EXPERIMENT MANUAL

NANOTECHNOLOGY

THAMES & KOSMOS

WARNING.

- Not suitable for children under 15 years.
- For use under adult supervision.
- Contains some chemicals which present a hazard to health.
- Includes a highly flammable liquid (Isopropanol).
- Read the instructions before use, follow them and keep them for reference.
- Do not allow chemicals to come into contact with any part of the body, particularly the mouth and eyes.
- Keep small children and animals away from experiments.
- Keep the experimental set out of reach of children under 15 years old.

WARNING

— Chemistry Set. This set contains chemicals and/or parts that may be harmful if misused. Read cautions on individual containers and in manual carefully. Not to be used by children except under adult supervision.

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First Aid Information

- **In case of eye contact:** Wash out eye with plenty of water, holding eye open if necessary. Seek immediate medical advice.
- **If swallowed:** Wash out mouth with water, drink some fresh water. Do not induce vomiting. Seek immediate medical advice.
- **In case of inhalation:** Remove person to fresh air.
- **In case of skin contact and burns:** Wash affected area with plenty of water for at least 10 minutes.
- **In case of cuts:** Do not touch or rinse with water. Do not apply any ointments, powders, or the like. Dress the wound with a clean, dry first-aid bandage. Foreign objects (e.g. glass splinters) should only be removed by a doctor. Seek the medical advice if you feel a sharp or throbbing pain.
- In case of doubt, seek medical advice without delay. Take the chemical and its container with you.
- In case of injury always seek medical advice.

Information on handling the laser pointer

The instrument included in this kit is a combination device including an LED flashlight (rear button) and a class 2 laser pointer (front button) with a power of less than 1 mW and wavelength of 650 nm. The following rules of conduct must be observed when using laser pointers:

Warning! Laser radiation – Do not stare into beam

Class 2 Laser Product according to DIN EN 60825-1:2008-5/ IEC 60825-1: 2007
$P \leq 1$ mW; $\lambda = 650$ nm

Warning! Laser radiation – Avoid direct eye exposure

- Laser pointers are not a toy. Do not let them get into the hands of children under 15 years of age. Always store the laser point in a location where it will be inaccessible to children.
- Never point the laser pointer at people, especially at their eyes or face, or direct the laser beam at people or animals. Laser beams in the eye can lead to eye damage, and blinding someone with a laser pointer can cause an accident.
- Do not look directly into the beam or into a reflected beam. Even if it is reflected off a mirror-like surface, the light of a laser can still be dangerous.
- If the laser beam hits you in the eye, close your eyes and move your head immediately away from the beam.
- When using the laser pointer, do not use optical instruments such as magnifying lenses or binoculars to observe the light source. This might lead to a violation of the exposure limits.
- Manipulations (changes) of the laser device are not permitted.
- Never direct the laser pointer at traffic.
- Only use the laser pointer as described in the instructions. Keep this instruction manual and provide it with the laser pointer if you pass it along to someone else.

Poison Control Centers (United States)
In case of emergency, your nearest poison control center can be reached everywhere in the United States by dialing the number:

1-800-222-1222

Local Hospital or Poison Centre (Europe)
Record the telephone number of your local hospital or poison centre here:

Write the number down now so you do not have to search for it in an emergency.

When in doubt, seek medical advice without delay. Bring the chemical and its container with you. In case of injury, always seek medical advice.

Information for handling the magnifying lens

Warning! Never leave the magnifying lens unattended in the sun — it could cause a fire! Never look at the sun with either the naked eye or with the magnifying glass. There is a risk of blinding!

Keep packaging and instructions as they contain important information.

››› ADVICE FOR SUPERVISING ADULTS

Dear Parents and Adults,

This experiment kit uses safe experiments to give young researchers their first look into the exciting world of nanotechnology. It is only suitable for users 15 years of age and older. This instructional experiment course is NOT A TOY! The experiments described in this manual are safe and nonhazardous. Nevertheless, some of the kit contents, such as the nanoliquids, components made of glass, and the laser pointer, will need to be handled carefully and responsibly. So please make yourself available for help and advice as a supervising adult.

A) Read and follow these instructions, the safety rules and the first aid information, and keep them for reference. This includes the instructions in this manual, the warnings on the front cover, the notes and first aid information on the inside front cover, the safety rules (page 4), and the information on handling chemicals and disposing of them in an environmentally responsible manner (pages 5 and 6). Always keep the safety information close at hand for reference.

B) The incorrect use of chemicals can cause injury and damage to health. Only carry out those experiments which are listed in the instructions. Please emphasize to your son or daughter the importance of paying attention to all this information and of performing only those experiments specifically described in the manual.

C) This experiment set is for use only by young persons over 15 years.

D) Because young people's abilities vary so much, even within age groups, supervising adults should exercise discretion as to which experiments are suitable and safe for them. The instructions should enable supervisors to assess any experiment to establish its suitability for a particular young person.

E) The supervising adult should discuss the warnings and safety information with the young person or people before commencing the experiments. Particular attention should be paid to the safe handling of the flammable liquid (anti-fog agent), the laser pointer, the fragile slides, glass containers, and the colloidal gold vial, as well as following safe procedures with experiments involving an open flame.

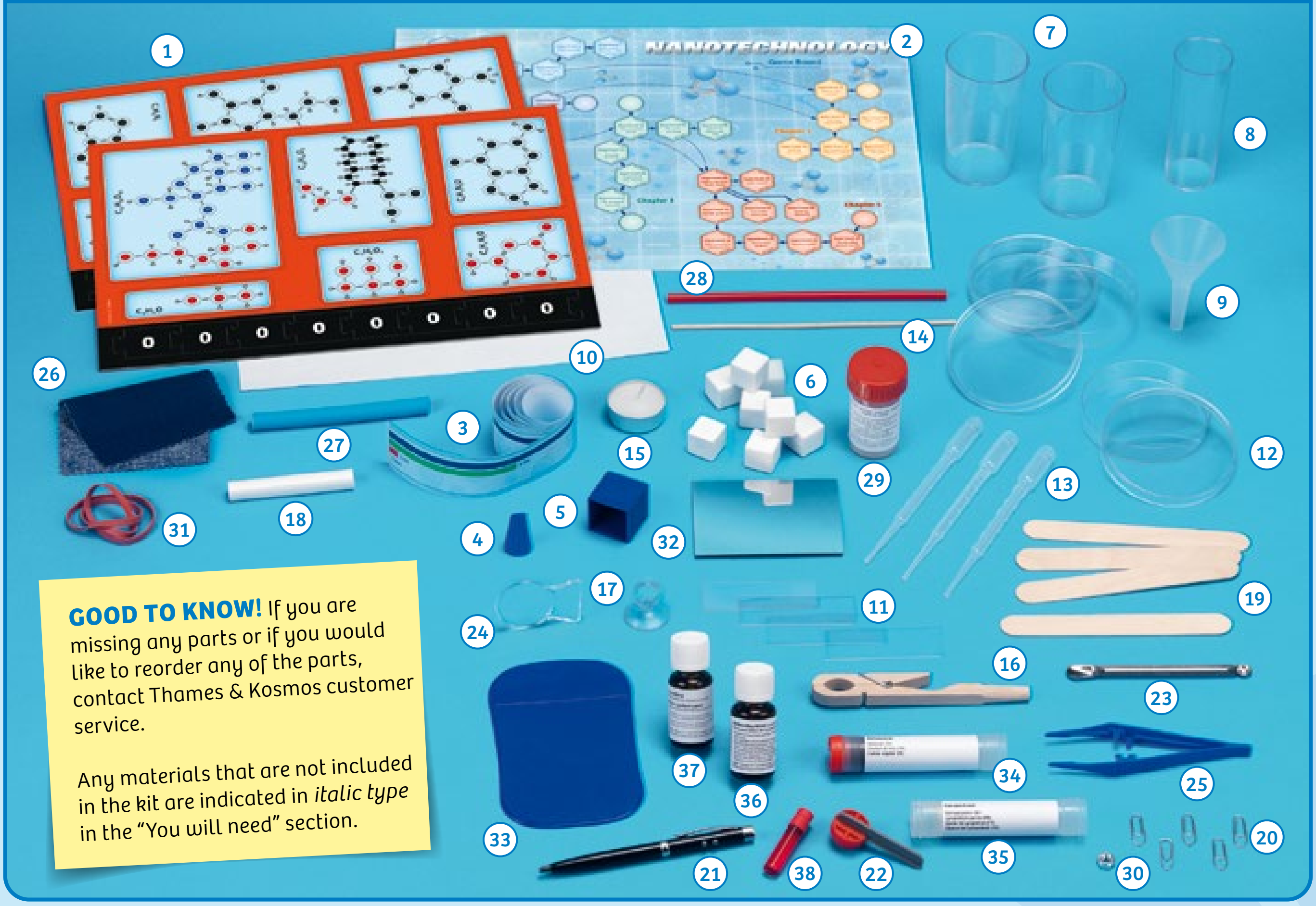
When performing experiments with chemicals, please be sure that they don't come into contact with your skin, eyes, or mouth. The colloidal gold vial is sealed tightly, and MUST NOT BE OPENED! It is also important not to let the kit components get into the hands of small children.

Please always follow fire safety procedures when performing experiments with an open flame. Always place the tea light candle on a flame-resistant surface, such as an old saucer. Make sure there are no flammable materials, such as curtains, tablecloths, or carpets, close to the experiment station. Never leave the candle burning unsupervised, and do not forget to extinguish it at the end of the experiment. Keep a bucket or box of sand ready in case of emergencies.

F) The area surrounding the experiment should be kept clear of any obstructions and away from the storage of food. It should be well lit and ventilated and close to a water supply. A solid table with a heat resistant top should be provided. A basement room would be ideal. After using any containers or utensils in the experiments, do not use them again in the kitchen. While working, always wear old clothes. Avoid loose sleeves, remove any shawls or scarves, and tie up long hair.

We wish you and your young researcher a lot of fun in the nanoworld!

What's inside your experiment kit:



GOOD TO KNOW! If you are missing any parts or if you would like to reorder any of the parts, contact Thames & Kosmos customer service.

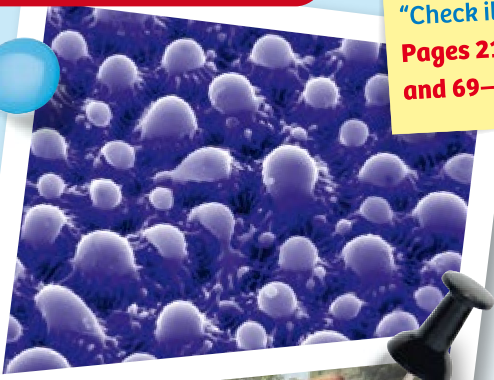
Any materials that are not included in the kit are indicated in *italic type* in the "You will need" section.

Checklist: Find – Inspect – Check off

✔	No.	Description	Qty.	Item No.
❍	1	Die-cut sheet	1	715 524
❍	2	Game board	1	715 526
❍	3	Measuring tape	1	715 527
❍	4	Game piece	1	715 528
❍	5	Open plastic cube	1	715 529
❍	6	White plastic cubes	8	715 530
❍	7	200-mL measuring cups	2	700 560
❍	8	100-mL measuring cup	1	701 206
❍	9	Funnel	1	086 228
❍	10	Filter paper sheet	1	702 204
❍	11	Slides	4	704 256
❍	12	Petri dishes	3	702 184
❍	13	Pipettes	3	708 761
❍	14	Wooden stick	1	713 654
❍	15	Tea light candle	1	702 232
❍	16	Wooden clip	1	000 026
❍	17	Suction cup	1	700 181
❍	18	Chalk	1	773 292
❍	19	Wooden spatulas	4	000 239

✔	No.	Description	Qty.	Item No.
❍	20	Paper clips	5	263 132
❍	21	Laser pointer	1	715 556
❍	22	Lid opener	1	070 177
❍	23	Measuring spoon	1	035 017
❍	24	Magnifying lens	1	311 137
❍	25	Tweezers	1	700 127
❍	26	Piece of blue cloth	1	715 555
❍	27	Floating bath putty	1	715 531
❍	28	Tube	1	704 331
❍	29	Container of sand (60 g)	1	774 748
❍	30	Screw nut	1	715 554
❍	31	Rubber band	1	714 730
❍	32	Mirror	1	702 221
❍	33	Gecko adhesive pad	1	715 552
❍	34	Activated charcoal (8 g)	1	033 202
❍	35	Lycopodium spores (3 g)	1	770 405
❍	36	Anti-fog agent (15 ml)	1	774 741
❍	37	Lotus-leaf fluid (15 ml)	1	774 742
❍	38	Colloidal gold (2 ml)	1	774 743

››› CONTENTS



TIP!
You will find additional information here:
"Check it out" and "Knowledge Base"
Pages 21, 22, 24, 26, 27, 40, 48, 59–61, and 69–71

You will also need:
Hair, tape, pebble (about 3 cm across), dry rice, aluminum foil, water, ink cartridge, paper, various drinking glasses, cooking oil, sugar, teaspoon, scissors, paper napkin, permanent marker or small stickers, teacup, paper towels, refrigerator, clock, various plant leaves (such as cabbage and lettuce), lighter, saucer, dishwashing liquid, kitchen scale, laundry detergent, salt, ruler, tablespoon, milk, cotton swabs, bowls, piece of white cardboard, clear apple juice, red fruit juice, egg, two new toothbrushes with long bristles, plastic wrap, table, various heavy books, tablecloth

Ground Rules for Safe Experimentation (Safety Rules)

››› 1. Read these instructions before use, follow them and keep them for reference. Pay special attention to the specified quantities and the sequence of individual steps. Only perform the experiments specified in this manual.

››› 2. Keep young children and animals away from the experimental area.

››› 3. Wear protective clothing (e.g. an old smock).

››› 4. Store this experimental set and extra materials out of reach of young persons under 15 years of age (e.g. in a lockable cupboard).

››› 5. Clean all equipment after use.

››› 6. Make sure that all containers (chemical vials and bottles) are fully closed and properly stored (in the experimental kit) after use.

››› 7. Ensure that all empty containers (chemical vials and bottles) are disposed of properly.

››› 8. Wash hands after carrying out experiments. If any chemicals get onto your skin by mistake, wash them off immediately under running water.

››› 9. Do not use any equipment which has not been supplied with the set or recommended in the instructions for use.

››› 10. Do not eat or drink in the experimental area. Do not use any eating, drinking, or cooking utensils for your experiments unless explicitly instructed to do so. Do not smoke around the experiments, since you will sometimes be experimenting with a flammable liquid.

››› 11. Do not allow chemicals to come into contact with the eyes or mouth. Do not breathe dust. Do not apply any substances or solutions to the body. Do not let any substances or solutions get onto your body.

››› 12. When you are studying food or food products (such as juice or cooking oil), pour the required amount into a clean, clearly marked yogurt container. Do not replace foodstuffs in original container. Dispose of immediately. Do not consume any leftovers. Dispose of leftover food (in the garbage or down the sink) immediately after the experiment.

››› 13. Make sure that any containers with liquids, or experimental setups that have to be left assembled for a while, are out of the reach of children under the age of 15. Any filled containers should have their contents clearly identified.

››› 14. Be particularly careful when handling the fragile chemical vials, the slides, and the vial of colloidal gold, and when using the laser pointer. Handle hot water cautiously.

››› 15. Experiments with open flame: For some of the experiments, you will need to use a tea light candle. Set it on a fire-resistant surface (such as an old saucer). Put out the flame once the experiment is completed in any case, but also extinguish it if you have to leave the experiment station even if just briefly. When performing experiments with open flame, make sure that there are no flammable objects, chemicals, or nanoliquids nearby. Keep a bucket or box of sand handy in case you need to extinguish any flames. If you can't put out a fire immediately, notify the fire department without delay.

Also pay attention to the information on the chemical tube and vial labels, the tips for handling chemicals (page 5), and the safety notes in the red and white warning boxes accompanying the individual experiments. When using additionally required products (such as laundry detergent), also note the warnings on the product packaging.

Safe Handling of Chemicals

Please read the following hazard and precautionary statements for the chemicals included in this kit.

This overview will show you the red-outlined **hazard pictograms** for the chemicals included in this kit that have been classified as hazardous. The signal word in all caps indicates the degree of risk: WARNING designates a limited risk, while DANGER designates a heightened or considerable risk.

The hazard statements (in blue) and precautionary statements provide further details about the chemical being described in each case.

You will find identifications of the chemicals contained in the kit on the outside packaging and on the labels of the chemical tubes or vials.

For the sake of completeness, you will also find information here about the permanently sealed colloidal gold vial, along with disposal information in case the vial breaks.

Anti-fog agent (Mixture 98% Isopropanol)

DANGER

Highly flammable liquid and vapour. - Causes serious eye irritation. - May cause drowsiness or dizziness.

Keep away from heat/sparks/open flames/hot surfaces. — No smoking. - Avoid breathing vapours. - Keep container tightly closed. - IF IN EYES: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing.

Clean up any inadvertently spilled liquids with a paper towel, let the paper towel dry in the open air, and then dispose of it in the household trash or garbage bin.

Lotus fluid

Water-repellant agent
Organofunctional polysilane system

This solution is not classified as hazardous.
Nevertheless we recommend the following:
Do not get in eyes, on skin, or on clothing. - Keep away from heat/sparks/open flames/hot surfaces. — No smoking. - Do not breathe vapours. - Keep container tightly closed.
If necessary, consult appropriate first aid information and/or a doctor.
Clean up any inadvertently spilled liquids with a paper towel, let the paper towel dry in the open air, and then dispose of it in the household trash or garbage bin.

Vial of colloidal gold

DO NOT OPEN THE CONTAINER!
Mixture of distilled water, gold, 3-oxoglutaric acid, sodium chloride

Disposal in case the vial breaks:
Do not get the colloidal gold in eyes, on skin, or on clothing.
Wear rubber gloves, clean up any spilled liquid with paper towels, and deliver to a special waste collection point along with the rest of the vial. Air out the room. If necessary, consult appropriate first aid information and/or a doctor.

Lycopodium (clubmoss spores)

–

Activated charcoal

–

WARNING! The following applies to **all** chemicals: **Store locked up. Keep out of reach of children.**
The following precautionary statement applies as well:
IF SWALLOWED: Get immediate medical advice/attention and have product, container or label of chemical vials, chemical bottles or manual at hand.

For the sake of environmental protection: Dispose of contents/containers (of no-longer-needed chemicals, nano liquids or colloidal gold vial) to a hazardous waste disposal location.

Cleaning and Disposal of Waste

Cleanliness is very important if you want the experiments to work. So always clean any containers and equipment as well as your work station immediately after completing an experiment. For cleaning the experiment equipment, use warm water and a little dish soap. Always use your own rag — never use the kitchen sponge or dishrag!

Then, rinse the experiment equipment well with clean water and dry it with some paper towels. Dispose of the paper towels in the trash afterwards. Always return the cleaned and dried equipment to its proper place in the experiment kit box.

You should also always clean the pipettes thoroughly after each use. To do that, fill them several times with soapy water, shake them, and squirt all the water out again. Then rinse with clean water and place them tip-down in a measuring cup to dry.

Have a rag or a roll of paper towels ready in case you have to wipe up any spills while experimenting. Rinse the rag thoroughly after use. Wipe up any spilled anti-fog agent immediately with a paper towel, let the paper towel dry in the open air, and then dispose of it in the household trash.

If you end up with vials containing residues of chemicals that you no longer need, have your parents take them to a special waste disposal point.

Empty tubes, vials, and waste such as foods or empty yogurt containers that were used in the experiments can be disposed of in the household trash or recycling bin.

Disposal of electronic components

The laser pointer contains recyclable electronic components, so in the interest of environmental protection it should not be thrown into the household trash at the end of its lifespan. Instead, deliver it to a collection location for the recycling of electrical and electronic devices, as indicated by the following symbol:

Please consult your local authorities for the appropriate disposal location.

WARNING! Do not throw used batteries into the household trash. They must be delivered to a local collection station or to a store that accepts used batteries for disposal.

Notes on Handling Batteries

WARNING — This product contains a Button or Coin Cell Battery. A swallowed Button or Coin Cell Battery can cause internal chemical burns in as little as two hours and lead to death. Dispose of used batteries immediately. Keep new and used batteries away from children. If you think batteries might have been swallowed or placed inside any part of the body, seek immediate medical attention.

››› Do not perform any experiments using the household current supply! The household voltage can be deadly dangerous.

››› You will need three 1.5-volt LR41/AG3 button cell batteries, which are included in the kit. Instructions explaining how to remove and insert the batteries are to the right.

››› Batteries are to be inserted with the correct polarity, as described to the right.

››› The supply terminals are not to be short-circuited.

››› Be careful to avoid any inadvertent short circuiting of the uninstalled batteries through contact with conductive metal objects such as coins or keychains. A short circuit could lead to a battery explosion.

››› Do not use any voltage source other than the specified batteries.

››› Different types of batteries or new and used batteries are not to be mixed.

››› Do not mix old and new batteries.

››› Do not mix alkaline, standard (carbon-zinc), or rechargeable (nickel-cadmium) batteries.

››› Non-rechargeable batteries are not to be recharged They could explode!

››› Rechargeable batteries are only to be charged under adult supervision.

››› Rechargeable batteries are to be removed from the device before being charged.

››› Dispose of used batteries in accordance with environmental requirements, not in the household trash.

››› Exhausted batteries are to be removed from the device.

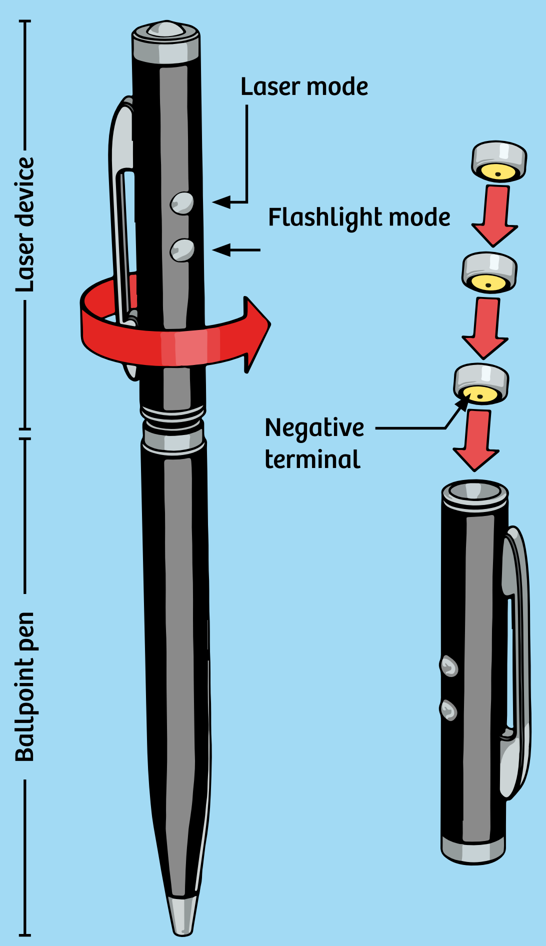
››› Avoid deforming the batteries.

Installing the Batteries in the Laser Pointer

››› The laser pointer has a double screw thread in its center connecting its two halves. On one side is a ballpoint pen, and the actual laser device is at the other end. Unscrew the laser device as shown in the picture.

››› Insert the three button cell batteries one by one with the rounded side (negative terminal) going first into the opening. Then screw the laser pointer back together again.

››› Push the front button to produce a red laser beam. The rear button makes the LED light up. That way, you can use the pen as a small flashlight, too.



Scientific Work Made Easy

Before you start, you will have to complete a few important preparations. Only once your experiment station is properly set up will you be able to work in complete peace and safety.

First, clear your work area of all unnecessary objects. That way, you will be able to experiment much more comfortably without having to push things out of the way all the time. Also make sure the surroundings are free of any obstacles. It will be useful to have a pen and notebook within reach too.

One of the most important “chemicals” for your experiments will be water. You will need it not just for cleaning, but for a lot of the experiments as well. If you don’t have a sink nearby, keep a bottle of water ready, such as a thoroughly cleaned dish soap bottle filled with tap water.

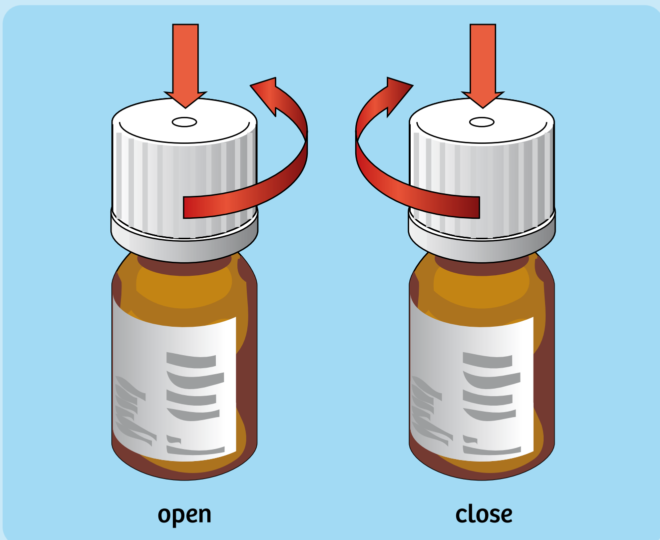
It is important for scientists to handle their laboratory equipment properly. This page and the next will show you how to open chemical tubes and vials and how to use the double-headed measuring spoon and the pipettes.

Chemical vials

1. Sometimes a small amount of the chemical will stick to the inside of the lid. To prevent any of it from falling onto your hand, bang the bottom of the tube several times on the work surface before opening it.
2. Slide the gray lid opener into the lid groove and carefully open the lid by levering the tool upward. Only remove as much of the chemical with the measuring spoon as you will need for the experiment. Then close the tube again right away.

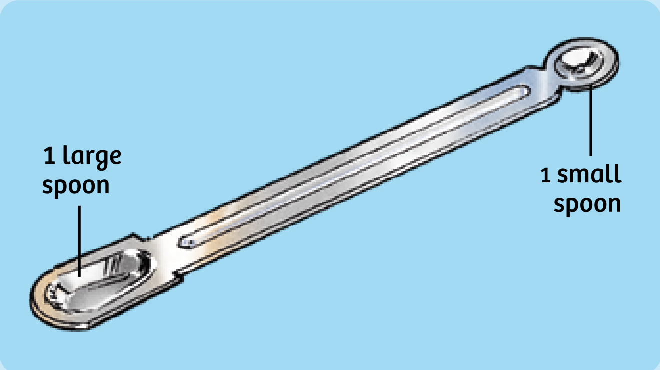
How to open the childproof cap

To open the bottle’s childproof cap, push down on the cap while turning it counterclockwise at the same time.



Using the double-headed measuring spoon

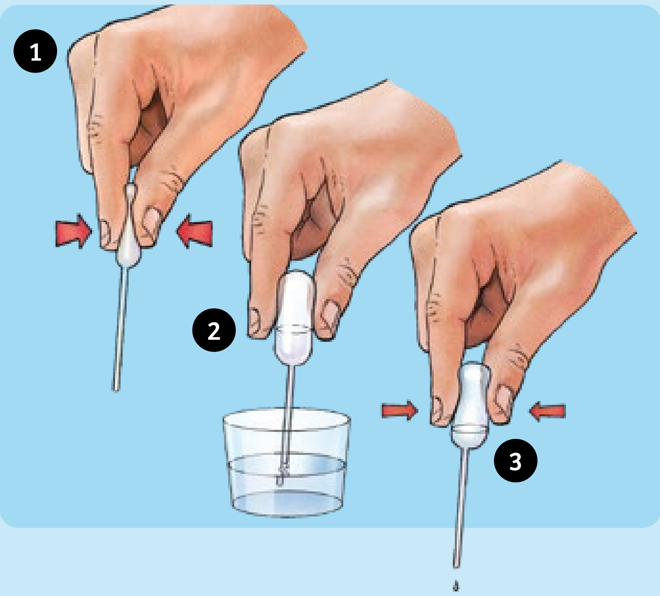
The double-headed spoon (also called a spatula) is used to take chemicals out of the tubes. It has one large and one small scoop. The indication "1 large spoon" means you should fill the large end, while "1 small spoon" means to fill the small end, with the scoop completely full in each case. Rinse and dry the double-headed measuring spoon after each use, so you don't contaminate other chemicals.



Precision use of the pipette

You will use the pipettes to add liquids drop by drop.

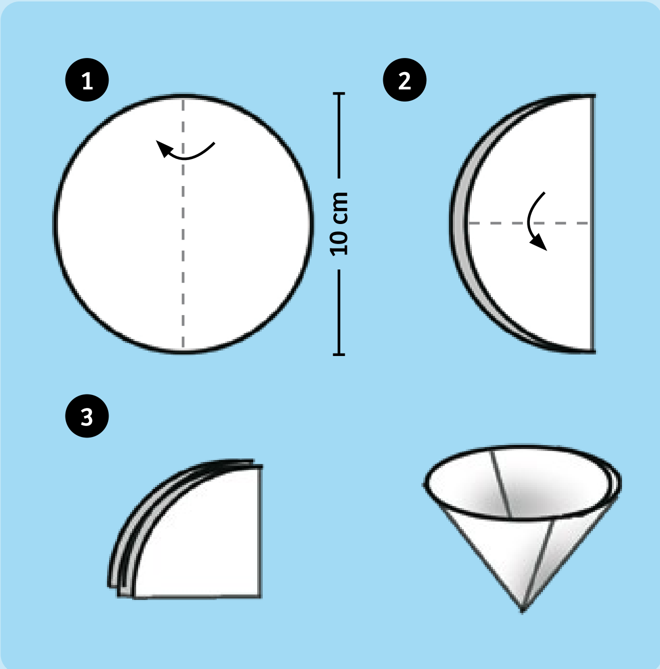
1. Squeeze the upper part of the pipette between thumb and index finger, and dip the tip of the pipette into the liquid.
2. As soon as you ease up on the pressure, the liquid will rise up the pipette.
3. By careful control of the pressure, you can make the liquid slowly drip out again.



How to filter

For filtering, you will need the funnel and the sheet of filter paper. Cut a disk about 10 cm in diameter out of the filter paper sheet. Use a compass or appropriately-sized cup or glass to help you.

1. Fold the disk in half.
2. Fold the resulting semicircle in half again.
3. This will give you a triangular cone. Place the cone in the funnel and moisten it with a little water so it sticks to the sides of the funnel.



Complicated concepts

Explaining nanotechnology concepts often requires using scientific terms that you may not be familiar with.

Therefore, at the end of this manual you will find a **glossary** — an alphabetical list of all the technical terms used here.

The Game Board

Welcome to nanoscopic world! In this experiment kit, you will find a whole array of astounding experiments to help you explore the world of nanotechnology.

There are five topic areas:

- ››› Sizes and Surfaces
- ››› Water-Attracting and Water-Repelling
- ››› Suspended Particles
- ››› The Tyndall Effect
- ››› The Secret of the Gecko

Nanotechnology is not a single branch of science. There are nanophysicists and nanochemists, just as there are nanomaterials researchers and nanocomputer engineers! All these disciplines are ones that study the very tiniest particles from a variety of points of view.

Many of the topics that you will be learning about in this experiment kit are interconnected and reveal very similar effects or are based on identical laws.

In order to help you gain a good overview of all these interconnections, all of the experiments are represented on a game board. There are various options for moving your game piece through the experiments:

››› Simply start with Experiment 1 and follow the arrows. Most of the experiments build on previous ones, but there are several places where you can make your own decisions about the sequence you want to follow.

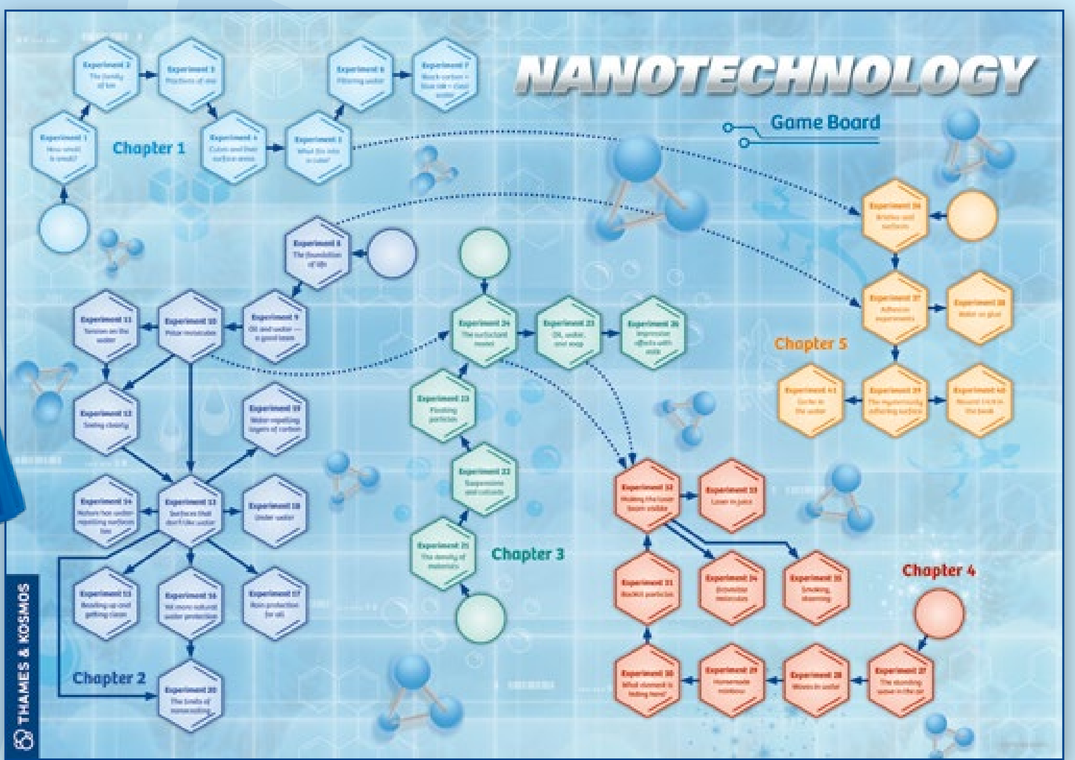
››› Enter at one of the starting points (round spaces). From that point on, follow the remaining experiments within the subject area.

››› Start with the experiment that seems most interesting to you. If there's something that you don't understand, jump back one experiment or back to the beginning of the chapter, until the relationships become clear to you.

Of course, you can also mount the game board on the wall, on a magnetic board, or on a bulletin board, and mark the spaces as you complete the experiments indicated in them.

And now, let's begin our voyage of discovery through the world of nanotechnology, where gold changes color and plants never get dirty!

Game piece



Sizes and Surfaces

Exactly how small is the nanoworld, and how large is a nanometer? Find out how scientists write these inconceivably tiny measurements and how an entire soccer field can fit inside a few grams of carbon.

How small is small?

YOU WILL NEED

› **Nanomeasuring tape**
› *Hair*
› *Piece of tape*

HERE'S HOW

››› Lay the nanomeasuring tape on the table in front of you with the light blue side facing up. There are four marks of different lengths printed on it.

››› Tape one of your hairs to the left end of the tiny yellow mark.

››› Estimate how long the four marks on the tape are and how many times a shorter mark can fit into the next-larger mark. How wide might your hair be?

WHAT'S HAPPENING?

The blue mark indicates a length of exactly **one meter (1 m).** The green mark is **one tenth** of a meter in length, or **one decimeter (1 dm).**

The red mark is once again one tenth of the green mark, or **one hundredth** of the blue mark in length. So it is **one centimeter (1 cm)** in length.

Ten times smaller than that in turn, and you get the yellow mark, which is **one thousandth** of the blue mark in length, or **one millimeter (1 mm).**

And your hair? It's not even as wide as the period at the end of this sentence: less than one tenth of a millimeter, or **one ten-thousandth of a meter.** (Don't worry if your hair is not exactly that wide. Some people's hair is thinner and some is thicker — it depends in part on your hair color!) So you would have to lay **ten thousand hairs** side by side in order to fill the entire span of a meter.

But what does all this have to do with nanotechnology? Just as your hair fits into a meter ten thousand times, **ten nanometers (10 nm)** are so small that they **fit into the width of your hair ten thousand times!** Even if you have a very good optical microscope, an object ten nanometers in size would not be visible.

EXPERIMENT 2

The family of ten

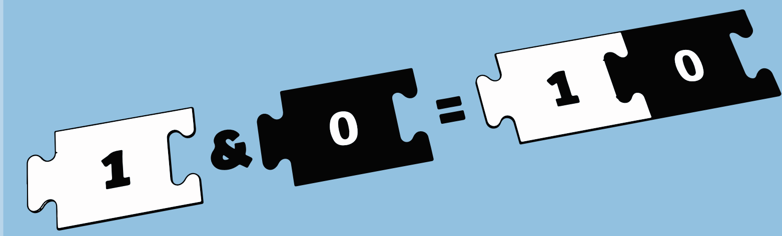
YOU WILL NEED

- All of the black "0" puzzle pieces
- White "1" puzzle piece
- Nanomeasuring tape

HERE'S HOW

››› You can stick the puzzle pieces together however you like to represent any numbers that are multiples of ten. The white piece corresponds to the number "1" and the black pieces correspond to the number "0." So the number 10 is perfectly simple to compose — the white "1" and one black "0."

››› Whenever you add a black piece at the end, you are increasing the number by a factor of 10. Using lengths as an example: From 1 meter you get 10 meters, from 10 meters you get 100 meters. When you take one big step forward, that's about 1 meter. (You can use the nanomeasuring tape to confirm that.) Ten meters is the length of two cars one behind the other, and 100 meters is the length of the 100-meter running track at your school.



TIP!
Of course, you can also write other numbers in front of the ten. Then, they are simply multiplied by "ten to the power of..." The circumference of Earth is almost exactly 40,000 kilometers, or 40,000,000 meters. Forty million meters equals
4 x 10,000,000 or
four times ten million or
four times ten to the power of 7 or
4 x 10^7 meters.

WHAT'S HAPPENING?

If you increase a number by a factor of 10 (in other words, by adding a zero to the number), you are changing it by one order of magnitude. The running track at school (100 meters) is greater than the length of one stride (1 meter) by two orders of magnitude.

To keep from tiring out your arm when writing all those zeros, there is a simple system you can use: Just write the number of zeros as a small number after the "10," and pronounce it "ten to the power."
For example: You can write 10 meters as 10^1 meters ("ten to the power of one"). 10,000 meters would simply be 10^4 meters ("ten to the power of four"). That can come in handy when you're dealing with gigantic numbers such as the weight of the Earth, which is on the order of 10^{24} kg. To represent "1," by the way, you can write 10^0.

Take a look at the pictures on the next page, and find out what order of magnitude each of them has. Don't forget that the difference between 10^2 and 10^4 is huge! The numbers are different by a factor of 100 — just like the difference between one stride and the running track!

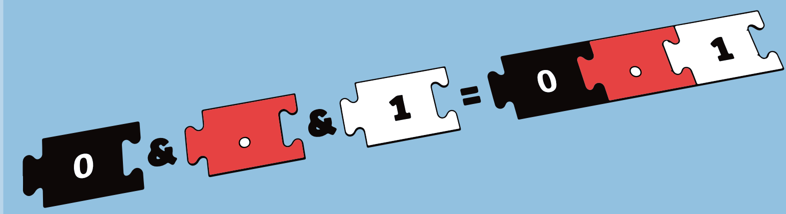
Measurement	Power of ten	Corresponds to	Order of magnitude
1 m	1×10^{0}	Nanomeasuring tape in the kit	0
1.7 m	1.7×10^{0}	Grown person	0
26 m	2.6×10^{1}	Height of Brandenburg Gate in Berlin	1
33 m	3.3×10^{1}	Length of a blue whale	1
137 m	1.37×10^{2}	Height of the Great Pyramid of Giza	2
828 m	8.28×10^{2}	Tallest building in the world (Burj Khalifa, Dubai)	2
980 m	9.8×10^{2}	Highest uninterrupted waterfall in the world (Angel Falls, Venezuela)	2
1,280 m	1.28×10^{3}	Length of the Golden Gate Bridge, San Francisco	3
8,848 m	8.848×10^{3}	Height of the world's tallest mountain, Mt. Everest, Tibet	3
10,900 m	1.09×10^{4}	Deepest ocean trench, Mariana Trench	4
13,000 m	1.3×10^{4}	Narrowest point of the Strait of Gibraltar (Spain-Morocco)	4
33,000 m	3.3×10^{4}	Narrowest point of the English Channel (England-France)	4
200,000 m	2×10^{5}	Distance from Pittsburgh to Cleveland	5
890,000 m	8.9×10^{5}	North-south extent of Germany	5
1,238,000 m	1.238×10^{6}	Length of the Rhine river	6
3,480,000 m	3.48×10^{6}	Diameter of the Moon	6
6,400,000 m	6.4×10^{6}	Length of the Great Wall of China	6
40,075,000 m	4.0075×10^{7}	Length of the Earth's Equator	7
299,800,000 m	2.998×10^{8}	Distance traveled by light in about 1 second	8
384,000,000 m	3.84×10^{8}	Distance between the Earth and the Moon	8
1,390,000,000 m	1.39×10^{9}	Diameter of the Sun	9
10,000,000,000 m	1×10^{10}	Distance traveled by light in about 1 minute	10
150,000,000,000 m	1.5×10^{11}	Average distance between Earth and Sun, known as 1 astronomical unit	11
1,400,000,000,000 m	1.4×10^{12}	Average distance between Saturn and the Sun	12
16,250,000,000,000 m	1.625×10^{13}	Distance of the Voyager 1 spacecraft from the Sun	13
9,460,000,000,000,000 m	9.46×10^{15}	Distance traveled by light in about 1 year (1 light-year)	15

EXPERIMENT 3

Fractions of one

YOU WILL NEED

› All of the black “0” puzzle pieces
› White “1” puzzle piece
› Red “decimal point” puzzle piece



HERE’S HOW

››› Stick one black, one red, and one white piece together. As in the previous experiment, the black piece represents a “0,” and the white piece represents a “1.” The red piece is the decimal point. So the number that you composed is “0.1”.

››› 0.1 (“zero point one”) equals a **one-tenth fraction** of 1, meaning that it fits ten times into the number 1. So if you insert another 0 between the decimal point and the 1, you get the number 0.01 — a **one-hundredth fraction** of 1. One centimeter equals one hundredth of a meter, as you saw in Experiment 1. Or, in other words: 1 centimeter = 0.01 meter.

KEYWORD: ORDERS OF MAGNITUDE

Even though “magnitude” can refer to a large size, the term “order of magnitude” is also used for small fractions. But be careful! The larger the number following the minus, the smaller the entire number will be. For example, 10^{-4} is one order of magnitude — or ten times — smaller than 10^{-3}!

WHAT’S HAPPENING ?

With every 0 that immediately follows the decimal point, the number becomes smaller! Here, too, we can consider a simplification for the sake of illustrating really small numbers, similar to what we did in Experiment 2. Write **the quantity of all the zeros in the number** (in other words, including the zero in front of the decimal point) as a **small superscript number with a minus following the number ten,** and you say **“ten to the minus…”** So one-hundredth (0.01) is “ten to the minus two,” and is written 10-2. Continuing with this example, one centimeter would be 10^{-2} meters.

And a nanometer? That’s one millionth of a millimeter, or a billionth of a meter, or 0.000 000 001 meter. Or even more simply: 10^{-9} meter.

TIP!
Here, too, you can put other numbers in front:
7 centimeters are 0.07 meters or 7 x 10^{-2} meters.

PANDORA VIRUS

RED BLOOD CELLS

Measurement	Power of ten	Equals	Order of magnitude
1 m	1×10^{0} m	Nanomeasuring tape in the kit	0
0.24 m = 24 cm	2.4×10^{-1} m	Diameter of a basketball	-1
0.03 m = 3 cm	3×10^{-2} m	Length of a match	-2
0.017 9 m = 1.79 cm	1.79×10^{-2} m	Diameter of a dime	-2
0.001 m = 1 mm	1×10^{-3} m	Microwave wavelength	-3
0.000 75 m = 0.75 mm	7.5×10^{-4} m	Largest bacterium (*Thiomargarita namibiensis*)	-4
0.000 1 m = 0.1 mm	1×10^{-4} m	Thickness of a sheet of paper	-4
0.000 07 m = 0.07 mm	7×10^{-5} m	Smallest object that can be seen by the human eye in daylight	-5
0.000 015 m = 0.015 mm	1.5×10^{-5} m	Diameter of a silk fiber	-5
0.000 007 5 m = 7.5 µm	7.5×10^{-6} m	Size of a red blood cell	-6
0.000 001 m = 1 µm	1×10^{-6} m	Chromosome	-6
0.000 001 m = 1 µm	1×10^{-6} m	Largest virus (Pandora virus)	-6
0.000 000 5 m = 500 nm	5×10^{-7} m	Green light wavelength	-7
0.000 000 35 m = 350 nm	3.5×10^{-7} m	Size of a single transistor of a computer chip in the year 1995	-7
0.000 000 1 m = 100 nm	1×10^{-7} m	Limiting magnitude for nanotechnology	-7
0.000 000 022 m = 22 nm	2.2×10^{-8} m	Size of a single transistor of a computer chip in the year 2012	-8
0.000 000 002 2 m = 2.2 nm	2.2×10^{-9} m	Diameter of a human DNA strand	-9
0.000 000 001 m = 1 nm	1×10^{-9} m	Largest X-ray wavelength	-9
0.000 000 000 034 m = 0.034 nm	3.4×10^{-11} m	Diameter of a carbon atom according to the van der Waals model	-11
0.000 000 000 024 m = 0.024 nm	2.4×10^{-11} m	Diameter of a hydrogen atom according to the van der Waals model	-11

DNA

EXPERIMENT 4

Cubes and their surface areas

YOU WILL NEED

› **8 small white cubes**

HERE'S HOW

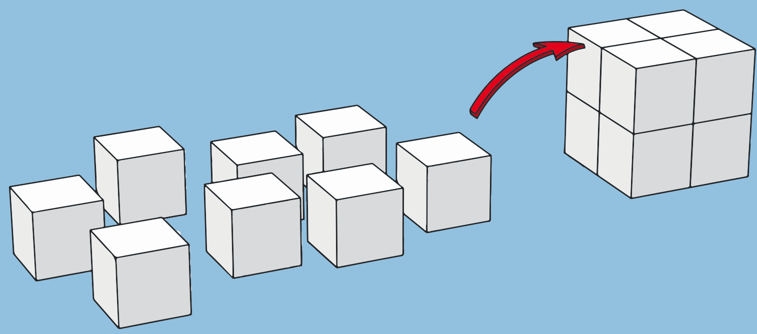
››› Take the eight white cubes in your hand. They will serve as units of measure for the next experiment. We will stipulate that one face of one of the small cubes represents **one unit of area (1 UA)**. In addition, the volume of one small cube in this experiment will be termed one **unit of volume (1 UV)**.

››› Assemble the eight small cubes into one big one — four cubes on one layer, and four on the next.

››› Now determine the surface area of the large cube by counting up all the small cube faces.

››› The volume of the large cube is easy to determine, too. If you start from the understanding that one small cube has exactly one unit of volume, then you know that the large cube contains 8 units of volume.

››› Disassemble the large cube again and perform a calculation of the surface areas and volumes of the individual cubes. What do you notice?



	Individual small cube	One large cube	8 Individual small cubes
Surface (UA)	6		
Volume (UV)	1		

DID YOU KNOW?

Fine dust, such as flour, can ignite in the air and even explode! The increased surface area of the small particles allows them to interact better with the oxygen in the air, which promotes fires.

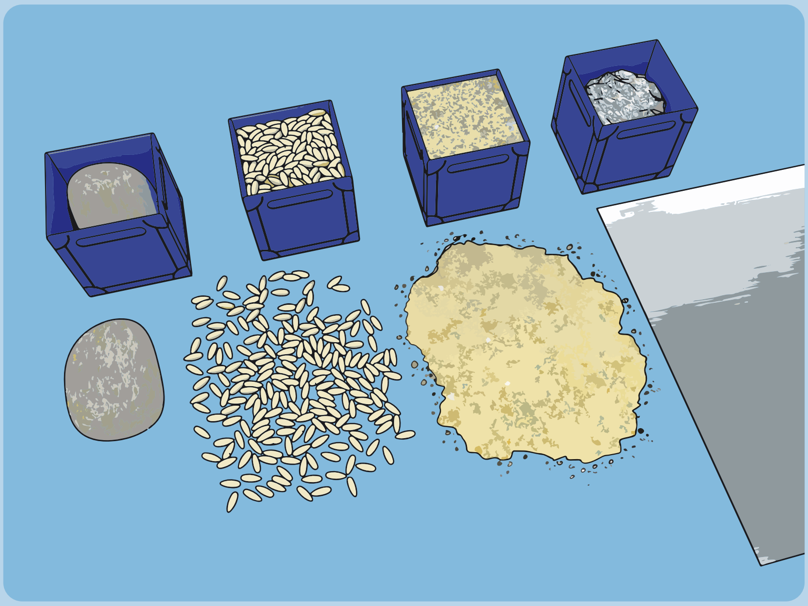
WHAT'S HAPPENING?

The volume of the **assembled cube** comes to **8 units of volume.** And when it is **disassembled** again, the eight component cubes still have the same volume altogether. With the **large cube**, you could see **24 cube faces** (4 faces per side x 6 sides = 24 faces). So the overall surface comes to **24 faces**. But when you disassemble the large cube into eight small cubes, you get a total surface area of **48 faces** (8 cubes x 6 sides). So simply by "breaking down" the large cube, you have doubled the available surface area!

And just like that, you have discovered one of the fundamental principles of nanotechnology! The large cube stands for the particle, or a small piece of whatever substance you like (such as iron or carbon). If you keep breaking down these particles, the volume won't change, but the surface area will! A lot of nanoeffects derive from the reduction of particles to the size of just a few nanometers in order to make their surface areas larger and larger. A larger surface area is important for chemical reactions, for adhesive forces (see the chapter about the gecko effect), and for filters (see Experiment 7).

EXPERIMENT 5

What fits into a cube?



YOU WILL NEED

- **Open plastic cubes**
- **Screw-top container with sand**
- *Pebble*
- *Some dry rice*
- *Some aluminum foil*

HERE'S HOW

››› Look for a pebble that fits just a little loosely into the plastic cube.

››› Obviously, no more pebbles of the same size will fit in, so you can just assume that the cube is "full" (at least, full of "pebble particles"). Take the pebble back out of the cube.

››› Place just one rice grain into the cube. Obviously, more could fit inside! Then fill the cube with grains of rice. Because the rice grains are smaller than the pebble, you can add quite a lot of "rice particles."

››› Now, instead of rice, fill the cube with sand. No doubt about it, there are more grains of sand in there than grains of rice! Pour the sand back into the screw-top container.

››› Finally, take some aluminum foil and make a ball out of it just small enough to fit into the cube. How much foil do you need?

WHAT'S HAPPENING ?

The smaller the particles, the more of them will fit into a given volume (the cube).

If you compare the surface areas, you will see that the small particles have a much larger surface area than the large ones.

That's particularly clear in the case of the aluminum foil: A lot of it will fit into the cube volume.

TIP!
If you find it hard to picture how the surface is getting larger, try to form a layer of the rice grains, sand grains, or foil "measured out" in the cube. The foil can be spread out over a much larger area than the sand and the rice (and naturally the pebble as well).

EXPERIMENT 6

Filtering water

YOU WILL NEED

- **100-mL measuring cup**
- **200-mL measuring cup**
- **Funnel**
- **Filter paper sheet**
- **Screw-top container with sand**
- **Double-headed measuring spoon**
- **Pipette**
- *Water*
- *Ink cartridge*

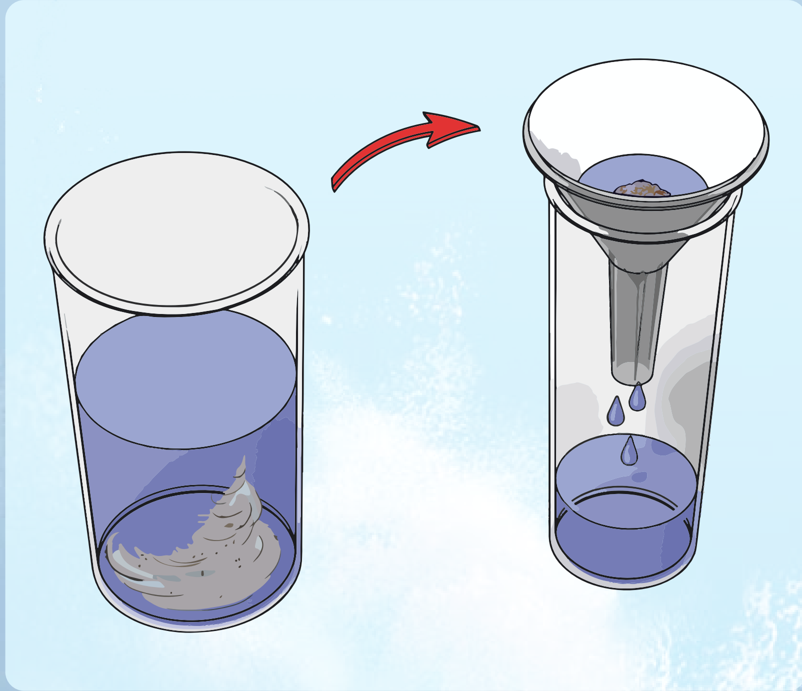
HERE'S HOW

››› Pour 25 mL of water into the larger measuring cup and add 2 spatula tips of sand. Carefully open the ink cartridge and add 5 drops of ink to the water.

››› Prepare the filter paper as described on page 9 and set the funnel on the smaller measuring cup.

››› Swirl the large cup and then carefully pour its contents through the filter.

››› Some liquid will slowly start collecting in the small measuring cup. Which materials passed easily through the filter, and which didn't?



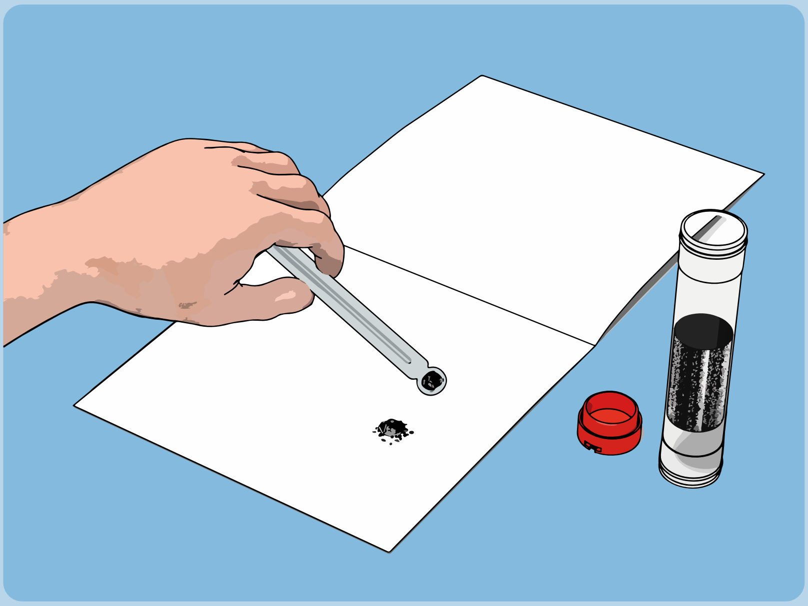
TIP!
If you place the smaller measuring cup on a white surface, such as a sheet of printer paper, you will be able to see the results better.

WHAT'S HAPPENING ?

At first, the filter paper holds back the coarse dirt (the sand). Only liquid gets into the measuring cup. Still, there is some color to the liquid, because there's still some ink in there. The pores of the filter paper (that is, the tiny holes in it) are small enough to block the grains of sand, but too large to hold back the ink particles.

EXPERIMENT 7

Black carbon + blue ink = clear water



YOU WILL NEED

- › **100-mL measuring cup**
- › **2 x 200-mL measuring cups**
- › **Funnel**
- › **Sheet of filter paper**
- › **Tube of activated charcoal**
- › **Double-headed measuring spoon**
- › *Water*
- › *Sheet of paper*
- › *A heavy object (such as a heavy drinking glass)*
- › *Ink cartridge*

HERE'S HOW

››› Pour 25 mL of water into one of the larger measuring cups. Open the ink cartridge and add 5 drops of ink to the water. Fold the sheet of paper once down the middle and unfold it again.

››› Add 2 spatula tips of activated charcoal to one half of the paper sheet and fold the other half over it. Pulverize the charcoal by grinding it carefully under the bottom of a drinking glass. You want to end up with a fine powder without any remaining large granules.

››› Now pour the black powder (using the crease in the paper to guide it) into the empty large measuring cup and add the ink water. Swirl the cup a little.

››› Prepare the filter paper as described on page 9 and set the funnel in the smaller measuring cup. Slowly pour the activated charcoal/ink water mixture through the filter. Watch to see what the liquid looks like as it drips out through the bottom. Again, it can help to place the cup on a white surface.

WHAT'S HAPPENING ?

By breaking down the activated charcoal into fine powder, you are increasing its surface area many times over. Even though its volume remains the same, there is more surface area available for filtering out tiny particles.

The filtrate, which is the name for the liquid that eventually drips through the filter, is practically free of color (especially when you compare it against the filtrate from the last experiment).

Just four grams' worth of pulverized activated charcoal, or about half the amount in the chemical tube, has a total surface area as large as a soccer field! How can that be? Each charcoal particle has a surface like a sponge, with countless pores and openings just a few nanometers in size. That's why activated charcoal is known as a "nanosponge."

The blue ink molecules get chemically "stuck" to the surface of the charcoal particles. The greater the surface, the less ink there is in the liquid at the end.

CHECK IT OUT

Filters

A filter is basically just a device for separating certain substances from one another. For example, a sieve is a (very large) filter, and a colander "filters" spaghetti from the water you cooked it in.

The filter paper works like a sieve too, except its holes (the so-called "pores") are much, much smaller and can't even be seen with the naked eye. Depending on the size of the pores, some substances will be caught and stay behind, while others will be able to get through.

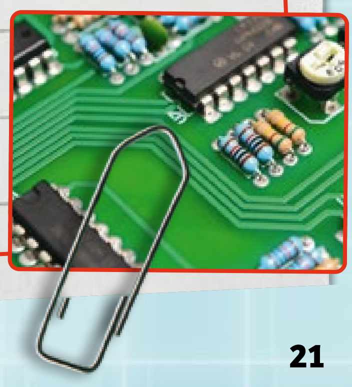
Some substances are so small that they can get through any pores, so they have to be chemically bonded. That means that certain other substances are present in the filter material with which the substances to be filtered out enter into a chemical bond.

In activated charcoal (which is used, for example, in a lot of drinking water filters), materials are "adsorbed," meaning that they become firmly attached to the charcoal particles. Because activated charcoal has a very large surface area, a lot of materials can get caught there. But sooner or later even that kind of filter will get "filled up," and will have to be replaced.

BOTTOM-UP AND TOP-DOWN

Manufacturing nanoparticles — that seems pretty simple on paper. But how are they actually produced for industry or research? Scientists have discovered two different ways to do it. One starts with larger structures that are then ground down or processed with lasers, for example. This is known as a "top-down" method. Grinding coffee beans is an example of a top-down process, because large coffee beans are made smaller by mechanical processing. (Of course, they are not reduced to the nanometer scale.)

The opposite way would be to take small units, such as chemical molecules, and build larger structures out of them. This is the method used when manufacturing computer chips. The first step is to use lasers that are so hot that they can vaporize metal. The metal from the vapor settles onto a special substrate. Depending on how long the laser melts the metal, the layers formed by the metal as it is deposited may be various degrees of thickness — as little as just a few nanometers! Masks (like stencils) are used to ensure that these metallic layers are deposited in just the right regions of the substrate. So, in other words, the computer chips are formed out of tiny building blocks — it's a "bottom-up" method. Usually, both methods are used in combination, in accordance with the materials and equipment available.



CHECK IT OUT

Nanoparticles and Light

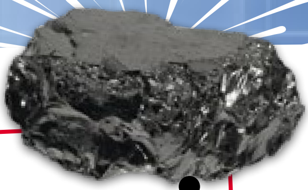
For a few decades, it has been possible to obtain electricity from sunlight with the help of solar cells. In some countries, like Germany, this kind of technology has been making considerable progress with the help of plenty of publicly-funded incentives. One important evaluation measure for solar cells is their degree of efficiency. This has to do with how much electricity the solar cells can actually produce from the sunlight that hits them.

Nanotechnology can be used to improve the efficiency of a solar cell with the help of a material known as silicon. The top layer of a solar cell is made of glass. A problem in the current state of the technology is that a portion of the sun's light gets reflected back by this layer. This light therefore doesn't reach the cell, and "gets lost" in the process of producing electricity. But if another layer is applied onto the glass containing nanospheres smaller than 50 nanometers in diameter, less light is reflected back than with an ordinary glass surface. So more light hits the silicon in the cell, and more electricity is produced. This is an example of a bottom-up process.

There is also a similar approach involving changing the surface of the silicon itself. For example, an etching process can be used to form shapes like ridges or pyramids a few nanometers in size, in order to reduce reflection off the surface. This is an example of a top-down process. Using this method, an Atlanta-based research team was able to reduce the degree of reflection of a certain solar cell from 35% down to just 1.4%. That means that almost all the available sunlight can be used for producing electricity.

Water-Attracting and Water-Repelling

On the most general level, all surfaces behave alike when you apply water to them: they get wet. But the leaves of a lot of plants are actually designed to repel water, so they remain dry. In this chapter, you will learn what's happening on a nanolevel, and how you can imitate this effect. You will also learn about the foundation of life and what plastic is really made of.

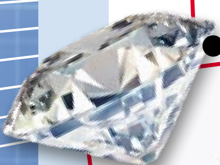


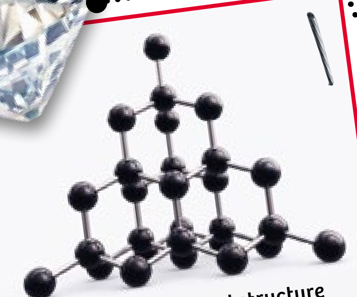
CARBON, CARBON EVERYWHERE

Here's a bold assertion: Carbon is everywhere. What first comes to mind might be charcoal, pencil lead, or maybe diamonds. But what else? Actually, the element carbon is the most basic component of all life on Earth — the so-called **biosphere**. Carbon is also found in petroleum and natural gas, which is what most plastics are made from. Chances are good that pretty much everything you see around you contains the element carbon, at least as long as it isn't made of glass.

Even pure carbon — sometimes known as **crystalline carbon** — can take lots of different forms. The carbon in pencil lead, for example, is present in the form of very **thin layers** that yield a soft gray material that will rub off on paper. In this form, carbon is known as **graphite**. The graphite portion in a pencil can be adjusted by adding more or less clay material during the manufacturing process. The higher the graphite portion, the softer the pencil.

Carbon in graphite structure





Carbon in diamond structure

But even just a small change in this crystalline structure can turn ordinary graphite into a **diamond**. Instead of occurring in layers, the atoms are organized into a sort of three-dimensional grid. This "small change," unfortunately, can only take place under enormous pressure applied over long periods of time, which is why diamonds are so rare and expensive. Diamonds can also be created artificially in the lab. Synthetic diamonds are normally used in industrial applications and not jewelry.

On the "Check it out" page in this chapter, you will see what other forms of crystalline carbon have been discovered and created in the last few decades with the help of nanotechnology.

In addition to carbon, petroleum contains other chemical elements such as hydrogen, oxygen, nitrogen, and sulfur. In this case, the carbon does not occur in crystalline form, but in large molecules. The carbon atoms can be arranged in chains, rings, or grids, for example. Since the molecules consist mainly of carbon and hydrogen, they are also known as hydrocarbons. These become separated when the petroleum is heated, which takes place in an oil refinery. The longer the carbon chains, the higher their boiling point. This is how petroleum is turned into gasoline, diesel, heating oil, and many other materials.

The most complex carbon compounds, though, are found in plants, animals, and of course inside your own body. These large molecules have important biological functions, which is why they are also known as **biomolecules**.

EXPERIMENT 8

The foundation of life

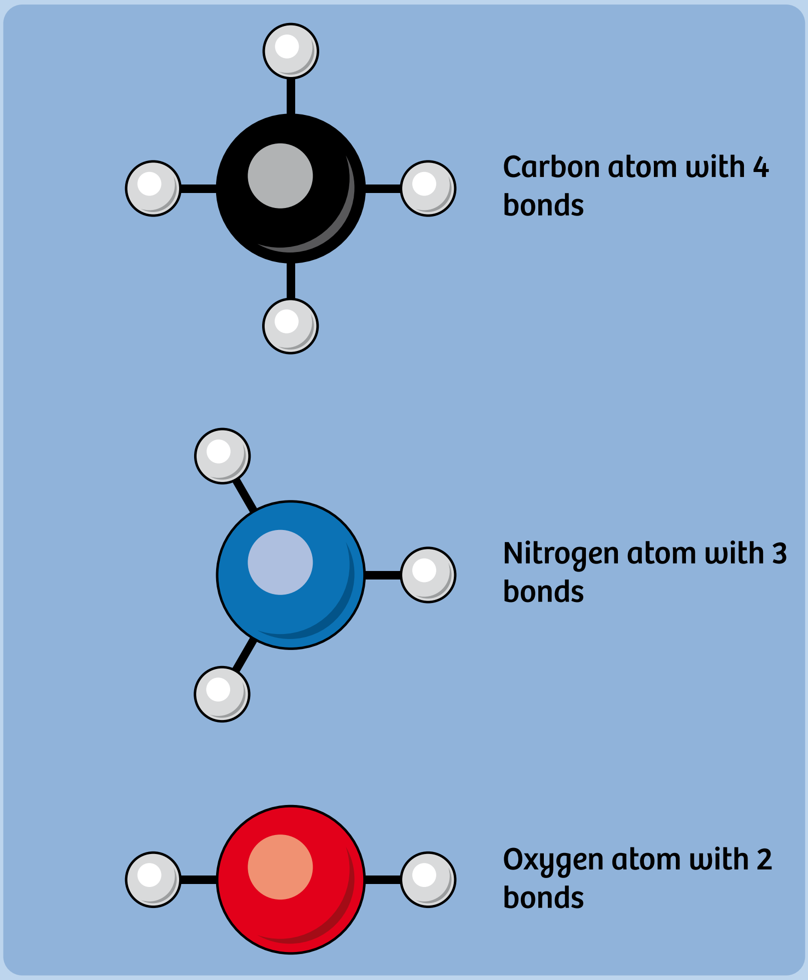
YOU WILL NEED

› **Molecule boards (die-cut sheet)**
› **Manual pages 26 and 27**

HERE'S HOW

››› As you probably already know, all the materials that make up our world are constructed from **atoms.** But atoms are very rarely found on their own. Usually, at least several of them will be combined through chemical bonding into larger building blocks known as **molecules.** Molecules can consist of just two or three atoms, but they can also be composed of several hundred. Some consist of only one chemical element, while others contain many different ones. The atoms can occur in chains, rings, or grids, among many other shapes.

You will find some important molecules on the small die-cut boards. **Unfortunately, the atoms got mixed up and have to be put into their proper order!**



››› Take the boards with the molecules and remove the individual atoms from them. They have different colors: The **red circles** are **oxygen atoms,** the **black circles** are **carbon atoms,** and the **blue circles** represent **nitrogen atoms.** The **white circles** are **hydrogen atoms,** which have already been inserted to get you started.

››› Now it's your turn to try to insert the atoms into their proper places in the molecules. It helps to know the rule that a given chemical element will only have a certain number of bonds with its neighboring atoms:
- **Carbon: 4 bonds**
- **Nitrogen: 3 bonds**
- **Oxygen: 2 bonds**

Important: So-called "double bonds" (═) are counted as two single bonds.

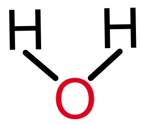
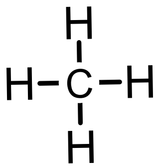
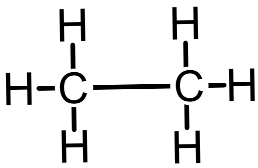
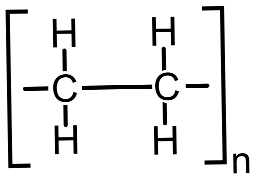
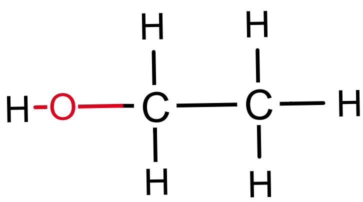
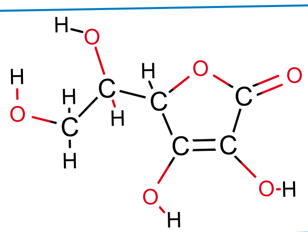
››› Once you have filled all the shapes, turn them over so you can see what molecules you have assembled. Which ones have you heard of?

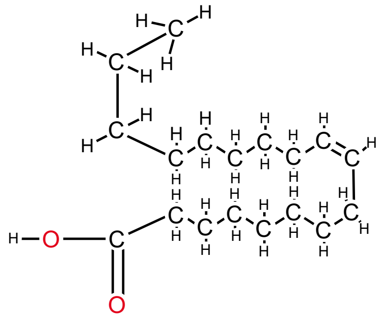
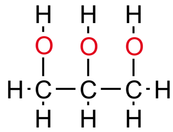
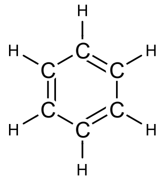
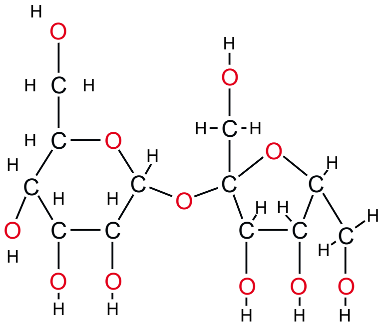
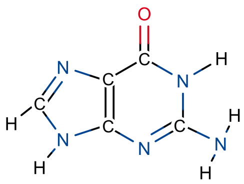
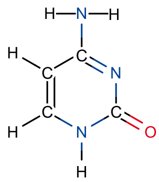
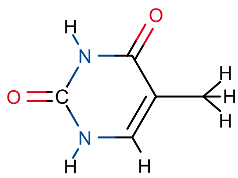
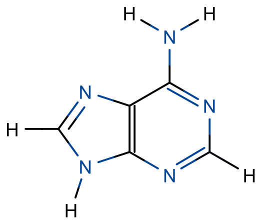
WHAT'S HAPPENING ?

Next to the molecules on pages 26 and 27, you will find information about where they occur and why they are so important. In almost all of these molecules, carbon is the main element holding the entire structure together. The chemistry discipline that deals with carbon molecules is known as **organic chemistry.** The branch known as biochemistry deals mainly with the complex molecules that occur in living things.

Important Organic Molecules

On these pages, you can see which molecules you have assembled and where these molecules occur. Except for water (H_2O), these are all organic molecules. Some of them are found in living things, others must be produced artificially.

Molecule	Representation	Occurrence
molecule name **Water** H_2O molecular formula		Water is the molecule that is most import for life on Earth. It occurs in solid (ice), liquid (water), and gaseous (steam or vapor) states.
Methane CH_4		Methane is a natural flammable gas. It is formed during the breakdown of biological materials by microorganisms, and is the foundation for the production of many organic molecules.
Ethane C_2H_6		Along with methane, ethane is a main component of natural gas and is burned for heating. Ethane is also a basis for the production of organic molecules.
Polyethylene (PE) (basic building block) $[C_2H_4]_n$		The "n" can stand for any number. It shows how often the basic building block of polyethylene (PE) repeats in a long chain. PE is the most commonly produced type of plastic in the world. Virtually all plastic bags and films are made of PE.
Ethanol C_2H_6O		Hydrocarbons that possess one or more OH groups in their molecules are chemically categorized as alcohols. Ethanol is the type of alcohol found in alcoholic drinks. The production of ethanol through the fermentation of sugar has been practiced by humans for thousands of years.
Vitamin C $C_6H_8O_6$		Vitamin C is an organic molecule that occurs in many foods and is important for various bodily functions. Insufficient vitamin C leads to a disruption of metabolism and illness.

Oleic acid $C_{18}H_{34}O_2$		Oleic acid is an import member of the so-called fatty acids group — typically long-chained hydrocarbons with an acid group (“COOH”) at one end. Fats and oils each contain three fatty acids linked with a glycerol molecule — hence the name “fatty acid.”
Glycerol $C_3H_8O_3$		Glycerol is a component of all fats and oils (see above). It is contained in cosmetics and in automobile antifreeze fluids, among other things.
Benzene C_6H_6		Benzene is a so-called aromatic hydrocarbon in which six carbon atoms are connected in a ring. Benzene is a raw material used in the production of many complex materials.
Sucrose $C_{12}H_{22}O_{11}$		Sucrose is the chemical name for crystalline sugar (household sugar). It has been produced since ancient times from sugarcane and more recently from sugar beets as well.
Guanine $C_5H_5N_5O$		The guanine molecule occurs in human DNA, which carries genetic information in your body. It forms a so-called base pair with cytosine via hydrogen bonds.
Cytosine $C_4H_5N_3O$		Cytosine is also found in DNA. DNA stands for **d**eoxyribo**n**ucleic **a**cid, a biomolecule in the shape of a double helix. Your DNA stores all the information about your body’s makeup.
Thymine $C_5H_6N_2O_2$		Along with adenine, thymine forms DNA’s other base pair. Our entire DNA has 3.27×10^9 of these base pairs, distributed across 46 so-called chromosomes.
Adenine $C_5H_5N_5$		Adenine is the fourth molecule important for DNA. In 2006, scientists decoded the sequence of all base pairs in humans. Unfortunately, though, it is still largely unclear what information is encoded in a given section of DNA.

EXPERIMENT 9

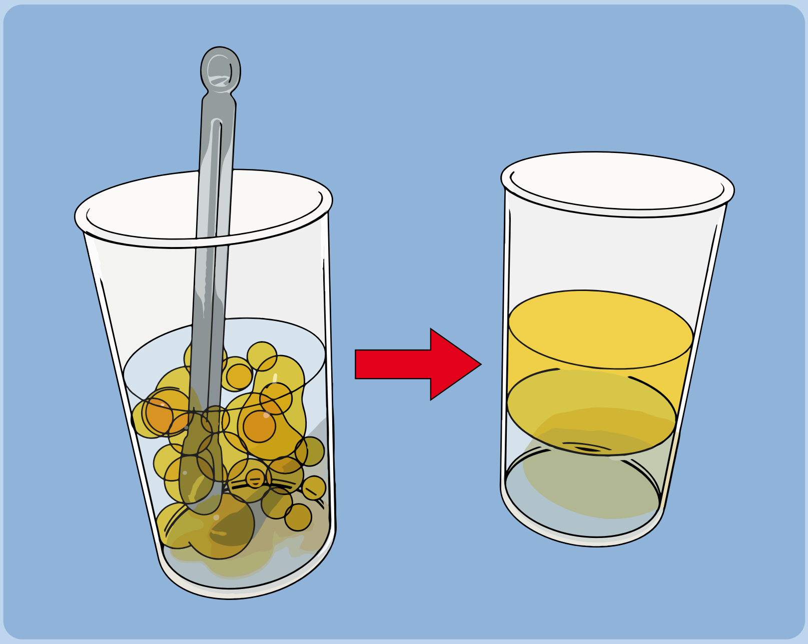
Oil and water — a good team

YOU WILL NEED

- **200-mL measuring cups**
- **Double-headed measuring spoon**
- *Cooking oil*
- *Water*

HERE'S HOW

››› Pour 25 mL oil and 25 mL water into the measuring cup and stir vigorously with the measuring spoon.



WHAT'S HAPPENING?

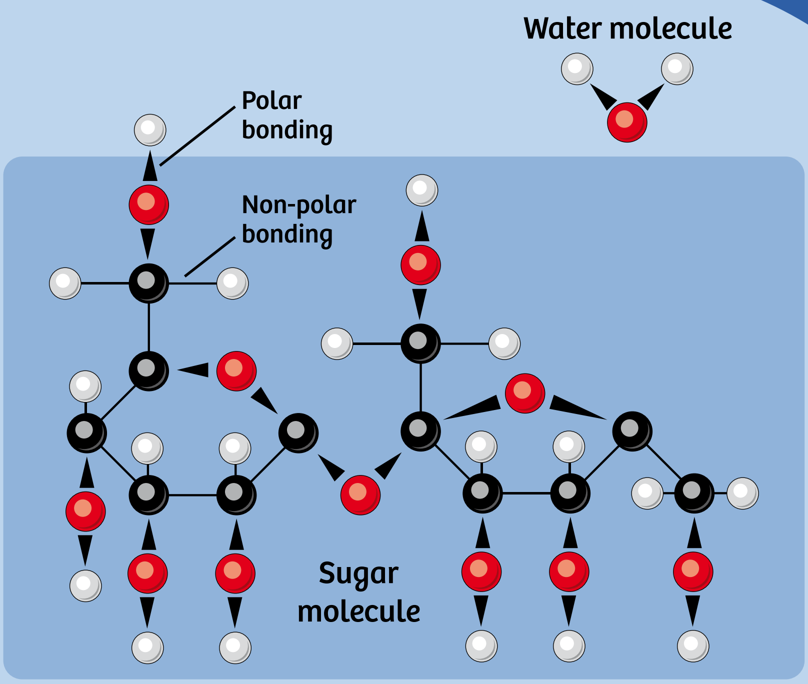
Cooking oil contains a lot of carbon atoms. Each oil molecule is composed of **three fatty acids** (such as oleic acid) and one **glycerol molecule.** That's why they are also known as **triglycerides.** You already worked with both of these components in Experiment 8. A glance at the table shows that a single oleic acid triglyceride contains 57 carbon atoms (3 x 18 carbon atoms from oleic acid + 3 carbon acids from the glycerol).

An important property of a lot of carbon compounds is their **hydrophobic** nature. The word comes from Greek *hydros* (= water) and *phobos* (= fear). It means that these materials don't like water — they won't dissolve in it, they won't mix with it, and they won't take part in any chemical reactions with it.

The more nonpolar-bonded (see Experiment 10) **carbon atoms** a molecule contains, **the more hydrophobic** it is. Obviously, oil won't dissolve in water. It immediately separates into a layer that floats on top. Ethanol, on the other hand — the substance that is normally called "alcohol" — contains just two carbon atoms along with one oxygen atom. That's why you can mix it with water. The next experiment will show you why the oxygen atom is so important!

EXPERIMENT 10

Polar molecules



YOU WILL NEED

- **200-mL measuring cups**
- **Double-headed measuring spoon**
- *Sugar*
- *Water*

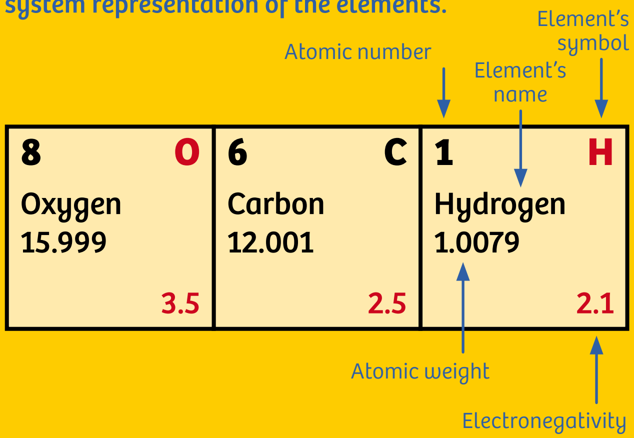
HERE'S HOW

››› Fill the measuring cup with tap water up to the 100-mL mark.

››› Add 5 spoons of sugar and stir vigorously. What happens to the sugar when you stir for one minute?

KEYWORD: ELECTRONEGATIVITY

Every chemical element has a certain electronegativity, which is often indicated in a periodic system representation of the elements.



Oxygen has an electronegativity of 3.5. Carbon has 2.5 and hydrogen 2.1. Carbon-hydrogen compounds are therefore somewhat non-polar, since the difference between the elements' electronegativity values only comes to 0.35. Compounds of these two elements with oxygen, on the other hand, are very polar — the differences are 0.89 (carbon-oxygen) and 1.24 (hydrogen-oxygen).

WHAT'S HAPPENING?

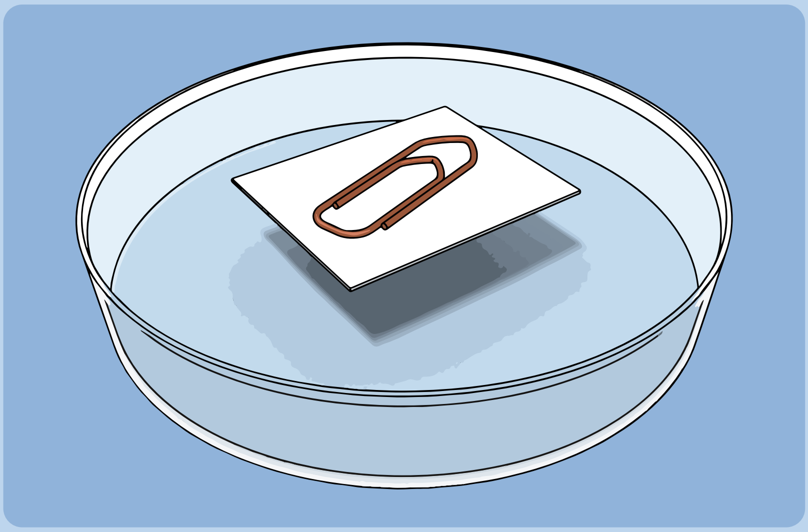
Even though household sugar — a.k.a. sucrose — does contain 12 carbon atoms, it still dissolves well in water. A long-chained alcohol with 12 carbon atoms, on the other hand, is practically insoluble in water. The reason has to do with the fact that the sugar molecule contains a lot of **polar bonds** (specifically, all the bonds that contain oxygen).

In chemistry, of course, the word "polar" has nothing to do with polar bears or penguins. If a chemical bond is "polar," that means that the two bonding partners have opposite properties — like two poles. The property involved in this case is **electronegativity**. This is the ability of an atom to attract electrons in a chemical bond.

A chemical bond often means that the two bonding partners share electrons (the electrically negatively-charged constituents of an atom). If one of the partners attracts the electrons to itself, there arises a **greater negative charge** on that side of the bond. But what does that have to do with solubility in water? Water itself is a very polar substance — which is why other polar substances will easily dissolve in it. A name for these kinds of substances is **hydrophilic**, from Greek *hydros* (=water) and *philos* (= love). In other words, they love water!

EXPERIMENT 11

Tension on the water



YOU WILL NEED

- › **Petri dish**
- › **Paper clip**
- › **Wooden stick**
- › **Tweezers**
- › *Water*
- › *Scissors*
- › *Tissue paper*

HERE'S HOW

››› Place the Petri dish at your experiment station and fill it with water.

››› Cut off a small section of tissue.

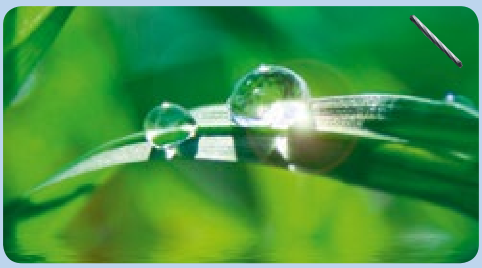
››› Use the tweezers to lay the tissue on the surface of the water and immediately set the paper clip on top of it.

››› Wait until the paper has become fully saturated and sinks to the bottom. If you like, you can help it along by carefully pushing down on the edge of the paper with the wooden stick.

››› What happens to the paper clip when the paper sinks?

DID YOU KNOW?

In freefall, water forms drops — surface tension ensures that the number of molecules on the surface is lowest when the water takes the shape of a ball. In Experiment 13, you will see that water can also form drops on certain surfaces!



WHAT'S HAPPENING?

The paper clip floats on top of the water even though it's made out of metal, which usually sinks. But why?

Each of the water molecules in the Petri dish is connected to its neighbor by weak bonds known as **hydrogen bonds.** These bonds are based on the strong polarity (see Experiment 10) of water molecules and exist in all directions — up, down, left, right, in front and behind. You might say that the surrounding molecules are "pulling" with a certain force — even if just a weak one — on each water molecule. But because it is pulled equally on all sides, the net result is that no force is exerted on the molecule.

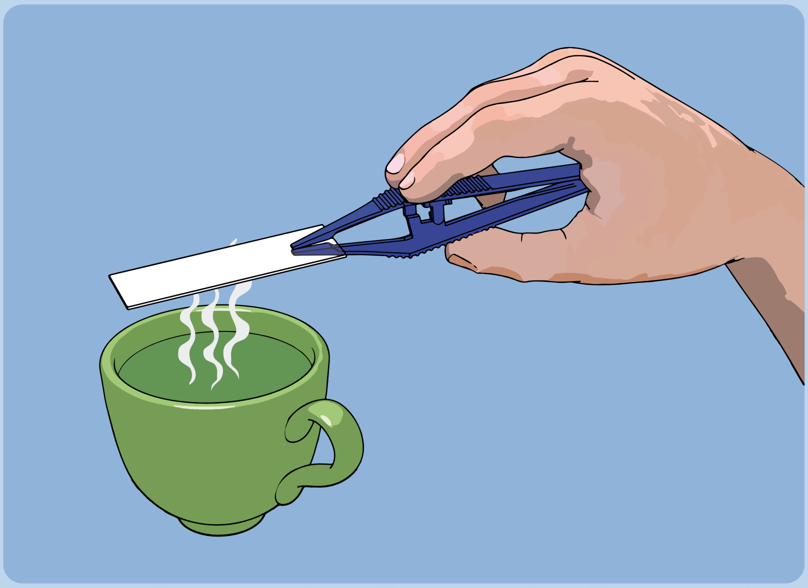
On the water's surface, though, not all a water molecule's neighbors are other water molecules. Some are air molecules such as nitrogen and oxygen. These exert a weaker pull on the water particles. One way of putting it is to say that the interactions between the molecules are weaker. So the net effect is a force exerted on the water particle to pull it away from the surface.

For this reason, as few water molecules as possible will always be at the boundary with the air. That gives a certain "solidity" to the surface known as surface tension. It can be strong enough to hold small objects such as a paper clip.

In Experiment 38, you will see all the other things that surface tension can do. For example, it can stick things together!

EXPERIMENT 12

Seeing clearly



YOU WILL NEED

- **2 slides**
- **Petri dish**
- **Bottle with anti-fog agent**
- **Tweezers**
- *Permanent marker or small sticker*
- *Hot tap water*
- *Cup*
- *Paper towel*
- *Refrigerator*
- *Watch*

CAUTION! Perform this experiment near an open window!

HERE'S HOW

››› Place one of the slides on a paper towel and mark it with a permanent marker or sticker, so you can tell it apart from the other slide later on.

››› Use the brush on the lid of the bottle to paint the marked slide with a thin, even layer of anti-fog liquid. Immediately close the bottle tightly again. Let the layer of liquid dry.

››› Use the tweezers to carefully place the marked and the untreated slide in a Petri dish and set the Petri dish in the refrigerator for 5 minutes.

››› Meanwhile, prepare the cup: Fill it halfway with hot water from the tap and set it on a level surface.

››› Get the slides from the refrigerator and hold them over the cup of hot water with the tweezers. Be sure to hold the treated side down. What differences do you observe?

WHAT'S HAPPENING?

The untreated slide "fogs up," or forms a thin layer of water droplets, as the steam from the hot water condenses due to the temperature difference. The water forms a lot of small droplets because of its surface tension (see Experiment 11). These droplets scatter the light so the slide no longer looks clear or transparent.

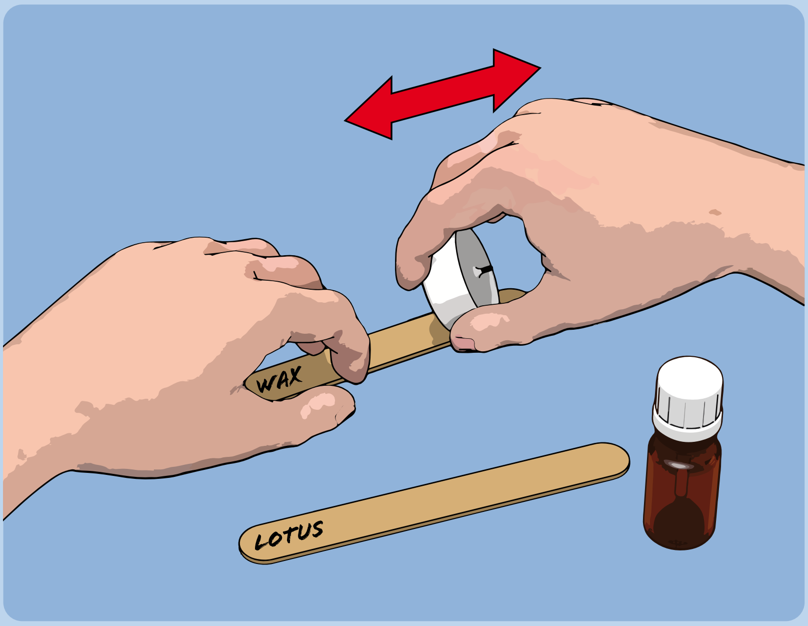
The anti-fog liquid produced an invisible layer of hydrophilic (water-loving) particles on the treated slide. The water molecules from the steam then attached themselves to the particles in this layer. That prevented the formation of water droplets. Instead, the water spread into a very thin film — so thin that it still appears transparent to your eye.

TIP!
You can use the anti-fog liquid on a lot of surfaces. Two places where it might come in handy are the bathroom mirror and eyeglass lenses. First, though, ask your parents' permission and have them help you. If you use the liquid on a piece of stiff film, you can write and send secret messages! The liquid is not suitable for the treatment of metallic surfaces.

Surfaces that don't like water

YOU WILL NEED

- **200-mL measuring cup**
- **3 Petri dishes**
- **3 wooden spatulas**
- **Pipette**
- **Bottle with lotus fluid**
- **Tweezers**
- **Tea light**
- *Permanent marker or small stickers*
- *Water*



HERE'S HOW

››› Prepare for the experiment by placing each of the three wooden spatulas in a Petri dish. Mark two of the spatulas with the permanent marker or stickers.

››› Take the tea light out of its metal holder and rub its bottom vigorously against one of the marked wooden spatulas.

››› Open the bottle of lotus fluid and paint one side of the second marked spatula with the little brush. Let the spatula dry for about 10 minutes until it no longer looks damp.

››› Add 50 mL of tap water to the measuring cup and fill the pipette with it.

››› Drip one or two drops of water onto each of the wooden spatulas. What do you observe? What happens if you tilt the Petri dish a little?

WHAT'S HAPPENING ?

The drops of water behave differently on each surface. On the untreated wood, the water disperses into little spots.

On the wooden spatula treated with wax, on the other hand, the water doesn't disperse so fast. Wax, like oil, will not mix with water (see Experiment 9), so the water won't disperse on the surface, but instead remains in little round drops (see Experiment 11).

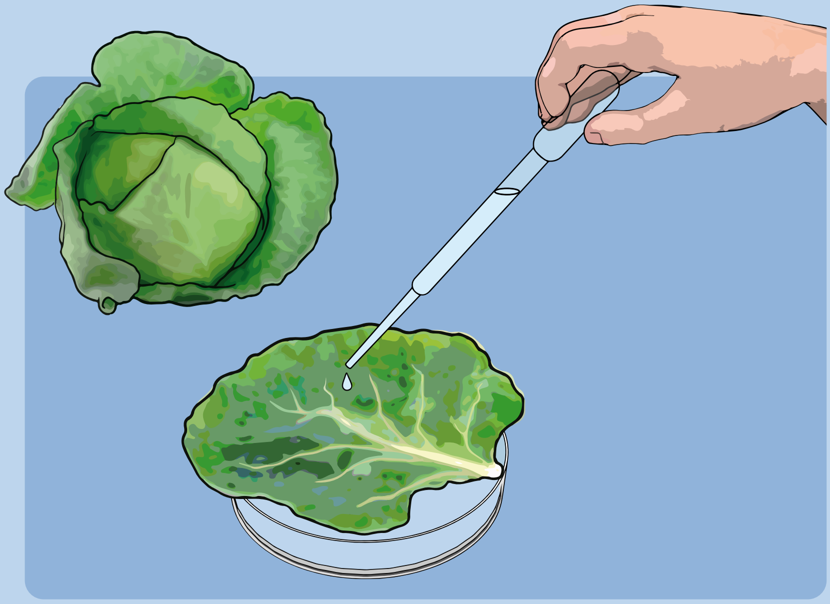
With the lotus fluid, you have also created a water-repelling layer resembling the surface structure of a lotus leaf — hence its name. This is actually much more effective than the wax layer. The lotus fluid molecules have arranged themselves with their water-repelling side pointing upward. These so-called "functional groups" are extremely water-repellent, or "super-hydrophobic," from a chemical perspective. The molecules of water have absolutely no chance of dispersing across the surface!

Water-repelling chemicals are also used in wall paints to prevent the walls from getting wet. As in this experiment, the water forms almost perfectly round droplets that simply bead up on the wall. Your lotus fluid works well on absorbent surfaces such as wood, stone, or fabric.

Save the wooden spatulas for a later experiment!

EXPERIMENT 14

Nature has water-repelling surfaces too



YOU WILL NEED

- **1 Petri dishes**
- **200-mL measuring cup**
- **Pipette**
- *Paper towel*
- *Various plant leaves: lettuce, cabbage, nasturtium, broccoli, lily pad*
- *Water*

HERE'S HOW

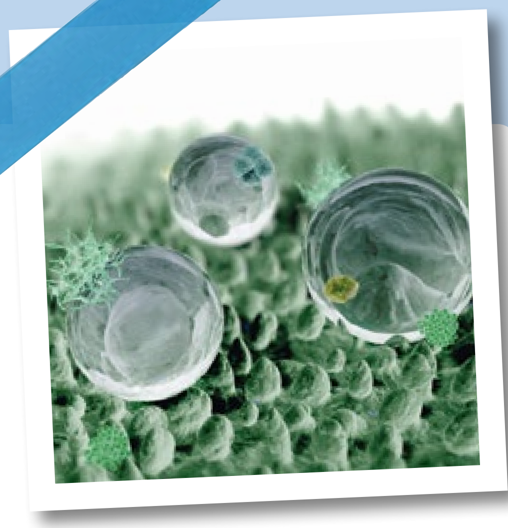
››› Place the various leaves in the Petri dish one after the other.

››› Fill the measuring cup with tap water and draw some into the pipette.

››› Place a few drops on the leaves and compare how the water behaves on them.

KEYWORD: LOTUS EFFECT®

Because the water-repellent, self-cleaning effect is especially easy to see on lotus leaves, it is also known as the lotus effect, and your water-repelling nanoliquid is called "lotus fluid."



WHAT'S HAPPENING?

With some plant leaves, such as lettuce, you won't see anything special. The water just spreads out and coats the leaves. But some plants have a natural ability to make water roll right off of them! The drops dart around on their surface without leaving any trace behind.

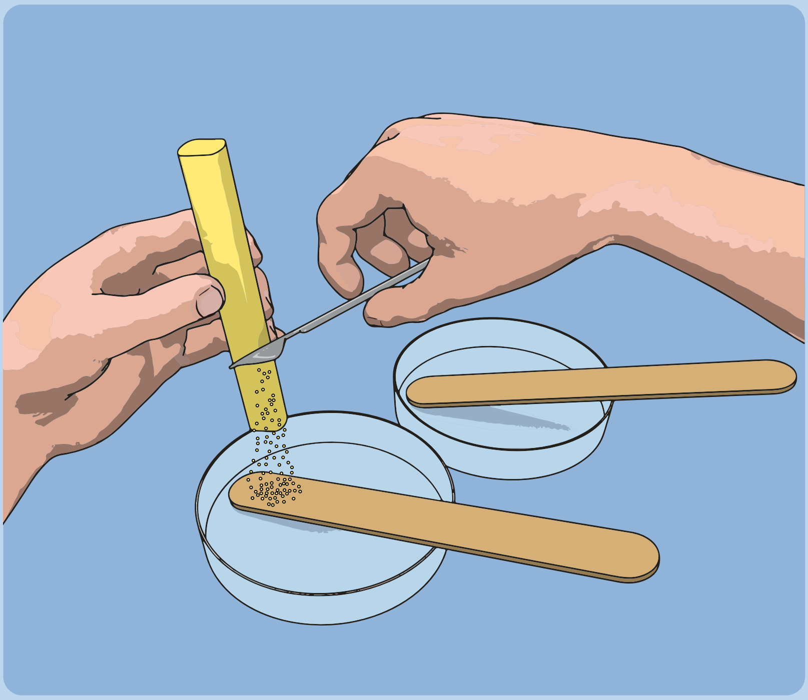
It took a long time for this effect to be explained. Part of it comes from the fact that the outer layer of the plant's leaf, the so-called epidermis, forms countless tiny points just a few nanometers in size. On this scale, the water drops appear gigantically large. Surface tension prevents the water from getting between the points and keeps the droplets held together. The effect also comes from the fact that these points have water-repelling molecules just as in the previous experiment.

So the surface that the drops touch is actually extremely small — just the very tips of the points. And these are also coated with water-repelling molecules! No wonder that the water droplets move so quickly!

For the plants, this has several advantages: Some use it to guide the water where they can use it, or they use it to clean themselves (see Experiment 15).

EXPERIMENT 15

Beading up and getting clean



YOU WILL NEED

- **Uncoated wooden spatula**
- **Wooden spatula coated with lotus fluid from Experiment 13**
- **2 Petri dishes**
- **Double-headed measuring spoon**
- **Chalk**
- **Pipette**
- **200-mL measuring cup**
- *Water*

HERE'S HOW

››› Place the wooden spatula from Experiment 13 in a clean Petri dish with the side with the lotus coating facing up; place the wooden spatula without any treatment in a second Petri dish.

››› Use the double-headed measuring spoon to shave a little chalk onto each wooden spatula until there's a thin layer of powder covering the surface.

››› Pour a little tap water into the measuring cup and fill the pipette. Place a few drops of water from the pipette onto each wooden spatula. Swirl the Petri dishes and watch how the drops behave.

WHAT'S HAPPENING ?

On the wooden spatula without any coating, the water spreads out a little and the chalk powder floats around in the layer of water.

The nanocoating ensures that the water doesn't spread out over the surface, but instead forms drops that move across the surface almost without touching it. As they do that, they pick up all the little chalk particles and clean the spatula!

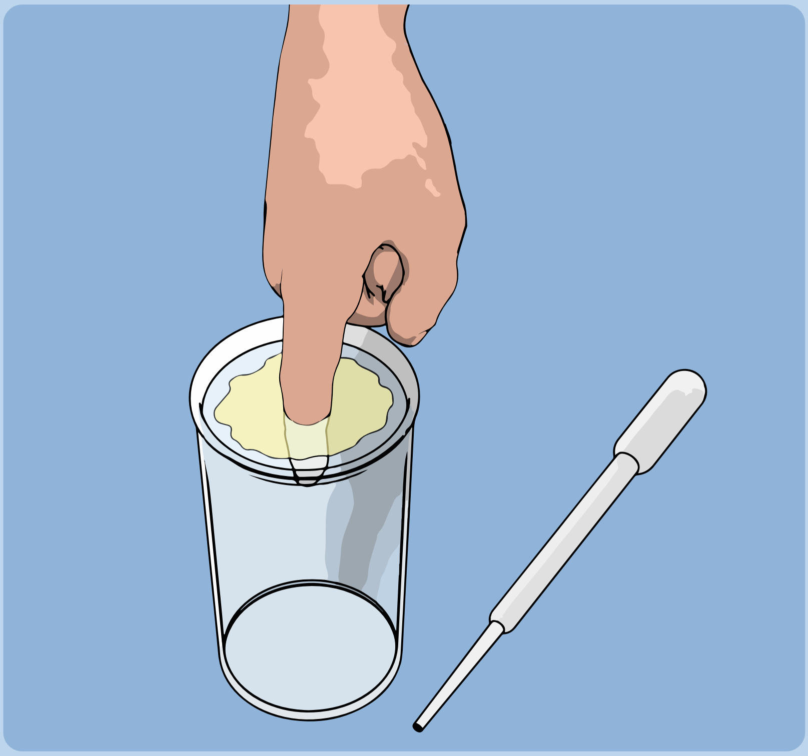
DID YOU KNOW?

In the Buddhist religion, the lotus plant is a symbol of purity because it's always clean, even when it grows in muddy ponds. It manages to be that way with the help of the nanostructure of its leaves.

There are already a few applications for water-repelling and self-cleaning surfaces — for paints used on cars and bicycles, for outdoor house paints, for glass shower walls, and even for clothing!

EXPERIMENT 16

Yet more natural water protection



YOU WILL NEED

- **200-mL measuring cup**
- **Tube of clubmoss spores**
- **Lid lifter**
- **Pipette**
- **Petri dish**
- *Water*

HERE'S HOW

››› Fill the measuring cup up to the 175-mL mark with tap water.

››› Open the tube with the clubmoss spores and sprinkle some of them into the Petri dish to form a small mound.

››› Use the pipette to pick up a few of the spores.

››› "Blow" the pipette over the water to form an even layer of clubmoss spores over the water's surface.

››› Carefully dip a finger through the layer about 1 to 2 cm deep into the water.

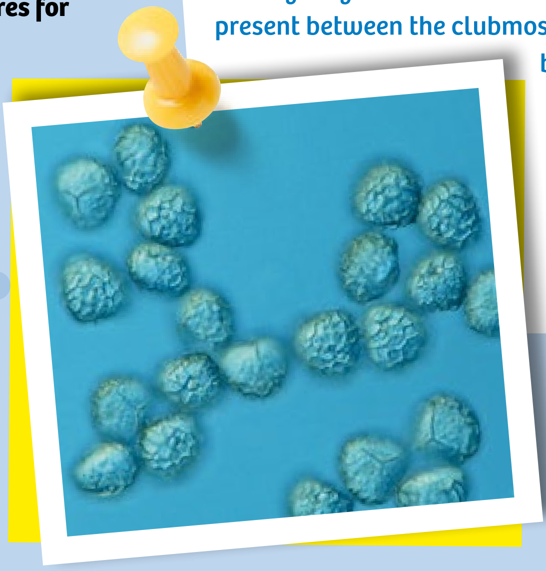
››› Repeat the experiment, paying attention this time to the way the part of your finger looks that's "under water." Wash your hands after the experiment.

Save the cup with clubmoss spores for Experiment 20!

WHAT'S HAPPENING ?

If the clubmoss layer is well distributed, your finger will stay dry! The spores form a protective layer between your finger and the water. They are very small (1000 nm) and also have a water-repelling surface.

When your finger is in the water, you can actually see a silver coating on your skin. This is created by the air that is still present between the clubmoss spores. It refracts and reflects back the light, just like a mirror. In the chapter about the Tyndall effect, you will find more on the topic of light and light refraction on tiny particles.



EXPERIMENT 17

Rain protection for all

YOU WILL NEED

› Petri dish
› Piece of blue fabric
› Bottle of lotus fluid
› 200-mL measuring cup
› Pipette
› *Water*

HERE'S HOW

››› Place the piece of fabric in the Petri dish and apply some lotus fluid (a). Then let the fabric dry for 10 minutes. Can you see the lotus coating?

››› Fill the measuring cup with tap water and draw some into the pipette. Add a few drops of water to the fabric (b). What happens to them?

WHAT'S HAPPENING ?

The water-repellent coating also works on a soft and irregular surface such as fabric. The molecules organize themselves in a layer just a few nanometers thick.

Fabric consists of fibers that can normally absorb water. That's why your clothes are heavy when they get wet. If you seal these fibers with lotus fluid, the water beads up and can no longer penetrate the fabric. This kind of process is called "impregnating."

EXPERIMENT 18

Under water

YOU WILL NEED

- › **200-mL measuring cup**
- › **Wooden spatula coated with lotus fluid from Experiment 13**
- › *Water*

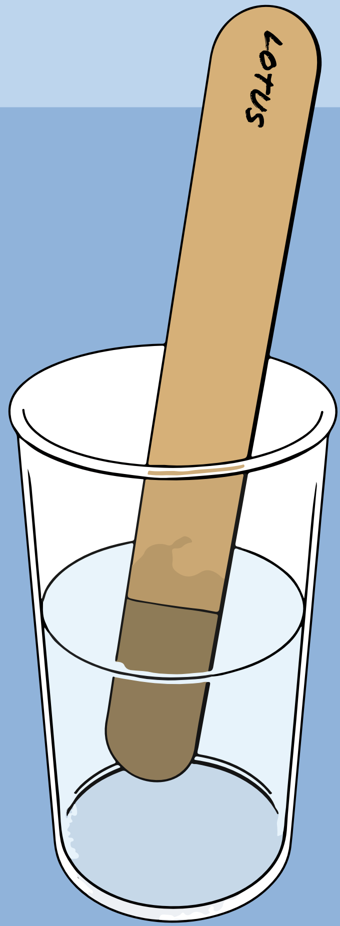
HERE'S HOW

››› Up to now, you have just placed a few water droplets and a little dust on the coating. What would happen if you submerged the entire coating in water?

››› Fill the measuring cup to the 100-mL mark with tap water.

››› Immerse the coated wooden spatula from Experiment 13 in the water.

››› Observe both submerged sides of the spatula — the untreated side as well as the coated one. Can you see a difference?



WHAT'S HAPPENING?

The coated side shows a silvery shimmer, while the uncoated side doesn't change at all.

Because the molecules of the nanolayer repel the water, a wafer-thin layer of air forms between the water and the wood. The light reflects off this film and creates a silver shimmer. On the other side, you won't see any shimmer because the water is contacting the wood directly there.

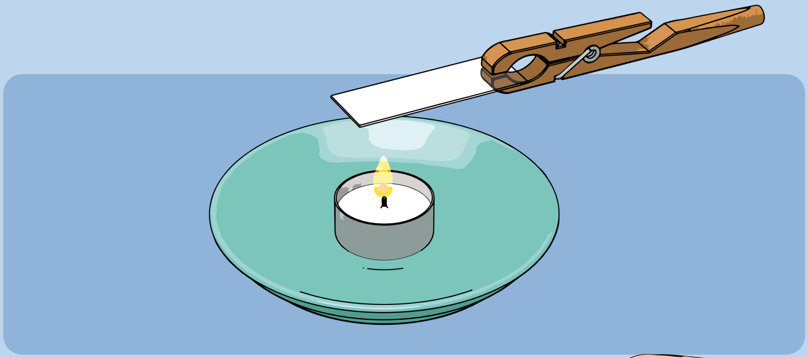
EXPERIMENT 19

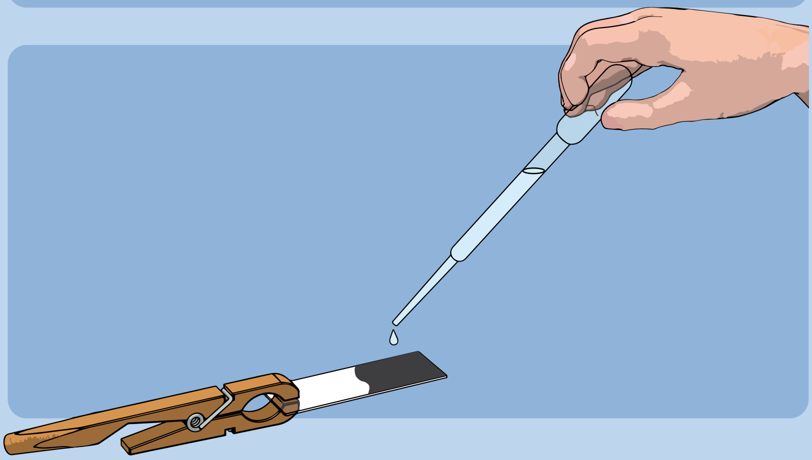
Water-repelling layers of carbon

YOU WILL NEED

- **Wooden clip**
- **New, uncoated slide**
- **Tea light**
- **200-mL measuring cup**
- **Pipette**
- *Lighter*
- *Saucer*
- *Water*

CAUTION! Perform experiments with candles on a suitable fireproof surface and note the warnings on page 4 (Experiments with open flame).





HERE'S HOW

››› Clamp the slide in the clip.

››› Pour a little tap water into the measuring cup and draw some into the pipette. Set it aside for now.

››› Set the tea light on the saucer and light it. Use the wooden clip to hold the slide carefully about 1 cm above the flame. Do not hold the clip directly in the flame! After a little while, you will see a black layer form.

››› Move the slide in such a way that one half of it gets covered with the black layer.

››› Blow out the candle and place the clip and slide on the saucer with the black layer you just created facing up. Let the slide cool for 2 minutes.

››› Use the pipette to drip water onto the black layer. How do the drops behave?

WHAT'S HAPPENING?

Congratulations, you have just made your very own water-repelling nanoparticle layers!

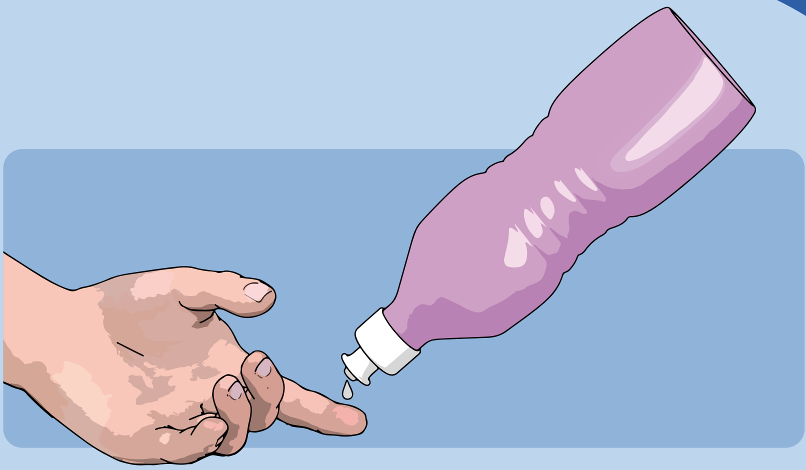
In the candle flame, the wax (which is made of organic molecules) burns and forms carbon dioxide and water vapor, which rises into the surrounding air. But not all the molecules are completely burned up. In so-called incomplete combustion, fragments of organic molecules are created — hydrocarbon chains of varying lengths — that gather together to form tiny black particles of soot. The soot then collects on the glass slide. Since the hydrocarbons are water-repellent, the thin layer of soot on the slide is likewise hydrophobic — which is why the water forms little drops that zoom around.

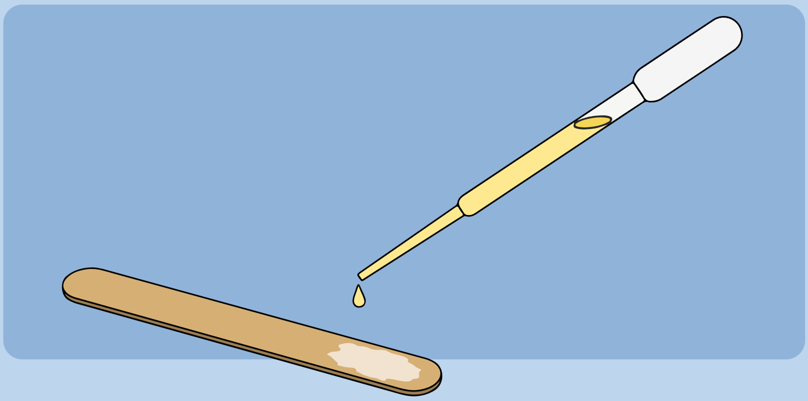
KEYWORD: SOOT

Soot is what causes the black color in chimneys. Along with a lot of gas components, it's also something that comes out of car exhaust pipes and industrial smokestacks. Soot nanoparticles are also produced on purpose, though. This so-called carbon black is used as a filler in the rubber industry, forming up to 90% of the composition of tires and improving their performance.

EXPERIMENT 20

The limits of nanocoating





YOU WILL NEED

- **Cup with clubmoss spores from Experiment 16**
- **Wooden spatula with lotus coating from Experiment 13**
- **200-mL measuring cup**
- **Petri dish**
- *Cooking oil*
- *Dishwashing liquid*

HERE'S HOW

››› Pick up the cup with the clubmoss spores. If the spores no longer form a complete layer on the surface, follow the instructions in Experiment 16 to refresh it.

››› Place a drop of dishwashing liquid on your finger and dip your finger into the layer. Can you still immerse your finger without water contact? Wash your hands afterwards.

››› Place the coated wooden spatula in the Petri dish and pour 1 cm of cooking oil into the measuring cup. Draw some oil up into the pipette.

››› Drip the oil onto the coated side of the spatula. Does the oil bead up?

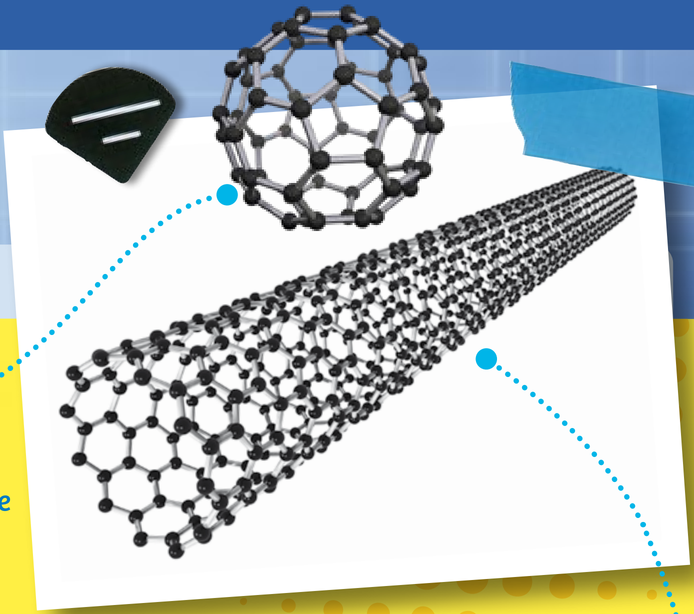
TIP!
For more exciting experiments with oil, water, and nanoparticles, take a look at the "Floating particles" chapter.

WHAT'S HAPPENING?

When you place dishwashing liquid on your finger, it reduces the water's surface tension holding the seeds together. Since the spores are no longer held together, your finger gets wet when you immerse it in the water.

The nanolayer on the wooden spatula repels water, but it doesn't repel oil at all. That has to do with the chemical structure of the molecules on the surface. They are hydrophobic — but also lipophilic, meaning "fat-loving." The oil molecules are therefore not repelled from the surface.

CHECK IT OUT



NEW FORMS OF CARBON

In nature, pure (crystalline) carbon occurs as graphite and diamond, while coal and petroleum are created from the organic remains of plants and animals that lived millions of years ago. All these forms of carbon have been used by humans for a long time.

In the 1970s, scientists started using powerful microscopes to study the soot formed by various kinds of combustion. In the process, they discovered new molecules that were composed of pure carbon organized into a spherical shape. While these spheres were just 1 nanometer in size, they could still carry other molecules inside themselves, so they could be used, say, to transport those molecules to certain parts of the body and release them there. That could be very useful in medicine, for example. With the help of new methods, nanoengineers have been able to create these special carbon spheres, called "fullerenes," and use them in their research.

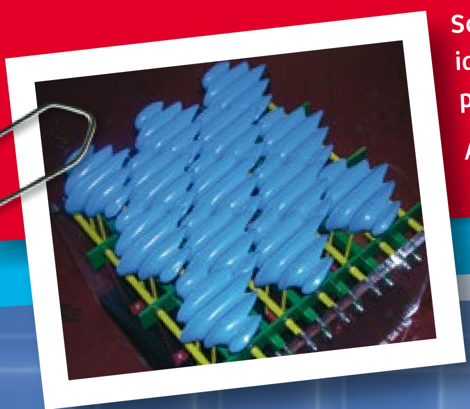
In additional to this spherical shape, carbon can also be made into tubes. These "carbon nanotubes" often occur in bundles and have features such as tiny fibers. They are extremely strong and have come to be used for strengthening building materials. They are particularly handy for making very light but strong materials for use in the automobile industry and in space travel.

AS SEEN IN NATURE

People have been fascinated for ages by the strange lotus plant, whose leaves never seemed to get dirty. They first suspected that the reason that nothing could stick to its leaves was simply that they were very smooth. Only when modern technology became available, such as the electron microscope (see "Knowledge Base," pages 59 to 61), were scientists actually able to study the structure of lotus leaves.

Soon they were looking for a way to copy that effect and create artificial lotus surfaces. Today, with the help of nanotechnology, practically any surface can be made to be water-repellent.

The idea of looking to nature to find solutions to engineering problems is known as "bionics," composed of the Greek root for "life" and the suffix "-ic," hence "lifelike." For swimsuits, ships' hulls, and even for airplanes, bionic engineers have been inspired by such natural objects as sharkskin, for example. The sharkskin scales have fine grooves that reduce the effects of friction when the shark is swimming quickly. With airplanes, fuel consumption can be reduced with the help of an artificial groove pattern on the outer surface.



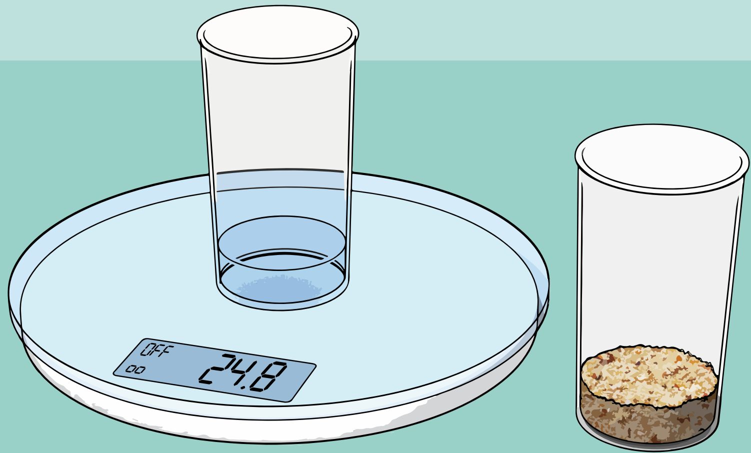
Some features of bone and plant growth have provided architects with ideas for new kinds of buildings and have helped in the development of particularly light but strong components for machines.

And there's always a lot more to be learned from nature!

Levitating Particles

Levitating particles? That sounds like magic. But with the right chemistry tricks, it's no problem: If the particles are small enough they will spread out into their surroundings without sinking to the ground. For that, chemical compounds known as surfactants will come in handy. In addition, this chapter tells you about mixtures of materials that actually can't be mixed at all!

The density of materials



YOU WILL NEED

- **2 x 200-mL measuring cups**
- **Screw-top container of sand**
- *Rice*
- *Kitchen scale*
- *Water*

HERE'S HOW

››› First weigh the empty cup on the kitchen scale and note its weight in the table to the right.

››› Fill the first cup with tap water up to the 25-mL mark, and the second cup with sand up to the same level. Set the two cups in turn on the kitchen scale and note the weight of each.

››› Pour the sand back into the screw-top container and now fill the same cup with rice, again up to the 25-mL mark. Place it on the scale and note the weight.

››› Which material is lightest, and which is heaviest? For correct results, always subtract the weight of the cup itself.

	Weight	Volume	Density
Empty cup		–	–
Tap water		25 mL	
Sand		25 mL	
Rice		25 mL	

WHAT'S HAPPENING ?

Water, sand, and rice have different densities: The same volume — in other words, the same fill level in the cup — will weigh different amounts.

The physical unit of density combines volume and weight: How much does a given volume of material weigh? The unit for density is grams per cubic centimeter (g/cm^3).

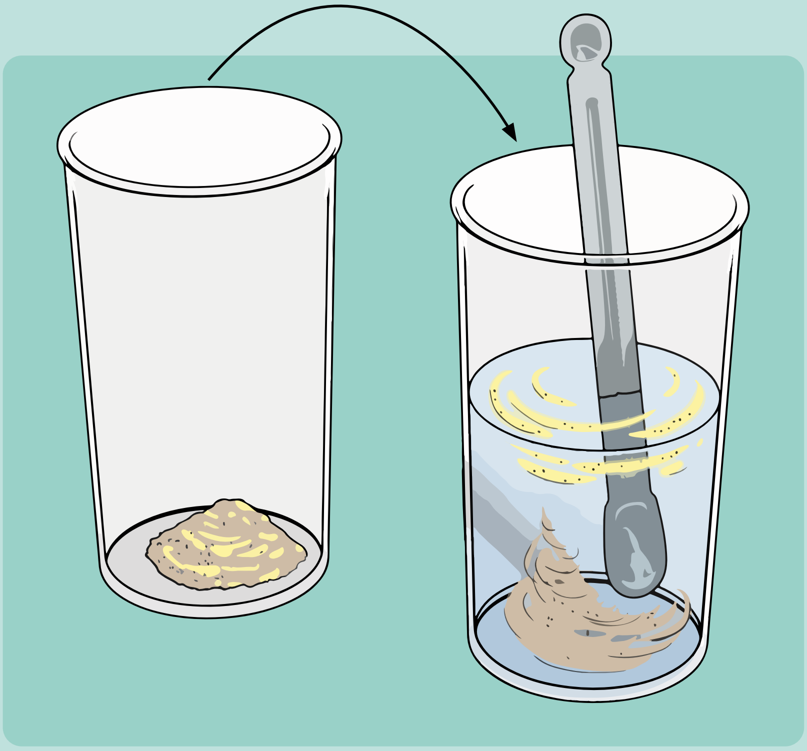
After determining the weight with the scale, you still need to know the volume. When the cup is filled to the 25-mL mark, the volume comes to exactly 25 cubic centimeters! And since the water weighs just about exactly 25 grams, it yields a density of 1 g/cm^3 for water.

$$\text{Density} = \frac{\text{Weight}}{\text{Volume}} = \frac{25\ \text{g}}{25\ \text{mL}} = \frac{25\ \text{g}}{25\ \text{cm}^3} = 1\ \frac{\text{g}}{\text{cm}^3}$$

For the other materials, you should likewise divide the weight by a volume of 25 cm^3 in order to determine the density.

EXPERIMENT 22

Suspensions and colloids



YOU WILL NEED

- **Screw-top container with sand**
- **Tube with clubmoss spores**
- **Lid remover**
- **2 x 200-mL measuring cups**
- **Double-headed measuring spoon**
- *Water*

HERE'S HOW

››› Measure 2 large spoons of sand and 2 large spoons of clubmoss spores together into a 200-mL measuring cup. Swirl the cup a little to mix the two materials. It doesn't really seem possible now to separate the sand from the spores, does it? And yet, there's a little trick you can use to do just that.

››› Fill the second measuring cup with 75 mL tap water. Add the sand-spores mixture and watch to see how the two materials behave. Stir vigorously. Does something change with the two materials? Wait a little while and compare.

DID YOU KNOW?

The principle of sedimentation is used in sewage treatment plants, for example. In so-called sedimentation tanks, sludge and sand will sink to the bottom as the water flows slowly through the tank.

WHAT'S HAPPENING?

After you have stirred, the grains of sand will swirl around a little before finally settling to the bottom of the measuring cup. The behavior of the material is dependent on its density, among other things (see Experiment 21). Materials with a density greater than water will sink. Conversely, materials with a lower density will float to the top. That's how you can separate materials with different densities.

Mixtures containing solid particles finely distributed through a liquid are called **suspensions**. The particles are big enough that they can only be kept in suspension by constantly stirring or by adding other stabilizing materials. In general, suspensions will settle or form **sediments** if they are left alone for a while: The solid particles collect on the bottom of the container.

In the next experiment, you will learn what happens if you reduce the solid particles to nanometer size.

Floating particles

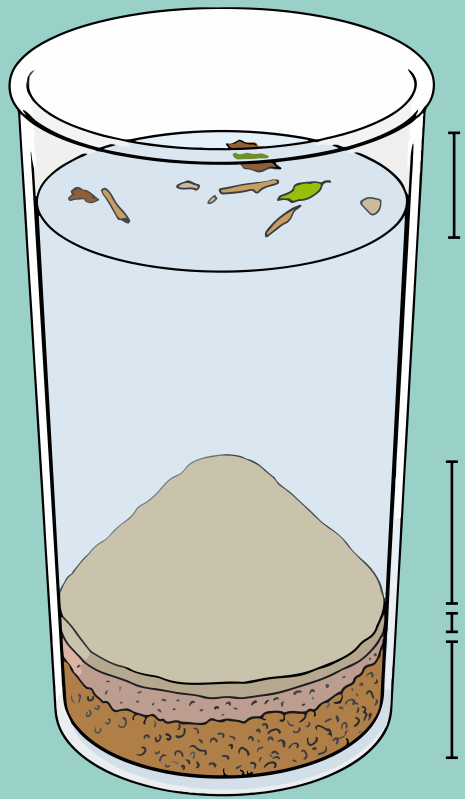
YOU WILL NEED

› **2 x 200-mL measuring cups**
› **Double-headed measuring spoon**
› *Teaspoon*
› *Soil sample (some earth, such as from the garden)*
› *Laundry detergent*
› *Salt*
› *Water*

HERE'S HOW

››› Fill both measuring cups up to the 150-mL mark with water. To one of them, add one large spoon of laundry detergent and one teaspoon of salt.

››› Add one teaspoon of soil to each cup and stir vigorously. Watch what happens. Note the date and time. Set the cups in a quiet location and check them every once in a while to see what's happening.



WHAT'S HAPPENING?

With this experiment, a so-called **sedimentation** test, you can see what sizes of particles make up the soil sample.

In the cup without laundry detergent, the first particles will start settling to the bottom of the container after very little time — those are the grains of sand and little rocks contained in the soil. Then it will take a while longer for a second layer of silt particles to settle. These particles will be 2 to 60 µm in size.

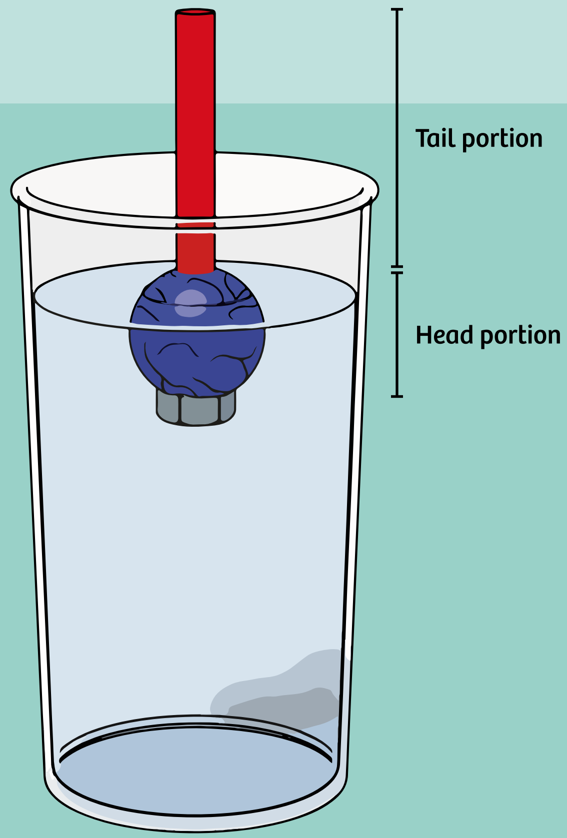
Depending on the type of soil, the water may still be murky after several hours or even several days, since the last remaining suspended material will be **clay particles,** which may be as small as 200 nm. (Any **plant matter** contained in the soil, by the way, will also be floating on the water's surface.)

So if solid particles are broken down to nanometer size (between around 1 nm and 500 nm), in other words, a separation process such as the one performed in Experiment 22 is no longer so easy. Instead, relatively stable suspensions will form. The reason, of course, is the huge surface area of the tiny particles compared to the volume. Even though the particles in your sample will "stay afloat" for a long time, though, they will still settle to the bottom sooner or later.

You can create a stable long-lasting suspension with the help of **surfactants,** such as the ones contained in laundry detergent. They collect on the tiny particles and act like chemical spacers. The salt raises the density of the water, which helps so-called **colloids** to form. The solids won't settle to the bottom then, even though the material they're made of would normally sink. Depending on the soil composition, the cloudiness in the cup with the detergent and salt can last up to several months! You will learn more about surfactants on the following pages.

EXPERIMENT 24

The surfactant model



YOU WILL NEED

- **200-mL measuring cup**
- **Floating bath putty**
- **Tube**
- **Screw nut**
- *Scissors*
- *Ruler*
- *Water*

HERE'S HOW

››› Cut the bar of putty in half with the scissors and shape one of the halves into a ball.

››› Press the screw nut into the bottom of the ball of putty.

››› Cut off a piece of the tube about 5 cm in length and insert it into the ball opposite the nut. Done! You have just made a model of a surfactant molecule.

››› Fill the measuring cup with water. Which part of the molecule model is under water, and which part is not?

WHAT'S HAPPENING ?

A **surfactant molecule** always consists of two parts: **a water-loving head portion** (in your model, that's the putty portion floating under the water's surface) and a **fat-loving tail portion** (the red tube sticking up into the air). In reality, the tail consists of a long chain of carbon atoms. In Experiment 9, you learned that long hydrocarbon chains are **hydrophobic**. So they try to remove themselves from water. The head portion consists of a **polar** molecule group (see also Experiment 10), which wants to stay in the water if it can.

Because of these qualities, surfactant molecules always collect on the border between water and air — that way, both portions of the molecule can "feel right." They arrange themselves into a layer only one molecule thick. Scientists call this a **"self-assembled monolayer."** This also has the effect of reducing the surface tension of the water.

Surfactants are contained in soaps, shower gels, and other washing and cleaning products, where they are responsible for these products' cleaning effect. This effect is based on the fact that surfactants collect on the border between water and fats. In the next experiment, you will learn some other things that this characteristic of surfactants is useful for.

EXPERIMENT 25

Oil, water, and soap

YOU WILL NEED

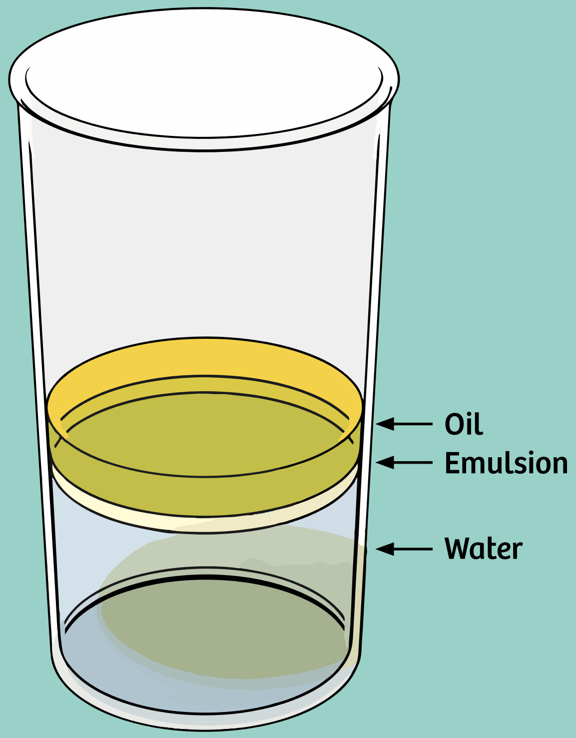
- **200-mL measuring cup**
- *Water*
- *Tablespoon, teaspoon*
- *Cooking oil (such as sunflower oil or olive oil)*
- *Dishwashing liquid*

HERE'S HOW

››› Pour 50 mL of water into the measuring cup and add 2 tablespoons of cooking oil.

››› In Experiment 9, you saw how the two liquids won't mix together. Add a teaspoon of cooking oil and stir vigorously.

››› What do you notice when the two liquids touch?

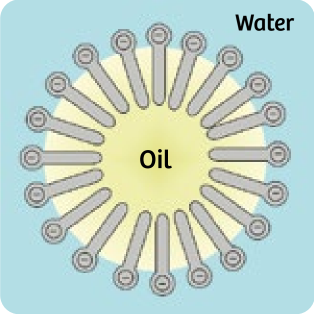


WHAT'S HAPPENING?

The water and oil will become milky and cloudy. To some extent, they have become mixed. Then, a portion of the cloudy liquid will separate again, but a thin layer above the water will remain.

The reason for the change is the dishwashing liquid. It contains **surfactants,** which are chemically structured like the model you made in Experiment 24.

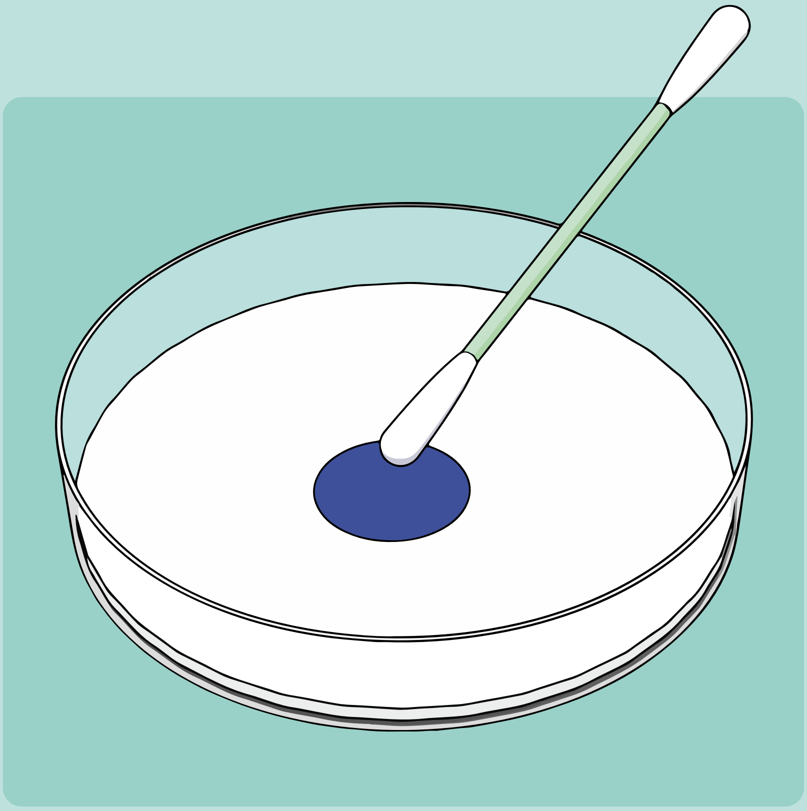
So if you combine water (polar), oil (non-polar), and dishwashing liquid (surfactant), the surfactants assemble their polar ends in the water and their non-polar ends in the oil. Since the spherical shape offers the best ratio of surface area to volume, little "droplets" known as **micelles** are formed.



The water is milky at first because oil is in the water in the form of micelles. And the oil is milky because water is in the oil in the form of micelles too! Liquids in which other liquids are present in the form of droplets are known as **emulsions.**

EXPERIMENT 26

Impressive effects with milk



YOU WILL NEED

› **Petri dishes**
› *Milk*
› *Ink cartridge*
› *Cotton swab*
› *Dishwashing liquid*

HERE'S HOW

››› Pour enough milk into the Petri dish to cover the bottom of the dish. Coat the cotton swab with dishwashing liquid.

››› Carefully open the ink cartridge and add a few drops of ink to the milk.

››› Touch the center of the blue spot with the cotton swab end that you coated with dishwashing liquid.

WHAT'S HAPPENING?

Milk is an emulsion of water and fat. If you add dishwashing liquid to the mix, its surfactants form tiny micelles. When that happens, they actually move as the molecules turn and zip through the liquid. Because you added ink, you can see this movement as the dye is carried along and swirled around. As soon as the action stops, all you have to do is tap the liquid with the cotton swab and off it goes again!

CHECK IT OUT

SURFACTANTS AND THE ENVIRONMENT

Surfactants can be useful when you want to clean something, of course. Practically all washing and cleaning products carry the information that they contain "5% anionic surfactants." In the 1950s, one surfactant that was cheaply produced in large quantities was called tetrapropylene benzene sulfonate (TPS). Wastewater systems carried it from households and factories into the natural water cycle, including lakes, creeks, and rivers.

But TPS cannot be broken down or decomposed by naturally-occurring microorganisms. So in locations where river water swirled around a lot such as at dams or retaining walls, huge mountains of foam would form. **"Detergent laws"** that placed restrictions on the chemical composition of washing detergents were passed to fix this.

According to this law, laundry detergents have to be at least 90% biologically decomposable if they are going to be released into the natural water cycle. This decomposition process takes place in water treatment plants. Fortunately, a different surfactant was able to be found which could be broken down, and which replaced TPS. After the detergent law was enacted, the mountains of foam became a thing of the past.

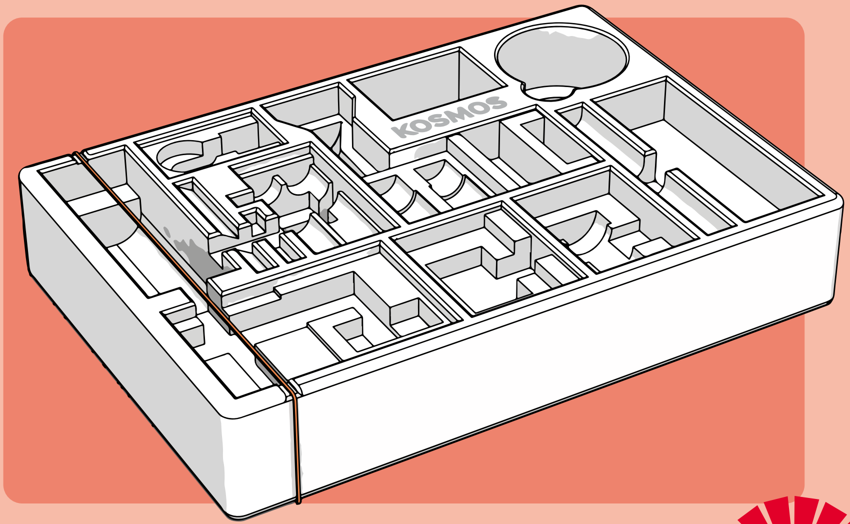
In 2004, the European Union came up with a law saying that all surfactants have to be shown to be completely biologically decomposable before they can be used. Still, surfactants represent a chemical assault on the water cycle, so judicious use of dishwashing liquids and laundry detergents can help to improve water quality.

Lofty mountains of foam on creeks and rivers due to TPS

The Tyndall Effect

Is there such a thing as invisible fog? What happens to gold when it occurs in the form of particles only a few nanometers in size? In this chapter, you will learn how particles like this behave. You'll also find out about how to use light and laser beams to turn these exciting nanoeffects into something you can see!

The standing wave in the air



YOU WILL NEED

› **Rubber band**
› **Your experiment kit's polystyrene tray**

HERE'S HOW

››› Stretch the rubber band securely through the little grooves of the polystyrene tray, as shown in the illustration.

››› Pluck the rubber band and watch how it moves. Try plucking it in different locations (near the edge, in the middle). Are there differences in the sounds it makes?

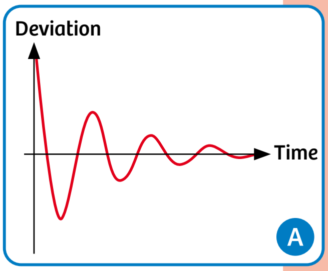
KEYWORD: VIBRATION

You just learned something about the basic principle behind stringed instruments! A guitar or violin works just like your rubber band: An elastic wire (the string) is stretched between two points and produces vibrations when you pluck or stroke it. That's what makes the sound you hear.

WHAT'S HAPPENING?

The stretched rubber band has a certain degree of freedom to move when you pluck it. Then, it starts to vibrate — mostly in the center, and hardly at all at the spots where it's attached. What you see here is a standing wave (also known as a stationary wave), held firmly at two points and moving in the middle.

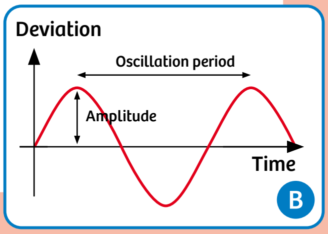
The rapid movement of the rubber band causes molecules in the air to start vibrating. This creates a so-called pressure wave that spreads out through the air. In your ear, the pressure is converted to sound — which is why this kind of pressure wave is also known as a "sound wave."



If you could see the middle of the rubber band under a magnifying lens, you would be able to make a sketch of its distance from its resting position (its deflection). Diagram A shows you how the rubber band's deflection becomes smaller over time.

The force that you apply to the rubber band to make it start vibrating quickly dissipates. As a result, the rubber band settles down again and the sound fades.

If the rubber band were to keep vibrating forever, the sound would never stop! The properties of this kind of endless vibration (diagram B) are easier to describe because it doesn't change over time. A wave has an amplitude, or height (which corresponds to volume in a sound wave) as well as oscillation period, which indicates how much time passes from one "wave peak" to the next. In sound waves, this affects the pitch of the sound (meaning how "high" it is). Of course, a lot of other factors come into play with sound, such as the materials from which the string is made.



You will discover the principle of the wave in lots of natural phenomena, including light, which is also a wave (see Experiment 29 for more).

EXPERIMENT 28

Waves in water

YOU WILL NEED

- **Pipette**
- *Cup or bowl*
- *Water*

HERE'S HOW

››› Fill the bowl almost completely with water.

››› Draw some water up into the pipette and hold the pipette next to the bowl until the water's surface has stopped moving.

››› Add exactly one drop to the bowl and watch how the surface behaves.

WHAT'S HAPPENING?

The drop creates a wave in the water that moves away from the spot where it fell until it meets the edge of the bowl. The water is called a carrier medium because it carries the waves. In the last experiment, the rubber band acted as the carrier medium for the standing wave, while the air acted as the medium for the sound wave.

If you repeat the experiment while paying attention to the bowl's edge, you will see the wave gets reflected back. So the wave is pushed back by an obstacle that does not itself pick up the vibrations. You have probably noticed that with the kind of sound wave produced in the last experiment: When a room "echoes" or reverberates, a lot of sound is reflected back off the walls, which the human ear perceives as unpleasant.

And one more thing: As was the case with the rubber band, you will notice that the waves settle down after a while.

Waves of sound or water are so-called mechanical waves. In addition to those, there are electromagnetic waves, which can spread without a carrier medium. You'll learn more about them in the next experiment.

KEYWORD: MEDIUM

Air is not particularly good at carrying sound waves. The speed of sound, which is around 1235 km/h in air, can be up to ten times greater in wood, glass, or concrete! That makes sense when you consider the structure of their particles: In solid materials or liquids, the molecules are much more closely packed together than in gases in the air. That means that the movement of the sound waves can be transferred from one molecule to the next much more easily.

EXPERIMENT 29

Homemade rainbow

YOU WILL NEED

- **Mirror**
- **Laser pointer**
- *Bowl, water*
- *Piece of white cardboard*

HERE'S HOW

››› Pull the protective film off of the mirror. Fill the bowl with water and place the mirror in the water at an angle. Set the laser pointer to flashlight mode and shine it on the water and mirror from above.

››› You can use the white cardboard to try to capture the reflected rays of light. What do you see?

››› What happens when you switch the laser pointer to laser mode? **Caution! Do not look into the reflected laser beam!**

WHAT'S HAPPENING?

When the laser pointer is set to flashlight mode, you will see a clear rainbow pattern on the cardboard. The physical effect behind this is called refraction. It gives you some insight into what white light is actually made of.

In addition to sound waves and water waves, there are also electromagnetic waves, which can spread without needing a medium (even in the vacuum of space). Depending on their wavelength, these electromagnetic waves have different properties and applications. They comprise an extremely broad range, from wavelengths of thousands of kilometers to ones of just 10^{-6} nanometers.

This entire bandwidth from the most gigantic to the tiniest waves is known as the "electromagnetic spectrum") (see also "Knowledge Base," page 59). There's just a very specific portion of this spectrum — comprising wavelengths between 380 and 700 nanometers — that you see as light. This portion is also known as the "visible spectrum." Some larger waves that will be familiar to you are radio waves, which are used to transmit radio and television signals.

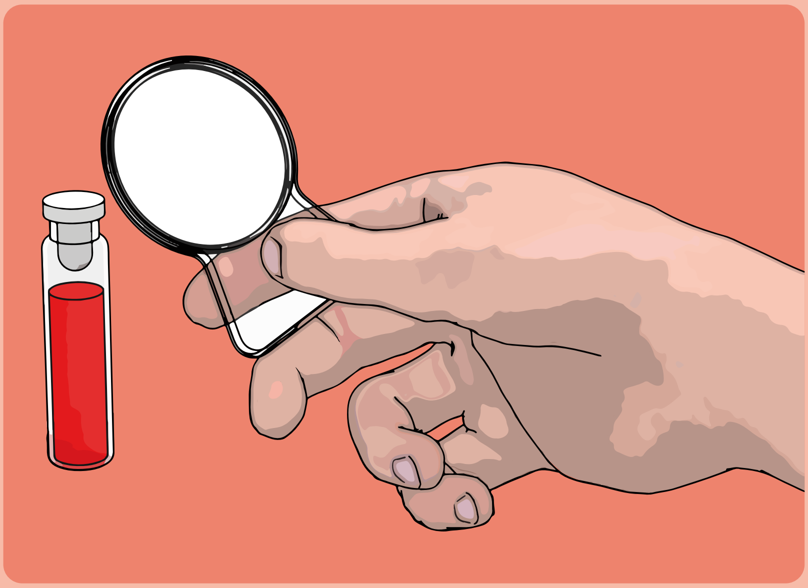
But back to the mirror in the water. The white light from the laser pointer is composed of all the wavelengths of the visible spectrum. Each one of these wavelengths of light has its own color.

The various wavelengths are deflected to varying degrees as they hit the water's surface — the border between the air medium and the water medium. That breaks the white light into its individual colors.

The laser beam does not break into the colors of a rainbow because it only emits electromagnetic radiation in a very narrow range of about 650 nanometers. That's why the beam looks red to our eyes. When light occurs in just one wavelength, it is called "monochromatic" (from the Greek *monos* = "single" and *chromos* = "color").

EXPERIMENT 30

What element is hiding here?



YOU WILL NEED

› Vial of colloidal gold
› Magnifying lens

HERE'S HOW

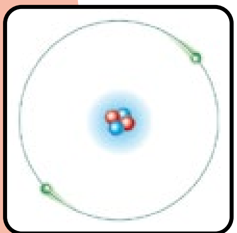
››› Study the container with the red liquid under the magnifying lens. The liquid gets its color from a material that you are no doubt familiar with. Can you recognize any of the particles?

WHAT'S HAPPENING?

The tube contains a suspension — or more precisely, a colloid. It gets its red color from a material that you are more familiar with in a different form and color: gold.

Various sizes of cadmium selenide particles

The precise explanation of the color of gold is very complicated and can only be provided very roughly (Albert Einstein's theory of relativity even plays a role in it, among other things):



Gold is a heavy element with 79 protons (positively charged particles) in its nucleus. Like all elements, it also has electrons, which move in "clouds" around the nucleus. You can also think of them as being located on specific paths (as in the atomic model of Niels Bohr).

Gold belongs to the class of metals and forms a metal lattice when it occurs in larger volumes. This metal lattice has a regular structure in which the electrons no longer orbit round their own atomic nucleus, but instead occur freely distributed through the lattice. This is also the reason why metals are good conductors of electricity, by the way.

Nevertheless, there are electrons that occur "closer" to the atomic nucleus than others. If light hits the gold, the range of wavelengths with a blue color (about 450 nm) is absorbed as certain electrons take up the energy of the blue light and move farther away from the nucleus. None of the other colors of light have any effect on the electrons, and they are simply reflected back. Because the blue portion is "filtered," the gold has the appearance of the complementary color of blue, which is yellow.

If you separate gold from its lattice and break it down to a particle with a diameter of just about 50 nanometers, the electrons will behave differently. They will no longer absorb the blue light, and instead absorb light in a range of 530 nm (which corresponds to the color green). The complementary color of green is purple, which is what gives the red hue to the solution in front of you. With other materials, such as toxic cadmium selenide, the influence of nanoparticle size on color is even prettier.

Backlit particles

YOU WILL NEED

› Petri dish
› Chalk
› Double-headed measuring spoon
› Laser pointer

HERE'S HOW

››› Use the metal spoon to scratch a little chalk powder into the Petri dish.

››› Darken the room as much as possible and set the laser pointer to flashlight mode.

››› Carefully blow a little of the chalk powder into the air. What do you see in the light of the laser pointer?

››› Switch the laser pointer to laser mode and observe the chalk dust in the laser beam. What do you see?

WHAT'S HAPPENING?

The chalk powder consists of lots of little particles that spread out in the air. Just with your naked eye, it might look like the air is a little dusty, but it won't be easy to see individual particles.

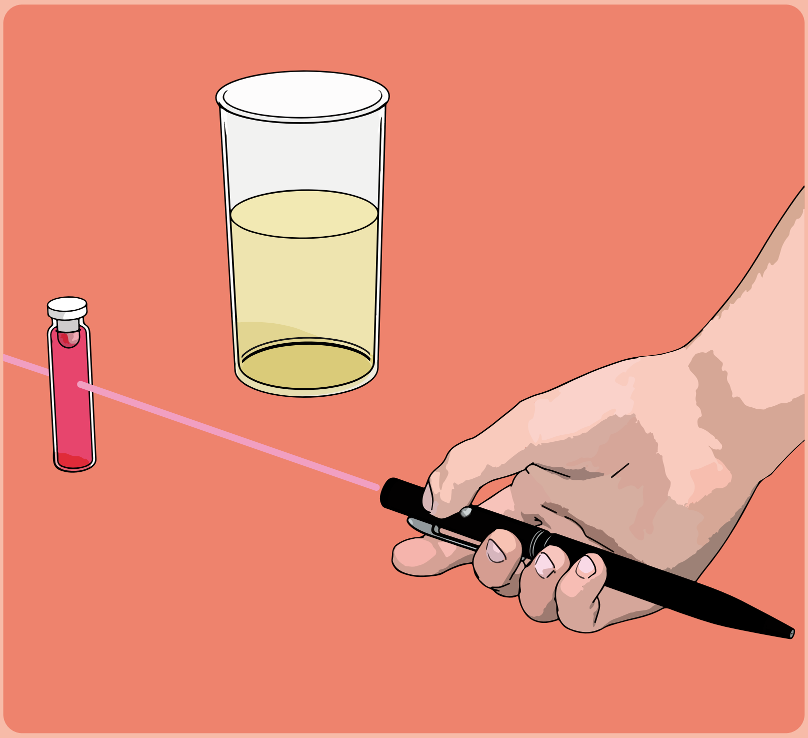
Using the laser point in a darkened room, you will see a lot of little grains of powder dancing around, falling, and floating in the beam. The strong light of the laser is reflected off the little particles and makes them visible, even though each one is just a few micrometers in size.

The general name for the effect by which light is deflected in different directions is "scattering." The degree of scattering of light depends on the size and properties of the object it deflects off of, as well as the light's wavelength.

In the next experiment, you will even be able to turn invisible particles visible!

EXPERIMENT 32

Making the laser beam visible



YOU WILL NEED

- **Colloidal gold vial**
- **Laser pointer**
- **100-mL measuring cup**
- *Clear apple juice*

HERE'S HOW

››› Pour a little juice into the measuring cup and set the colloidal gold vial next to it.

››› Shine the pointer's laser beam through both liquids.

››› In which liquid do you see the beam? In which don't you? What might be the explanation?

KEYWORD: COLLOID

The colloidal gold particles don't settle to the bottom of the vial the way you would expect from larger particles. Instead, they bump against one another without accumulating. The reason has to do with electrostatic forces (forces of repulsion between equal electrical charges) and surfactants acting as "chemical spacers."

WHAT'S HAPPENING?

In the last experiment, you learned how light can be scattered by small particles. So there must be a difference between the two liquids. In one case (the colloidal gold) the laser's light is scattered, and in the other it's not.

The reason has to do with the particles in the liquid and their size. Apple juice is mostly water, plus substances from the fruit: sugar, acids, and pigments. All these materials consist of relatively small molecules. For example, a sugar molecule, the structure of which you learned in Experiment 8, has a size of about 1 nm. Acid and pigment molecules also occur in about this size. They won't have any influence on the laser beam because they are too small in relation to the laser light's wavelength (650 nm).

The colloidal gold contains particles 50 nanometers in size. That makes them large enough to reflect the laser's light.

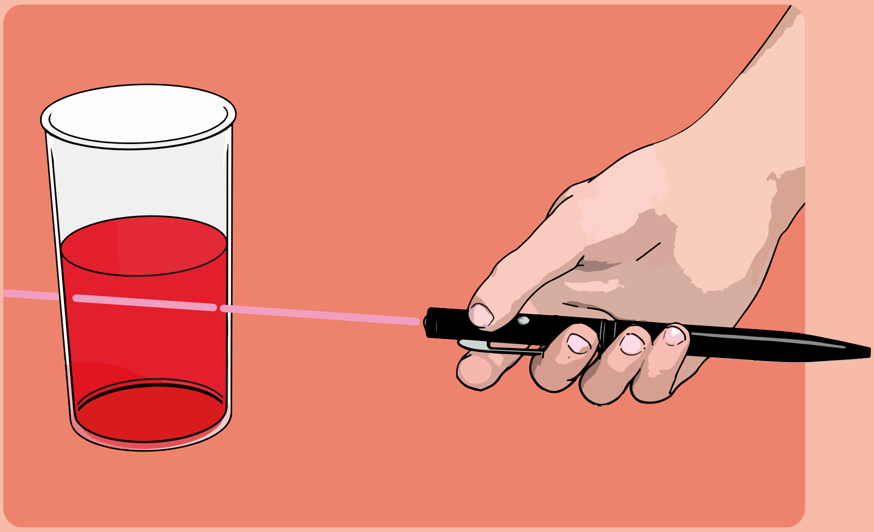
So a direct comparison shows how the fruit juice particles are too small to influence the laser, while the nanocolloid contains larger particles that scatter the light.

EXPERIMENT 33

Laser in juice

YOU WILL NEED

- **100-mL measuring cup**
- **Laser pointer**
- **Double-headed measuring spoon**
- *Water*
- *Red fruit juice (such as cherry juice or red currant juice)*
- *Tablespoon*



HERE'S HOW

››› Pour 50 mL water into the clean measuring cup and add a tablespoon of fruit juice. Stir thoroughly with the measuring spoon.

››› Shine the laser pointer into the liquid. Can you see the beam? You might have to turn the laser pointer a little and look at it from a different angle.

KEYWORD: TYNDALL EFFECT

In principle, whether it comes from a laser or a different source, light itself is invisible. It is only when the light strikes our eye directly or its rays hit another object's surface and get reflected back to our eye that we can perceive anything.

Light can also be reflected by little particles such as particles of dust in the air or drops of water in fog. These particles have similar dimensions to the wavelengths of light, and the term used for this kind of reflection is light scattering. The exact process was studied by the British physicist John Tyndall. Larger wavelengths (in the red range) pass more easily through objects while shorter ones (in the blue range) are scattered.

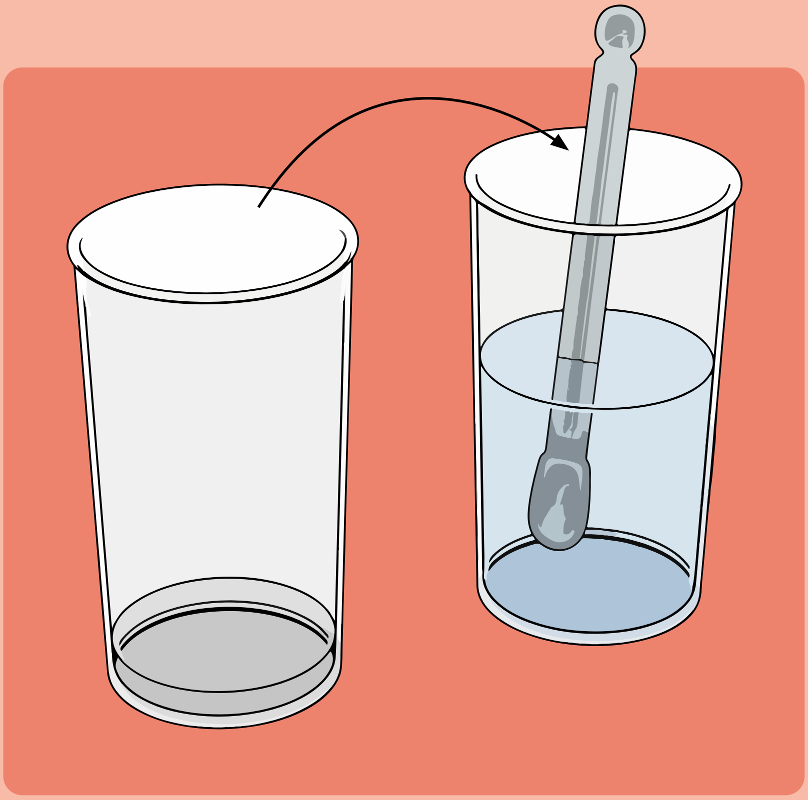
Optical smoke detectors take advantage of this so-called Tyndall effect when a normally focused beam of light becomes dispersed by smoke particles and the scattered light is detected by a sensor.

WHAT'S HAPPENING ?

If you adjust the laser properly, you will also be able to see the beam in the liquid here. Fruit juice has a lot of natural sugar and pigment molecules. They are too small to disperse the laser beam. But there are also fine bits of suspended matter in the juice that come from the fruits used in the production process. Even though the juice has been filtered, you can render those remaining materials visible with the laser. At 10 to 100 nanometers, they are too small to be seen with the naked eye, but they can still scatter the laser's light.

EXPERIMENT 34

(In)visible molecules



YOU WILL NEED

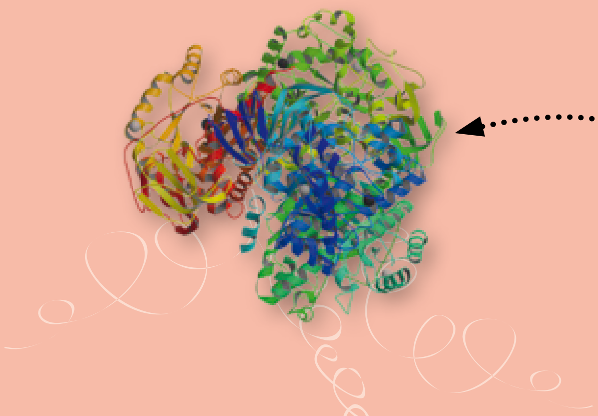
- **2 x 200-mL measuring cups**
- **Laser pointer**
- **Double-headed measuring spoon**
- *Raw egg*
- *2 bowls*
- *Salt*
- *Water*

HERE'S HOW

››› Break open the egg and separate the white and the yolk into two bowls. You might want to ask an adult to help you. Transfer the white to a measuring cup.

››› Add 3 large spoons of salt to the other measuring cup and then fill it up to the 150-mL mark with tap water. Add the egg white and stir thoroughly with the measuring spoon.

››› You should end up with a clear liquid. Shine the laser pointer through it. Can you see the beam?



WHAT'S HAPPENING?

Egg white is made of about 10% proteins, which are a specific class of molecules. Proteins are among the building blocks of life and are very important for many different natural processes.

What is decisive for this experiment is their size: Proteins are macromolecules (from the Greek *macros* = "big") – in other words, especially large molecules. They consist of lots of molecular chains connected together and folded into a three-dimensional structure. Even when folded up like this, they can be up to 100 nanometers in size.

There are dissolved proteins in your liquid made of water and egg white. They are too small to be seen directly, but the laser reveals their secret presence. Like the particles in the last experiment, the large protein molecules also scatter the laser's light, rendering the "path" of light through the liquid visible!

EXPERIMENT 35

Smoking, steaming

YOU WILL NEED

- **Tea light**
- **Laser pointer**
- *2 saucers*
- *2 drinking glasses without any design or imprint*
- *Matches or lighter*
- *Water kettle*
- *Water*
- *Clock*

CAUTION! Perform experiments with candles on a suitable fire-resistant surface and note the information of page 4 (Experiments with open flame).

HERE'S HOW

››› Set the tea light on one of the saucers.

››› Bring some water to a boil, let it boil for 2 minutes, and pour a little of it into one of the glasses. Place the second saucer over it.

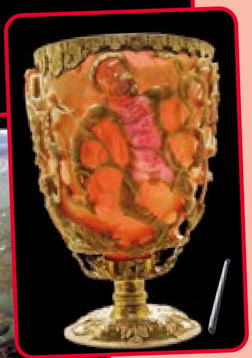
››› Light the tea light, let it burn a little, blow it out, and quickly place the second glass over it.

››› If everything worked right, you should now have two glasses with the candle's smoke collecting in one and steam from the water in the other. Shine the laser pointer through both glasses. What do you see?

KEYWORD: THE LYCURGUS CUP

Did you know that the ancient Romans were already working with nanoparticles in the 4th century? Of course, they didn't have all the background information about atoms and molecules, but they gained a lot of understanding through trial and error. A special work of art from this time is a glass goblet depicting the Greek myth of Lycurgus, after which the cup is named. The artistically crafted glass looks green until you illuminate it from the inside, at which point it turns red. That's because the glass contains the same little collections of gold particles contained in your vial of nanocolloids.

Those particles don't change the color of the glass on its surface, but when light passes through they give the cup a red color. That's pretty impressive for a 1600-year-old cup! This technique for coloring glass was apparently passed down to the Middle Ages. A lot of cathedral windows from the Gothic period also shine with a red color due to colloidal gold embedded inside them by glass artists. It wasn't until a few decades ago that scientists were able to explain the role of nanoparticles in this effect.



WHAT'S HAPPENING ?

The laser beam breaks up against the little particles trapped inside the glass. In the case of the candle, those particles are soot, while the other one has water droplets that show up as steam. If you're lucky, you will also see the laser beam where you can't see either smoke or steam — if the light is hitting tiny particles that can't be seen with the naked eye. In any case, the particles and droplets will tend to bind together and drop to the bottom. So they aren't stable in the long run.

How the Nanocosmos Became Visible

The limits of enlargement

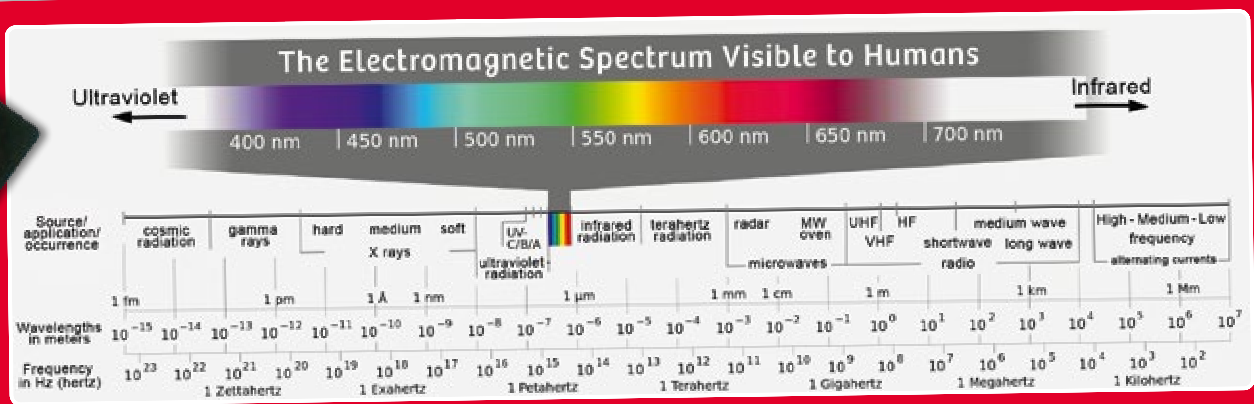
Nanoparticles can't be seen either with the naked eye or with an **optical microscope.** Even the best-quality instrument can't reveal such tiny structures. The reason is that a **maximum resolution** of a microscope is in the range of the wavelengths of the radiation used, which in the case of an optical microscope is the range of visible light. The best possible resolution is about **380 nm**, in other words. That means that a microscope will just barely let you recognize that two points 380 nm apart are two points instead of one.

A new invention

As you learned in Chapter 4, visible light is just a tiny portion of the electromagnetic spectrum. There are also other forms of electromagnetic radiation that have much smaller wavelengths. An example is so-called **electron beams.** You already learned that electrons are components of atoms. If electrons are accelerated through a strong electrical voltage, they act like a wave with very short wavelengths.

Just as you can focus visible light through optical lenses, the electron beam can be focused through so-called **electron-optical lenses,** which use electrical or magnetic fields. That's the basic principle behind **electron microscopes,** which can be used to produce images of nanostructures!

An electron beam of 100 keV of electrical energy has a wavelength of about 0.0037 nm. The resolution of a corresponding microscope, however, is just about 0.1 nm, since even the most modern instrument produces certain image errors.

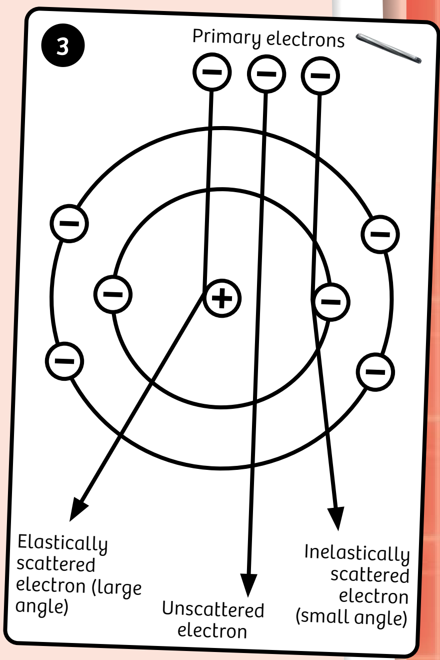


Visible light is just a tiny portion of the electromagnetic spectrum.

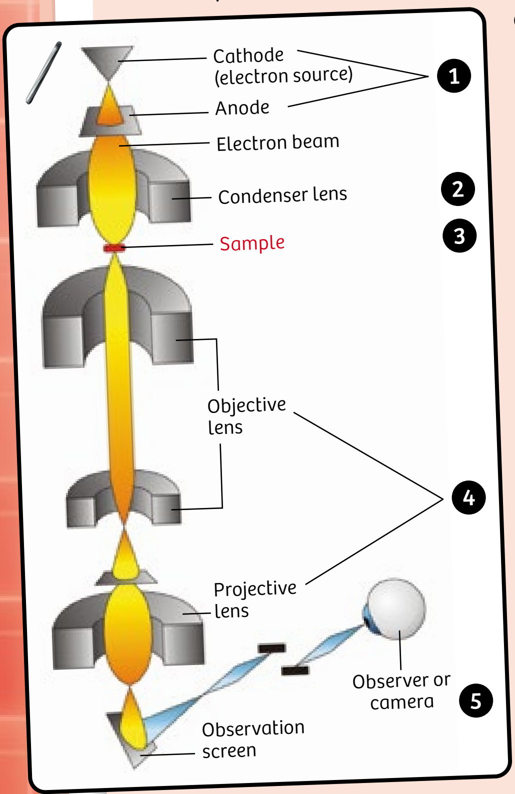
Transmission Electron Microscope (TEM)

In terms of its basic construction, a TEM resembles an optical microscope turned on its head. It has a radiation source, various lenses, and a device for observing the enlarged image. Transmission electron microscopy works particularly well for very thin objects. In order to achieve images with high resolution, they should not be more than 10 nm thick.

1. Generation of the electron beam takes place in the upper portion of the instrument. Electrons are emitted from a thin glowing wire — the so-called cathode — and are accelerated toward the anode with the help of a very strong electrical voltage.
   Inside the instrument, a high vacuum ensures that the accelerated electrons don't get slowed or deflected by collisions with air molecules.



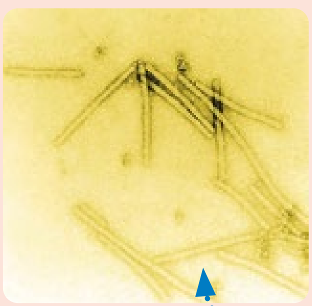
2. Next, the electron beam crosses so-called condenser lenses that make it more even and straight.



3. Then, the accelerated electrons — also known as **primary electrons** — penetrate the sample. When that happens, they may hit a positively charged nucleus and be strongly deflected — which is known as **elastic scattering**. But they can also hit electrons in the atomic shell, in which case they are less strongly deflected but still lose energy and speed. This is known as **inelastic scattering**. Some of the electrons will not be scattered at all. Because inelastically scattered electrons reduce the sharpness of the image, they are filtered out and no longer observed.

4. After that come more electron-optical lenses (objective and projective lenses) responsible for the actual enlargement.

5. Finally, the electrons hit a fluorescent observation screen. Wherever the electrons hit the screen, a point of light is created and recorded by a camera.

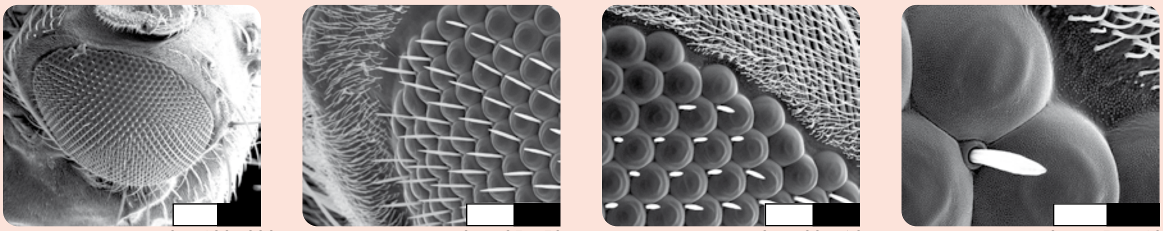


DID YOU KNOW?

The fact that electron beams behave like waves of light was discovered in 1924 by Louis-Victor de Broglie. That insight was the prerequisite for the creation of the electron microscope. In 1926, the first electron-optical lens was developed, and the first electron microscope in 1931.
The study of hitherto invisible disease vectors (viruses) was an important application of the new technology. One of the first objects observed was the tobacco mosaic virus.

Scanning Electron Microscopy

Scanning electron microscopes (SEM) scan the studied object "line by line" with a fine electron beam. To do that, the object's surface must be electrically conductive. The electron beam causes electrons on the sample surface to be released. These so-called **secondary electrons** are captured by a detector brought above and to the side of the sample. Scanning electron microscopes are often used to study surfaces, since they can create images with excellent depth of sharpness.

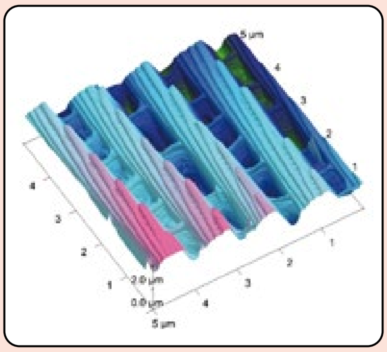


SEM images of a fly's eye

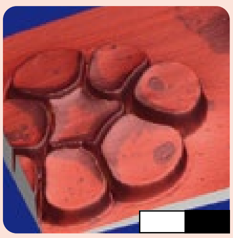
Atomic Force Microscopy

In this technology, a fine measuring tip is computer-guided along a surface a few nanometers above the sample. At this tiny distance, certain mutual reactions such as the van der Waals forces arise between the atoms of the measuring tip and the atoms and molecules of the object under investigation.

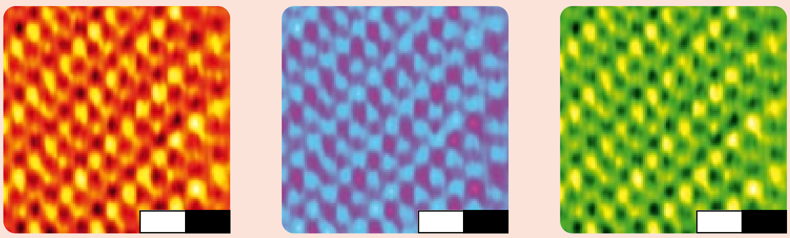
Depending on the nature of the surface, these forces can be stronger or weaker, and they will therefore deflect the measuring tip to varying degrees — in other words, they will cause the tip to move up or down by a few nanometers. These tiny movements can be measured and recorded to produce a precise image of the object's surface. An atomic force microscope can produce resolutions of up to 0.1 nm — allowing even individual atoms to be shown!



Structure of a butterfly's wing



Red blood cells



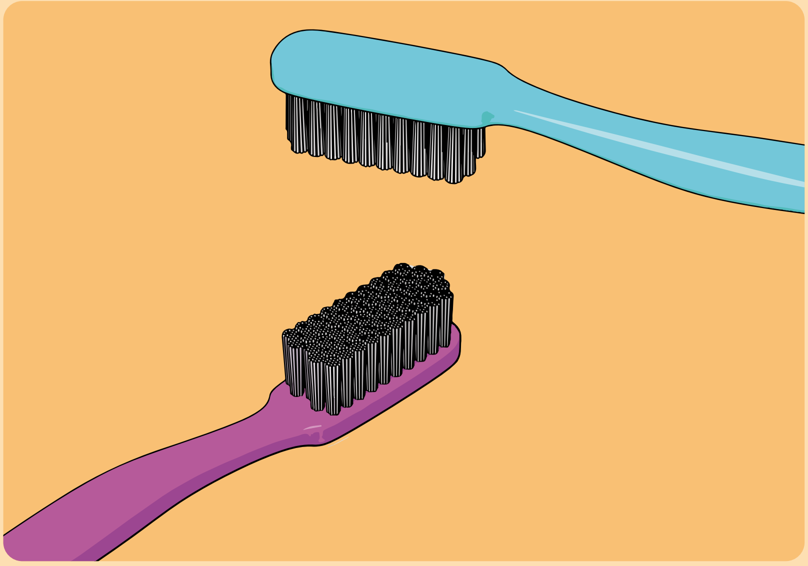
Individual atoms in a calcite crystal

The Secret of the Gecko

Humans can use their two legs for walking on the ground. A lot of other animals, on the other hand (such as insects), can easily land on the ceiling without falling off. There's even a reptile that can do that — the gecko. For many years, people studied geckos to figure out how they were able to run up seemingly smooth surfaces such as glass or tile. It was only around the turn of the millennium that they were able to look beneath the feet of a gecko using special microscopes. This chapter will show you the nanostructures that were found there.

EXPERIMENT 36

Bristles and surfaces



YOU WILL NEED

› *2 new toothbrushes with dense, equally long bristles*

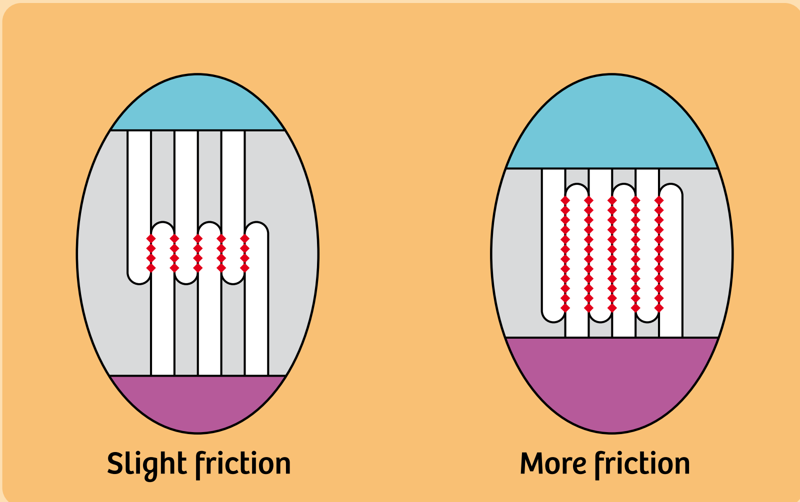
HERE'S HOW

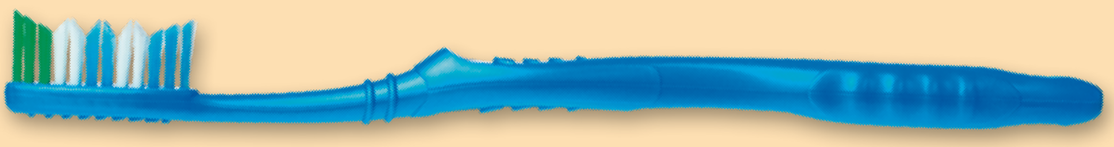
››› Place one of the toothbrushes on the table with its bristles pointing up.

››› Take the second toothbrush and press the brush head down onto the first toothbrush so their bristles intermesh to a depth of about half a centimeter.

››› Lift the top toothbrush up. Does the bottom one lift up with it?

››› Intermesh the two brush heads to their full depth. Is it easier to lift the lower one now?





WHAT'S HAPPENING ?

The bristles interlock with one another. Any individual bristle is clamped by a group of others surrounding it.

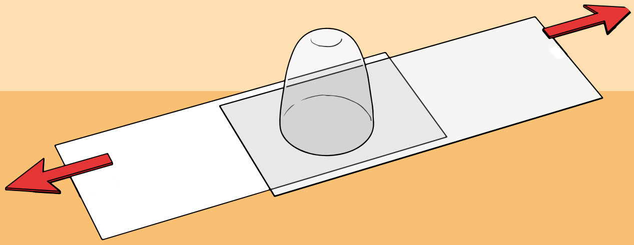
If only a portion of the bristle is surrounded, those other bristles won't hold it as well as when they are completely intermeshed to their full depth.

The decisive factor is how many little irregularities there are along the bristles that can interlock with one another. More irregularities will result in a better hold.

In Experiment 4, you saw how the surface to volume ratio is greatly enlarged in the nanorange. This experiment with the toothbrushes confirms this rule: The little irregularities over a large surface area (along the entire bristle) will give rise to lots of places that promote good adhesion.

EXPERIMENT 37

Adhesion experiments



YOU WILL NEED

› *Plastic wrap*
› *Paper*
› *Scissors*
› *Small, stable drinking glass*
› *Ruler*
› *Tablecloth*

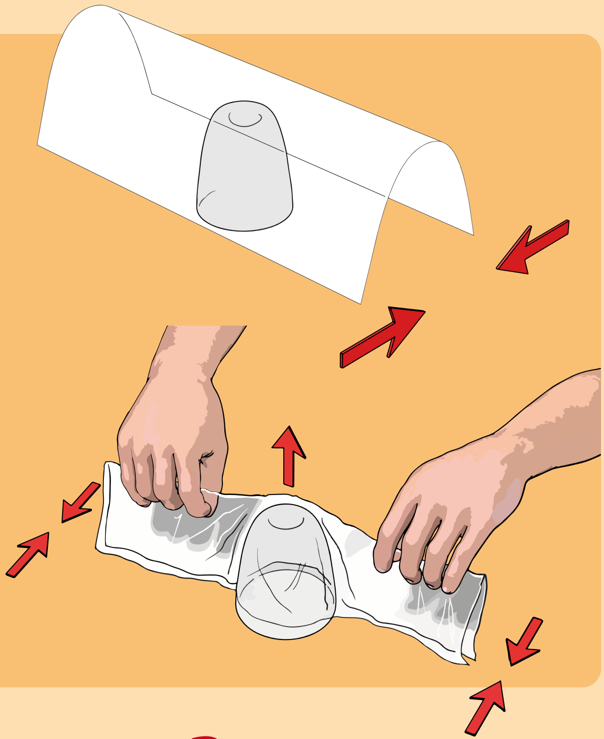
HERE'S HOW

››› Cut two strips of plastic wrap about 10 cm x 30 cm in size and place one on top of the other so they overlap somewhat. Use the glass to weigh down the spot where they overlap.

››› Try to pull the pieces of plastic wrap apart by pulling on their ends. Can you do it? Repeat the experiment with ordinary paper instead of plastic wrap. What's the difference?

››› Fold the tablecloth several times and lay it on the table. Cut a piece of plastic wrap 30 cm x 30 cm in size. Set the glass bottom-up on the tablecloth and fold the plastic wrap once around it. Grab the ends of the wrap and carefully lift the glass 1 cm.

››› Repeat the second experiment step with the paper instead of plastic wrap. Does it work?



KEYWORD: ADHESION

Adhesion is the name for a **force of attraction** between two surfaces due to the van der Waals effect. This kind of effect also occurs inside a material, between or within its molecules. In that case, the term used is **cohesion**.

WHAT'S HAPPENING ?

In the first part of the experiment, you can easily determine that it's not so easy to pull the pieces of plastic wrap apart. In the second part, the plastic wraps remains stuck to the glass, allowing you to lift it up. Neither experiment step works with paper.

The plastic wrap is made of polyethylene plastic (a polymer containing a basic unit that you may have constructed in Experiment 8). Polyethylene forms a modest attractive force on the border with certain other materials. This so-called force of adhesion is named a **van der Waals** force after the person who discovered it. A van der Waals force is strongest when there's the greatest possible surface area between the two materials. Paper, on the other hand, will not form any van der Waals forces.

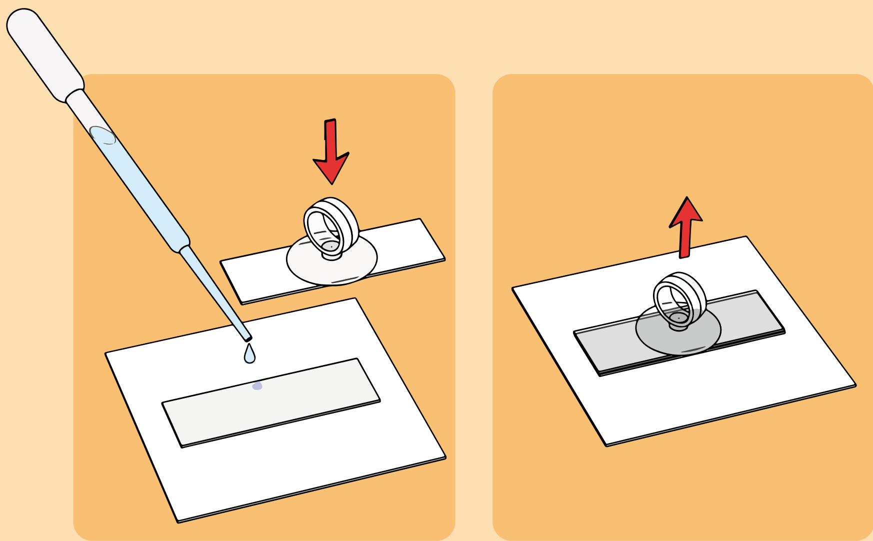
Van der Waals forces play an important role in nanotechnology, since that is where large surface areas and small particles come together. The force that you felt when the plastic wrap stuck together becomes greater as the particles get smaller and as the available adhesion surface gets larger.

EXPERIMENT 38

Water as glue

YOU WILL NEED

› **2 slides**
› **Suction cup**
› **100-mL measuring cup**
› **Pipette**
› *Paper towel*
› *Water*



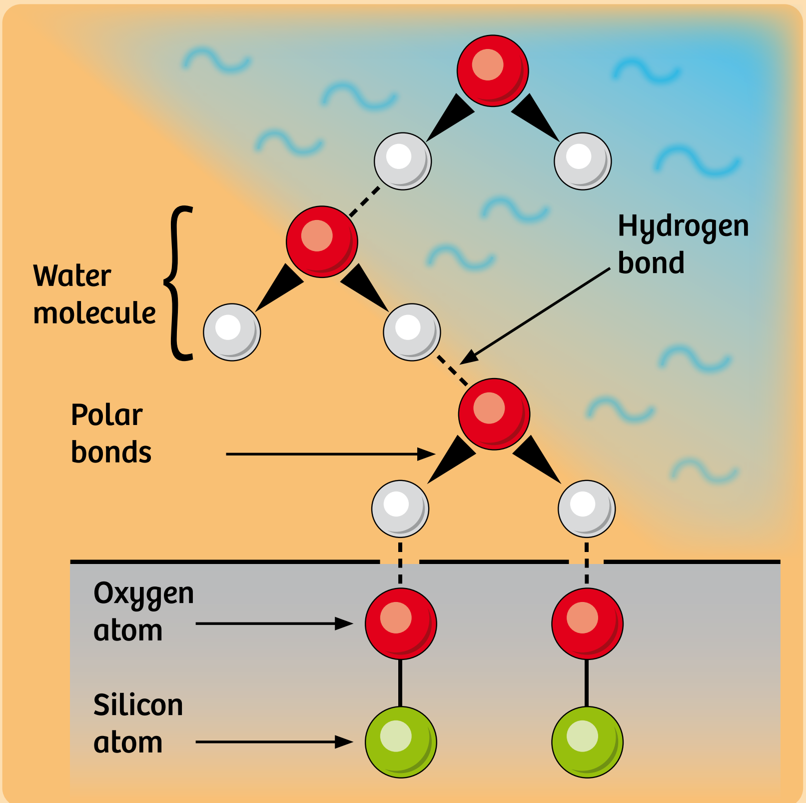
HERE'S HOW

››› Place the slide on the paper towel. Set the second slide next to it and carefully press the suction cup onto it so you can pick up the slide with the cup.

››› Pour a little water into the measuring cup and draw some into the pipette.

››› Use the pipette to apply a few squirts of water to the slide without the suction cup. Then place the other slide directly on top of the wet one. Try to adjust the glass surfaces so that there's a continuous layer of water between them.

››› Carefully lift the slide with the suction cup again. What happens to the slide beneath?



WHAT'S HAPPENING ?

To temporarily glue together the two glass surfaces, you made use of another kind of attractive force known as a hydrogen bond.

In this process, the polar-bonded hydrogen atoms in water (see Experiment 10) enter into interactions with other, electronegative atoms. In the water, hydrogen bridges are formed to the other water molecules' oxygen atoms. Between water and slide, the bridges form to the oxygen atoms of silicon dioxide, which is what the glass is made of.

Individually, the bonds are very weak, but as a group they are strong enough to lift up the glass slide given that the surface area is relatively large.

EXPERIMENT 39

The mysteriously adhering surface

YOU WILL NEED

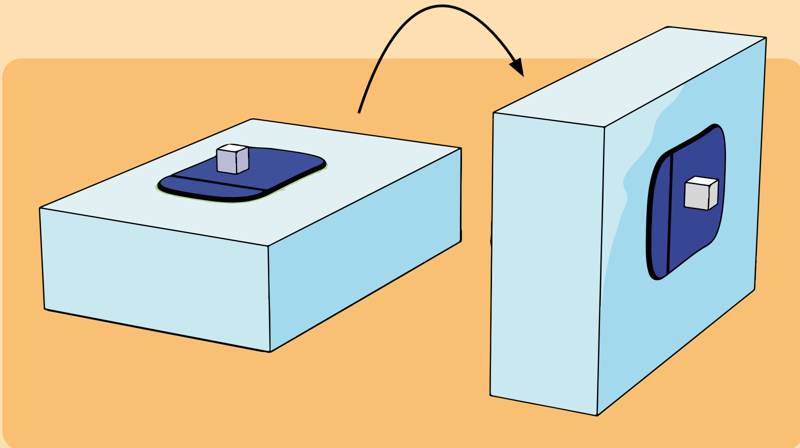
› Gecko adhesive pad
› White cube
› Experiment kit box

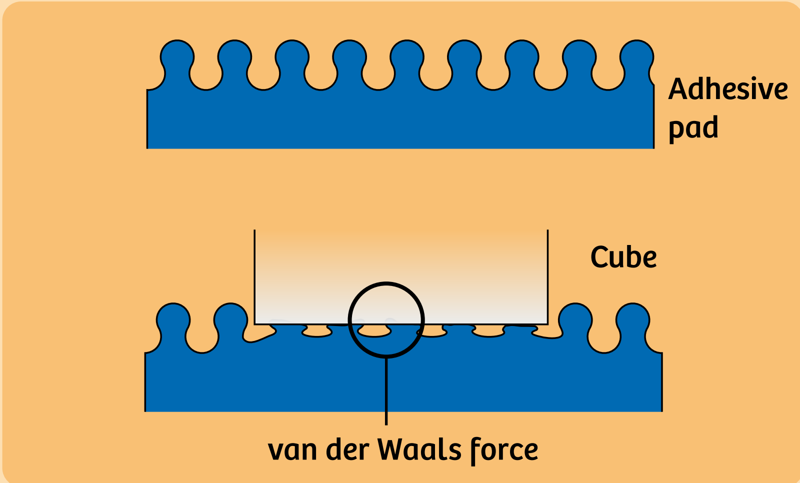
HERE'S HOW

››› Study the gecko pad before using it. The blue plastic has one smooth side and one patterned side.

››› Place the pad smooth-side-down on the experiment kit box. Set the cube on the pad.

››› Gradually lift up on one edge of the box until it is standing on its side. What happens to the cube?





WHAT'S HAPPENING ?

The cube adheres to the blue surface, which in turn adheres without any difficulty to the box. The design of the adhesive pad was based on a model provided by nature. It has lots of little nubs just a few hundred nanometers in size. Wherever the nubs touch another surface, they push apart a little to form adhesive forces in that location. These adhesive forces are van der Waals forces, similar to those you encountered with the plastic wrap in Experiment 37. For a long time, researchers thought that geckos held themselves up with hydrogen bonds (as in Experiment 38), even though their feet were never moist. With the help of modern microscopes, it was discovered how the gecko is actually able to run across a ceiling.

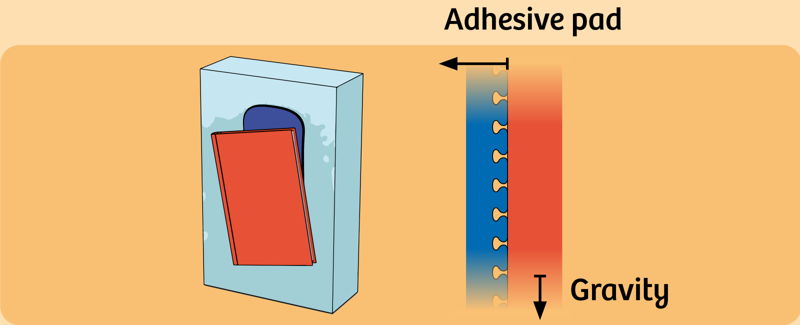
The secret of the blue pad — just like the secret of the gecko's foot — lies in its nanostructure. The gecko's foot divides into so-called "setae," or tiny hairs in the micrometer range, which are in turn covered with tiny "spatulae," which are a kind of platelet just a few nanometers in size. Regardless of the roughness or smoothness of the surface across which the gecko moves, it can always hold on with the help of the special design of its feet. A gecko has 6.5×10^6 setae. Using those, it would still be able to hold himself up even if he weighed 140 kg — the weight of two adult humans!

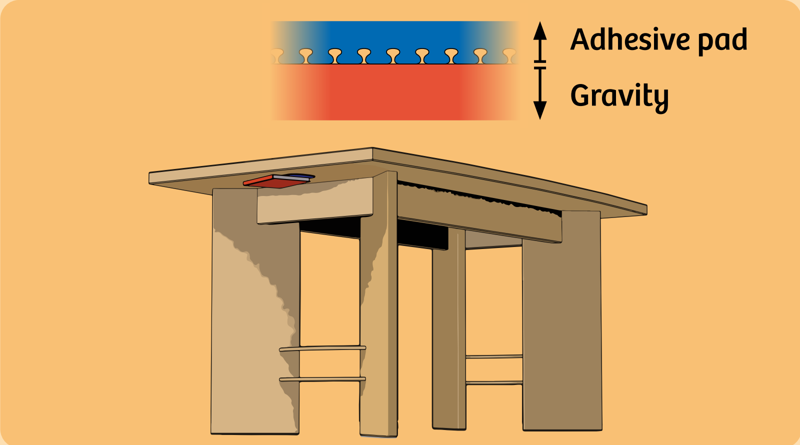
EXPERIMENT 40

Newest trick in the book

YOU WILL NEED

- **Gecko adhesive pad**
- **Experiment kit box**
- *Table*
- *Several heavy books*





HERE'S HOW

››› Stick the adhesive pad to the experiment kit box and set the box upright on the table.

››› See how heavy a book you can get to adhere to the pad.

››› Stick the adhesive pad to the bottom of the table and repeat the experiment. Do the books hold just as well now?

DID YOU KNOW?

A project carried out at Stanford University has even equipped miniature robots with adhesive pads on their feet. The robots can use them to climb up panes of glass, just like geckos in nature!

TIP!

You will quickly find out that the pad will also have dust, dirt, and little crumbs stick very well to it too. As soon as a layer of dirt has formed, the adhesive strength is reduced. If that happens, simply clean the pad under running water and let it dry in the air. When it's clean and dry again, its adhesive force will return.

WHAT'S HAPPENING ?

The adhesive pad doesn't just hold little cubes. It can also hold really heavy books. Its adhesive strength is strongly influenced by the surface area involved. The adhesive pad has a surface area of about 120 cm², all of which is used when you stick a book to it, for example.

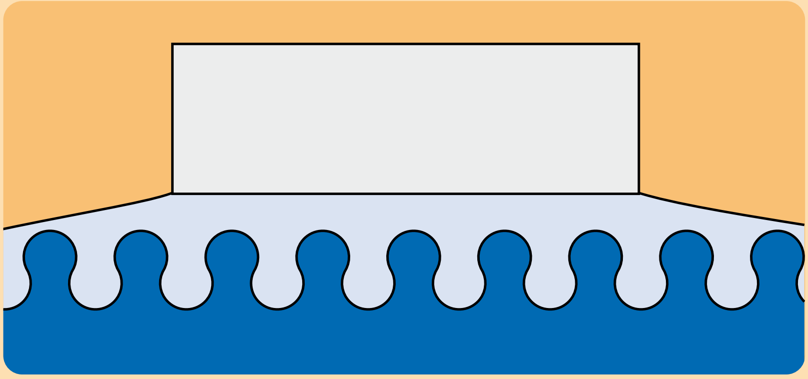
The pad holds particularly well against shear forces. These arise when something is positioned parallel to the surface, as in the first part of the experiment. Then, all the van der Waals forces would have to be released at the same time for the object to fall. If the pad is hanging on the table, gravity is simultaneously pulling downward as well and acting against the adhesive forces.

Try the pad with various objects from around the house. In the car, it could be used to hold sunglasses, for example, or it could hold the remote in the TV room.

CAUTION! The pad sticks so well that printed patterns or letters can be pulled off of objects. Do not stick any imprinted objects to it, and don't stick it to carpets, varnished furniture, etc. Also, its adhesive strength can be reduced by layers of dust or oil. So don't ever hang valuable objects from it. It would be best to ask an adult for help.

EXPERIMENT 41

Gecko in the water



YOU WILL NEED

- › **Gecko adhesive pad**
- › **White cube**
- › **100-mL measuring cup**
- › **Pipette**
- › *Water*

HERE'S HOW

››› Pour some water into the measuring cup and draw some up into the pipette.

››› Set the adhesive pad in front of you and use the pipette to drip some water onto it.

››› Place the cube on the wet adhesive pad. Does it still stick?

WHAT'S HAPPENING ?

As soon as the surface of the pad gets a little wet, its adhesive force fails. Part of the reason has to do with the fact that the nanostructure of the surface becomes "flooded" and won't let the nubs adhere. Also, there are no attractive forces (whether van der Waals forces or hydrogen bonding) between the molecules of water and the pad's adhesive surface which would make objects like the cube stick. But fortunately, the surface is not damaged by the liquid. As soon as it dries, it will stick well again.

CHECK IT OUT

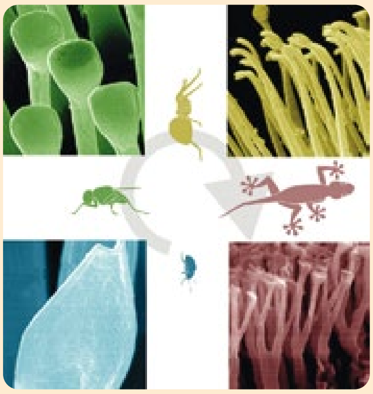
PERMANENT ADHESION

Why don't a gecko's feet get dirty when it walks across the walls? It wasn't until recently that it was discovered that the little animal wipes off its feet with every step to remove any larger particles. Smaller particles stick deep between the hairs of the foot, where they don't interfere with adhesion. By imitating these structures in the laboratory, researchers may one day be able to develop tape that can be used over and over.

TURNING A NEW LEAF

Sometimes when you're reading (a newspaper, for example), you may have a hard time turning the page because two sheets of paper "stick together" due to electrostatic and molecular forces. If you moisten your finger, you create temporary hydrogen bonds between your skin and the paper which are stronger than the bonds between the pages. Then, the paper sticks to your finger and you can easily turn the page. That's a lot of physics for such a little move!

Gecko and Company



Other animals also use little hairs to hold onto things. In the process of observing them, an interesting relationship came to light: the bigger and heavier the animal, the smaller and more densely-packed the setae are on their feet. Light insects like tiny flies only have a few hairs per 1000 μm^2, while lizards like the gecko have up to 10,000 hairs over the same surface area.

Glues and adhesive tapes also work by the principles of adhesion and cohesion, by the way. Chemistry helps a lot too, though. Normal all-purpose glues contain an organic solvent (hence the odor) and an adhesive. The molecules adhere to the surface of the thing to be glued, and harden as the glue hardens. So it makes sense to be sure that the surfaces to be glued are clean and dry (just like the gecko and its feet). Modern glues have become so effective that light electric cars use nothing but glue to hold together their body parts.

The Opportunities and Risks of Nanotechnology

Physicist Richard Feynman is regarded as the "father of nanotechnology." In a 1959 lecture at Caltech University, he spoke about the "room at the bottom" between micrometer magnitudes and the magnitudes of atoms and molecules. That got the idea into the heads of a lot of researchers to make their instruments and methods smaller and smaller.

A little later in the 1960s, we got the first scanning electron microscopes (SEMs), which used a beam of electrons to render tiny

structures visible (see "Knowledge Base," pages 59 to 61). Two decades later, with the invention of scanning tunneling microscopes and atomic force microscopes, researchers were finally able to reveal the nanoscale world. The technology allowed resolutions down to 0.1 nm and resulted in the first images of individual molecules. That in turn enabled fundamental chemical processes to be proven by permitting molecules to be observed before and after reactions.

But let's get back to our story. In 1986, engineer K. Eric Drexler published a book titled "Engines of Creation," in which he laid out his vision for creating artificial machines with the help of new technologies such as the computers that were flourishing at the time — machines that might be as small as biological cells. Drexler imagined the existence of entire factories in which these nanomachines would communicate with one another in the process of working together to build things out of molecules. A lot of science fiction writers and filmmakers took inspiration from his ideas, although most scientists found them just too crazy at the time.

Almost 30 years later, nanotechnology is viewed quite differently in research and in everyday life. Constantly-improving microscopes have allowed various branches of research to extend their domain to the level of nanodimensions. Interestingly, a lot of very different fields of science such as medicine, chemistry, and material physics have encountered very similar phenomena and challenges. Today, nanotechnology is regarded as an interdisciplinary science, with a lot of researchers from different fields working together on the same problems.

Not many people are working seriously on the little machines. But new, nanometer-large structures with a huge range of application possibilities are being discovered or designed all the time.

For example, in the automobile industry: Automobile varnish is being made harder by incorporating ceramic nanoparticles into the paint. At a temperature of about 150 °C, the particles bond into a dense network. It's almost as if an invisible coat of armor has been applied over the paint! This kind of nanopaint has been in existence for almost ten years.

Medical doctors would like to use carbon nanotubes or nanospheres to deliver pharmaceutical products to the exact part of the body where they are needed. That way, the dosage of the medicines can be much more precisely adjusted to achieve a much better effect (see "Check it out," Chapter 2).

These same carbon nanotubes can also be used to make plastics and metals stronger and lighter at the same time, since they can withstand much greater tensile forces than the strongest steel. And there's still a lot more to be discovered in the nanouniverse!

That's why a lot of people view nanotechnology as the ultimate technology of the future.

An opposing view, however, is held by many who reject the application of nanotechnology to cosmetics and foodstuffs. Many people interviewed in a study about nanomaterials stated that they were against the use of nanotechnology in cosmetics and foods. This negative opinion is not without justification.

Nanoparticles are showing up more and more often in everyday products. One example is titanium oxide. Titanium oxide is basically just a very white pigment that has been used for a long time in laundry detergents to make white clothes look especially clean. But it also shows up in the form of nanoparticles in sunscreen, where it reflects harmful UV radiation. It is also used in toothpaste to whiten teeth. You will even find it every once in a while in chewing gum and salt!

However, nobody has completely studied the kinds of effects that nanoparticles may have on the body. Some experiments have shown that inhaling titanium dioxide is neither more nor less hazardous than inhaling other substances. But as you learned in the experiments, nanoparticles are awfully small. So it's possible that there might be problems when they encounter living tissue. The tiny particles can even get through cell walls, and nobody really knows whether they might be dangerous when they get inside the cells. So for now, it would be better to avoid products that bring nanoparticles into direct contact with the outside or inside of your body — at least until it has been confirmed what kind of impact they may have there.

The nanomaterials in the kit, of course, pose no danger. Still, the lotus fluid and anti-fog agent contain chemicals that require careful handling. Nanotechnology will continue to yield a lot more exciting discoveries and technical developments. But a lot of basic research is still needed before they can be used on a widespread basis.

GLOSSARY

Adhesion: Force of attraction between two surfaces due to van der Waals forces.

Atom: The building block of our world. Atoms consist of a nucleus (which contains protons and neutrons) and an atomic shell (which contains electrons). There are 118 different "types" of atoms (chemical elements) differentiated by the number of their protons and electrons (and therefore by their mass, too).

Cohesion: Force of attraction between or within the molecules of a substance due to van der Waals forces.

Colloid: A colloid is a suspension or emulsion in which the suspended particles are smaller than 500 nanometers. They are usually kept in a stable state by their molecular movement.

Electronegativity: The ability of an atom to attract electrons in a chemical bond. (A chemical bond often means that the two bonding partners share electrons.)

Electrons: Electrically negatively-charged components of an atom that move around the nucleus and form the so-called atomic shell or electron shell.

Electrostatic interactions: Forces between electrically charged particles (for example, electrons) or parts of molecules. Equal charges (negative-negative or positive-positive) repel each other, while unequal charges (negative-positive) attract.

Emulsion: A finely dispersed mixture of two liquids that are actually not mixable, enabled by special chemicals known as emulsifiers. Example: Milk is an emulsion of fat in water.

Gravity: Force that pulls all objects to the center of the Earth.

Hydrogen bonds: Attractive interactions in a molecule between a polar-bonded hydrogen atom and the free electron pair of an (ideally electronegative) atom.

Hydrophilic: Water-loving, from the Greek *hydros* (= water) and *philos* (= love).

Hydrophobic: Water-repelling, from the Greek *hydros* (= water) and *phobos* (= fear).

Molecule: A molecule is a group of two or more atoms held together by chemical bonds. Example: H_2O (water) is a molecule.

Polar bond: Chemical bond between two atoms with very different electronegativity (for example, hydrogen-oxygen or carbon-oxygen). The more electronegative partner attracts the bonding electrons to itself so a stronger negative charge occurs on its side. Polar substances are generally hydrophilic.

Surface tension: Effort on the part of water molecules to move as far as possible from the surface. Caused by powerful interactions of the water molecules among one another (hydrogen bonding) and weaker interactions with other materials (such as air molecules). This provides a certain solidity to the water's surface and is also the reason for the formation of droplets (sphere = smallest surface area for a given volume).

Surfactant: Surfactants are carbon-based molecules consisting of a hydrophilic and a hydrophobic part. They can be used as a cleaning agent to dissolve oil in water, for example.

Suspension: A mixture of a liquid and a solid substance finely distributed in it. If certain conditions are met, the suspension will be stable (for example, house paint). Otherwise, the solid and liquid will separate again after a certain amount of time.

van der Waals forces: Forces between molecules arising through charge displacement and by which molecules will attract or repel one another.

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