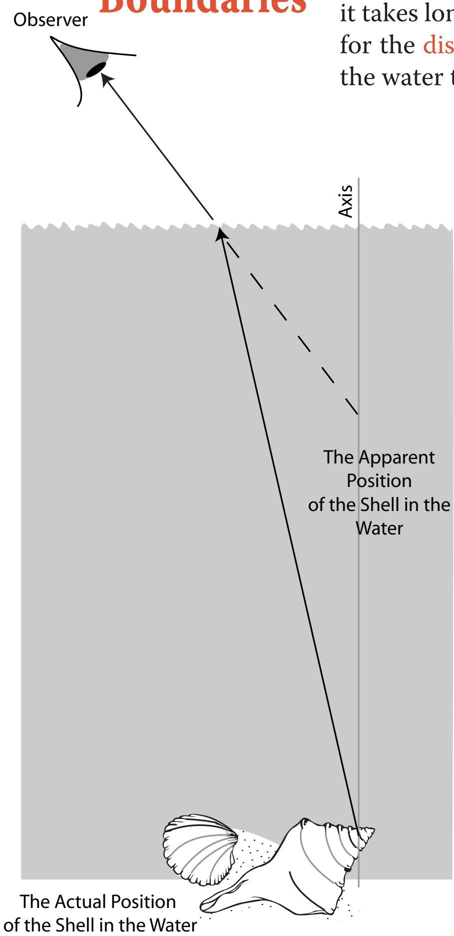
OPTICS: REFRACTIONS

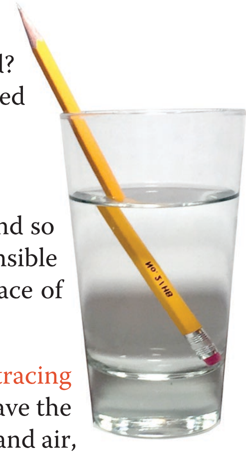
Supermarket Science

LEARN

Bending at the Boundaries



Put a pencil in a full glass of water. Do you see how the pencil appears to bend? Have you ever spied a pretty shell in the water only to find, when you reached down and tried to grab it, that it was a lot deeper than it looked?



What's going on?

Light travels slower through water than through air—water is denser than air and so it takes longer for light to travel through it. It's this speed difference that's responsible for the distortion of the pencil, and it makes the shell appear closer to the surface of the water than it really is.

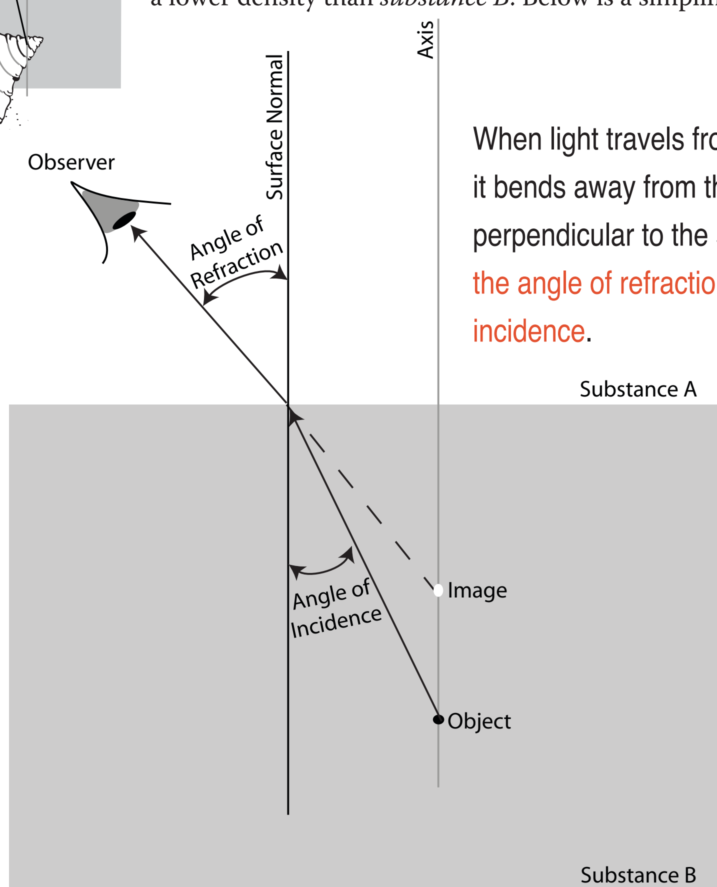
To understand how the image gets distorted, we can draw some ray tracing diagrams. Let's start with the shell in the water. The rays of light leave the shell and travel through the water. At the boundary between water and air, the rays of light get bent. This bending of light as it travels from a substance of one density to a substance of a different density is called refraction. Our eyes only see the direction from which light appears to travel and do not see the bend. Our brains assume that the light rays are straight. In this case, it's an assumption that's wrong.

Light doesn't only bend at the boundary between water and air. It bends at *any* boundary between materials of different densities: air and glass, for example. Glass is denser than air, so light travels slower through glass. Glass is also denser that water.

What would it look like if the shell if was embedded in glass instead of water?

If we looked at the shell in a glass from the top, would it seem deeper or closer to the top than it did when it was in the water? How about if we get into the water and look up at a bird flying in the air? How would the true position of the bird be different from the image of the bird we see?

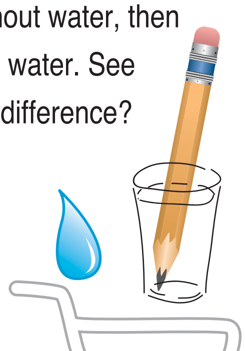
To answer these questions, let's ray trace! Let's use a dot instead of a shell or a bird. And let's consider a boundary between two substances of different densities: *substance A* (which could be air) and *substance B* (which could be water). *Substance A* has a lower density than *substance B.* Below is a simplified ray tracing diagram.



When light travels from dense to less dense material, it bends away from the surface normal (the line perpendicular to the surface). Saying it another way, the angle of refraction is greater than the angle of incidence.

Conversely, when light travels from less dense to more dense material, it bends towards the surface normal—or the angle of refraction is less than the angle of incidence.

Try the pencil experiment—first look at the pencil in a glass without water, then add water. See the difference?

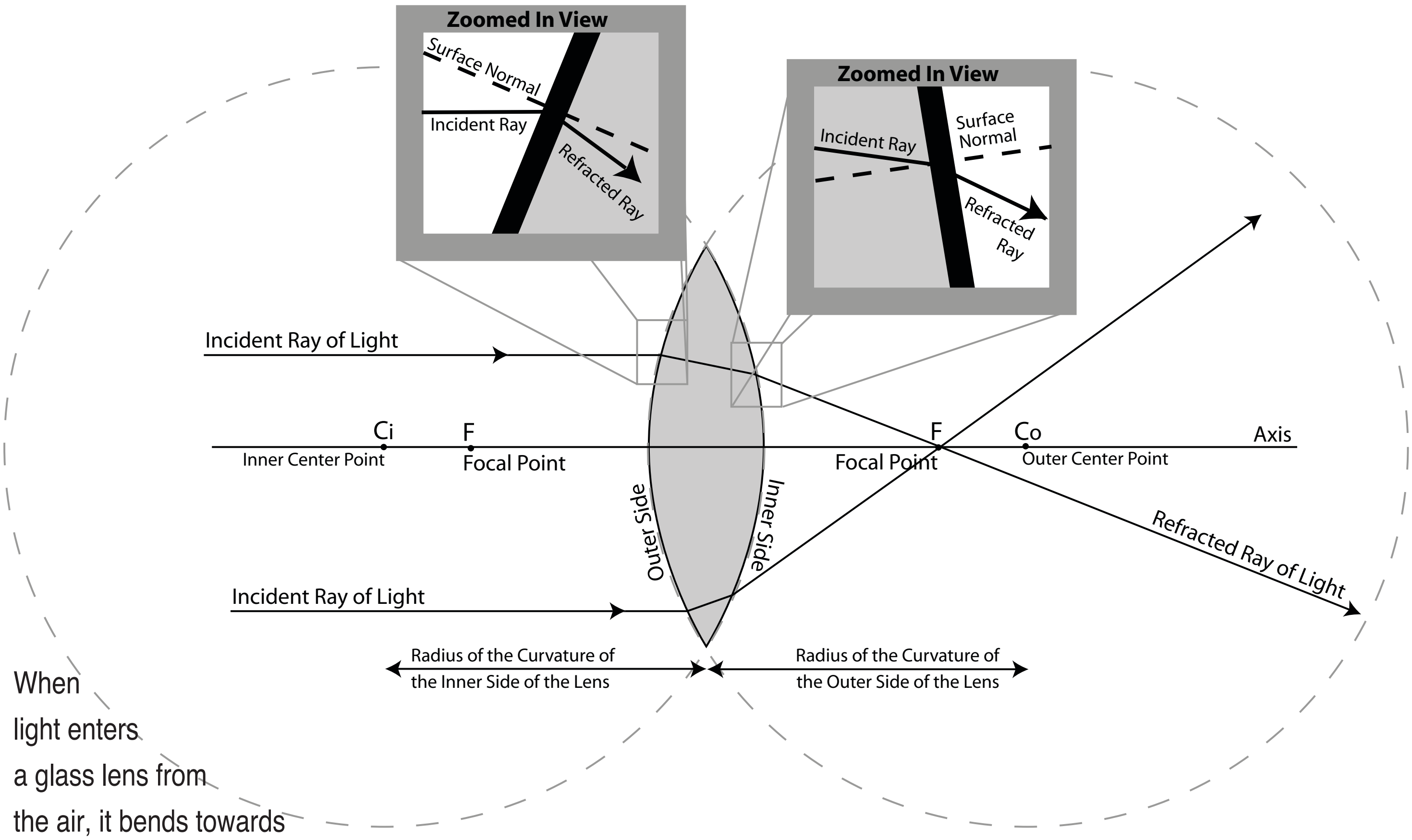


LEARN

Lenses: Controlling the Bending of Light

We encounter the refraction of light every day: windows, eyeglasses, cameras, telescopes, microscopes, and magnifying glasses. In all these devices, light gets bent multiple times as it passes the boundaries between air and glass and back again. In fact, we rely upon this property of light to see—our cornea bends light to focus an image onto our retina. In all these cases, how much the light bends depends on the difference in densities of the materials it passes through, the wavelength of the light itself, and the curvature of the lens at the point where the ray hits.

Consider a magnifying glass, which is a double convex lens. Unlike mirrors, lenses have two sides that we have to consider: the outer and the inner side. We're defining the outer side as the one through which light travels first. The inner side is the one through which light exits the lens. The curvature (the radius of the surface) of the outer side of the lens can be different than the inner side, but for magnifying glasses and most simple telescopes, the curvature is the same. Although the rules work for asymmetrical lenses, we're only considering the simpler, symmetrical lens.



When light enters a glass lens from the air, it bends towards the surface normal. When it exits, it bends away from the surface normal. These simple rules can be used to guesstimate ray tracing diagrams of very complex lenses.

The incident ray of light has to pass two surface boundaries: from the outside air to the inside of a glass lens and from the inside of a glass lens to the air again. This means that the ray of light travels from less dense to more dense to less dense material. Every time it does that, it gets refracted—bent from its previous direction. So in a two sided lens, each ray of light gets bent twice.

On a curved lens, as with a curved mirror, we can zoom in so close to the surface of the lens that, for the very small area being examined, the lens looks flat. When we draw a perpendicular from that flat area, we have the surface normal at that point. We can talk about the direction in which the ray of light gets refracted by comparing its direction to the surface normal.

Rule: when traveling from less dense to more dense material (i.e. air to glass), light bends towards the surface normal.

Rule: when traveling from more dense to less dense material (i.e. glass to air), light bends away from the surface normal.

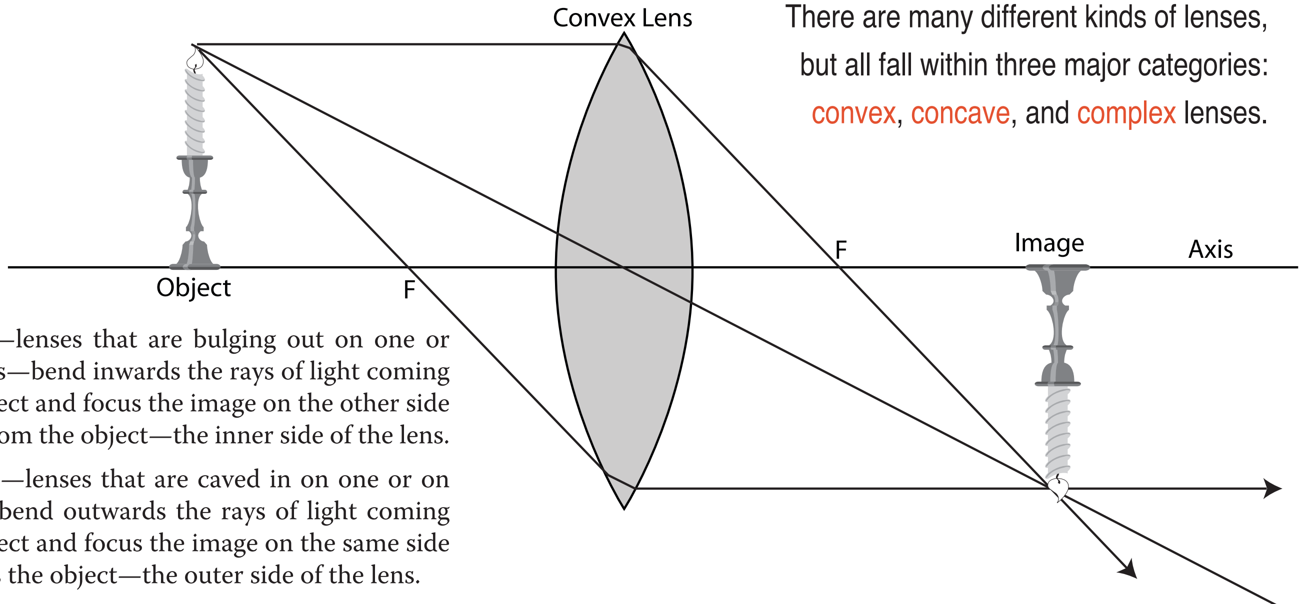
Supermarket science

LEARN

Lens Come in All Shapes and Sizes

The hand looks upside-down and flipped left to right as seen through this glass ball—a double convex lens.

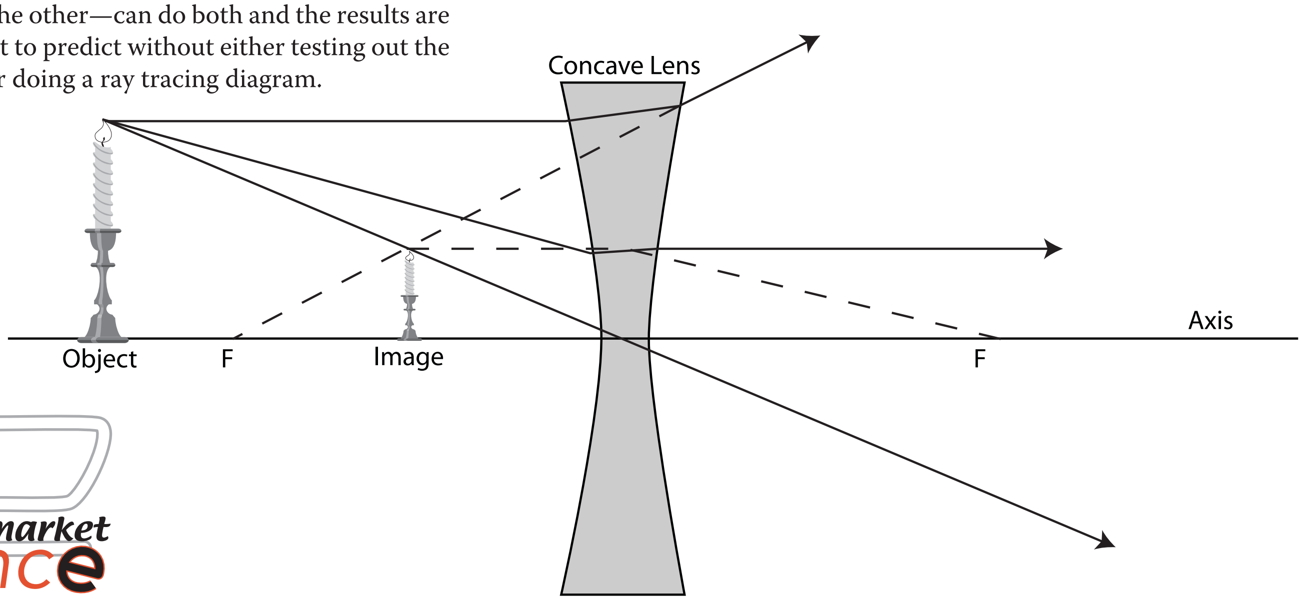
There are many different kinds of lenses, but all fall within three major categories: convex, concave, and complex lenses.



Convex lenses—lenses that are bulging out on one or on both sides—bend inwards the rays of light coming from the object and focus the image on the other side of the lens from the object—the inner side of the lens.

Concave lenses—lenses that are caved in on one or on both sides—bend outwards the rays of light coming from the object and focus the image on the same side of the lens as the object—the outer side of the lens.

Complex lenses—lenses that are convex on one side and concave on the other—can do both and the results are more difficult to predict without either testing out the actual lens or doing a ray tracing diagram.



Supermarket science

DO

Lens Diagnostics

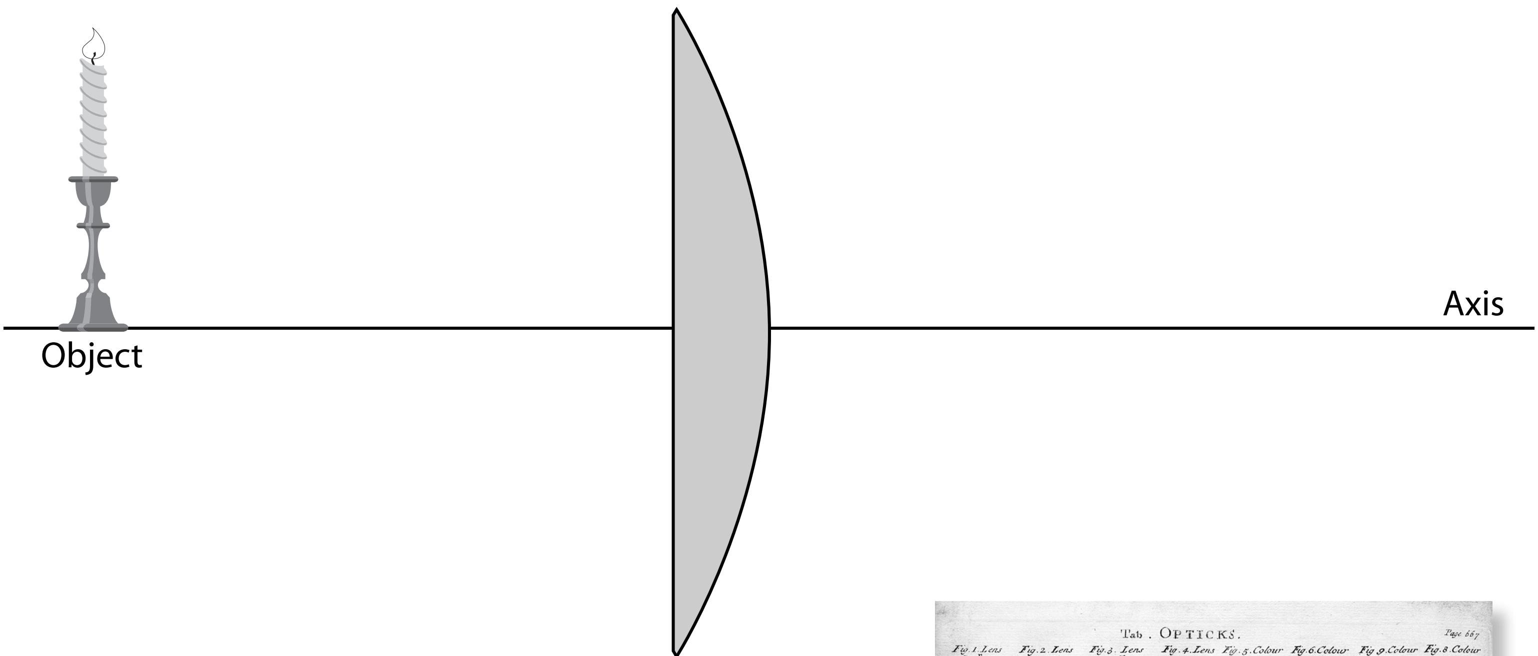
Diagnose the lens below using the ray tracing diagrams to guide you. To diagnose the lens, ray trace three incident rays from the top (as shown in the example on the previous page). Draw the approximate position of the image that the lens would produce.

Would the lens make an image that was right side up or upside down?

Would it be a bigger or a smaller image than the actual candle?

Would the image be on the outer or the inner side of the lens?

Hint: The radius of curvature of the flat side of the lens is zero. That puts the focal point on the surface of the outer side of the lens. Happy ray tracing!

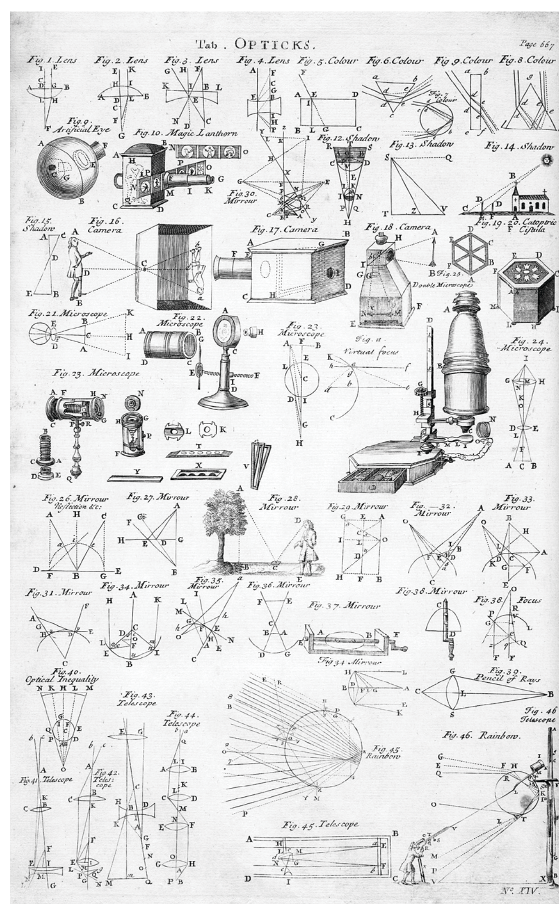


What You Need:

Use a red pencil for Incident Ray and a green pencil for Reflection.

Use a rule and a protractor to make sure your light rays are straight and the angle of incidence is equal to the angle of reflection.

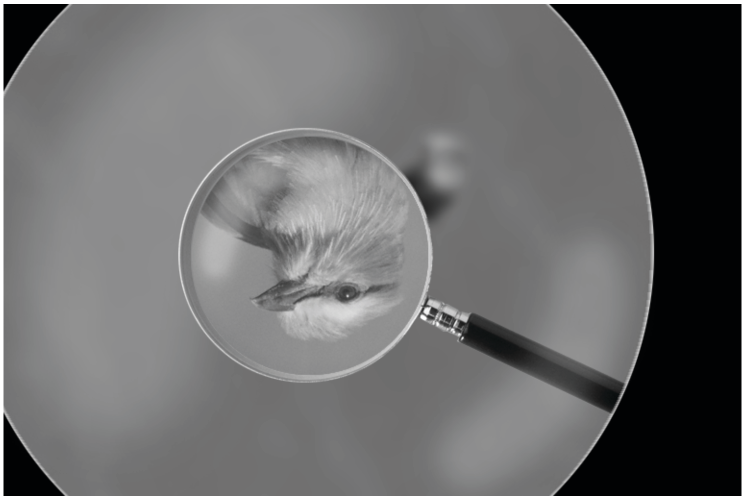
People have been thinking about lenses and how they change the path of light as it goes through them for hundreds of years. And all that time, we were using ray tracing diagrams to figure out what happens.



DO

Telescope Workshop

What You Need:



Two magnifying glasses, one held at the eye and the other held at arm's length, make an effective telescope.

For this activity, you need two magnifying glasses. Each magnifying glass contains a double convex lens within a bezel attached to a handle. It's best to have one of the lens smaller and more powerful than the other.

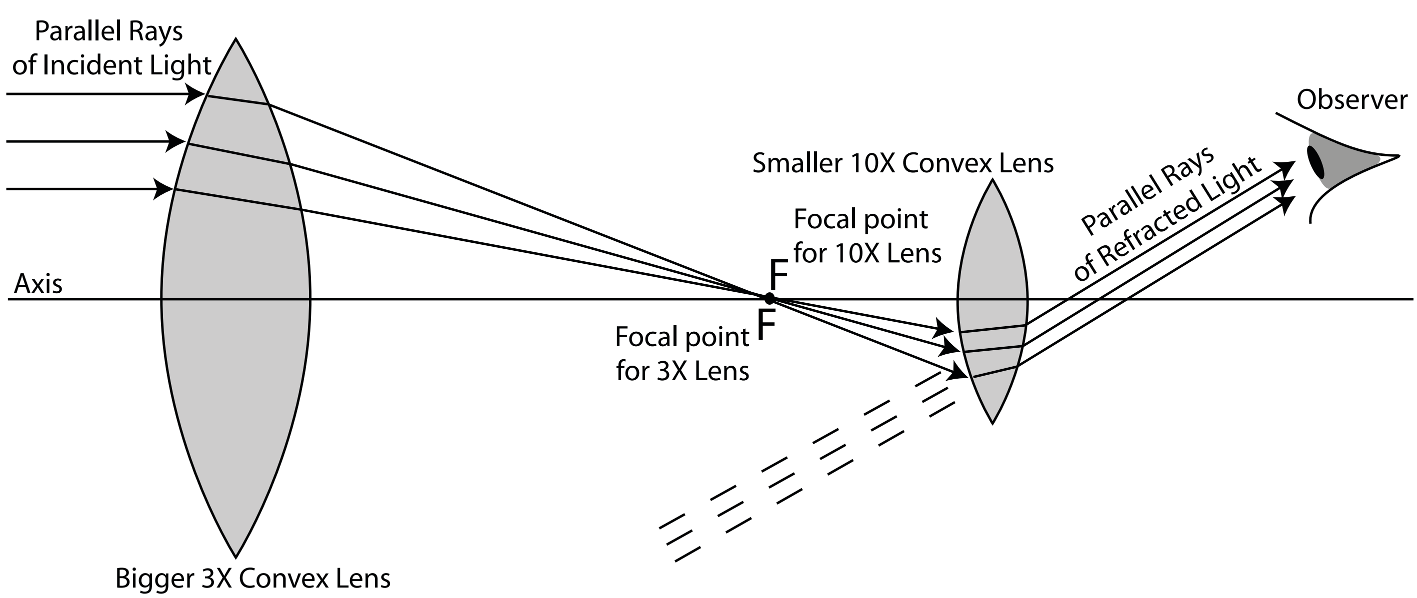
The illustration on the left shows a magnifying glass that is 2 inches in diameter and 10X power coupled with another that is 4 inches in diameter and 3X power. This is an ideal combination for this experiment, but any combination of magnifying lenses would work, even two of the same size.

(Magnifying glasses of this type are inexpensive and can be found in any drug store.)

Take the smaller lens and hold it to your eye. Take the larger lens and hold it at arms length. Look at something over 20 feet away (like the trees outside). Then slowly move the big lens closer to your eye until the image is in focus.

Congratulations! You've just made a telescope.

A simple telescope is just two double convex lenses separated by the right amount of distance to put far away images in focus. The diagram below shows how the light is bent by each lens prior to hitting your eye. Note that the lenses need to be separated by their combined focal lengths—in other words, the focal points of each need to overlap at the same spot.

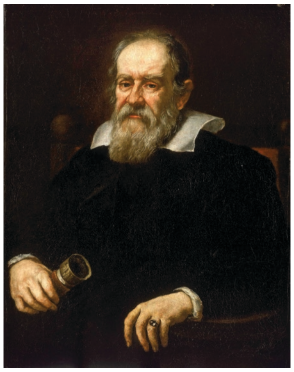


The Ray Tracing Diagram of the two magnifying lens shows how the image becomes both inverted and magnified. The lenses must be held apart by a specific distance, which is the sum of the focal points for each lens. In practice, this is discovered by moving the lenses back and forth until the image comes into focus.

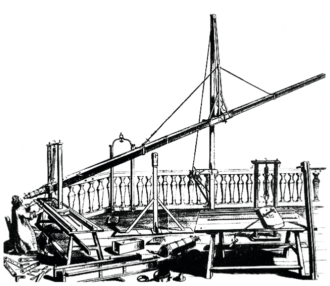
Supermarket Science

LEARN

The Invention of The Telescope



Above is a portrait of Galileo Galilei, 1636. On the right is Galileo with his telescope in the Piazza San Marco, Venice. Wood engraving.

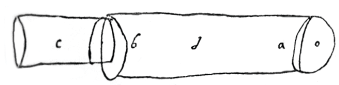


People have been aware of the way in which convex and concave lenses distort light for hundreds of years. But it was not until good quality, reasonably priced transparent glass was available that the grinding and polishing of lenses became widespread. Magnifying glasses became common about 1200 A.D. and from about 1350 we have early illustrations of lenses being used to correct vision. The disks of glass that were made into glasses were shaped like lentils and were called "lentils of glass." The word "lens" comes from the Latin version of this phrase.

We may never know for certain who invented the telescope. Around 1608, a lot of people claimed to have made that discovery, but we have writings from 1589 that explain the basic optics of the telescope. One thing we do know for sure is that Galileo did not invent the telescope, even though he tried to patent it as his invention.

It may have been two kids playing around with lenses in an optometrist's store that really made the discovery of how to make things bigger in the distance by putting two convex lenses together. The owner of that Holland shop, Hans Lippershey, got interested in what the kids were doing and even improved on the idea by putting the two lenses inside a tube. Hans liked the idea so much that he tried to patent it with the Belgian government. But to get the patent, he had to make three more telescopes and keep the process secret, which proved very hard to do. Hans Lippershey never got his patent.

Giambattista della Porta of Naples wrote about the newly discovered properties of convex and concave glass lenses and included this sketch in a letter written in August 1609. This is the earliest known sketch of the telescope.



In the Summer of 1609, the stories of the telescope reached Galileo. He quickly experimented with lenses and made a few improvements. Galileo made the telescope famous by his observations of Jupiter and the discovery of Jovian moons: Io, Europa, Ganymede, and Callisto. Keep in mind that while Galilean telescopes marked the birth of modern scientific instruments, their quality was extremely poor. While the shape of the lenses was pretty good, the polish was spotty and the glass itself, greenish in color, was filled with tiny bubbles. Typical Galilean telescopes consisted of two convex lenses each attached to the end of a tube, one inside the other for focusing. The telescopes were roughly five feet long.

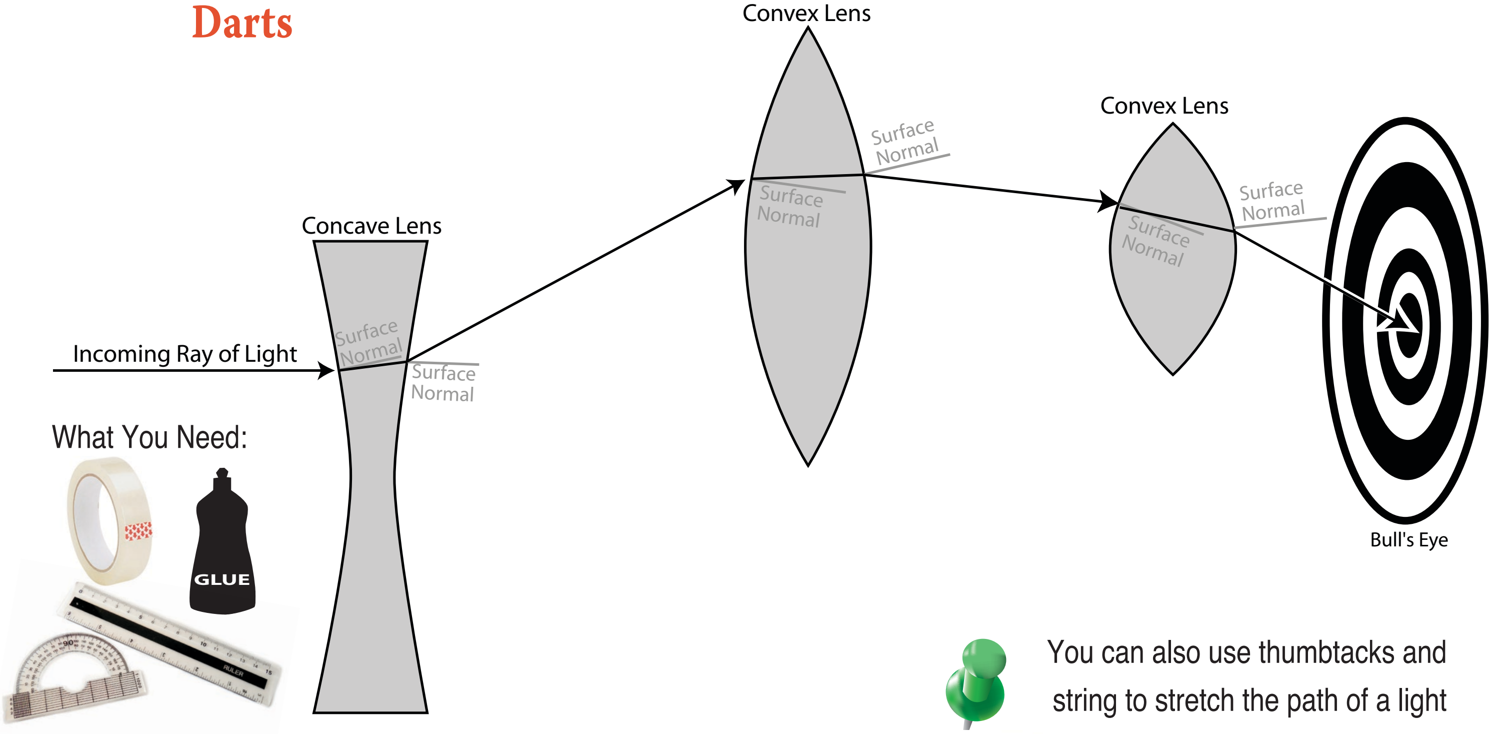
By the 1670s, some telescopes reached 140 feet in length. These telescopes used multiple convex lenses and provided higher magnification than Galilean telescopes. But they were also hard to handle—any slight wind would make the whole telescope vibrate and sway.

Supermarket Science

DO

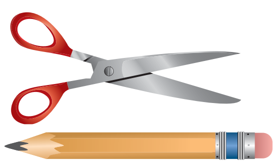
Bull's Eye Optic Darts

If you can ray trace, you can play Bull's Eye Optic Darts. It's playing darts with rays of light. You start with an incoming ray of light on one side of the page and end with a bull's eye on the other. The incoming ray of light won't hit the bull's eye unless you bend it. To divert the ray, you need to place one or more lenses in front of its path. Below is an example of how this game is played. To choose the first direction for you ray of light, roll a dice.

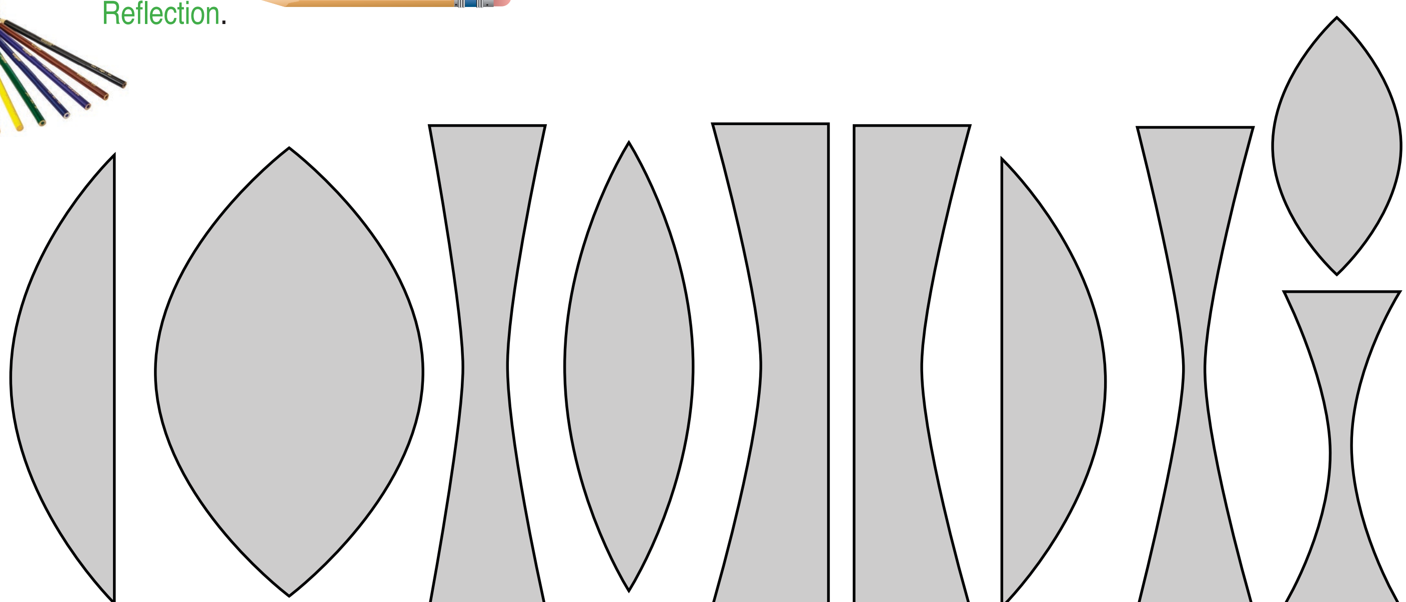


What You Need:

Use red pencil for Incident Ray and green pencil for Reflection.



You can also use thumbtacks and string to stretch the path of a light beam through your lenses.



To do your own Bull's Eye Optic Darts game, cut out the lens shapes above and take out a clean piece of paper. Draw the incoming ray and the bull's eye. Now arrange the lens in such a way as to hit it. If you need more lenses, you can create your own using these patterns. When you have solved the puzzle and drawn the complete path of the light, take lenses off the paper and pass your puzzle to a friend. Your friend will now have to figure what lenses you used to get your path and hit the bull's eye. *Good luck!*