

# OPTICAL SCIENCE

A hand holding a magnifying glass over a colorful, abstract background of light patterns and a blurred parrot. The background features a vibrant blue and green color palette with circular light patterns and a blurred parrot in the upper right corner.

**WARNING** — Science Education 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.

## What's in your experiment kit



## Checklist: Find – Inspect – Check off

| ✓                        | No. | Description                        | Qty. | Item No. |
|--------------------------|-----|------------------------------------|------|----------|
| <input type="checkbox"/> | 1   | Tracing paper                      | 1    | 705 800  |
| <input type="checkbox"/> | 2   | Lens                               | 1    | 702 342  |
| <input type="checkbox"/> | 3   | Rubber band                        | 1    | 161 412  |
| <input type="checkbox"/> | 4   | Wooden bead                        | 10   | 772 632  |
| <input type="checkbox"/> | 5   | String                             | 1    | 350 134  |
| <input type="checkbox"/> | 6   | Tube                               | 1    | 707 448  |
| <input type="checkbox"/> | 7   | Mirror                             | 1    | 702 221  |
| <input type="checkbox"/> | 8   | Red translucent film               | 1    | 161 415  |
| <input type="checkbox"/> | 9   | Blue translucent film              | 1    | 702 230  |
| <input type="checkbox"/> | 10  | Green translucent film             | 1    | 161 416  |
| <input type="checkbox"/> | 11  | Rainbow film (diffraction grating) | 1    | 707 449  |
| <input type="checkbox"/> | 12  | Chalk                              | 1    | 705 361  |
| <input type="checkbox"/> | 13  | Top                                | 1    | 703 548  |
| <input type="checkbox"/> | 14  | Optical fiber                      | 1    | 707 450  |
| <input type="checkbox"/> | 15  | Modeling clay                      | 1    | 000 588  |
| <input type="checkbox"/> | 16  | Cup                                | 1    | 707 451  |
| <input type="checkbox"/> | 17  | Mounting foot                      | 5    | 701 384  |
| <input type="checkbox"/> | 18  | Pushpin                            | 1    | 707 452  |
| <input type="checkbox"/> | 19  | 3D poster                          | 1    | 707 446  |
| <input type="checkbox"/> | 20  | Flip book paper sheet              | 1    | 707 445  |
| <input type="checkbox"/> | 21  | Die-cut sheet 1 (thick cardboard)  | 1    | 711 210  |
| <input type="checkbox"/> | 22  | Die-cut sheet 2 (thin cardboard)   | 1    | 711 211  |
| <input type="checkbox"/> | 23  | Transparent film sheet             | 1    | 707 447  |
| <input type="checkbox"/> | 24  | "Town" paper sheet                 | 1    | 710 980  |

## Additional things you will need:

*scissors, tape, glue, 3 small flashlights, pencil, dull knife, old newspaper, soup bowl, water, large hand towel, desk lamp, energy-saving bulb, white paper, water, non-permanent marker, set square, compass*

Any materials not contained in the kit are marked in *italic script* in the "You will need" boxes.



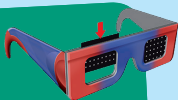
Please check all the parts against the list to make sure that nothing is missing. If you are missing any parts, please contact Thames & Kosmos customer service.

## Light: What Is It? Pages 3 to 11

This is where you will learn about all the things that light can do.



## Eye and Camera: How We See Images Pages 12 to 22

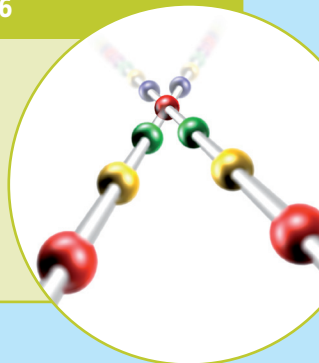


Discover how your eyes see.



## Seeing in 3D Pages 29 to 36

Why we have two eyes



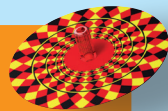
## Seeing Colors Pages 23 to 28

How all colors come from three



## Optical Illusions Pages 37 to 48

Let your eyes deceive you.



## CHECK IT OUT

You will find supplemental information on pages 10, 11, 21, 22, 35, 36, and 48.



## Dear Parents!

What is light? How does vision work? And can we really believe our eyes? This experiment kit will give your child a basic but well-grounded introduction into the world of optics.

The experiments in this box will act as an entertaining and playful guide to careful observation, and they will help to awaken a curiosity about the natural sciences.

The topic of optics is complex, and experiments with optical illusions often require a certain amount of practice, concentration, steadiness, and patience. Please do stand by your child with help and advice, and provide support when it is needed.

Please also pay attention to the adjacent list of basic rules for safe experimentation. It is best to review the rules with your child before starting.

We wish you and, above all, your young researcher a lot of fun and exciting discoveries!

- Individual parts of this kit have sharp or pointed edges or corners. Do not injure yourself!
- Not appropriate for children under 3 years of age. There is a danger of suffocation due to small parts that may be swallowed or inhaled.
- Save the packaging and instructions, as they contain important information.

## Rules for safe experimentation

- Carefully prepare your workplace for the experiments. Be sure that you have enough room and get everything ready that you might need.
- Carry out the experiments calmly and carefully, and follow the instructions precisely.
- Read the instructions before use, follow them, and keep them ready for reference.
- Never shine your flashlight directly into your eyes or the eyes of another person.
- For experiments that are to be performed in a darkened room, be sure to clear away any tripping hazards first.
- Keep young children and pets away from the experiments.
- Store the experiment kit out of the reach of young children.

# Light: What is it?

A silhouette of a child standing and holding a glowing light source, possibly a flashlight or a small lamp, which creates a bright lens flare effect. The child is positioned to the right of the main title text.

You might say it's obvious. Turn on the light, and it's bright, turn it off and it's dark. But did you know that you can't see rays of light? It's true! Rays of light traveling through completely empty space are invisible. Only when they hit something and get reflected back do they turn bright and colorful.

Just a minute — colorful? Where do the colors come from? On the next few pages, you will learn more about the exciting topic of light.

# Making rays of light visible



## EXPERIMENT 1

### YOU WILL NEED

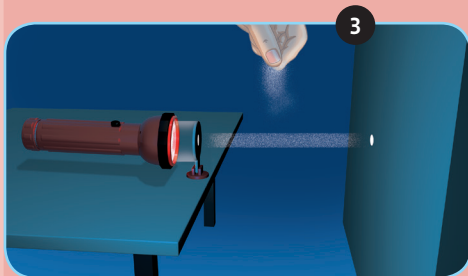
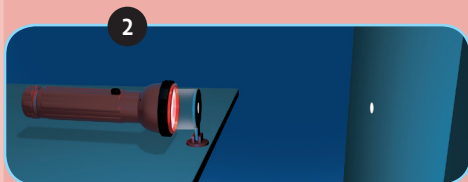
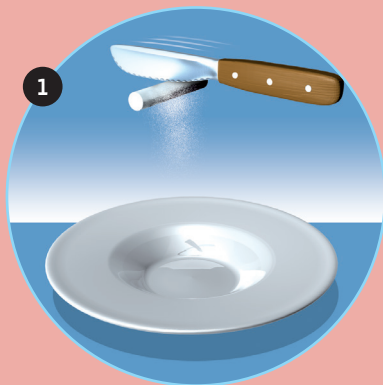
- pinhole card from die-cut sheet 1
- mounting foot, chalk
- *dull knife, plate, small flashlight, old newspaper, white paper*

### HERE'S HOW

1. Use a dull kitchen knife to scrape some chalk dust off the piece of chalk, and collect the dust on a plate. Find a room that you can darken with blinds or a curtain.
2. Use the mounting foot to set up the pinhole card a good 10 cm away from a light-colored wall. Spread out an old newspaper on the table and floor to keep chalk dust from getting all over the place! Keep your flashlight and chalk dust ready.

Switch on the flashlight and darken the room. Point the flashlight right at the pinhole card so the light only passes through the tiny pinhole and you see a point of light on the wall.

3. Now take some chalk dust and let it sprinkle down between the pinhole card and the point of light on the wall.



### → WHAT'S HAPPENING?

A fine ray of light will reveal itself in the chalk dust. You can only recognize it because the space between the light source and the light point is no longer empty. Now it's filled with the fine chalk dust, which reflects the light.

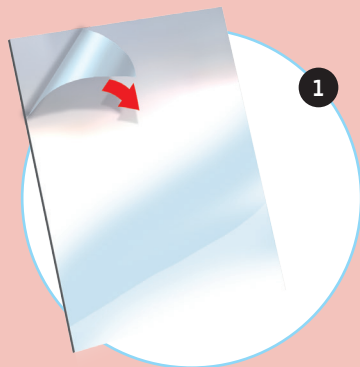
# Rainbow colors

## YOU WILL NEED

- mirror
- flashlight
- sheet of white paper
- soup bowl filled with water

## HERE'S HOW

1. Pull the protective film off the mirror.
2. With one hand, shine the flashlight on the mirror and water from above. Try to “catch” the reflected rays of light with the sheet of paper.



## → WHAT'S HAPPENING?

If you succeed in finding the right position for the flashlight and sheet of paper, you will suddenly see rainbow colors on the paper. White light is actually composed of all the colors of the rainbow, from violet to deep red. So in this experiment, what you did was separate the light into its individual colors.

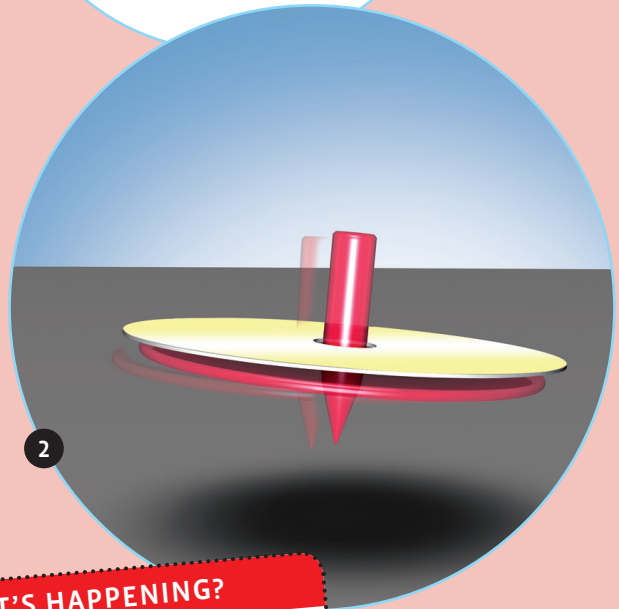
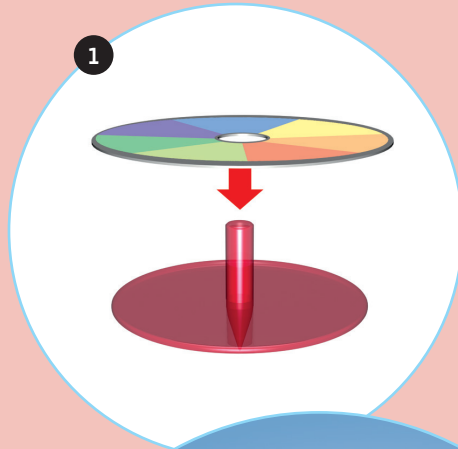
## Getting colors from white

### YOU WILL NEED

- disk from die-cut sheet 2
- top

### HERE'S HOW

1. Stick the disk onto the top.
2. Give the top a powerful twirl, and watch what happens to the colors.  
*What do you notice?*



### → WHAT'S HAPPENING?

If the top rotates quickly and evenly, the surface of the top takes on a uniformly light color, almost white. The colors on the top are more or less the same ones you find in a rainbow. When you mix them, they become white.



# The world in bright colors



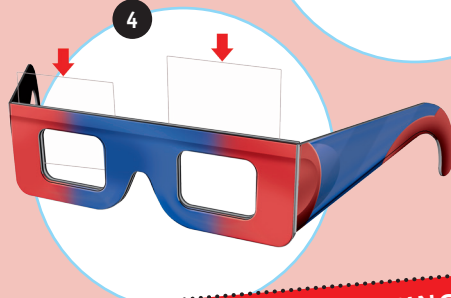
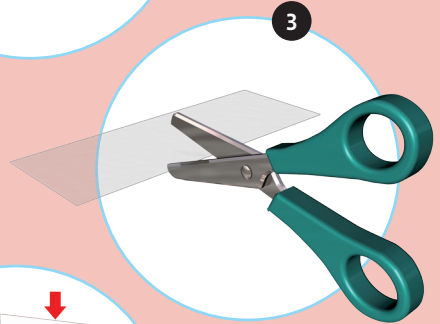
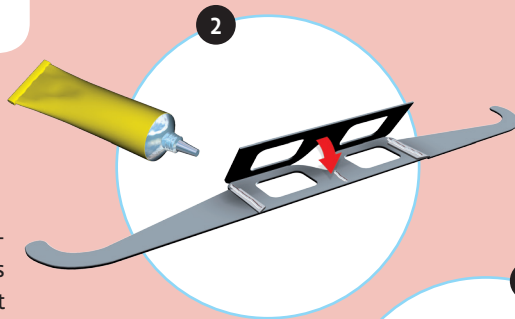
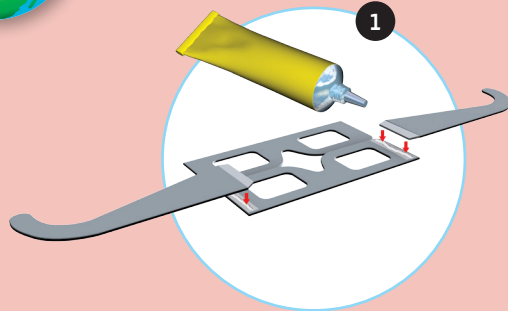
## YOU WILL NEED

- rainbow film
- glasses parts from die-cut sheet 1
- glue, scissors, paper clips

## HERE'S HOW

1. Remove the parts of the “multi-purpose glasses” (you will be using the glasses for other experiments as well) from the die-cut sheet and glue on the side arms.
2. Now, apply glue to the locations indicated in the illustration. Fold over the center section of the glasses. Ideally, clamp the glued locations with some paper clips, to make sure the glue holds well. Let the glue dry completely.
3. Carefully cut the piece of rainbow film down the center.
4. Insert the rainbow film “lenses.”

What do you see when you look through your rainbow glasses?



### → WHAT'S HAPPENING?

Now everything looks nice and colorful. The special film in your rainbow glasses separates the light into its component colors.

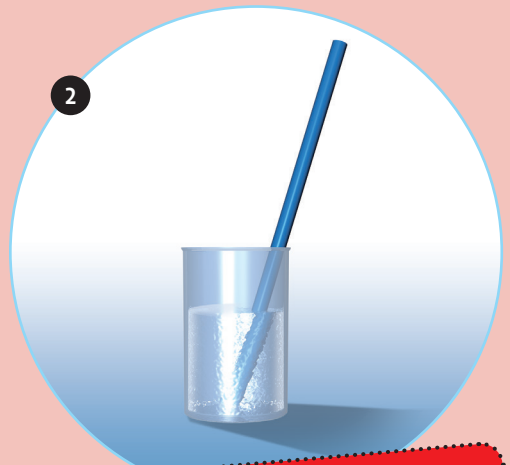
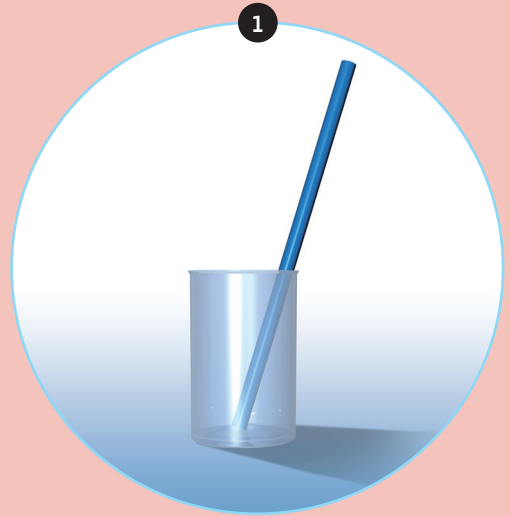
# A kink in your eye?

## YOU WILL NEED

- tube
- cup
- water

## HERE'S HOW

1. Set the tube in the cup and observe it from the side.
2. Now fill the cup with water.  
*What happens to the tube?*



### → WHAT'S HAPPENING?

The tube looks like it has a bend in the spot where it emerges from the water.

# Captured light

## YOU WILL NEED

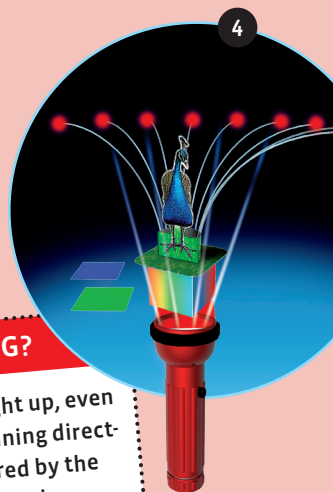
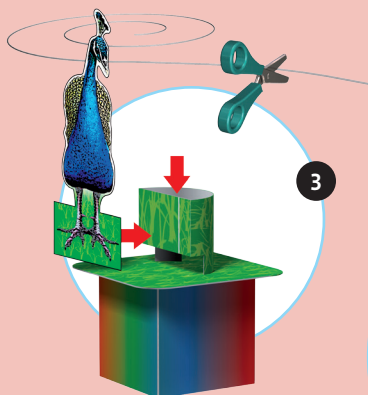
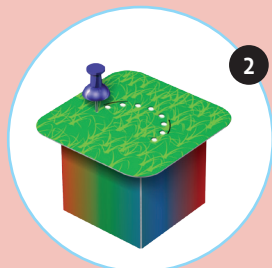
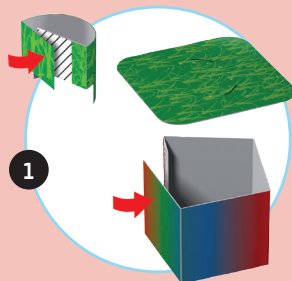
- “peacock parts” from die-cut sheets 1 and 2
- optical fiber
- colored films
- pushpin
- *scissors, glue*
- *flashlight*



## HERE'S HOW

1. Fold and glue the peacock base together. Glue the cardboard strip into a semicircle.
2. Use the pushpin to poke holes through the white dots of the “grass plateau.”
3. Insert the semicircle’s cardboard feet into the pre-cut slits of the plateau, and glue on the peacock. Cut 9 sections of optical fiber, each one about 15 cm length.
4. Carefully insert the optical fiber sections into the holes of the plateau. Now illuminate the base from below with the flashlight.

Hold various colors of film in front of the flashlight.



## → WHAT'S HAPPENING?

The peacock's tail feathers light up, even though the flashlight isn't shining directly on them! The light is captured by optical fibers and carried upward — even if the fiber is curved. When you change the color of the film, the color of the light in the tail feathers changes too.

**KEYWORD: OPTICS →**

The word optic comes from Greek, and more or less means “the study of visible things.” But since this branch of physics deals primarily with the propagation of light, it is also known as the “study of light.”

**FAR-AWAY LIGHT SOURCES IN SPACE →**

The light passing through empty space is invisible. That’s why it looks dark at night. All we see is the distant sources of light – the moon and stars. Rays of light travel at a very specific speed: in empty space, it’s exactly 299,792.458 km per second. So if you were to shine a powerful flashlight at the moon, it would be about 1.3 seconds before anybody there could see your light.

**Note:**

Rays of light radiating out from a light source always take the shortest route. Light always travels in a straight line.

# Optical fibers

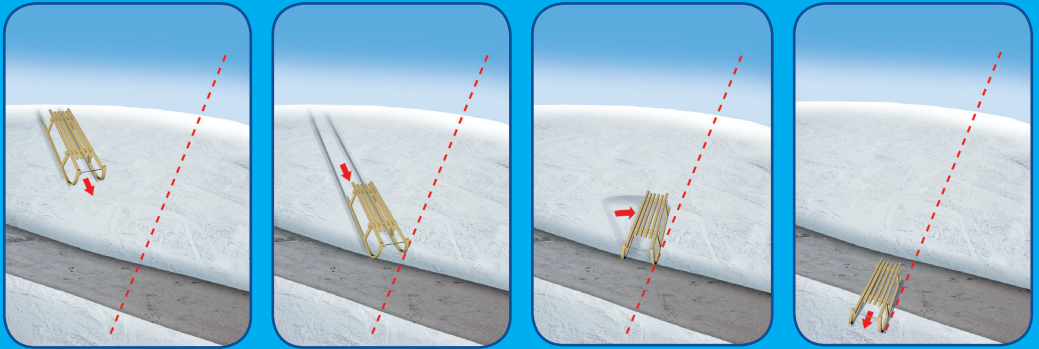
Optical fibers, such as the ones you used for the peacock’s tail feathers in Experiment 6, “capture” the light and carry it along.

You can see quite clearly how practically the only point where the light leaves the optical fibers is at their ends.



# KEYWORD: REFRACTION

→ The apparent bend in a tube standing in a water glass comes from the fact that the rays of light have to penetrate two different materials – air and water. In water, which has greater density, light can't move as fast as in the less-dense air. The light ray is diverted by the change in speed – it changes direction. But why?



→ Imagine that you're sledding down a hill in winter. Suddenly, you hit a sandy path at an angle. Here, the sled travels slower than on the snow. As the right runner reaches the path, but before the left runner has reached it, the sled starts to turn. The same thing happens with rays of light in water.

Taking photos is easy. Just press the button on a digital camera and the picture is ready and instantly viewable. Any questions? Sure. How do we see images in the first place? You might think it's a silly question — because we have eyes. But how do our eyes work? You can actually understand it pretty well by comparing your eyes to a camera. First, though, you have to understand how a camera “sees” images.

# Eye and Camera: How We See Images



## EXPERIMENT 7

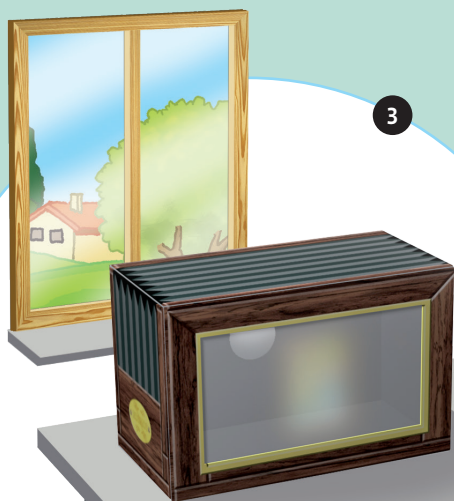
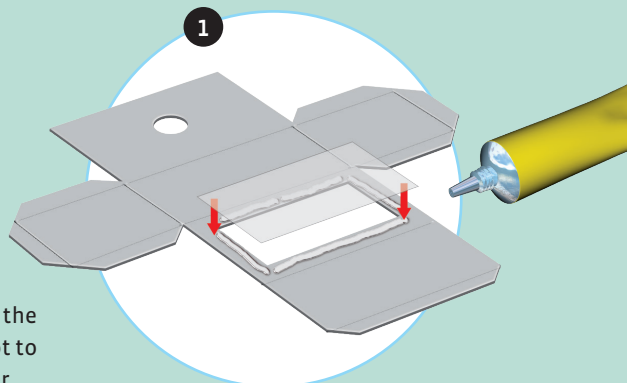
## YOU WILL NEED

- pinhole camera from die-cut sheet 1
- tracing paper
- glue

## HERE'S HOW

1. First, glue the tracing paper behind the opening in the screen. Be careful not to get any glue on the part of the paper viewable through the opening.
2. Fold over all the folding sections, apply glue to the gluing surfaces, and assemble the camera box. Let everything dry well.
3. Now point the pinhole camera toward a window so the tracing paper, or screen, is on your side and the little hole is aimed at the window.

Can you see anything on the screen?



### → WHAT'S HAPPENING?

In the best-case scenario, you might see the dim outline of the window, or maybe of a building in the distance. It's not a very convincing demonstration, though. We will still have to work at it.

## Sharper please!

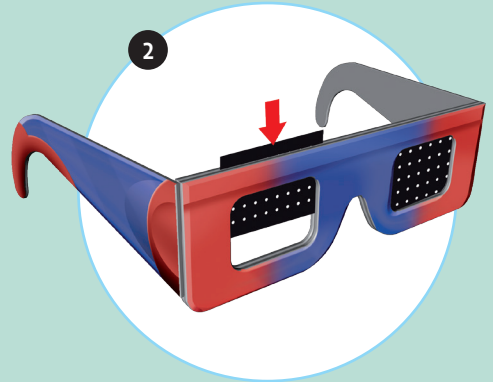
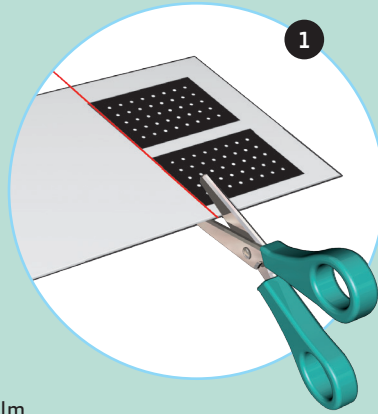
### YOU WILL NEED

- “multi-purpose glasses”  
from Experiment 4
- film with pinhole pattern
- *scissors*

### HERE'S HOW

1. Carefully cut out the rectangles of film with the pinhole patterns.
2. In your multi-function glasses, replace the rainbow film with the pinhole-pattern film.
3. Now take this instruction manual and move your head so close to it that the letters get too blurry for you to read the writing. Then put on your “pinhole glasses.”

What happens to the blurry letters?



### → WHAT'S HAPPENING?

With the pinhole glasses, you will be able to read writing that is so close that it would just look blurry to the naked eye. So we can see things more sharply through very small openings. This is a discovery that we can use to our advantage in the pinhole camera.



## Camera with aperture

### YOU WILL NEED

- lens apertures from die-cut sheet 1
- pinhole camera from Experiment 7
- large hand towel

### HERE'S HOW

1. Hold the aperture with the larger hole over the opening at the front of the camera, and point the camera at a window. It is crucial that it be brighter outside than inside the room! If necessary, drape a large hand towel over your head, as photographers used to do in the old days.
2. Now try the same thing with the aperture with the smaller hole.  
*Do you notice a difference?*

### → WHAT'S HAPPENING?

Now you can see objects more sharply, especially if they are far away – although they will also appear darker.

With the aperture, the image becomes darker because less light gets through the smaller opening. At the same time, the image is sharper, just like with your pinhole glasses in Experiment 8. And another thing you'll notice – everything is turned upside down.



# The light collector

## YOU WILL NEED

- lens
- *energy-saving bulb*
- *sheet of white paper*
- *non-permanent marker*
- *desk lamp*

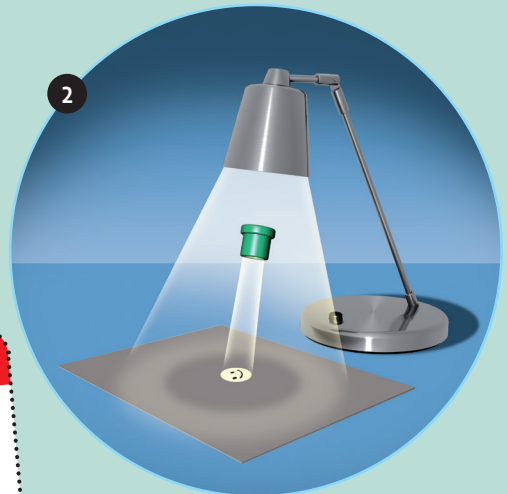
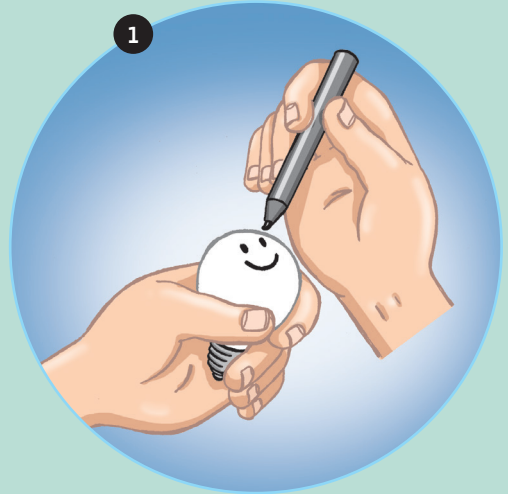
## HERE'S HOW

1. Draw a smiley face on the cold light bulb and have an adult screw the light bulb into a desk lamp.
2. Pull the curtains closed and shine the desk lamp on your sheet of paper. Use the lens to try to produce a sharp image on the paper. To do that, you will have to position it at the exact right distance between the lamp and the paper.

Never touch the hot light bulb when it is turned on — you will burn your fingers!

### → WHAT'S HAPPENING?

There is just one specific location where the lens will produce a really sharp image of the smiley face painted on the bulb. The lens gathers the scattered incoming light and collects it right on the "image surface" — in this case, on the sheet of paper. That's why it's sometimes called a collector lens.



## Full view with lens

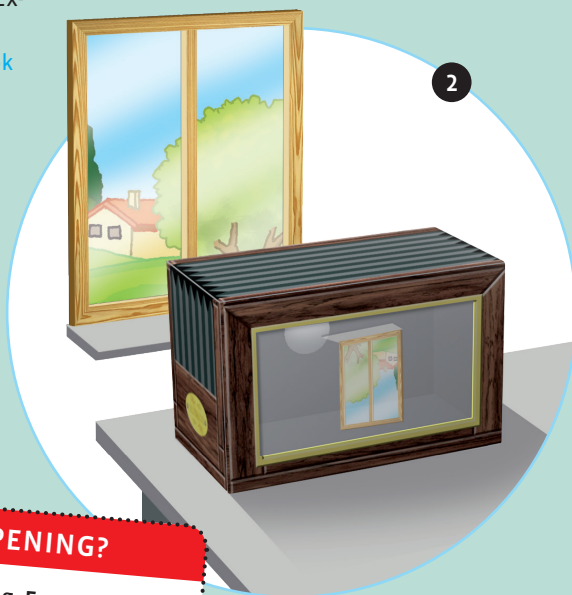
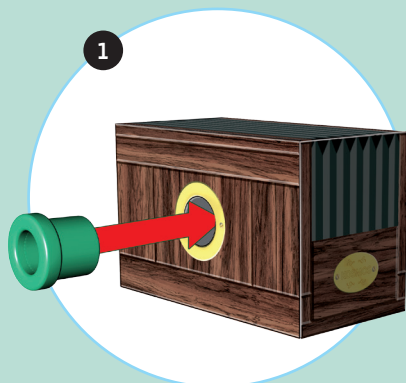
### YOU WILL NEED

- pinhole camera
- lens

### HERE'S HOW

1. Carefully insert the lens into the pinhole camera opening.
2. Now hold the camera with its lens so it's pointed at the window, as in Experiment 7.

Does the image on the screen look any different now?



### → WHAT'S HAPPENING?

The effect is astonishing. Even without an aperture, the images are sharp now, as well as a lot brighter. Here, too, the lens has collected the light. But as soon as you remove the lens from the camera, the image becomes blurry again.

# Wandering sharpness

## YOU WILL NEED

- wooden beads
- cord

## HERE'S HOW

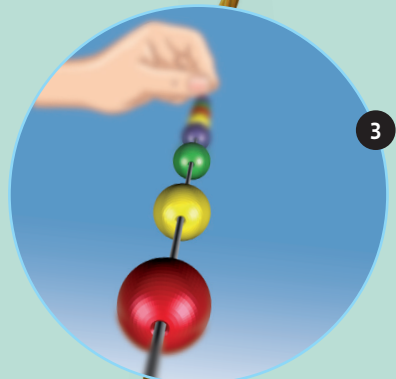
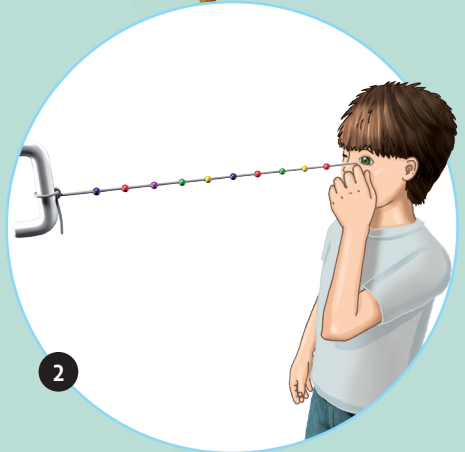
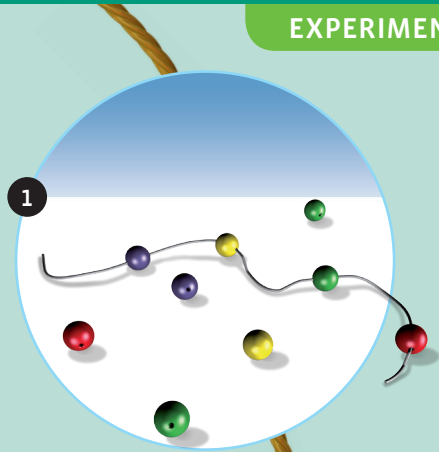
1. String the beads onto the cord. Make sure that the beads are all spaced more or less evenly along the cord.
2. Tie the end of the cord to something solid. Squint one eye and look along the string of beads with the other as you pull the cord taut and hold it right in front of your eye, as shown in the illustration.

*How many of the beads can you see sharply at one time?*

3. Now squint both eyes.  
*What changes?*

### → WHAT'S HAPPENING?

When you look at, say, the second bead with your eyes wide open, the first, fourth, and fifth beads will look blurry. If you squint your eyes, you will get “sharper” beads — squinting your eyes works like having an extra aperture in front of your eyes.



## The blind spot

### YOU WILL NEED

→ the illustration below

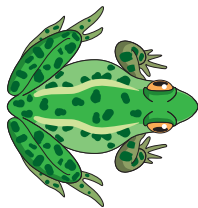
### HERE'S HOW

Hold the illustration in your right hand with your arm stretched out straight, and cover your left eye with your left hand.

Now slowly move the drawing towards you, keeping your eye on the frog the whole time. Pay attention to what happens to the fly — but be sure to keep watching the frog!

### → WHAT'S HAPPENING?

Most of the time, you will be able to see the fly off to the side. But suddenly, when the illustration is about 30-40 cm away, the fly disappears. So there seems to be a spot in your eye where you can't see anything. That's why this spot is called the "blind spot." Usually we don't notice it at all — the brain outsmarts our eyes and tricks us into thinking we see things everywhere across our entire visual field.



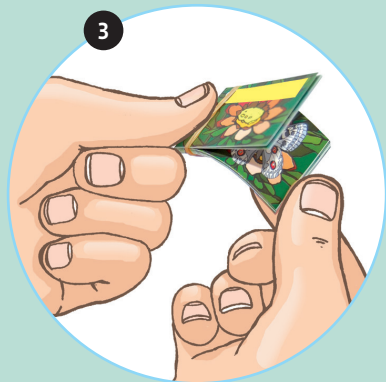
# Time-delayed vision: the flip book

## YOU WILL NEED

- “flip book” paper sheet
- rubber band

## HERE'S HOW

1. Cut apart the individual pictures and arrange them in the correct sequence (numbers 1-24).
2. Tie them together securely with the rubber band.
3. Right-handers should take the flip book in their left hand, left-handers in their right. Now quickly flip through all the pages.



## → WHAT'S HAPPENING?

Now, in place of individual pictures, the butterfly looks like it's moving and taking flight. Your flip book works by the same principle underlying everything you see on television, on the computer, or in a movie theater. There are lots of individual images that follow each other so quickly that your eye can't keep up — so instead of individual images, it sees continuous movement.



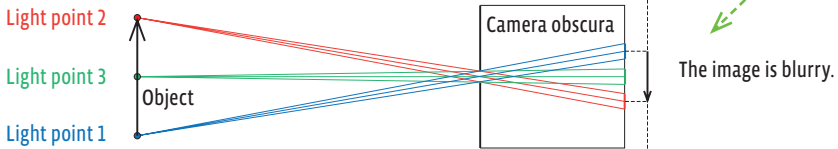
# PINHOLE CAMERA & EYE

## → How the image gets onto the pinhole camera screen

Every point of any object emits rays of light in all directions.

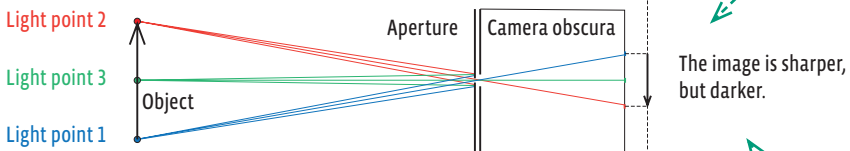
Without an aperture, the image on the screen is bright, because a lot of light finds its way through the hole. However, all the light rays land on all sorts of different spots on the screen — which is why the image is blurry. ↓

### Pinhole camera without aperture



When the aperture is used, a lot fewer light rays find their way through the hole, but they arrive at the screen closer together. That makes the image a lot sharper, but unfortunately darker as well. ↓

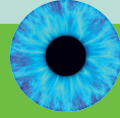
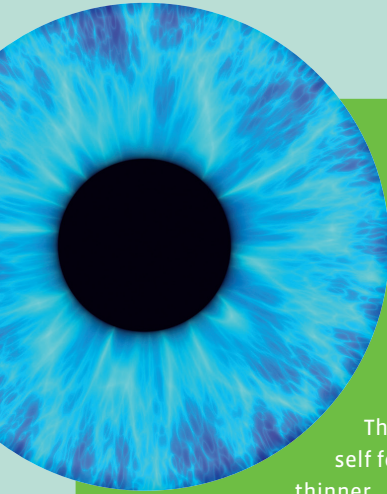
### Pinhole camera with aperture



## → What does the lens do?

With the lens, the image is crystal clear and bright. The lens collects all the scattered incoming light rays and displays them on one point of the screen.

In the two diagrams, you can also see why the image on the screen is turned upside down.



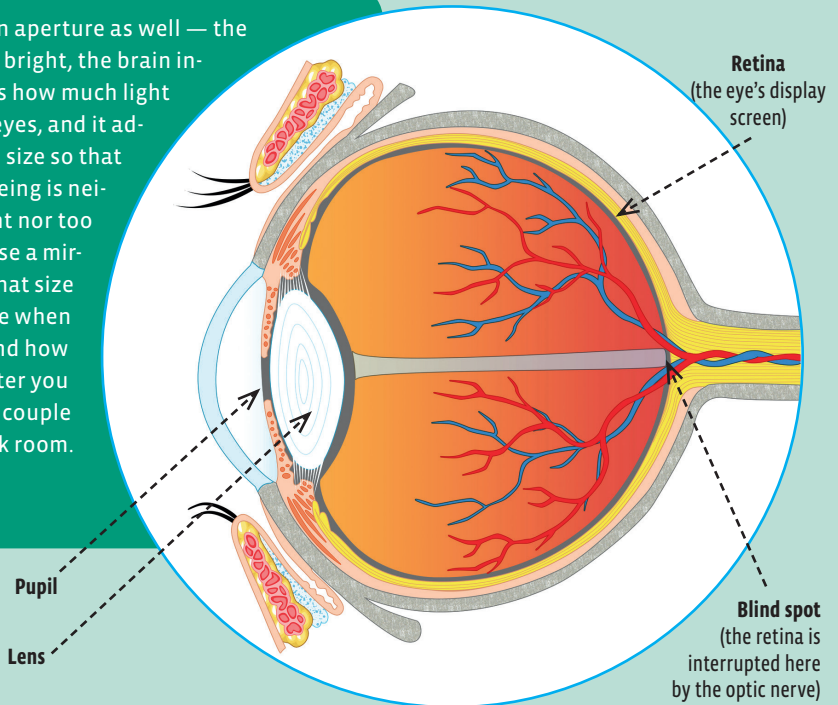
## → Screen and lens in our eye

Our eye also has a collector lens. In our eye, the image is projected upside down and mirror-reversed onto its display screen, or retina. Luckily, we don't notice that at all, because the upside-down image is automatically "corrected" by our brain.

The lens is located at the front of the eye, and can adjust itself for near or distance vision by making itself thicker or thinner.

## → The pupil: the eye's aperture

The eye has an aperture as well — the pupil. When it's bright, the brain instantly registers how much light is striking the eyes, and it adjusts the pupil size so that what you're seeing is neither too bright nor too dark. You can use a mirror to see what size your pupils are when it's bright and how large they get after you have spent a couple minutes in a dark room.





# Seeing Colors

Red is red and green is green, right? Not always! Anyone who has walked in the woods at night knows that sometimes you may see gray, black, or white, but no colors. Only when the sun comes up or you turn on a strong light do the colors appear. On top of that, even when we are able to see colors, we can only see three of them. How does that work? See for yourself!

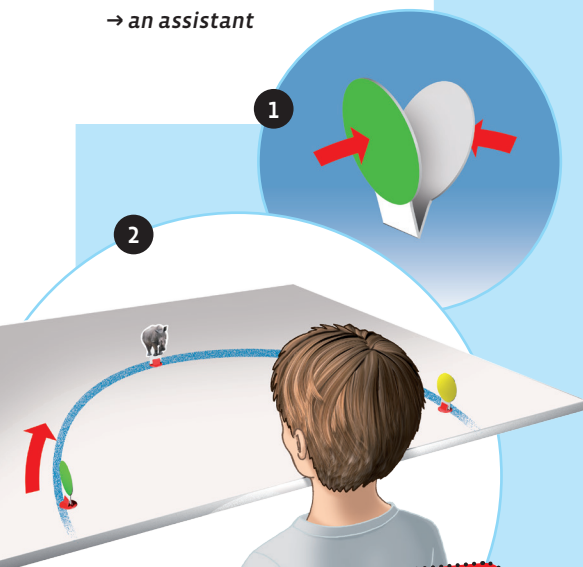
# Invisible colors

## YOU WILL NEED

- colored disks and “rhino” cardboard figure from die-cut sheet 1
- chalk, three mounting feet
- *glue, kitchen table (washable)*
- *an assistant*

## HERE'S HOW

1. Fold over the colored disks and set them on the mounting feet.
2. Mount the rhino on another mounting foot and place it on the table about 50 cm away from the table's edge. Now draw a semicircle on the table with the chalk. Place the colored disks near the ends of the semicircle arch. Position your head at the front with your chin resting on the edge of the table.



## → WHAT'S HAPPENING?

You can quickly see that something is moving on the table. You will only be able to recognize its color, however, after the disk has been moved farther toward the center. That's because the color vision “detectors” are not evenly distributed across your eye. There are a lot fewer of them along the edge of your field of vision than toward the center. That is why you only see shapes at the edge of your visual field. The point at which colors become visible is different for everyone.

Have your assistant take one of the colored disks and push it slowly along the semicircle arch from the edge of the table toward the center. Meanwhile, just focus on the rhino the entire time, but pay attention to when you can start to see the disk at the edge of your field of vision. Your assistant should mark this point on the semicircle with the chalk. Can you recognize the color? If not, have your assistant keep moving the disk. Say “Stop!” as soon as you see the color. Your assistant should mark this spot as well.

Now do the same thing from the other side, and then try the other colored disk, and then switch roles with your assistant.

## Ghost writing from nowhere

### YOU WILL NEED

→ the illustration on the right

### HERE'S HOW

1. Look at the letters to the right for about 15 seconds, focusing on the black dot in the center.
2. Then look at the black dot in the empty space beneath.

What do you see?

Red

### → WHAT'S HAPPENING?

The word "red" appears as if written by the hand of a ghost — but now it really is red.

.

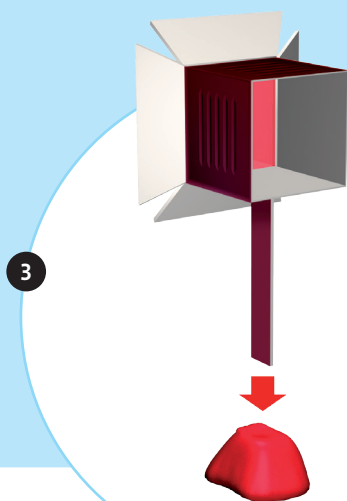
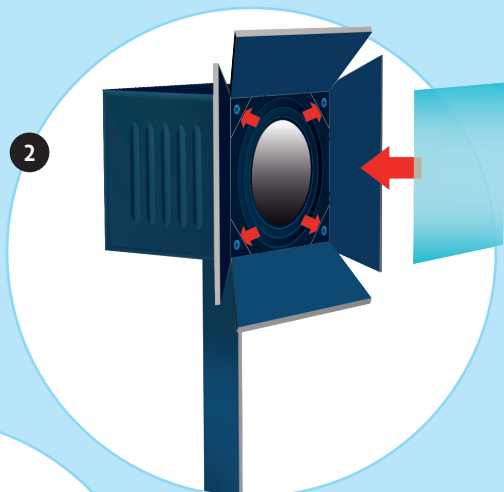
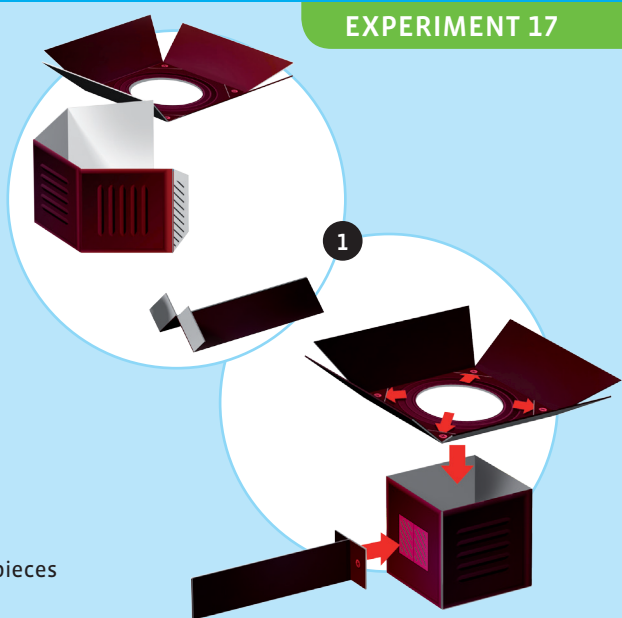
## Mixing colors

### YOU WILL NEED

- “spotlight parts” from die-cut sheet 1
- colored film, modeling clay
- pencil, 3 small flashlights, sheet of white paper, ruler, compass
- at least one assistant

### HERE'S HOW

1. Assemble the individual spotlight pieces as shown in the illustration.
2. When everything is good and dry, mount the colored film sections by inserting them into the slots at the four corners of each spotlight.
3. Now make three “feet” out of clay and mount the spotlights on them.

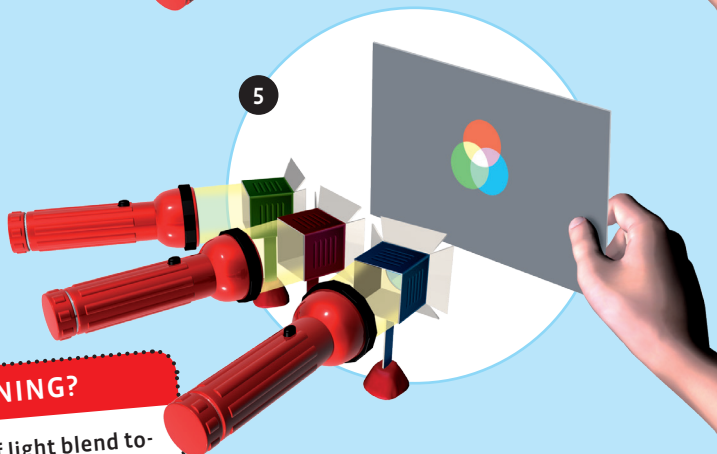
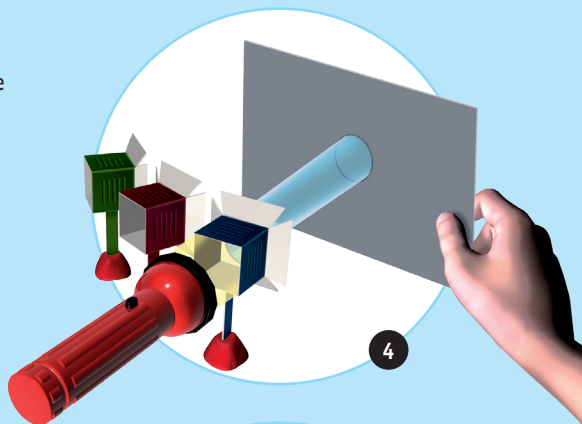


## EXPERIMENT 17

## HERE'S HOW IT CONTINUES

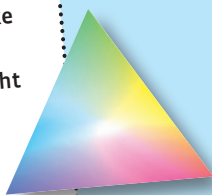
4. Draw a circle with a diameter of about 7 cm on the sheet of white paper. Hold it in front of the spotlights like a screen. Now each person should take his or her flashlight and shine it through one of the three spotlights, so the cone of light hits the circle as closely as possible.
5. Now watch what happens when you shine light through two or all three spotlights at the same time.

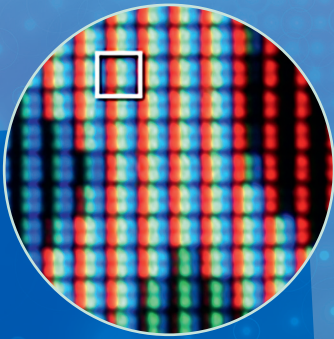
What happens when you vary the light intensity by holding the flashlights a little farther away or by switching off one of the flashlights?



### → WHAT'S HAPPENING?

The colors of the cones of light blend together to produce other colors: red and green make yellow, red and blue make purple, blue and green make bluish that you shine through the spotlights, you can get further color variations. And all three on full power produce: white!





## Monitor screen colors

→ On your computer screen, all the different colors are made by mixing the three basic colors red, green, and blue. Study a white section of your screen image with the magnifying glass. Through the magnifying glass, you can see small dots of red, green, and blue. Without the magnifying glass, however, the eye can't separate the colors, and only perceives them as mixed — which is why this part of the screen looks white.

## CHECK IT OUT



## The “color detectors” in your eye

→ We have three different “detectors” for color in our eye. One type is best at recognizing red, another type recognizes green, and another type is best at recognizing blue. How is it, then, that we can see so many different colors and color gradations? We saw in Experiment 17 how all the different colors can be produced from just three basic colors.

That's exactly what our eye does too. Our brain creates the colors we see by calculating how strongly the three different types of “detector” are stimulated.

Since these “detectors” require a certain amount of light in order to become “activated,” though, we cannot perceive any colors at night.



All colors together produce white

## THE COLORS OF THINGS

→ But why do we perceive the grass as green, the sky as blue, and a rose as red? You will recall that white light is actually composed of many colors. When this light arrives, for example, at a green tree, most of the light-colors are “swallowed up” by the leaves, and only the green rays are reflected back. The color of the rays that are reflected is the color of the object — in this case, green.

# Seeing in 3D

Have you ever wondered why you have two eyes? If you shut one, you will quickly notice that something is amiss. Now try walking down the stairs (but hold on tight to the handrail!). A little unsteady, aren't you? In this chapter, you will learn why it is that two eyes are better than one.

## Target practice



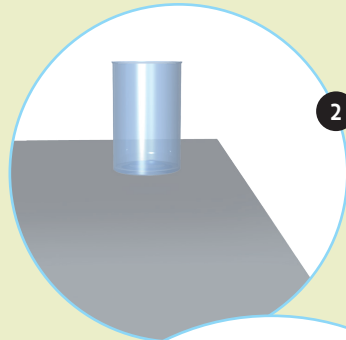
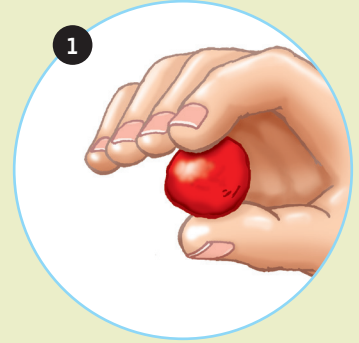
### YOU WILL NEED

- clay
- cup
- table
- an assistant

### HERE'S HOW

1. Make a small ball of clay, about the size of a marble.
2. Place the cup on the table. Hand the ball of clay to your assistant.
3. Stand about 4 or 5 meters away from the table and cover one eye with your hand. Now you'll have to give directions: Tell your assistant exactly where to move his or her hand in order to drop the clay ball into the cup.

How often does the ball make it into the cup? And how often does it work when you keep both eyes open?



### → WHAT'S HAPPENING?

If you hold one eye shut, it's a lot harder to tell exactly when the marble is above the cup. Left and right are no problem — it's forward and backward that are difficult. We can only come up with accurate distance estimates when we use both eyes.



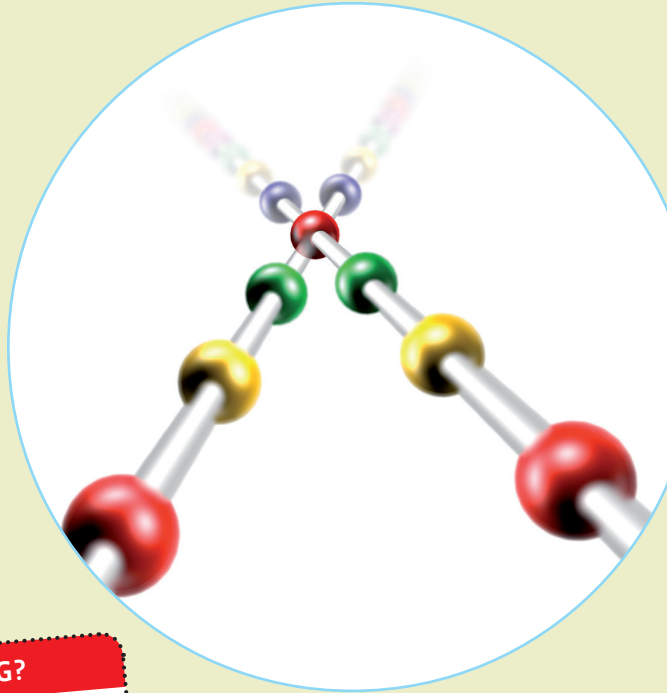
## X or Y?

### YOU WILL NEED

→ string of beads from  
Experiment 12

### HERE'S HOW

1. Hold the string of beads right in front of your nose — in other words, right between your eyes — and look along it.
2. Shut your left and then your right eye, one after the other.
3. Open both eyes and try to focus on one of the beads close to you, and then on one in the middle distance.



### → WHAT'S HAPPENING?

When you close each of your eyes in turn, the different viewing angles make it look as if the front end of the string were jumping back and forth. If you look at one of the close-up beads with both eyes, the far end of the string will look like a Y, while if you focus on a bead in the middle, you will see an X. Your brain composes an overall impression from the images conveyed to it from the eyes, and it's that overall impression that lets us see in 3D. In the process, though, several other strange things happen as well.

## EXPERIMENT 20

## A hole in your hand

### YOU WILL NEED

→ sheet of letter-sized paper

### HERE'S HOW

1. Roll the sheet of paper into a tube.
2. Hold the tube in front of your left eye and carefully guide the palm of your right hand toward the tube from the right.



### → WHAT'S HAPPENING?

What? Your hand has a hole in the middle! This illusion is easily explained. Eye number one looks off into the distance, while eye number two looks at your hand. Your brain has a hard time combining the two things in a way that makes sense. Result: You look off into the distance through your hand!

## EXPERIMENT 21

## Look out! A giant fish!

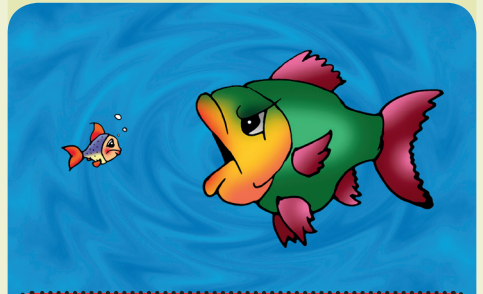
### YOU WILL NEED

→ the picture with the two fish from die-cut sheet 1

### HERE'S HOW

1. Look at the picture from a little distance away. First focus your eyes on the little fish.
2. Then move the sheet closer toward your eyes, but without changing your focus. You will be looking “through” the sheet and focusing on the point where the fish used to be.

Where does the little fish swim to?



### → WHAT'S HAPPENING?

When you move the sheet closer, your left eye stays on the little fish while your right eye moves to the big one. Because the brain cannot process two separate images in parallel, it blends both of them together. So if you're not careful, the little fish will get swallowed up!

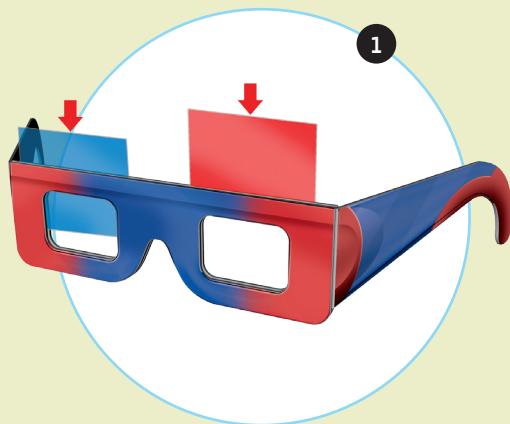
# Pictures pop with 3D glasses

## YOU WILL NEED

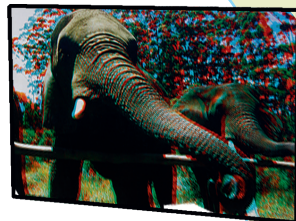
- “multi-purpose” glasses
- red and blue colored film
- 3D poster

## HERE'S HOW

1. Insert the red and blue pieces of film into the left and right sections of your glasses.
2. Hang up the poster and look at it through your 3D glasses. Close each eye in turn. Move your head back and forth.



2



## → WHAT'S HAPPENING?

Wow, it really looks like the elephant's trunk is coming out at you! If you move your head back and forth, the trunk moves as well. The elephant poster contains two almost-identical different-colored pictures — they are only a little different because they were taken from two slightly different perspectives, matching the distance between your two eyes. Thanks to the colored film, you see only the red image with one eye and the blue image with the other. When you combine both images in your brain, you see a single image in three dimensions (3D).



# Cubes projecting into the room

## YOU WILL NEED

→ the picture below

## HERE'S HOW

1. Sit down, relax, and hold the picture about 40 cm away from you.
2. Now try looking "through the picture" into the distance. You will probably have to practice a little.  
**What happens?**
3. Point at one of the cubes with your finger.

### → WHAT'S HAPPENING?

The cubes suddenly look three-dimensional, because your eyes overlap adjacent cubes as you look off into the distance. Your brain uses that to create a three-dimensional effect. For this to work, the overlapping objects have to look almost identical. The image might be a little shaky. And when you stick your finger into it, the magic instantly disappears. But if you succeed in holding onto the 3D image, you will see two fingers.





# Depth Perception

We need two eyes in order to orient ourselves properly in space. Our two eyes send two slightly different images of the same object to our brain, because each one is focusing on it from a slightly different perspective. In a flash, the brain uses the two images to calculate the exact shape and location of the object.

All of that works well enough, but only if we use our eyes in a normal way. When, on the other hand, we deliberately set our eyes to “distance vision” as we look at an object up close, the images that our two eyes convey to our brain don’t fit together properly. And that’s when you can start seeing nonsense, such as the hole in your hand in Experiment 20.



**Note:**

You can't always trust your eyes!





## YOUR BRAIN “SEES” TOO

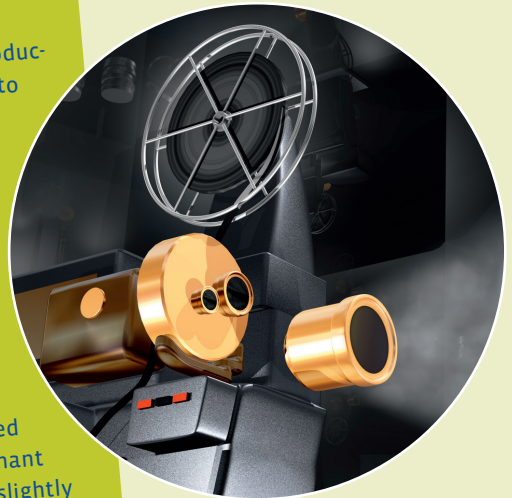
But why is it that we experience TV and movie images as having depth, even though we’re only seeing a single image on a flat, two-dimensional screen? And why is it that we usually still know what’s in front and what’s in back if we close one eye — even if it’s not quite as precise as with two eyes? The explanation lies in the fact that our brain also calculates the locations of objects based on experience. It “knows,” for example, that ob-

jects look smaller as they get farther away, and that parallel lines (such as railway tracks) converge in the distance. All of that is factored in during the perception process.

## 3D MOVIES

The first 3D movies were made in the 50s. Film producers thought they could use this new technology to entice larger audiences into theaters, since 3D movies couldn’t be shown on black-and-white TV.

In recent years, 3D technology has been developed quite a bit further. To show these modern 3D movies, theaters need special equipment. But the 3D experience has become more and more popular, so there are a lot of theaters where you can see these movies. They are filmed with the use of two lenses placed a certain distance apart — just as the two elephant images in Experiment 22 were taken from two slightly different perspectives.





# Optical Illusions

Now things are going to get a little crazy. Colors from black-and-white patterns, fixed circles that start to rotate on the page, wrong sizes and straight rooms that look crooked. Everything is relative, and the things we see with our own eyes aren't necessarily true!

# Ghostly rotating circles

## YOU WILL NEED

→ the picture below

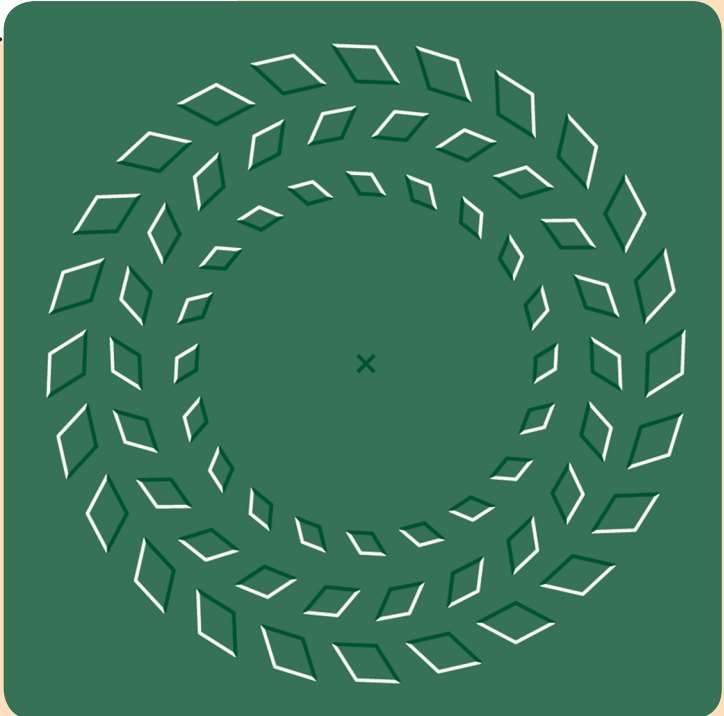
## → WHAT'S HAPPENING?

When you move closer, the circles start to rotate in opposite directions. If you move the picture away from your face again, you will see the carousel rotate in reverse.

## HERE'S HOW

1. Place the manual on the floor and look at the circle in the center.
2. Now slowly move your face closer to the picture. Keep your eyes on the center circle. Then stand back up again.

What do you see?





## EXPERIMENT 25

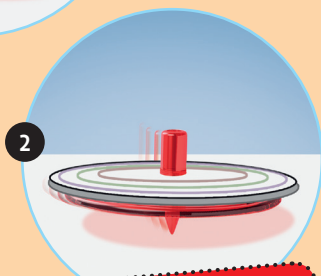
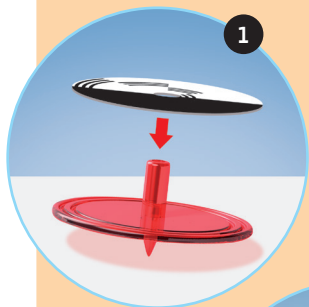
## Color illusions

## YOU WILL NEED

→ black-and-white disk from die-cut sheet 2, top

## HERE'S HOW

1. Remove the disk from the die-cut sheet and place it on the top.
2. Spin the top as quickly and smoothly as you can and watch it from above until it starts to wobble.



## → WHAT'S HAPPENING?

If the top spins quickly, at first you will just see equally light gray rings. But then different-colored rings will start appearing, which will become more and more obvious as the rotation speed drops.

## EXPERIMENT 26

## What's growing there?

## YOU WILL NEED

→ black-and-white disk from die-cut sheet 2, top

## HERE'S HOW

1. Spin the top as fast as possible in a clockwise direction, and closely watch the rotating disk — the longer the better.
2. Before the top starts to wobble, look quickly at the back of your hand.



## → WHAT'S HAPPENING?

It looks like something is growing out of the back of your hand! Fortunately, it's just an optical illusion. Your brain can't return to a stopped position so quickly, so you end up seeing something that's the opposite of the top's whirlpool effect.

## EXPERIMENT 27

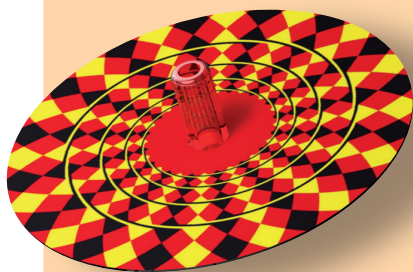
## No beginning and no end

### YOU WILL NEED

- colored disk from die-cut sheet 2
- top

### HERE'S HOW

1. Examine the spiral closely and trace the line with your finger. What's going on here?
2. Now spin the disk on the top.



### → WHAT'S HAPPENING?

It's not actually a spiral, it only looks like one. When your eye follows the black-and-yellow lines, it is guided toward the center because the background pattern seems to disappear into the depths like a funnel and the black-and-white circular lines are all "twisted." When you spin the top, you can see at a glance that they are actually nothing more than separate individual circles.

## EXPERIMENT 28

## Crooked or straight?

### YOU WILL NEED

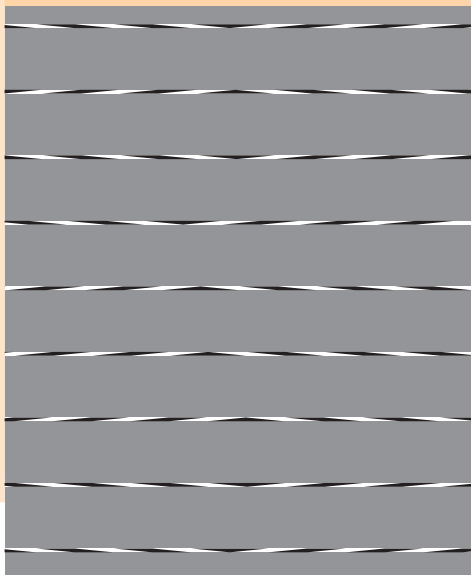
- the picture below
- ruler from die-cut sheet 1

### HERE'S HOW

1. Look at the black-and-white lines.  
*They're slanted and crooked, right?*
2. Check the lines with your ruler!

### → WHAT'S HAPPENING?

This optical illusion also deceives you with its alternating black-and-white pattern. The lines look like they're crooked.



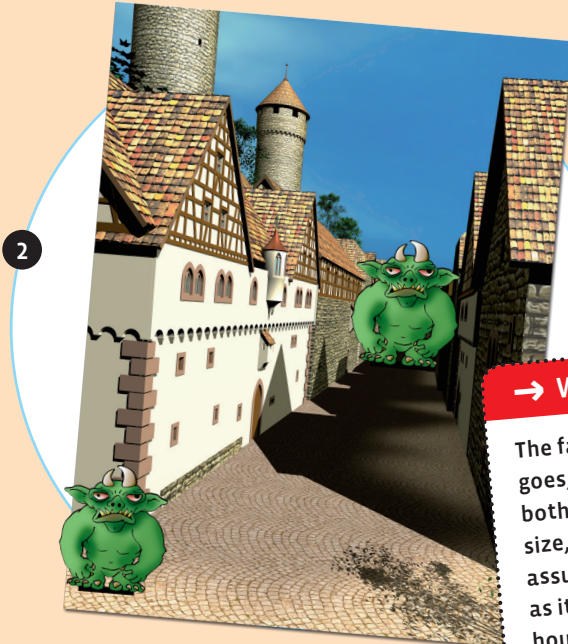
# Dwarves become giants

## YOU WILL NEED

- “monsters” from die-cut sheet 1
- “town” paper sheet

## HERE'S HOW

1. First, put both monsters in the lower left part of the picture — the place where the street begins.
2. Leave one monster there. Move the other one up along the road.



### → WHAT'S HAPPENING?

The farther along the road the monster goes, the larger it appears. Of course, both monsters are actually the same size, no question about that. Our brain assumes that everything looks smaller as it moves away from us — just like the houses in the picture. The monster, though, doesn't get smaller — and ends up looking like a giant.

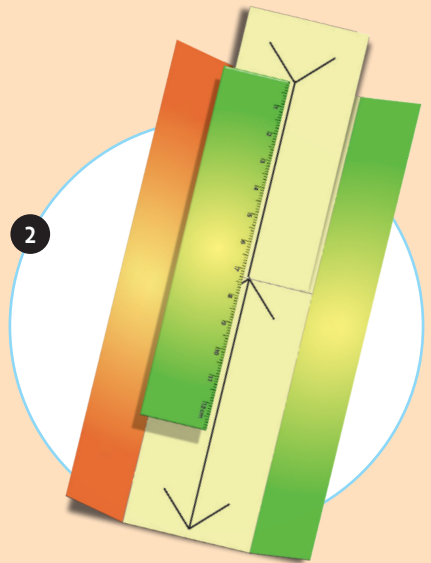
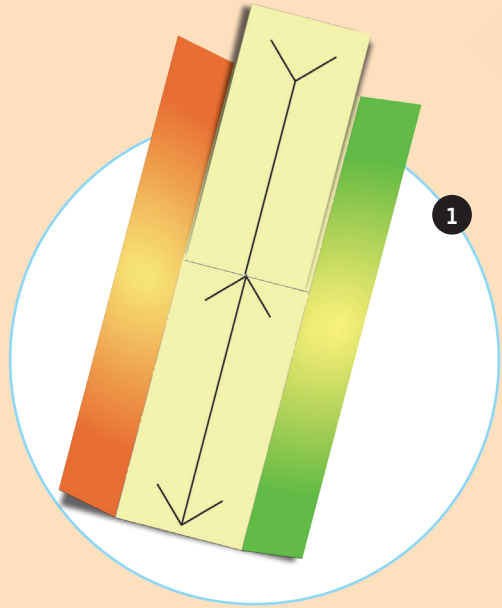
## How's your visual judgment?

### YOU WILL NEED

- ruler from die-cut sheet 1
- slider parts from die-cut sheet 2

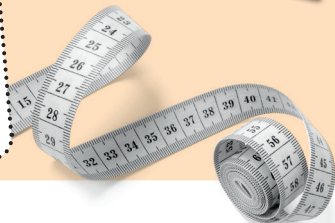
### HERE'S HOW

1. Insert the cardboard strip into the pre-cut opening and adjust the slider so that there appear to be two equally-long lines.
2. Now check the results with the ruler.



### → WHAT'S HAPPENING?

Did you misjudge the length? Don't feel bad — everybody does. The different ends trick us into seeing different perspectives: The arrowheads convey the impression of an edge pointing toward us. The arrow tails make it seem like we're looking into the back corner of a room. We assume that this line is farther away and that it therefore appears smaller than it actually is. That's why we misjudge its length as being greater than it is.



## EXPERIMENT 31

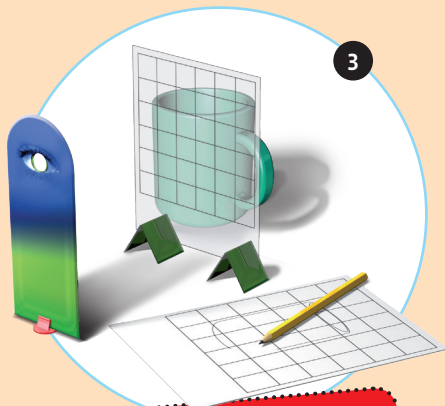
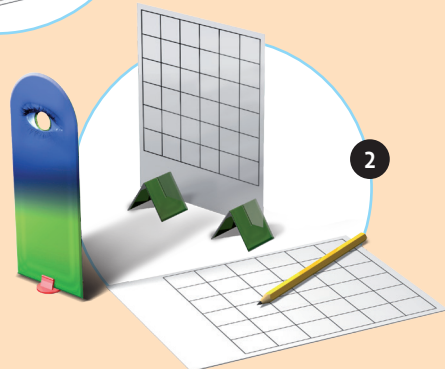
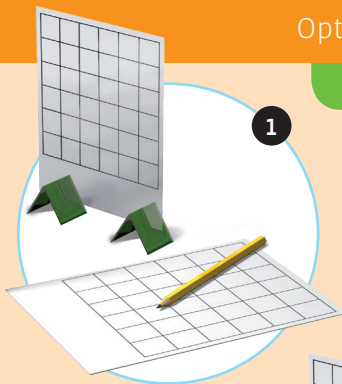
## Drawing in perfect perspective

### YOU WILL NEED

- film
- film holder and viewing panel from die-cut sheet 1
- mounting foot
- *paper, pencil, set square, scissors*

### HERE'S HOW

1. Cut out the film with the grid and mount it with the help of the brackets. Then draw a grid of 6 x 6 squares on the piece of paper. Each square should be exactly 2 cm along its edge.
2. Now set up the viewing panel with the help of the mounting foot, as shown in the illustration.
3. Look for a simple object to draw, such as a mug, and position it behind the film. Then look through the viewing panel hole and draw exactly what you see through the individual squares on the film. Ideally, first look for the corner points and connect them.



### → WHAT'S HAPPENING?

The grid method helps you convert the edge lines you see in 3D into a 2D image – which in turn helps you derive an image drawn in perfect perspective. You can also use this method to make perspective drawings of more challenging subject matter, such as a view onto the street out your window. To do that, tape the film directly onto the windowpane.

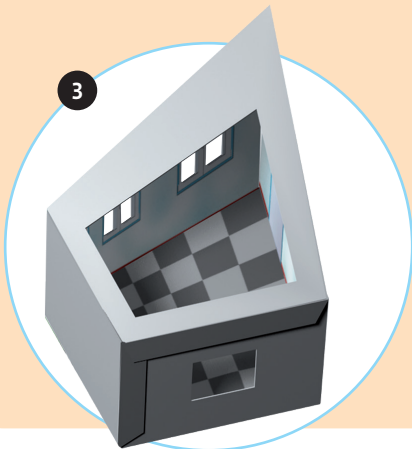
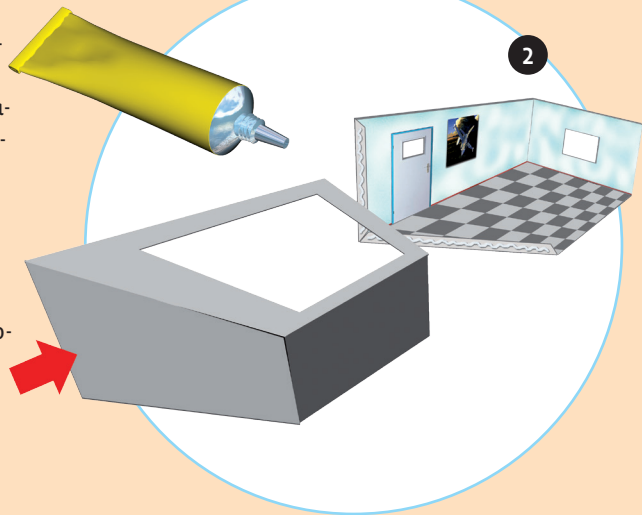
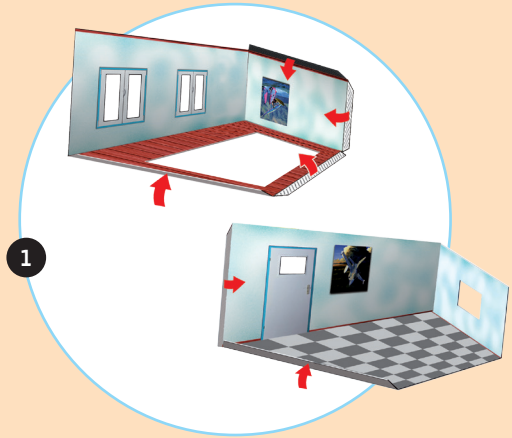
# Slanted but straight!

## YOU WILL NEED

- “Ames room” parts from die-cut sheet 2
- glue

## HERE'S HOW

1. Remove the parts from the die-cut sheet and carefully fold over the shaded gluing flaps.
2. Apply glue to the shaded surfaces and assemble the two room sections as shown in the illustration. All of the illustrated surfaces go on the inside, and the “crooked box” will end up all white on the outside.
3. Look into the room through the opening on the front (the side toward the front in the illustration).



### → WHAT'S HAPPENING?

If you look at the room from the outside, there's no question — it's totally crooked. But when you look into it through the opening, you'll suddenly be seeing a totally normal right-angled room!

## EXPERIMENT 33

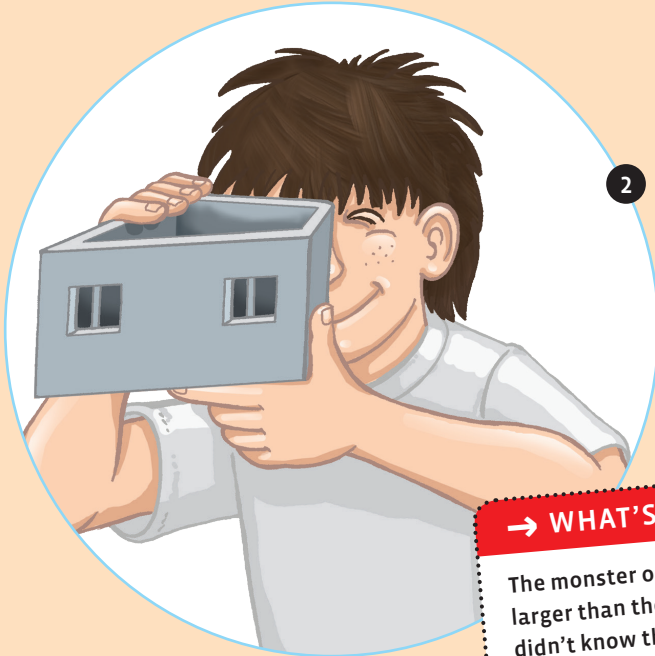
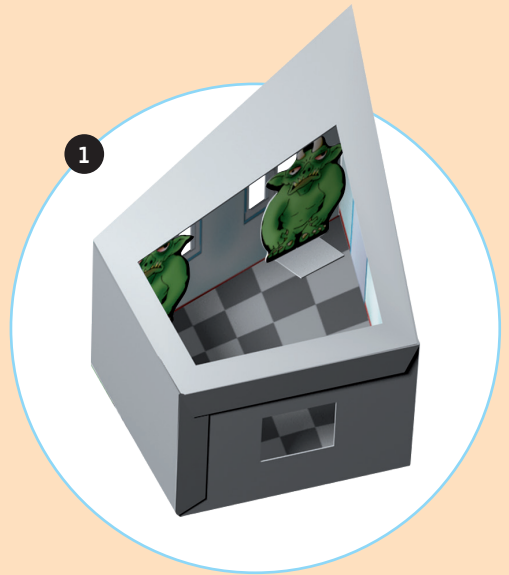
# Big and little monsters

## YOU WILL NEED

- “Ames room” from Experiment 32
- “monsters” from Experiment 29
- glue

## HERE'S HOW

1. Glue one of the monsters into the rear left corner, and the other into the rear right corner.
2. Look through the window into the crooked room again.



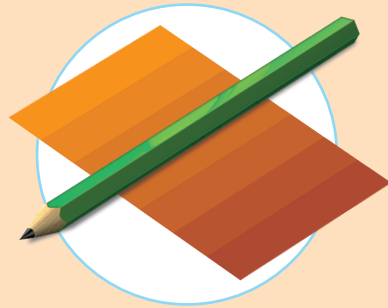
### → WHAT'S HAPPENING?

The monster on the left looks distinctly larger than the one on the right! If you didn't know that the right monster is actually positioned farther away, you would have no doubt that it was smaller.

# The Chevreul illusion

## YOU WILL NEED

- the illustration below
- *pencil*



## HERE'S HOW

1. Sit down, relax, and take a look at the illustration below.

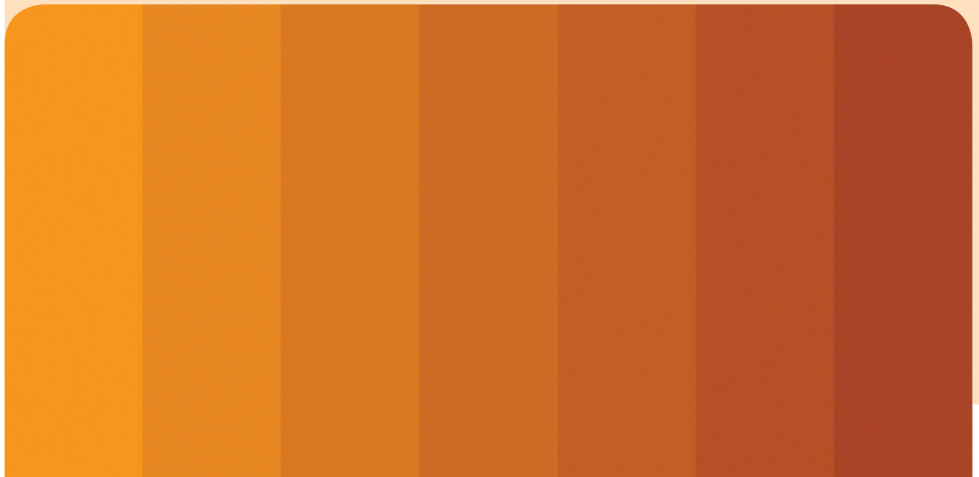
*What strikes you about it?*

2. Now take your pencil and place it along the lines between each of the adjacent strips of color, one after the other.

*What do you see?*

### → WHAT'S HAPPENING?

It first looks like each of the seven reddish-orange columns is colored unevenly, becoming darker as you go from left to right. But if you place the pencil along the border between two colored columns, each of the two strips looks consistently colored. The color that we see, in other words, depends on the color next to it.





## Color is relative

### YOU WILL NEED

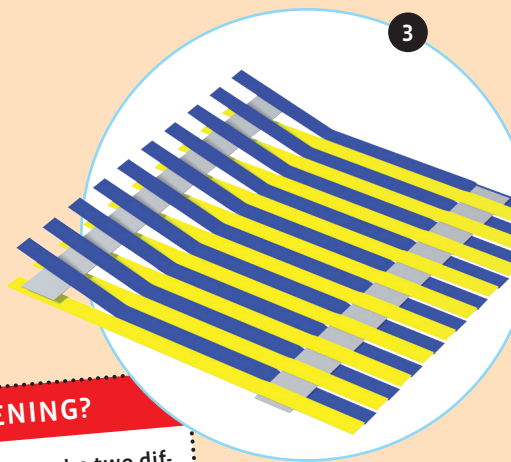
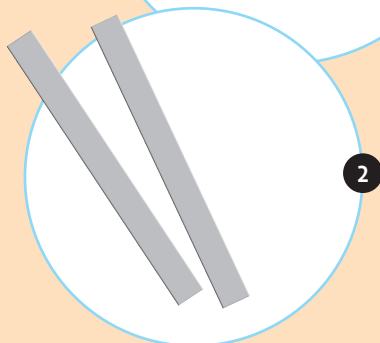
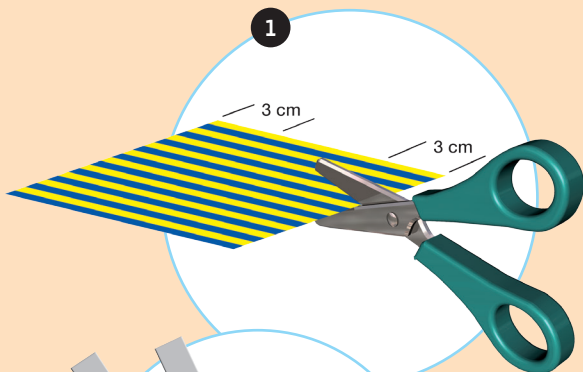
- blue-and-yellow-striped sheet and gray strips from die-cut sheet 1
- *scissors*

### HERE'S HOW

1. Cut 3 cm into the blue-and-yellow-striped sheet from each side, cutting along the boundaries between the colors. Be careful not to cut all the way through into the center of the sheet!
2. Take a careful look at the two gray cardboard strips. They are the same shade of gray.
3. Now weave the gray strips along each edge of the blue-and-yellow sheet, with the yellow bars on top on one side and the blue bars on top on the other.

Take a look at both edges.

How do the gray strips look?



### → WHAT'S HAPPENING?

The gray strips now appear to be two different shades. Once again, what this shows is that our perception of a color is influenced by the color next to it. So everything we see is relative — our eyes are easily deceived.



## PERSPECTIVES

What we actually see only comes into existence after the brain processes the images supplied by the eyes. And what we see doesn't necessarily have to match reality. The eyes always provide us with images in perspective: What is in front appears larger, and what is farther away looks smaller to us. Parallel-running lines, such as railroad tracks, seem to meet in the distance. In the same way, pictures that are drawn according to the rules of perspective will make a three-dimensional impression on us.



## Incorrect colors

The Chevreul illusion from Experiment 34 is named after the French chemist Michel Eugène Chevreul (1786-1889). As director of a tapestry factory in Paris, he was in charge of reviewing customer complaints. Some customers complained that their expensive tapestries were poorly dyed. Chevreul determined that the colors were sometimes perfectly correct, yet still looked "wrong." In this way, he was able to figure out that adjacent fields of color can affect one another's color and brightness.



## → Ames Room ←

The first Ames room was constructed in 1935. When you look into the room, all the wall, ceiling, floor, and window image points lie along perspective lines, just as we used in the perspective drawing in Experiment 31. So on your eye's retina, you get an image that looks like it came from a completely normal right-angled room. When processing what it sees, your brain always opts for the simplest solution. So when we look with one eye into the Ames room, we assume that it's right-angled.

This kind of trick is also used in movies. To make the hobbits look small compared to the magician Gandalf in the first part of "The Lord of the Rings," the scenes were filmed in an Ames room.





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Concept: Dr. Bernhard Epping

Revision: Anne Kuhn

Project management: Ita Meister, Kristin Albert

Product development: Elena Ryvkin

Design and layout: Atelier Bea Klenk, Klenk/Wiedau-Lorenz

Illustrations: Wolfgang Peschke, Grafikdesign, Ostfildern; Friedrich Werth, werthdesign, Horb-Betra

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Phone: 800-587-2872; Email: [support@thamesandkosmos.com](mailto:support@thamesandkosmos.com)

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