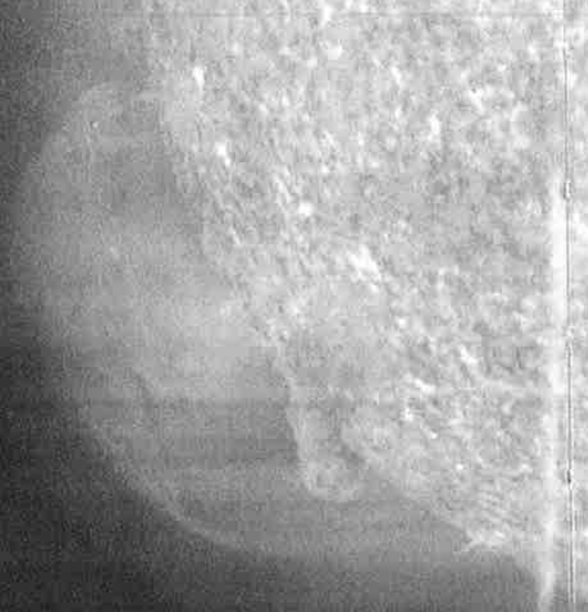
VISIBLE WAVES

LIFE ON EARTH COULD NOT EXIST WITHOUT LIGHT. It enables plants to grow and animals to survive. Light is a form of energy that we can think of as traveling in waves. It forms the small visible part of the electromagnetic spectrum, which also includes radio and television waves, microwaves, infrared (heat), ultraviolet (UV), X-rays, and gamma rays. Things that do not produce their own light are visible because light from another source is reflected off them. The Sun produces most of the natural light on Earth, while electric lighting is a common source of artificial light.



The visible part of the electromagnetic spectrum

NATURAL LIGHT

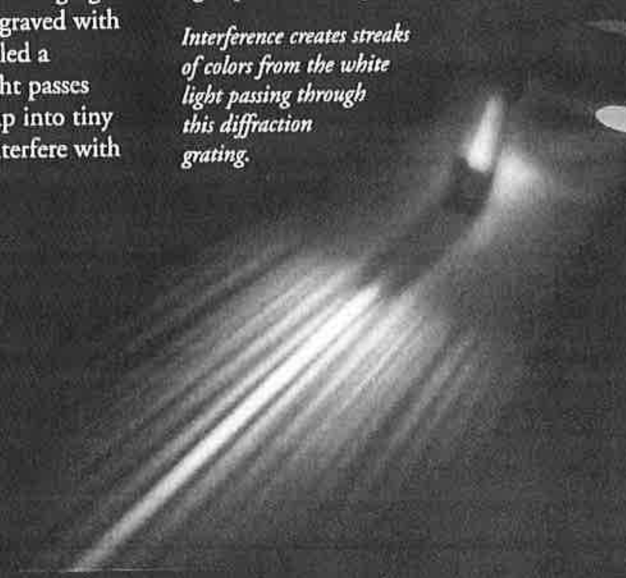
On Earth, the main source of natural light is the Sun. Nuclear reactions at the core of the Sun create energy in the form of light (and heat). A few organisms, such as fireflies and glowworms, produce natural light in their bodies through a chemical reaction called bioluminescence. For centuries, scientists debated whether light traveled as waves or as particles. In the early 20th century, research by German physicists Max Planck (1858–1947) and Albert Einstein (1879–1955) led to the current theory. Scientists now believe that light can travel both as waves and as tiny particles of energy called photons, but never both at the same time.

INTERFERENCE

When two beams of light meet, they interfere with each other (p. 118). If the peaks of one light wave line up with the peaks of the other, constructive interference occurs and the waves add together to produce a brighter beam. However, if the peaks of one wave line up with the troughs of the other, destructive interference takes place and the beams cancel each other out. This combination results in a pattern of dark and light known as an interference pattern. These patterns can be obtained by shining light through a small glass slide engraved with thousands of narrow lines called a diffraction grating. As the light passes between the lines, it is split up into tiny beams that spread out and interfere with each other.

LASERS

A laser produces a highly concentrated beam of light that can be strong enough to cut through metal. Most lasers have either gas, or a crystal such as a ruby, trapped inside a small space with mirrors at each end. A burst of very bright light or electricity causes the gas or crystal to produce light. The color of this light depends on the substance trapped – rubies give red light, for example. This light reflects to and fro off the mirrors in the cavity. Each time the light passes through the crystal or gas, it



Interference creates streaks of colors from the white light passing through this diffraction grating.

c. 300 BC Greek mathematician Euclid investigates the reflection of light.

c. 1010 Arabian scientist Alhazen describes human vision and explains how lenses work.

1621 Dutch mathematician and physicist Willebrord van Roijen Snell discovers the law of refraction.

1665 English physicist and mathematician Isaac Newton uses prisms to split sunlight into a spectrum of colors.

1801 English physicist Thomas Young discovers interference of light.

1808 French engineer and physicist Etienne Louis Malus discovers polarized light.

Timeline

Picture of the Sun taken by the SOHO probe.

The red beam from this helium-neon laser is used to perform laser eye surgery.

causes them to give off even more light. Finally, an extremely powerful laser beam emerges from a small hole in one of the mirrors. Lasers have many uses, from medical surgery, to creating holograms, to reading the data on compact discs.

POLARIZED LIGHT

Electromagnetic waves such as light waves have two parts, an electric field and a magnetic field. The two fields travel at right angles to the direction of the wave. The electric field is the part of the light wave that interacts with matter. Normally, the electric field vibrates in many different directions, but if it is restricted to only one direction, the light is said to be polarized. Sunlight reflecting from a road tends to be horizontally polarized. Therefore, wearing sunglasses with polarizing filters that only let through vertically polarized light will block the glare.

FLUORESCENCE

When neon gas is sealed in a glass tube and electricity is passed through it, the neon glows red. Often used in signs, neon lights based on this principle were the forerunners of fluorescent lights. Instead of using neon gas, fluorescent lights use mercury gas inside a glass tube.

Neon lights in Las Vegas

When electricity passes through the mercury gas, it gives out ultraviolet light. Because we cannot see ultraviolet light, the insides of the tube are coated with fluorescent crystals which convert the ultraviolet light into visible light. Fluorescence also occurs in nature. For example, a fluorescent rock will glow under an ultraviolet lamp.

LIGHT YEARS

Most stars are an extremely long way from the Earth. Miles or kilometers are not practical ways of measuring such enormous distances. For instance, one of the stars in the constellation Cygnus is approximately 60 million million miles (100 million million kilometers) away from Earth. Astronomers need a larger unit of measurement to describe distances in space, so they use light-years. A light-year is the distance that light travels in one year. Light from our next nearest star, Proxima Centauri, (the Sun is our nearest star) takes 4.3 years to reach us here on Earth, so it is 4.3 light-years away.

Polarized light interference produces colored stress patterns on this plastic hook.

1840s English astronomer Sir John Herschel and French physicist Edmond Becquerel take colored photographs of light spectra.

1864 Scottish physicist James Clerk Maxwell concludes that light is an electromagnetic wave forming part of an electromagnetic spectrum.

1880s American scientists Albert Michelson and Edward Morley use interference to determine that the speed of light is constant.

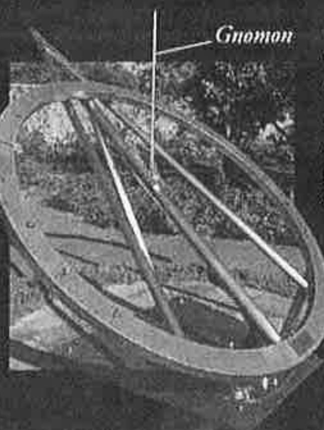
1895 French chemists Auguste and Louis Lumière publicly screen motion pictures.

1905 German physicist Albert Einstein publishes his quantum theory of light.

1948 Hungarian physicist Dennis Gabor invents holograms.

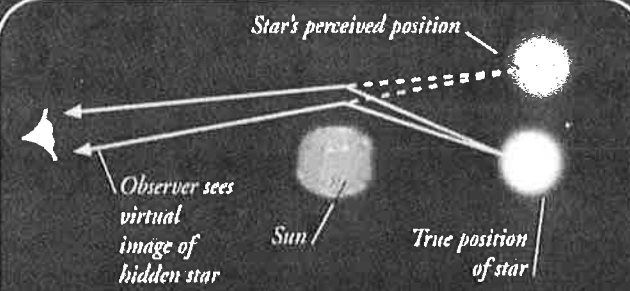
LIGHT AND SHADE

TRANSPARENT SUBSTANCES, SUCH AS GLASS, let light through, but opaque materials, such as wood, block light. Light travels in straight lines. If it falls on an opaque object, a dark shadow is cast in the shape of the object where the light could not pass through. Every night we are plunged into shadow by the Earth. As it rotates, each place on the surface becomes shielded from the Sun's light for a few hours by the rest of the Earth. Shadows also fall over parts of the Earth's surface during solar eclipses.



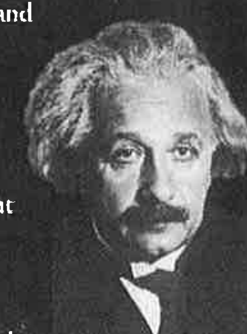
The shadows of time

Shadows can be used to tell the time. A sundial marks the time of day by the shadow cast on its surface as the Sun moves gradually across the sky. The object on a sundial that is used to create the shadow is called a gnomon. On this sundial (left), the shadow falls on a large metal ring raised at an angle to the ground. The ring has the hours of the day marked on it and the position on which the shadow of the gnomon falls tells the time.



GENERAL RELATIVITY

The German-born theoretical physicist Albert Einstein (1879–1955) wrote two theories of relativity. His "general" theory of relativity published in 1916 describes gravity. It suggests that the force of gravity can bend light, so the gravity of planets and stars makes them act like giant lenses. British astrophysicist Arthur Eddington tested this theory during the solar eclipse of 1919. Eddington photographed stars whose light passed near to the Sun during the eclipse and compared them with photographs of the same stars taken when the Sun was in another part of the sky. The stars appeared to have moved slightly, proving that the Sun's gravity was indeed bending the light from them just as Einstein had predicted. This result made Einstein famous. 137

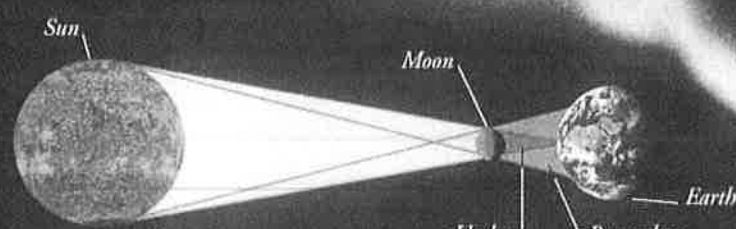


Albert Einstein

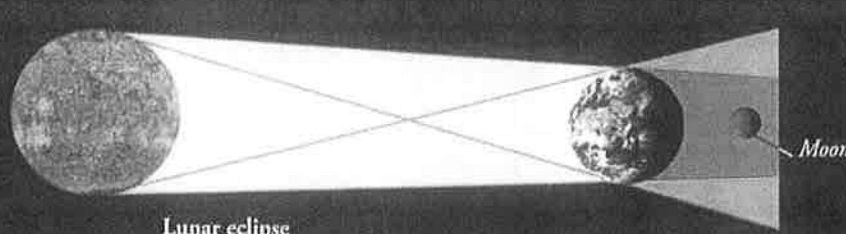
The diamond ring effect during a solar eclipse

ULTIMATE SHADOW

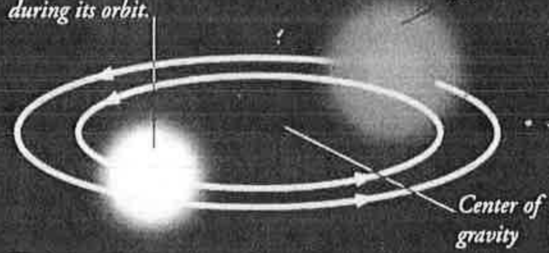
A solar eclipse occurs when the Moon blocks out the Sun's light and casts a shadow on the Earth. Since the Moon does not completely obscure the Sun, a blurred shadow is produced. The dark middle of the blurred shadow is called the umbra, and the lighter shadow around the edges is the penumbra. During a solar eclipse, people in the umbra see a total eclipse, while those in the penumbra see a partial eclipse. Lunar eclipses occur when the Moon moves through the Earth's shadow. During a lunar eclipse, the Moon usually becomes red rather than completely dark. This color comes from small amounts of sunlight refracted (pp. 124–125) by the Earth's atmosphere that still reach the Moon. Other planets, moons, and stars also produce eclipses.



Solar eclipse

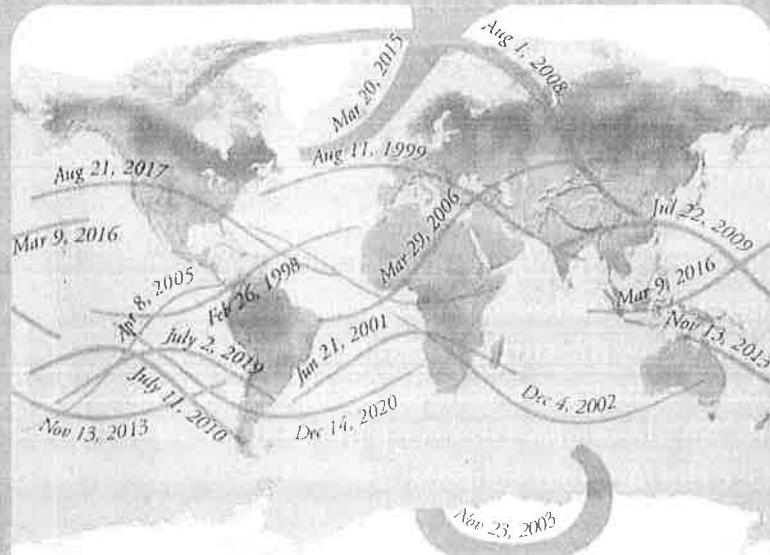


Lunar eclipse



BINARY STARS

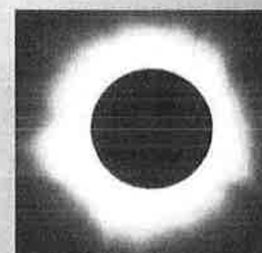
Many of the stars we see are in fact binary stars. These are pairs of stars attracted by gravity to orbit around each other. Some binaries are a type of variable star called an eclipsing binary. Their position in the sky means that when we look at them from Earth, each star repeatedly passes in front of the other blocking out its light. Astronomers identify eclipsing binaries from these changes in brightness. This nebula (right) photographed by the Hubble Space Telescope has a binary star at its center.



Total solar eclipses 1998–2020

Forecasting an eclipse

A solar eclipse occurs when a "new" Moon passes between the Earth and the Sun, and casts a shadow on the Earth's surface. There is a new Moon every 29.5 days, but solar eclipses only occur about every 18 months. This is because the path of the Moon's orbit around the Earth is tilted at an angle of five degrees compared to the path the Earth takes as it orbits around the Sun. Most of the time therefore, the new Moon's shadow passes above or below the Earth. When viewing a solar eclipse, never look at the Sun without eye protection.



The corona at total eclipse of the Sun

LET'S EXPERIMENT
SHADOW PUPPETS

MAKE FUN SHADOWS with shadow puppets. **You will need**: pencil; heavy construction paper or cardboard; scissors; adhesive tape; flashlight.

1 Draw the outline of a character onto the paper. (You may want to copy these ghosts.) Carefully cut out the character and tape it to the end of the pencil.

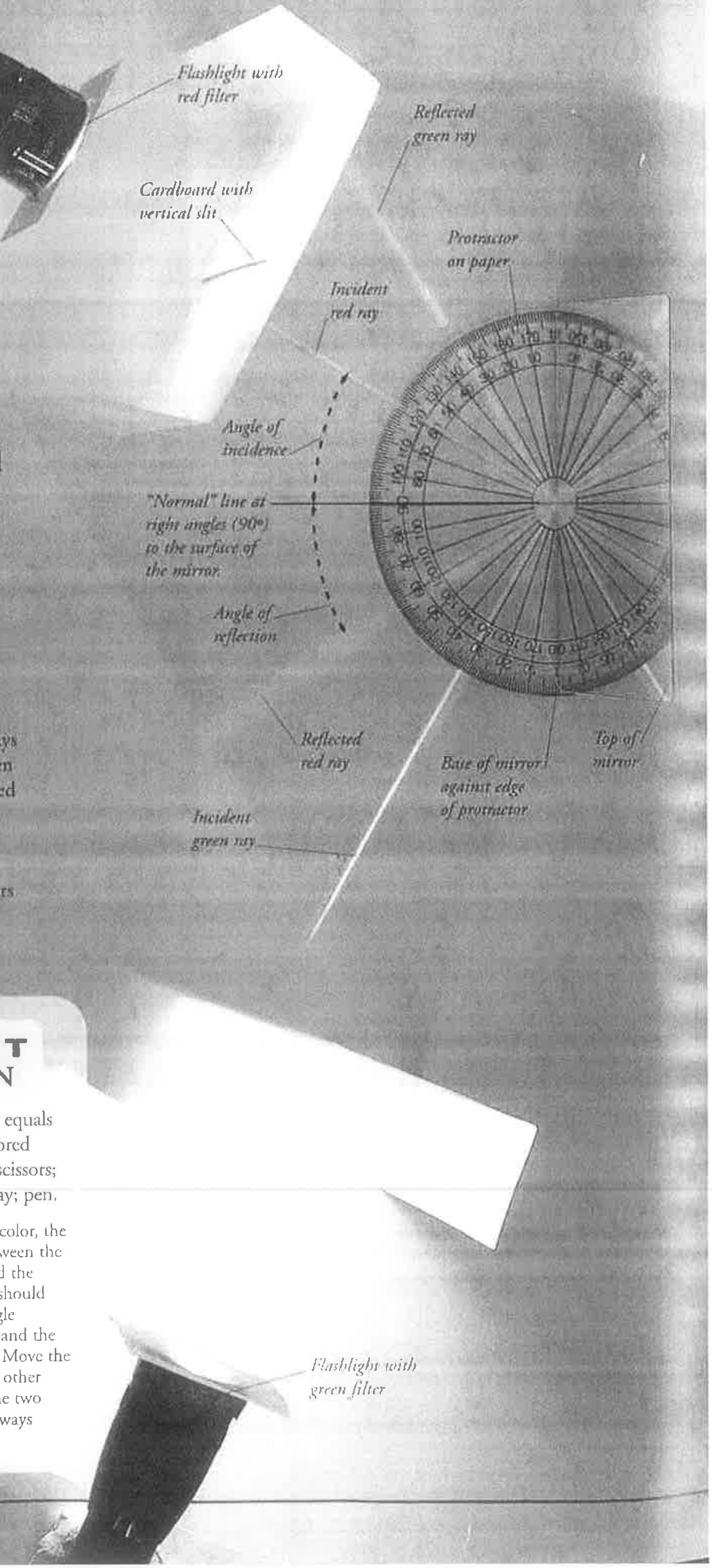
2 Hold the puppet near a wall, then shine the flashlight on it to make the shadow appear. Or, hold your hands in front of the light and see what patterns you can make on the wall. Try clasping your hands and moving one or more of your fingers. Also note the effect of moving the flashlight to different positions.

History of shadow

Shadow theaters are traditional in parts of Asia. In the 17th century, they spread to Europe, becoming the forerunners of modern movies. The rods attached to these Javanese puppets allow their jointed limbs to be moved.

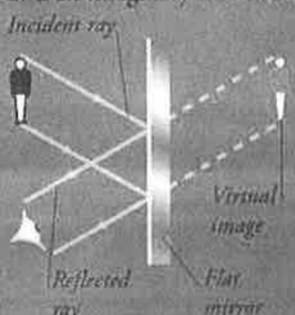
REFLECTION

MOST OBJECTS DO NOT produce their own light. We only see them because light is reflected off them. That is why we cannot see in the dark. Rough and dark objects reflect less light than lighter, shinier things. Mirrors reflect back almost all of the light falling on them. They can form images of objects because, unlike rough surfaces, which scatter reflected light in many directions, they reflect light rays in one direction and in the same pattern in which they arrive.



LAWS OF REFLECTION

There are always two rays involved in reflection – an incident (incoming) ray and a reflected (outgoing) ray. The angle between the incident ray striking any mirror and an imaginary line called the "normal" that hits the mirror at right angles is always the same as the angle between the "normal" and the reflected ray. Both the rays and the "normal" lie on the same imaginary flat surface. Images formed by flat mirrors are virtual (appearing to be behind the mirror) and the wrong way around.



LET'S EXPERIMENT
THE LAWS OF REFLECTION

PROVE THAT THE ANGLE of incidence of light on a mirror equals the angle of reflection. **You will need:** two flashlights; colored filters (such as candy wrappers); two pieces of cardboard; scissors; large sheet of paper; protractor; small mirror; modeling clay; pen.

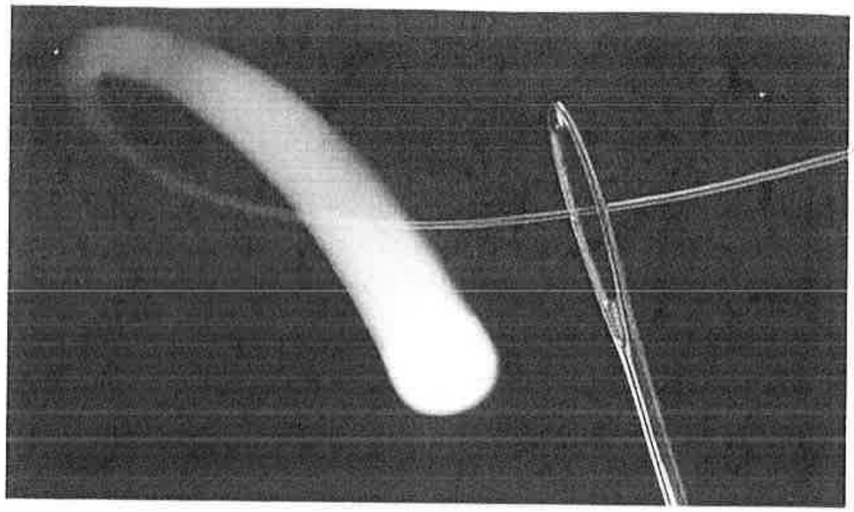
1. Attach a different color filter over each flashlight. Cut a vertical slit in each piece of cardboard. Put the flashlights on the floor. Place the pieces of cardboard in front of each, so a narrow strip of light shines onto the mirror (see Step 2).

2. Put the protractor on the paper on the floor. Supporting the mirror with clay, stand it against the straight edge of the protractor. On the paper, mark the 90° line, and the incident ray and reflected ray for each color.

3. For each color, the angle between the 90° mark and the incident ray should equal the angle between 90° and the reflected ray. Move the flashlights to other positions. The two angles will always be equal.

OPTICAL FIBERS

Most of our telephone calls and emails are converted by electronics into pulses of light and carried by optical fiber cables to their destination. On arrival, more electronics turns the light back into sound or data. Optical fibers like the one on the right (pictured with a needle to show its size) are made from a very thin core of glass that can refract (bend) light strongly. This core is surrounded by a coating of glass, known as the cladding, that cannot bend light as much. If light enters the fiber at certain angles, the boundary between the core and the cladding acts like a mirror and reflects it to and fro down the fiber. Light pulses can travel long distances in this way.



Endoscope

Bundles of optical fibers inside endoscopes (long, thin, medical instruments for seeing inside the body) transmit detailed images to television screens or an eyepiece for doctors to see. The area being studied is illuminated by light delivered by another bundle of fibers. Here surgeons are using an endoscope during keyhole surgery to remove a gallbladder.

Reflecting telescope

A large concave mirror, called the primary mirror, collects the light from stars and planets inside reflecting telescopes. The light reflected off this mirror falls onto a smaller flat mirror and an image is created. The image can either be recorded on photographic film or viewed through the lenses in an eyepiece that magnify it. There are different shapes and arrangements of mirrors in reflecting telescopes. This version (right) was designed by Sir Isaac Newton (1642–1727). The world's largest telescope mirror (left), belonging to the Hobby-Eberly telescope at the McDonald Observatory in Texas is 36 ft (11 m) wide.

The Hobby-Eberly telescope mirror has 91 segments.

CONCAVE AND CONVEX

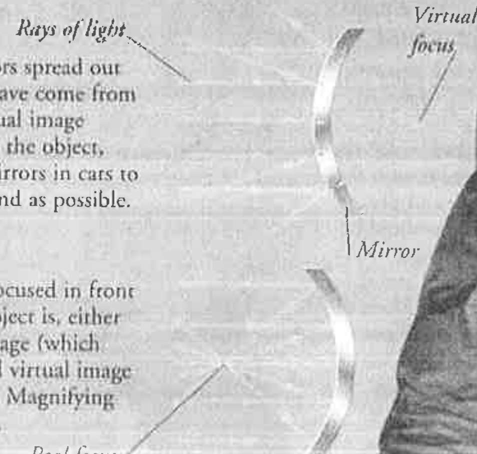
Curved surfaces can either be concave, which means that they curve inward, or convex, which means that they curve outward. The mirrors we use to see our reflections are flat because although the images they produce are reversed from right to left, they are the same size and shape as the object. Curved mirrors produce distorted images that can be larger or smaller than the object reflected.

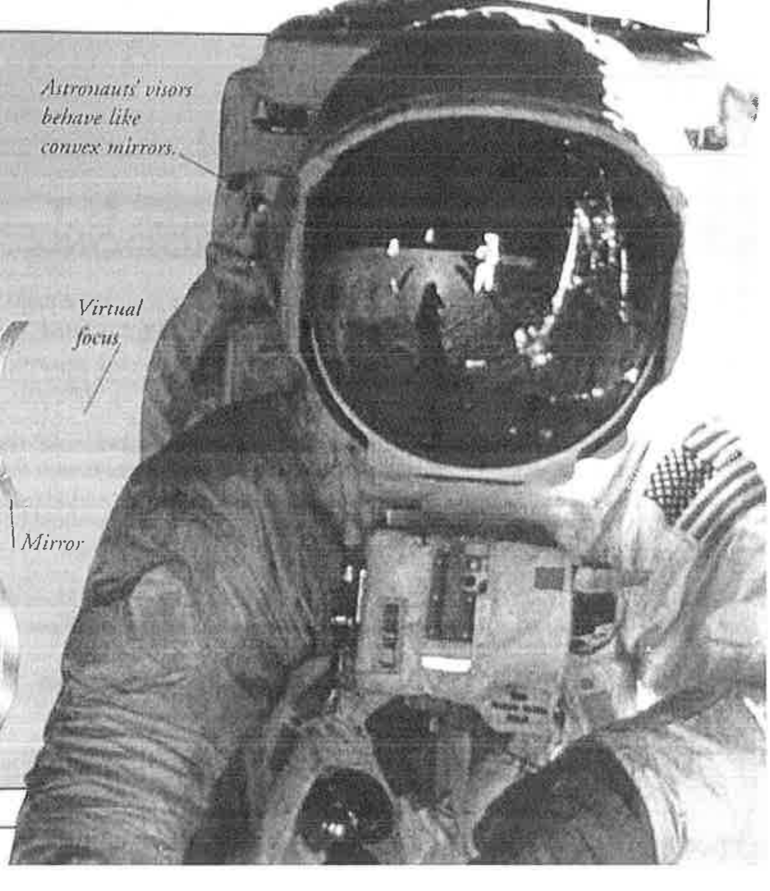
Convex mirror

Rays of light reflected from convex mirrors spread out (diverge), which makes them appear to have come from a focal point behind the mirror. The virtual image formed behind the mirror is smaller than the object, so convex mirrors are used as rearview mirrors in cars to help drivers see as much of the road behind as possible.

Concave mirror

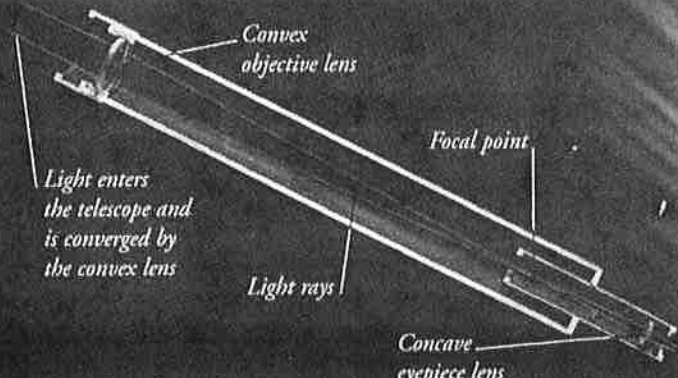
Light reflected from concave mirrors is focused in front of them. Depending on how close the object is, either a magnified, same size, or smaller real image (which lies in front of the mirror) or a magnified virtual image (which lies behind the mirror) is formed. Magnifying makeup and shaving mirrors are concave.



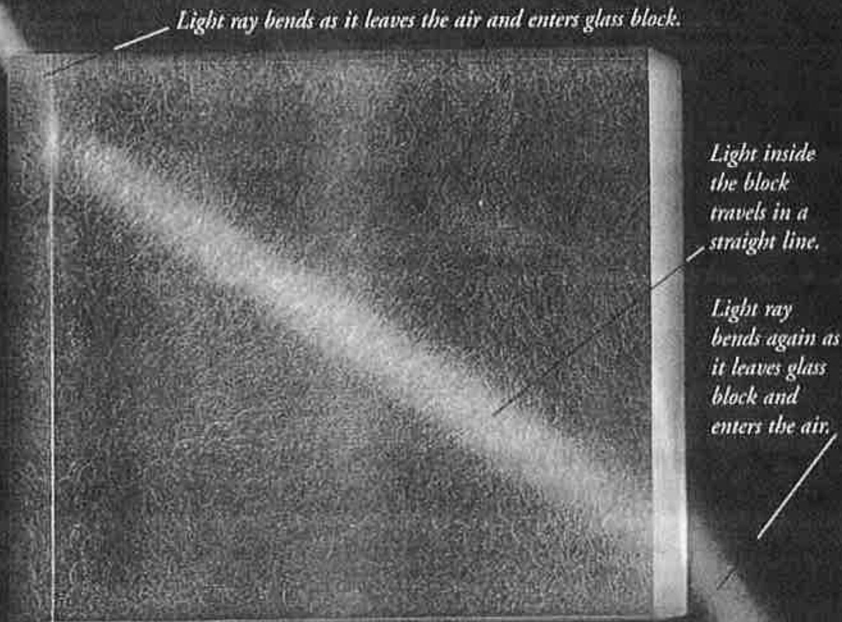


REFRACTION

WHEN LIGHT TRAVELS FROM ONE TRANSPARENT substance into another, it changes direction slightly. This bending of light is known as refraction. If you look down at your legs while standing in water, they will appear bent. This is because light refracts as it passes from water to air. Curved pieces of transparent material that can refract light in a particular way are known as lenses. Most optical instruments, including binoculars, telescopes, and cameras, have lenses that focus light and produce an image of whatever is being viewed.



The refracting telescope
Lenses inside refracting telescopes are used to produce magnified images of distant objects such as planets and stars. The large lens at the far end of the telescope collects light from the object and creates an image of it. The smaller lens at the near end is the eyepiece lens, which magnifies the image.



LAWS OF REFRACTION

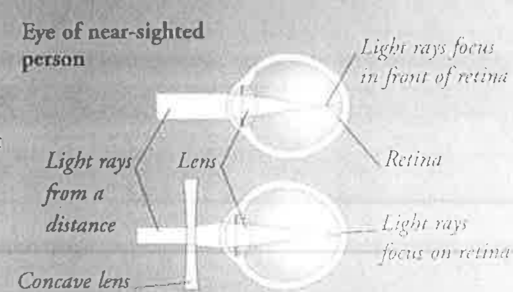
The picture on the left shows a ray of light bending as it moves from air into the top of a glass block, and bending again as it leaves the block at the bottom. In 1621, the Dutch mathematician Willebrord Snell (1580–1626) discovered that there is a precise mathematical relationship between the angle at which a light ray enters a substance that refracts it, and the angle it is refracted to. This relationship produces a number known as the refractive index and tells us how strongly a substance refracts light.

Willebrord Snell

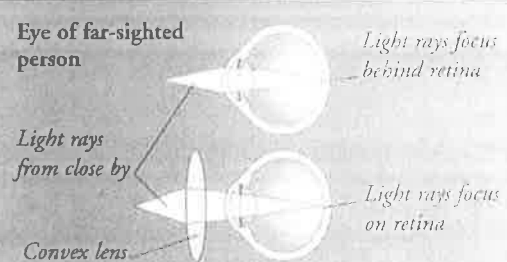
LENSES

Transparent materials such as glass and plastic are used to make lenses. Lenses refract light. Convex lenses cause light rays to converge (come together). The light focuses where the converging rays meet. Convex lenses make objects look larger or smaller, depending on their distance from the lens. Concave lenses cause light rays to diverge (spread out) and appear to come from a virtual focal point the same side of the lens as the light enters. Concave lenses make objects look smaller.

Near-sighted
For the human eye to see clearly, light rays coming into the eye should focus on the retina. A near-sighted person can see close objects clearly, but distant objects are blurred. This is because their eyes are too long, so light rays focus before reaching the retina, rather than on it. Glasses with concave lenses correct the problem.



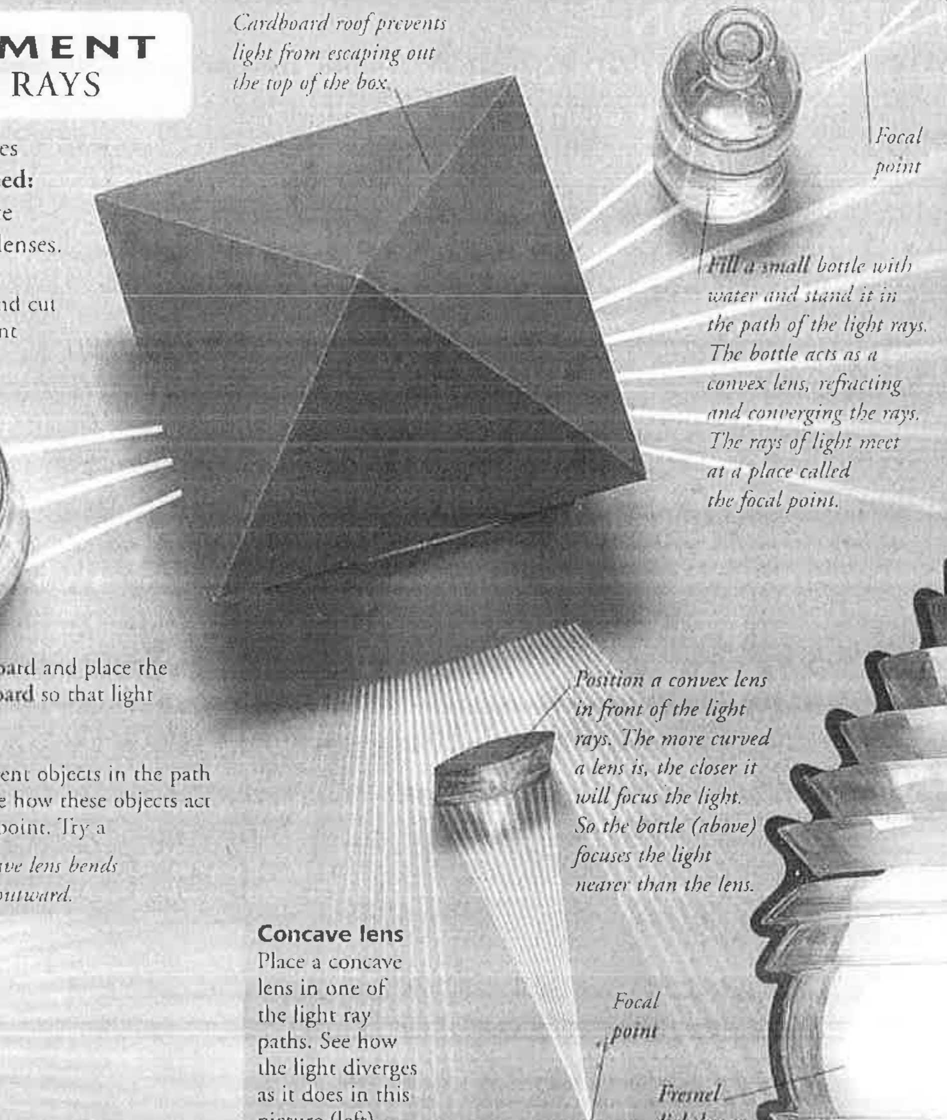
Far-sighted
Distant objects look clear to a far-sighted person, but closer objects look blurred. Their eyes are too short, so light rays from close by focus behind the retina, rather than on it. A young person's natural lens can correct for this, otherwise glasses with convex lenses are used.



LET'S EXPERIMENT
BENDING LIGHT RAYS

SEE HOW LIGHT is refracted when it passes through transparent objects. **You will need:** cardboard box; scissors; small lamp; white cardboard; transparent jars, bottles, and lenses.

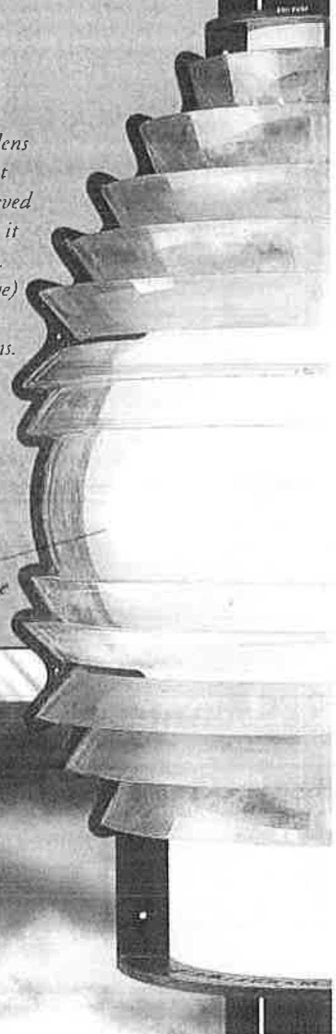
1 Remove the top and bottom of the box and cut narrow slits in each of its sides. Experiment by cutting a different number of slits in each side, for example, cut seven close together on one side and three spaced out on another.

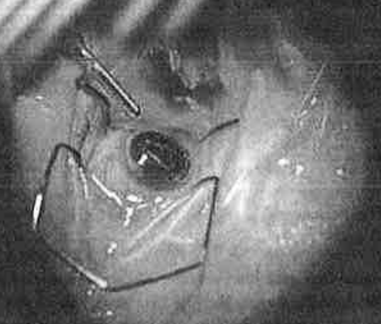


2 Put the lamp on the sheet of white cardboard and place the box on top of it. Make a roof with cardboard so that light does not escape through the top of the box.

3 Darken the room, then place the transparent objects in the path of the light rays coming from the box. See how these objects act as convex lenses, bringing the rays to a focal point. Try a concave lens as well (below).

Concave lens
Place a concave lens in one of the light ray paths. See how the light diverges as it does in this picture (left).

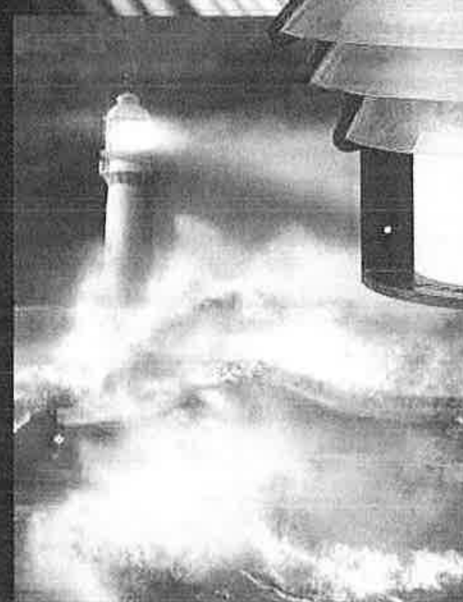




Cataract surgery
Old age and certain diseases can cause an opaque area – through which light cannot pass – called a cataract to form on the normally transparent lens of the eye. Cataracts cause blurred vision or blindness. To correct this, the affected lens is removed in an operation and replaced by a plastic lens.

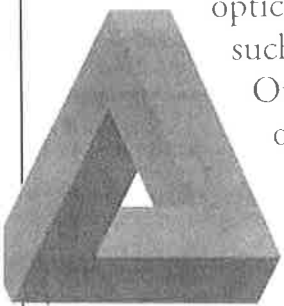
LIGHTHOUSE

Ships can be warned of potential danger, and find where they are, by the light from a lighthouse like this one in South Africa. French physicist Augustin Fresnel (1788–1827) designed a lighthouse lens like this one in the 1820s. The lens gives a strong beam of light, and versions of it are used today to project beams visible for 28 miles. The first lighthouse was built around 280 BC, and guided ships into the harbor at Alexandria in Egypt.



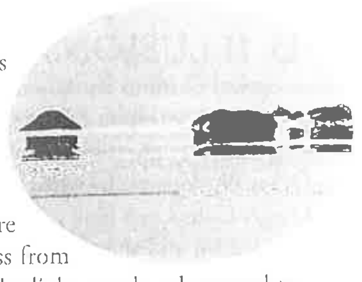
OPTICAL ILLUSIONS

MOST OF THE TIME OUR BRAINS INTERPRET THE signals coming from our eyes correctly. But occasionally we're tricked into thinking we see something that isn't really there. We call this an optical illusion. Some optical illusions, such as mirages, occur naturally. Others, such as the illusion of depth on a flat surface, or pictures with impossible shapes, are artificially created for fun. The way we interpret information from our senses is called perception. Past experience of sensing things is a factor that can shape perception.

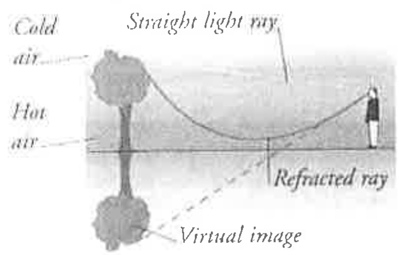


Our brains interpret this tribar as an impossible 3D shape.

MIRAGES

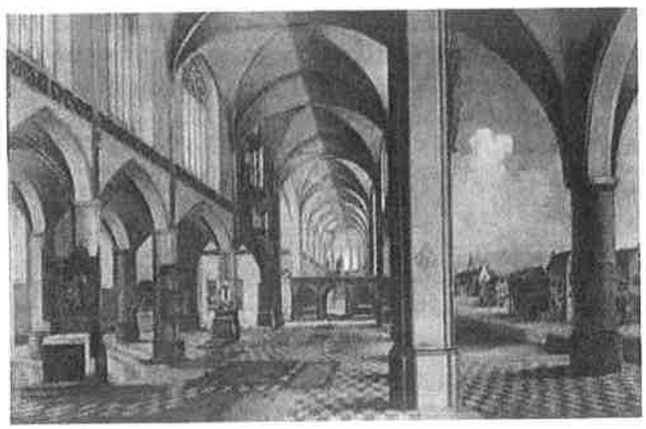


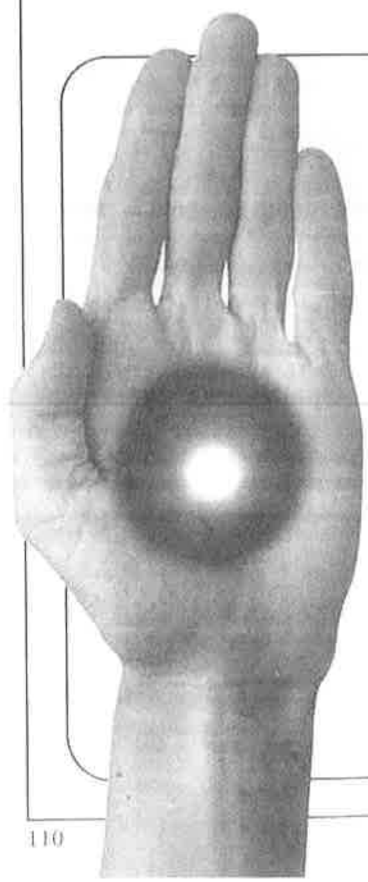
If a layer of warm air forms near the ground beneath a cooler layer of air, an effect known as an oasis mirage may occur. Light rays from distant objects are refracted (bent) as they pass from cool air into warmer air. The light rays bend upward to our eyes and appear to be coming from the ground. We therefore see an upside-down image of the object – as in this mirage (above) photographed in the Western Desert in Egypt. It appears to be in a pool of water, which is in fact an image of the blue sky. No wonder mirages have driven many thirsty travelers to despair!



PERSPECTIVE

In real life, objects appear more blurred, and paler and bluer in color, the further into the distance they are. Artists mimic this effect when painting landscapes to give a three-dimensional (3-D) illusion on a two-dimensional (2-D) canvas. This technique is called atmospheric perspective. When looking into the distance, we also see any parallel lines – such as the sides of a long, straight road – converge. They appear to meet at an imaginary "vanishing point." Artists use this optical illusion, known as linear perspective, as another way of giving a picture depth. Objects are drawn smaller and closer together the nearer they are to the vanishing point.





LET'S EXPERIMENT
HOLE IN YOUR HAND

WE USUALLY SEE through both eyes at the same time. We are not aware of seeing with two separate eyes, because our brains add the images from each eye together, as you will see in this experiment. **You will need:** a sheet of paper.

1 Roll the paper into a tube and hold it with your right hand to your right eye. Look down the tube while keeping your left eye open.

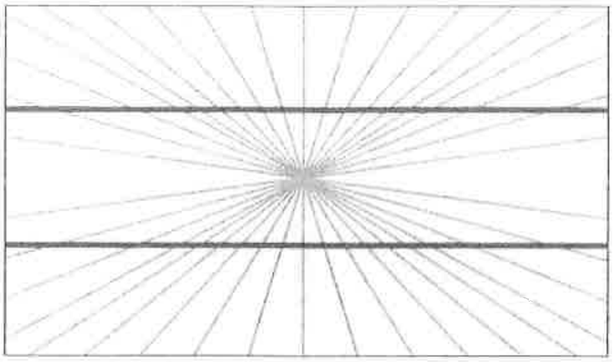
2 Position your left hand with the palm toward you against the tube, about two-thirds of the way down its length (as shown, right). You should now see a hole in your hand as your brain adds together the two separate images from each eye.

Holograms

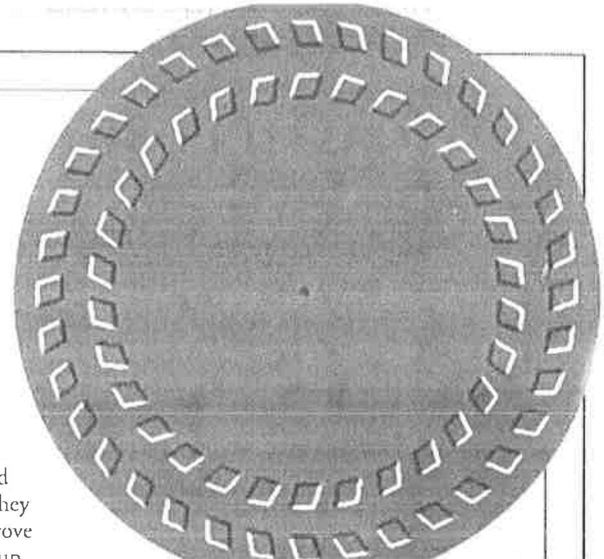
Three-dimensional photos called holograms are created with lasers. One half of a laser beam is shone onto a special holographic film while the other half is scattered off the subject. The pattern of light recorded on the film where the beams meet represents both how bright and how far away from the film each part of the subject is. Shining a light at the developed film from a certain angle reveals a 3-D image.

2-D ILLUSIONS

Some optical illusions work because our brains do not have enough information to interpret correctly what we are seeing. We fill in the missing pieces by guesswork based on our knowledge of the world around us. Other illusions occur when the surroundings of what we are looking at change. Colors can look different depending on what colors they are surrounded by, and shapes can seem altered with different backgrounds.



Straight lines?
The thick lines going across this drawing appear to bend outward at the middle. In fact they are straight. You can prove this by putting a ruler up against them. It is the pattern of lines behind them that has tricked you into thinking they are curved.



Moving circles?
Pictures cannot really move around a page, but they can appear to move. Stare at the spot in the middle of these circles while moving the page toward then away from your eyes. The circles seem to rotate.

STEREOGRAMS

We can see three dimensions because each of our eyes views an object from a different angle and produces a slightly different image of it. Our brains interpret these two images as a single image that not only has shape, but depth and distance as well. Pictures with hidden 3-D images are called stereograms (the one below creates a depth illusion). They are made by laying a two-dimensional, repeating pattern over a 3-D picture to disguise it. It can be difficult to see the hidden image. One way is to focus your eyes on a more distant object, then look at the stereogram without altering the focus of your eyes.

Can you tell what this is?

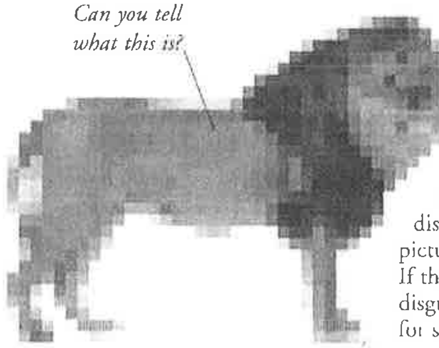
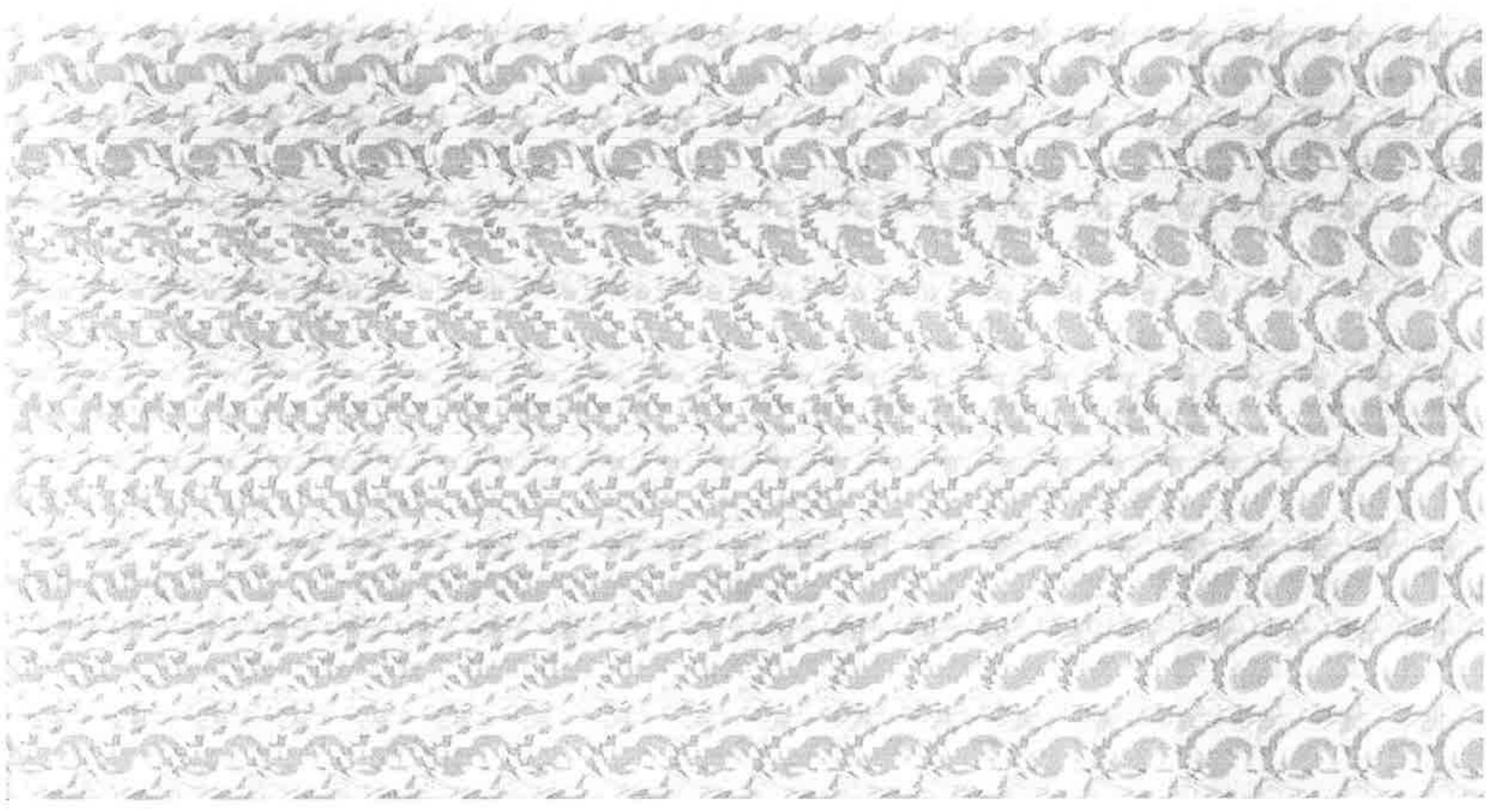
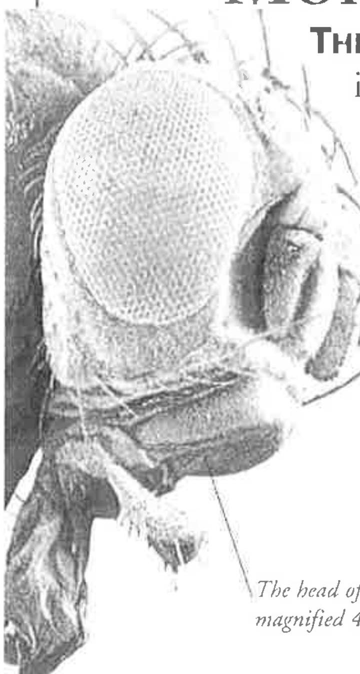


Image recognition
We identify different things because our brains compare what we see with images of objects stored in our memories. When a match occurs, we recognize whatever it is. If objects are blurred or disguised in some way, as in this picture, recognition becomes harder. If this picture were more heavily disguised, our brains might mistake it for something similar, such as a tiger.



MORE THAN THE EYE CAN SEE

THE HUMAN EYE CAN SEE A SURPRISINGLY LONG WAY into the distance. Even neighboring planets are visible on a clear night, although it is impossible to make out much detail without telescopes or binoculars. We cannot see details on very small things either, so use microscopes to reveal more about them or to see objects that are so small they are invisible to our unaided eyes. By using night-vision devices we can even see in the dark. Such devices amplify the small amounts of light present at night to produce a visible image.

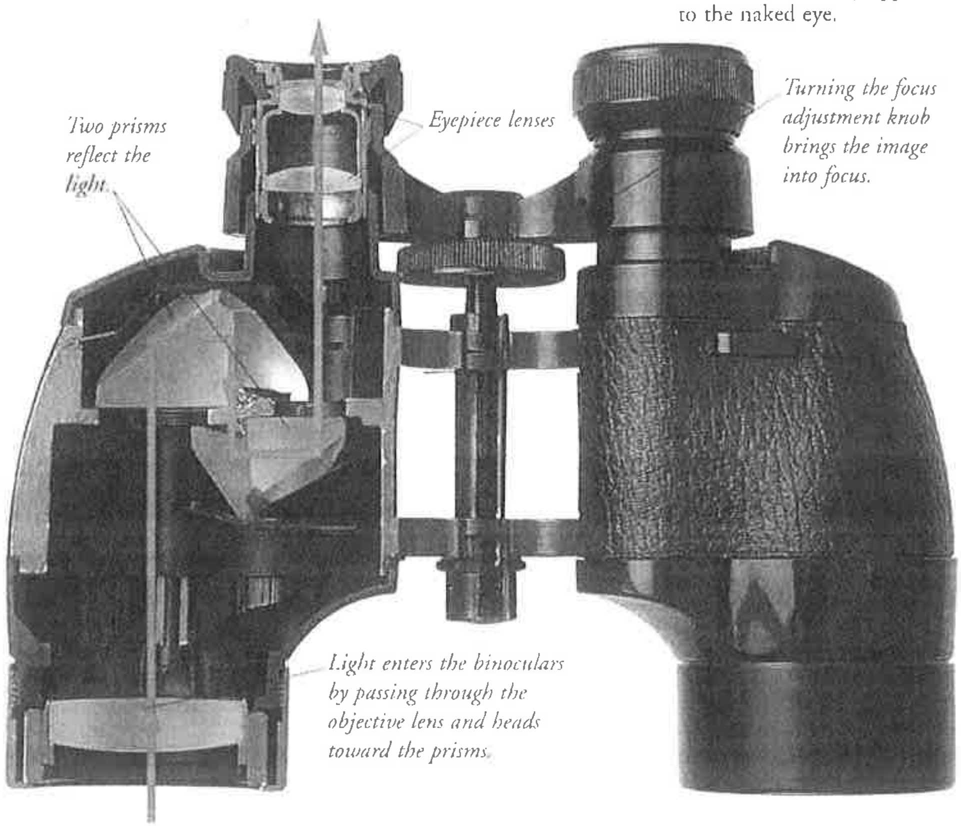


The head of a fruit fly magnified 45 times

Naked-eye astronomy
Before the invention of telescopes in the 17th century, astronomers observed the night sky unaided. This photograph shows Jupiter (top), Venus (center) and the Moon (near the horizon) as they appear to the naked eye.

BINOCULARS

Like telescope lenses, the lenses in binoculars collect and magnify the light from objects. Light passes through the objective lenses, which produce an upside-down reversed image of the object (pp. 114–115). Inside the binoculars are specially shaped prisms that reflect light from two of their faces. There are two prisms in each half of a pair of binoculars. One prism turns the image the right way up, and the other turns it the right way around. The four successive reflections provide a long path for the light within a small space, allowing binoculars to be made much shorter and more portable than telescopes.

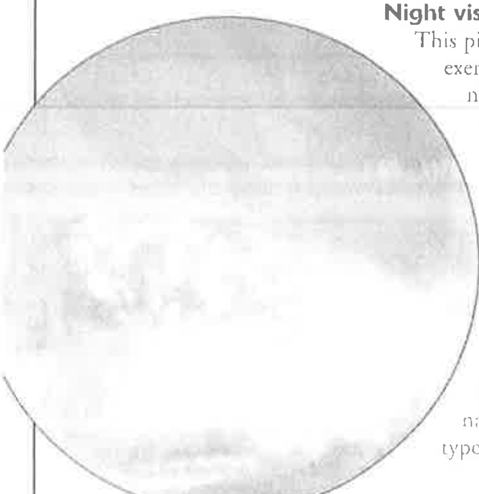


Two prisms reflect the light

Eyepiece lenses

Turning the focus adjustment knob brings the image into focus.

Light enters the binoculars by passing through the objective lens and heads toward the prisms.



Night vision
This picture of security police on a training exercise shows what an onlooker with a night-vision device could see. Night-vision equipment amplifies the moonlight and starlight reflected from objects so they appear many times brighter. It does this by converting each photon (pp. 102–103) of light into an electron (pp. 42–43), then multiplying each electron into many more electrons. A screen at the end of the device then glows brightly whenever one of these electrons hits it, producing a visible image. Military personnel as well as nature and bird watchers use this type of powerful equipment.

Hubble Space Telescope
The Earth's atmosphere distorts the images obtained by ground-based telescopes. By orbiting Earth above the atmosphere, the Hubble Space Telescope, launched in 1990, can obtain very clear images of stars and planets. This picture taken by Hubble shows a spiral galaxy 60 million light-years away. The outer stars are younger than those in the center.

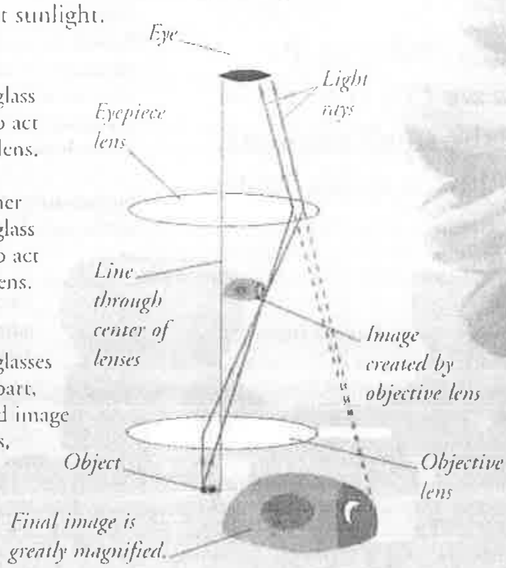
LET'S EXPERIMENT
MAKING A MICROSCOPE

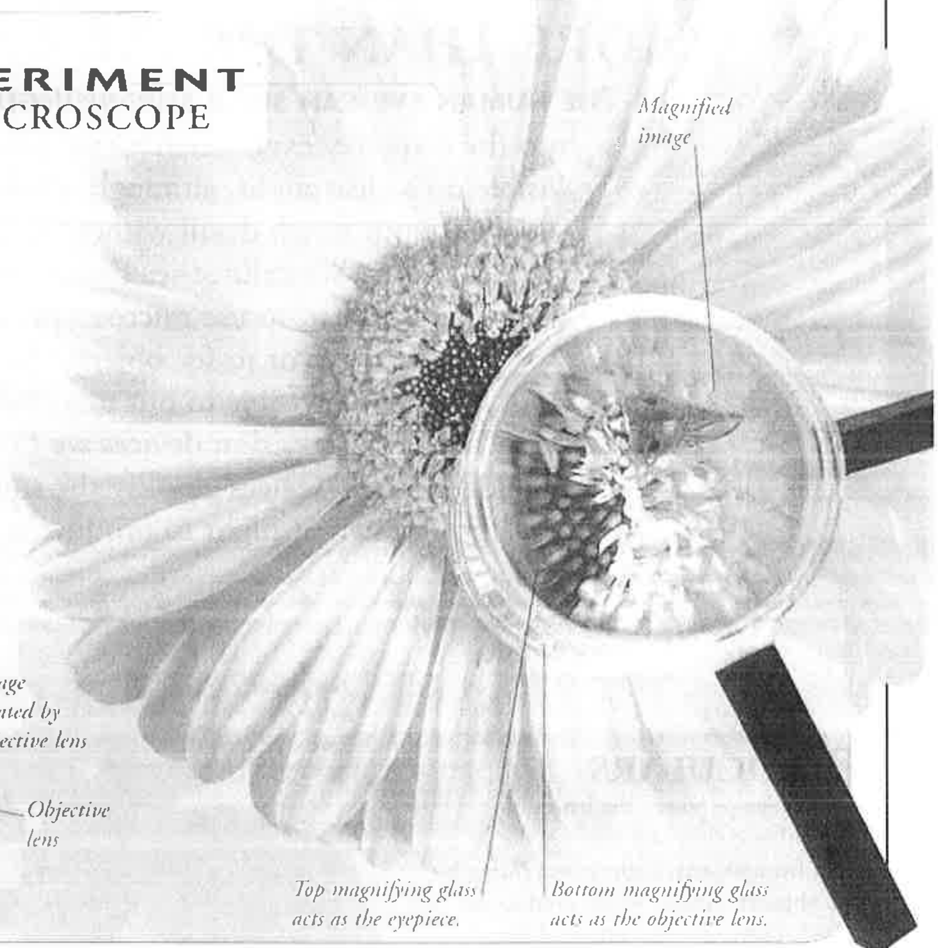
YOU CAN USE ORDINARY magnifying glasses to make your own microscope. (The convex lens of a single magnifying glass is actually a simple form of microscope.) **You will need:** two magnifying glasses. Remember, do not use magnifying glasses in direct sunlight.

1 Hold one magnifying glass near an object to act as the objective lens.

2 Hold the other magnifying glass near your eyes to act as the eyepiece lens.

3 Move the magnifying glasses together, then apart, until a magnified image comes into focus.





OPTICAL MICROSCOPE

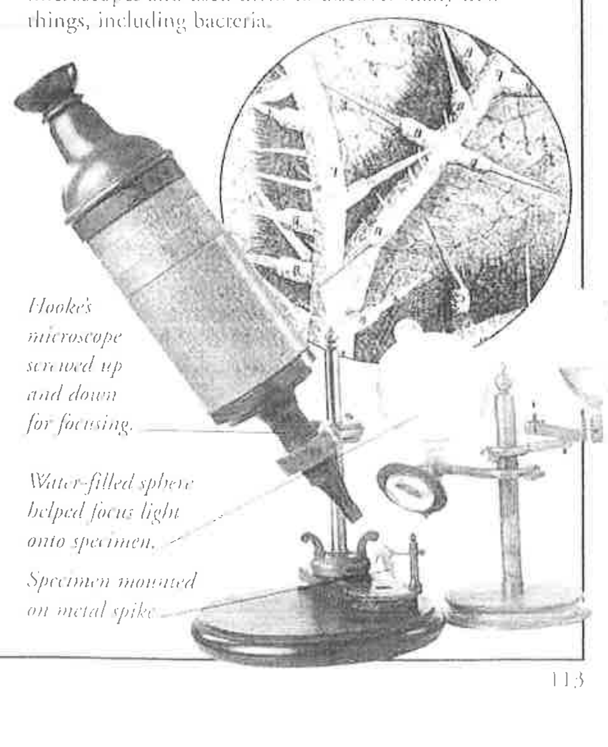
Most optical microscopes are compound microscopes containing at least two lenses. These lenses are convex (curved outward). The objective lens (or lenses) near to the specimen collects light reflected from it and forms a magnified image. The eyepiece lens (or lenses) that scientists look through then magnifies the image even more. Magnifications up to about 1,000 times are possible. The picture on the right shows onion cells magnified 330 times by an optical microscope.

Electron microscope

To magnify things hundreds of thousands of times, electron microscopes, which use beams of electrons rather than light, are needed. Very small objects cannot be seen through optical microscopes. Light won't reflect off the specimen because the length of the light waves is much larger than the object. However, tiny objects can interact with electron beams, which behave like incredibly small waves, to form images such as the one shown here of an ant's head.

The first microscopes

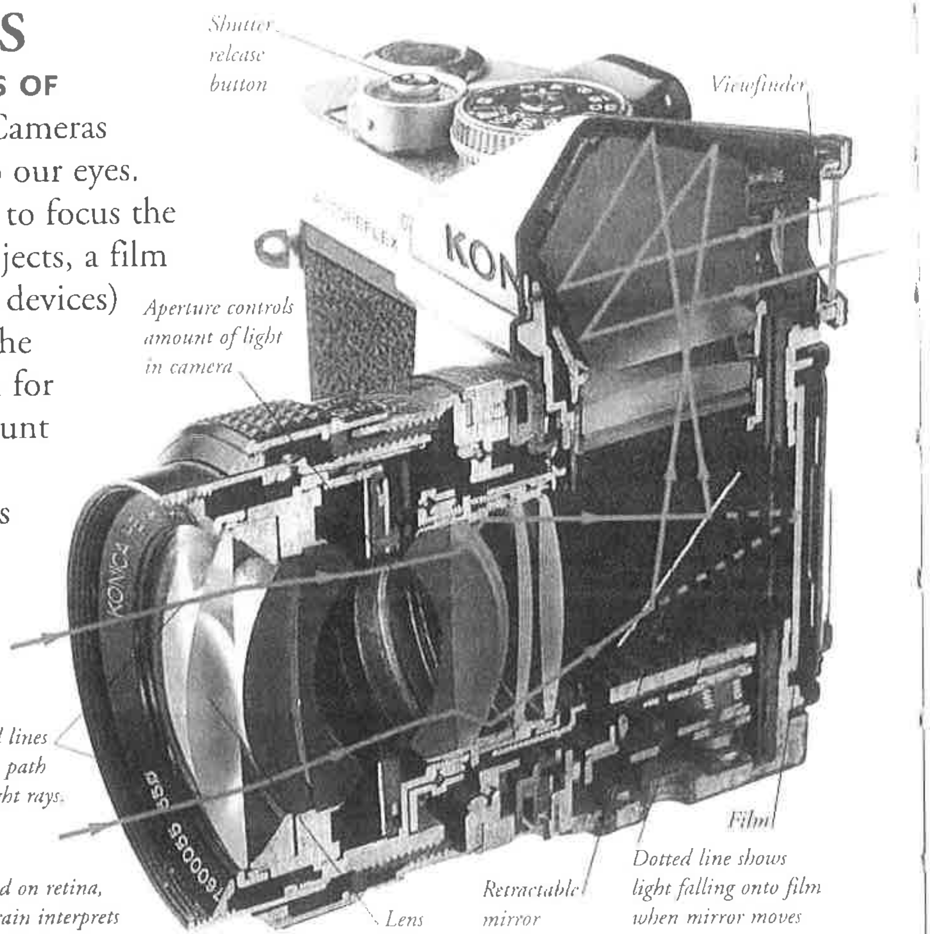
English physicist Robert Hooke (1635–1703) carried out experiments with compound microscopes like this replica (below) of his design. In 1665, he published a book called *Micrographia* containing drawings of what he saw through his microscope, including this illustration of the stinging spines on a nettle leaf. Around this time, Dutch microscopist Anton van Leeuwenhoek (1632–1723) made hundreds of simple microscopes and used them to discover many new things, including bacteria.



PICTURE THIS

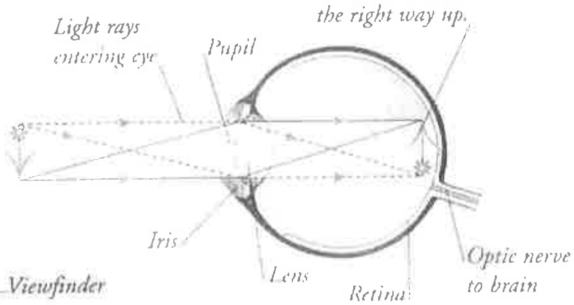
High-speed action photo

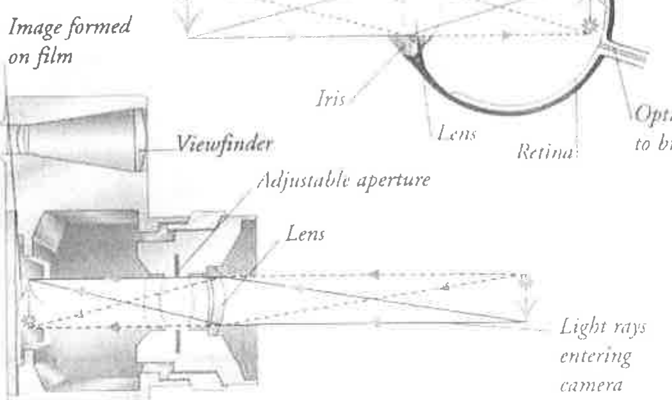
WE CAN RECORD IMAGES OF objects using a camera. Cameras work in a similar way to our eyes. All cameras have a lens to focus the light reflected from objects, a film (or rows of electronic devices) on which to record the image, and a system for controlling the amount of light that falls on the film. In order to see the photographs taken with a camera, the film must be developed and printed. French inventor Joseph Niepce (1765–1833) took the first permanent photograph in 1826 on a pewter plate coated with light-sensitive bitumen. Modern film has a coating of silver salts to record the image.



SLR CAMERA

All cameras have the same basic parts, but there are many different designs. In the single-lens reflex (SLR) camera, small mirrors and a prism reflect the image produced by the lens onto the viewfinder, so that it is exactly the same as the image that will be recorded. When the shutter-release button is pressed, the mirror moves out of the path of the light coming from the lenses and the shutter in front of the film opens. Light now falls onto the film at the back of the camera, recording the image. In many cameras, the image that is produced by the lens and recorded is not quite the exact image seen through the viewfinder.





EYE VERSUS CAMERA

A camera has much in common with the human eye. In the human eye, the muscles in the iris cause the small hole in the middle (the pupil) to contract in bright light or enlarge in dim light. A camera has a hole called an aperture that can be made larger or smaller to control the amount of light entering through the lens. The lens in the eye focuses light rays onto a light sensitive layer at the back of the eye called the retina. Cells in the retina send signals along the optic nerve to the brain, which interprets them as an image. In a camera, the lens focuses light onto a film, and the image is revealed when the picture is printed.

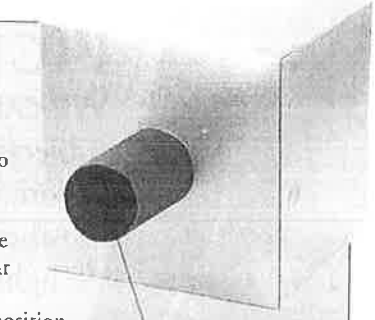
Digital photography
Light entering a digital camera is focused onto rows of small electronic devices at the back of a digital camera where the film would normally be. These devices convert the light into electronic signals which are saved onto a memory card in the camera. A small liquid-crystal display at the back of the camera acts as a viewfinder, and allows pictures in the memory to be viewed. Pictures taken on digital cameras can be stored on computer discs, viewed on a computer screen, and printed out.

LET'S EXPERIMENT
MAKE A CAMERA

MAKE A SIMPLE MODEL CAMERA to show how a real camera works. Your model camera will form an image in a similar way to a real camera, but it will not be able to make a photograph. **You will need:** cardboard box (such as a tissue box); scissors; cardboard tube (from toilet paper or paper towel roll); pen; adhesive tape; tracing paper; magnifying glass.

1 Carefully cut the bottom off the cardboard box. Hold the cardboard tube against the opposite side of the box and draw around it to make a circle.

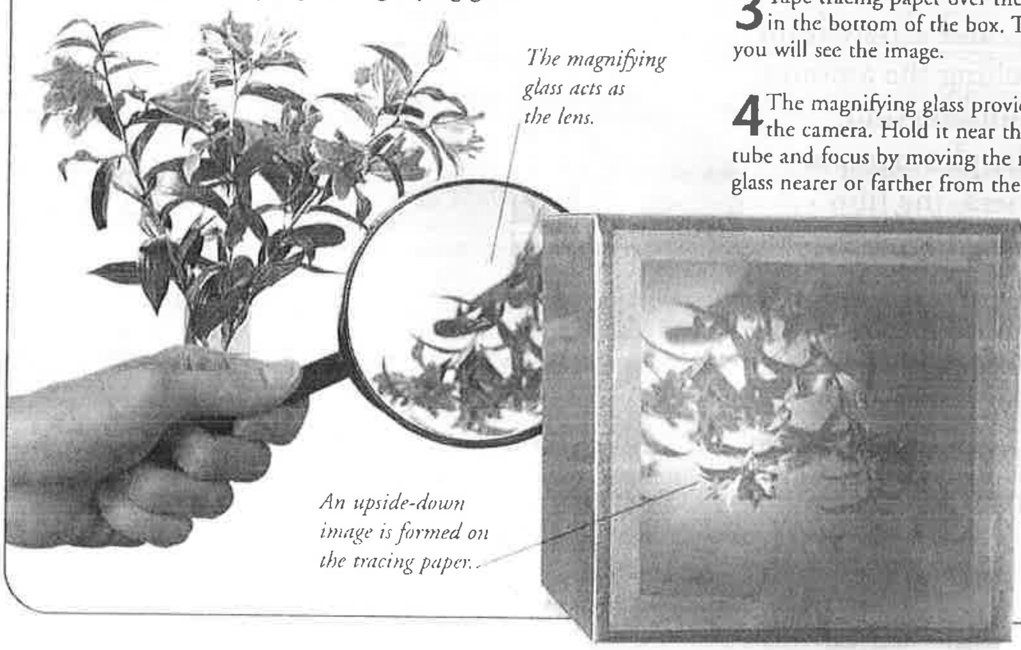
2 Carefully, cut out the circle in the box. Put the tube into the circular hole so that about 2 in (5 cm) sticks out of the top of your box. Tape in position.



Cardboard tube fits into hole in box.

3 Tape tracing paper over the large opening in the bottom of the box. This is where you will see the image.

4 The magnifying glass provides the lens for the camera. Hold it near the end of the tube and focus by moving the magnifying glass nearer or farther from the tube.



The magnifying glass acts as the lens.

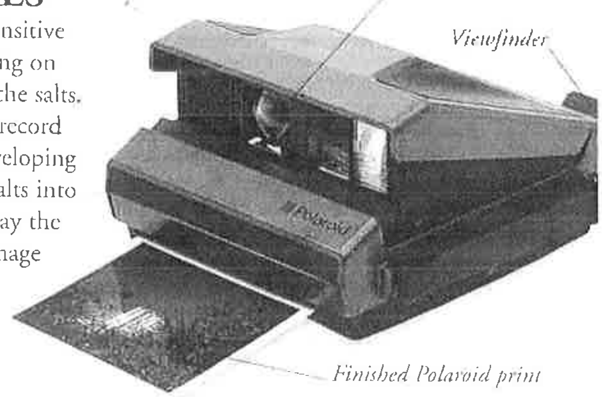
An upside-down image is formed on the tracing paper.

5 Find a well-lit object to look at. Hold the model camera so that you are looking at the end with the tracing paper.

6 An upside-down and reversed image of the object will form on the tracing paper. If the image is out of focus, try moving the magnifying glass until you see a sharp image. In a real camera, this image would be formed on photographic film.

PROCESSING PICTURES

Photographic film is coated with a light-sensitive emulsion containing silver salts. Light falling on the emulsion causes a chemical change in the salts. The first stage of film processing creates a record of these changes. The film is soaked in developing chemicals that convert the exposed silver salts into metallic silver. A fixing solution washes away the unexposed silver salts, leaving a negative image that is darkest where the brightest light fell onto the film. Light is then shone through the negative onto photographic paper. The paper makes a print that is brightest where the negative is darkest, reproducing the photographed scene.



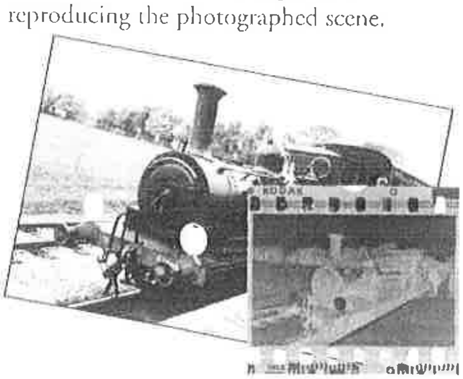
Lens

Viewfinder

Finished Polaroid print

Color negatives

Color film has three layers of emulsion, one for each primary color of light – blue, green, and red. During developing, each layer produces a dye of the opposite (complementary) color to the light that fell on the film – yellow dye for the blue layer, magenta for the green layer and cyan for the red layer. Each dye in the negative absorbs light of its complementary color. After printing, the complementary colors formed by the dyes in the paper absorb and reflect the colors in white light. This results in the original colors of the subject.

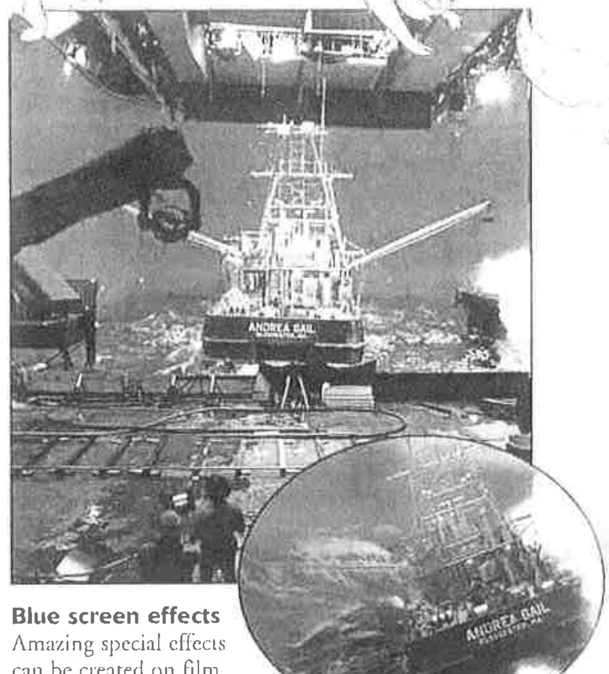


Polaroid pictures

Instant photographs are available with a Polaroid camera. The American inventor Edwin Land (1909–1991) demonstrated the Polaroid camera in 1947. It uses a special type of film that is combined with printing paper. Developing chemicals are stored in packets between the negative and print layers of the Polaroid film. Once the film has been exposed, it passes through rollers which break the storage packets and release the developing chemicals. Modern Polaroid cameras produce pictures in less than a minute.

MOTION PICTURES

A MOVIE IS MADE UP OF A SEQUENCE OF STILL pictures. The continuous movement seen on the movie screen is an illusion. The human brain remembers an image for about a tenth of a second after the image disappears. This effect is called persistence of vision. When two pictures appear in quick succession, persistence of vision blends the first picture into the second, so that a single moving image is seen. The still pictures that make up a movie are called frames. At the movies, 24 frames per second are projected onto the screen. The frames blend together, creating the illusion of a continuous moving image – a movie.

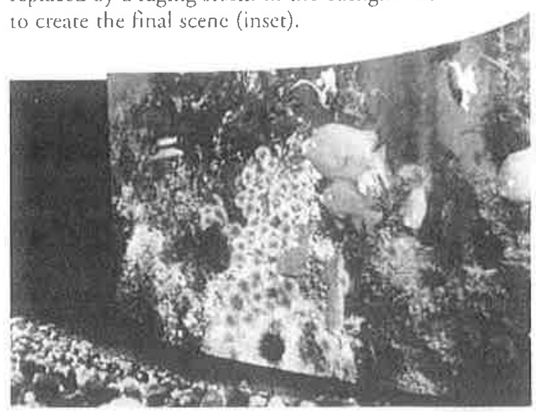


Blue screen effects
Amazing special effects can be created on film with the help of a giant blue screen. First, the scene is filmed in front of the blue screen. A computer is then used to remove the blue and replace it with another background that has been filmed separately. These pictures show a scene from the film *The Perfect Storm* (2000). The actors were filmed on the boat against a giant blue screen. Then the blue was replaced by a raging storm in the background to create the final scene (inset).

EARLY FILMS

An early movie recorded on Eastman's film

The American inventor George Eastman (1854–1932) brought flexible film onto the market in 1889. A year later, William Dickson (1860–1935), an assistant to the American inventor Thomas Edison, developed a way of moving this film through cameras and projectors. He punched tiny holes down the sides, so that metal claws could pull the film along. The first motion picture to be screened for the public was shown in Paris in 1895. It was a silent movie made by French brothers Auguste (1862–1954) and Louis Lumière (1864–1948). Early films had only 16 frames per second. This meant that the pictures seemed to flicker on the screen, instead of blending into a continuously moving image. In 1927, *The Jazz Singer*, starring Al Jolson, became the first "talking" feature film, adding sound to moving images.

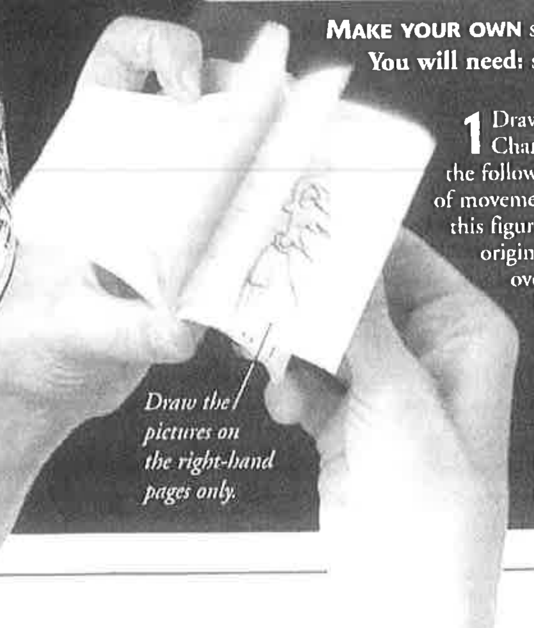


IMAX CINEMAS

Most films are shot on 35mm film, but IMAX films are recorded on 70mm film, which has frames 10 times bigger than normal. IMAX screens are curved so that the picture fills the viewer's entire field of vision. Some IMAX films are three dimensional (3-D). Human brains combine the separate images from our eyes into a single image that has depth and shape. A 3-D camera mimics this by recording images from two lenses. The movie is projected by switching from the "left eye" film to the "right eye" film 96 times per second. Viewers wear special headsets that stop light from reaching the right eye while the left eye image is on the screen, and vice versa. The result is a lifelike, 3-D film experience.

LET'S EXPERIMENT
MAKE A FLICK BOOK

MAKE YOUR OWN simple motion picture.
You will need: small notebook; pen.



Draw the pictures on the right-hand pages only.

1. Draw a picture on the top page. Change the picture slightly on the following pages to create a sense of movement. For example, to make this figure wave his arm, copy your original drawing several times over, moving the arm slightly higher in each picture.

2. Flick the pages of the notebook. The figure appears to be waving in a continuous moving image because your brain blends the pictures together.

ANIMATION

Thousands of drawings are needed to make our favorite cartoon characters come to life. A cartoon feature film contains about 65,000 pictures. Animators draw the characters in different stages of motion onto pieces of transparent film called cels. A succession of these transparent cels are laid over the top of a background drawing which remains the same. For each sequence, animators draw the extremes of movement first, like the takeoff and landing of this squirrel, before completing the in-between stages. The outline of the character is drawn on the front of each cel, then the color is painted onto the back.

The outline shows all of the squirrel's features.

Colors must be consistent throughout.

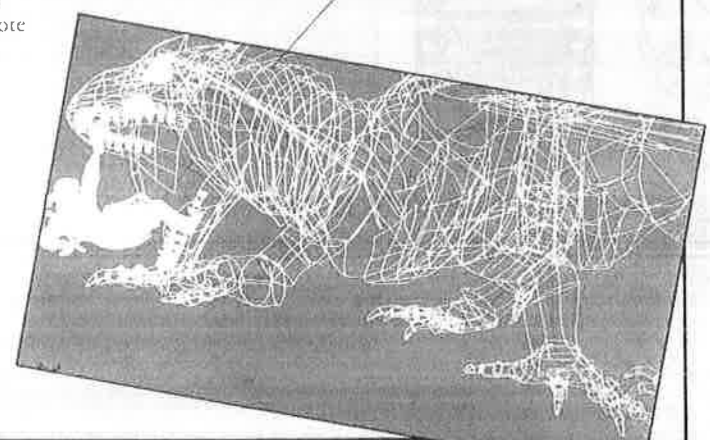
Shifting the background behind the cel is another way of giving the character a sense of motion.

Extremes of movement are drawn first.

Finished cel

3-D animation

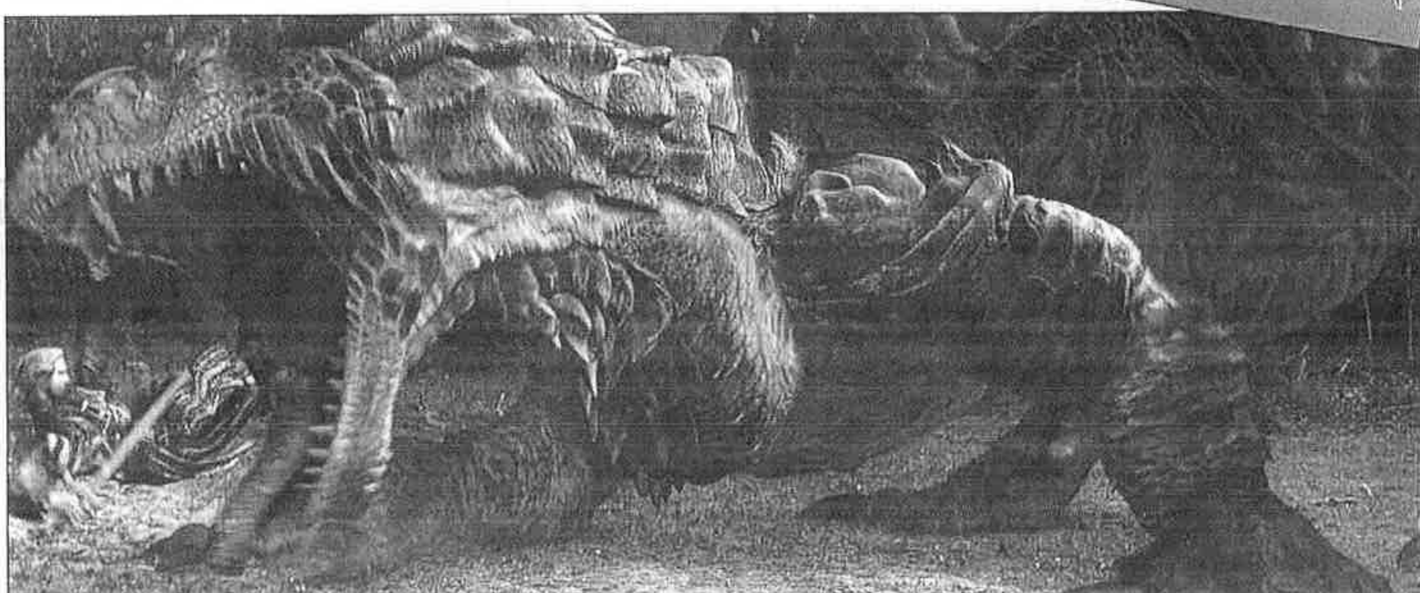
Like 3-D film, 3-D animation adds visual depth to the images. Modeling clay is used to create characters like the one shown on the left. Each frame is filmed separately so that the position of the limbs and facial expressions can be changed slightly in between, giving the impression of continuous movement in the film. Some models have a range of cable or radio controlled motors, allowing the puppeteer to move them via remote control during normal filming. Models are also used in ordinary films to create special effects.



Wire frame image of CGi character

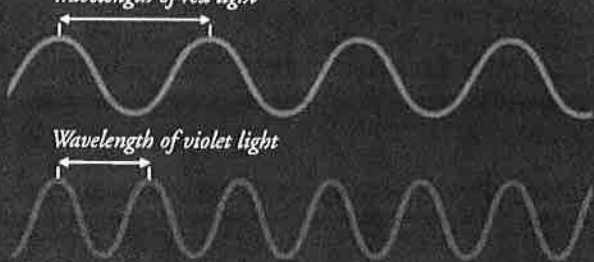
COMPUTER ANIMATION

Many films now use computer generated images (CGi) to create different effects. To produce a CGi character like this dragon from the film *Dragonheart* (1997), a 3-D representation called a wire frame is created on a computer (see right). This acts like a skeleton for the character. Muscles are added to the digital skeleton, then color and fine detail put on top. Computer software enables the CGi character to move in a realistic way. Separately filmed background footage can be combined with the CGi later (see below) to create the finished scene.



WAVES AND COLORS

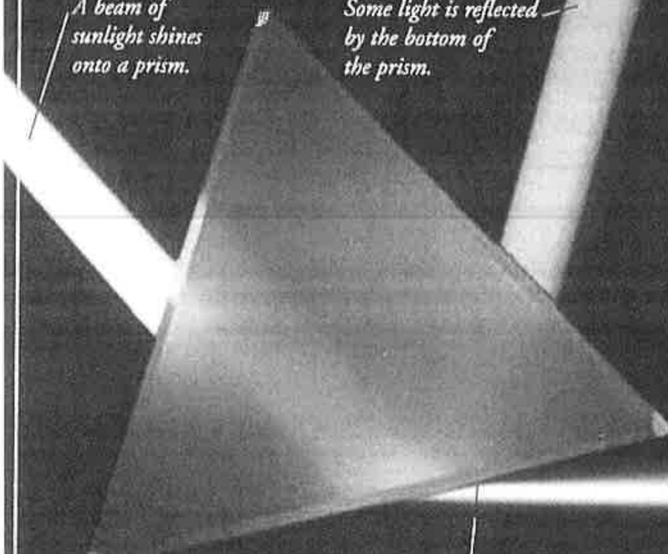
LIGHT TRAVELS IN THE FORM OF TINY WAVES. These light waves have peaks and troughs like waves on the sea. The distance between two peaks is known as the wavelength. Different colors are different wavelengths of visible light. However, white light, such as sunlight, is not just a single wavelength. The famous English scientist Isaac Newton (1642–1727) discovered that sunlight is made up of the spectrum of colors that we see in a rainbow – red, orange, yellow, green, blue, indigo, and violet. Red has the longest wavelength, while violet has the shortest.



Comparative wavelengths of red and violet light

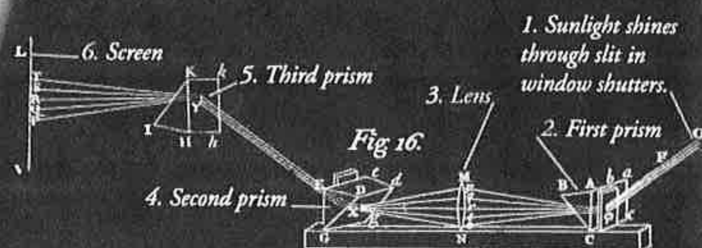
SPLITTING SUNLIGHT

When sunlight shines on a triangular block of glass called a prism, we can see that it is made up of a combination of different colored light waves. The prism bends (refracts) the beam of sunlight. Each color is refracted by a slightly different amount, separating the sunlight into the familiar spectrum of red, orange, yellow, green, blue, indigo, and violet.



NEWTON'S PRISMS

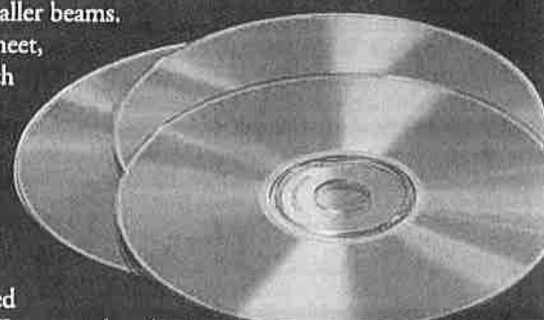
Isaac Newton discovered the light spectrum in 1665 by conducting an experiment similar to the one shown below. (Read the diagram from right to left.) Sunlight shines through a slit in the window shutters and onto a prism. The prism splits the sunlight into the seven colors of the spectrum. The separated light waves then pass through a lens that focuses them onto a second (upside-down) prism. There, the colors recombine to produce another beam of white light. As the beam passes through a third (right way up) prism, the light disperses yet again, displaying the color spectrum onto the screen. When Newton blocked out individual colors before they reached the lens, he noticed that these colors did not appear in the final spectrum on the screen.



This diagram from Newton's book, *Opticks*, published in 1704, shows the dispersion and recombination of the light spectrum.

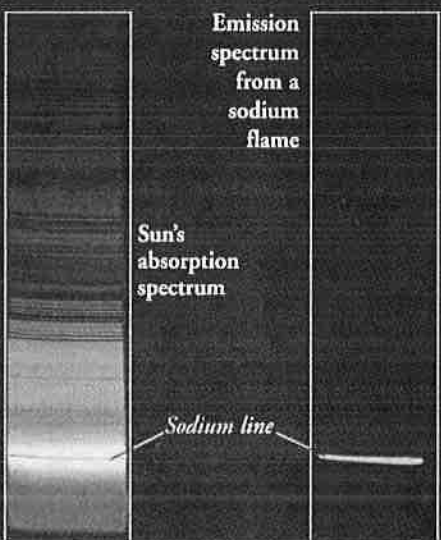
INTERFERENCE

The changing colors of certain objects are produced by interference. These colors are called iridescent. For example, a compact disc has tiny grooves that separate a ray of light into hundreds of smaller beams. Where these beams meet, they interfere with each other. If constructive interference occurs for a particular color, the light waves combine and become brighter. If destructive interference occurs, this color is cancelled out. When viewed from different angles, the colors change. Soap bubbles have iridescent colors that are created when the light reflected by the outer surface interferes with the light reflected by the inner surface.



Stellar spectra

The color of light often indicates temperature. For instance, we can tell how hot a star is by its color. The hottest stars are blue, while the coolest are red. Yellow stars like our Sun are in between, with a surface temperature of approximately 9,900°F (5,500°C). Most light emitted by a star is of a particular wavelength, but other colors do appear in the spectrum. Astronomers can analyze the spectrum to find out which chemical elements are present (below).



Spectroscopy

Different types of atoms absorb and emit different colors of light, so a spectrum can be used to identify elements in a substance. An absorption spectrum is obtained by shining a white light through a substance, then splitting the light into a spectrum. Dark lines on the spectrum represent atoms that absorb that specific color. The Sun's spectrum (above left) shows several dark lines. One line shows an absorption of yellow light by sodium in the Sun's outer layers. An emission spectrum shows the color of light emitted from a substance. A sodium flame gives off yellow light, as shown in this emission spectrum (above right).

LET'S EXPERIMENT
PRODUCING A SPECTRUM

YOU CAN DO THIS VERSION of Newton's spectrum experiment in front of a window at home. **You will need:** cardboard; scissors; straight-sided glass filled with water; adhesive tape; white paper. For the best results, carry out the experiment on a sunny day. You can also use a flashlight beam instead of sunlight, although the spectrum won't be as clear.

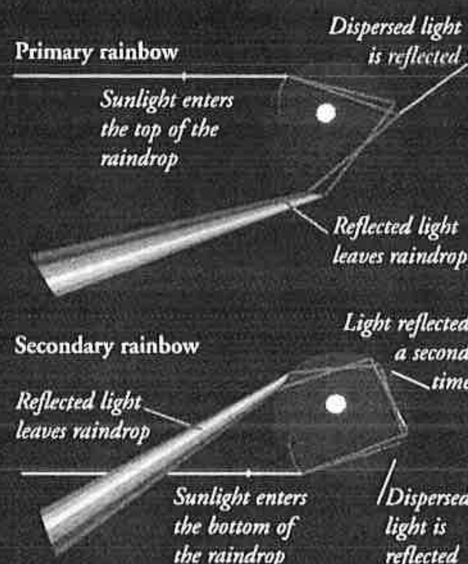
1 Cut a long vertical slit in the cardboard. Tape the cardboard to the glass of water. (The glass of water will produce the same effect as a prism.) Stand the glass on a sheet of paper placed in front of a window, so that sunlight shines through the slit in the cardboard and onto the glass.

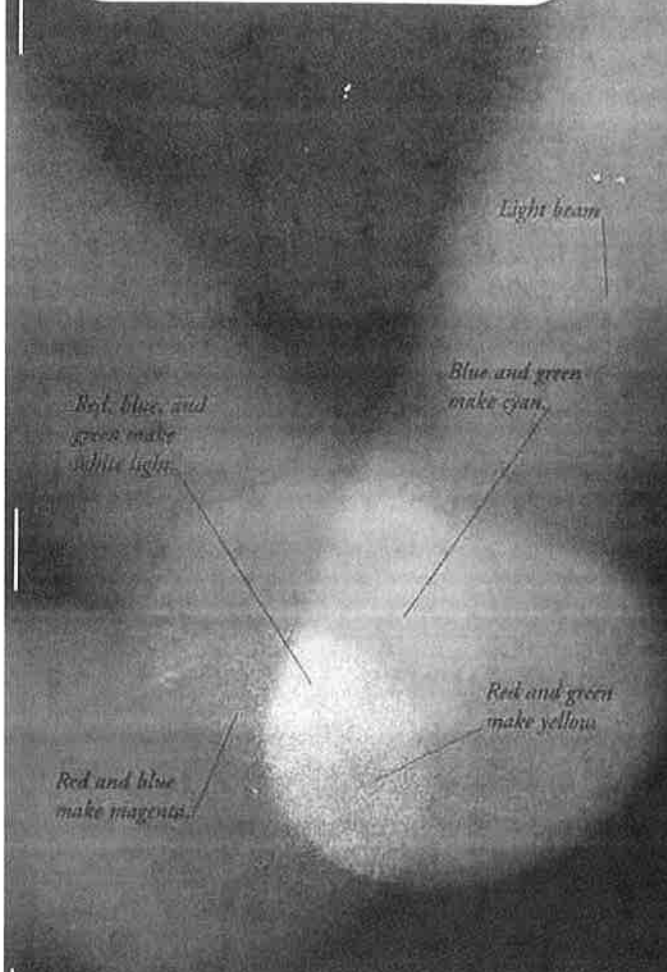
2 The sunlight coming through the slit is refracted by the glass of water. Each color in the beam of sunlight is refracted by a slightly different amount, causing a spectrum to appear on the paper.

A spectrum forms on the paper.

RAINBOWS

When there is sunshine and rain at the same time, a rainbow may appear. Sunlight is bent (refracted) as it enters a raindrop. It is then reflected off the back of the raindrop before being refracted again as it leaves the drop. Each color in the white sunlight bends by a slightly different amount as it enters and leaves the drop. This splits the sunlight into the familiar colors of the spectrum – red, orange, yellow, green, blue, indigo, and violet. Occasionally, you can see a double rainbow with a fainter, secondary rainbow outside the primary one. The secondary rainbow forms when sunlight enters the bottom of the raindrops instead of the top. The sunlight is then reflected twice off the inner surface of the drop, which means that the order of the colors in a secondary rainbow are reversed.



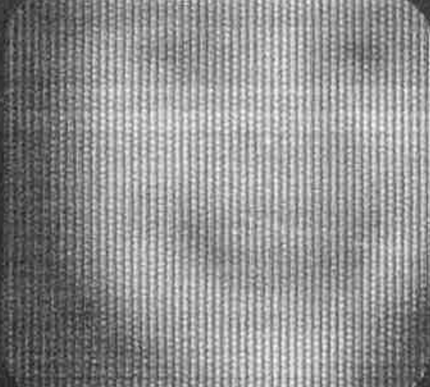


MIXING COLORS

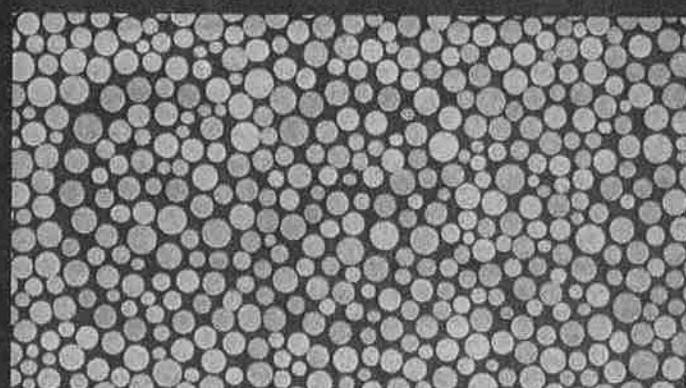
WHITE LIGHT IS MADE UP OF ALL the colors in the spectrum (pp. 118–119). It is also possible to make white simply by adding together the three primary colors of light – red, blue, and green. Amazingly, by combining these primary colors in different proportions, you can produce any color you wish. This process is known as "color addition," and it is how a range of colors is produced on television screens. However, unless an object is a source of light, for example a flashlight, it does not give out its own distinct color. The things that surround us appear to be colored because they reflect a single color or a mixture of colors back to our eyes from the white light that falls on them, while absorbing all other colors. Paints and pigments work in the same way. Forming colors like this is called "color subtraction" because colors are taken away from white light to make the color that we can see.

PRIMARY COLORS OF LIGHT

Red, blue, and green are the primary colors of light. Combinations of these three primary colors can make any other color (see above). A mixture of red light and green light gives yellow, while mixing blue light and red light makes magenta. Blue light and green light together produce a bright turquoise blue called cyan. Varying the amounts of each light in any mixture allows many more colors to be produced. Mixing all three primary colors together in equal amounts produces white light. Color addition like this is used to produce the different colors on the screens of color televisions.



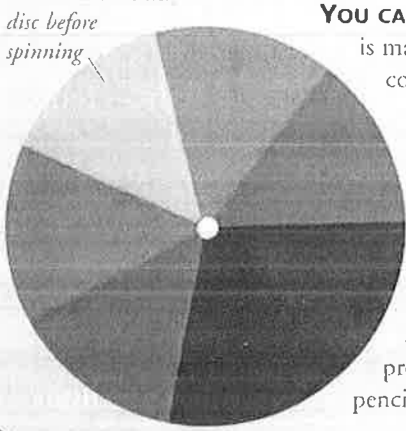
Television
Tiny dots or strips of phosphor are arranged all over color television screens in groups of three (left). In each group, one dot will emit red light, another blue, and the remaining one green. Varying the amounts of each of these primary colors of light creates a full range of different colors when the screen is viewed from a distance.



COLOR VISION

Light is focused on the retina inside the eyes, and millions of light-sensitive cells send signals along the optic nerve to the brain. Rods and cones are the two main types of such cells. Rods work in dim light and cannot detect color. Cones come in three types – one responds to blue light, another to red, and the third to green. As these are the primary colors of light, all other colors can be seen as they stimulate different combinations of cones. Not everyone can see all colors. People who are color blind have defective cones, so they confuse colors. Color blindness can be diagnosed using tests like this picture (above). People who cannot see the difference between red and green do not see the number 683.

LET'S EXPERIMENT
SPINNING DISC



Colored cardboard disc before spinning

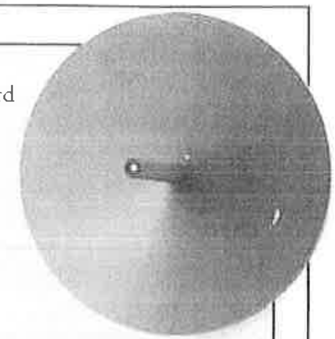
YOU CAN SHOW THAT white light is made up of a mixture of colors. Each color painted on a disc will reflect a different color of light. When you spin the disc, these colors will mix together to produce white. **You will need:** piece of cardboard; saucer; pencil; scissors; protractor; colored paints; pencil sharpener.

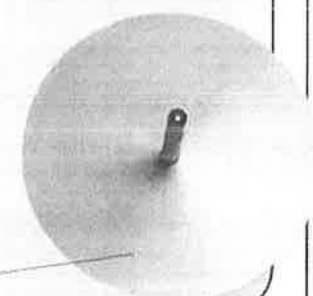
1 Place the saucer on the piece of cardboard and draw around it. Carefully cut out the disc, and use a protractor to divide it into seven equal segments.

2 Color in the segments with the colors of the spectrum in the order that they appear in a rainbow – red, orange, yellow, green, blue, indigo, and violet.

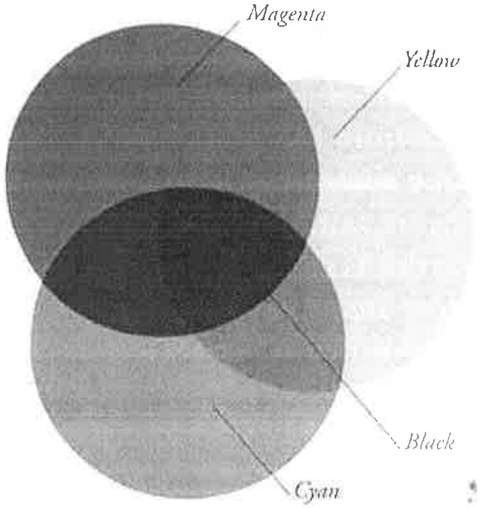
3 Sharpen the pencil and carefully push it through the center of the disc. Position the disc halfway along the pencil's length.

4 Stand the pencil on its point and use the other end to spin the disc as quickly as possible. The colors merge together and the disc looks almost white.



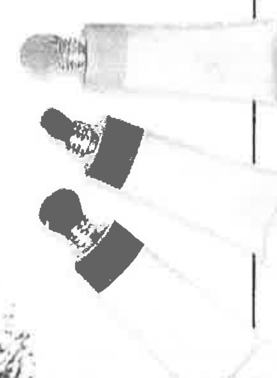


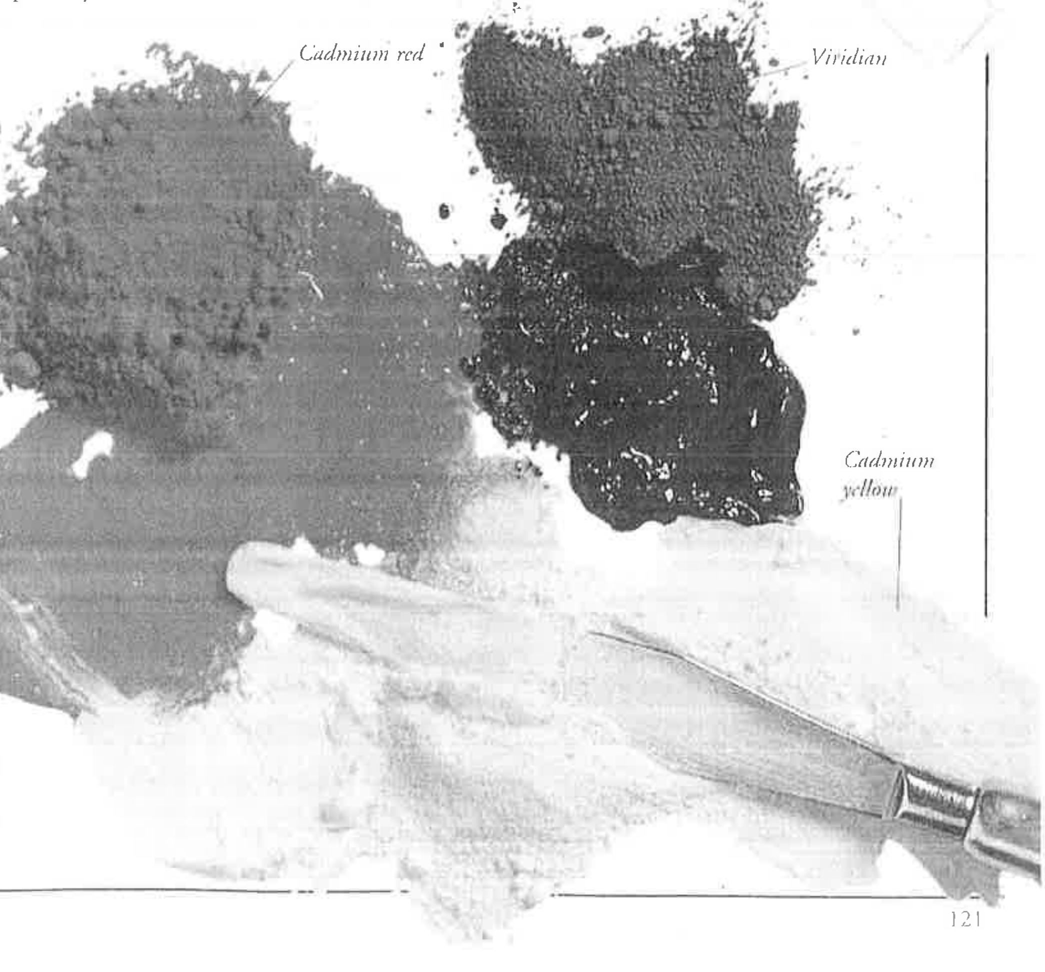
The colors disappear as the disc spins.



PRIMARY COLORS OF PIGMENTS

Pigments absorb certain colors from the light that falls on them and reflect others. Magenta, cyan, and yellow are the primary colors of pigments, and each absorbs one of the primary colors of light. For example, yellow pigment absorbs blue but reflects green and red light, which our brains add together so we see yellow. Different combinations of primary pigments produce every color except white. If equal amounts of all three primary pigments are mixed together, they absorb all three primary colors of light and we see black (left). When painting, red, blue, and yellow are used as primary colors instead.





Natural dyes and pigments

Many of the dyes and pigments that we use today are artificially created, but in the past they were made from natural substances. The earliest cave paintings used colors made from ground-up rocks and clays, charcoal, and chalk. Cave painters only used a limited range of colors – mainly reds and browns – but by the Middle Ages a much larger variety of dyes and pigments had been discovered. Many were made from crushed minerals, which produced vivid colors. Viridian, for example, is a bluish-green mineral called chromium oxide found in a type of clay called "terre verte." Cadmium yellow is a bright yellow pigment that contains the metallic compound cadmium sulfide.