Experiment Manual

TK2 scope

Thames & Kosmos

Warning!

Only suitable for children at least 8 years of age. Instructions for the parents or other persons in charge are enclosed and must be followed. Keep the packaging, since it contains important information. Not suitable for children under 3 years of age due to small parts that can be swallowed.
Three 1.5 volt AA batteries (LR6), which cannot be included in the kit due to their limited shelf life, are required for the experiments.

Tips on Protecting the Environment

Depending on where you live, you may be required to dispose of the electrical and electronic components in this kit at a collection point for the recycling of electrical and electronic devices, and not in the household trash. Through re-use, recycling of materials, and other forms of utilization of old devices, you are making an important contribution to the protection of our environment. Please inquire with your local government about the appropriate disposal site.

Safety Tips

Read the instructions before beginning to experiment, follow them and keep them nearby for reference.
Keep the experiment kit out of the reach of small children and animals.
Do not use any devices other than those that were provided with the experiment kit, unless specifically called for in this manual.
Do not use any power supply other than that indicated.

Advice for Supervising Adults

Before beginning with the experiments, please discuss the warnings and safety rules with the child and accompany them during the experiments to advise them and lend them a hand. An adult should verify before getting started that the batteries are properly inserted.

Battery Warnings

Never recharge non-rechargeable batteries! They could explode!
To change the 1.5 volt batteries: Remove all of the batteries from the battery compartment. Then insert the new batteries.
Insert the batteries with the correct polarity!
Never use different battery types, or new and used batteries, together!
Remove depleted batteries from the microscope.
Do not dispose of used batteries in the household trash, but rather in accordance with national environmental regulations.
Never short-circuit the terminals of the battery or of the battery holder. A short-circuit can lead to the overheating of wires or to the exploding of the batteries.
Make absolutely sure that no batteries are placed together, for example, with coins, a key chain, or other metallic objects.
Do not throw batteries into fire!
Avoid deformation of the batteries.

Caution!

Certain parts of this kit have pointed or sharp corners or edges related to their functions. There is danger of injury! This is especially true of the scalpel, the dissecting needle, and the glass components.

The right to technical changes is reserved.

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Experiment Manual

TK2 scope

by Jan Haller

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Table of Contents

What's Included in Your Microscope Kit

1 Microscope, with ocular lens (Caution! The ocular lens sits loosely. Heed the tip on page 5)

2 Plastic box with:

- Permanent prepared slide of sodium chloride crystals
- Permanent prepared slide of pollen grains
- Permanent prepared slide of paramecia
- Permanent prepared slide of oral mucous membrane cells
- Special slide with concave trough

3 Plastic box with 5 slides

4 Plastic box with cover slips

5 Pipette

6 Tweezers

7 Dissecting needle

8 Scalpel (Caution! Follow the safety tips on pages 3 and 10)

9 Petri dish with cover

10 Blue stain (Brilliant Blue FCF)

11 Red stain (Ponceau 4R)

12 Adhesive labels for your own prepared slides

13 Lens cleaning paper

14 Dust cover for the microscope (not shown)

15 Experiment book (not shown)

Also required: Three 1.5 volt AA batteries

In the event of missing or defective parts, please contact technical support by phone at 1-800-587-2872 or by e-mail at support@thamesandkosmos.com.

What You Should Know

Dear Parents and Supervising Adults,

Children are curious by nature. They want to explore, study, and understand their environment. This microscope kit will give them a good introduction to the fascinating world of the microcosmos.

In order to observe objects under the microscope, they need to be obtained and prepared. To do this, young researchers will need the accessories provided in this kit as well as other common household items.

The equipment you have before you is compliant with US and European safety standards. These standards impose conditions on the manufacturer — for example, approved ingredients, safety measures for electric toys, etc. However, they also demand that parents or other adults be present with their children to guide and help them with their new hobby.

This is why we have addressed this section to you, the parents and supervising adults. Please leaf through this instruction manual together with your child and abide by the following important rules when performing experiments.

Some Basic Rules for Safe Experimentation

1.) Read the instructions for the experiment carefully before you begin, follow them, and keep them nearby for reference. In particular, pay close attention to indicated quantities and the sequence of the individual tasks. Perform only the experiments and additional experiments described or suggested in this instruction manual.

2.) You should set up a suitable place for using the microscope and for preparing your specimens. Make sure there is good lighting, a level work surface, enough space for the experiment materials and your microscope, and always have a rag or a roll of paper towels ready in case you have to wipe up spilled experiment materials. Make sure that the table surface is resistant to staining, especially when you are working with the dyes. For this reason, you should also use older clothing that you don't mind getting stains on. Always wash your hands after experimenting, especially before you eat or drink anything.

3.) When working with the dissecting needle and while cutting objects with the scalpel or a razor blade, there is a risk of injury. Particularly when using the scalpel or razor blade, and during preparation of the razor blade (masking-off or wrapping of one side of a blade, see also page 11), you should let your parents help you. Cover slips break easily and then have sharp edges.

4.) In some experiments, stain solutions and other household chemicals (iodine solution, nail polish) are used. Be sure to heed the warnings of the manufacturer. Handle the liquids with caution and care and close the containers immediately after use. It's best that you have your parents lend you a hand with these experiments.

5.) If foods are required for experiments, place them in appropriate containers and label them. Dispose of left-over materials and do not by any means put them back into their original containers. In the case of experimental objects of plant origin from the household (fruit, vegetables), you should cut the portion of the object that is to be used for the experiment off or out before beginning. Dispose of them immediately after use. It is necessary here that a strict separation be made between household and experimental accessories.

6.) Some of the suggested experimental plants (e.g. box tree, ivy, etc.) are mildly toxic. So wash your hands after performing an experiment!

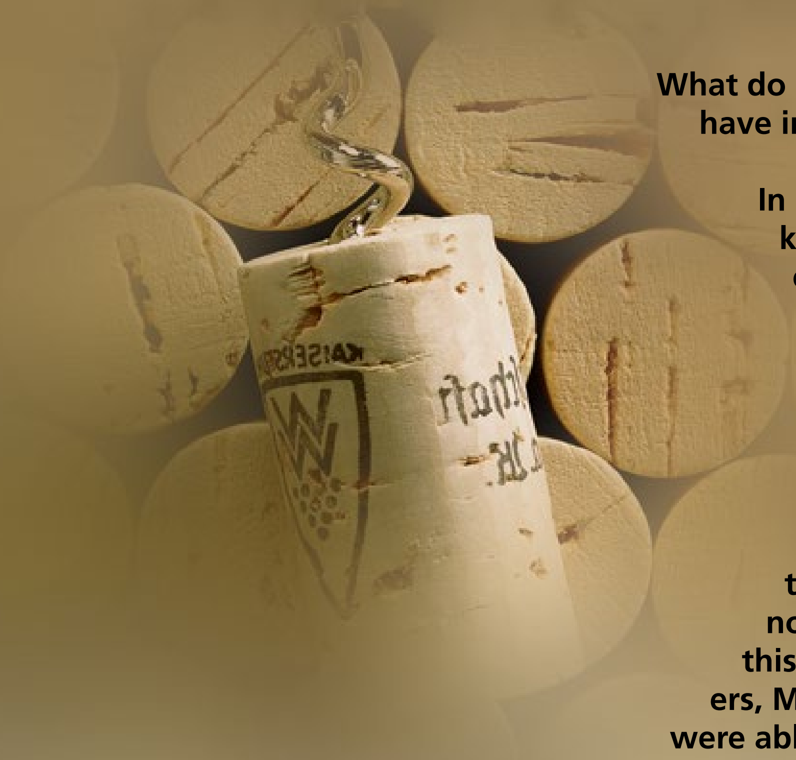
7.) After finishing an experiment, immediately wash the equipment used in the experiment, such as tweezers, dissecting needles, or slides. Old, dried incrustation is often very difficult and sometimes even impossible to remove. For this, use running water and, as needed, a drop of dish-washing liquid. Dry the equipment carefully using paper towel and dispose of the paper in the household trash.

You should also clean the drop pipette thoroughly after each use. To do this, fill it several times with diluted dish-washing liquid and empty it out again. Then rinse it out several times with clear water and allow it to dry.

8.) After experimenting, you should straighten up your work area. Be sure that the experiment accessories are not in the reach of smaller children or animals.

If you follow our tips, you're bound to have a lot of fun exploring the world of the microcosmos. Don't get discouraged if something doesn't work the first time around. It takes time and practice to learn to adjust the microscope and to produce a good preparation. If something doesn't work, then start again from the beginning, first reading the instructions carefully through again (did you miss a step?) and then going through the steps one by one. The more times you deal with these procedural methods, the more natural they will be for you to work with, and your results — with which you can then impress your parents and friends — will improve, too. Now go have lots of fun experimenting with your new microscope!

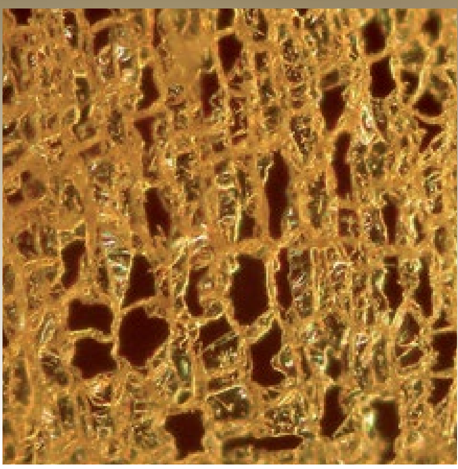
1 I See Something That You Don't See



What do a bottle cork, a carrot, and an elephant have in common?

In 1665, Robert Hooke apparently did not know that he was making one of the discoveries of the millennium when he observed that a common bottle cork consists of tiny hollow spaces. He called these small spaces "cells."

At this time, it was not yet known that all life on Earth is constructed of such cells. Early "microscopes" (we would refer to them as magnifying glasses today) were not yet good enough in those days to see this. More than 150 years later, two researchers, Matthias Schleiden and Theodor Schwann, were able to demonstrate that all animals and plants are made of cells using improved microscopes.



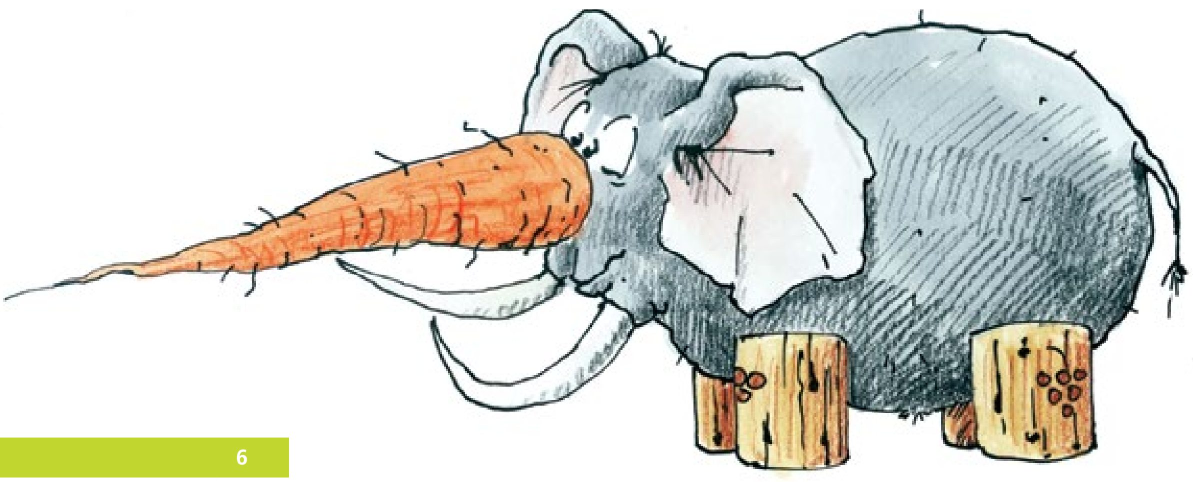
This is what the cells of a bottle cork look like. Cork is made from the bark of the cork oak. What you are looking at here, therefore, are plant cells.

So the gigantic body of an elephant is also composed of cells. Are there differences between "elephant cells" and "carrot cells?" What makes up the strong frame of the elephant? Are its cells larger, or does it simply have more cells than a carrot to form its trunk, ears, and belly?

These are just a few of the endless number of questions that you can investigate and answer with your new microscope. An elephant will most likely not fit under the microscope. But you will definitely be able to get a sense of the differences between animals and plants.

In these instructions for your new microscope, you will find out how your microscope works. What is more, we have brought together many examples that will give you a first impression of the "little world" under the microscope. In order to make it easier to get the hang of it, the instructions for preparing the objects as well as tips and tricks are highlighted in colored boxes around the microscopy techniques.

Before you really get going and prepare your first specimens and slide, you should read through the following pages to learn how to use the microscope and the included accessories. Have fun!



2 Your New Microscope

Regardless of whether you are sitting in front of a microscope for the first time or have already used another microscope before and know how it works, use the following sections to get to know your new microscope and to find out what is in it.

How to Use the Microscope

Microscopes are delicate and sensitive optical instruments. Avoid shaking your microscope and use all of the moving parts with care. Carry the microscope with the base resting in the palm of one hand and the other hand holding the arm handle. Never carry it by the tube, stage, or nosepiece. Any time you are not working with it, you should place it back in its packaging in order to protect it from dust. You can also put the enclosed dust cover over it for this purpose. You will be rewarded for this kind of protective handling with awesome and, above all, clear images.

You will find the battery compartment on the underside of the stand base. Before you can get started using the microscope, you will need to insert three AA batteries (1.5 volt, LR 6 type).

Caution! Before you turn the microscope upside-down, you need to pull the ocular lens out of the tube and lay it to the side. Otherwise, it could fall out and break when you turn the microscope over.

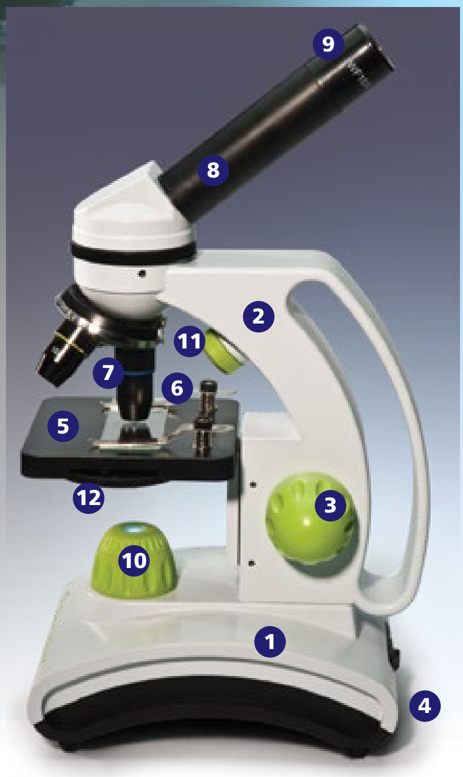
The First Steps

Now it's time to take your first look through the microscope. Your microscope works as both a high-power magnifying glass and a microscope. You may be asking yourself, "microscope, magnifying glass... what's the difference, really?" This will become clear as you read the following two sections. Let's start with the simpler of the two types of viewing modes: the magnifying glass.

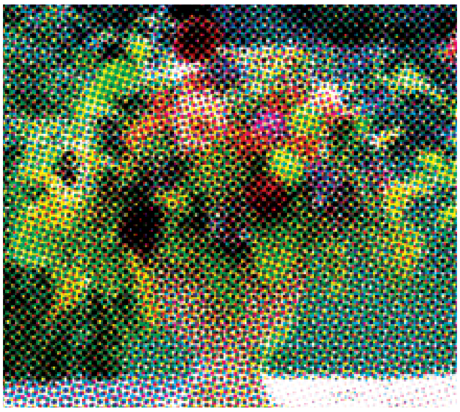
The Microscope as a Magnifying Glass

When observing an object under a magnifying glass, we use the light that falls onto the object from above, such as from the sun or a lamp. This is called incident light. When using an actual microscope, the object is illuminated from below, so when you look through the ocular lens of the microscope, you are seeing the portion of the light that has made its way through the object. This is called transmitted light. Can you think of the problem that this poses? To be observed through a microscope, objects have to be very thin. Very few things are naturally so thin that you can place them directly onto the microscope stage (you will get to know some later in these instructions). Most of the time, they have to be cut in order to look at them at all. This sounds complicated — but you will learn to do it with a little practice. You will find tips on cutting methods in several places in this manual.

If using the microscope with transmitted light is so complicated, why not just use it in the magnifying glass mode? The microscope mode makes it possible to examine



1 Base
2 Arm
3 Focus adjustment knob
4 Switch for the illumination
0 = Off
I = Bottom light (transmitted light)
II = Top light (incident light)
5 Stage
6 Stage clips
7 Revolving nosepiece with three objective lenses (4×, 10×, and 40x magnification)
8 Tube
9 Ocular lens (10x magnification)
10 Bottom lamp (for transmitted light)
11 Top lamp (for incident light)
12 Aperture wheel



Pixels of a newspaper photograph, zoomed in close

Using the microscope as a magnifying glass (macro-view)

The microscope should always be protected from dust

The light switch for incident light (II) and transmitted light (I)

an object much more closely and clearly at higher powers. With this microscope, you can determine the magnification with which you are observing an object quite easily in the following way: You multiply the number on the ocular lens (the eyepiece lens) by the number on the objective lens that is pointing perpendicularly downward. The light passes through the objective lens and then the ocular lens to your eye.

Let's get to it and view an object in magnifying glass mode. Using the focus adjustment knob, put the stage in its lowest position. Set the toggle switch for the illumination to "II." The lamp for illumination from above (incident light) will come on. Place a piece of colored paper from a magazine onto the stage so that it lies directly over the hole in the middle of the stage. Now rotate the revolving nosepiece so that the objective lens with the lowest magnification (red ring, 4x) is pointing perpendicularly downward. Close one eye and look with the other one through the ocular. Can't see anything? Of course not — you also have to focus. To do this, move the stage slowly upward using the focus adjustment knob. The entire time you are doing this, look through the ocular lens. Out of nowhere, blurry colorful blotches will probably appear and then, quite suddenly, a sharp image.

Would you have thought that a colorful picture from a magazine is composed of lots of individual colored dots? The magnification with which you are now observing the paper is the magnification of the ocular times the magnification of the objective, or 10 × 4 = 40. So you are seeing the paper 40 times larger than it actually is, and that is actually the special thing about this microscope magnifying glass. Images seen through normal magnifying glasses usually have a magnification of no more than 10x. By contrast, even at the lowest magnification, you can see an object four times more closely than that with your microscope! Is it possible to use even more magnification? Of course it is. Just turn the revolving nosepiece clockwise so that the yellow objective (10x) is pointing downward perpendicularly and focus the image again. You'll see that the area in which you see a clear image at this ten-fold magnification has become much smaller and that you had to move the objective lens closer to the object. Consequently, when examining thick and, above all, even hard objects (e.g. rocks, crystals, coins, etc.), you have to be very careful not to allow the objective lens to hit against the object and scratch the lens. Hence the following rule:

When using the microscope as a magnifying glass (macro-view with incident light), only use the red (4x) and the yellow objective (10x)! The blue objective (40x) is only intended for transmitted-light microscopy!

As you can see, in order to observe objects with really strong magnification, natural scientists can't get around using transmitted-light microscopy techniques.

When I look into the ocular, everything is dark.

- Are there batteries in the battery compartment, and are they installed in the correct directions?
- Are the batteries fresh? Check the batteries with a battery tester.
- Is the (correct) lamp turned on?
- Setting "0": Lamp off. Setting "I": Light from below for using the microscope with transmitted light. Setting "II": Light from above for the magnifying glass with incident light.
- Is the objective properly engaged?
- Turn the revolving nosepiece carefully back and forth to ensure that the respective objective lens is engaged ("snaps in place") and is exactly perpendicular.

There is light but I can't find a focused object.

- Is there an object directly under the objective lens?
- Place objects that can be seen with the naked eye exactly in the middle of the light opening.
- Is the objective lens over the light opening?
- The objective lens only picks up the object in this area (naturally, the higher the magnification, the smaller the visible area becomes).
- Maybe you were too fast!
- Turn the knob slowly to move the stage downward. Careful with the blue objective (40x) — don't bump into the object or slide!

Using the Microscope with Transmitted Light

In the last section, you learned quite a lot that will help you with using the microscope. Nevertheless, we suggest that you still read this section carefully in order to avoid mistakes later when you start your microscopic explorations.

What do you need for the next exercise? Of course, the first thing is an object. The best thing to use in order to become familiar with the microscope is one of the prepared slides included in the kit.

First, set the toggle switch for the illumination to "I." The light comes on from below. Then fasten one of the prepared slides under the stage clips. Incidentally, these can be lifted up by pressing lightly on the short sides of the clips. Push the slide under the clips and, at the same time, make sure that the object (see illustration) is lying directly over the hole through which the light from the lamp is shining.

Now we proceed as already described for the magnifying glass. Slowly raise the stage by turning the knob and bring the object into focus. Once you have observed the object at this magnification, turn the revolving nosepiece clockwise to the yellow (10x) and finally to the blue objective (40x). Now you are looking at the object with the highest possible magnification. It's enlarged 400 times!

A word on the aperture wheel (the rotating disk) underneath the stage: When you turn it, you will see that openings of different sizes open up in the disk. You would think that, as a matter of principle, the largest opening — which lets the most light through — is also the best. But that is not always the case. Sometimes you can see more with less light! However, there is no rule of thumb for this. You will need to simply try it out with your specimens to see whether you get a better image with a different setting of the aperture wheel.

When using the blue objective lens, a special level of fine tuning is needed. If you raise the stage too high so that it bumps against the cover slip on the underside of the objective, then this can cause two problems:
1. The cover slip or even the slide can break and your prepared slide (or whatever it is that you happen to be looking at in that moment) is destroyed.
2. The sensitive lens on the underside of the objective can be scratched and, in the best-case scenario, from now on you will always see these scratches. In the worst-case scenario, you will not be able to see anything clearly through the scratched objective.

If the objective lenses should get dirty at some point, then clean them carefully with a sheet of lens cleaning paper. When you do so, do not use any water or cleaning agents! The same also applies to the ocular lens, which gets dirty again and again from the oil on your eyelashes (this can't be avoided) and consequently has to be cleaned regularly. Last but not least, here's another tip: From my own experience, I suggest that you start with the red (4x) objective for each new object and then work up to the yellow (10x) and then to blue objective (40x). Many objects can be seen sufficiently at the smallest magnification. Moreover, it is helpful to always gain an overview of an object before looking at individual details at the strongest magnification.

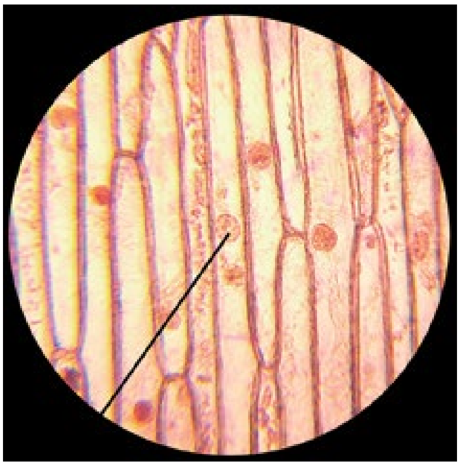
How does the microscope actually "make" the magnification? And why does the image in the microscope move left even though you move the slide right? In the next section, which is about the inner workings of your microscope, you will find the answer to these questions.

There's a funny black streak in my image...

The ocular of your microscope is equipped with a so-called "ocular pointer." There is a fine wire with a needle tip on the inside that can be rotated when looking through the ocular lens (and moving the object) in such a way that it points, for instance, to certain cells or other interesting areas of the object. This makes it easier to show these areas to others.

If the pointer bothers you during everyday use of the microscope, the wire can be removed quite easily from the ocular using the tweezers (and put back in again later). To do this, you simply take the ocular out of the tube. Have an adult help you with this so that the sensitive lens in the ocular is not scratched. It's best to store the fine wire in an envelope or a small bag in the microscope's box so that it isn't lost.

Use as a transmitted-light microscope



Using the pointer (here, the pointer is pointing to a cell nucleus.)

Removing the pointer tip from the ocular

A drop of water works like a magnifying glass on a leaf

Different refraction of light in water and air

Did You Know?

The magnification of a light microscope cannot be increased infinitely through the skillful combination of magnifying lenses.
There are limits to a light microscope's resolving power. Resolving power is understood as the distance that two points can have between each other and still be perceived as two distinct points under the microscope.

Understanding Optics

Why does a straw that is inserted into a glass of water suddenly have a break where there was none before? This is because light diffuses differently in air than in other environments — water in this case. When light strikes the surface of water, a portion of the light is reflected at the water's surface. The rest of the light that enters into the water changes its direction a little. It is said that the light is refracted.

The light that is striking the leaf through a drop of water is first refracted, reflected on the surface of the leaf, and then makes its way through the water drop and into the eye of the observer. Here, the light is refracted again in such a way that the underlying leaf surface appears to be enlarged. People knew how to make use of this characteristic of light quite some time ago by using the refraction of light in a drop of water as a magnifying glass. This early water-based magnifying glass had its limits, of course.

It was only with the invention of "artificial water drops" made of glass that it became possible to perfect the magnifying glass. Biology was given a tremendous boost through the invention of magnifying lenses, because details could suddenly be observed that remained hidden to researchers before. If lenses' shapes are changed (thickness, curvature of the surface, etc.), then their magnifying characteristics change as well. The lenses in the objectives of your microscope differ from each other, resulting in the different magnifications of the object.

Instead of changing the shape of the lens to achieve higher magnifications, however, it is also possible to simply use several lenses in series. In your microscope, there are two lenses in the objective and one in the ocular.

So, in effect, you are looking at the image (enlarged by the objective) with a magnifying glass (ocular). You get the total magnification of the microscope by multiplying the individual magnifications of the lenses together. In most microscopes, the individual magnifications can be found on the ocular and objective, respectively. Sometimes, however, the total magnification is already indicated on the revolving nosepiece.

When magnifying an object using a so-called lens system — in the case of your microscope, the system consists of three lenses — something else happens in addition to the magnification: the image is upside-down. What is "up" in the object is "down" in the view through the eyepiece. What is "left" on the slide is "right" when looking through the microscope. You will quickly become accustomed to this. After a short time, you will automatically move the slide upward when you want to look at a detail further down.

3 The Basic Equipment

Your new microscope set contains almost all of the essential things to get started immediately. How to use them will be explained either later on or in the chapter in which the part or tool is used for the first time. In addition, there are several things that are useful when using a microscope or are used for the experiments that we suggest in these instructions. There is an overview of these below.

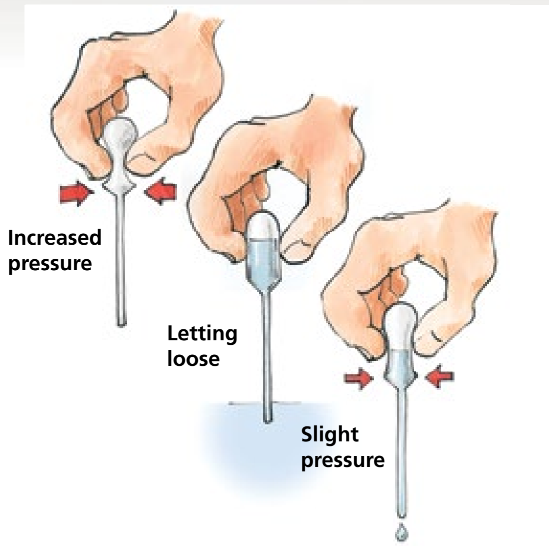
The most important elements of your microscope's basic equipment are the slides and cover slips. The procedure for preparing a slide is explained in Chapter 4. Also, you can label particularly successful prepared slides using the enclosed stickers. In addition to the "blank" slides for your own research, you will find a box with four already finished preparations, so-called prepared slides. They are particularly suited to the very first steps (Chapter 2) and are explained in more detail in other chapters — the oral smear in Chapter 4, the pollen and salt crystals in Chapter 8, and the paramecia in Chapter 7. Last but not least, another special slide is included in the set. It has a small recess (a concave trough) in the middle. You might use this slide when you want to look at larger objects under the microscope — for example, amphipoda from a pond. In any case, it will be of great help to you in the experiments described in Chapter 7.

The boxes with the slides and cover slips

The use of the tweezers surely needs no special explanation. How they are used in conjunction with the microscope as well as how the dissecting needle is used is explained in the respective experiments.

The dropper pipette is very helpful when working with water and other liquids. Perhaps you have already had some practice working with one previously. The illustration demonstrates how it's done: When you squeeze the top part of the pipette, some air escapes below. Dip the pipette into water (that you have prepared in a beaker, for example) and loosen the pressure between your fingers. The water will rise up in the pipette. Now you can release the water in the pipette drop by drop by slightly reducing the pressure and allow it to drip, for example, onto a

Pipette, dissecting needle, and tweezers from your microscope set



How to use the pipette.

The ocular must be cleaned with great care.

slide. After use, always rinse the pipette out several times with clean water so that it is ready again for new experiments.

The cleaning of the lenses was already mentioned in the previous chapter. For this purpose, use the special cleaning cloths (so-called lens papers) that are included in a little pad in the kit. When all of the cloths have been used up, you can also use a clean, dry, soft cotton or microfiber cloth (eyeglass cleaning cloth) or buy more lens paper.

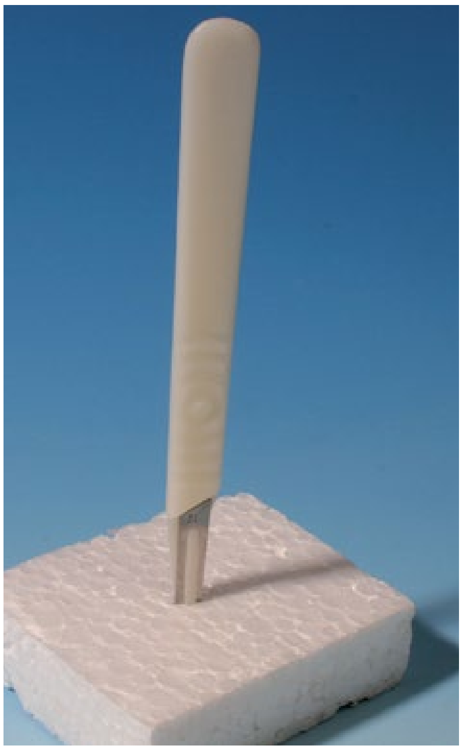
Some objects only begin to show their full splendor when stained. Biologists therefore often stain their preparations before looking at them under the microscope. In this way, certain structures (e.g. cell walls) are sometimes made more visible. In your microscope set, you will find two small bottles with staining solutions. A very easy way to apply the staining solutions under the cover slip is described in Chapter 5. When selecting the staining solution — whether red or blue or ever perhaps none at all — there are no general rules. "Learning by doing" is the idea here; finding out by trial and error what stain works best for which objects. The criterion here for success is, of course, that you see more with the stain than without it! Microscopy professionals often use very special colorants with which only very certain structures (e.g. cell nucleus, cell wall, or the like) are stained. If you look on the internet under the search terms "microscopy" and "staining methods," you will find lots of interesting tips on the staining of preparations. But it's also a good idea to simply experiment with household items. Red and blue dye (corresponding to the microscopic stain reagents eosin red and methylene blue) are excellent choices for this. What's more, an iodine solution is helpful for some objects. For this, you can use povidone-iodine solution, which is available in pharmacies for wound infections.

You can use the small petri dishes to store collected objects. But you can also place, for example, a water sample or a dead insect you found, directly on the stage in the dish and observe it using your microscope's magnifying glass function.

The scalpel will be very useful when you need to make large objects smaller before cutting them. Careful — the scalpel is very sharp! Before being used for the first time, it needs to be carefully unpacked and the protective plastic cover on the blade broken off. Have an adult help you with this! After use, it's best to protect the scalpel blade with a piece of styrofoam and to store the scalpel safely inside the microscope box.

Objects can be stained using food coloring or even with some household items.

Here, the Petri dish is being used to store a sensitive object.



The following things are not included in the kit, but are useful when using the microscope: To absorb excess liquids and to clean all of the equipment, it makes sense to always have a few paper towels handy. Some sheets from a kitchen roll, paper tissues, or even paper from a roll of toilet paper fulfill this purpose terrifically!

To cut objects for your preparations, you are going to need razor blades. You can buy them at a drug store or supermarket. Of course, it goes without saying that sharp blades need to be handled with care. Nonetheless, it is recommendable that you cover the blades on one side. There are basically two methods for this. Try both out and, in the future, work with the method that you like best. Have your parents help you with both of the following steps.
1. Insulating tape method: You simply take sturdy electrical tape and stick several strips of it over the blade on one side of the razor blade.
2. Bottle cork method: Using a knife, cut a slit along the length of a bottle cork (about to the middle) into which you can then stick a razor blade. Then you can simply hold the razor blade by the "cork grip."

Paper tissues or paper towels are useful for wiping up liquids or rubbing the slides dry. They are also used to absorb liquids under the cover slip (see Chapters 4 and 5), although a piece of blotter paper can prove useful for this too. When using staining solutions, follow the safety precautions on page 3.

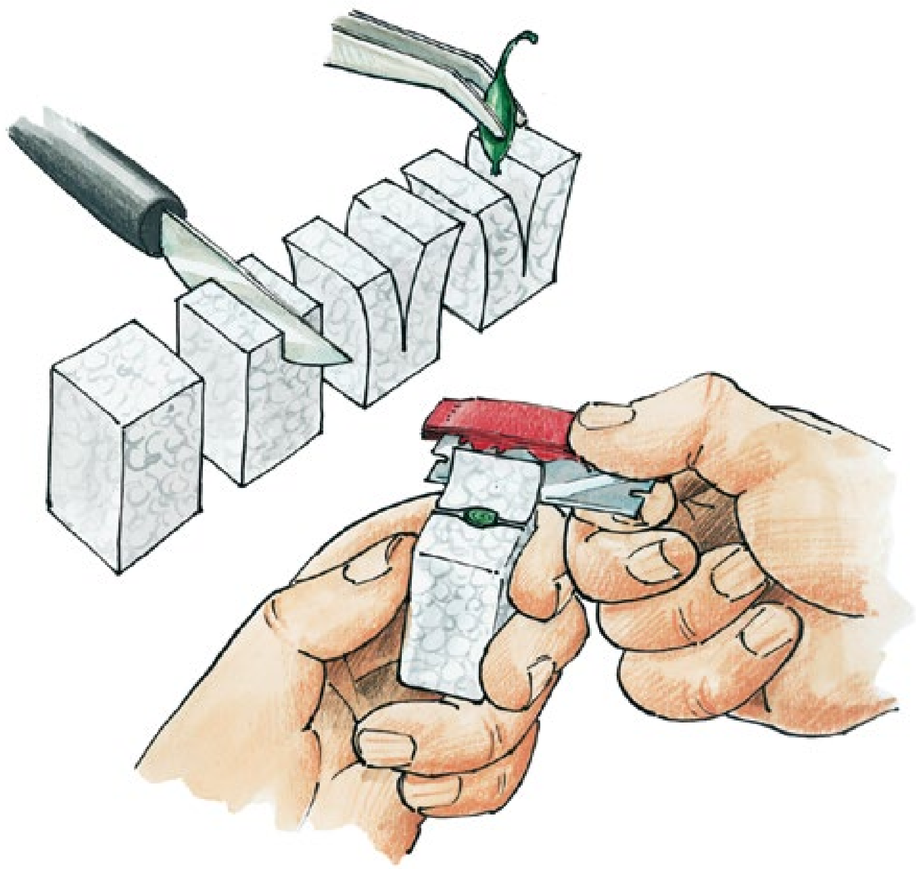
To produce thin slices, a cutting aid is often needed (see also Chapter 12). For this, arrange some pieces of styrofoam such as that used for packing, for example. Another possibility is to use a piece of carrot for this purpose.

You can get other preparation accessories such as dye reagents, prepared slides, etc. from specialized microscope and science stores, who often sell through mail order on the internet as well.

But that's enough of an introduction. In the next chapter, you will finally get to work on your first self-prepared slide!

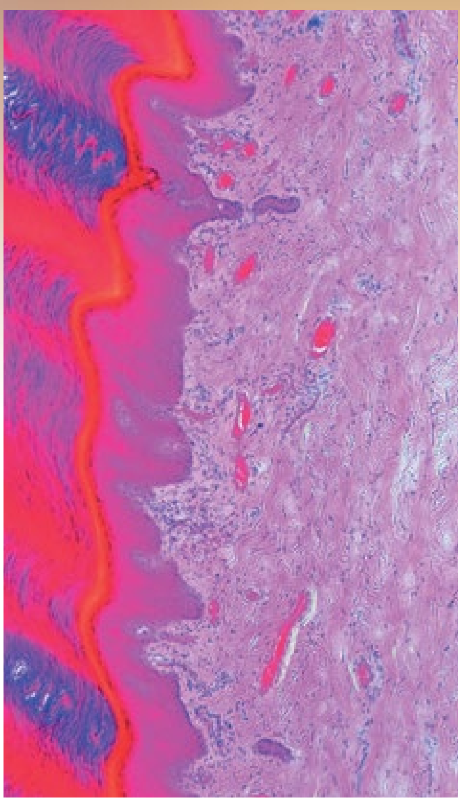
The insulating tape grip greatly reduces the danger of injury.


A cork is helpful here, too.


Take a styrofoam cube (or a piece of carrot) and cut a slit into it from above. Then stick your object into it (a piece of grass stalk, a leaf, a root, etc.). Make sure that the object is standing straight in the styrofoam (or carrot). Now you can put the razor blade to the styrofoam and slice through the styrofoam and the object.

4 Cells — If You Know One, Do You Know Them All?

It's mind-boggling when you try to imagine that our body consists of teensy weensy cells from our head to our feet. After all, about 70 trillion cells (that's a 7 with 13 zeros!) make up our bodies along with their organs. And there are cells in a wide variety of sizes which are usually indicated in micrometers (µm). A micrometer is a thousandth of a millimeter. Human cells come in all different sizes: from sperm, measuring only 2 micrometers, to large mucous membrane cells from the mouth measuring 60 – 80 micrometers all the way up to ova (egg cells) measuring a whopping 100 micrometers (that's a tenth of a millimeter). If all of the cells from your body were to be lined up in a row, they would form a cell chain several kilometers long!



Cross-section through human skin.
This and many other photos were made available courtesy of Johannes Liefer.

Animal Cell Design

Can you tell from looking at a cell where it came from? Indeed, because a liver cell looks different than a skin cell or a cell from the intestinal wall. But that's not surprising if you consider that every part of our body has very specialized tasks to perform. In fact, every part of the body generally has several tasks to perform at the same time. For example, the skin has a number of duties to fulfill. It is our outer wall and has to prevent undesired intruders such as pathogens or toxic substances from penetrating onto our "grounds." After a 100 meter sprint, the skin has a different function: It sweats and hence prevents our body from overheating. But the skin is also one of our most important sense organs, since it tells us whether an object is hot, cold, sharp, soft, or sticky. It's wrong, therefore, to simply say "skin cell." As you can see in the image to the left, human skin is actually composed of a number of different types of cells. Each cell type looks a little different than the others, depending on what task the cell performs.

The Prototypical Animal Cell

It's very easy for you to observe cells from your own body under the microscope. To do this, you will need:

a cotton swab, a slide, a cover slip, the pipette, water

First prepare a slide with a drop of water. To do this, and to learn the most important steps when making a preparation, also read the tips in the following box.

Use the cotton swab to rub along the inside of your cheek. When you do this, individual cells from the mucous membrane in your mouth come loose and stick to the cotton swab. You should rub with plenty of pressure but not too hard; you don't want to hurt yourself! Rub the cotton swab in the water drop on the prepared slide. Now just lay a cover slip on top of it and put it under the microscope!

Microscopy Technique — How to Put an Object under the Microscope

Any object that you would like to observe under the microscope needs to be in a liquid (usually water). The optics of your microscope is set up for objects that are surrounded with a liquid medium. This has to do with the fact that the light refraction in the air is completely different than in liquid. So, in general, dry objects cannot be observed under the microscope, except in magnifying glass mode.

Consequently, slide preparation usually begins with the placement of a drop of water in the middle of a slide. Either you can use the pipette for this purpose, or you can simply dip your finger into a container of water (e.g. a beaker) and dab the drop of water hanging on your finger when you pull it out in the middle of the slide. Next, the object is placed into the water drop.

Now a cover slip still needs to be placed on top of it. When doing so, make sure that as few air bubbles as possible remain under the cover slip. They are a nuisance when working with a microscope because they appear black at their edges and can sometimes obscure the object you are trying to examine. It's best to proceed as follows.

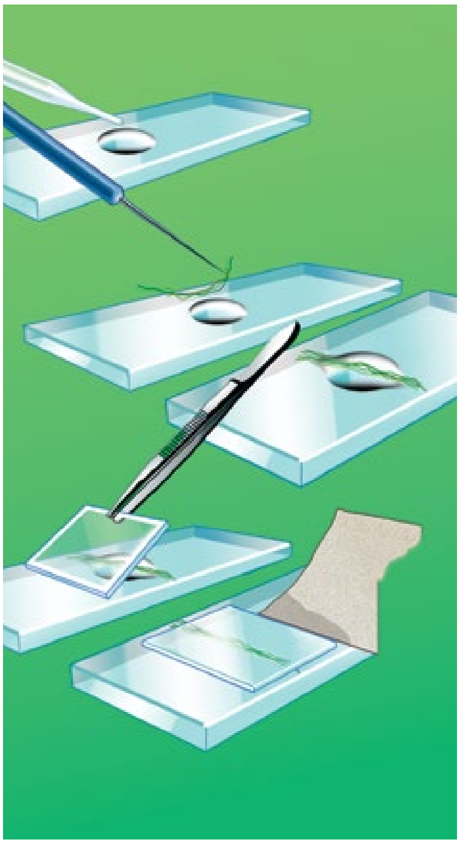
Take a cover slip by its edges using two fingers and place one of its edges right next to the drop of liquid on the slide. Then slowly slide the cover slip up to the drop. As soon as the cover slip touches the drop, the lower edge gets wet with the liquid immediately. Now you can slowly lower the cover slip down onto the slide. Tweezers can be helpful here.

If some air bubbles should get under the cover slip, simply lift it up with the tweezers on one side of the slide and try it again. With a little practice, it will become easy for you.

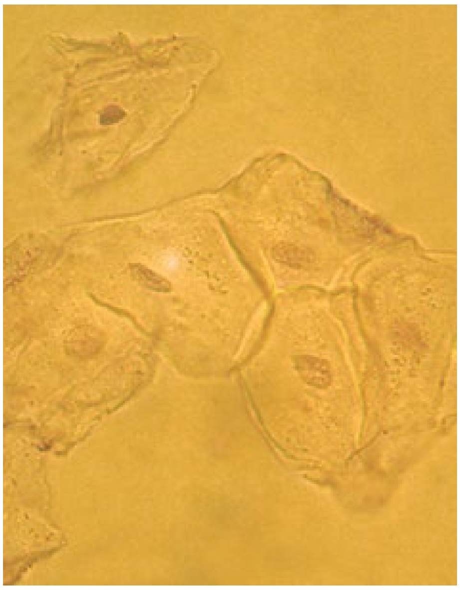
What do you do if there is too little or too much water under the cover slip? The space between the cover slip and the slide should be completely filled with liquid. It's possible that the drop that you dabbed onto the slide initially was too small, so that there is no water under the cover slip at the edges. That's undesirable, since parts of your object could dry out and then not produce a useful image under the microscope. You can resolve this problem quite easily by dabbing a drop of water at the edge of the cover slip under which the liquid is located.

The liquid is sucked up under the cover slip as if by magic. However, there should not be too much liquid under the cover slip, either. If there is too much liquid under the cover slip, you will notice the liquid swelling out from under the cover slip, or there may even be droplets next to the cover slip. You can simply absorb the excess water using a strip of blotting paper or a paper towel. This is important above all because in this way you prevent liquid from getting onto your microscope during use, which can soil or even damage it.

Here's how a water drop can be applied to the slide even without a pipette.

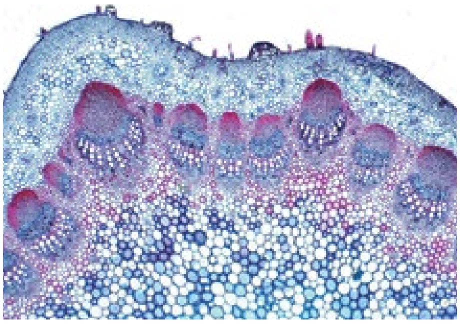


Steps in preparing a slide



Cells from the mucous membrane of a human mouth

The mucous membrane cells from the mouth all look about the same. Shapeless formations with pockets and a sphere on the inside. This sphere, which generally cannot be seen with the microscope without staining the object, is the famous cell nucleus. Perhaps you've already heard that the police take so-called "DNA swabs" in their search for a murderer. If we were to compare the cell to a computer, DNA, which is the genetic material, is the cell's hard drive. It is packaged up nicely in the nucleus of every cell. There, all of the information is stored that our body — and hence every single one of the 70 billion cells of our body — needs in order to function properly. While some of the information is the same in every human being — for example, that five toes grow on our feet while we are developing in our mother's stomach — DNA changes from person to person in certain places. Forensic police take advantage of this fact in order to compare traces of DNA found



Cross-section through the stalk of a sunflower

at crime scenes (skin cells or blood residues of the culprit, for example, which also contain DNA) with the DNA of possible perpetrators. To do this, the police obtain DNA for comparison from the mucous membrane skin cells in the mouths of the suspects.

Are your mucous membrane skin cells different from those of your parents? Are the cells of older and, above all, larger organisms larger too, perhaps? Or does your father simply have more cells? The prepared slide labeled "Mouth mucous membrane skin cells" from your microscope set is the red-stained smear from an adult's mouth. There, it is particularly easy to see the cell nuclei. So you can compare your mouth mucous membrane skin cells with those of an adult and answer the question yourself!

This is how the onion skin is prepared.

It Depends on the Function

Now you've become acquainted with a typical example of an animal cell. So do plant cells look different, or what?

That brings us back to the elephant and the carrot from the introduction. What differences are there between an elephant cell and a carrot cell? As you already learned, there is actually no such thing as an "elephant cell." And there is of course no such thing as a "plant cell," either. Just like the cells in our bodies, the cells of a plant must also carry out a wide variety of tasks. With some practice that you can acquire by using the objects presented in these instructions, it is often possible to determine the function of a plant cell just by its appearance.

In the figure, you can see a cross-section through the stalk of a sunflower. Even in this small section, it becomes clear how many different kinds of cells a plant can be made of. You'll encounter several of these cell types later on. In the next object, you can see several examples of typical plant cells. By the way, the slide preparation, which you can easily prepare using the following description, is also included as a stained prepared slide in your microscope set. You will find a description of this permanent preparation in Chapter 16.

TIP

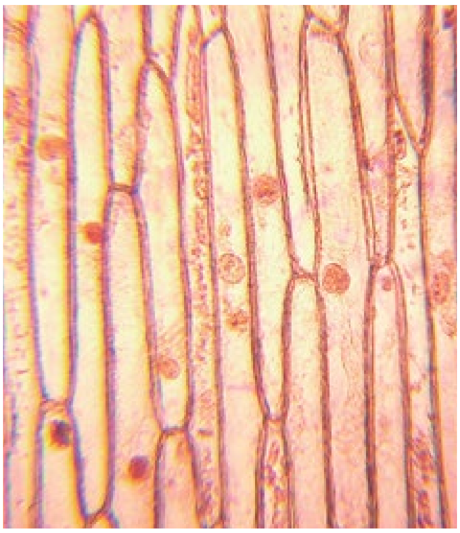
When preparing slides, very sharp cutting tools are important. But in order to ensure that you just cut the object of study and not your finger, you should prepare the razor blade appropriately with insulating tape or a cork. Follow the advice on page 11 and have an adult help you.

Onion Cells

Onion cells are good examples of typical plant cells that can be obtained very easily for observation under the microscope. For this, you will need:

- a slide and a cover slip
- the pipette and water
- a quarter of a cooking onion
- a razor blade (see page 11)
- the tweezers

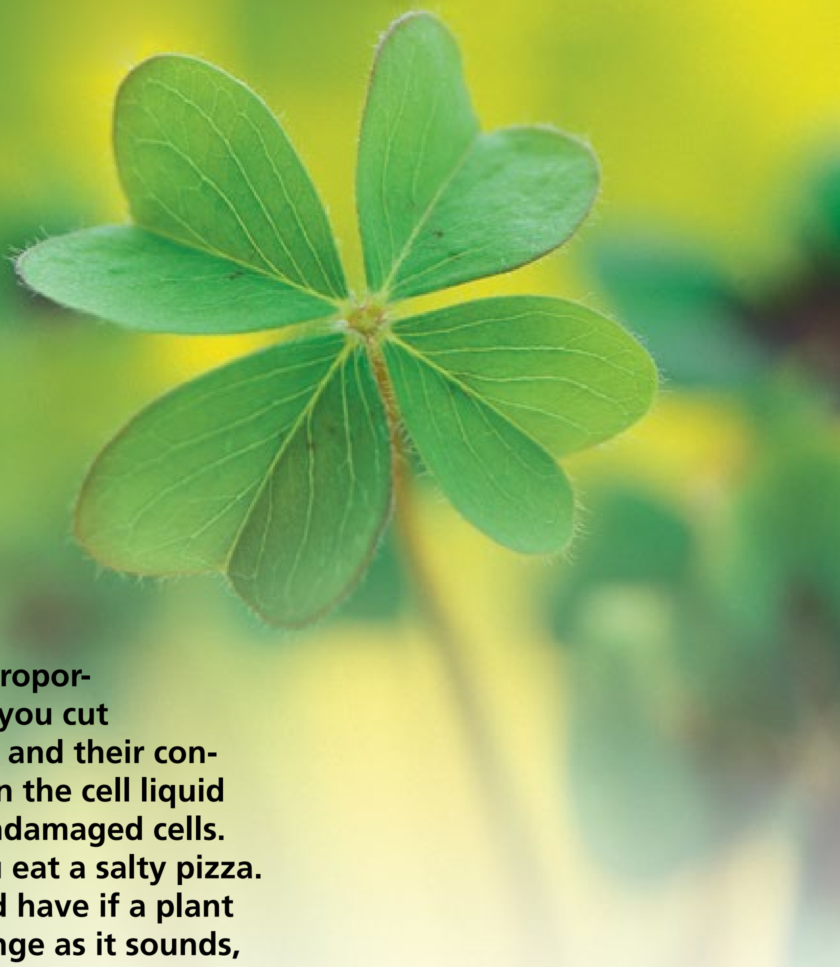
Peel the onion and take one of the outer layers. Using the razor blade, carefully cut a checkered pattern on the inside of this layer of onion. Now, using the tweezers, you can peel a square piece of tissue quite easily from the sample. The little piece of tissue detaches from the tweezers almost on its own if you dip it into the water drop on your slide. Now place a cover slip on it so that there are no bubbles (cf. box on page 13). Now look at your preparation under the microscope, first under low magnification and then under the higher magnifications. If you are unable to make out a clear cell pattern, your piece of onion tissue may be too thick.



Onion skin cells

In addition to the fact that the cells of the onion skin, with a length of 400 micrometers, are larger than the cells of the mucous membrane skin from your mouth, another important difference between plant and animal cells becomes apparent: They are clearly shaped differently. While the cells of the mucous membrane skin from your mouth are irregularly shaped blobs and covered with lots of recesses and protrusions, the cells of the onion skin look like small, pointed bricks. Is this a coincidence simply due to the two examples we have selected? You'll find the answer to this and many other questions regarding the differences between plant and animal cells in the next chapter.

5 Life in a Shoebox — The Plant Cell



Suppose for a minute that you ate a wonderful pizza covered with heavily salted cheese and pepperoni for lunch. After a while, you might get terribly thirsty. Is that a coincidence, or is the pizza (or its topping) responsible for this? To find out, perform the following experiment at dinner: Cut a radish into two halves and sprinkle one half with salt. After a short time, you will see that small drops of water are coming out if its cut surface, whereas the initially moist cut surface of the other unsalted half slowly dries out.

A radish is composed of cells, too. A large proportion of the content of a cell is water. When you cut the radish open, you destroy countless cells and their contents spill out. The sprinkled salt dissolves in the cell liquid and removes water from the underlying, undamaged cells. Basically the same thing happens when you eat a salty pizza. You can surely imagine what effect it would have if a plant were to be watered with saltwater. As strange as it sounds, it would dry up even though you were watering it. You can even observe this under the microscope!

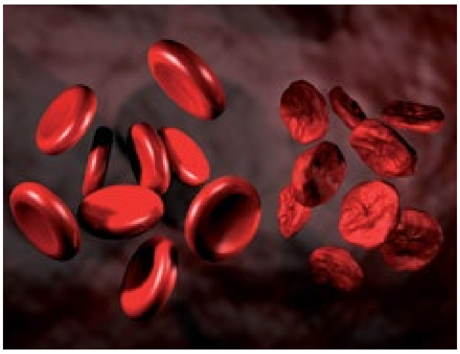
Plants Know How to Stay in Shape

Although a plant loses water, it retains its shape for some time afterward. This is because plant cells — in contrast to animal cells — are surrounded by two coverings and not by just one.

The Cell Membrane

Both animal and plant cells are enclosed by a so-called cell membrane. This cell membrane is like a skin that protects the cell from intruders. But, strangely, this "cell skin" is not completely tight. So you shouldn't imagine a cell as if all of its contents were packed into a kind of clear plastic wrap, such as shrink-wrapped foods in which the packaged contents are completely sealed off in order to protect the food from germs. But that wouldn't make any sense because, for example, nutrients have to get into the cell and wastes (which are produced in great quantities in a cell) have to get out of the cell. Surprisingly, water — which is the most important substance for life on Earth — is able to pass freely through the cell

We humans also consist of a good 60% water? That, however, is nothing compared to jellyfish, which are over 98% water. Even dried wood still contains water. When it is burned in the fireplace, the residual water vaporizes suddenly and blasts parts of the wood. That's why a wood fire "crackles" and "pops" so nicely.



Red blood cells in living state (left) and dried state (right)

This is how you can imagine a living plant cell that is full of cytoplasm.

This is what a plant cell looks like when it has given off some of its water.

Using a piece of blotter paper, it's very easy to draw liquids under the cover slip.

membrane. Cells have evolved to retain their water and not dry out under normal conditions. As you saw in the experiment with the radish, however, sometimes conditions make it impossible for a cell to retain its water. Cells don't have any quick defenses against concentrated solutions of salts or even sugar and other solids. Their water is taken from them because it is drawn to where the most highly concentrated solution is.

The Cell Wall

Animal cells that are treated with a concentrated salt or sugar solution shrivel up. In extreme cases, this can even mean the death of the cell.

So how do plant cells manage to retain their shape even when they lose water? It's because the actual plant cell enclosed by the cell membrane is also enclosed by the so-called cell wall. You can imagine it as being like a water-filled balloon in a shoe box. The water is the liquid inside the cell, called cytoplasm or cell sap, the balloon is the cell membrane, and the shoe box is the cell wall.

The nice thing about this analogy is that the cardboard in the shoe box (as well as paper and pulp) is in fact made from the cell wall material of plant cells, namely cellulose.

If the water is now taken away, then the water balloon inside the box shrinks. A hollow space is thus created where the balloon and the shoe box had been touching previously.

Exactly the same thing happens in the radish experiment — only that the resulting space is not filled by air but by salt solution which penetrates through the cell walls. The whole thing can also be reversed if water is fed to the cell.

Staining Technique — Exchanging Solutions

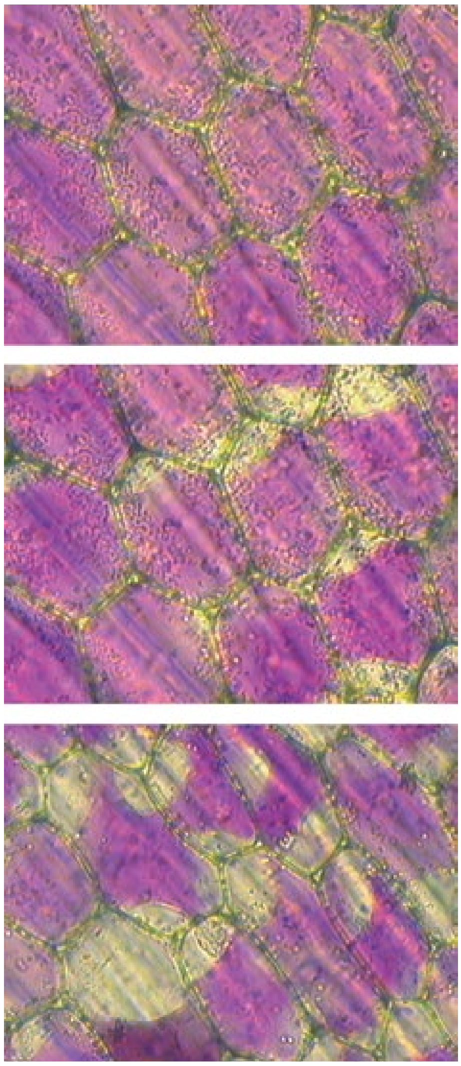
For the microscopic experiment on this page, the liquid in which your object is lying needs to be exchanged for another liquid. To do this, however, you don't need to lift the cover slip each time. There's a more elegant way: The method for drawing excess water out from under the cover slip was explained in the introduction. You can apply the same technique in order to suck another liquid under the cover slip. Simply dab a drop of the liquid (e.g. the stain) onto the slide next to the cover slip and suck it up under the cover slip from the other side using blotter paper or a tissue. After leaving it for a moment so that the stain takes effect, it is recommendable (especially when using dark stains) to rinse the slide one or two times (i.e. to repeat the procedure with water) in order to get a clear image under the microscope.

When Cells Shrink

In principle, any plant will work for this microscopic experiment. The process can be observed especially well with some red-colored plant parts. You'll find out below why not all colored plant parts are equally suited to this.

You will need:
- a slide and a cover slip
- water and the pipette
- a razor blade (see page 11)
- the tweezers
- a quarter of a red cooking onion
- a beaker (or glass) with a salt or sugar solution
- a piece of blotter paper, paper towel, or tissue

First prepare the salt (or sugar) solution: In a beaker, stir a level tablespoonful of salt or sugar into three tablespoonfuls of water. Drip a drop of the salt or sugar solution onto the slide. Prepare a little piece of onion skin (as on page 14) and place it in the drop on the slide. Place a cover slip on it and now quickly look at it under the microscope! Observe it for a while under medium magnification: After a while, you can see how the red-colored cell contents pull away from the cell wall. The salt or sugar solution slowly penetrates in between the cell wall (light-colored lines) and the red cell. Perhaps you can even observe how the cell contents turn a darker red over time. This is because the red colorant in the cell becomes more concentrated after the loss of water and hence becomes darker. If you don't take it too far, you can also reverse the process. To do this, simply suck normal water up under the cover slip (see "Staining Technique — Exchanging Solutions" on the previous page).



The cells of the red lily have a red cell sap. The colored interior of the cell shrinks in a salt solution.

In Living Color

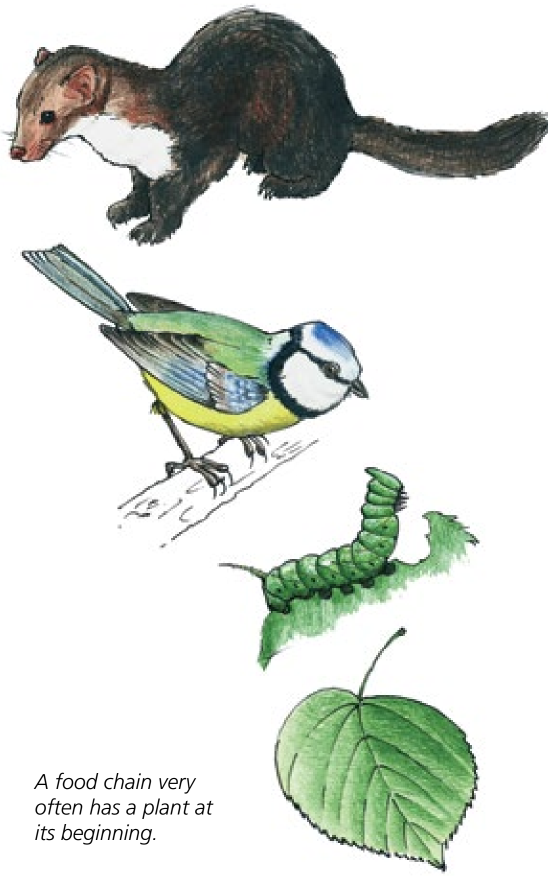
"Actually, a lion eats grass, too," says your biology teacher. What does he mean by that? On TV, you may have seen how a lion devours a captured gazelle with great skill. "Yes, but the gazelle got its flesh from eating plants." Ok, the gazelle is a plant-eater and eats grass or leaves, for example. That is to say that it derives all of its life-energy and the building material for its bodily cells from its plant diet. The lion, on the other hand, lives from consuming all of the energy of the gazelle. So when he eats the gazelle's flesh, he is essentially eating up the energy that was stored in the gazelle's plant diet.

There are innumerable other examples to illustrate similar relationships. One comes immediately to mind: A butterfly caterpillar is nibbling with pleasure on the leaf of a lime tree. A bird snatches the caterpillar in an opportune moment. But the bird can be eaten, too: If it isn't fast enough, it will be caught by a predator, such as weasel. Biologists call this a food chain. Every living thing on Earth is part of such a food chain, and there is always a plant at the beginning of a food chain that, with its stored energy, serves as food for a plant eater.

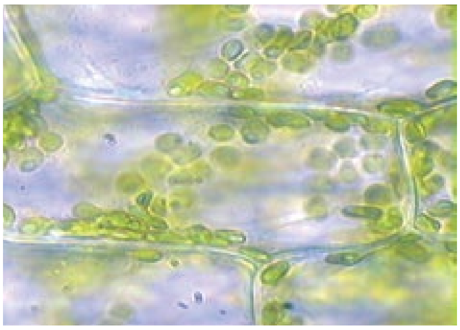
But where does the plant get its life-energy? Plants are special organisms, because they can do something that only they (and a few bacteria) are capable of: Plants use the energy of the sun. Just imagine spending two hours in the sun each day and being nourished for the rest of the day. That would be fantastic! All of the world's nutritional problems would be solved if we were able, like plants, to eat our fill of the sun's energy! We would just have to get used to one small detail: People would all be green like plants!

The Chloroplasts

In the red onion, you got to know an example of why some plants or plant parts are colored. A red colorant is dissolved in the cell sap of the onion skin. The color of the blossom of the larkspur plant or the deep, dark red color of red cabbage comes about in the same way. The green color in plants, however, comes from something else. You will find small green granules in the plant cells of green plant parts. These are chloroplasts. They are responsible for the green color of plants and are also plants' fuel factories. With the help of the chloroplasts, the plant is able to make use of the sun's energy to produce dextrose from carbon dioxide (that's a component of the air surrounding us) and water. This process is called photosynthesis. The energy that is stored in dextrose is used by the plant in order to grow, bloom, and form fruit — or another creature makes use of the dextrose in eating the plant. As a by-product of this unique process, oxygen also happens to be produced too. So we don't live just from the sun's energy that is converted by plants with their green leaves, but rather we also breathe in the by-product that is formed in the process.



A food chain very often has a plant at its beginning.



Cells of the egeria with chloroplasts

Did You Know?

Some gardeners feed their plants with carbon dioxide. Greenhouses make it possible to pamper plants especially well. Sufficient heat and light usually make plants thrive more than in the open field. In addition, some gardeners "fertilize" their plants in greenhouses with the gas carbon dioxide, which the plants need in order to produce dextrose with light and water.

Chlorophyll

You will find chloroplasts in all green plant parts. It is especially easy to study the chlorophyll in the leaves of some typical aquarium plants because the leaves are only two layers thick. Different species of egeria are frequently used in aquariums (elodea is another scientific name for it). Maybe you know someone who has an aquarium who is willing to give you a couple such leaves. Or you can ask for some in a pet or aquarium store.

To prepare the object, you will need:
- a slide and a cover slip
- water and the pipette
- the tweezers
- a small egeria leaf

Using the tweezers, pinch off a small leaf from the egeria and place it into a drop of water on the slide. In the six-sided cells, you will find the round chloroplasts. You will probably need to move the focus adjustment of your microscope back and forth a bit in order to see one of the two layers of cells really clearly. Often, in this specimen you can also observe how the chloroplasts in the cell move about in circles.

On Green and Red Tomatoes

The chloroplasts of plants are not just fantastic energy converters — they're also able to metamorphose at a given time. Very many fruits are still green as long as they are unripe. Apples, tomatoes, cherries, or grapes change their color over the course of ripening. Through the altered color, often supported by emitted aromas, the plant signals that its ripened fruits are now suitable for consumption. Why does it do that? To have the seeds hidden in their fruits distributed by animals, of course. They eat the seeds with the fruits, are not able to digest them and then drop them somewhere else together with the other remains of their digestion. In this way, the plant is able to provide their progeny with a sunny place to grow and prosper without budging from their fixed location.

Here too, the green color of the fruits comes from the chloroplasts in the cells of the fruits. As the fruits slowly become ripe, the chloroplasts gradually transform into granules of a different color, or chromoplasts. In so doing, they often change shape, too, resulting in a great variety of chromoplasts to discover out there.

Ripe and unripe tomatoes

Cutting, Part 1 — First Tips

Theoretically, the number of objects that you can look at with your microscope is unlimited. However, all microscopic preparations must fulfill one condition: They need to be thin enough so that light is able to pass through them. As a rule, excessively thick specimens do not let enough let through and they also usually contain several layers of cells on top of each other. This makes it very difficult to see anything clearly.

Cutting is an art in and of itself, and the preparation of good, thin cuts is probably not going to come to you (or anyone else) right away. A bit of consolation: Professionally prepared slides, including those that were used for many pictures in these instructions, are not done by hand but rather with a special device. So please don't despair if you haven't performed a master cut even on the fifth try! With a little practice, you will soon begin to notch up your first successful cuts.

Here are some tips for cutting (for more, see pages 38 and 42):

- Always use a sharp razor blade. Even an experienced hand won't be able to make good cuts using a dull blade. A dull blade will only lead to frustration and poor cuts and be a waste of time.
- Of course, sharp razor blades also tend to injure skin. Use one of the two possibilities shown on page 11 for protecting yourself from this by "taking the edge off" one side of the razor blade.
- Always perform several cuts while you're at it. Normally, your object is not so large, so several sections will fit under the cover slip at once.
- When cutting, you should always be sure not to push the blade through the object, but rather cut it by pulling. Otherwise, you may only end up with squashed cell fragments under the cover slip.

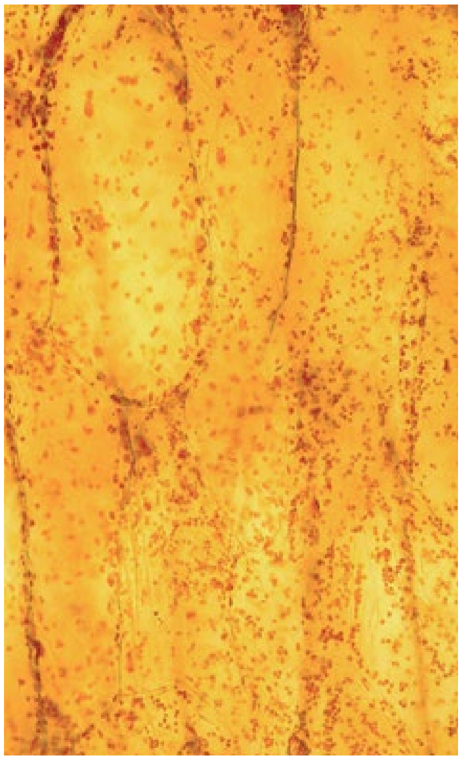
How to make thin cuts using the razor blade.

Red and Ripe

You can find different shaped chromoplasts in the fruit peels of the tomato or the bell pepper, for example. Even the orange color of a carrot is produced by chromoplasts. To prepare the object, you will need:

- a slide and a cover slip
- the pipette and water
- a razor blade (see page 11)
- the tweezers
- a kitchen knife
- a tomato, bell pepper, or carrot

You won't get far without properly slicing the object when preparing this slide (see "Cutting, Part 1" on this page). Using the kitchen knife, cut out a piece from the tomato (or another fruit or vegetable). It should be large enough that you are able to comfortably hold it in your hand and then cut it. Place the razor blade flat on the cutting surface and slowly cut toward yourself. Don't get discouraged if you don't produce a usable cut the first time. It's best to always go ahead and make several cuts and place them into the water drop on the slide using the tweezers. Usually, the cuts are thin enough along the edges that you will be able to recognize individual cells clearly. There, you'll probably also be lucky and be able to make out the individual chromoplasts in the cells as well. Depending on the object, they have a round, egg-shaped, or stretched-out shape and are colored an intense red or orange.



Cells of a red bell pepper with many small chromoplasts

6 Absolute Power

After every breath, you exhale carbon dioxide. Anytime anything is burned, regardless of whether it is gas inside an automobile motor or grilled hot dogs, this colorless gas is produced. Perhaps you've already heard carbon dioxide referred to as a greenhouse gas. Together with other gases, it is likely responsible for the heating-up of the Earth's atmosphere — like in a greenhouse. For plants, however, this carbon dioxide is a substance that is essential to their survival. They use it together with water and sunlight to produce dextrose (see also "Life in a Shoebox," page 15). This process takes place continuously without interruption during the day in every green plant. You might be asking yourself now, "What? Dextrose is a sugar. And it is supposedly produced in this process? Neither a cucumber nor a potato nor spinach tastes sweet! So where did all the dextrose go?" Did the plant perhaps already use it all up?

Starch — Power from Plants

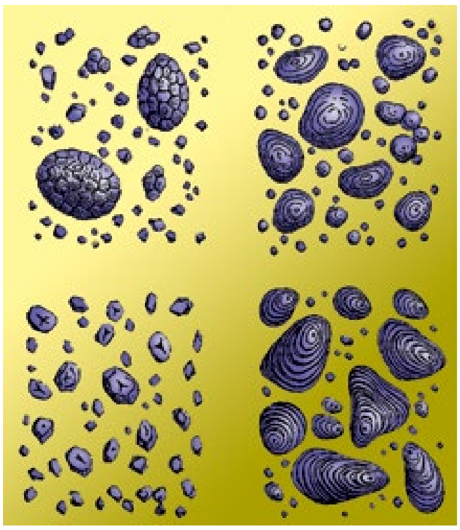
Even if a plant is constantly feeding on its self-made dextrose, there is still plenty left over in the plant — it's just in another form. Plants store their dextrose in the form of starch. To do this, lots and lots of sugar parts are simply joined together in a long, winding chain. And starches don't taste sweet. You can test this out simply enough by trying some flour. Flour is practically nothing more than starch. Depending on what plant the flour came from, it can also be referred to as wheat, corn, or potato starch.

You can perform a simple test for what foods still contain starch using iodine solution. Iodine and starch result in a deep blue coloring. If a lot of starch is present, such as in flour or in potatoes, then the color is so intense that it looks almost black. You should not eat the food after the test. Starch is stored in plant cells in the form of so-called starch granules. These are large clusters of starch chains. The starch granules will look different depending on what plant the starch is from.

TIP

When using the microscope, really sharp cutting tools are very important. But in order to ensure that you just cut the object of study and not your finger, you should prepare the razor blade appropriately with insulating tape or a cork. Follow the advice on page 11 and have an adult help you.

Rice starch (top left), wheat starch (top right), corn starch (bottom left), potato starch (bottom right)



Starch in All Forms

It's quite easy to study the various forms of starch granules under the microscope. You will need:

- slide and a cover slip
- the pipette and water
- a razor blade (see page 11)
- the dissecting needle
- the tweezers
- iodine solution (see tip on this page)
- starch-containing foods, e.g. potatoes, various types of flour, grains, garden beans, and so on
- a beaker

It will work well for all of these specimens to stain the starch granules with iodine. To do this, you can either place the specimen directly into iodine solution or you can subsequently exchange the water under the cover slip for iodine solution (see "Exchanging Solutions" on page 16).

Potato starch: In order to get potato starch onto the slide, simply scrape with the razor blade over the cut surface of a halved potato and dab it on a slide. After adding water or iodine solution and covering it with a cover slip, you should have a look at the starch granules at different levels of magnification. It works exactly the same with the other starch-containing vegetables.

Starch in different types of flour: It is simplest to stir a pinch of flour into a beaker with a little water and place a drop of the cloudy liquid onto the slide.

Starch from rice, beans, peas or other foods: For beans and peas, it's best to cut the seeds in half, pinch a little off from the inside using the tweezers or the dissecting needle, and rub it in a water drop or in a drop of iodine solution on the slide.

The Starch Leaves and Sweetness Follows

Perhaps you've seen a potato that has been waiting too long to be cooked? Pale yellow sprouts grow out of the tuber from which entire potato plants would grow if the potato were ever to make it out of the dark potato drawer and into the light of day. The energy and the "construction material" for growth come from the stored starch. You can test this out quite easily by allowing a (small) potato that has begun to sprout to grow in a bowl with moist paper towel covered by a box that does not allow any light in. Monitor the growth for a few days and check periodically whether there is enough moisture. As long as the sprouts continue to grow, the potato still has enough starch reserves, but over time it clearly shrivels up. In the dark, the sprouts remain yellow, and without light and chlorophyll, the plant cannot perform photosynthesis. Once the starch reserves are used up, then the plant urgently needs light or else it will die.

You can monitor the breaking-down of the starch in another way, too. Have you ever asked yourself why green bananas are tart while ripe bananas are so sweet? At the beginning, when you first buy them, they are still almost green and anything but sweet. After a few days, their peels become yellower and yellower and the fruit sweeter and sweeter. Starch is being broken down in them too.

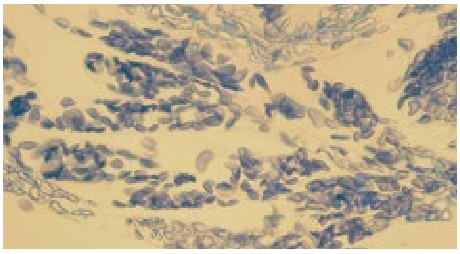
Metamorphosed Bananas

You can observe the breaking-down of the starch in bananas using your microscope. To do this, you will need:

- a slide and a cover slip
- the pipette and water
- a knife
- a razor blade (see page 11)
- the tweezers or the dissecting needle
- iodine solution (see tip on page 10)
- a green banana

Get a banana that is as green as you can find. Using the knife, cut a thick piece off of it and drip a bit of iodine solution onto the cut surface. Using the tweezers or the dissecting needle, you can remove several pieces from the stained area and wipe them in a drop of water on the slide. Work your way step by step to the higher magnifications. The starch granules are most visible under the highest magnification (400x).

Repeat the experiment after a few days. In the meantime, the rest of the banana has ripened. Examine the ripened banana as described above and compare the results.



Starch granules in the cells of banana fruit flesh

In the unripe banana (bottom), the iodine solution turns blue-black, whereas it remains unchanged in the ripe one (top).

Did You Know?

Bananas and other exotic types of fruit are harvested in the producing countries in a completely unripe state? But naturally only if they are going to be transported far away. They ripen only on the ship — or in your kitchen. Consequently, fruits usually have a much more intense taste in the countries in which they are grown, since they are allowed to ripen on the tree or vine.

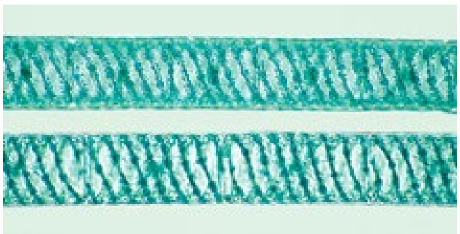
7 The World on a Tiny Scale

Up to now, you've used your microscope to look at small sections of large organisms. But there is another, otherwise invisible world for you to discover. Invisible to the naked eye, a colorful and fascinating variety of microscopic plants and animals can be found in water barrels, flower vases, and ponds. Green plants, mostly algae, with uniquely shaped chloroplasts make up many animals' diets. Extremely tiny crabs or cnidarians, in turn, have a go at the plant eaters. You can find an entire microscopic world of predators and prey inside a water droplet.

The alga Volvox. Image: Stephen Durr

The unbelievable variety of animals and plants that you can find in water makes it difficult to give just a quick overview. Even seasoned biologists have difficulty identifying every organism under the microscope by name. It is the microscope experts who often best know their way around in this world. With your microscope, you can study a wide variety of habitats and perhaps become an expert yourself. Here are a few tips and tricks on how and where you can find worthwhile specimens from watery habitats, and how to prepare them for viewing.

Lots of types of algae live in this kind of a pond.



The alga Spirogyra with spiral-shaped chloroplasts

Searching and Finding

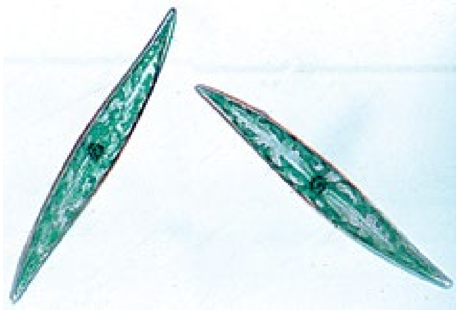
Looking at tap water isn't worth the trouble. Our drinking water is subject to strict cleanliness guidelines and is therefore mostly germ- and microbe-free. The observations begin to get interesting when you are looking at waters that don't exactly entice one to bathe in them: ponds and puddles with green alga growth offer a true paradise for interesting creatures to investigate.

You can take samples from the water in a number of different ways. Just like in the human world, the inhabitants of lakes and ponds have a wide variety of lifestyles and can be found in very different places. Many algae float freely in water in order to get as close to the light as possible. Water fleas rudder through the water with their antennae and use their legs to filter out small algae and animals.

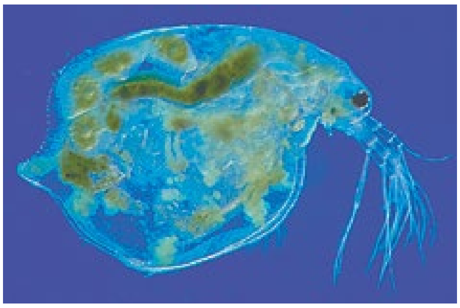
A limnologist, which is someone who studies inland waters like lakes, ponds, and rivers, would fish out these animals and plants with a very fine net (a plankton net). But you can also catch them by simply taking a water sample using an empty jelly jar. Some animals can already be seen with the naked eye. These "microscopic giants" can best be observed with the special slide with the concave trough. The problem of catching too few of these tiny creatures and consequently having to search for a long time with the microscope can be solved with a so-called hay infusion (see page 24).

Many plant and animal species settle as so-called aufwuchs (from the German term meaning "upgrowth") on rocks or underwater plant parts. Many algae and even some animals prefer a permanent, fixed home. The advantage is obvious: The danger of simply being washed away by currents is lessened. But what does an animal do that has grown in place but feeds on other animals? Precisely — it grabs hold of whatever happens to swim by. One example of a feared predator from the pond is the hydra, a freshwater polyp. Using its tentacles, it fishes for its food. But that's not all! To make matters worse, this animal also has small harpoons loaded with toxin with which it spears its prey in order to paralyze and ultimately kill it. While these monsters of the pond can be found with the naked eye — some animals get up to 2.5 centimeters in length — their small prey can only be seen under the microscope.

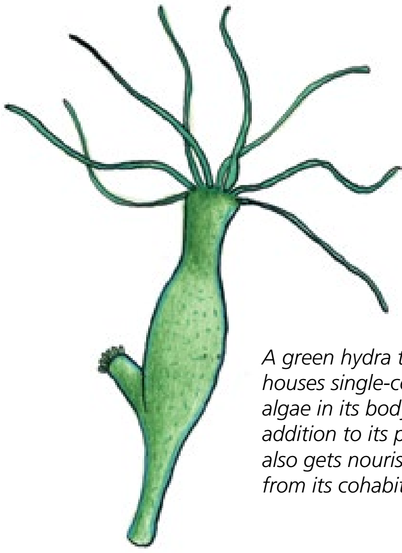
If you scrape the film off of rocks in order to collect pond specimens, you will probably unwittingly destroy many of these organisms. So follow this tip: Simply let algae and animals grow directly on the slide.



Diatoms



Water flea



A green hydra that houses single-cell algae in its body. In addition to its prey, it also gets nourishment from its cohabitants.

Fishing without a Net

You can fish for microscopic algae and animals in your rain barrel or, even better, in a forest pond or your garden pond.

You will need:
- 4 slides
- 3 bottle corks
- a knife
- a string (the length depends on the depth of the location, see below)
- a plastic bag filled with rocks or sand
- kitchen towels (or other paper towels) and cover slips later for the microscope

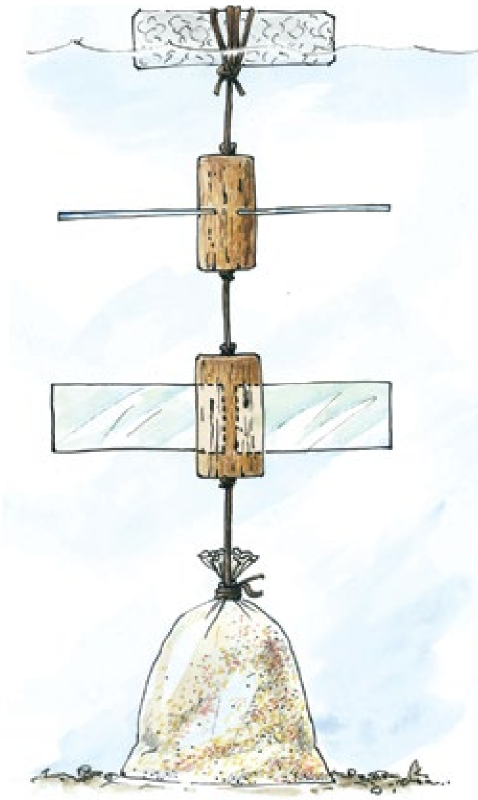
Assemble a "fishing" apparatus as shown in the figure. To do this, fill the plastic bag (a zip-lock bag, for example) with rocks or sand and tie it closed at the top using the string. The string needs to be long enough so that it reaches from the bottom of the pond or water barrel (wherever your "plastic bag anchor" will be lying) up to the surface. So, simply measure the depth using a stick, add another 30 centimeters to be on the safe side and cut the string accordingly. Now the glass slides are stuck into the corks. To do this, make approximately 1.5 centimeter cuts into the corks from both sides with a knife, then stick the slides into them. Have an adult lend you a hand with this tricky and delicate task.

Prepare a second cork with slides and tie both corks to the string with spacing of about 10 centimeter. Now lower the whole thing slowly into the experimental water until the plastic bag is sitting on the ground. Now you just need to attach a cork or piece of styrofoam to the upper end of the string as a bobber — and wait for a few days.

As a rule, in the summer, enough organisms will have settled on the slides after one to two weeks. You can then transport them in a bucket of pond water and observe them at home under the microscope. To do this, pull a slide out of one of the corks and clean off the bottom side with a paper towel. Place the slide onto another piece of paper towel with the clean side down and let it dry a little before you put the cover slip in place (or several cover slips next to each other) and put it under the microscope.

At different magnifications, observe the colorful microcosmos that has settled on your slide.

Later, you can put the apparatus in the pond again, collect more specimens, and then observe how the composition of the aufwuchs has changed over time. You could also study different areas of the pond. For example, you could compare one location in the pond that is in full sun with one that is in the shade of overhanging branches.



"Fishing" apparatus

Paramecia (stained prepared slide)

You can keep the pond samples alive for an extended period of time. Cover a jar or bucket containing the slide and the original water loosely with a piece of cardboard. This is just to protect against dust. However, oxygen needs to be able to get in; otherwise your guests from the pond will die! But the water is automatically supplied with fresh oxygen by algae, too. They, however, need light in order to survive. You should just avoid putting the jar or bucket in full sunlight, since the water will get too warm, which the organisms don't like. A window sill in a north or east window is a good place for your micro-aquarium.

The Hay Infusion — A Classic

You can also grow your algae and animals at home on the window sill.

You will need:

- a little hay (or dry grass, wood shavings, and straw for small animals)
- pond water
- a canning jar (0.5 – 1 liter)
- a kitchen hand towel
- a kitchen sieve
- a pipette
- and of course your microscope with accessories (slide, cover slip, …)

Into a large jelly jar or canning jar that has been rinsed out several times with hot water, pour some water from a pond, a rain barrel, or an aquarium over some hay (not more than a small handful) up to about 5 centimeters below the brim. For the reasons outlined before, cover the jar loosely with a piece of cardboard. The hay will be used by your guests as a source of nourishment. Here — as is so often the case — more is not necessarily better: Too much hay spoils the set-up. Place your hay infusion into a lit place (a north facing window) and give your guests some time to populate their new living space. You can take samples at an interval of 3-4 days to check how the living space is coming along. Are there suddenly new species that you hadn't encountered before? Do some species eventually disappear from the picture over the course of time?

Living paramecium from the hay infusion

A typical inhabitant of such hay infusions is, for example, the paramecium, of which you will also find a few stained specimens on a prepared slide in your kit. The name of this creature, which measures from 50 to a maximum of 300 micrometers, comes from the Greek word paramekes, meaning oblong or oval. From the prepared slide, you might be able to guess how these creatures propel themselves. The entire cell is covered by approximately 10,000 very fine hairs, also known as cilia. They row together rhythmically like oars on a rowing shell so that the "ciliate" (an organism with cilia) is able to move freely through its living space. This kind of ciliate can of course not see where it's swimming — after all, it is only composed of a single cell. If it bumps into a barrier, then it simply changes the direction in which the cilia beat for a while and swims backwards in the "hope" of going around the barrier when it swims forward again.

Dark spots are often visible on the inside of the cell. These are either the cell nucleus or the "stomachs" of the paramecium (biologists refer to these as food vacuoles or vacuoles). It feeds primarily on bacteria that it ingests enclosed by a little bubble. In these bubbles, the bacteria are digested and all the nutrients are absorbed into the cell. The paramecium then releases the indigestible waste back to the outside. One astounding thing here is that the absorption of the nourishment and the excretion of waste take place at very specific places in the cell. So you could say that a paramecium has what you could call a cell mouth and a cell anus. Several different types of paramecium live in the indigenous ponds, pools, or even puddles. So chances are good that you will come across a living specimen sometime during your research work.

This kind of hay infusion produces lots of exciting objects.

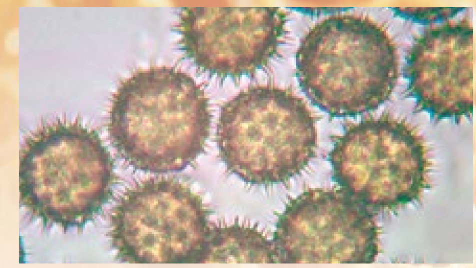
8 Food Detectives on the Case

Pretend for a moment that you are an archaeologist excavating artifacts at an Aztec pyramid. The Aztecs were an indigenous people who lived in what is now Mexico. Their powerful empire had its heyday more than 500 years ago in the 14th and 15th centuries. The Spanish conquerors of the New World destroyed the empire in the years 1519 – 1521. Now, suppose you found an ancient clay pot full of honey during your archeological dig. What could this honey tell you about the Aztecs or the times during which they lived? What secrets could a simple substance like honey hold? If we performed a microscopic analysis of the honey, we might uncover some important and revealing particles inside: pollen grains.

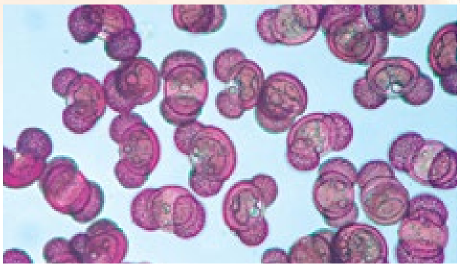
An Aztec pyramid

Pollen Grains — The Business Cards of Blossoms

During their flight from blossom to blossom, honey bees collect nectar from which they produce the honey. Besides the nectar, however, they also collect pollen which, when kneaded with the nectar, serves as food for the bee larvae. Have you ever observed a bee on the hunt for blossoms? They often emerge from a flower dusted from head to toe with yellow pollen, so it's no wonder that a grain or two of pollen ends up getting into the honey.

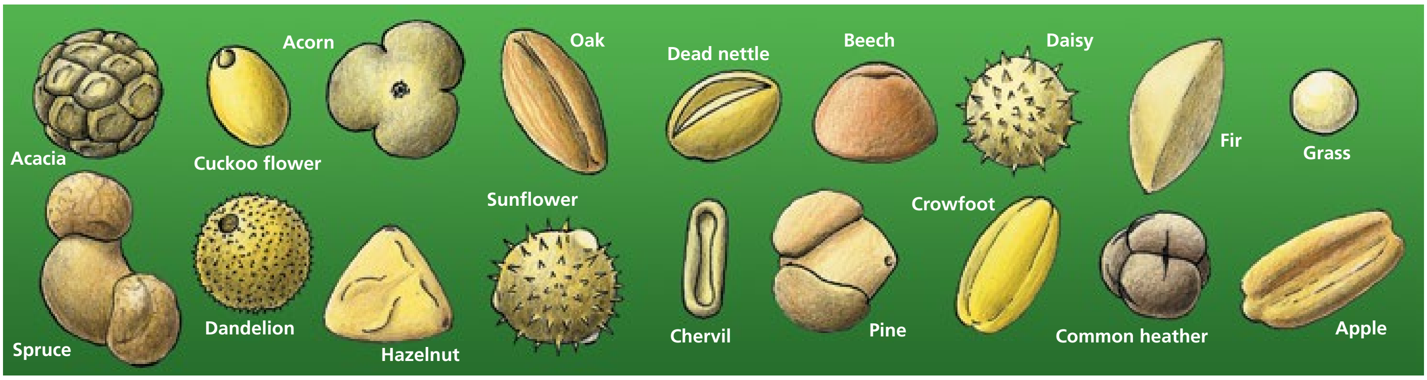


Pollen from a sunflower (above) and a pine (below)



But all pollen grains are not the same. The round, thorny pollen of a sunflower, for example, looks completely different than the pollen of a pine or a spruce, which has air sacks. Some examples of how different pollen grains look can be found on this page and on one of the prepared slides in the kit.

The fact that the pollen grains from different plants have very characteristic shapes, surface structures, and sizes has led to the existence of pollen grain experts. With the aid of a microscope, they study the pollen composition of a wide variety of samples — to determine, among many other things, the country from which a honey originated. You can imagine that it is no easy task to know the appearances of all of the pollen normally occurring in honey and comparing them with honey samples — especially if you consider that it's pollen from plants all over the world!



Did You Know?

The honey bee is not only one of the oldest but is also one of the most useful animals in the world today. Stone-age rock paintings show that honey was taken from bees over 8,000 years ago. The oldest man-made bee habitations can be found on the island of Crete. They are about 3,500 years old!

In this rock drawing, honey is being take from a beehive.

Pollen Grains in Honey

In order to dive into the bizarre world of pollen grains, you will need:

- a slide and a cover slip
- water
- a cup and a teaspoon
- some honey
- a pipette

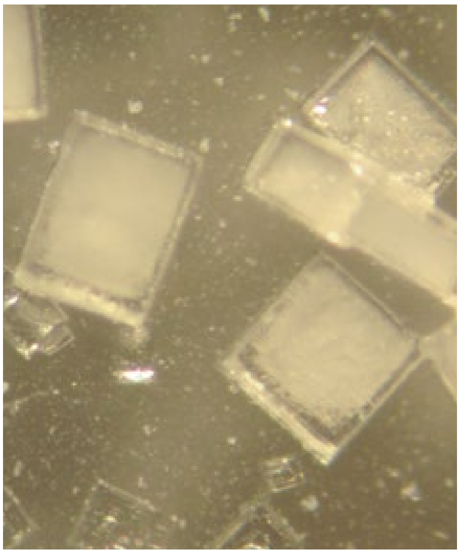
When working with honey, the utmost care should be exercised. Not because it is dangerous, but because you don't want your microscope to become a sticky mess. But surely you've already grown accustomed to the clean and routine-filled manner of working like a true microscopist, so you won't have any trouble. In order to prepare the honey solution, take about one teaspoon of honey and stir it in the cup with about three teaspoons of water. Use the pipette to transfer a drop of the cloudy solution onto the slide — and off you go! Examine the honey solution at different magnifications and find out how many different types of pollen there are. Maybe you can even match some of the pollen types to a plant species if you compare them to the overview on the previous page. After concluding your investigations, you should dispose of the honey solution in a drain. It is neither suitable for consumption nor should it be put back in the honey jar.

Now, let's get back to the Aztec dig. Assume that the old clay pot full of honey was found in the grave of an Aztec ruler. As a burial offering, his people gave him this pot of honey to take with him to the next world. The honey would surely no longer be edible today. But the pollen grains in it would very likely still be there. Pollen grains have a stable covering, so they are able to survive several centuries, provided that the storage conditions are suitable. Scientists take advantage of this fact to draw conclusions about the vegetation in earlier times. From the honey in the clay pot, a specialist could say what plants were in bloom hundreds of years ago when the bees collected nectar for the Aztec ruler's honey. In this way, pollen grains are a window to the past.

A bee collecting pollen on a willow blossom

The Salt in the Soup

The following wouldn't be a investigation for an Aztec archaeologist, but rather for a chef or baker: Suppose there is a crystalline, white substance in a bowl in the kitchen. Is it salt or sugar? One easy way to answer that question would be to taste it. But what if you didn't know if it was even edible? And if you were to solve the problem by tasting, you would also deprive yourself of aesthetic pleasure for your eyes. Under the microscope, crystals are astonishingly regular and beautiful structures — and sugar and salt can indeed be differentiated on the basis of the shape of their crystals! While crystals that are as regular as the sodium chloride crystals in the prepared slide are not so simple to produce, interesting results can be achieved with very little effort nonetheless.



Common salt forms regular, rectangular crystals.

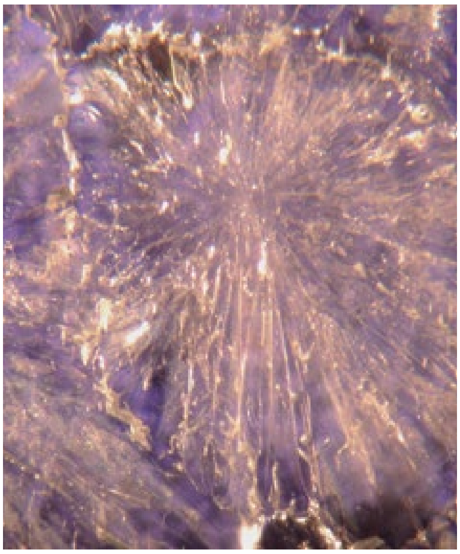
Growing Microcrystals

In order to grow microscopically small crystals directly on the slide, you will need:

- a slide
- the pipette and water
- the dissecting needle for stirring
- common salt, sugar, mineral (inorganic) fertilizer (such as fertilizer for potted or garden plants). When using mineral fertilizer, heed the warnings on the packaging and have an adult help you!

Respectively place about three grains of salt, sugar, and fertilizer on the middle of a slide. You can already check now whether the grains can be differentiated with a microscope. This time, you can even choose whether you would like to work with the magnifying glass (macro-view with incident light) or the microscope (with transmitted light). Try both — you'll see that both are worthwhile! Now drip two or three drops of water onto each slide, right onto the grains. If you stir gently with the dissecting needle, they will dissolve more quickly. Now you'll have to wait until the water has evaporated again. Depending on the temperature, that may take several hours. Once all of the water has evaporated, you will be able to see a white crust with the naked eye where the clear water drops had been. Under the microscope, however, the crust turns out to be a "crystal garden." With some luck, you'll find some larger crystals that are as nicely formed as the ones in the prepared slide.

Another tip: The slower the water evaporates, the greater the possibility of beautiful crystals forming. So it's not a good idea to help the evaporation along using a blow drier or radiator!



Sugar often crystallized in irregular shapes. Star-like structures are visible here.

Did You Know?

Mineral water got its name because it contains minerals — salts, to be precise. You can allow one drop each of tap water and mineral water to dry next to each other on a slide and have a look at the difference under the microscope.

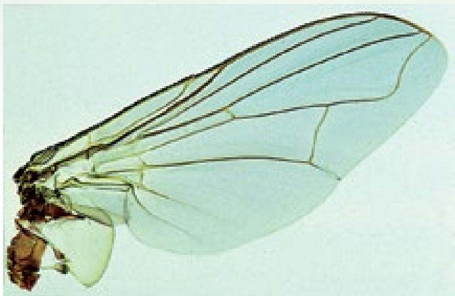
Sea salt recovery in Portugal. As the water evaporates, fine salt crystals are left behind. Image: Marisol

9 The Vast Kingdom of the Insects

Insects are by far the most successful group of animals in the world. There is almost no living space that they have not occupied since their emergence about 300 to 400 million years ago. From the snow- and ice-covered Himalayas to the hot, dry deserts of Africa, from the Antarctic with temperatures of below -35 °C to the open sea to 50 °C hot springs, a tremendous variety of insects has exploited living spaces everywhere. Of the 1.4 million animal species known today, 1 million of them are insects, and insect researchers suspect that there are another 1 million "new" species waiting to be discovered. It is truly an animal group of superlatives.

And yet no insects are known to be much more than 30 cm long (the stick insect Pharnacia serratipes reaches a body length of 33 cm!). Why is it, that such successful animals are generally no bigger than a few centimeters?

The goliath walking stick (Eurycnema goliath) grows to more than 30 cm in length.



Wing of a house fly

Did You Know?

Many species of insect can only be distinguished based on their wings. Some insects are so similar to each other that the pattern and appearance of the veins in their wings have to be used as the sole distinguishing feature.

Sizing Up Insects

It could be said that their success is often a result of their small size. Insects are often capable, precisely because of their tiny size, of making use of living spaces that would be unavailable to them if they were larger. For example, the parasitic Trichogramma wasps are so tiny (one of the largest species of that genus has a wing span of 3 mm!) that their larvae are able to grow in the eggs of other insects.

But there are other reasons for why larger species of insect have not developed over millions of years. In looking at the wings of many insects, probably the most important reason for this becomes clear.

Delicate lines run through the filigree wings of insects: the wing veins. In some insect orders such as the butterflies, for example, these are only covered by scales. The name already gives away a bit of what task these "veins" are charged with. You know that all animals need oxygen to survive. The land vertebrates have lungs for this purpose. Aquatic animals such as fish get the oxygen they need from the water with the aid of their gills. Once the oxygen has been breathed in, it is transported by a special bodily fluid — the blood — and distributed throughout the body.

The insects have developed a completely different principle for supplying their bodies with oxygen. If you look at the sides of the rear body of an insect using a magnifying glass, you will see tiny little dots. These dots, called stigmas, are actually little holes through which fresh air gets into the insect's body. Starting at these stigmas, a richly branched system of tubes extends through the entire insect body, even into the wings. The wing veins are thus a component of the fresh air supply system in insects. The distribution of oxygen in the blood of larger animals is possible because the blood is constantly pumped through the body by the heart. Insects don't have such a pump system. While the circulation of air in the tubes is supported by bodily movements, this principle is not sufficient for transport over long distances. So if the insect were too large, then all of the body parts would be constantly under-supplied with oxygen. Consequently, insects' size must remain within certain limits.

Insect Wings

It goes without saying that we only use already dead animals for the examination of insects. For example, you will find plenty of material for observation on cellar steps, in spider webs, windowsills, or on the radiator grille of automobiles. To observe an insect wing, you will need:

- a slide and a cover slip
- tweezers (your tweezers will work here, too, but so-called spring steel tweezers are even more practical for working with insects)
- an assortment of insect wings

Insect wings can also be laid dry on the slide and, as needed, covered with a cover slip so that they are not blown away by a breath of wind. Both observation methods (transmitted light microscopy and magnifying glass mode with incident light) give interesting results here. Besides the wing veins, you can also discover other things on the wings. Very often, the wings of insects are covered, for example, with tiny hairs. Butterfly wings also have many colorful scales on them.

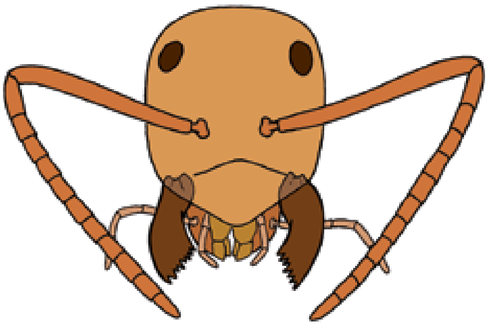
Veins of an insect wing and butterfly wing scales

Sting, Bite, or Lick?

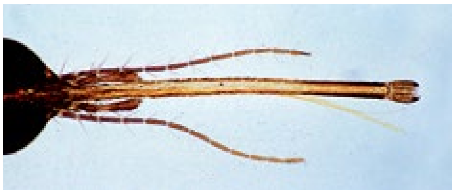
As varied as the living spaces of the insects are, the insects themselves are of course just as varied. One of the few characteristics that they all have in common is this: All insects have six legs (spiders have eight legs and therefore are not included among the insects). When they don't happen to be flying, then they're moving along on their six legs in search of food. There are several unique features here too. Insects take in their food with their specialized mouthparts which, incidentally, are not in the mouth — as they are in humans — but rather in front of the mouth. Depending on what kind of nourishment the insect prefers, its mouthparts are also adapted to their respective requirements.

A butterfly feeds from the nectar of blossoms, which is sometimes buried deeply in the blossoms. Consequently, it needs a long proboscis with which it can suck its food from the hidden corners of a bloom. To keep the proboscis from getting in the way during other activities, the butterfly rolls it up like a fire hose. The mosquito also uses sucking to feed — but in this case, it's the blood of other animals. First, however, it has to poke through the tough skin of its victim in order to get at the desired juice. The mosquito's mouthparts are specifically designed for both poking skin and sucking up liquid food. Ant soldiers possess true pincers with which they can fight, break things down, or carry things.

The proboscis of a butterfly



The mouthparts of an ant



The biting apparatus of a mosquito

Mouthparts of Insects

Use your microscope to have a closer look at the variety of mouthparts of various insects. You will need:

- a slide
- tweezers
- the dissecting needle

The objects are generally too thick to fit under a cover slip. For this reason, simply place your object on the slide and observe it at the lowest magnification (40x). Here your microscope proves itself as a true jack of all trades! This is because you now have the possibility of looking at the object with the magnifying glass (with incident light) or the microscope (with transmitted light). Try it out and, in that way, gain the best possible insight into the mouthparts of the insect you're studying!

Can you match the mouthparts under the microscope up with one of the types just presented?

Did You Know?

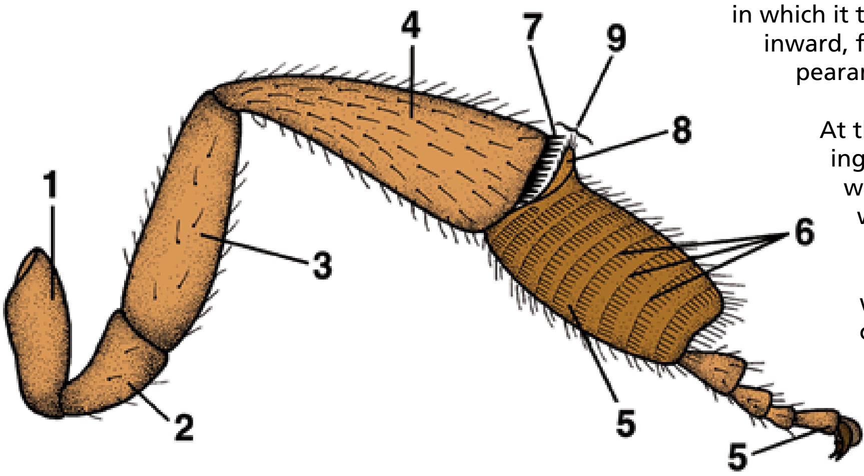
Only female mosquitoes suck blood. They need our blood to feed their young. Although the little males do possess biting and sucking mouthparts, they only use them to poke into plants and suck out the juice.

The Fascinating Structure of Insect Legs

The fixation disc and claws on a fly tarsus

The legs of insects have come to be every bit as varied as the mouthparts. In many cases, it would be presumptuous to regard insect legs as being mere means of transportation. For example, the honey bee has three different tools on the rearmost of its three pairs of articulated legs: a brush to brush the pollen from its fur, kneading tools for processing the collected pollen into transport packages, and a little basket consisting of bristles in which the pollen packages are transported.

The hind legs are especially interesting. It contains ingenious devices that the bee uses when collecting pollen. When a bee flies out of a blossom, oftentimes it is covered from head to toe with yellow pollen. On one of the leg segments, it has a thick bristle coat, the brush that it uses to brush the pollen out of its fur. The brushed-out pollen is stuck together with honey and kneaded in the pollen pincers. You've probably already seen how bees transport the pollen that has been kneaded into pollen packages. Namely, the bee also has a basket in which it transports the pollen. Long brushes that are bent inward, forming a basket, often give the loaded bee the appearance of having yellow pants on.

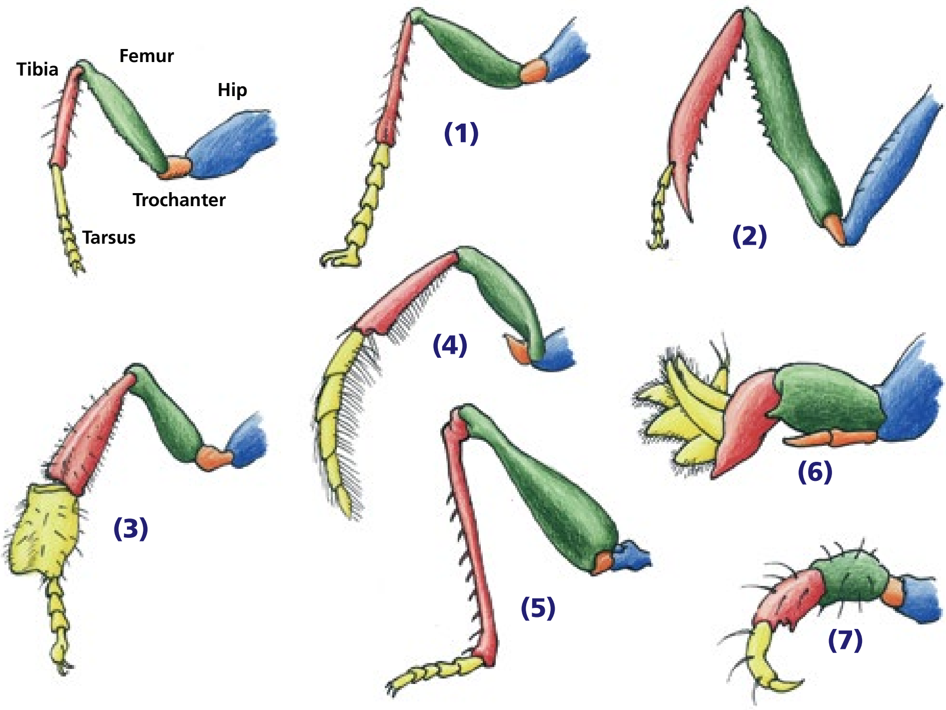


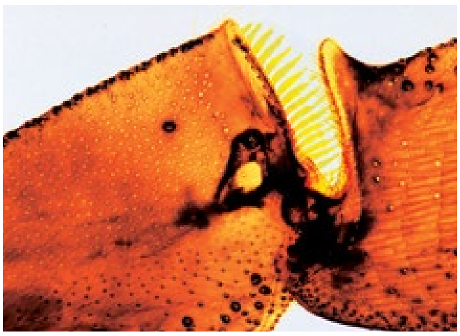
At the end of a bee's leg, there are even more astonishing things to be found. All six legs end in two claws each with which the bee can hold tightly onto surfaces, even when upsidedown. Using these claws, it would not be able to hold onto a very smooth surface, however. This is why bees — and many other insects as well — have cushions between their claws that are covered with little hairs. Using these tiny hairs, a bee can hold tightly onto even the smallest unevenness and is therefore able, for example, to walk up a window pane.

In the figure below, you will find even more examples of different insect legs. The only thing that all insect legs have in common is the fact that they have articulated (segmented) legs. Because of this common trait of insects, as well as centipedes, millipedes, spiders, and crabs, all of these animals are grouped into the common group of the arthropods (from the Greek for "jointed feet").

The leg of a honey bee; as viewed through the microscope; and above as a schematic drawing: (1) hip, (2) trochanter, following the narrow femur (3) is the triangular, oblong tibia (4). The first of the five tarsus (foot) segments (5) is strongly prevalent and equipped with the scopula (6). Located between the tibia and the first tarsus segment are the pollen comb (7), pollen pusher, (8) and pollen pincers (9).

Primary construction of an insect leg:





Pollen basket at the joint of a honey bee

Different insect legs: House fly (1), praying mantis (2), honey bee (3), creeping water bug (4), grasshopper (5), mole cricket (6), and head louse (7)

10 Mushrooms: Plants or Animals?

At first glance, the question in the chapter title may strike you as silly. The closer one looks at a mushroom, however, the harder it becomes to answer this question. In a very strict sense, mushrooms fall somewhere between animals and plants. This is why they are not classified under either of the large kingdoms, but rather make up their own kingdom, the fungi. But you might say next that a mushroom is very clearly a plant. After all, mushrooms grow in the ground, cannot move, and have an appearance that is completely unlike any animal. But do they look that much more similar to a plant? What differentiates them so much from a plant that makes them belong to a different group altogether?

Fungi — Specialized Recyclers

You learned in Chapter 5 how plants feed themselves. So how does a fungus get its food, anyway? Fungi, unlike plants, are not capable of absorbing the sun's energy and converting it into life energy. It's lacking the essential components for this: the chloroplasts. Like us, fungi nourish themselves off of other organisms. This is why many fungi are also scroungers, parasites, or even pathogens. But they also take on one of the most important tasks on our planet: They decompose dead organisms. So one could say that fungi are an important part of the cycle of life. In this way, they also ensure that the stored-up life energy does not go to waste. For the fungi then serve as food for other organisms. Just imagine how the forest would look if nothing ever removed the old, dead trees!

A tree trunk that is overgrown with tree fungi

A Unique Texture

In the case of a chanterelle mushroom, you can taste where it came from. Its wonderfully earthy taste is an immediate reminder of the aromatic fragrance of a forest in late summer. Many people don't like mushrooms. However, that's not so much because of how mushrooms taste as their texture when you bite into one. Their texture is quite different from that of a bell pepper or a leaf of lettuce. The cause for this special consistency can already be figured out with the naked eye. Under the microscope, it becomes clear once and for all what separates the fungus from the plant leaf.

The entanglement of fungal hyphae remains invisible underground. We usually only see the above-ground fruiting bodies.

The Inner Life of Fungi

To explore the inner life of a fungus, you will need:

- a slide and a cover slip
- water and the pipette
- the dissecting needle
- a kitchen knife
- a button mushroom or another kind of culinary mushroom

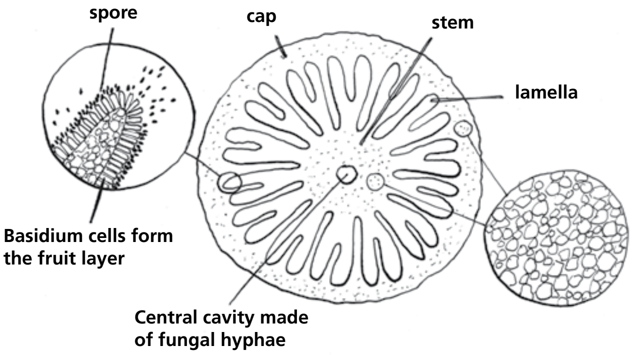
Cut the entire mushroom using a knife along its length into two halves and use the tweezers to pluck a bit from the inside of the stem. Usually, fungal material obtained in this way is still too thick to be observed under the microscope. You should therefore pluck the piece apart even more using the tweezers and a needle in a drop of water on the slide. Cover your specimen with a cover slip and examine it at gradually higher magnifications until you reach the highest one. Under the microscope, you can see that the fungus is constructed of individual, long threads, the so-called fungal hyphae. These threads are woven together and hence produce a stable, net-like structure. But this is not a solid tissue complex as is the case with plants. This is how fungi differ clearly from the compact structure of plants.

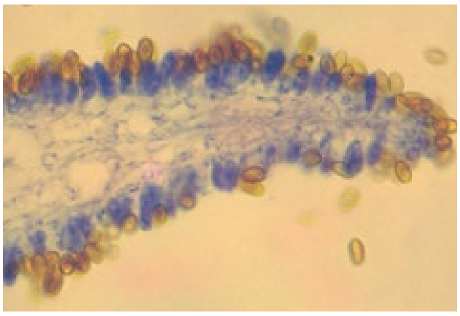
Many fungi have lamellas on the underside of their cap (head) on which the spores are formed.

Fungal hyphae run through the entire forest floor but are invisible to us. Only in some places, and when it's warm and moist enough, do fruiting bodies grow out of these fungal threads — which we then refer to as actual mushrooms in our everyday language. So what we see of forest mushrooms is actually only the "tip of the iceberg," so to speak.

Although the stem and cap of a mushroom are referred to as a fruiting body, fungi do not spread by means of fruit and seeds like most plants, but rather by means of spores. In the case of a button mushroom, you will see many thin lamellas on the underside of the cap. It is in these lamellas that tiny little grains, the fungal spores, are formed. They are so light that they are carried by the wind in all directions. If they land in a suitable spot, then they germinate into new fungal threads and form a new fruiting body when the time and conditions are right.

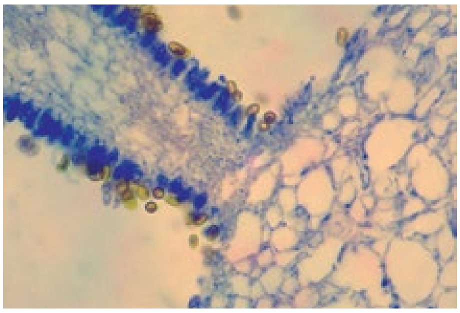
You can also study these spores and the lamellas using a button mushroom or another culinary mushroom. For this, pluck the lamella of a mushroom that is as young as possible and place it under the microscope. Or try to make a thin cross-section of the cap of a young button mushroom. What you will see there is explained below using the example of another fungus along with microscopic photographs.





Lamella with spores

Top view of the cap cross-section



Point at which the lamella is attached to the stem

A Fungus Introduces Itself

The photos to the right show a thin cross-section through the cap of an inky cap mushroom (Coprinus), which is commonly found in forests and gardens.

For the pictures, an entire cap from a young and very small mushroom was cut crosswise through the stem and crosswise through the lamellas. And what can you see in the pictures?

In the middle of the images, you can make out the cut fungal threads which extend from the ground in the stem upwards and finally form the cap. Starting from this central point the lamellas extend outward. At lower magnification, the lamellas look as if they were surrounded by a black fringe. At higher magnification, you can finally see that these are actually vast numbers of small, dark dots, the fungal spores. While the spores are still ripening, the lamellas are closed. Only when they are ripe do they open up, and the spores are then released freely. You can also see very similar structures under the microscope yourself, for example in a button mushroom.

Friend and Enemy

Many fungi are a true enemy of plants and animals, because they grow where they shouldn't: on living organisms. In some cases, they can cause great harm to the organism on which they grow as a pathogen. For us humans, fungal diseases are normally not very dangerous. As long as our body is healthy and in good condition, it is able to successfully defend itself against the establishment of fungi. If a fungus, such as a foot fungus, does take hold, it is generally a nuisance but not a hazard.

This is not the case with plants. The majority of all plant diseases are fungal diseases. If a plant is damaged somewhere, for example because an animal has nibbled on it, then fungal spores — which constantly surround us in great numbers — can penetrate into the plant, germinate, and wreak lots of havoc.

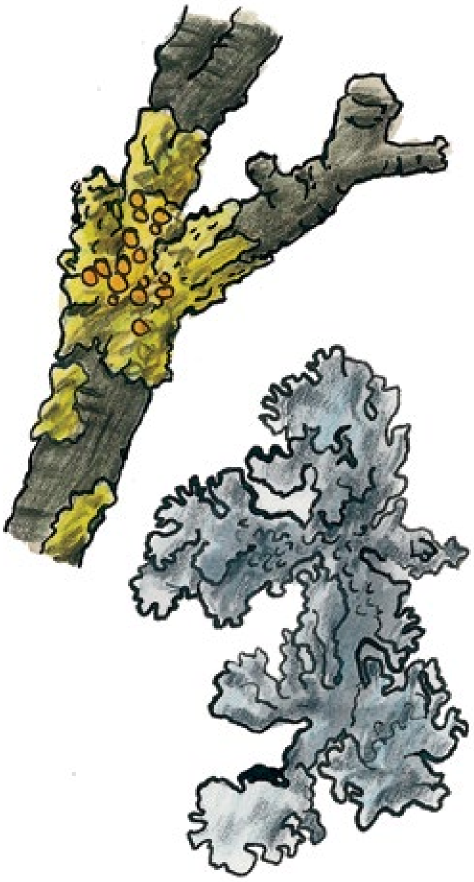
But fungi are not fundamentally plants' enemies. There are also fungus-plant partners that cannot survive without each other. This is referred to as symbiosis. One example of this can be found in lichens.

The fungus known as pear rust is a plant disease and causes these rust-brown spots.

Did You Know?

We have a fungus to thank for our first big victory against pathogenic (illness-causing) bacteria. In 1928, bacteria researcher Alexander Fleming discovered by coincidence that the mold fungus known as Pencilium notatum produces a substance that kills bacteria. This substance was named penicillin after the name of the fungus and was the first antibiotic used by mankind.

When observed more closely, a lichen is a community consisting of a fungus and many single-cell algae. The algae converts energy from the sun into food for the fungus, and the fungus makes it possible for the algae to live out of water in the first place. The success of this living arrangement is proven by the tenacity with which lichens inhabit even the most unpleasant of living spaces, including on walls and stones, on tree trunks and even on bare rock in the high mountains where they are exposed to wind and weather and lead a meager existence. Such lichens grow extremely slowly — only a few millimeters per year, in fact, and sometimes even fractions of a millimeter. So during your next nature walk, when you see a lichen, you can try to estimate how old it is.



Lichens live on trees and stones.

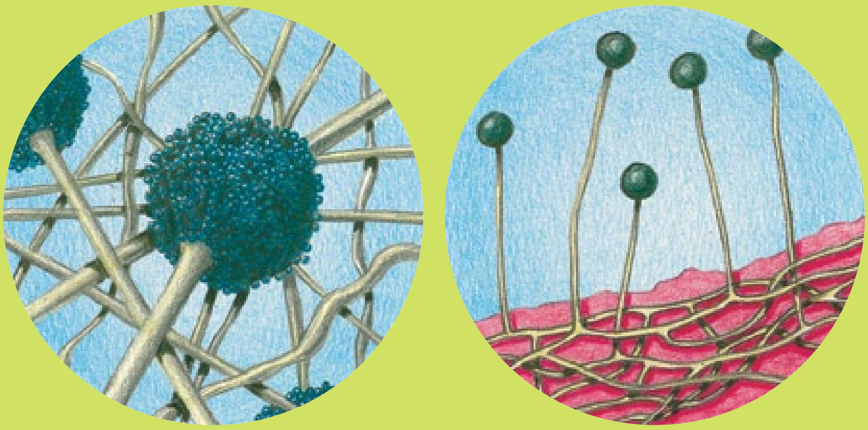
Cross-section through a lichen with fungal hyphae and alga cells.

Pretty Mold

It happens time and again: Fungal spores get into a jelly jar or bread box and germinate on the foods. Up to now, it's just been a hassle because the spoilt food had to be thrown out (and that's of course the right thing to do). But it's also worth having a look at mold fungi under the microscope. To do this, you will need:

- a slide and a cover slip
- the pipette and water
- a razor blade (see page 11)
- the tweezers
- a small sample of mold fungus, from a piece of moldy bread, for example

You can pluck a little of the fungal hypha mesh on the moldy food with the tweezers and transfer it to a drop of water on the slide. After putting the cover slip in place, examine it under different magnifications. Besides the thread-like fungal hyphae, you will also find various types of fruiting bodies that have very different shapes. The capitulum mold shown here is but one example from the wonderfully varied world of mold fibers.



Very different types of mold can be found on different types of foods.

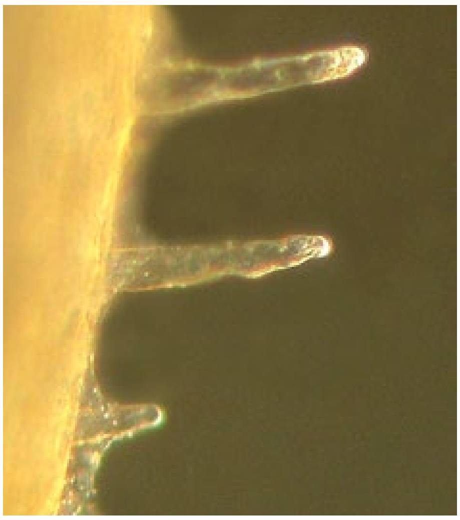
11 How Does Water Get into a Watermelon?

A watermelon is made of up to 95% water. So it's the ideal thirst-quencher for hot summer days. But have you ever wondered how the water gets into the melon in the first place?

From the Ground into the Roots

Have you ever seen a tree that was uprooted by a storm? Thick, twisting roots are visible. In the case of a stately oak tree, the ripped-out roots can sometimes protrude upward over 2 meters. Even so, the parts of the root system exposed here are only a tiny fraction of what's under the ground. Even before the storm, these powerful, wooden roots were no longer capable of absorbing water. They merely served to anchor the tree in the ground. In order to absorb water, a tree has extremely fine, microscopically small root hairs through which the groundwater is able to travel into the roots. But these root hairs are located at the very end of the long root system and are so sensitive that they are mostly left behind when the roots are torn out.

The root hair zone of a cress seedling



Root hairs of a cress plant

Root Hairs

It is generally not possible to pull a full-grown plant out of the Earth along with the zone in which the root hairs are located. Consequently, you are better off using the roots of seeds that have just sprouted. You will need:

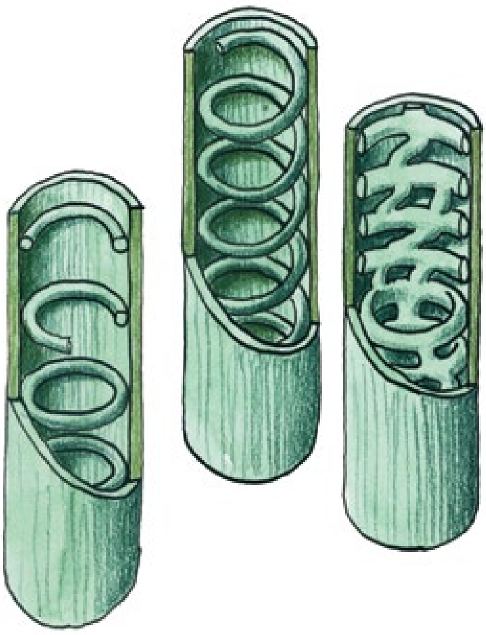
- cress seeds (they can be found in the garden center or supermarket)
- an empty margarine tub (you can also use a small bowl or a saucer)
- cotton wool or tissues
- a slide and a cover slip
- the pipette and water
- a razor blade (see page 11)
- the tweezers

In order to get the cress seeds to germinate, place some cotton wool or tissues into an empty margarine tub, wet it well with water, and place the seeds on the wet cotton or paper. Put the tub in a window. After one or two days, the first seeds will sprout, and little cress plants will emerge. As soon as you see the first little white roots, you can remove a young germinating seedling and separate the roots from the rest of the plant using a razor blade. Place the root in a drop of water on the slide and cover the whole thing with a cover slip. If the root is already too thick and the cover slip is somewhat raised as a

Symbiosis between the roots of a tree and a fungus

Did You Know?

The roots of 80% of all plants are covered by fungal hyphae. The plants are not sick, however, but rather live in a tight biotic community with the fungus. The fungus takes water from the ground and passes it on to the plant, and the plant supplies the fungus with nutrients. By virtue of the entanglement of fungal hyphae, the root surface is increased 100- to 1000-fold — a great deal for the plant! Such living arrangement between fungus and plants are called mycorrhiza.



Conduction vessels can be constructed in very different ways, but what they have in common is always a cell wall reinforced with rings and ridges.

result, then simply press on the cover slip carefully with the butt end of a pen. The root will be pressed flat a bit by this. The root hairs at the edge of the root will not be harmed much by this. Root hairs are actually protuberances of a cell in the outermost layer of a root. If you start searching at the tip of the root, you won't find any root hairs at first. The so-called root hair zone only begins a bit above the tip. At first, only cells with small recesses are visible, but as you move away from the tip, they become longer and longer and finally grow into root hairs of varying length.

From the Root into the Melon

The cell walls of the root hairs are so tender that the water is able to pass through them into the cells of the root. But how does the water then travel to the other parts of the plant? Transporting the water from cell to cell would not only be tedious but also much too slow. Just as there are veins in humans to take care of transporting the blood (and hence water), there are specialized vascular ducts in plants too — the so-called vessel cells (tracheary elements and tracheids). They extend from the root through the entire plant and into every leaf, blossom, and fruit (i.e. into the watermelon).

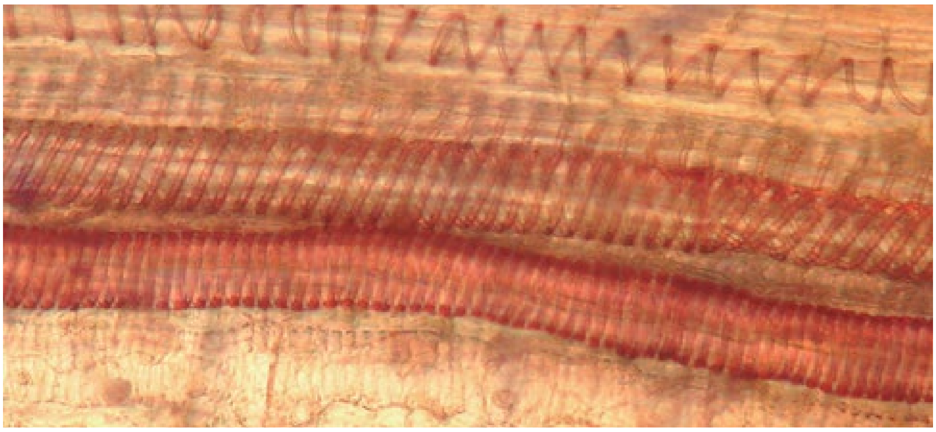
The amazing thing about these ducts is that the cells from which they are constructed die off before the water duct operates. As soon as water flows through them, nothing is left of the original contents of the cell. Only the cell walls remain as a sort of water pipe. To stabilize the tubes, ring- or screw-like reinforcements are also present.

Water Ducts in the Melon

It's easiest to go ahead and get water ducts directly from a watermelon. You will need:

- a slide and a cover slip
- the pipette and water
- the tweezers
- a piece of watermelon

If you take a close look at a piece of watermelon, you can see light-colored, twisting lines in the red flesh. These are the water ducts that have transported the water from the root into the melon. Using the tweezers, pluck a little piece of one of these ducts and dab it in a drop of water on a slide. The same thing applies here as before: If the plucked preparation is a bit too thick, simply press down carefully on the cover slip with the end of a pen. An examination of the object reveals the various types of vessels with their ring-shaped or spiral-shaped structures.

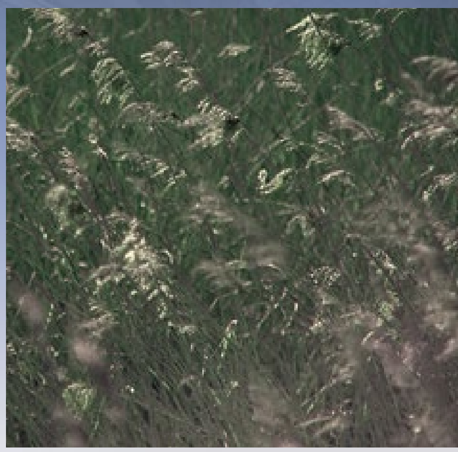


Conduction vessels from a pumpkin stem

12 Bionics — Ingenious Phenomena of Nature

"I'm sitting on the uppermost floor of a high-rise building. The wind is blowing relentlessly and makes the skyscraper rock ominously back and forth. At some point, it happens: The tip of the skyscraper bends down so low that it even touches the ground. 'Now it's surely going to break,' I think. But the thought has hardly passed when the high-rise stands up again and the incessant back-and-forth continues. But thank goodness — the building is holding together." This is how a lonely ant might sound when reporting about the experiences it has as it holds tightly onto the tip of a blade of grass in a gusty windstorm.

So how does a 50 centimeter-tall blade of grass measuring only one centimeter thick manage not to be blown over by the gentlest of breezes? How do the leaves of a lotus plant clean themselves? More and more engineers are interested in these and other similar questions as they try to adapt ingenious systems found in nature for use in engineering and technology.



Grasses are built to be rigid in order to withstand the wind.

Blades of Grass and Roots — Botanical Architecture

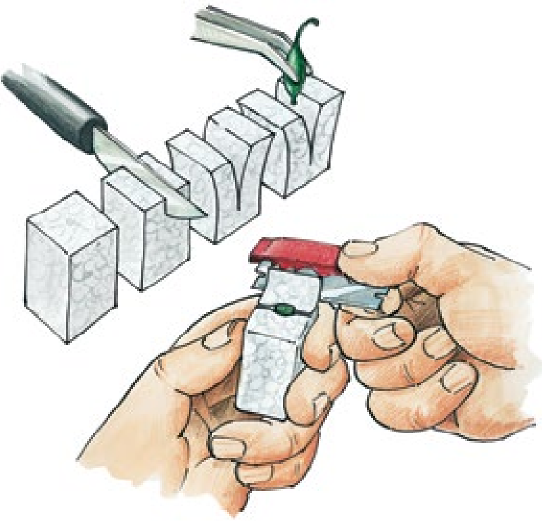
Every skyscraper architect is faced with complicated problems. They must ensure that their skyscraper doesn't simply break in half under strong wind, for example. Nature also faces the same problems when it decides to build upward — and it has found some incredible solutions.

Grass Blades — Rigid, Light Design

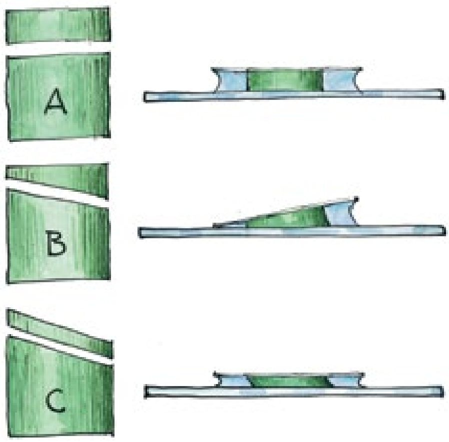
The blade of grass on which the ant is sitting has to be both stable and flexible at the same time. Sufficient flexibility is already ensured by the construction material alone. Plant cells can be compressed and stretched to a limited extent. But what stabilizes a grass blade?

Plants have invented certain cell types whose task it is to ensure stability. Botanists call it support tissue. You can imagine that especially stabile cells must also look stable. The most striking feature of these cells is that they have particularly thick cell walls. But that's not all. A special cement called lignin is also lodged in the cell walls which makes the cell wall even more rigid. Lignin is a wood-like substance which is found in great quantities, of course, in tree trunks. Tree trunks and even bark are made up almost exclusively of this cement tissue. Water ducts that travel upward through a plant stem have two tasks: They conduct the water through the plant and provide stability with their thick cell walls.

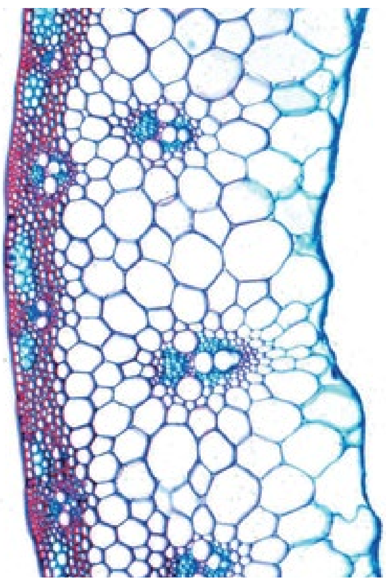
Even transmitter towers and television towers follow the constructional principle found in grasses.



Here's how to cut thin sections of leaves and stems using styrofoam.



Although object A in the figure is cut nice and straight, it is much too thick to be able to see anything. Here's the rule of thumb: If the cover slip is lifted off of the slide, then the cut is too thick. Make a thin cut and still can't see anything? That may be because you cut the object on a slant. The object in example B is cut slanted. This can be a very useful method for some objects, especially very hard, lignified branches or pieces of stem. On one side, the object is definitely too thick. But on the other side, lots of things may be visible. Finally, example C is the result when the object is crooked in the styrofoam. In this case, even if thin sections are made, there will generally not be much to see.



Section from the wall of a grass blade. The air-filled pith cavity is visible on the right side.

But a blade of grass is not the same thing as tree trunk. It has to achieve as much stability as possible with minimal material. Let's have a look at a blade of grass under the microscope.

Cutting, Part 2 — The Styrofoam Trick

Producing a good microscopic preparation is truly an art in and of itself and requires some practice. So here are some more tips and notes on common errors. Many objects are too thick to look at in their entirety under the microscope. At the same time, however, they are usually thin enough to yield to the razor blade when cut. So here's a tip:

Take a styrofoam cube (or a piece of carrot) and cut a slit into it from the top. Then stick your object into it (a piece of a blade of grass, a leaf, a root, etc.). When doing this, make sure that the object is straight in the styrofoam. Now you can place the razor blade on the styrofoam (or the carrot) and pull through the styrofoam and object (important: do not simply press the razor blade through the object, since that will crush sensitive parts of the object and make it unsightly). Always make several cuts while you're at it and then place several of them under the cover slip. By doing this, you will simply increase the possibility of getting a good cut.

Hollow Constructions

To study a blade of grass, you will need:

- a slide and a cover slip
- the pipette and water
- the tweezers
- a small piece of styrofoam, or carrot
- a bit of grass blade

Definitely read through the tips on cutting before getting started (see above). Now, make several cuts cross-wise through the blade of grass and place them into a drop of water. Observe the object under the microscope after you have put the cover slip in place. At the lowest magnification (40x), you can first get an overview of the entire cross-section. It is typical with most grasses for the stem to be hollow inside. Around this so-called pith cavity are large cells with thin cell walls. Such cells are often typical storage cells. By virtue of their thin cell walls, they are quite sensitive. Some are sure to have been crushed by the cutting. Located in these large cells are usually small agglomerations of smaller cells: the vascular bundles. Here, you will notice several cells with a large diameter. These are the water ducts that you were able to have a look at with the watermelon (see "How Does Water Get into a Melon?"). This time, however, they are cut cross-wise, so you can't see the ring- or spiral-shaped pattern. You will find other cross-cut vascular ducts among the smaller cells as well. These do not transport water from the root to the rest of the plant, but rather nutrients that are formed with the aid of the sun (see "Living in a Shoebox"). The other cells in the vascular bundle have the task of stabilizing the ducts and providing them with goods to transport. Finally, on the very outside, you will find cells that are responsible for the unbelievable strength of the grass blade. Directly under the outermost layer of cells — the epidermis — there are small groups or even a closed ring of small cells with thick cell walls. Just like in the water ducts, these are mostly dead cells whose sole purpose here is to stabilize the long blade. So if you take another look at the cross-section as a whole, you will notice that the blade achieves maximum stability with little effort and while saving as much material as possible. It's any engineer's dream! It can prove interesting to stain this particular specimen with a blue stain (see page 16). Look at the specimen under the microscope — you will notice that the various types of cells have absorbed the color to varying degrees.

Anchorage in the Ground

Even the greatest of bending strength won't do the blade of grass any good if its anchorage in the ground doesn't hold. Whether the base of a tower or the roots of a plant, extreme reliability is a must. It's apparently most favorable to change the construction principle in comparison to the stem, since the stabilization tissue of a root, which also serves as a vascular duct, is not wrapped around the rest of the root as a sheath, but rather as a central strand in the middle of the root — like a steel cable with a sheath!

A Root in Cross-Section

You will need:

• bean seeds (e.g. broad beans or scarlet runners)
• an empty margarine tub or the like
• cotton wool or paper towels
• a slide and a cover slip
• the pipette and water
• a razor blade (see page 11)
• the tweezers

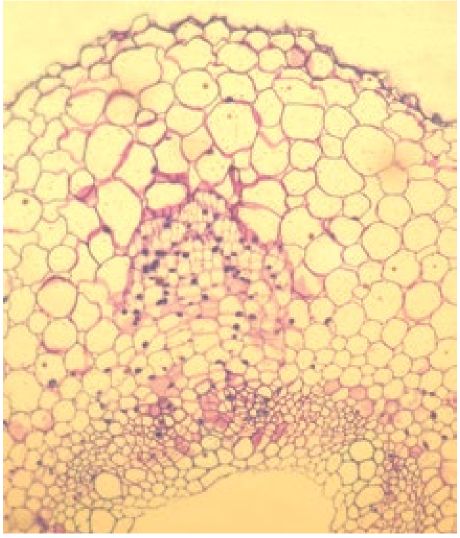
Place a layer of cotton wool (paper towels work fine if none is available) into the empty margarine tub or another plant container and wet it well with water. Lay a few bean seeds on top with some spacing. Then place the tub in a windowsill. You should make sure that the cotton is always sufficiently wet, but the beans should not be swimming in water. After a few days, a few of the beans will begin to germinate. Give the young plants another two or three days' time to develop and then take the roots of the several-days-old seedlings to study.

Cut the root down the middle using the razor blade. Use the thicker upper portion of the root to make thin sections for the microscope. Since the young root is still very soft, it may be quite difficult to place into your cutting aid (see page 38). In that case, you can also simply use the "cutting board method." To do this, place the piece of root onto a slide, hold it in place using the tweezers, and cut as thin pieces as possible from the root — just like cutting a cucumber. Add a drop of water to the cuttings, and the root cross-section is ready. In cross-section, you see a thick layer made of large, thin-walled cells on the outside of the root. In the center of the root, you will find the other types of cells composing the vascular tissue.

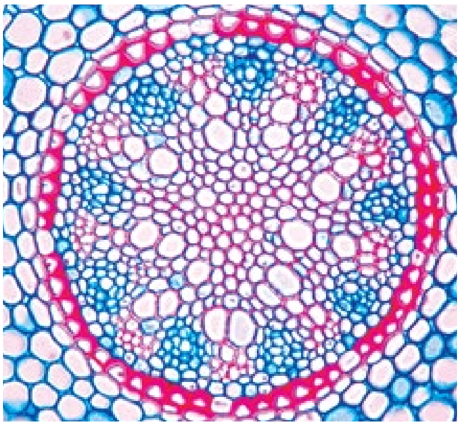
Crazy Surfaces

How does a surface have to look so that as little fine dust and other contaminants stick to it as little as possible? If you think about highly polished car bodies shining and glistening in the sun, you'd probably say that the surfaces would have to be especially smooth. Not so! Surely you've seen how cars are dustier after a downpour than they were before — and without moving an inch. This is because the rain washes the fine dust out of the air and leaves it behind on the cars. Whereas the rain water flows off of the car, the dirt sticks. It's no coincidence that car washes are equipped with all sorts of brushes.

Just imagine the surprise of the people who discovered of the now-famous "lotus effect" when they found that the self-cleaning leaves of the lotus plant have an extremely rough surface. Like the leaves of almost all plants, the rough surface is covered with a layer of wax. So water drops are not able to wet the surface of a leaf any more than your skin right after you've rubbed sun-tanning oil onto it. As they roll down the leaf, the water drops take the dirt that has collected on the leaf along with them.

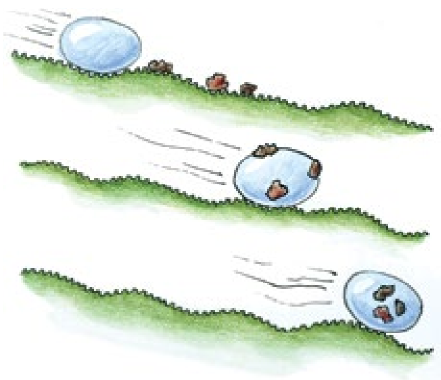


Cross-section through a bean root



Cross-section through a sunflower

The lotus flower, which originated in Asia, looks similar to a water lily.



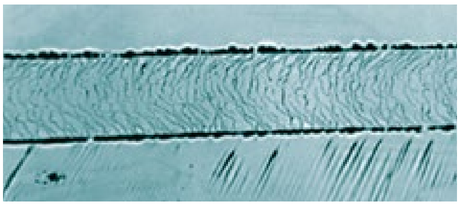
On the surface of the lotus plant, water drops bead and roll off, taking all of the particles of dust and dirt with them (the lotus effect). This is similar to a water lily.

The surfaces of practically all plants are more or less structured. The silky appearance of the petal of a pansy, for example, comes from the fact that the petals have lots of small protuberances on their surface which reflect the light differently than a smooth surface would.

Unfortunately, surfaces cannot be observed directly with a microscope like they can with a magnifying glass. Although sections of surfaces can be prepared, that is practically impossible to do by hand when it comes to delicate objects. But there's a little trick you can use to dive into the fascinating world of surface structures.

Water drops bead on the leaf of a lotus plant.

Paint film from the underside of an ivy leaf with stellate hairs



Paint impression of a human hair

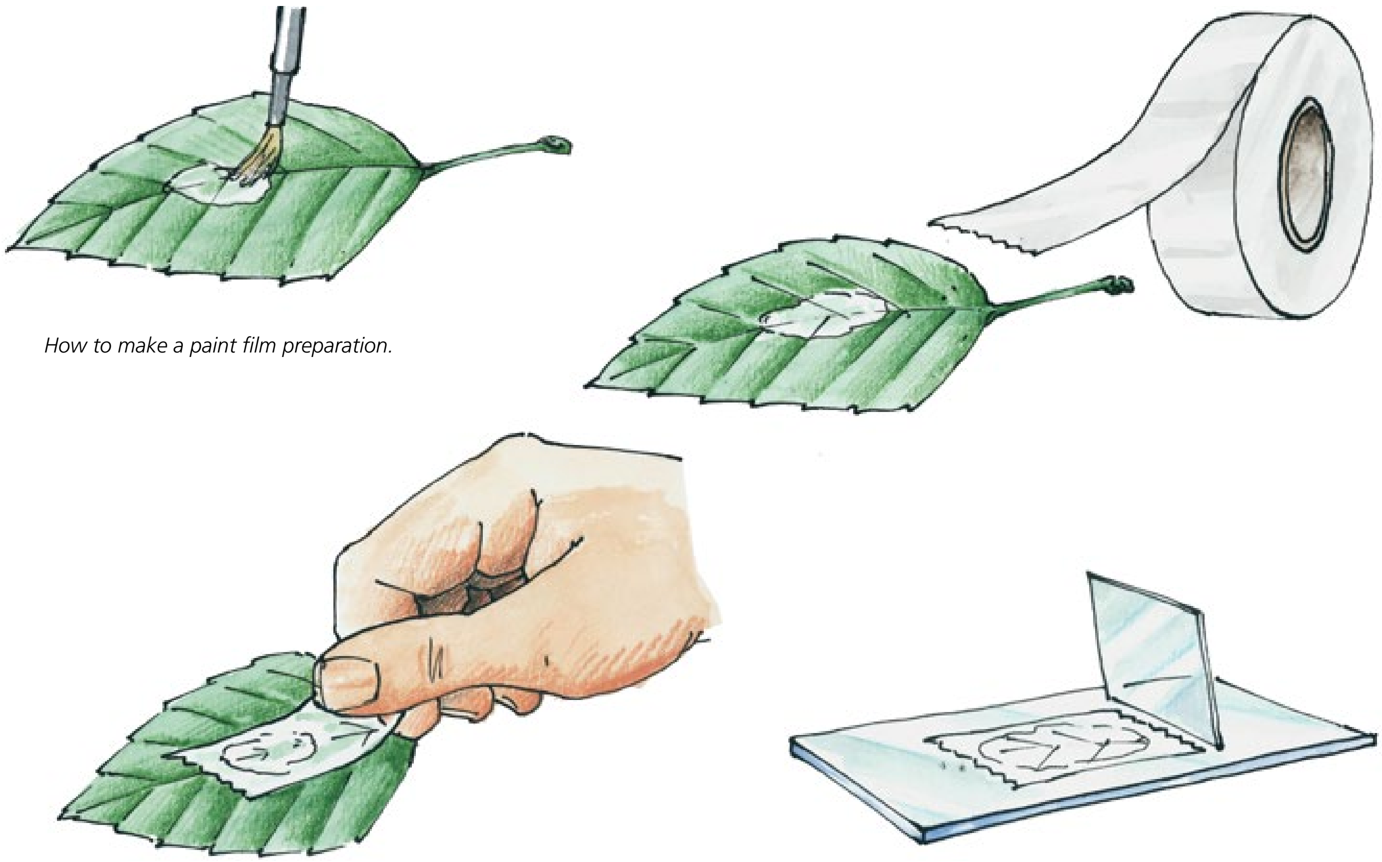
Impressive Impressions — The Nail Polish Trick

It's easy to make impressions of surfaces that you can have a closer look at using a microscope. You will need:

- a slide and a cover slip
- colorless nail polish
- adhesive tape
- a wide variety of materials, such as leaves, blossoms, or fruits

First, paint a small portion of the surface that you want to study with the colorless nail polish. Now you'll need to let it dry. Depending on the air temperature, this will take 5 – 10 minutes. Then stick a small strip of clear adhesive tape onto the painted surface and carefully pull the strip off again. The dried nail polish separates from the surface. Affix the adhesive tape with the impression on a slide and cover it with a cover slip. Now you can observe the impression under the microscope as you do other objects.

Try making impressions of other objects such as a piece of wood or a rock. You should keep in mind, however, that the nail polish may be absorbed into your object, depending on its surface characteristics. In that case, you may not be able to remove the nail polish film, or the surface may be marked permanently. So it's best to steer clear of furniture or other important objects that may not come clean later.



How to make a paint film preparation.

13 Leaf-by-Leaf Task Distribution

Aside from the impressive stature of some tree trunks, leaves are certainly the most conspicuous plant organs. And there's a reason for this: While the pollination of blossoms, for example, only takes up a limited portion of a plant's life, the leaves are used throughout the year. You already found out in the chapter about plant cells (see page 14) where the green color of the leaves comes from and what a plant uses its chloroplasts for. But the astonishing thing is that not all cells of a leaf contain chloroplasts. Not all cells have the same shape either. An ingenious division of work has been established in the leaf in which each cell layer is assigned certain tasks.

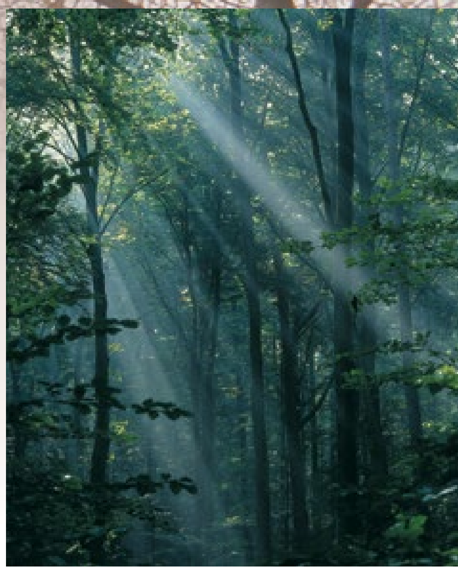
Together We're Strong

The surface of a leaf is formed by a special cell layer — the epidermis. The most conspicuous thing about the cells of the epidermis is that they don't contain any chloroplasts. So it's not their job to absorb and convert sunlight. The epidermis is specialized in protecting the inner workings of the leaf and preventing a lot of water from evaporating from the leaf.

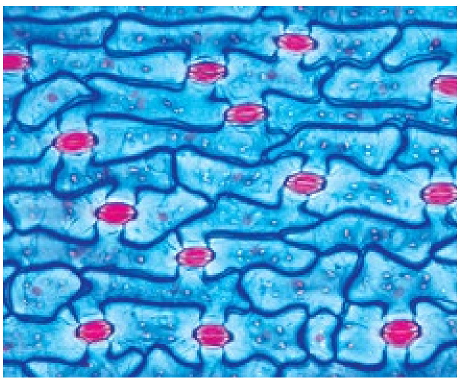
Both tasks of the epidermis are visible in the structure of the cells. If you look at the epidermis from above, you will notice that its cells — which are different from plant to plant — often have bizarre shapes. Little "arms" fit together like a puzzle. Just like in a puzzle, the interconnected nature of the individual cells brings about greater stability.

Cutting, Part 3 — Surface Sections

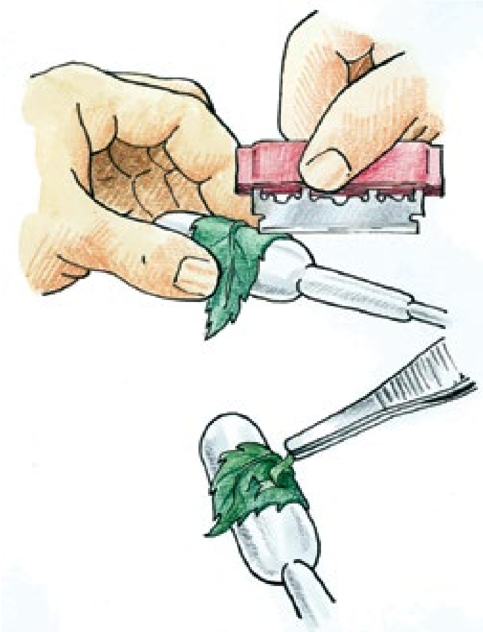
To observe the surface of a leaf under the microscope, you will need to prepare a so-called surface section. This essentially involves slicing a thin piece of the epidermis from the leaf surface. To do this, it's best to lay the leaf over a curved surface, such as the bulb of the pipette or a thick marker, and hold it with your thumb and index finger. Then place the razor blade flat onto the leaf and cut a flat piece off. Here, too, the cut should be thin enough to produce a good microscopic image. Make sure you cut very lightly, as you do not want to cut into the object below.



How many chloroplasts must there be in all of the trees in a forest combined?



Dermal tissue with stomata



How to make a surface section

Stomata

A bath sponge has an enormous surface

You can also make impressions of leaf surfaces using nail polish (see page 40). Very beautiful growth patterns on the epidermal cells then often become visible.

Death By Thirst or Hunger?

At the same time as the chloroplast-containing cells on the inside of a leaf have to absorb carbon dioxide from the air, the leaf cannot allow water to evaporate from inside it in an uncontrolled manner. Otherwise, many plants would dry out before they even begin fabricating starches. In order to reduce the evaporation, the surface of a leaf is covered with a relatively thick layer of wax called the cuticle. The cuticle ensures that the leaf is well-insulated from the outside — so well, in fact, that practically no water is able to escape. However, no carbon dioxide is able to get through either. Nature's inventive spirit was able to resolve this dilemma. In the epidermis on the underside of a leaf, you will often find differently shaped cells. They are scattered as little bean shapes across the leaf's surface. These openings are referred to as leaf pores or stomata (singular: stoma). They are, in a certain sense, the leaf's doorkeepers. When carbon dioxide is needed, or even when the humidity in the air is high, they open up and allow the gases to pass through. If too much water is in danger of escaping, especially when the temperature is high and humidity is low, they close again. The cells require energy to open and close the stomata. They generate this energy with their own chloroplasts.

But the evaporation of water from the stomata has a positive side too. You already learned how water gets from the ground into the other plant organs (see also Chapter 11). It so happens that the driving motor for the transport of water in a plant's vessels is the evaporation of water from the leaves. This creates a sort of suction that draws fresh water upward from the root.

On Sponges and Palisades

What do a bath sponge, your lung, and the leaf of a plant have in common? Not much at first glance. But the answer lies in the detail.

Air reaches one of your two lungs through the trachea. But the lungs are not simply empty sacks. In the lungs, the bronchia branch out into extremely tiny vessels. This is advantageous in that your lung increases its surface area many times over. It's through this surface that the lung absorbs oxygen from the air and passes it on to the blood. A sponge also has a very large inner surface area. That's the reason why sponges possess such excellent absorbency. Most sponges that are used in the household are made of plastic. But there are natural sponges too. Natural sponges are actually animals (but they are not alive when bought in the store). Sponges feed themselves by filtering the smallest of nutrient particles or small animals and plants from the water. The larger the inner surface of a sponge, the more water it is able to absorb at the same time.

But where is the analogous large surface area in leaves? A cross-section gives it away. It is generally possible to distinguish two layers of cells on the inside of a leaf. An (upper) layer made of oblong (or palisade-shaped) cells and a (lower) one made of cells of a wide variety of shapes. The cells of the upper layer are packed tightly together and contain many chloroplasts. They are chiefly responsible for the absorption of sunlight. The lower cell layer has a much looser construction. There are large gaps between the individual cells. Here, it is precisely this unique layout of cells that serves to enlarge the surface area. In nature, it is usually true that any place where substances are absorbed or exchanged, there are structures that enlarge the surface area through complex branching or folding. This lower cell layer in leaves is also referred to as sponge tissue due to its appearance and is primarily responsible for the absorption of carbon dioxide from the air.

The Fine Art of Leaf-Cutting

In order to gain an overview of all of the tissues in a leaf, it's best to make a cross-section through it. You will need:

- a slide and a cover slip
- the pipette and water
- a razor blade (see page 11)
- the tweezers
- various leaves, preferably thicker ones such as those of a boxwood, ficus, ivy, or even an evergreen tree
- styrofoam or a piece of carrot

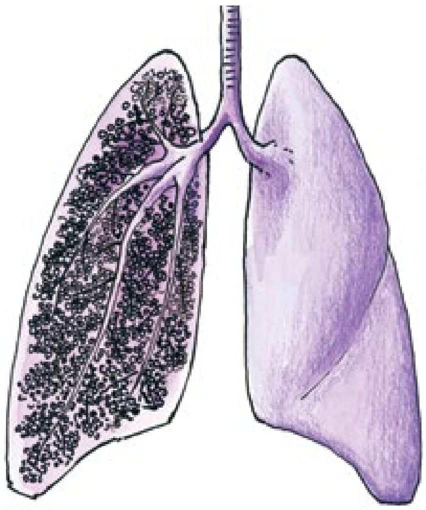
As easy as preparing a cross-section of a leaf may sound, unfortunately it is usually rather difficult. Use the same procedural principles as those you followed on page 38. First cut a slit into the styrofoam and stick the leaf into it. You can also use a piece of carrot for this purpose. Then cut a layer off with styrofoam and all. That way, the leaf and the styrofoam are in one plane. Now place the razor blade on the styrofoam and cut the leaf and styrofoam as thinly as possible. Go ahead and make 10 or 15 cuts like this while you're at it. This will greatly increase the chances of their being a sufficiently thin section among them.

The problem with preparing leaf cross-sections is that many leaves are very thin and soft and are consequently also very difficult to cut. It's best to use somewhat thicker or tougher leaves for practice at the beginning — such as boxwood or ivy — before moving on to more tender objects. But sometimes it is very difficult to get good, clean cross-sections. Leaves that are too thick have the unpleasant tendency of folding over when cut, so that what you're looking at is not the cross-section but a top view of the top or underside of the leaf. So here's another tip: Cut very thin wedges. You surely won't be able to see anything on the thick end, but you will generally get a good cross-section on the thin end. Apart from that, the rule is: Practice makes perfect!

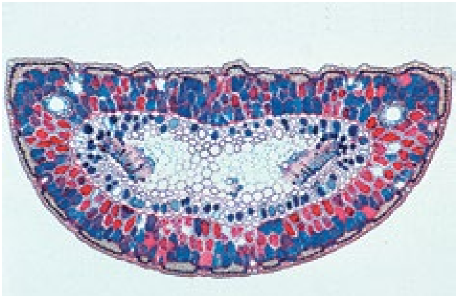
In leaf cross-sections, one finds many round or oval cell groups at the boundary between the palisade and sponge tissues. These are leaf vessels that you have cut transversely. You may already be familiar with the types of cells in them from other objects we have looked at. They contain vascular bundle tissue with tracheary elements and are usually also surrounded by thick-walled cells of the reinforcement tissue (see also Chapters 11 and 12).

Did You Know?

The inner surface of the lung of an adult human is as large as a 4-bedroom home? In fact, the inner surface is 90 m2 on average! That makes it clear how effective the fine branching of our air passages is. A horse that is able to9 run very fast can even have an inner lung surface of 500 m2.

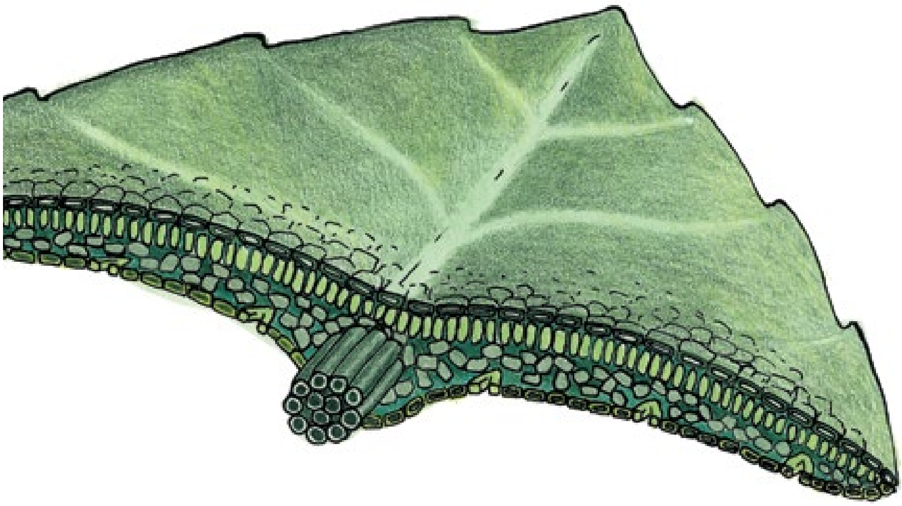


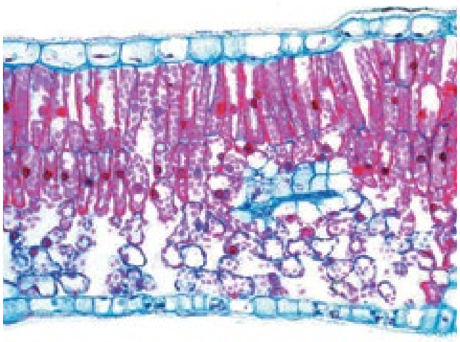
Because of its many branches, the lung has a very large surface area.



Cross-section through a needle leaf (tamarack)

Needles from firs, pines, or spruces are leaves too. However, since they don't have clearly defined upper and lower sides, their internal structure is a little different than that of deciduous plants (in contrast to the evergreen needle trees, deciduous trees lose their leaves each winter). But a nice, thin section of a pine needle is an aesthetic pleasure that you shouldn't miss. The same also applies to the leaves of many grasses, which often have very interesting cross-sections.





Cross-section through a lilac leaf

14 Hair-Raising Sights

While they're not an exclusive characteristic of mammals, hairs are certainly one of their typical traits. In contrast to fish, frogs, and lizards, mammals are warm-blooded (or homoiothermic) animals. This means that their body temperature is independent of the outside temperature. Mammals maintain a more or less constant temperature in their bodies. That uses up a lot of energy but also offers significant advantages. For example, while a lizard must first warm itself up in the sun in order to be agile enough to search for food, the mouse has already been nosing its way around for hours.

Unlike the lizard, however, the mouse also has to be careful to not lose too much heat. Its fur helps out in this respect by retaining air between the individual hairs, which is heated by the body and therefore provides a warm air cushion against the cold. A cozy wool sweater keeps you warm in winter in the same way.

The Men and Women of the Criminal Investigation Department

You'd likely find the very best specialists in microscopic images of hairs in the forensic unit of the criminal investigation department. When it comes to finding tiny traces and clues at a crime scene, these detectives are masters of their art.

One aspect of forensic work is the identification of hairs. The hairs of humans and animals can be distinguished under the microscope, and often small details in the structure of the surface are all that allow the hairs of different animals to be differentiated from each other, or sometimes it's the thickness of the hair. Under the microscope, animal hairs, plant hairs, plant fibers (such as flax or linen), and synthetic fibers can all be differentiated from one another.

Did You Know?

A blond person has approximately 150,000 hairs on his or her head. There apparently really are people who find the time to count the hair on other peoples' head. In any case, we know that the number of hairs on a person's head depends on the hair color. Accordingly, blonds have the most with 150,000, followed by people with brown hair (110,000), black hair (100,000) and, finally, red hair (90,000). Add to that about another 420 eyelashes and 600 eyebrow hairs.

Hairs and Fibers

These objects pose no problem at all. You will need:

- a slide and a cover slip
- the pipette and water
- the tweezers
- a wide variety of hairs and fibers from articles of clothing, shopping bags or rugs, and from animals and plants, too, if you wish

Simply place the objects onto a slide under a cover slip and away you go. Experiment with observing the objects dry or in water to see which provides the best image. In this respect, different fibers can behave very differently.

You can also make a quiz with your friends or family. Prepare lots of different objects ranging from cat hair to human hair, from artificial fibers to a couple of fibers from a cotton bag to plant hairs from leaves or fruits. Now, it's up to the others to try to match the microscopic images of the hairs to the objects of their origin. If you'd like, you can even think up a mystery story involving your objects that the participants have to solve.

Plant Hairs

Even the invention of innumerable synthetic fibers for the clothing industry has not been able to replace cotton to this day. It currently comprises about 44% of the entire textile consumption in the world. Almost everyone wears this pure plant product every day. But have you ever given any thought to why the cotton plant forms its 6 inch-long fibers?

Plants have a wealth of strategies for distributing their descendants. The more widely the fruits and seeds can be spread, the higher the chance of populating a place that's not already overgrown. The hairs of the cotton plant are seed hairs that serve as flight organs. So it's the wind that ensures that the descendants of a cotton plant are scattered to the four winds — literally. Many plants propagate their seeds using the wind.

But plant hairs are capable of lots more. Many plants with white leaves have a thick fuzz on their surface made of dead hairs which reflect the light of the sun. In this way, those plants prevent their leaves from heating up too much.

Also, flesh-eating plants, such as the venus flytrap, have tactile hairs. When an insect touches one of these hairs, the trap falls shut.

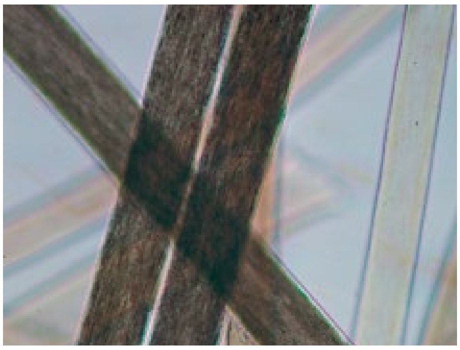
Stinging nettles have especially ingeniously constructed hairs. The stinging hairs operate on a simple but clever principle. The hair is shaped like a pipette — and works like one too. On the lower part, the hair thickens to a bubble, gets thinner and thinner toward the top, and is finally topped off with a round little head at the tip. Directly underneath this head, the cell wall is particularly thin and, due to the deposition of certain substances, quite fragile. This location serves as a breaking point. When you come into contact with a nettle hair, the tip breaks off immediately. Left behind is a sharp, hollow needle that can easily bore through the skin. What's more, there is slight overpressure in the nettle hair before the tip is broken off, so the stinging and itchy contents are injected under the skin. So the stinging nettle has a great weapon against predators and others who would trample it.

When You Have Itchy Fingers...

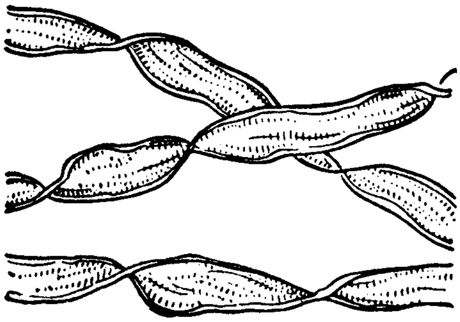
Preparing a nettle hair for viewing is not difficult. You will need:

- a slide and a cover slip
- the pipette and water
- a razor blade (see page 11)
- the tweezers
- garden gloves or thin leather gloves
- a piece of the stalk of a stinging nettle

In order to avoid getting stung by the hairs while you're trying to observe them under the microscope, it's best that you wear garden gloves at first. The stinging hairs of the nettle can be seen readily with the naked eye on the stalk. Carefully cut off a few hairs from the base and transfer them to a drop of water on the slide. During preparation, a few hairs may break off on the base or at the tip. So use this tried-and-true method: Place several hairs under the cover slip at the same time, so you are more likely to have a perfect specimen in the bunch. Now observe your preparation at different magnifications and compare them with the image on the next page.



Human hairs



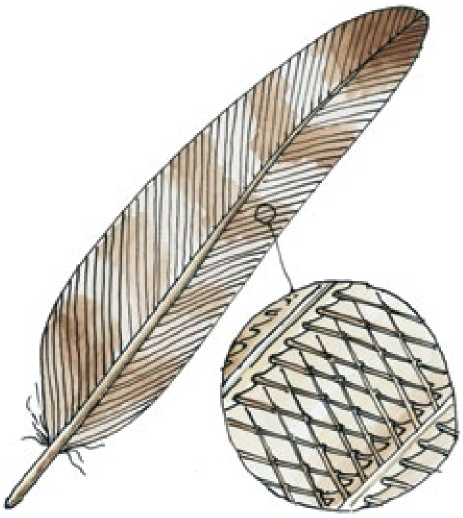
Cotton fibers

Fruit capsule of a cotton plant with fringe hairs

Fruits of the dandelion

Venus flytrap — an insect-catching plant

Stinging hair of a nettle



Bird feather with hooks and radii

Did You Know?

Reptiles and birds are very closely related to each other. The astonishing discovery of a petrified creature that was a mix between a dinosaur and a bird plunged the scientific community into turmoil. The “archaeopteryx” unites some characteristics of dinosaurs, such as a tail or teeth, with the wonderful invention of the feather in one and the same animal. But birds’ close relationship to the dinosaurs is visible even in birds living today: Their feet are, like the entire body of a reptile, covered with scales.

The Dream of Flight

Time and time again, nature has brought forth creatures that have been able to lift themselves off of the ground and glide through the air. But birds are the only ones among them that have truly been able to conquer the skies. There movement is like a beautiful art form to us humans. Have you ever watched swallows in their swift flight on a warm summer evening? Or the elegant sailing flight of large sea birds such as gulls or terns? A bird’s body structure has many peculiarities that make this enviable manner of locomotion possible. The characteristic that you surely think of first — and rightly so — is the feathers.

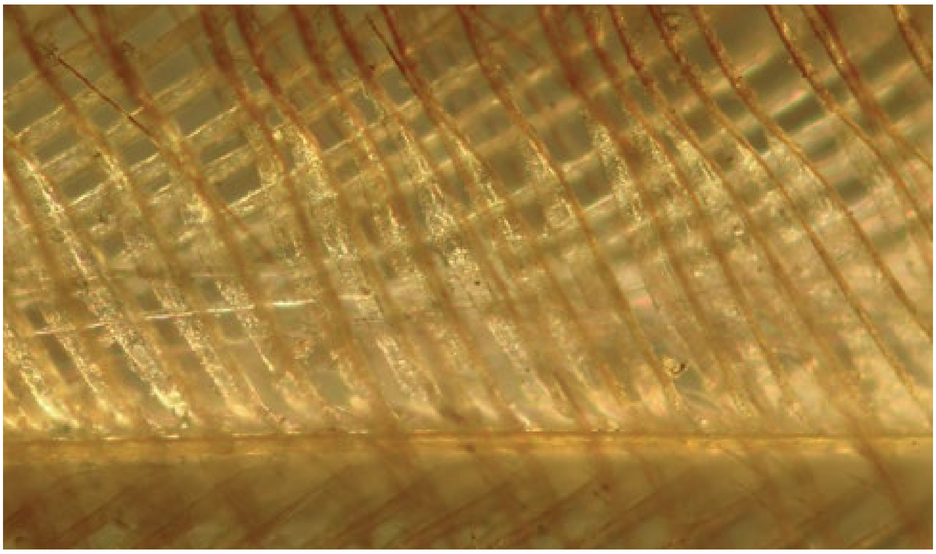
A feather is an amazingly light and, very often, wonderfully colorful natural structure. Using the microscope, you can learn more about its microstructure. When you stroke downward with your fingers along a bird feather, the individual feather segments are separated from each other. If you stroke in the opposite direction, then the gaps are closed again. How is it that the individual barbs stick together? In the microscopic image, you can see that the barbs are joined together with tiny hooks.

What’s Fowl Is Fair

You’ve likely seen how water rolls off the feathers of water fowl. This is because the birds oil their feathers regularly. Wet feathers would no longer keep the bird sufficiently warm, and that would be fatal for the bird. But when using the microscope, the oil is a nuisance, of course — which is why you’ll need the following for this preparation:

- two slides
- the tweezers
- water with a drop of dish washing detergent
- adhesive tape
- a feather

Place a piece of the feather into a drop of the prepared water. The detergent will prevent too many air bubbles from forming in your preparation. Then place the second slide on top of this and affix it to the bottom slide using two strips of adhesive tape. Bringing your object into focus may be somewhat trickier than usual. Observe your object at low and medium magnifications and try to make out the hook structures.



Bird feather under the microscope

15 Even Smaller and Finer

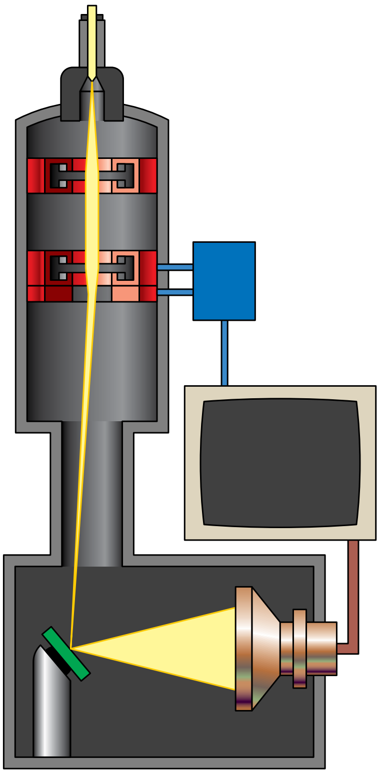
How were the wonderful, colorful pictures on this page produced? As you read in the introduction, there are limits to the resolving capacity of a light microscope. What's more, only very thin objects or thin sections can be observed using a light microscope. The maximum magnification power for light microscopes is about 2,000 times, and special additional technologies must be used to achieve this. Magnifications higher than this require a different method altogether.

On the Smallest Particles

Even the ancient Greeks pondered the question of whether there is such a thing as the smallest particles out of which all life and all non-living things are constructed. The Greek philosopher Democritus claimed over 2,000 years ago that if one were to break down anything in the world into smaller and even smaller pieces, one would eventually come across the smallest, indivisible particles. The Greeks called these smallest particles atoms. Of course, Democritus and his colleagues were not able to prove their claim, so there were others, such as the famous philosopher Aristotle, who vehemently rejected this theory.

However, the results of the research of the 19th and 20th centuries support this theory and even demonstrated that the smallest particles are composed of even smaller particles. Although the indivisibility of the atom was refuted with the advent of nuclear fission in nuclear reactors, Democritus and his contemporaries were right in their claim that everything in the world and in the entire universe is made of atoms.

One of the even smaller particles out of which an atom is constructed is called the electron. You know the electron from your everyday life. For example, when you plug any electric device into a power socket, then the electrons start to move in this device's wires together in a common direction. The electric current is nothing more than flowing electrons.



Schematic cross-section through a scanning electron microscope

Seeing Better with Electrons

Just like light, electrons can be bundled and shot at an object. Researchers have already used this characteristic of electrons in several inventions, such as electron microscopes that can magnify objects up to 2 million times. One of these microscopes is the scanning electron microscope, or SEM for short. All of the impressive images shown here were made using one.

To do this, the object of study is bombarded with an extremely thin beam of electrons. The beam moves over the object in a scanning motion, line by line. Depending on the height of the object at any one point, more or fewer electrons are released from the object by the electron beam hitting it. These electrons are then registered by a detector and translated into an image by a computer. Black-and-white images are produced using this method, which are then colored artificially on the computer.

Despite all advantages and possibilities that an SEM offers, even this device has its limits. As lively as the pictures of ants or other animals may look, they were already dead at the time at which the images were made. In order to be observed in the SEM, the objects have to be coated with an extremely thin layer of gold and are in a vacuum while they are being observed. With an SEM, you can only dream of simply going out into nature and studying a pond sample with living organisms in it like you can do with your light microscope.

Make Your Own Microscope Logbook

One of the most important tasks in any scientific endeavor is keeping detailed, accurate, and complete records of all the findings. What good is an experiment if you cannot remember the results well enough to apply the information?

Today's scientists have elaborate technology to help them record their data: computer-controlled sensor systems, video and audio recording devices, and huge databases in which to store information.

One of the most basic and important recording devices is the logbook. This is a special notebook that scientists and lab technicians use to record their data in the form of drawings and notes. Here's how to make your own.

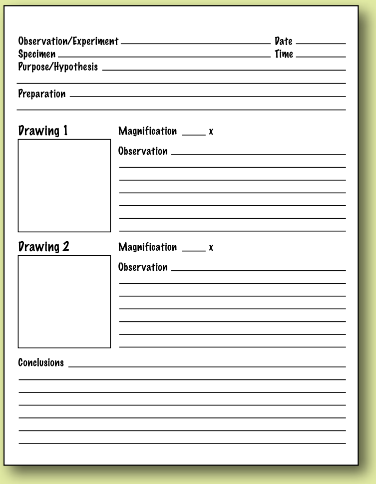
Materials

- sturdy notebook: depending on your preference, it can be spiral bound or flat bound, lined or unlined, or with a grid. It should have a thick, hard cover to protect it during all of your experiments. You can also choose to use a three-ring binder and loose paper.
- pens: you should always keep your permanent data in pen, rather than pencil, as pencil will fade over time.
- ruler
- markers, tape, glue, labels and other art supplies, as needed

1. Design an observation template page

A template is a kind of outline or guide, that helps you know what information you need to remember to record and where to put it on a page. This is the page on which you will record your findings for a single observation or experiment. It is a special form for you to fill out every time you perform an observation with your microscope. This page needs to have spaces for the following information:

- experiment/observation title
- name of the specimen that you are viewing
- date and time
- purpose or hypothesis: what you hope to learn by viewing this specimen
- preparation procedures: what you did to prepare the specimen and the slide
- drawings of the specimen, and the magnification level
- written descriptions of the observation
- any conclusions you can make about the specimen



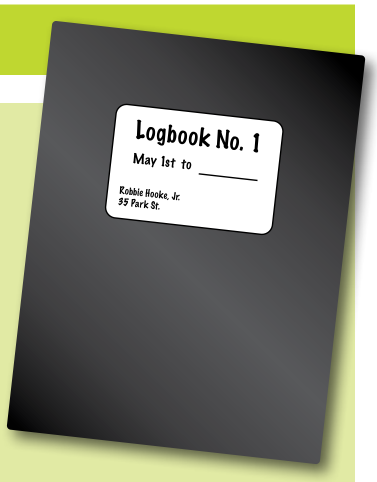
2. Duplicate the template page

You should make a number of copies of the template page so that you always have a new and clean one available when you want to begin a new observation. There are three ways to do this:

Option 1: You can simply reproduce the page by hand. It is okay if the templates do not all look exactly the same, but they should all have the same fields for information.

Option 2: If you have access to a photocopier, you can make copies of this one template page and glue it into your logbook. Or, if you prefer this photocopier method, you can simply use a three-ring binder as your logbook and store your observation template pages in that.

Option 3: If you feel comfortable with word processing or layout programs on the computer, you can create your template pages on the computer and then print them out.



3. Make a cover

On the cover of your logbook, you should put the following information:

- your name and contact information (should the book be lost)
- the date the book was started (and the date it is finished, when you get to that point)
- a title, such as "My TK_2 Scope Logbook No. 1"

4. Create a table of contents page

On this page, you will list the experiments and observations you have performed. It will help you find them when you are looking for them later, and it serves as a good chronological record of your microscope work. Put it at the front of your book.

This page should be set up as a list with the following columns:

- experiment/observation: title and brief description, including the specimen that was viewed
- date and time
- page number

Drawing From Microscopic Observation

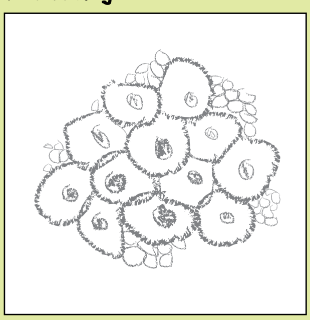
Drawing diagrams and pictures of the specimens that you are viewing through your microscope will help you to analyze them, to communicate information about them to others, and to remember what you saw.

You do not have to be an exceptionally talented artist to draw good pictures from your slides. Take a careful look at what you are seeing when you look through the microscope, noticing all the details. Then, try to draw what you see a little bit at a time, making sure the different parts match up in relation to one another.

It is not necessary to create a perfectly replicated image of the specimen. Rather, you want to capture the important aspects of the image: whether it is the shape of the cell walls in a plant or the orientation of spikes on a pollen ball or the number of hairs on the leg of a bee.

And remember, the more you practice drawing these microscopic images, the better you will be at it.

Drawing 1



Drawing 2