferns have stems, leaves (called fronds), and roots. One of the most beautiful things about ferns is the way their new shoots unroll. Once you have seen one, you will understand why they are called fiddleheads. It may not count as microscopy, but they repay close study, probably as a time series in a potted fern.

The life cycle of a fern

You don't really *need* this, but you may possibly *want* it, so here it is. Skip it if you don't care. The other thing worth studying in ferns comes from the dots that show up on the back of some fern fronds. I am a botanist by original training, and I have had people ask me if ferns with these dots on them are suffering some sort of disease, but the sporangia (to give the dots their correct name) are what ferns use to reproduce.



Chromosomes are the packages of genetic material that make a cell part of a grouse, a mouse or a louse. When two cells fuse in

reproduction, the cell they form has twice as many chromosomes as the 'parent' cells. If this doubling kept on going, soon each cell would be crammed full of DNA, so there is a neat mechanism called **meiosis** that halves the number of chromosomes that end up in the sex cells.

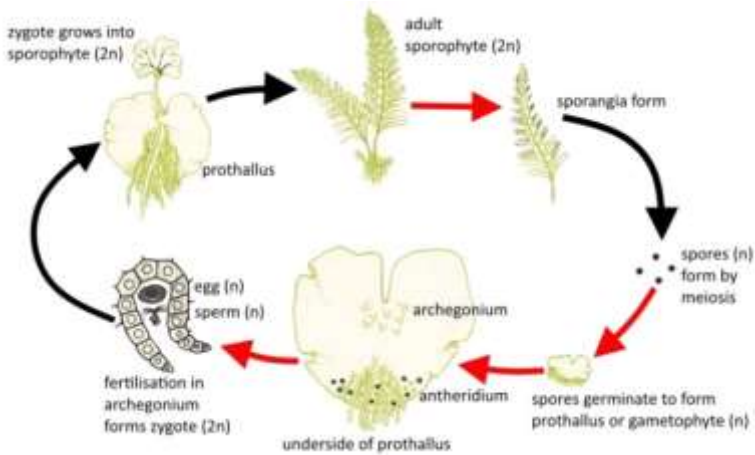
Biologists call those special cells **haploid**, while normal cells are **diploid**. Human sperm and ova have 23 chromosomes each, the haploid number, but all the rest of our cells contain 46 chromosomes, the diploid number.

In biological shorthand, haploid and diploid are represented by (n) and (2n). And that's enough: now, you are ready to look quickly at the life cycle of a fern, some parts of which can only be seen under a good microscope, while other bits show up under a hand lens.

The simple version of fern breeding

If it gets enough moisture, a spore starts to grow, and forms a heart-shaped flat green layer, between 3 and 8 mm across. This is called a **prothallus**, and it is like the flower of a flowering plant, because it forms both male and female cells, which combine to make a new adult plant, but only if water splashes on them, to carry the male cells to the egg cells.

The main thing is that ferns reproduce from (usually) brownish spores that develop on the under-side of some of the fronds. These spores can blow around, taking ferns to new places, but a spore will only germinate in damp conditions.



The stages of a fern's life cycle: usually, we only see the sporophyte, the part that produces the spores.
All the technical names are here in case you want to learn more, but they aren't important.

Technical version: When they germinate, little green sheets form, which can be 2 mm across. Each of these is called a **prothallus**, and the prothalli develop male and female parts. The male **antheridia** produce sperm cells, while the female **archegonia** form eggs. Fertilisation only happens when the prothallus is wet enough for the sperm cells to swim to the archegonium. This is why ferns are so commonly found in damp places.

Raising your own ferns

Before you tackle this work, you need to read and understand fern life cycles (described above). You will need some mature fern fronds, scissors, a jar, and other things that depend on the method you choose. Some plastic toothpicks may be useful.

Fern sporangia with a clip-on. In the left-hand shot, I was using a 10-cent coin to weigh the frond down (think focal planes), and also to act as a sort of scale.

To collect fern spores, cut a few pieces of a frond with sporangia on them, chop the bits into pieces small enough to fit into a jar, and leave them to dry for several days, covered with a cloth to keep out dust. Then put a lid on the jar, shake them together, remove the pieces of frond and collect up the powder that remains. This powder is mainly made up of spores, which are very tough.

There will also be the spores of fungi, so the experts say you should pour boiling water on the fern spores in a saucer. Later, when the water cools, pour the water onto whatever you plan to grow the prothalli on. I have never needed to do this washing, but if you do, be careful: I was scalded while making tea, more than 60 years ago, and I still remember the pain.

You can germinate spores by sitting a brick in a bucket in 2 cm of water in a bucket. Sprinkle spores on the brick, then seal the bucket with cling-wrap, opening it every day or two to check on progress and the water level. Fern spores grow best on damp soil or wet rock, but I often use mud agar. This uses boiling muddy water and 1% agar.

The prothalli can take two to six weeks to grow out. Once they start to appear, mark three or four of them with different colours of toothpick (or beads), and take photos of them, twice a week. Once prothalli form, you have material to study, but remember to splash water on the prothalli. At its maximum size, the prothallus will fill the field of the Go Micro, with no digital zoom.

Look out for these:

- As part of a bush regeneration project, I have been trying to get a 'swamp marker' fern, *Gleichenia*, to germinate. Also called 'coral fern', this plant grows like a weed around swamps, but the spores just don't seem to work. If you can achieve this, publish it on the internet and become famous.

Bryophytes

Looking at mosses

Sometimes when you look closely at a moss, instead of the usual velvety green carpet, you can see little stalks poking up with what look like windsocks on the end. These are called capsules (or *sporangia*), and they release spores. Most of the sporangia have a neat structure called the *peristome teeth* that push out spores when the air is damp and humid. These are accessible to the microscopist who knows what to look for.

Moss capsules release spores that grow into a new generation of mosses.

I have never been able to grow mosses from spores successfully, though mosses seem to manage it when they produce spores and release them into the wind. On the other hand, I have been able to establish successful plantations of mosses on the sloping sandy surface of a terrarium tank. I just take a small sample of a moss, break it into several smaller parts, and embed each at a different level down the slope (see chapter 6, **Setting up a terrarium**). After that, it is up to the mosses to slug it out.

Growing mosses on rocks

I haven't tried this one because we don't have a blender that works, and my wife says that even if we did, it probably wouldn't work *after* I tried this (she said this not long after I dried the sand for my angle of rest measurer in the microwave, but that's another story). While I'm writing this book, I am keeping an eye out for a cheap blender in an op shop, but so far, no good!

The experts say that if you want mosses on garden rocks around a pond or in a terrarium, take some healthy moss and crumble it into your blender. Then add 2 cups of buttermilk to 2 cups of water and blend at the lowest speed until it is completely mixed. It needs to have the consistency of a thin milk shake, so add more water if necessary. Then paint this slurry on rocks, or just pour it on the ground where you want moss to grow.

Other writers say you can replace the buttermilk with a can of light beer and a half-teaspoon of sugar. Another recipe that I found calls for about 2 cups of yogurt, and about 4 ounces of potter's clay to make the moss mixture stick to the rocks better. It also recommends regular 'misting' of the stones with water.

I know that even if I can pick up a cheap blender, I will be getting rid of most of the soil from the moss sample by washing it first. Then I will look carefully at the water, because there are usually wee beasties living in the moss mats.

Looking at liverworts

Liverworts are a rather specialised interest. They look like mosses, but the 'leaves' are much larger, and lie flat on the ground. They are hard to keep alive, but the methods described above for mosses will work on liverworts. They make an interesting study, but they may be hard to spot. Look at any 'big mosses' and you will probably have a liverwort.

If you want to go looking for liverworts, try bogs, swamps, shady gullies and moist woods. You can also look under the tables in an old-established greenhouse. At least you will have an enjoyable fossick, and you are looking for something like what you see in these shots. In the right-hand picture, you can see archegonia. To

get the shot, I put a liverwort from our plant nursery on North Head on blue cardboard, and snapped it with a tablet.

Look out for these:

- Look up <**liverwort reproduction**>, as I am leaving that out here;
- Examine your liverwort and see if you can see the reproductive parts (some of them are visible above).

Flowering plants

Leaves

Almost all the flowering plants have leaves. A few have **phyllodes** or **cladodes** that work like leaves. Apart from that, there is a huge amount of variation to look for. They also have a few things in common. Most of the **photosynthesis** in a plant, the work of food-making, happens in the leaves. The pictures below show a member of the pea family called *Bossiaea* (pronounced 'bossier'). They are hard to find where I live, and these are the best shots I have. Notice how the leaves are reduced to little scales, poking out from the sides of the flattened stem, which is called a cladode.

Leaves also have openings called **stomates**, which we will come to shortly. Most leaves are green because of the **chlorophyll** in them. Chlorophyll is the molecule plants use to capture the sun's energy to drive photosynthesis. Some leaves are coloured because they contain other pigments that hide the chlorophyll.

Old leaves get their colours because plants break down the chemicals in the leaves and try to take back as much goodness as possible before the leaves fall off. The autumn colours are leftovers. Most leaves have different upper and lower surfaces, but try to find

a top or a bottom on a gum leaf! Most leaves are free to wave around in the breeze, catching as much sunlight as possible, but gum leaves hang down vertically, which is why the two sides are identical.

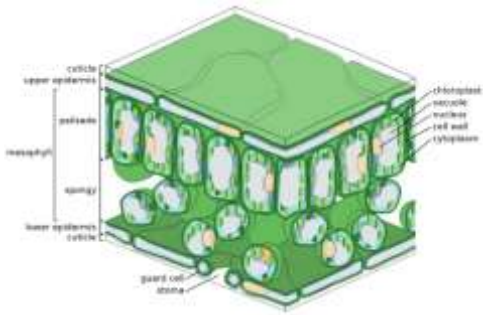


Image credit: based on a Wikipedia Commons image, Leaf Tissue Structure by Zephyris.

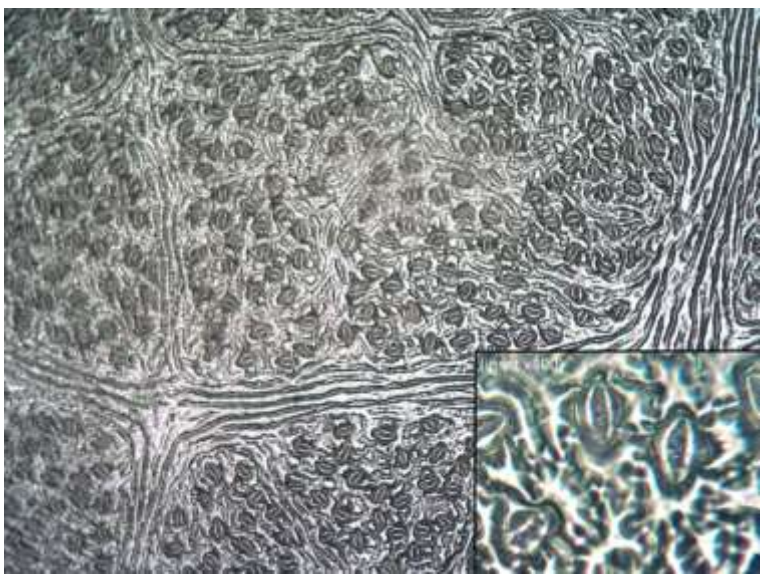
You would never see the picture above under the microscope: it is built up from different views under high-powered microscopes. Ignore the names, but note that there are openings into the leaf, and air spaces inside. The chloroplasts inside the cells are the places where photosynthesis happens.

Seeing stomates

The stomate is identified in the leaf diagram as a *stoma*: that is a Greek word, with the plural stomata. In English, we say stomate and stomates, but whatever name we use, it's time to look at these pores. The lower surfaces of most leaves are covered in stomates, and while they require a good microscope to see them *well*, we can take a cast of a leaf surface and look at that, using either a clip-on or even a hand lens!

The cast is usually called 'a peel', and in my youth, peels were made with stuff called collodion. Now, there's a simpler way. All you need now is some clear nail polish, some sticky tape and a glass slide. Choose a leaf: it seems that most leaves work, but not *Camellia*, and leaves without hairs on their lower surface are best. Using a small amount of clear nail polish, paint a thin strip on the lower surface, about 1 cm wide and 3 cm long (accurate measures aren't really important).

Leave the nail polish 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 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, you are ready.

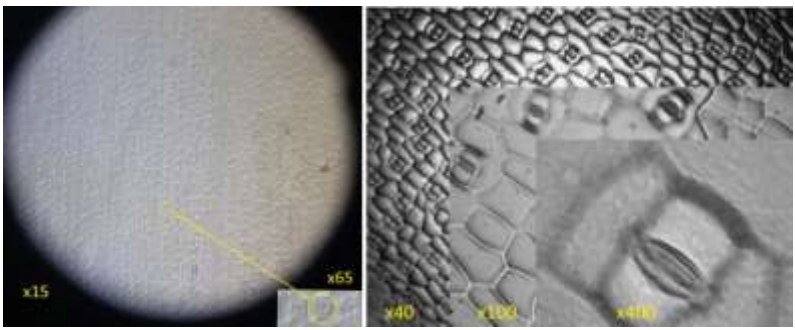


Above, you can see two views of a peel from the lower surface of a bay leaf, at x100 and x400 (the inset). Stomates let carbon dioxide in and oxygen out. They also let water vapour escape, so plants need to control their stomates, which are very tiny, about 0.05 mm ($^{1}/_{20}$ mm) across, so you won't see them with the naked eye. Still, once you know what you are looking for, you can see them with a good hand lens, but only as closely-packed dots.

Sometimes research is just trying out ideas, and that was the case when I tried looking for stomates on fishbone fern. They are indeed there, but another form of scientific research involves reading 'the

literature', the things other scientists have seen, noticed or discovered. That revealed that other people had already seen fern stomates. I found it has clear stomates on the under-side.

Another literature search told me that the very best plant for this exercise is *Tradescantia pallida*, a garden favourite with purple leaves, and one that grows easily from cuttings. Here on the left is what you can see of *Tradescantia pallida* with a clip-on at x15 and x65 (in the inset). Then I reached for a microscope, and the results are on the right. The same 'peel' is now seen through a high-end monocular microscope, at x40, x100 and x400. This is better!



Once you see this, the clip-on and hand lens views will make sense. Each stomate looks like two fat sausages (or lips) lying side by side: when they curve around, the stomatal pore opens and gases go in and out. The stomate is made up of two guard cells: these are the 'lips' of the 'mouth', but in *Tradescantia pallida*, there are two other cells, one at each end, making a rectangle.

It turns out that you can see the stomates on the plant's actual leaf with a clip-on, if you know what you are doing! The shot above is *not* a peel: it is the actual plant that is under a clip-on. The first shot is with no digital zoom, the second is with full zoom. Look for the pale squares. This view is looking at the leaf itself, with reflected light. The stomates are the pale square shapes. The stomates are very visible at x60, but you can even see them with a hand lens offering x10, if you know what you are looking for. That's neat!

Sundews

Some leaves trap and digest animals. We call those plants insectivorous, which means 'insect-eating'. (You probably know 'herbivore' and 'carnivore' as they apply to dinosaurs. Well, my favourite plants, the sundews or members of the genus *Drosera*, are insectivores: they eat insects.)

There are three other genera in the family Droseraceae: the *Drosophyllum* of the western Mediterranean, *Dionaea*, from the Carolinas (USA) and *Aldrovanda*, which is "widespread in the Old World". Sundews are found in swamps and marshes in much of Australia. Their leaves have sticky hairs (you can see them below) that hold drops of protein-dissolving enzymes.

Three views of North Head (Sydney) sundews.

When an insect sticks to a leaf, the enzymes break the insect's protein down to amino acids, and this stimulates the leaf to curl over, slowly, bringing more hairs into contact with the insect, holding it better and dissolving it faster. The process generally takes several hours, so this would be a good subject for time-lapse studies.

You can try feeding a sundew on tiny bits of cheese or meat, but if you are growing a sundew in a pot, you need to use very pure sand, and *never* add any fertiliser, because these plants won't produce the sticky 'dew' if they can get enough nitrogen and phosphorus from the soil. Don't feed them too much.

Look out for these:

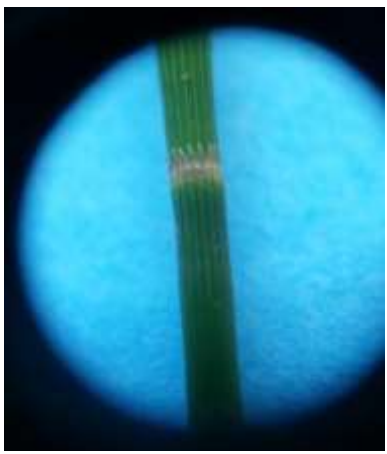
- Do the plants 'react' faster at a warmer temperature? How would you find out?
- How do different species compare?
- There is less protein in cheese: does this produce a slower reaction?
- Do sundews like sugar?
- Do sundews react to small pieces of metal or glass?

The leaves of the sheoak

Sheoaks are found all over Australia, and in much of the south-west Pacific. If you look at the 'needles' of a sheoak, you will find that each needle is really a branchlet with tiny leaves attached to it. Each of the things that look like joints show their true nature under the hand lens: each is a ring of leaf tips with the leaves starting one joint further down.

Most older works (and even older people) call the sheoak *Casuarina*, but when Laurie Johnson examined the genus, he split it into two genera. The species that was first named *Casuarina* and its relatives kept their original name, but the "others" were given the name *Allocasuarina*, which simply means "other Casuarina". To save squabbles, I'm just calling them sheoaks here, and I hope that everybody will just accept that.

Just don't call them "pines"!



When you look at them closely, the 'needles' which should really be called branchlets, look a bit like bamboo, but just as they aren't pines, the sheoaks aren't bamboos either. Bamboos are giant grasses while sheoaks are trees. Some species, like *Allocasuarina distyla* have male and female flowers on separate plants. Those are female flowers on the right in the picture two back. This is the view from a clip-on of the 'needle' of *Allocasuarina distyla*. Notice the leaflets around the joint: those are the tips of leaves that stretch all the way down to the next joint, out of the picture.

The other thing that makes sheoaks look like pines is that they have a fruit that looks a bit like a tiny pine cone. The seeds they drop are worth looking at.

Here, you can see how the closed 'cone' on the left opens to drop out little winged seeds that blow away. The cones open when a plant dies or is burned, or after a certain period of time. Sheoaks are easy to raise and fun to watch. Over to you! We will look at the seeds later.

Sometimes there are surprises in sheoaks in the bush or in your garden, because some of the fruits look very different. The sheoak on the right was attacked by a midge, called a gall midge, which laid an egg inside the bud that was going to be a fruit.

The midge takes control of the fruit and turns it into a home. If you find one of these in your garden, you can slice it open (though if you are young, it's a good idea to ask for some help: the fruits are tough and woody, and it's hard to get the grub out, without either slicing it—or you! Use pliers to hold the fruit, and *cut away from you*.

There is a curious relationship between the number of leaflets around the stem, and the number of seed places around the 'cone', but you'll have to find that out for yourself.

Leaves under the microscope

Plants with any sort of texture to their leaves must have it for a reason. Furry leaves, slippery leaves, non-slippery leaves, all have secrets to reveal. Of course, if you want to get down to it, you will probably want to make some thin sections as well, or peel some epidermis from a leaf. Thin sections will be a problem unless you go back to read chapter 3 on microtomes again.

Some plants, like the thistle above, have spines that are immediately obvious, but defences are only as good as the enemies let them be. Consider this Dorrigo rain forest plant below: it looks safe from chewing, but the second picture shows that *some* small animals can get around those spines.

An unidentified rain forest plant, Dorrigo Plateau, New South Wales.

Many Australian grasses have silica hairs on them. A good example is *Spinifex*, a grass which grows on sand dunes, but some other grasses have silica hairs that can be seen with a hand lens. Other plants have spines that are immediately obvious.

Most parts of Australia have one or more species of needlebush or *Hakea* (see an example above) but for the rest, ask around. Roses have thorns that are technically different from spines: look into this and explain why cacti are hard to carry in your pocket…

Which are the most interesting spines?

Still, one way and another, leaves are worth studying.

Other curious leaves

Sometimes, it can be worth taking a closer look at a leaf that has been eaten or chewed, to see if the eater is still there. Find a plant with a number of chewed leaves, and examine them carefully to see how many different chewing patterns there are.

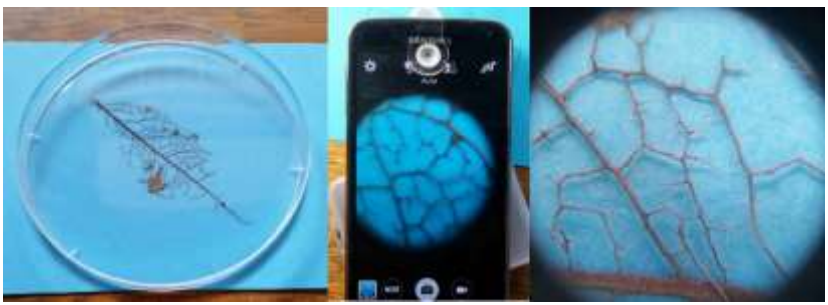
Some leaves are eaten from the inside by leaf miners, small beasts that burrow into and through the inner cells of a leaf, while larger animals bite whole pieces off. Snails, caterpillars and birds must all be suspects. See what you can find!

What chewed these leaves?

Then again, we sing about the seasons, about spring, about the autumn leaves, but have you ever tracked the changes? Try exploring leaves in spring and autumn. A really thorough study needs access to leaves, for six or eight months across the summer, and a camera or device. Choose your own plants if you wish, but annuals and deciduous plants are probably best.

When I did something like this with secondary students in the 1970s (yes, I'm that old), we marked the leaves of interest with short lengths of pipe cleaner wrapped loosely, twice around the petiole, which is the stem of the leaf. You could also use a loop of thick wool…

Don't forget also to look at 'leaf skeletons'. That's a wonder thing, too!



The leaf above was prepared by pill bugs in my desktop compost heap, described in chapter 10. The Petri dish sits on top of the leaf to flatten it. The middle photo shows how I set up my phone on a box, with a microscope slide (look for it carefully, and you'll see it as a pale rectangle in the first shot!).

I found the weight of the phone helps the flattening. So: which parts of a dead leaf last longest? What's the best way to find out? What you look at will depend on what you use, but some leaves you see won't look like leaves at all. The tendrils of peas, the winding bits that wrap pea plants around things are modified leaves, and so are the spines on cacti. Then there are the leaf scales on sheoaks (*Allocasuarina*), and the insect-catching leaves of the sundews (*Drosera*), which we looked at earlier.

You can either pluck weeds from the garden or use seedlings that were planted a few weeks earlier. Choose your weeds with some caution, but dandelions, cobblers' pegs and birdseed are all easy to use. Where possible, use local material. If you live in an area where a produce or other store sells wheat for poultry, try wheat.

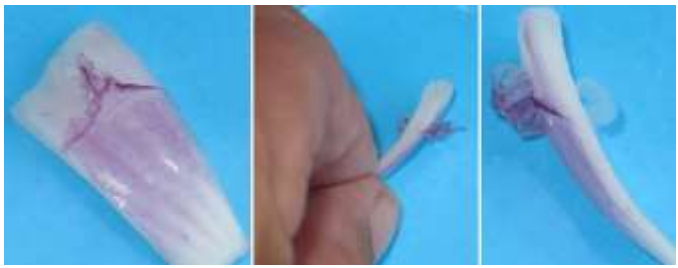
You should try to get some dicots (the 'broad-leafed' plants like peas, beans and most fruits), because the dicots form tap roots. To balance this, you need monocots (the 'narrow-leaved' plants like grasses, onion weed, wheat and maize), which form fibrous roots. Just explore what you have, and you will be surprised by what you discover. Look for the hairs on the stem and on the leaves. Consider these shots, taken after I plucked a weed from a seedling tray outside my front door:

Three views of one weed seedling: all of these fields are 9 mm across.

Onion skin cells

Because the epidermis of a leaf is a single layer of cells, you should be able to see inside the cells. With good back-lighting, you can see the cells in a piece of epidermis with even a x20 hand lens. Some kitchen plants are excellent for getting a layer of epidermis: red or white cabbage, leeks and spring onions among them.

Wear safety goggles if you are tackling an onion: the rings of an onion are really modified leaves. With care, you can peel the epidermis off a piece of onion and make a wet mount of it. There are several ways to strip the epidermis off.



Take one layer, snap it inwards, then pull one-half past the other, and you should see a thin tough film like a piece of cling wrap. This filmy stuff is the onion epidermis. (In the picture, I used a red onion to make the epidermis stand out: as you will see shortly, this isn't necessary.)

I would normally have put this membrane on a slide, made a water mount, and covered it with a cover slip before photographing it, but there is more than one way of skinning the cat (and if you don't mind fur between your teeth, you don't even need to skin the cat).

First, I did this and tried a wet mount without a cover slip. It didn't work, and the strip became tangled. So I took a much larger piece, set it on a slide and looked at it. Look hard at the next picture, and you will see the cells, even at x15.

The largest field on the Go Micro, the one seen above is 9 mm diameter, and I estimate there are 40 or 50 cells across the field. If

we split the difference and call it 45, there are five cells per millimetre, so each cell is ~0.2 mm or 200 μm long. Below, here's what I got with my microscope. The first image is x40, the second is x100.

You can also peel off the epidermis from the leaves some garden plants. Bend the leaf until it 'breaks', and then see if you can pull one half back and peel some filmy 'skin' from the other half. You can also see cells in the stamens of some flowers. The weed called 'Wandering Trad' (*Tradescantia*) is one that works well.

Look out for these:

- The ways cells pack together;
- Any cell contents that you can see (hard without using stains).

Flowers

Photographing flowers

When I am photographing wildflowers, I carry a few pieces of thick copper or aluminium wire. This bends easily, and I can use the wire to make hooks to attach the flower stem to a solid branch, or my tripod. Even though it is out of the shot, the hook will slow the flower's movement in the breeze.

Of course, if the day is sunny enough, then the speed of the shutter will 'freeze' the picture in any case. I also use gaffer tape, bulldog clips and string at times, but these pictures show some other handy tricks. These four pictures tell the story.

You can get better shots when your subject is against a plain background. Carry some A4 sheets of coloured manila cardboard in a folder and hang these behind a flower (or get somebody to hold them) and you can also put insects on them.

Grass flowers

Are these grass flowers or grass seeds? The only way to find out is to look inside. Most people see the flowers on grasses and dismiss them as 'seeds'. They are actually worth looking at if you have a hand lens or a clip-on, but you will find it easier with a dissecting microscope.

Grass won't excite most people, but here are some terms, in rough order of importance, to search for on the internet if you want more

information. As a rule, the most helpful sites will be those with images that use these terms: **spikelet**, **glume**, **floret**, **stigma**, **anther**, **lemma**. Once you have some idea of what you are looking for, use a pin to pull a few flowers apart.

Look out for these:

- Stamens: we will be looking at pollen soon, and you may be able to work on grass pollen as well.

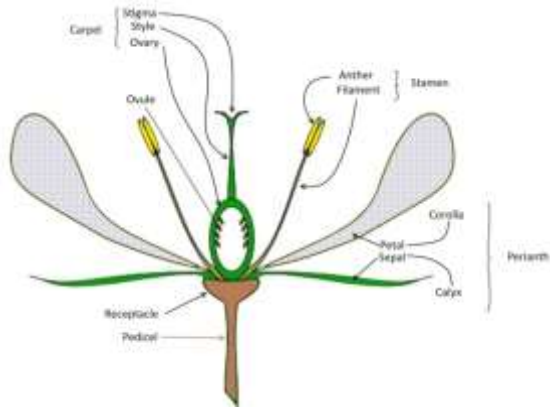
Exploring the variability of flowers

If you live in an urban area and there is no garden, target street weeds. Then again, if there are parks nearby, talk to the gardeners, or settle for looking and photographing without causing any damage. Note that some 'flowers' are actually *inflorescences*, whole collections of flowers. The daisy is a multiple flower, and the 'petals' are actually called bracts. Wattle is another multiple.

Watch out for damaging somebody's prize blooms, think also about hay fever and prickles and thorns. Plan ahead and watch out for bees and wasps! The flower wasp shown here is a nectar feeder, but the females may sting, I am told. Always beware of brightly coloured animals, even if some of them are bluffing!

Technical: the parts of a flower

Flowers have evolved over a very long time to do just one thing: mix up the genes from different plants, to give evolution new combinations to work on, but what follows is the short version, giving you the terms to look up. The main parts of a flower are the stamen and the carpel. The anther and the filament form the stamen, but it is the anther that produces the pollen grains that will fertilise the ovules.



The parts of a dicotyledon flower.

The stigma is the part of the carpel where the pollen grains, often from a different plant of the same species, attach. If the pollen grains find a receptive place there, they burst and grow a pollen tube that grows down through the style, delivering a genetic payload to the ovules. When that combines with the ovule's genetic package, a seed will form. The perianth, made up of the petals and the sepals, is there to attract the animals that spread the pollen: usually birds or bees (hence the expression "birds and bees" to refer to sexual reproduction). Still, as we will see shortly, there can be other visitors as well. All members of the fig family are pollinated by wasps, for example. As you are checking out the flowers in your garden, or in the bush, be prepared for a few surprises!

Looking at pollen grains

The study of pollen grains is called palynology, and you can do marvellous things with a bit of knowledge. For example, you can tell where honey was made; on archaeological sites, you can work out what plants grew near the location, and sometimes what the climate was like; and CSI people can sometimes get interesting stuff from pollen. You may need to be careful if you suffer from allergies to things like pollen. There is a common weed called *Plantago lanceolata*, the plantain, which used to make me sneeze badly. Here it is:

You will definitely need a microscope with a magnification of x400 or better, and the patience to piece together different views. Pollen grains are too small to see with the eye, or even with a hand lens, but they are too large for you to focus on the whole grain at one time under high power. See my comments on the free ImageJ software in chapter 8.

The clearest views of pollen come from scanning electron microscopes, but those cost more than a private individual can afford. Under x100, you will just be able to make out the 'sculpting' on the surfaces of pollen grains, and you may even be able to see that they are different shapes. Under x400, it will be much easier to see details. Pollen grains are sometimes hard to wet, so air bubbles cling to them, and once they are wet, some of them will burst, sending out a pollen tube, as mentioned above. To beat the bursting problem, all you can do is work fast.

I did a literature search, and found a list of plants with large pollen grains at the end of http://www-saps.plantsci.cam.ac.uk/pollen/index2.htm. To save you time, the following plants are known to have large pollen grains, with sizes in micrometres: maize (*Zea mays*), 95 µm; banana, (*Musa rubra*), 110 µm; bird of paradise flower, (*Strelitzia alba*), 150 µm; ginger, (*Zingiber officinale*), 150 µm. These grains should all be visible with a hand lens.

Here are some other possibles that may be in your garden or growing nearby: *Geranium*, Morning Glory, lilies, *Hibiscus*, *Iris*, and

Pelargonium. Many pines also have large pollen grains, but the grains are hard to collect.

This is pollen from Cobbler's Pegs, *Bidens pilosa*, a common weed. I think this old shot from my files was x100 (see the shot near the foot of the page as evidence).

Measuring pollen grains

After my literature search on pollen grains, I went looking at *Strelitzia* (bird-of-paradise) flowers for their pollen, and also at geraniums. The *Strelitzia* in my garden looks like the shot below, left.

I removed some stamens from the flower, and photographed the pollen, as it sat on a millimetre scale (centre). I concluded that there were ten grains in a string, 1 mm long, so each grain was 0.1 mm across, though scientists usually write this as 100 micrometres or 100 μm across.

The geranium pollen failed to form strings, so I used cunning graphics (above right). I took shots of the scattered grains and also of a millimetre scale at the same magnification. I then superimposed the scale on the pollen shot. Next, I used a graphics program to do a string of dots, the same size as one grain. There were 29 of them, so they were each 85 μm across. Over to you!

Seeds

Putting down roots is good for plants but having roots means that plants can't move around, to find new and better places to live. The successful plants are the ones with seeds that travel somehow.

I once worked in a lab during a hot Canberra summer and each afternoon, wattle seeds would bang against one of the western windows as seed pods broke open in the hot sun. The pods would curl back suddenly, sending seeds flying, but none of the seeds would have gone more than six metres from the tree that was three metres from the window. Still, the method helped the plant extend its reach.

Other plants have seeds that 'fly' away from the tree. Australian sheoaks and hakeas have winged seeds, and so do pine trees, but none of these would get very far from the parent tree. Here is a time-series I did of *Hakea* fruits opening.

Hakea fruits drying and opening.

Maybe those seeds carry a little further than the exploding wattle seeds (if the wind blows), but dandelions have a better way. Each seed is like a small parachute, so that even if it lands, wind gusts may pick the seed up and carry it further along until it falls into a crack.

Bathurst burrs came to Australia from South America, either in contaminated seed or maybe on imported livestock. Plants of the burr were seen on the banks of the Nepean River, west of Sydney in the late 1830s and soon after, they crossed the Blue Mountains and got onto the Fish River, probably on horses' tails. A flood in 1844 carried burrs down into the Macquarie River valley and after that, the burr's clinging ability took it all over Australia.

Other seeds are sticky. The cassia (*Senna pendula*) is a common weed across Australia, and it spreads because its seeds get sticky

when they are wet. I suspect that birds eat some of the seeds, but fly away with other seeds sticking to them, seeds that later fall off. Some have seeds that can survive being eaten by birds, and some even have fruits that actively attract birds to get them to swallow the seeds. By the time the seed passes through the bird, it is going to drop out a long way from where it was swallowed. Now see if you can work out what tricks evolution has played to spread the seeds in your garden.

Exploring the seeds of Cobbler's Pegs

Even if you don't know its name, most everybody knows Cobbler's Pegs, *Bidens pilosa*, because it is a common weed in eastern Australia, southwest and northeast WA, and in parts of other states.

If you have ever walked across weedy ground, you have probably seen how 'cobbler's pegs' attach to your socks, jumpers, skirts or trousers, but take a closer look at one of these clinging seeds and you may be amazed. To get a range of seeds like that, go and roll in some grass, or drag an old woollen garment or blanket through some weeds or undergrowth and see what attaches.

Bidens pilosa is used in herbal medicine, so it probably has some biologically active chemicals in it, but it is used as a leafy vegetable in southern Africa, so it's *probably* safe. The biggest risk is probably spreading the seeds further. Look around the streets, on waste ground, and you should find some plants. Collect one seed head, and pluck off two or three seeds. Test them to see how they stick to clothing. Then use your embiggener of choice to investigate to see how they manage. This is what you will see with a clip-on. The lower spike in the first view is the same one in the other two shots.

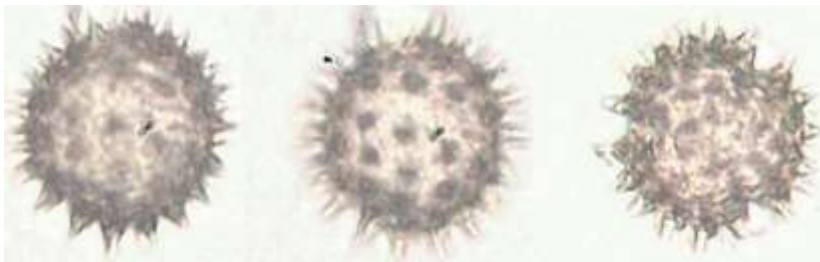
These are from a monocular microscope, but the left shot below would be visible with a hand lens:

The proper name for one of these barbed spikes is **awn**. The awns that we see above are superbly well-adapted for something! Take ten seeds and plant them on wet tissue. Notice how many of the seeds sprout: what does that tell us about why cobbler's pegs are weeds?

Look out for these:

- If you plant a few of these in small pots, and water them carefully, you should be able to grow them to the flowering stage, and if you watch them outside, you may be able to work out what pollinates them;
- (I have no idea what the answer is: *do some science*!)

Comparing pollen grains



The spiky grains of *Bidens pilosa* (cobbler's pegs), x400.

From left to right *Gompholobium* sp. (a pea) and *Kunzea capitata* (bachelor's buttons, Myrtaceae), and an unidentified lily, all x400.

Look out for these:

- The different outsides and shapes of pollen grains;
- How similar the pollen is in related species (*or are they different?*).

Watching seeds germinate

Many seeds germinate on moist cotton wool or a damp face tissue. Try wheat, tomato, cucumber, lettuce and white mustard and radish—or make your own choice from the garden. Most weeds including cobbler's pegs and dandelions work, because weeds need to germinate fast. Birdseed from a pet shop is also worth trying. As they grow, you can observe them under a hand lens.

You will need a container, either a dish or a plastic box. The tissue stays damp longer in a Petri dish with a lid, so I have described using that, but you can always adapt the details, and sometimes I use a plastic berry or chocolate box. Fold a tissue or paper towel, sit it in a container, add water (not too much: just saturate the paper) and seeds, and put the lid on. Then wait and watch, and unless you are sprouting weed seeds, see if you can find a place in the garden for them.

One of the interesting things to look for is the way seedlings grow towards the light, and in the pictures that follow, I played with this:

When I saw the seedlings leaning towards the nearest window, I marked the window side with a pebble and turned the plastic box around.

While testing ideas for this book, I worked with what was available. One day, I used scented "eucalyptus and aloe" face tissues as a base on which to germinate cobbler's peg seeds. The seeds grew more slowly than usual.

If you can't get those, you can still measure how eucalyptus oil affects germination. Set up some seeds to germinate on damp paper and prepare a second container with a tissue and a few drops of eucalyptus oil. Put both containers in a plastic bag and seal each with a fair amount of air inside. Use goggles to keep the eucalyptus oil out of your eyes!

> **Probe**: It occurs to me to wonder if other natural products affect seeds the same way. I suspect that garlic and onion juice might do something. Find out!

And why grow dandelions at all? The answer is because they give you some interesting root hairs to look at, as we will see later.

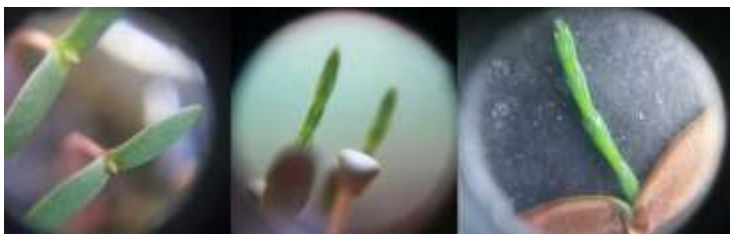
Look out for these:

- Unexpected things.

Watching seeds grow

You need a selection of seeds and small plants: you could either pluck weeds from the garden or take weed or other seedlings that were planted a few weeks earlier. If you want to use native plants, sheoaks (*Allocasuarina* sp.) germinate almost as well as weeds. Just cut off a few mature 'cones' from a mature tree with secateurs, and leave them in a dish for a week or so (see above). If your room is windy, put a lid on the dish or use a glass jar instead, because these seeds will 'fly'.

As well as seeds, dishes (saucers, jar lids, Petri dishes or the cut-off bases of PET bottles), tissues or paper towelling, something to add water with. You can also use flower pots and potting mix, if you want to grow plants to maturity, or the lidded plastic containers that salad vegetables and some fruits come in. The advantage of these containers is that shoots can rise up and move towards the light.



Very young sheoak seedlings (*Allocasuarina*).

If the containers have holes in the bottom, sit them in a saucer (or a tray) and water them by adding water to the saucer or bowl. For another way to raise young plants in cardboard tubes, as described later. Looking at the leaves, the stem and the roots, there will be all sorts of whiskers and outgrowths, maybe even a few tiny inhabitants. When sheoak seeds germinate, the first shoot looks like

the picture on the left above, but over the next week, it changes, and looks more like the typical needles of *Allocasuarina*. Those first two 'leaves' are cotyledons, the food supply that gets the seedling growing.

Look out for these:

- Surprises;
- Things living on the seedlings;
- Root hairs and whiskers.

Exploring winged seeds

Sydney's North Head is a dry sandstone ridge, some 70 metres above Sydney Harbour. I chase down new weeds there, and that is how I know that some weeds are very good at spreading along some of the fire trails in the area. The problems are the ones that got away, blown along by the wind.

To look at this, you need *Hakea* fruits, *Allocasuarina* fruits, *Banksia* fruits, or maybe dandelions. Many of the winged seeds found in the Australian bush are held securely inside woody fruits until there is a bushfire, but if the fruits are separated from the plant, the seeds will fall in just a few days.

As an indication, *Hakea* seeds take about 12 days to drop out, Winged seeds blow around, usually until they slip into a dip in the ground or a crack, the sorts of places where run-off goes when it rains. Try dropping the seeds and decide: which is the best flyer, and what makes it good?

Look out for these:

- How far do the winged seeds of Norfolk Island pines fly?
- Different ways of catching the wind.

Making simple seedling pots

You will need cardboard cylinders from rolls of toilet paper or paper towels; scissors, containers to stack them in; and a large diameter drill to make a set of biodegradable pots. Each year, I probably plant 400 – 500 small plants, and I know that the roots get a bit disturbed when we take them out of the plastic pots.

If you are growing trees from seed, these cardboard tubes are much better: just dig a hole, pop the whole thing in, pack soil in, and water well. In time, the tree will burst out, the cardboard will rot and roots will spread.

Toilet rolls are ideal for this, but longer rolls (cling wrap, aluminium foil etc.) can be halved with a bread knife or scissors. I use old-style ice cream containers to hold them until I am ready to plant them out. Take a cardboard tube, 10 to 12 cm long, and make four equally spaced (90º apart) cuts in the bottom, each cut a bit longer than the radius of the tube. Then turn the tube up and bend down the four flaps you have made.

Fold the flaps, one over, one under, as shown. Then drop them in a plastic container with drainage holes to let excess water run out.

The 'pots' are now ready to be filled with potting mix. Then a seed or seedling can be added. The container has holes in it for drainage. When you see roots coming out of the base of the tubes, it is time to plant the tubes out. The location of the drainage holes in the

container is that there is a reserve of water down at the bottom. If a neighbour (or a storm) adds water, only a certain amount can stay there, without 'drowning' them. Just as frogs will drown if they are trapped in water, plants can drown as well.

Exploring roots

You need a selection of small plants to look at. You could either pluck weeds from the garden or take weed or other seedlings that were planted a few weeks earlier. Choose your weeds with some caution: dandelions, cobblers' pegs and birdseed are all cheap and easy to use. Root systems on onion weed (left and centre) and *Lantana* (right).

Where possible, use local material. If you live in an area where a produce or other store sells wheat for chickens (sadly, this is getting rarer), wheat is good. You should try to get some dicots (the 'broad-leafed' plants like peas, beans and most fruits), because these plants form tap roots. To balance this, you need monocots (the 'narrow-leaved' plants like grasses, onion weed, wheat and maize), which form 'fibrous' roots.

Onion weed is a real annoyance to gardeners, because when you pull the plant out, you usually leave a number of small barb-like shoots behind in the ground, because they were sticking out from the main bulb. These shoots, called corms, break off as you pull the plant out. Left on their own, they make new plants. I gently lifted this specimen out of sandy soil with a trowel and washed it clean. This left the corms attached: they can be seen in the centre shot, sticking out like little horns.

You can also get clean roots by germinating seeds on a damp paper towel, and look at bean sprouts. When the roots are better developed, look for branching in the roots, and you may even see

root hairs. The root hairs make a closer contact with the soil, gathering in more water.

In a garden, flood the soil, before easing target plants out, using a trowel or even an old spoon.

Look out for these:

- Other things growing on the plants;
- Different sorts of roots;
- Root hairs on the roots: there is more on those coming up next.

Root hairs

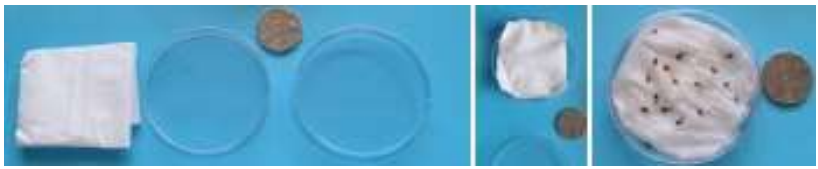
Roots do two things for plants: they hold the plant in place so it doesn't blow over, but they also collect the water and minerals that all plants need to survive. To get a grip and to find water, plants need to make as much contact as possible with the soil, so most roots branch and then branch again into smaller and smaller bits, ending in root hairs.

Root hairs are fragile. If you are taking small plants from soil, you need to lift the plants in a soil clump, use a trowel, and gently wash the soil away. You need to rinse the roots to get more soil off, and the wet root hairs may be hidden under a thin film of water. You should be able to see root hairs, maybe even with a hand lens. You need to put the root in water, or pat it dry on paper towel. The hairs are just visible under a x20 hand lens, and quite visible under a x20 dissecting microscope if they are lit from below, or viewed on a dark background.

Perhaps the easiest way to get root hairs is to germinate some dandelion seeds on damp paper or in water and then snip off a small piece of root to look at. Take a saucer or a Petri dish, and line it with a face tissue or a piece of paper towelling. Make it wet but not sodden by adding water in small amounts, then put a few seeds on the surface and wait a few days.

Aside from weeds, other possibilities are seeds from tomatoes (cherry tomatoes are best), but you could also try apple seeds, orange pips, pumpkin seeds or any seeds you can find in the garden. Plant about twenty seeds, and take one seedling up each day after

the second day and examine it for progress. Make sure you keep the lining damp by adding water each day.

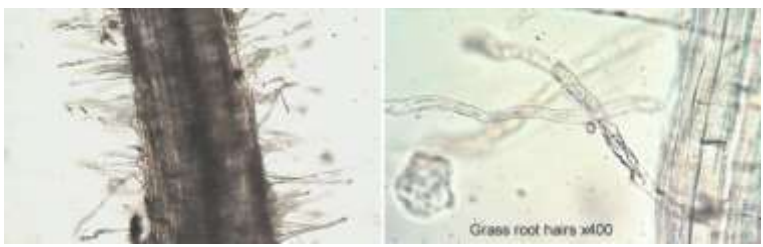


Growing *Allocasuarina* seedlings, shown for method only.

Once the seeds sprout, look for a root, and as the root develops, use forceps (tweezers) to lift one onto black cardboard to photograph. To make photography easier, sandwich the roots of by selected grass between microscope slides, two Petri dishes, or two flat pieces of a broken CD case, to hold them flat. If you don't flatten the roots, there will be too many focal plane blurs.

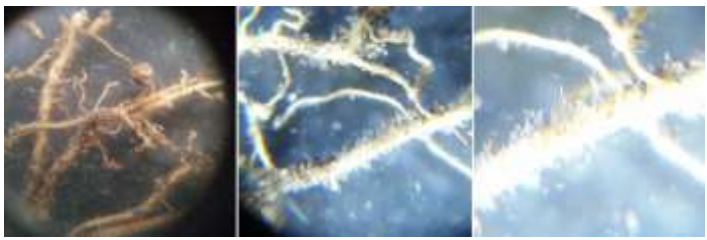
A quick and dirty root-flattening method, using a microscope slide.

You will see no root hairs at the very end of the root, which is pushing down through the soil. Roots grow by forming new cells at the tip, an area called a **meristem**. Knowing that, you can see how fast a root grows, and see how long it takes for the root hairs to emerge in the area called the root hair zone.



Root hairs seen on the roots of an *Oxalis* plant (left) and a young winter grass (*Poa annua*) seedling (right).

If you look at a clover plant (which has a trefoil or three-part leaf a bit like oxalis), you may find lumps on the roots. These are called nodules, and many species in the pea family (clover is in that family) have them. They provide a safe home for tiny organisms that can turn nitrogen gas in the atmosphere into the nitrogen compounds that living things need. This arrangement is called **symbiosis**, because both parties benefit from it. If you take a closer look at the roots of clover and oxalis, the leaves may look similar, but the plants are very different.



Can you see the root hairs?

Looking at and under bark

The outer bark of trees may just look like a covering, but it is always worth close examination. Bark provides a protective layer, but it also contains the tissues (called **xylem** and **phloem**) that carry water up from the roots to the leaves, and also carry food, made in the leaves, down to the roots.

Animals use bark as well. Search on and under the bark with a hand lens, prospect with a pooter or better, a portable vacuum cleaner like a 'Dust Buster', and see what you can catch. The sheets of bark dropped by some gum trees are even better, but almost every tree has interesting things living on or in its bark, or in the crevices where branches come out.

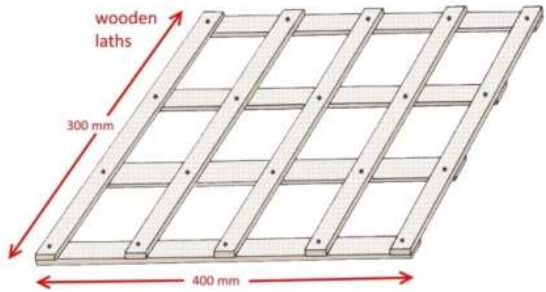
If you get a good tree, you will find lots of animals, but if you choose the wrong one (that includes smooth-barked trees), you may find nothing, so choose trees with rough bark! You need a small portable vacuum cleaner with a clean filter and a tree with rough or fissured bark, a dish ad either a pooter or a small paintbrush. Run the vacuum cleaner over a tree, take it inside and empty the bag or dust compartment onto a dish, and sort the 'catch' with the paintbrush.

Get pictures of what you see, before you move onto another tree. Keep good records. You can always collect animals with a wallpaper brush and an umbrella. You are likely to go past small spiders, mites, beetles and tardigrades (water bears, chapter 9), among others. Best of luck in finding them, though!

Collecting dried plants

This is also not really about microscopy, unless you decide to start some fine investigations on flowering plants. It's here, in case you do that. If you decide to study pressed, dried plants under the microscope, wet them with water containing a drop of detergent.

Pressing flowers by putting them in a book may have been fun in the 1800s, but it usually stains the pages. You can use a press like this in the same way. Once a small flower is dried, you can glue it to a rectangle of cardboard with PVA glue (woodworkers' glue) to make a bookmark.



A design for a plant press: you will need two of these frames.

If you are going to collect plants in a scientific way, you should use a proper plant press. This drawing shows a good design for one of the two identical frames you need. The best material is 19 x 6 mm softwood, held together with small nails (ask for 1 inch flatheads) that go right through both pieces, but be sure to turn the frame over and knock the points down flat (and think about where the nail points will go when you first drive them through: don't use the best dining table!). The size needs to be about that of a sheet of tabloid newspaper, because you will use a lot of newspapers to dry your specimens.

You need to know something about plants before you start collecting specimens, so do some research or ask. You need to be able to guess which species might be protected, and you need to know if you are allowed to collect or not (*in a botanic gardens or a national park, the answer is always "no!"*).

Your specimen size will depend on the mounting paper the plants will go on. Use secateurs or clippers to make a neat cut. The ideal time to take a specimen is when it has both flowers and seed on it. Unless you are carrying your press with you (not a good idea because it will be large), put each specimen in a separate plastic bag with a slip of paper noting where and when you collected it, the type of plant (herb, shrub, tree, big tree), other nearby plants and whether you are in forest, scrub or something else, and if possible, the type of soil. If you have one, use a GPS device to locate the plant.

Noting the soil type might seem odd, but some plant species are very fussy about where they grow, and your records might reveal

this. Around Sydney, geologists used to work out where shale was in the local rock from aerial photographs. If they could see cabbage-tree palms, there was shale rock beneath the tree canopy.

When you get home, put the specimen and the finder note inside two sheets of newspaper, stack the specimens on one frame and place the other frame on top and use weights, a rope or a belt to squeeze the two frames together. You will probably have collected a number of insects and spiders with your plants, so try to store the press somewhere outside that is dry and warm.

You should change the newspaper every day, and don't forget to transfer the finder note over at the same time. The old paper can be put in the recycling, but don't use it for other plants, because it will be damp. After about a fortnight, once the plant specimens are really dry and flat, you can tape or glue them to sheets of white paper. Use PVA wood glue and apply light pressure for an hour. Glue the finder note to the same sheet and store your specimens in a box. Now you need to name them.

You have several choices to identify plants. You can ask an expert, you can look at a book with photos produced by an expert, or you can use a dichotomous key, a set of questions that you work through until you have only one species left. Using a key is hard, but if you are able to ask an expert, you are also able to ask an expert to help you by showing you how to use a key.

Pressed and dried plants can keep for hundreds of years, and specimens collected by Joseph Banks and Daniel Solander in 1770 are still available for professional botanists to study. The trick is to squash the specimens flat while they dry, so they dry flat. If you change the paper sheets around the plants each day, they will dry flat and keep their appearance. Banks dried his specimens in the sun, but a press is better.

A herbarium sheet, photographed at the National Herbarium of Australia, Mt. Annan.

Look out for these:

- Unusual plants;
- Flowers of an unexpected colour;
- Leaves of an interesting shape.

12 Odd bits

When I go out to talk to, play with or entertain young people (of any age), I always take along this box of what I call "dead bits" (and I use my best horror movie voice when I say it).

To be honest, most of the bits have been dead for a long time, especially the fossils and rocks, but I also include bits of wood, shells, corals and even fish scales. Most of the bones are fairly old as well, but some of the seeds may even still be alive. Look closely: what can you see here?

The sort of science I am doing is more like prospecting and exploring, but it's still science!

Bony animals and their bits

Growth rings in timber

Also called tree rings and annual rings, a tree's growth rings are the layers of woody growth laid down by a tree, with more growth in summer, and more growth in good years, so that the rings act as a record of past climate conditions. In a tree, each ring forms the growth record of a single year. In most parts of the world where there are recognizable seasons, trees will grow better at certain times of the year when conditions are better. Good times produce larger cells than in the 'off' season. The smaller cells appear darker.

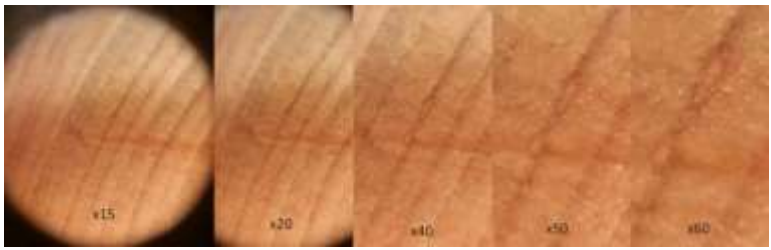
Tree loppings are best for this work. An annual ring starts after winter, when the cambium divides, producing large growth cells, while the cells formed later in the year are smaller, producing a dark

ring which finishes off the growth ring for that year. For this reason, light-coloured wood is easier to work with.

A section of a pine branch, cut for me by our contractors.

This only occurred to me as an afterthought, because I have been writing about earth sciences of late (small advertisement: my *Australian Backyard Earth Scientist* was published in February 2019, and *Mistaken for Granite*, which is earth science for big people came out as a Kindle book in March 2020).

Afterthought or not, look at what you can do, using a clip-on:



Dendrochronology, the art of dating wood and also seeing past climate was discovered by A. E. Douglass at the University of Arizona. He said that the growth rings of trees were much wider during wet years, and narrower during drought years. "A tree bears its own witness", he wrote.

Douglass felled three post-oaks, two of them more than 130 years old, took a section of each and planed it smooth. He varnished all three surfaces, and prepared tables showing the thicknesses of the rings which matched perfectly. He offered this as proof that rainfall alone causes the difference in annual rings.

The record took him back as far as 1725, revealing 67 wet summers in 133 years, the rest being divided into dry, very dry and average seasons. By itself, this was nothing very much, but when older wood is available, the inner rings on a younger tree can be associated with the outer rings on an older piece of wood, to give a continuous record, year by year, for a period longer than either of the trees could have lived. All that is needed is a reasonable overlap.

It is possible to detect trends in the climate, but also one-off events such as volcanic eruptions, and the data may be combined with data from ice cores bog deposits and sediment cores. The lignin in a growth ring is laid down using fresh atmospheric carbon, with a full dose of carbon 14, and after that time, the carbon clock is running. This means that we can get accurately calibrated and aged carbon for the recent past, but this is still not a great deal of use in dating geological formations.

Professional scientists have tools that drill into trees to take core samples, but making holes isn't good for the tree, so you need to find a tree stump or a section of a log that you can cut. You may

need to sand or smooth the surface with a plane or a sander, and the rings are clearer if you varnish the wood or rub grease into it. See how much detail you can find.

The parts of a feather

The feathers of birds do two main things. They keep the birds warm and they also help birds fly. There are two kinds of feather, and there are differences between these feather types.

You will need a supply of feathers from different types of birds, a hand lens and a notebook. The site of a 'kill' where a predator has eaten a bird is one of the best sources, because you can find a range of feathers from a single bird of a single species. The 'down' feathers are the fluffy, curly ones. The flight feathers are longer and stiffer. Study the feathers closely with and without a hand lens, and notice how one side is wider than the other on some of them. As mentioned in chapter 2, these uneven plumes are the flight feathers and the narrow side is called the **leading edge**.

A flight feather from a seagull, and a down feather, probably also from a gull.

If you have down and flight feathers from several species, try to decide whether down feathers from two different species are more similar than the down and flight feathers from one species. What conclusions can you make?

Look closely at the flight feathers: do any of them have downy fluff near the lower end? Try separating the bits of the feather, and notice how they are joined to each other. Can you re-join the threads after they have come apart? If you have access to a microscope, examine a feather more closely, to see how the barbules link to each other.

Looking at skulls

Skulls are not single bones: they form when multiple bones join together, along curious wriggly lines that anatomists call sutures. These are perfect for study with a hand lens or clip-on.

This is a rabbit skull, 9 cm long. The square in the first shot marks the portion seen on the centre, through a clip-on. Any 3-dimensional object is hard to fit onto a microscope stage, making clip-ons useful. In one lab that I worked in, I had a binocular microscope on a long arm attached to a stand. That would let me look at anything up to an elephant!

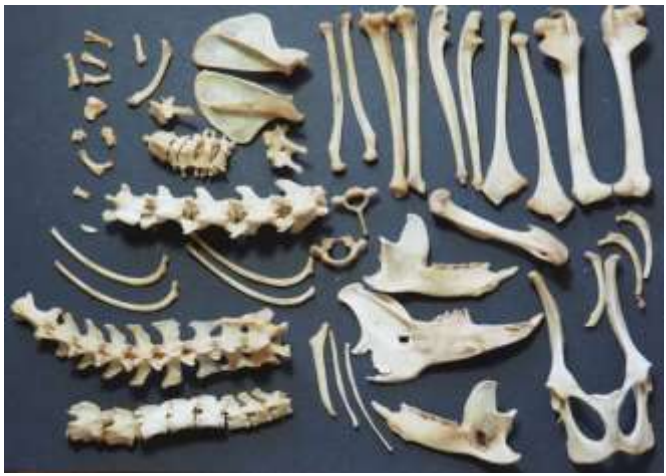
Over time, though, bones 'weather', and you can get curious effects with back-lighting. The third shot is of the sutures in an old skull was taken with back-lighting, but also some ambient lighting.

Always remember that with dead material, there is a risk of decay bacteria, or zoonoses, even on very old bones. Check your local regulations, and see my preparation notes below. You need safe, clean, skeletal material. Meals are a good source for *some* bones, unless you are vegan. Sadly, the most interesting bones (heads, spines and feet) will be less available.

You can find dry skulls on farms, by roadsides and on beaches. Treat them with normal care as potential sources of disease. I usually freeze the bones in a sealed container for a week, rinse them in running water and use tongs to drop them into a bucket of warm water with a biological (enzyme) washing powder for a few days.

Then I rinse the bones and leave them in 3% hydrogen peroxide for a few days in a covered (*but not sealed!*) container in a safe place, before rinsing them. (This is for home use: if the bones are for use

by young people in schools, check for local health regulations that may apply.)



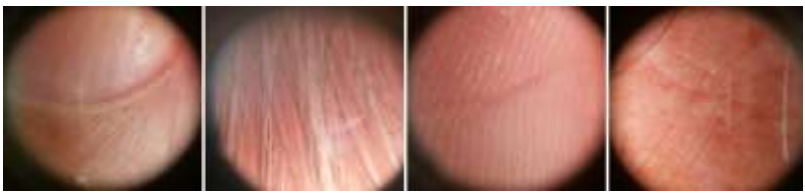
Mostly the parts of a single rabbit. (Can you find any 'extras' here? There's at least one…).

Looking at human skin

Whenever I show any sort of embiggener to interested people, two things really seize their imagination. One is the sight of fabric under high magnification, and the other immediate interest lies in their own skin and hair. In the 50 years that I have been teaching scientific ideas to children, this has always been the case with any magnifier from hand lenses to microscopes. They look first at themselves.

Call me an aging alarmist libertarian info-hippie, but I don't like the idea of making identified fingerprints available online. It's worth a short discussion: are there any good reasons to do so? Are there any conditions under which harm might emerge? You can photograph other parts of the skin, but before you decide, try taking a couple of shots. Could evil people use a fingerprint shot to do evil? It's never too early to look at cyber-safety. (I think the images are too poor to be misused.)

Photograph parts of yourself: the creases in the palms of your hands, the hairs on your arm, your fingernails, and so on. Could any of these be used for identification?



The author's left index fingernail, his mostly grey head hair, a crease in his palm, and his hairy leg, just above the knee.

Can you tell whose head a single hair came from? (From one test, I suspect the answer is "no".)

Things decaying

Exploring timber that has weathered.

Some modern buildings in Europe use timber cladding that is left untreated and allowed to slowly 'weather' on the outside. In Australia, weathering is less of a feature, and rather more of an annoyance, though we certainly let our paling fences and telegraph poles grey up. If you have to take the microscope to the object, a clip-on is best.

Piles of rotten logs often contain or shelter undesirable animals: these logs can be looked at, but they should not be touched, turned or moved. There is plenty of *safe* weathered timber around… You need weathered or rotten timber in a post like the one below, found in a playground.

Compare newer and older timber: fences are a good place to begin, but look around, and see what else is available. The tops of old posts like the one shown above (note the coin for scale) are a good place to start, and fallen logs are always interesting.

You probably won't find any bracket fungi like these, but you never know your luck! Left to itself, wood slowly breaks down under the attacks of air, water and the sun's ultraviolet rays. Rock weathers, and wood does as well, unless it is protected. The wood cracks, and the attacks spread inside. Fungi and animals may get a hold, but the main risk is splinters! Old timber can sometimes be home to rusty nails, and snakes and spiders may hide under stacked timber. Be prepared!

Look out for these:

- Wildlife in the cracks;
- Evidence of something eating the wood;
- Unexpected things!

Examining weathered rocks

These are the pinnacles or hoodoos of Bryce Canyon in Utah in the USA. They are all formed by weathering. All rocks weather to become dust, mud, sand, sediment and sometimes, chemicals that dissolve and flow down to the sea. The solid bits, the sand, mud, dust and gravel were all rocks, once upon a time.

You will need some exposed rocks that can be closely approached, because the idea is to look closely at the process. Just be careful, though, because some of the most interesting weathered rocks are up high, or in cliffs that can drop rocks without warning. Others will be on busy streets, or in remote bush. Plan ahead!

It's acceptable to pick up weathered pebbles, so long as you aren't in some sort of reserve, but *never* break pieces off! Try to get samples of granite (or an igneous dyke) from roadsides, pumice from a beach, sandstone and shale as a minimum.

If you can get some slate or marble, that would be good, as well. In early 2019, you could still find pumice, high up at the back of beaches on Australia's east coast, six years after the submarine volcano on L'Havre Seamount in New Zealand's Kermadec Islands erupted (see chapter 4).

Given time, all rocks weather, shaping the world we live in and can create amazing forms, like the pinnacles or 'hoodoos' at Bryce Canyon in Utah in the USA. These have been largely shaped by water soaking into the sides of the pinnacles where it freezes, chipping bits of the sides away. Water plays a major part in weathering. Most rocks have planes of weakness through them called joints. There are often two sets of joints, more or less at right angles to each other. Geologists are unsure about what causes the joints, but whatever the process, it results in gaps in the stone.

There are two forms of weathering: chemical and physical. In physical weathering, rocks are broken down to smaller pieces, but they are still recognisably the same. In chemical weathering, the minerals break down, and they will never be the same again. We will look at lightning strike sites in the next section: these are one of the most extreme and sudden forms of physical weathering. At other times, it takes training to see the weathering.

This is argillaceous sandstone, which is halfway between sandstone to shale. With a clip-on, clay minerals are visible, if you know what to look for.

Curious weathering, northern side of Uluru.

Look out for these:

- Debris under a rock or a cliff;
- Strange shapes;
- Interesting patterns.

Exploring lightning strike sites

The main point of this exercise is to make readers aware of the places where lightning strikes, because once you know what to look for, lightning strike sites are common. They are an important form of physical weathering, because they represent a way in which solid stone can be blasted apart, letting chemical weathering begin on a fresh surface.

This means going out into the open, on hills and the tops of ridges, where lightning has struck in the past. Choose fine weather, and think about the prospects for falling off rocks. The thin plates of stone that mark these sites are fragile: please don't walk on them, or try to pick them up: apart from the danger to the stone, there may be venomous animals underneath.

Always take a 50-cent coin for scale, and a towel to kneel on. Most importantly, you probably need a guide who knows what to look for.

These shots were all taken on sandstone peaks and ridges within 200 km of Sydney.

The places that you are seeking look like the pictures above, with thin layers of rock lifted up from the rest of the stone. All of the sites I know are on sandstone, but look around on other stony ridges and peaks. There is a huge amount of energy in a lightning blast, and if it comes after rain has fallen, water that has soaked into the rocks flashes into steam, and the surface rock is blasted away. Once seen, the appearance will never be forgotten.

Look out for these:

- Can you capture the detail of the edges?
- Can you find any melted rock? (I never have…)

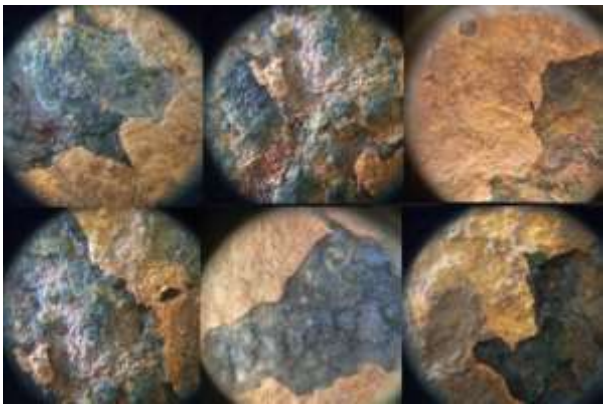
Exploring rusted items

Rusty nails. This one was recovered from a former Army base in Sydney.

Old barbed wire fences and rusty razor blades are clearly dangerous. Rusty nails can be used with care. Obviously, there are a few safety issues here, but nail heads sticking out of a paling fence make a good starting point. You will need to look around with safety in mind.

Rust is complex. It is mostly hydrated iron oxide, Fe_2O_3. nH_2O, but there are other forms as well. Rust happens faster when the iron is wet, or when it is subjected to salt spray. Rusting is a natural phenomenon, and some of the fine detail you can see on the surfaces is breath-taking at close range.

If you have a secure place to try it, you may be able to expose some iron products to the weather. Try things like steel wool (available at hardware stores), a large nail and any other ungalvanised iron that may come to hand. Try looking at the superficial rust on garden tools: is it the same? This exercise is what you make of it.



These were portions of a rusty plate found on the same site.

Exploring small fossils

This is another chancy one: you need the knowledge (or somebody with the knowledge), and access. A lot of building stones contain fossils, even metamorphic rocks. It's just a pity shale isn't a building rock! For some reason, older banking chambers (now usually converted into something else, like a hotel foyer) seem to offer rich pickings: Seek and you may find.

Coral remnants in marble.

I own a marble table with a cast iron base, and once these were common in milk bars across Australia. (What was a milk bar? Ask your grandparents!) Marble forms when limestone is heated, so here's a quick look at my marble table, which looks beautiful because I treat it with beeswax. I can see corals above. Notice how most of these shots have a coin (or in one case, the toe of my shoe) for scale.

Next, we have a mystery item, probably a cephalopod, which I found in the marble floor of the Nordic Museum in Stockholm, and a cephalopod fossil found in the marble floor of the Suomenlinnen fortress in Helsinki. (Because I write a lot, I need to travel to gather material.) Notice the shoe and coins for scale.

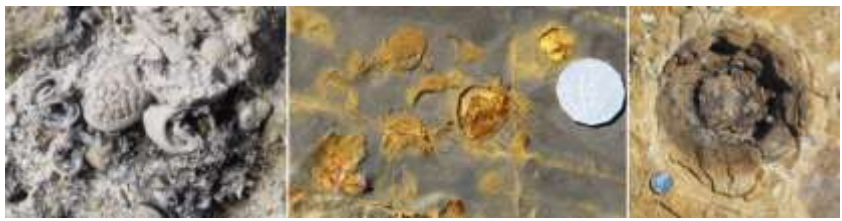
The last two shots are a probable nautiloid and a definite graptolite, right in the middle of the walking track at Maligne Canyon in British Columbia (Canada). When people saw me kneeling down, they checked to see if I was all right, and then got excited, and rushed around, finding more fossils. You just need a few hints, and you, too, can be a fossil finder!

These are the sorts of things you need to look out for, when you are inside buildings. Sometimes though, the best finds will be outdoors, and that means using a clip-on.

In Sicily, near Agrigento, we were walking with two American science teachers, competing in a friendly way to see who could find the most interesting stuff. They probably won, but they missed the circled (or ellipsed) fossils in the limestone wall above. I found this next one at Fossil Bluff,, in Tasmanian limestone:

Limestone with fossils, northern Tasmania.

Just look for something different:



Fossils, (left) Mandurah, W.A., (centre) North Head, Ulladulla, N.S.W. and (right), fossil tree trunk, Swansea Heads near Newcastle.

Three Portuguese fossils, found in paving stones, the first two in Coimbra, the third from Obidos. Note the coins for scale.

Talking of fossils, I looked closely at an illustration of an ammonite: Can you do something like this?

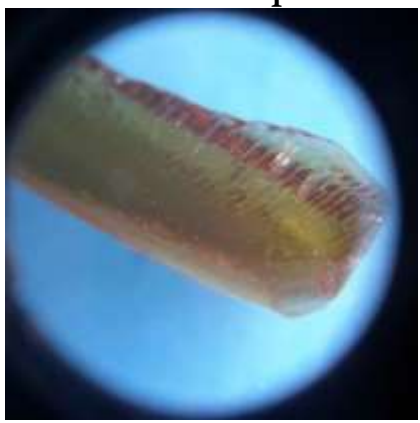
Exploring the torn edges of paper

That reminds me: this is something I have used, all through my career, as a way of teaching people new to the art of microscopy how to use a hand lens, and it works just as well with other embiggeners. The best part is that the print on the paper is easy to focus on, then beginners can move across to the torn edge.

Try as many grades of paper as you can find. The minimum is newsprint and photocopy paper, but try for tissue paper, face tissue (separate the two plies) and brown paper as well. A sheet of black cardboard to use as background will improve the contrast. Compare the paper samples under low and high magnification. What differences can you see?

Two newspaper samples, x15 and x60, and two photocopy paper samples, x15 and x60.

Exploring conchoidal fracture patterns in glass



Technically, glasses are liquids, which means they have no crystals in their makeup, and this means they have a very odd way of breaking. Humans knew about this sort of pattern first from obsidian, which is a volcanic glass. We looked at the facture patterns found in glass in chapter 1.

You will need gloves to handle some pieces of broken glass, and if you can, quartz and obsidian. I gather most of my specimens while walking around the local beach, mainly hunting plastic, but also picking up broken glass.

Once you know what a conchoidal fracture looks like, see if you can find some quartz samples that show the same break pattern. If you happen to own some obsidian (or have access to some of this volcanic glass), get photos of the fracture patterns.

About Peter Macinnis

I was once a high school science teacher; museum educator; bureaucrat; many other things, but always a naturalist and enquirer into curious things, always a gadgeteer and always the writer of books. In my spare time, I am a bush regenerator.

I am a practising grandfather, and for some years, as part of the CSIRO 'Scientists in Schools' program (now 'STEM Professionals in Schools', though I care more about STEAM), I have been the 'visiting scientist' at Manly Vale Public School in Sydney, which gives me 500 extra grandchildren without the usual effort.

My scientist wife, our scientist children and I all care passionately about the future—and there is no key to the future quite like children. Youngsters are where the battle for the future begins, and winning their minds begins with instilling a sense of wonder. Wonder is important.

In 1962, I was an aspiring journalist on the University of Sydney student newspaper, *honi soit*, where Laurie Oakes was the editor. He 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. Laurie asked me to come along, as I was enrolled in the science faculty.

I hadn't told him I had decided to transfer to the Arts faculty, but I was always up for fun, so we went along to Sydney airport with a (then) novel portable reel to reel 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 kept an interest in amazing things. My sense of wonder was in overdrive.

Three years later, with my plans to become a pre- and post-Islamic mediaeval Javanese historian shredded by outside events (the aborted 1965 communist coup in Indonesia), I set my partly-completed Arts degree aside, took up botany, and the rest is history, just not of the pre- and post-Islamic mediaeval Javanese kind. I later became a science teacher, and always had some curious rig or other on the front bench, an item which I refused to discuss in class, dismissing it as something I was trying out.

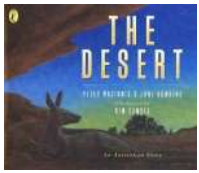
The mystery might be a home-made eucalyptus oil extractor; a Masonite and plastic bag hovercraft powered by a vacuum cleaner; a square wave generator; a pill-bug farm or a gas discharge tube. Another day, it might be a long cardboard tube that boomed when placed over a Meker burner; bent-wire bubble-makers; 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 would stay behind or come in early, demanding details—and getting them. In my world, education involves all of teaching, wisdom, knowledge, learning, culture, training, understanding and erudition, but most of all we must foster enthusiasm—and wonder and curiosity.

This book is for people like me. Now, a word to teachers:

Pedant:	"But *where* do these things fit in the curriculum?"
Me:	"They fit in the slot marked *Wonder*…"
Pedant:	"But there *isn't* any slot marked Wonder!"
Me:	"Then you must *make* one."

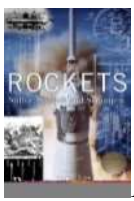
The author's other related books:



The Desert. Puffin Penguin, 1997. ISBN: 9780140561326. With Jane Bowring and Kim Gamble, a picture book for youngies. This book is written for young readers, and my aim was to take a complex story, a desert ecosystem and tell it in a simple form. The notional desert was near Cameron's Corner, and the biology was managed so that anything described in the book could be seen there, if the conditions were right.

The Rainforest. Puffin Penguin, 1999. ISBN: 9780140378559. With Jane Bowring and Kim Gamble, a picture book for youngies. Same deal, this time the notional site was northern NSW, so no cassowaries. Shortlisted for the Wilderness Society's Environment Award for children's literature, took out a Whitley, because we faced down the marketing clowns at Penguin and stayed firm on the last page.

Bittersweet. Allen and Unwin, 2002, ISBN-10: 1865086576. For adults: Sugar cane travelled from Papua, 9000 years ago to Indonesia, from there to India, and from India to China and Persia, where the Muslims found it, not too long after the time of Muhammad, and they carried it to the Mediterranean, where Crusaders found it. Amazon has it: https://www.amazon.com/Bittersweet-Story-Sugar-Peter-Macinnis/dp/1865086576

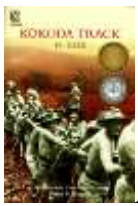


Rockets. Allen and Unwin, 2003, ISBN-10: 1865087947 Long before the space race, people were fascinated by rockets, and people dreamed of going into space, long before it seemed feasible. Telling the story took me into the

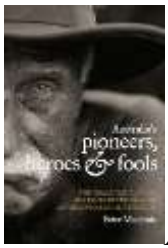
politics of the Duke of Wellington and the habits of hairy-chested chemists with death wishes. https://www.amazon.com.au/Rockets-Sputnik-scramjets-Peter-Macinnis-ebook/dp/B01M9HY58K

The Killer Bean of Calabar and Other Stories. Allen and Unwin, 2004, ISBN Poisons and poisoners, lots of translations under a variety of titles. Poisons were used both for financial gain, and also, sometimes for the benefit of the one poisoned. You may need to think about that one for a while: in reality, poisons do far more good than harm. https://play.google.com/store/books/details?pcampaignid=books_read_action&id=SRk2dCCCrtMC

It's True: You Eat Poison Every Day. Allen and Unwin, 2006, ISBN 9781741146264. I wanted to call it *Poisons for children* (for the extra sales), but they wouldn't let me. Before we understood germs, deaths were blamed on poisons, either natural ones that crept in, along with bad smells, or poisons that were administered by some nefarious person. Still in print, and also in simplified Chinese.



Kokoda Track: 101 Days. Black Dog, 2007, ISBN 9781876372965. The Kokoda Track wasn't about Kokoda at all, but it's story is one of soldiers on the ground achieving, while drunken cowards of the rear echelon made up lies. Short-listed for the NSW Premier's History Prize, 2007 and Honour Book (= runner-up)in the Children's Book Council of Australia 2010 Eve Pownall awards for Information Book of the Year.



Australia's Pioneers, Heroes & Fools. Pier 9, 2007, ISBN 9781741960488 The true history of Australian exploration. Not many dates here: it looks at what they took with them, how they planned their trips, how they navigated and surveyed and mapped, how they found food and water, how they managed their animals and their humans, how they mended the sick and broken, and how a few of them died when mending wasn't enough.


The Speed of Nearly Everything. Pier 9, 2008, ISBN My commissioning editor said "write me a book about fast stuff that people can read on the john", so I did. I managed to sneak in some good physics… I set out to look at some of the ways we can work out how fast a salmon leaps out of the water, how fast you fall from the top of a high building, speed records for really slow animals, snail races

Mr Darwin's Incredible Shrinking World. Pier 9, 2008, ISBN 9781741962796. In 1859, Darwin published *Origin*, and it was the time when professional scientists began to dominate in science — and the time when two leading scientists might find that they could no longer understand each other's work. Translated into Korean. https://www.amazon.com.au/Darwins-Incredible-Shrinking-World-Technology-ebook/dp/B00Z95GU1E


100 Discoveries. Pier 9, 2009, ISBN: 9781741961423 The enabling discoveries, the inflection points in science, the key discoveries that made science what it is, and made us human: glass, writing, pottery, genetics, the thermometer, moveable type and gutta percha, which was the forerunner of rubber. Also in

German as *100 große Sprünge: Die bedeutendsten Entdeckungen und Erfindungen der Menschheit.*

The Lawn: a social history. Pier 9, 2009, ISBN: 9781741960396. The simple lawn mower made lawns possible, which made suburbs and sport on grass possible, changed the way women dressed, and the pivotal year in this revolution was 1859. Without the lawnmower, there would be no football, cricket or Olympic Games. Lawn, in a few generations, became a cause of official bullying, court cases, terrible waste and pollution.

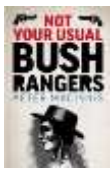

Australian Backyard Explorer, ISBN 9780642276841, paperback, National Library of Australia, August 2009. This looks at how the explorers actually did what they did, and who helped them. Winner of the Children's Book Council of Australia 2010 Eve Pownall award for Information Book of the Year, entered into the 2011 White Ravens list of the Internationale Jugendbibliothek München (International Youth Library).

The Monster Maintenance Manual, Pier 9, 2010, ISBN 9781741968088. Long listed by the CBCA: a romp through strange monsters like long-legged underbed pigs, moat monsters, dangerous goldfish and thin blue lions. https://www.amazon.com.au/Monster-Maintenance-Manual-Peter-Macinnis-ebook/dp/B00Z95GUF0 Grown-ups who get that should look at *Sheep May Safely Craze.*

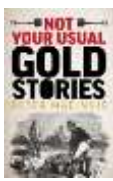

Australian Backyard Naturalist, ISBN 9780642277428, National Library of Australia, 2012, Recipient of a Whitley Award from the Royal Zoological Society of NSW, joint winner for the W.A. Premier's Book Award for Children's Literature, 2013. How to enjoy nature.


Curious Minds ISBN 9780642277541, October 2012, National Library of Australia. Written for adults, a close and loving look at the naturalists and painters who came to study Australia's flora and fauna. Now out of print and selling at a premium in pretentious shops.

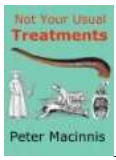

The Big Book of Australian History, National Library of Australia, four editions, 2013, 2015, 2017, 2019. ISBN 9780642279491 (fourth edition, released in mid-2019). Rated by the Children's Book Council of Australia as "notable" (one of seven books by the author gaining that rating). This is a boots and all approach to Australian history that has caused apoplexy in several Australian Prime Ministers.



Not Your Usual Bushrangers, ISBN 9781760065690 , Five Mile Press, 2015. Following stupidity in the publisher's internal squabbles, the rights were seized by the author, and a new Amazon editions (e-book and paperback) are there. These are the bushrangers people never hear about, some of the 2000 who operated for over a century. https://www.amazon.com.au/Your-Usual-Bushrangers-Peter-Macinnis/dp/1728936934



Not Your Usual Gold Stories, ISBN 9781760065706, Five Mile Press, 2015. Following publisher inertia, the rights were seized by the author, and a corrected and improved copy was published as a Kindle book and as an Amazon Print-on-Demand paperback. Who really discovered gold in Australia and when, and who got the money? https://www.amazon.com/Not-Your-Usual-Gold-Stories-ebook/dp/B07DK4MZVZ



Not Your Usual Treatments Kindle e-book ASIN B06XWJQ2RV; Amazon Print-on-Demand paperback ISBN 9781973560531, 2017. Quackery and bizarre cures. In the age of pandemic, when people are selling tuned quartz crystals to kill coronavirus, you need this book! If you don't read it, somebody will try to treat you with half-plucked ducks, tobacco smoke up the rectum and dog droppings. https://www.amazon.com/Not-Your-Usual-Treatments-medicine-ebook/dp/B06XWJQ2RV


Sheep May Safely Craze Kindle e-book ASIN B077R7FC45; Amazon Print-on-Demand paperback ISBN 9781973441700, 2017. A novel involving mad sheep, higher mathematics, lower mathematics, ravens who used to be dragons, time travel, rats, IT jokes, Norse mythology, and the dark side of pea soup. This will proof you against con-men for years to come. https://www.amazon.com/Sheep-Safely-Craze-Peter-Macinnis-ebook/dp/B077R7FC45


Australian Backyard Earth Scientist. ISBN 9780642279347, National Library of Australia, 2019. Winner, Australian Awards for Excellence in Educational Publishing: Student resource: Arts/Science/Humanities/Social Sciences/Technologies/Health and Physical Education/Languages, 2019. This is earth science to protect the next generation from the stupidities of past generations.


Mistaken for Granite: earth science for rock watchers. Kindle e-book ASIN B085BGM95Z; B0858W4YSK (POD), ISBN 9798620093632. Rocks and earth science for adults. Volcanoes and inside one, glaciers, obscure geological formations in Australia, Heidiland and Scandinavia, and bothered rocks in more than 50 countries to assemble this book. https://www.amazon.com/gp/product/B085BGM95Z

Playwiths: STEAM explorations for the curious and the young-at-heart: 2020 Kindle e-book ASIN B086BRJCMT; Amazon paperback ISBN 9798630095190. This is science, technology, engineering, arts and mathematics for the lockdown era. From bubbles to doing with maths with spreadsheets to making paper and balsa planes, engaging activities for the young at heart. https://www.amazon.com/gp/product/B086BRJCMT

Survivor Kids: Get Ready for Wild Australia, National Library of Australia, 2020, ISBN 9780642279514. How to survive in the wilderness. The author has spent his life lighting bushfires (for research!), leading bushwalkers, playing with venomous things, training sailors and blatting around in the wilderness. As a retired anarchist/surrealist bureaucrat, he is admirably experienced to explain the art of survival.