Contents

"Hello!
You want to learn more about the science of optics? This is the right place. I also think this is a fascinating subject and even know a little about it. Every once and a while I appear in this booklet to give you tips or information.
I hope you have a lot of fun building your models!"

■ You are certainly familiar with the word optics. The optician in the mall is the man who sells eye glasses. And the glasses he sells are also optical instruments. The word originally came from ancient Greek and means "the science of sight and light". That's what makes optics so interesting: You can see it everywhere you look. That's right - without optics we would not be able to see! Without a lens in your eye you would only be able to recognize the difference between light and dark. But you would not be able to recognize what you were looking at and everything would be completely fuzzy.

People have given a lot of thought to eyesight for a long time. A lot of attention has been given particularly to poor, or fuzzy eyesight. This is the reason they discovered how to use eye glasses and magn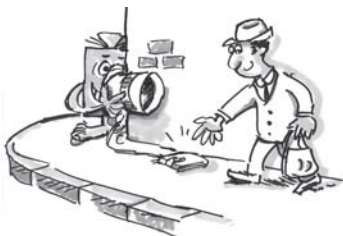ifiers nearly 700 years ago. These glass lenses make it possible to correct optical errors in the human eye. We will try this a little later. We cannot 'discover' the magnifier - it already exists. But we can copy it - and do a great deal more. We even show you how to build instruments for looking at the stars. The trick used here is called refraction.

In addition to bending or refracting the light, it can also be reflected. You may already know how a mirror works, but we are going to do something very special with it. We are going to 'bend' the light around a corner, we will even turn it around completely - 180°. You will be able to see people, who cannot see you. You can watch them without them even noticing.
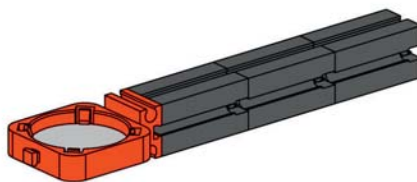
A famous philosopher once said "Where there is light, there is also shadow." He was right. When the moon shines in the sky, it is dark night for us here on earth - or what did he mean? And why can we sometimes see only half the moon, or only a sliver? If you have ever wondered about this, you will now have an opportunity to build your own fully functioning 3D planetary model.

When you have tried out all the models, you will also be an expert in the field of optics. But regardless of how much you think you know - don't trust your eyes - at least not all the time. But we will go in to that at the very end.

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Refraction (lenses): Magnifier

■ Hundreds of years ago people also wondered why the world looked different when viewed through a drop or glass of water.

Have you ever noticed how a spoon looks in a glass of water; as if it were bent just below the surface of the water? This is the result of refraction. The direction of the light is diverted (bent or refracted) slightly by the surface of the water. This happens to light any time it hits a transparent material with a different density. In this case from air to water or as with a lens: From air to glass and back to air.
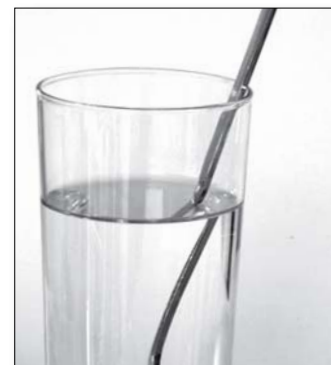
■ Build the model of a magnifier as described in the assembly instructions.

Experiment 1:
Observe your room through the magnifier instead of holding it close to an object. Slowly move the magnifier away from your eye until you can see a sharp image. This will be at approximately the point when your arm is slightly bent. What do you see - or rather: How does it look to you?

Is everything upside down? If so the lens in your magnifier is perfectly okay. And while you are still wondering, start working on the next experiment.

Experiment 2:
Hold the magnifier between a white sheet of paper and a light source such as a flashlight or floor lamp. Hold the sheet of paper approximately 30 cm away from the light source. Position the magnifier approximately in the middle between the sheet of paper and lamp. Then slowly move the magnifier closer to the lamp, then closer to the sheet of paper.
Tip: A candle can also be used, but in that case be sure an adult is present to help you with the experiment! It also works with a television set as a light source.
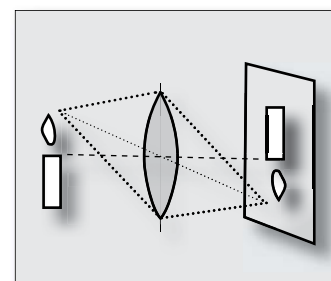
Path of light through lens

Your light source (lamp) appears on the sheet of paper - but backwards and upside down. The light rays are diverted as they pass through the lens. They change sides, so to speak, from top to bottom and from right to left (the picture helps you understand this).

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Magnifier with light

■ When you have trouble reading or recognizing something, the problem may be that the letters or the objects are too small (here a simple magnifier can help) or the light is bad. That is why we have added something to the magnifier.
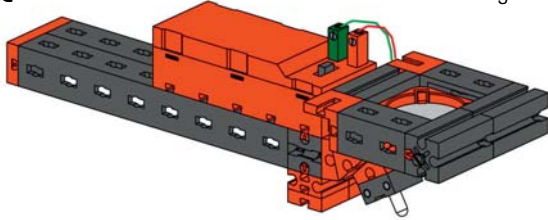
■ Build the magnifier with light as described in the assembly instructions.

Experiment 1:
   Take the magnifier in your hand and look at the lines in this activity booklet. Once with and once without light.

It is astonishing how just a little bit of light makes the letters appear sharper.
Observe older people, who don't see as well any more. When they want to read the small print on a food package, they often go to the window or turn on the light. Light increases the contrast, the difference between the light and dark points therefore allows the letters to appear sharper.

■ When looking at the letters you moved the magnifier back and forth a little to get the letters focused correctly. Why did the focus change with the distance?

Experiment 2:
Place the magnifier flat on the activity booklet. Slowly move the magnifier away from the booklet and watch the letters trough the lens. What do you notice?

f
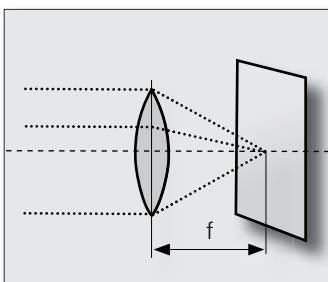
f = focal length

First the letters appear larger and larger and remain in focus. Up to a certain distance, then they start becoming fuzzy. This happens with all converging or convex lenses. This distance corresponds approximately to the focal length (f). This is the distance from the lens to the point that all light rays come together (converge) at one spot. Thick lenses have a shorter focal length than thin lenses because they "refract" (bend) the light to a greater extent.
When the sun shines you can also measure the focal length of your lens. Hold the magnifier above a rock so that the dot of light is as small as possible. The distance between the rock and lens is the focal length in centimeters. But be careful: Focused sun rays can get very hot.

!
• Never look at the sun though the magnifier -> **Injury Hazard!**
• Never hold the magnifier over combustible material such as wood or paper in the sunlight -> **Fire Hazard!**
• Never leave the magnifier laying around unattended in the sunlight -> **Fire Hazard!**

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Slide viewer
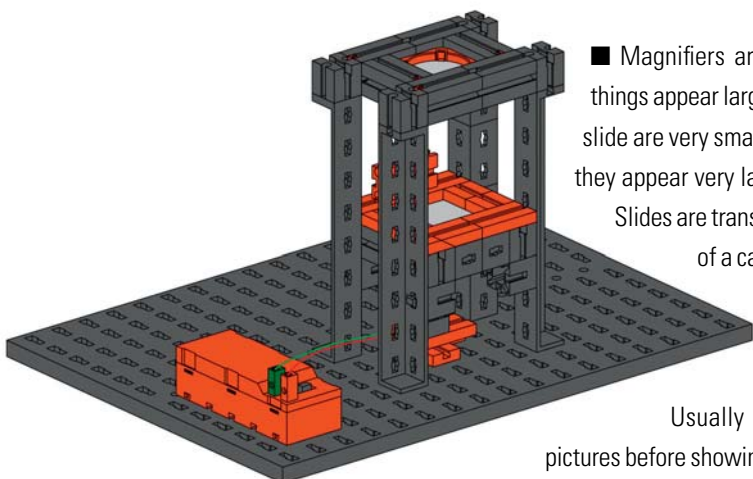
■ Magnifiers are particularly good at making small things appear large. For example the pictures on a photo slide are very small, however with the aid of a magnifier they appear very large.

Slides are transparent photographs made with the aid of a camera. When inserted in to a projector, the picture can be projected big as life on the wall of the room, almost like in a movie theater.

Usually people sort out the boring or fuzzy pictures before showing them on a large screen, to keep from boring friends and relatives. Slide viewers are used for this purpose. The small slides can be inserted into the slide viewer where they can be viewed and evaluated in a satisfactory size with the aid of light and a magnifier.

You can do this yourself in just a minute.

■ Build the slide viewer as described in the assembly instructions.

Ask your parents if they can give you a few slides from the good old times and you can enjoy jumping back into the past, maybe even before you were born.
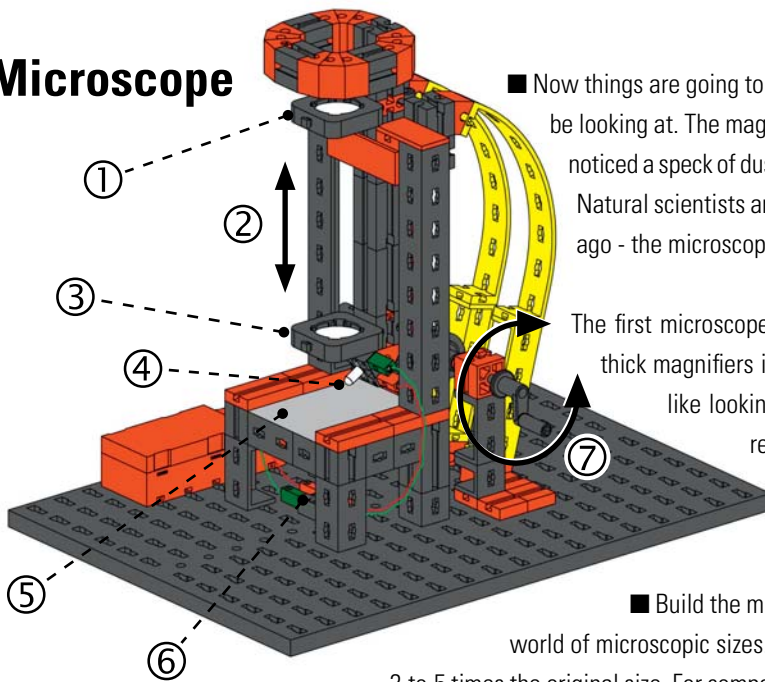
As an alternative you can paint a transparent foil from the construction set yourself and place it in the slide viewer.

Tip: Simply place the slide on the red frame in the model. Do not remove the transparent foil. It distributes the light from the lamp uniformly on the slide.

Microscope

■ Now things are going to get really small. Not the model, but rather, what you are going to be looking at. The magnifier enlarged things quite well, but we probably would not have noticed a speck of dust. Magnifiers made people curious about the world of small things. Natural scientists and lens grinders then developed a wonderful instrument 300 years ago - the microscope - opening up the door to a miniature cosmos.

The first microscopes were little more than strong magnifiers. The disadvantage of thick magnifiers is that they tend to distort the resulting image highly. Something like looking through a crystal ball. The trick with a second lens was what really made the microscope powerful. The second lens acts like a turbo-charger, so to speak, enlarging the image from the first lens even more.

■ Build the microscope as described in the assembly instructions and enter the world of microscopic sizes. Start with version 1 of the model, with a magnification factor of 3 to 5 times the original size. For comparison you can then replace the lens with the lens for version 2 for a magnification factor of 7 to 10 times.

1   Ocular lens
2   Height adjustment
3   Objective lens
4   Reflected light lamp
5   Specimen holder
6   Transmitted light lamp
7   Focusing crank

Task 1:
Find a transparent object to look at. For example the thin leaf from a plant; it doesn't matter if it is already somewhat dry. Disconnect the plug for the microscope light and take a look at it under your new microscope.

After focusing with the crank (7), you not only see the leaf, but through the leaf, almost like an X-ray machine. Do you see the fine veins that supply the leaf with water right down to the last tip? Fascinating. When light shines through the object placed in front of the lens, we call this transmitted light microscopy.

Magnification factor

Model
Version 1 = 3 to 5 times
Version 2 = 7 to 10 times

Task 2:
Now switch on the reflecting light by plugging the connector back into the bulb socket. Now look at your leaf. You can see the difference even more clearly when you switch the light on and off while viewing.

With reflected light you cannot see through the leaf as well, but the surface is clearer. This is an advantage when you want to view objects which are not transparent. One of the features of your new microscope is that it can do both. It is a transmitted as well as reflected light microscope.
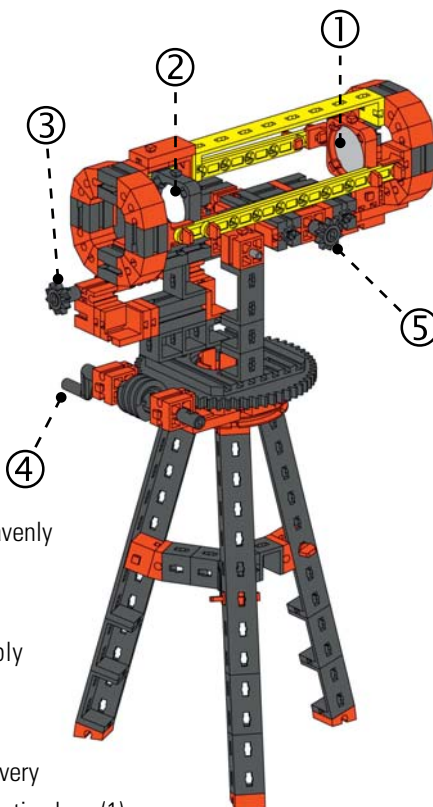And now you can start your discovery trip. Have you ever seen a sewing needle under a microscope? You probably think the point is smooth and sharp. You are wrong! Or did you know that the colored pictures in the newspaper consist of numerous colored dots? Then cut out a picture and view it with the reflecting light switched on; you will be surprised!

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Astronomical telescope

■ Galileo Galilei. This is a man you should be familiar with when it comes to astronomy or "observing stars". He was a genius in the fields of science and astronomy. Around the year 1600 the telescope had already been invented, but it was not very powerful. He built a better one himself, making him the first human to view the surface of the moon so precisely that he could see mountains, valleys and craters. At that time, 400 years ago, this was a real sensation. Up until that time everyone thought the heavenly bodies were round and smooth as a billiard ball.

■ Build the telescope as described in the assembly instructions and observe distant objects.

Your telescope has a magnification factor of 3.2. This is very easy to calculate! Just divide the focal length of the objective lens (1) = 80 mm, by the focal length of the ocular lens (2) = 25 mm   80: 25 = 3.2.

1   Objective lens (f = 80 mm)
2   Ocular lens (f = 25 mm)
3   Tilt telescope
4   Turn telescope
5   Focus

Erecting telescope

■ When looking through the telescope you have certainly noticed that everything is upside down. When you look at the stars it makes no difference, but in this form the telescope is of little use for viewing objects on the earth.

Task 1:
What will we need to change, add or convert on the telescope to turn the reversed image back the right way around?

During the second experiment with the magnifier at the beginning of this activity booklet, you remember, that you can reverse an image when the lens is positioned at the right distance.
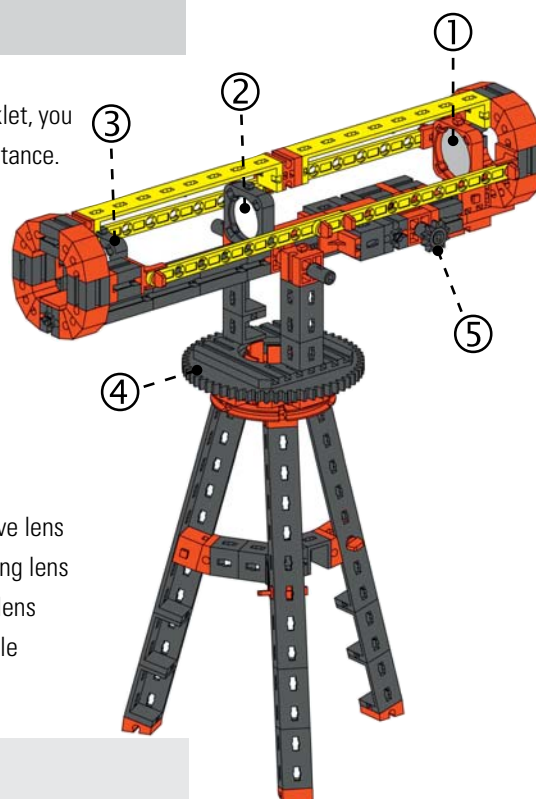
Task 2:
Build the model as described in the assembly instructions. Use all three lenses and check whether the image is turned around correctly by the third lens.
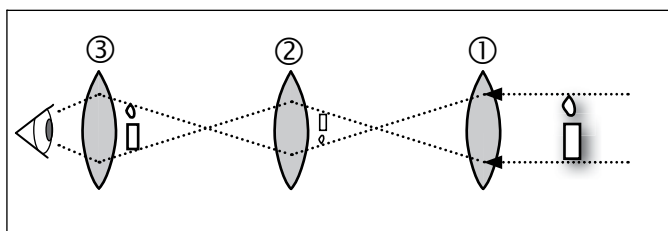
1   Objective lens
2   Reversing lens
3   Ocular lens
4   Turntable
5   Focus

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Reflection (mirror course)

■ First we refracted the light, now we will reflect it. At the beginning of this activity booklet I promised you that we would do other things with the mirror than just looking into it.

■ First, build the mirror course as described in the assembly instructions.

Room ceiling

45°   45°
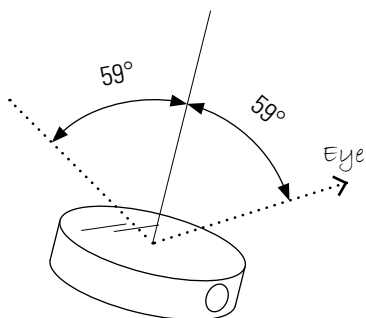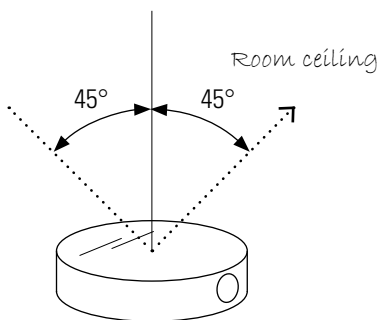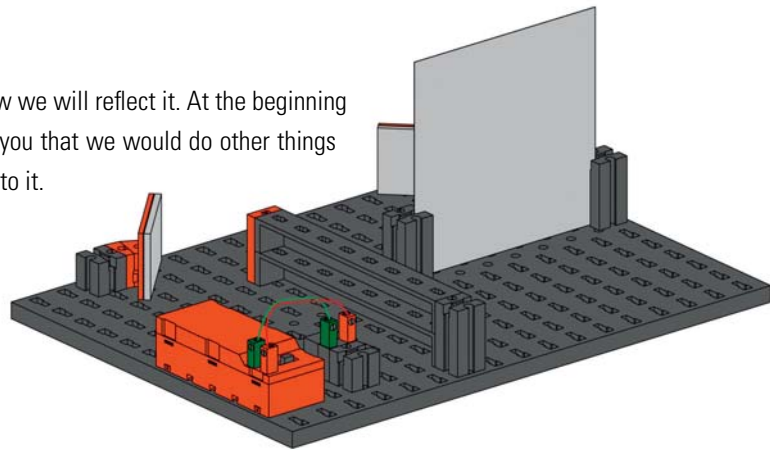
Task:
Switch on the lamp and observe the path the light travels (preferably in a dark room).
Why does the light shine in exactly the same direction and where is it coming from?
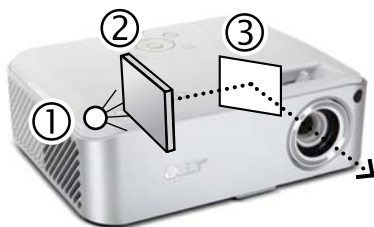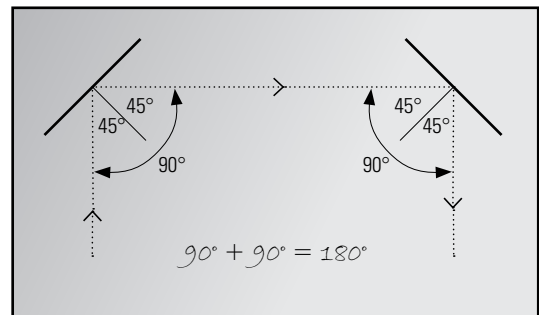
Naturally the mirrors are responsible, but the angle the light hits the mirror is important.

You have probably experienced this yourself before. For example as you reflected sunlight with a watch and watched the bright spot of light on the ceiling.

If you wanted to shine it into your neighbors eyes instead of onto the ceiling, you had to turn your wrist to the right angle. When the light hit the glass at a flatter angle, it was also reflexed flatter. Here you were making use of a natural law! The law of reflection, which says:

Angle of incidence equals angle of reflection

59°   59°

Eye

That fits so well, we will have to try it out with our model.

The light hits the first mirror at an angle of 45° and is reflected at an angle of 45°, together that makes 90°. With two mirrors we have 180°. Now it is clear why the light is reflected back in the same direction it was coming from - it is turned around 180°.
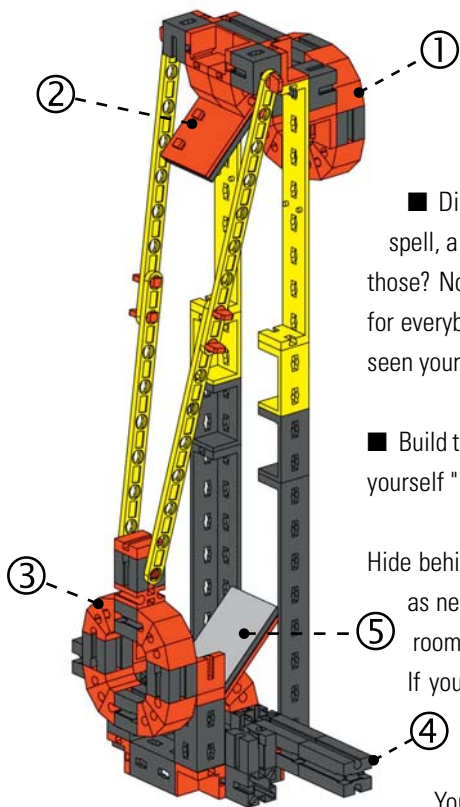
45°
45°
90°

45°
45°
90°

$$90° + 90° = 180°$$

Many optical instruments make use of reflection.

• Single lens reflex cameras
• Daylight projectors
• Video projectors (beamers)
• Periscopes

② ③
①

1   Bulb
2   TFT monitor
3   Mirror

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Periscope

■ Did you ever want to be invisible? To do that you need a good magic spell, a magic cap or a ring to make you invisible. You don't have any of those? No problem, we have another way. It doesn't make you invisible for everybody, but if you are cleaver you can watch others without being seen yourself.

■ Build the periscope as described in the assembly instructions and make yourself "invisible".

Hide behind the couch and push the top of your periscope up only as far as necessary above the backrest. Now you can see everything in the room without being seen yourself.

If you hold the periscope in a horizontal position you can also look around corners. For example you can stand in the hallway and spy around the door frame into the living room.

You can look out a window without standing in front of it or spy on the neighbor over the hedge or fence.

You can certainly think of other things to do with your new periscope.

1   Objective
2   Objective mirror
3   Ocular
4   Ocular mirror
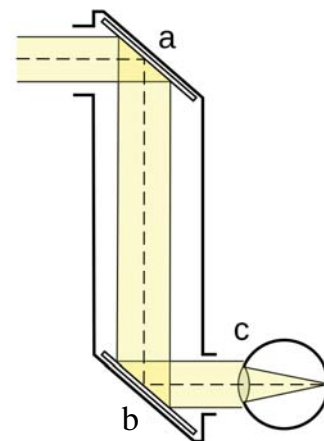5   Handle

a   Objective mirror
b   Ocular mirror
c   Eye

■ Periscopes were first used as aids for astronomers when observing stars and comets. Later soldiers used them to peek out of trenches without being seen or being hit by enemy bullets.
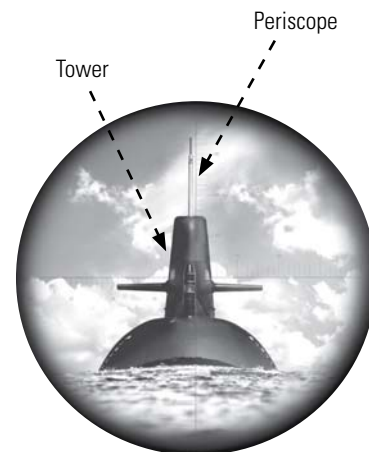
As the first submarines sailed the seas, it was vital to be able to see above the surface of the water while remaining submerged. Special submarine periscopes were developed for this purpose. The submarine moved just below the surface of the water and pushed the periscope up out of the "tower" above the surface of the water like a telescoping tube. Naturally the optical part of submarine periscopes is supplemented with special features for this purpose. Additional lenses allows the periscope to also act as a telescope. In today's submarines periscopes are frequently equipped with laser distance measuring equipment and infrared imaging features for seeing things in the dark.
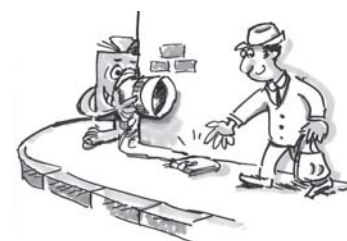
Tower

Periscope

View through a submarine periscope while submerged

Light and shadow
Sun dial

■ Have you heard? A clock was found in the desert, which had been buried in sand for hundreds of years and the unbelievable part is - it still worked! "Naturally" you say, "it was probably a sun dial".
Right! And the sun dial is more than just a few hundred years old - to be exact, it is over 3,000 years old. How do we know that? Archaeologists found one in the grave of an Egyptian pharaoh. This proves: Even the old Egyptians had sun dials. Do you think they work just as well today as they did 3,000 years ago? Why don't you try it out, then you will also discover *how* they work.

■ First, build the model as described in the assembly instructions.

12 noon

Find a quiet, sunny place for your sun dial. For example, a good place is a window sill with a view to the south. That is any window though which the sun shines directly at noon.
By a quiet place, I mean that the window should not be opened continuously, because otherwise you would have to realign the sun dial all the time. If necessary, you can make a mark on the window sill with a pencil.

Align with sun dial with the sun. The sun should shine on the scale from the rear. It is best to set the exact time at 12 noon. Then turn the sun dial back and forth slightly until the pointer's shadow falls precisely on the vertical mark on the scale.
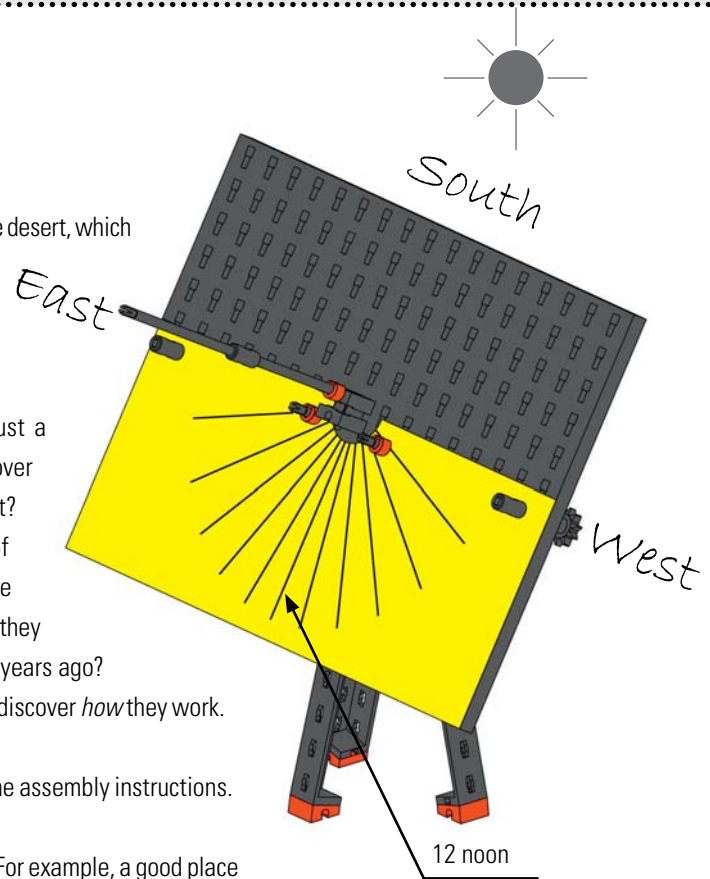
Task:
Try to imagine where the next mark for 1 p.m. should be. In which direction will the shadow travel? Tip: Take a look at the illustration.

In the summer the pointer's shadow will be shorter and in winter longer. This is because the angle between the sun and the horizon is lower in winter than in summer. This also allows you to add a solar calendar feature to your sun dial.

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Partial and full shadow
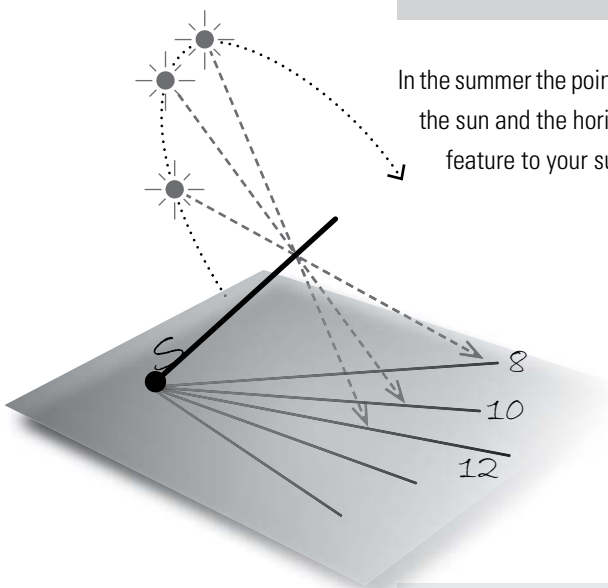
■ Have you ever seen a solar eclipse? If so you were born before 1999 and were in Germany on August 11th or in Australia in 2003 or in Turkey in 2006. These are the dates of total solar eclipses at the locations mentioned. We will explain what a solar eclipse is actually, how they occur and what is so 'total' about them.
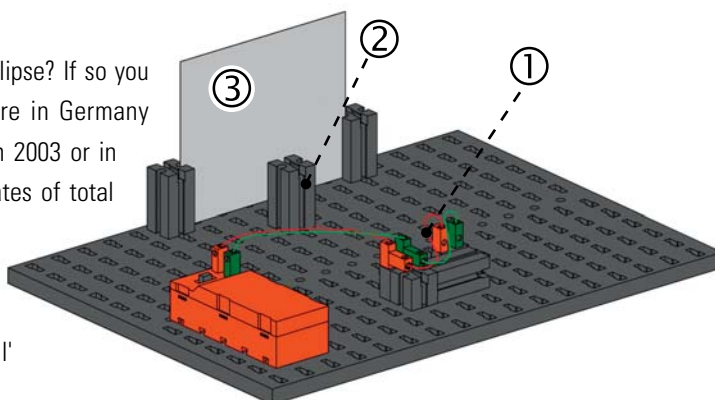
1   Light source
2   Obstacle
3   Projection wall

For a solar eclipse to occur it is necessary for the earth, the moon and the sun to be in a straight line with one another, like pearls on a string. In this case the moon is between the earth and the sun.
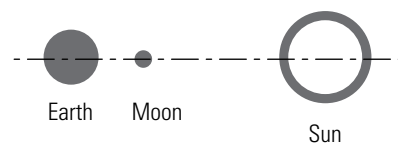
■ Build the partial and full shadow model as described in the assembly instructions.

Earth   Moon

Sun

When an object is illuminated, it casts a shadow - nothing new about that. However if the light source consists of two spots of light as on this model or one large light source such as the sun, there are two shadow areas: partial shadow and full shadow.

Task
Switch on the light on the model and observe the projection wall. The dark shadow in the middle is the full shadow, the lighter field around it is the half shadow. Imagine this model was our constellation of sun-moon-earth. Lamp = sun, building block = moon. The projection wall represents the surface of the earth. In which area of the earth (projection wall) would you have to stand to experience a total solar eclipse?
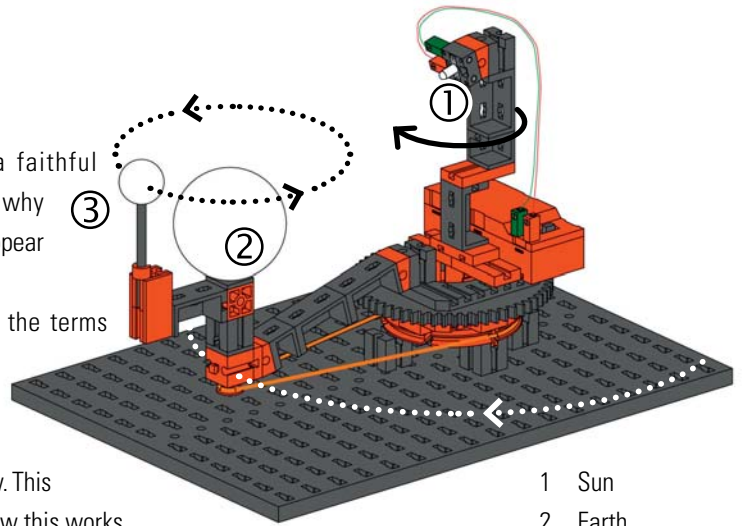
Total solar eclipse

You should stand in the full shadow, the darkest area cast by the shadow. In your model this is the nearly black strip in the middle. If you could stand there you would no longer be able to see the lamp (sun) because it would be concealed completely by the construction block (moon).
On the earth the full shadow during a solar eclipse is a round spot. And because the earth and moon move, it also moves across the surface. After a few minutes, the spectacle is over. The moon is no longer in line and thus no longer blocks the view of the sun.

By the way, the next total solar eclipse in Germany will be on September 3rd 2081.

Planetary model

1 Sun
2 Earth
3 Moon

■ People say the moon is a faithful companion. If it is so faithful, why does it get so 'thin' and even disappear regularly?

Naturally you are familiar with the terms waxing and waning moon, new moon and full moon. This has to do with the light from the sun, the position of the earth and its shadow. This planetary model shows exactly how this works.

■ Build the model as described in the assembly instructions. Observe the different height positions of the moon in task 1 and task 2.


15 mm
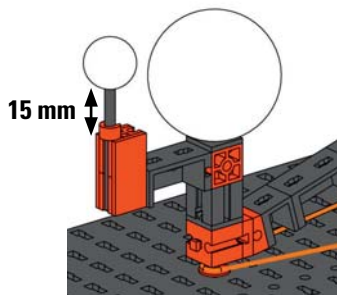
Task 1:

First we will simulate a solar eclipse. Do you remember how to do that? If not, just turn back one page to the chapter "Partial and full shadow". Now you remember - the sun, moon and earth form a straight line in precisely this sequence. The 'sun' is switched on and casts a shadow of the moon on the earth. Imagine you were standing in the middle of this shadow and looking at the sun. What would you see?

Right - the moon because in the ideal case it conceals the sun completely. However since this situation occurs very rarely, we usually see a new moon in this position.

Your room should be dark for the next task, so that the light and shadow have their optimum effect.


30 mm
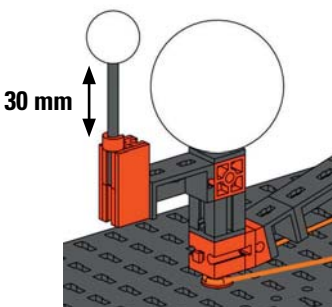
Task 2:

Turn the planetary model around so that the moon turns counter-clockwise (see illustration above). Imagine you were standing on the earth looking at the moon. Now you can run through all the moon's phases. When does the waxing/waning moon phase start?

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Phases of the moon

The illustration shows the answer. Right-hand figure: Position of the moon in relation to the earth looking at it from outer space. Left-hand figure: Here is what the moon looks like from the earth in each position.
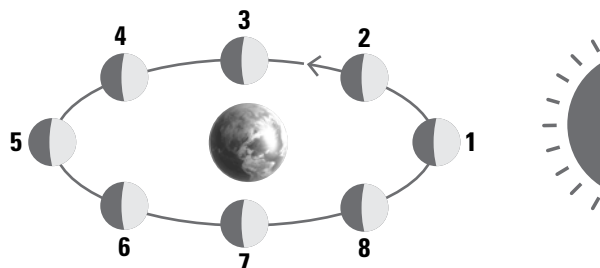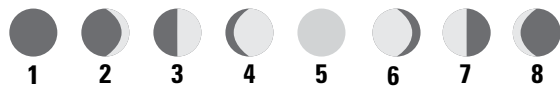
1	New moon	4	Waxing moon	7	Half moon
2	Waxing moon	5	Full moon	8	Waning moon
3	Half moon	6	Waning moon		

Moon calendar

The moon takes **29.53 days** for one complete cycle from new moon to new moon. This corresponds approximately to one month. This is not a coincidence, because at one time our calendar was based on the moon. In this period of approximately 29 days the moon also turns once around its own axis. This means that the same side of the moon is always pointing toward us. Before the first flights to the moon, we had never seen its far side.

Earth

The earth orbits around the sun at a speed of **107,000 km/h** and you travel with it. Who ever thought we are all racing through space at such a speed? For comparison: That is three times faster than the space shuttle flies.
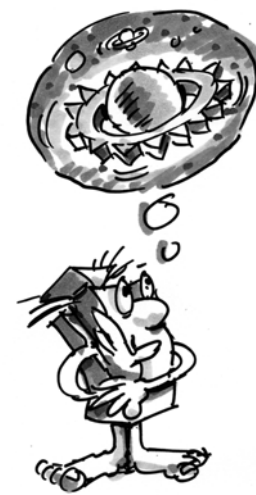
Light

Light travels **300,000 km** in just one second. That corresponds to one billion kilometers per hour. For comparison: Sound travels through the air at a speed of 'only' 1,200 km/h.

Light can reach such a high speed because it does not have any mass. It consists of electromagnetic waves just like radio waves, microwaves or radar waves. Only a small range of the entire spectrum of electromagnetic radiation is visible for humans - we call this range light. It travels in straight lines; that is why we frequently represent light rays by drawing a straight line.

"White" sunlight is made up of all colors of the spectrum (distribution of all colors). For example this is what we see when we look at a rainbow. The light is refracted by the drops of rain, dividing it up into red, changing to orange, yellow, green, blue and violet. By the way the colors are always in this same sequence.
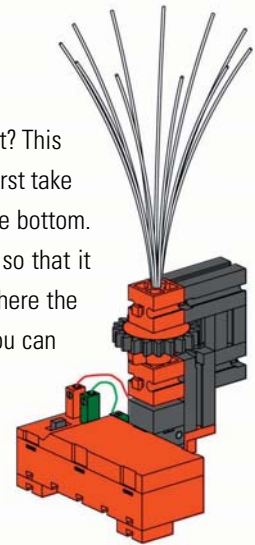
Light effects
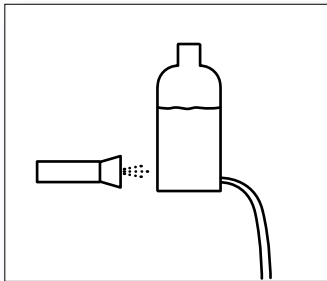
Experiment with water bottle

■ Are you familiar with the experiment with the water bottle and a flashlight? This experiment shows you how you can send light through a stream of water. First take a water bottle (plastic) and drill a small hole in the side of the bottle at the bottom. Now fill it with water. Hold the flashlight opposite the hole in the bottle - so that it shines more or less into the stream of water from the rear. At the point where the water hits the floor (naturally the bottom of the sink and not the carpet) you can see a bright dot of light.
The Irish Physicist John Tyndall first tried this experiment in 1870. However at that time no suitable material existed to use this knowledge from the experiment for technical applications.
Just as Tyndall, you will probably ask why the light is caught in the stream of water or the fiber optic cable and exits only at the end?

■ Build the light effect model as described in the assembly instructions.
Important when building:
• Use the rainbow LED for the "lamp". It is the only source which produces different colors of light. It can be identified by the marking "RB" on the base.
• Connect the positive pole to the side with the red marking.
• The fiber optic cable must be positioned directly in front of the LED:

Task:
   Switch on the LED lamp and observe how the light shines through the fiber optic cable. Do you notice anything?
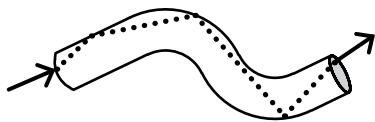

Beam of light traveling through
bent fiber optic cable

When you look at the fiber optic cable from the side you cannot tell that there is any light in it at all. It becomes visible only at the end where it exits.
The light cannot escape through the wall of the fiber optic cable, because it is always reflected back. This is called total reflection. The light is reflected completely because it hits the wall of the fiber optic cable at a flat angle. After reaching a certain angle, called the critical angle, the light can escape through the wall of the fiber optic cable. This is the case at the end of the fiber optic cable. Here it exits and is visible as a light spot.
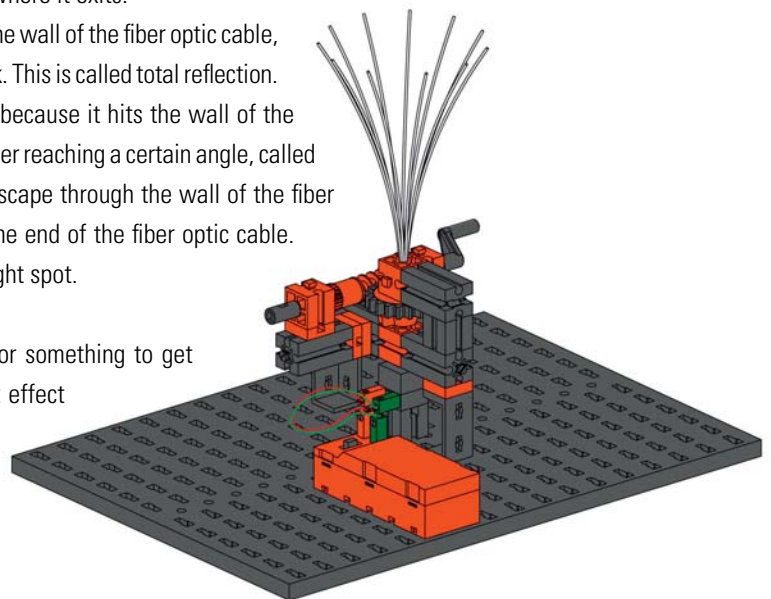
Light effects with crank

■ If you think it is about time for something to get moving, build the advanced light effect model with crank. Now if you make it dark in your room, you can enjoy the changing colors.

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Morse telegraph

■ This also makes it very clear what I have tried to explain to you about light traveling through the fiber optic cable using your light effect model as an example. It is astonishing how the light follows every curve, no matter how you bend it. But watch out: Don't bend it too much.
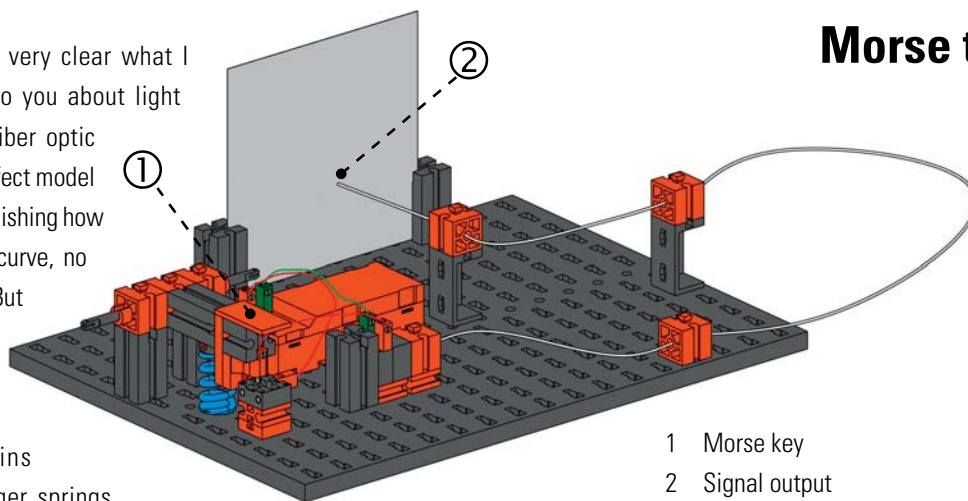
1. Otherwise the fiber optic cable remains kinked and no longer springs back (at a bending radius less than 2 cm).

2. Then the fiber optic cable may no longer function properly. If the bending radius is too small, the light can escape from the fiber optic cable. See also description on critical angle in the Chapter Light effects.

1   Morse key
2   Signal output

The Morse Code

■ Before telephones were invented, messages were sent by telegraph using the Morse code. This was a simple and reliable method. Telegraphs using Morse code required only one cable and two signals. Short and long or dot and dash. That was the code for the letter "a".

You could say that the Morse code was something like Grandma's Internet. At that time there were no fiber optic cables, but the principle is very similar.

Today the Internet also works with only two signals. Instead of dots and dashes, it uses 1's and 0's as signals. Instead of a man at the telegraph office, today a computer decodes the signals and gives us the message, but much quicker, of course. Today we have fiber optic cable and it is required to transport gigantic quantities of data. Today fiber optic cable envelops our planet, forming the backbone for global communication and transfer of information.

Presently 26 terabits can be transmitted using one single glass fiber. This corresponds to the contents of 700 DVD's - this quantity is transmitted every second.

You don't have to be quite that fast for your last assignment.

a · -	n - ·
b — · · ·	o — — —
c — · — ·	p · — — ·
d — · ·	q — — · —
e ·	r · — ·
f · · — ·	s · · ·
g — — ·	t —
h · · · ·	u · · —
i · ·	v · · · —
j · — — —	w · — —
k — · —	x — · · —
l · — · ·	y — · — —
m — —	z — — · ·
Wait · - · · · ·	
Start · — · — · —	
End · · · — · —	

Task:
Send the following string of characters on your Morse telegraph: " · · · — — — · · · ".
What is the meaning of this string of characters? (See solution below.)

Solution for task on this page: It is the international emergency call SOS.
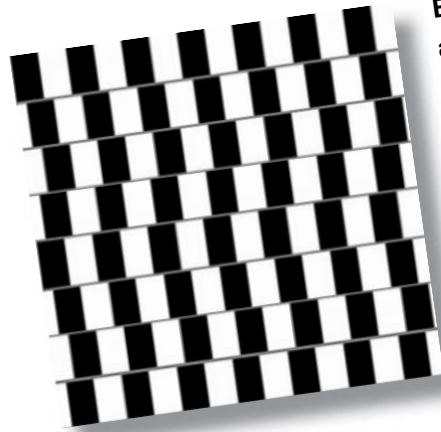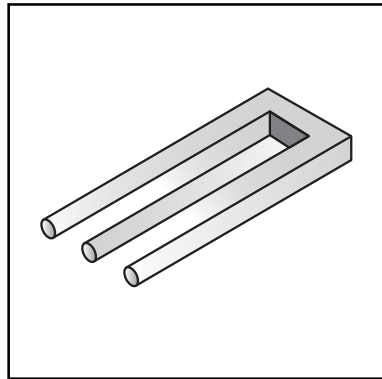
Optical illusion

"As I said at the beginning of this activity booklet: "You can't always trust your eyes".
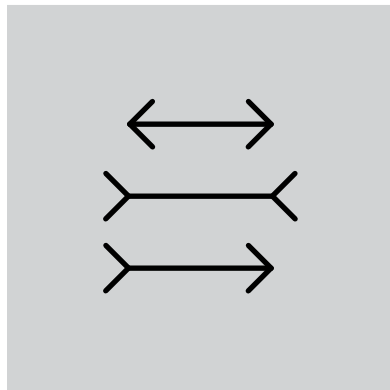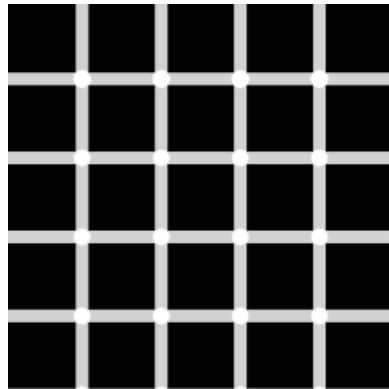
Something is missing!
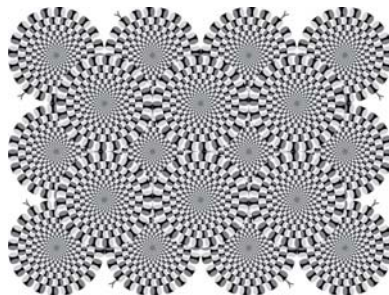The brain searches for a three-dimensional object. However the eye cannot find one.

Everything crooked and out of line?
You think so? Than place a straight edge on the horizontal lines.

Count the black dots
Whoops, that was one just a minute ago.

Which line is longer?
The one in the middle, you think? Well then measure them!

Fantastic circles...
are shown in the assembly instructions in color and much larger. What you see at the left is just a small preview in black and white.
You'll be surprised. You've certainly never seen anything like this before.

The assembly instructions even include a model of an "optical illusion". Just a quick tip: Turn slowly!".

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