PART I

Inventions That Use Light

We have been experimenting with light since our prehistoric ancestors first lit fires. Our ancestors didn't know it, but now we know that light is a form of energy. Light is packets of energy called **photons.** When the packets are traveling through a **vacuum**—a space that is empty of all matter—they travel very fast (186,000 miles or 300,000 km per second) in a straight line.

When light encounters matter, such as the gases in the Earth's atmosphere, water, or a mirror, it no longer travels in a straight line. The path of the photons is changed. Some kinds of matter, such as mirrors, **reflect** (bounce back) the light. Others, such as water, **refract** (bend) the light so that it passes through at an

angle. If photons hit a pane of clear glass at a *right angle* (a 90° angle), they pass through without change.

The ancient Mesopotamians experimented with reflected light and, as early as 1500 B.C., invented mirrors made of shiny metals. The ancient Greeks figured out how to focus reflected light off a curved mirror to start a fire. (Archimedes is said to have set enemy ships on fire with a huge version of such a mirror, but that's probably a tall tale.) As you will see in this section, inventors in the nineteenth and twentieth centuries used reflected light to make the kaleidoscope and the periscope.

People have long noticed that light is refracted when it passes through water. (Next time you're at a pool, stand in the water and stretch out your arm under water. It will look as though your arm is broken because the light reflecting off your arm is slowed down and bent by the water.) Once glassmakers learned to make transparent glass, inventors noticed that light was also bent by glass. They put their observations to use and created a multitude of devices including magnifying glasses, spectacles, telescopes, and microscopes, which worked by bending light. Gem cutters around the world learned how to shape *transparent* (clear) and *translucent* (almost clear) minerals so that light refracted within them and reflected off them, making them sparkle.

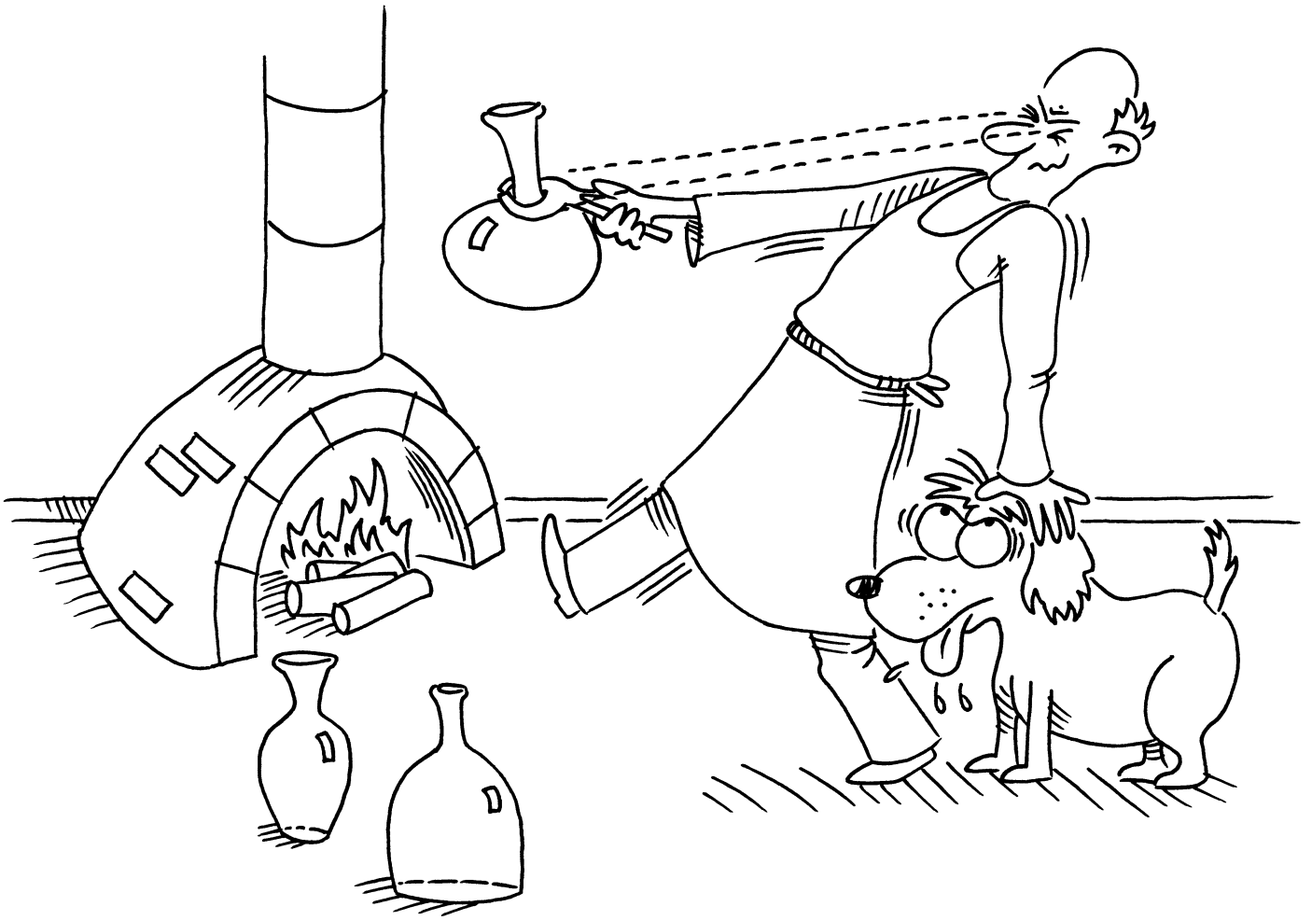
Until about A.D. 1000, most people thought that eyes produced or *emitted* light, which then bounced off objects so that they were seen. Then, Arab mathematician Al-hazen suggested that eyes receive light that comes to them. Slowly, over the following centuries, scientists came to understand the workings of the eye and how the brain interprets the light it receives. The phenakistiscope, which you will find described in this section, resulted from an optical scientist's study of how long the brain sees images.

1 Spectacles

The Problem

You are a glassmaker on the island city of Venice (in what is today Italy) in the late 1200s. You and your fellow craftspeople at the Venetian glass factories are renowned throughout Europe for the beautiful, light, transparent blown-glass objects you make. You love your work and are expert in decorating glass with intricate patterns of gold, silver, and enamel threads melted on its surface.

You are now 45 years old and, unfortunately, your eyesight is declining. In order to clearly see the object you are working on, you need to hold it almost at arm's length. Soon, your arms won't be long enough! You don't want to give up your craft. What can you do?



Glass is made from sand, sodium carbonate (a chemical found in the ashes of burned vegetation or as deposits in the earth), and lime, which is chalk. The ingredients must be combined at temperatures of about 2,500° F (1,400°C). No one knows for certain who invented glass, but glass dating to 2250 B.C. was found in Mesopotamia, the area between the Tigris and Euphrates Rivers (in what is now Iraq). It may be that Mesopotamian potters created glass by accident. They needed to bake their pots at high temperatures to make them hard and waterproof. In heating the pots, they may have fused sand and some minerals on the surface of the pot, making a glassy surface.

At first, people made only beads out of glass. Then, they discovered they could pour hot glass into molds and form cups and other useful objects. About 1000 B.C., glassmakers learned how to blow glass into shapes. By blowing through a long metal pipe into a blob of molten (melted) glass, they could create bubbles in the glass. The bubbles could then be shaped into glasses and bowls and even flat pieces.

Observations

Because the glass made at your factory is quite clear, it is especially good for making "reading stones." A reading stone—an invention that the Europeans borrowed from the Arabs—is a hemisphere of clear glass that a reader places, flat-side down, on a page. The letters directly beneath the center of the stone are greatly enlarged, making it possible for people with failing eyesight to read.

A reading stone is cumbersome and only works when lying flat on a page, so it wouldn't help you at all. But, it gives you an idea . . .

MATERIALS

small pot
water
spoon
package of unflavored gelatin
small bowl as nearly hemispherical (half of a globe) as possible
page from a newspaper or magazine
plastic wrap
pan
two small plastic resealable bags about 1¼ × 1¼ inches (3 × 3 cm), available at craft stores
tape

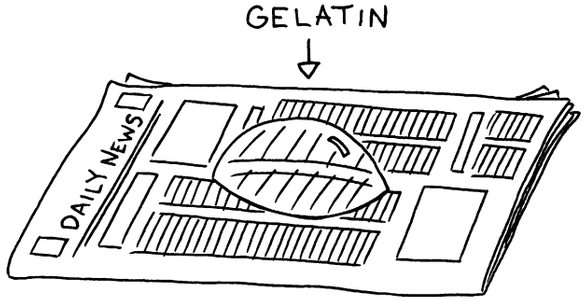
Experiments

1. Use the small pot, water, and spoon to prepare one package of gelatin according to the package instructions.

2. Fill the bowl with gelatin. Put the bowl in the refrigerator.

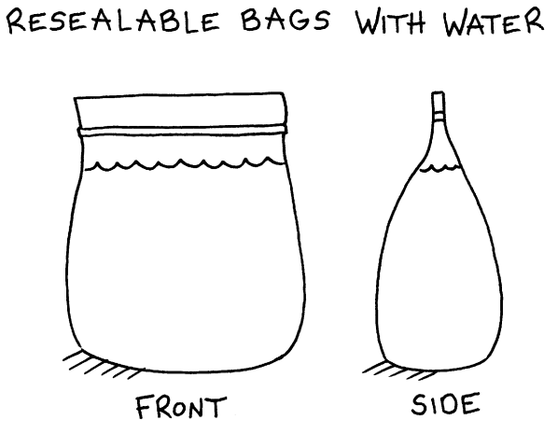
3. Cover a page from a newspaper or magazine with a piece of plastic wrap.

4. When the gelatin is completely solid, remove the bowl from the refrigerator. Put the bowl in a pan of hot water so that the water level is just below the rim of the bowl. Wait 1 minute. Turn the bowl upside-down on top of the newspaper. A dome-shaped block of gelatin should slip out. (If it doesn't, put the bowl back in the hot water for another minute.) This is your reading stone.



5. Observe how the reading stone magnifies the words beneath it. Lift your reading stone from the page and look through it. Does it still work?

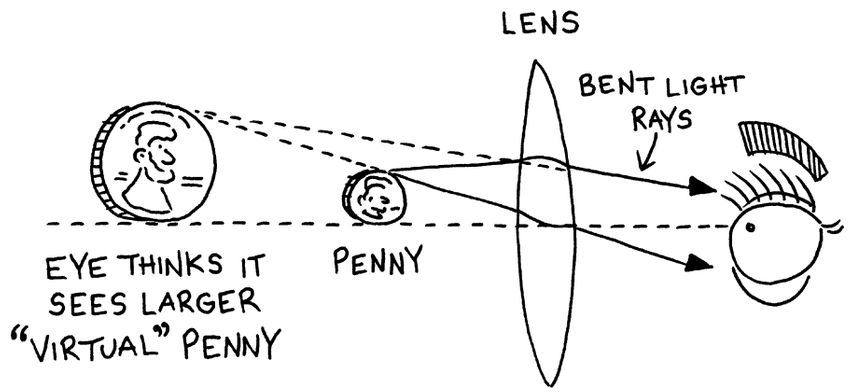
6. Fill one of the resealable bags with water and seal it. Note how the bag looks when you view it from the side. Try placing the bag directly on the page. Does it make the print look larger? Hold the bag flat a few inches above the page and look down through it. Does this make the print look larger? Experiment with holding the bag close to your eye, and then, with your other hand, moving the page toward your eye. At what distance does the print look the largest?



7. Fill the other resealable bag with water and seal it. Take the plastic wrap off the newspaper or magazine page and tape the page to a wall

A **magnifying** (enlarging) lens has two surfaces. One of the surfaces must have an outwardly curving (**convex**) shape. The other surface can be flat or also convex. When a magnifying lens has two convex surfaces (meaning the lens is **biconvex**), each surface magnifies. A biconvex lens is slimmer and weighs less than a lens with only one convex surface.

Convex lenses bend light in a way that makes objects appear larger. When you hold a magnifying lens in front of your eye, the light reflecting from the page toward your eye bends. Your brain assumes, however, that the light rays have reached your eyes in the usual way, in a straight line. Your brain traces the path of the light back in a straight line, to where it would have come from if it hadn't been refracted by the lens. You actually see a "virtual" image of the page. The enlarged virtual image isn't real: your brain has constructed it!



or other surface at eye level. Hold a water-filled bag in front of each eye and approach the page until the print becomes large and clear. You've made a pair of reading spectacles! Of course, thirteenth-century spectacles weren't made of water; they were made of glass. It is the shape of the clear material (whether water or glass) that makes them work.

Answers from the Past

The earliest people must have noticed that the domed shape of a water drop on a flat surface makes whatever lies beneath it look larger. Ancient Greek and Roman writers remarked on the fact that a glass globe filled with water would magnify items placed in it or behind it. It wasn't until the Middle Ages, sometime after A.D. 1100, that people put the magnifying ability of a clear, curved surface to work.

When the Crusaders returned from their efforts to recapture Jerusalem in the 1100s, they brought back the writings of a gifted Arab mathematician named Al-hazen. Among Al-hazen's works were detailed studies of precisely how light is refracted by water and glass and how images are magnified. European monks read Al-hazen with interest. As avid readers (and among the few literate people of the time), they recognized the practical value of his studies. They took pieces of clear quartz (called rock crystal) and the semiprecious stone beryl, and ground and polished them into hemispheres. They invented reading stones, which magnified words on a page just as your gelatin reading stone does.

By the Middle Ages, the art of glassmaking had been practiced around the world for thousands of years, but the glassmakers who lived and worked in Venice in the thirteenth century took the art to a stunning new level. Not only did they blow the most artful shapes and apply the most elegant designs to their work, but they worked with very clear glass. Rock crystal and beryl were expensive, so the glassmakers found a ready market for reading stones made out of glass.

No one knows exactly who invented spectacles, but we do know they were invented in Italy in the last few decades of the thirteenth century. An aging Venetian glass craftsman could have been the inventor. This person would have had the skills to make lenses. He also would have had the motivation to make them: most people over the age of 40 develop **presbyopia,** which means an inability to see close objects clearly.

Presbyopia has Greek roots. ***Presby*** **means "old man" in Greek and** ***opia*** **means "relating to the eyes." If you have presbyopia, you have "old man eyes."**

Whoever invented spectacles would have made a fortune if there had been patent laws in the thirteenth century. Spectacles to remedy presbyopia caught on immediately, and their use spread quickly across Europe. At first, people simply held the lenses, one in each hand, and looked through them. A little later, they encircled each lens with a metal or wooden frame and a bit of a handle and attached the ends of the handles with a rivet. The wearer balanced the joined ends on the bridge of his nose! It was not until a century later that someone invented frames with sidepieces that wrapped around the ears.

Inventor's Challenge

Using the two lenses you made and other materials you can find around the house, can you invent a new device (not the traditional frame for glasses) that will hold the lenses in place in front of, but not touching, your eyes?