The
Video
Encyclopedia
of
Physics
Demonstrations™

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CHAPTER 58

CURVED MIRRORS

Demo 22-01 Concave and Convex Mirrors

Using a thread screen to make the light rays visible, the focal properties of convex and concave lenses are investigated. Concave mirrors with 30 cm and 15-cm focal length focus incoming parallel rays, as seen in the video and in *Figure 1* for the 20-cm concave mirror. Convex mirrors of the same focal lengths diverge the parallel rays so that they appear to originate at the focal point, as seen in the video.

Figure 1

One of these shaving mirror produces an enlarged image of a person's face because of the way the curved surface of the mirror reflects light.

We'll use this thread screen to show just how a curved mirror reflects light.

This mirror has a concave surface with a 30-centimeter focal length.

Here is a second concave mirror with a 15-centimeter focal length.

This mirror has a convex surface with a 30-centimeter focal length.

Here is a second convex mirror with a 15-centimeter focal length.

Equipment

1. Shaving mirror.
2. Concave mirror.
3. Source of multiple parallel light rays.
4. Thread screen.
5. Second concave mirror with differing focal length.
6. Convex mirror.
7. Second convex mirror with differing focal length.

Demo 22-02 Spherical Aberration in a Mirror

Using a large optical board, this demonstration illustrates the difference between a spherical and a parabolic mirror in focusing incoming parallel rays of light. Parallel rays focused in two dimensions by a circular surface exhibit spherical aberration; the outer rays are focused too close to the mirror, as seen in *Figure 1*. Substituting a parabolic mirror removes this aberration; a parabolic reflector is exactly the right shape to focus parallel rays to a point. In the video sets of rays at different distances from the central ray are made different colors to enhance visibility of the effect.

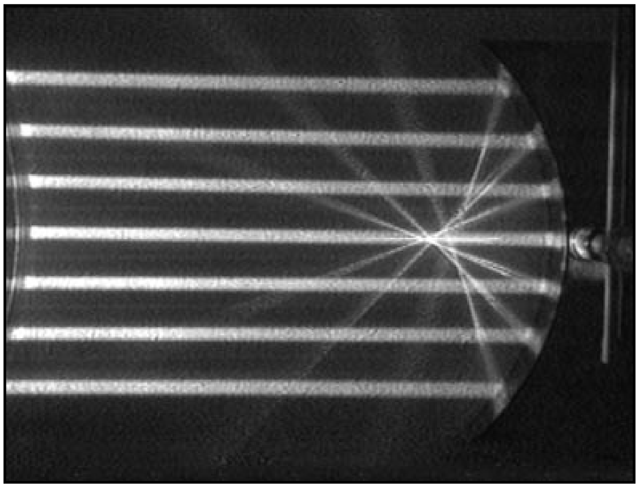

Figure 1

We will now illustrate spherical aberration in a concave mirror. A bright point source of light is collimated by an array of slits and the resulting diverging rays focused into a beam of parallel rays.

The parallel rays are focused by a circular mirror. Notice that the focus exhibits spherical aberration.

Rays further from the optic axis focus closer to the mirror, indicating that the outer part of the mirror is curved too much.

This effect can be seen more clearly by giving a different color to each set of rays at a different distance from the axis.

Now the mirror is rotated to insert a parabolic mirror with the same focal length. The spherical aberrations disappear. The difference in shape between the circular and the parabolic mirrors allows even outside rays to be sharply focused.

Equipment

1. Source of parallel light rays with reflecting background.
2. Circular mirror.
3. Three pairs of color filters.
4. Spherical mirror whose focal length matches that of the circular mirror.

Demo 22-03 Energy at a Focal Point

When the adjustable lens and mirror system is removed from an overhead projector, the internal mirror can be used to focus the lights, as shown in *Figure 1*. If a piece of paper is held at the focal point of the mirror, it will quickly be set on fire, due to the heat generated by the 500-watt lamp in the projector, as seen in the video.

Figure 1

We'll use the large concave mirror inside this overhead projector to show how such a mirror concentrates energy near its focal point.

A 500-watt light bulb inside the projector provides the radiant energy, which the mirror collects and focuses at a point not far above the projector.

A piece of paper inserted into the beam at that point quickly bursts into flame. Notice the concentration of radiant energy at the focus, shown by the brightness of the light reflected from the smoke.

Equipment

1. Overhead projector with a concave mirror and with its projection head removed.
2. Pieces of newsprint, some mostly white, some mostly black.
3. Pan of water to drop burning paper into.
4. AC power for overhead projector

Demo 22-04 Heat Focusing

This demonstration shows that electromagnetic waves other than light have properties similar to the properties of light. In this video, heat, or infrared radiation, from a nichrome heater is focused by concave parabolic reflectors onto a match, which quickly ignites.† If a match is placed about one meter from the heater, the heat is insufficient to light the match. Placing a concave mirror behind the match such that the match is at the focal point of the reflector increases the intensity and the match is ignited, as shown in *Figure 1*. If the heater is turned around and a second concave reflector is used to focus the heat onto the first reflector and then onto the match, the effective solid angle for heat collection is increased and the match ignites faster. A graphics sequence illustrates the focusing of the heat rays for each case.

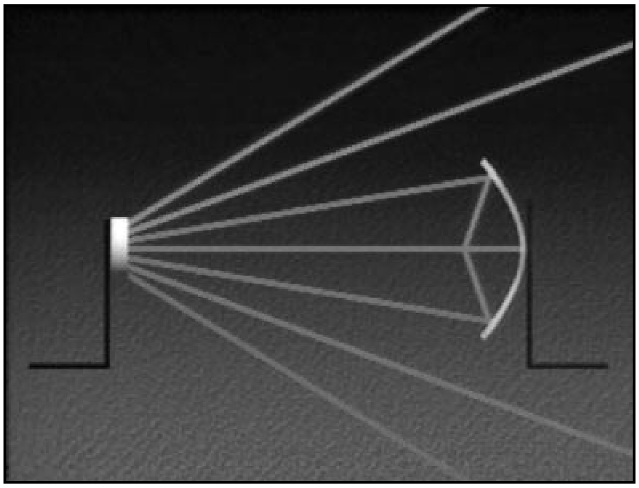

Figure 1

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† Sutton, *Demonstration Experiments in Physics,* DemonstrationsH-150, Focusing of Radiation, and H-151, Focusing of Infrared Radiation.
Freier and Anderson, *A Demonstration Handbook for Physics,* Demonstration Oc-9, Lighting a Cigarette.

Heat waves, which are infrared radiation, can be focused. In this demonstration we will ignite a match by focusing infrared radiation onto the match head using concave reflectors.

A match is placed about 50 centimeters from the heater. Radiation from the heater is not sufficient to ignite the match.

A concave reflector is now positioned behind the match so that it focuses the radiation from the heater onto the match head. The match ignites in less than 10 seconds.

Now the heater is turned around so that it faces away from the match. A second concave reflector, closer to the heat source than the first reflector, gathers heat waves from the source and directs them toward the first reflector. Now the match ignites even more quickly.

The first mirror collects radiation from the heater and focuses it onto the match.

The second mirror collects much more radiation from the heat source than the first mirror because it is closer to the heat source.

Equipment

1. Pair of concave reflectors.
2. Heater held at the axial height of the reflector.
3. A match held at the axial height of the reflector.
4. AC power for the heater.

Demo 22-05 Large Concave Mirror

A large concave mirror is used to create an image of a burning candle. When the candle is positioned at the center of curvature of the mirror, the image is the same size as the object and at that same point, but inverted, as shown in *Figure 1*.[†] The demonstrator can pinch the image of the candle flame with his fingers; the image of the fingers appears to be in the real candle flame! A bouquet of flowers at the center of curvature of the mirror likewise produces an inverted real image.

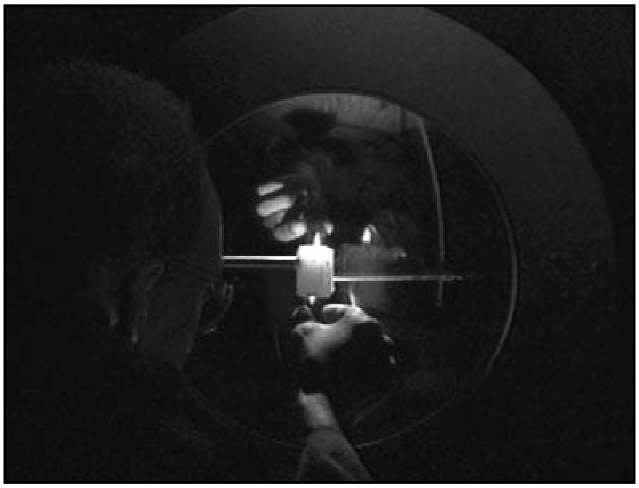

Figure 1

[†] Sutton, *Demonstration Experiments in Physics,* Demonstration L-23, Concave Mirror—Phantom Bouquet.
Freier and Anderson, *A Demonstration Handbook for Physics,* Demonstrations Oc-10, Image of Flower in a Vase, and Oc-11, Cold Candle.

Large Concave Mirror / Script

This large concave mirror produces a variety of different images at different distances.

When the candle is between the focal point and the center of curvature, we see a large real image.

Now we'll place the candle at the center of curvature of the mirror.

An identical but inverted image of the flame appears at the bottom of the candle.

A set of plastic strawberries placed at the same point shows a similar effect.

Equipment

1. Very large concave mirror.
2. Candle held at the axial height of the mirror.
3. Trio of plastic strawberries held at the axial height of the mirror.
4. A flashlight mounted on the rim of the mirror and aimed to illuminate the strawberries will enhance the real image.

CHAPTER 59

REFRACTION AND INTERNAL REFLECTION

Demo 22-06 Refraction / Reflection from Plastic Block

A ray of light incident at an angle onto a clear rectangular plastic block will be divided into reflected and refracted components, as shown in *Figure 1* and on the video. This video shows how the reflected and the refracted rays change as the angle with which the light ray is incident onto the plastic block is varied.

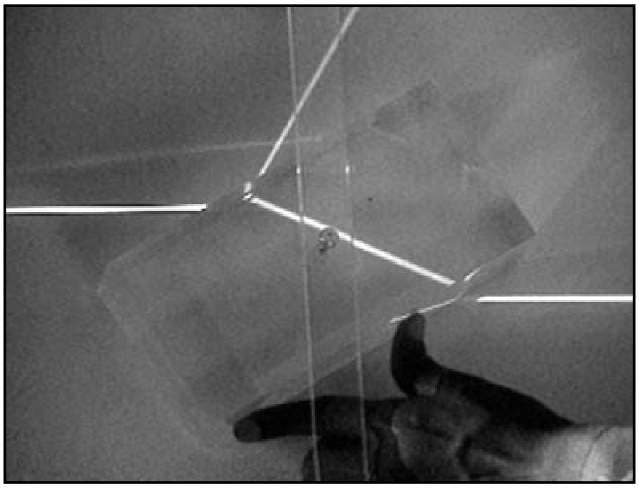

Figure 1

Refraction / Reflection from Plastic Block / Script

When a beam of light strikes the surface of a transparent material, the beam is both refracted and reflected at the surface.

This is the reflected beam and this is the refracted beam.

Notice how the angle of each beam changes as the block is rotated.

Equipment

1. Optics board setup with a single beam of light.
2. Rectangular block with optical surfaces and its support bracket.
3. Transformer.
4. AC power.

Demo 22-07 Small Refraction Tank

This demonstration uses a light bulb immersed in a water tank to illustrate the refraction of light.[†] A light positioned in an opaque tank is not directly visible, because the light does not bend around and over the front edge of the tank. When the tank is filled with water, the filament becomes visible because the bending of the light toward the observer as it leaves the water allows it to reach the observer, as shown in the video. *Figure 1* shows both cases, without water at the left and with water at the right.

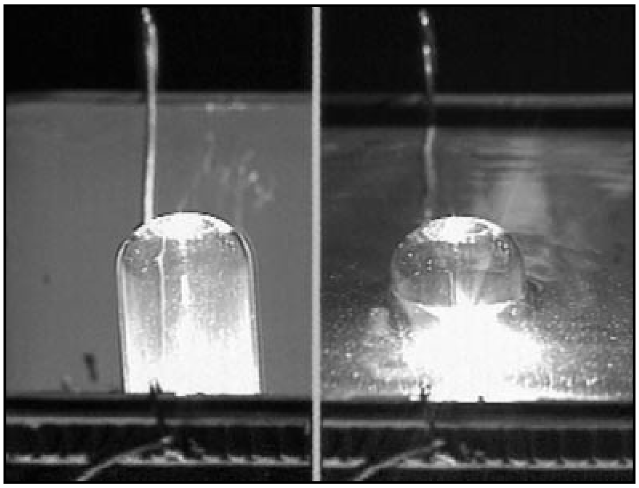

Figure 1

[†] Freier and Anderson, *A Demonstration Handbook for Physics,* Demonstrations Oe-2, Light Below Surface, and Od-4, Seeing a Coin.

Have you ever noticed that you often see two images of a fish when it swims near the corner of an aquarium? We'll demonstrate the reason for that optical effect using this small tank and a light bulb.

When the light bulb is placed in the tank, light escaping over the walls of the tank goes too high to be picked up by the camera and the filament of the bulb cannot be seen.

When the tank is filled to the top with water, the light refracts downward at the water surface and the filament becomes visible.

Light passing through the corner of a fish tank is refracted in the same manner, producing two images of the fish.

Equipment

1. Small black tank.
2. Point filament type of lamp, its socket, its wiring arrangement, and a switchable transformer.
3. Supply of water.
4. AC power.

Demo 22-08 Acrylic / Lead Glass Refraction

A solid rod is placed behind rectangular slabs of acrylic and lead glass, and the system is viewed normal to the surfaces of the transparent slabs. The image of the rod appears unbroken. When the slabs are rotated, the different index of refraction for the two slabs results in different angles of refraction and the images appear to be at different locations, as seen in the video and in *Figure 1*.

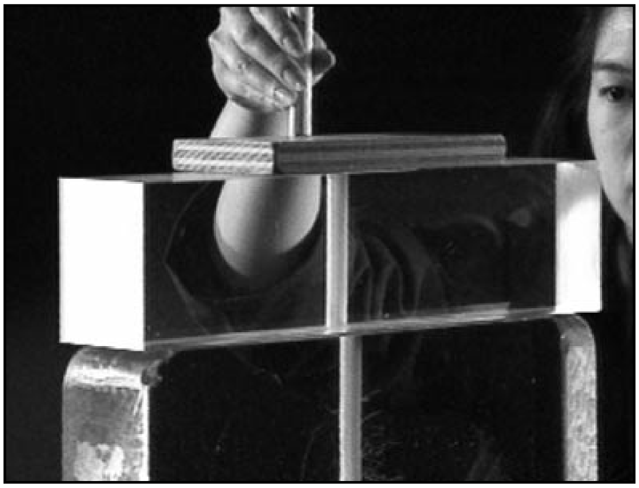

Figure 1

Acrylic / Lead Glass Refraction / Script

You've probably noticed that a stick appears bent when placed in a glass of water.

We'll demonstrate the same effect using these square acrylic and lead glass blocks to make the effect more visible.

This stick is lowered onto the blocks with the camera looking straight on, and the image of the stick appears unaffected.

When we rotate the blocks, the images of the stick are shifted to the side by a different amount in each block.

Equipment

1. Clear container of water.
2. Straight stick.
3. Small Lazy Susan.
4. Sizable piece of thick lead glass.
5. Piece of acrylic whose thickness is approximately equal to that of the lead glass.
6. A vertical straight stick running through he near edge of a horizontal piece of plywood.

Demo 22-09 Three Different Prisms

Prisms of three materials with different indexes of refraction are used to simultaneously bend and disperse white light from a single source.[†] As seen in the video and in *Figure 1*, both the refraction of the light and its dispersion increase. The original optic axis intercepts the screen to the right of the picture in *Figure 1*.

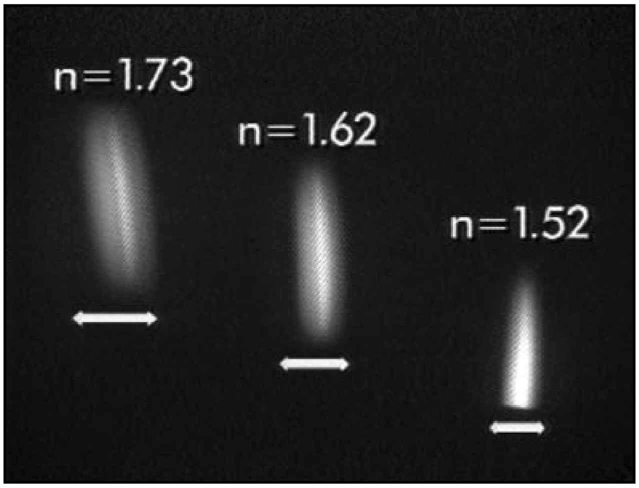

Figure 1

[†] Freier and Anderson, *A Demonstration Handbook for Physics,* Demonstration Oj-6, Dispersion in Different Media.

Three Different Prisms / Script

These three prisms are made of three types of glass, each with a different index of refraction.

When we shine white light from a slide projector through the prisms, they produce three different spectra, each refracted at a different angle. The angle of dispersion of the different colors is also different for each prism.

Equipment

1, Three prisms of differing indexes of refraction bonded together in a vertical stack and mounted on the upper end of a vertical rod.
2. Vertical rod base.
3. 35-mm slide projector.
4. 1-mm slit in a 2-inch by 2-inch metal mask.
5. AC power.

Demo 22-10 Disappearing Eye Dropper

Glass inserted into a liquid of the same index of refraction will become nearly invisible because there will be no reflection off the interface between two materials with the same index.[†] In this demonstration this effect is shown using glass eye droppers in a liquid that has very nearly the same index of refraction. When the eye dropper is immersed in the liquid, only the center of the eye dropper is seen. When liquid is pulled up into the eye dropper it becomes completely invisible, as shown in *Figure 1*.

Figure 1

[†] Sutton, *Demonstration Experiments in Physics,* Demonstration L-33, Refractive Index—Christiansen Filters.

Disappearing Eye Dropper / Script

When we look at a transparent object such as this glass eye dropper, we can see it even though it is perfectly clear. Differences in the refraction indexes of the glass and air allow us to see the edges of the glass.

When we put the eye dropper in a liquid that has the same index of refraction as the glass and fill the dropper with the liquid, the eye dropper nearly disappears.

Equipment

1. Clear glass eye dropper bottle.
2. Liquid whose index of refraction essentially matches that of the glass eye dropper.

Demo 22-11 Critical Angle / Total Internal Reflection

A collimated beam of light originating within a tank of water leaves the water from the top surface, as shown in *Figure 1*.† As the angle at which the light strikes the water surface becomes more oblique, the angle of the refracted ray leaving the water also becomes more oblique, as can be seen using the thread screen in *Figure 1*. When the critical angle is reached, total internal reflection is obtained, as is clearly shown in the video.

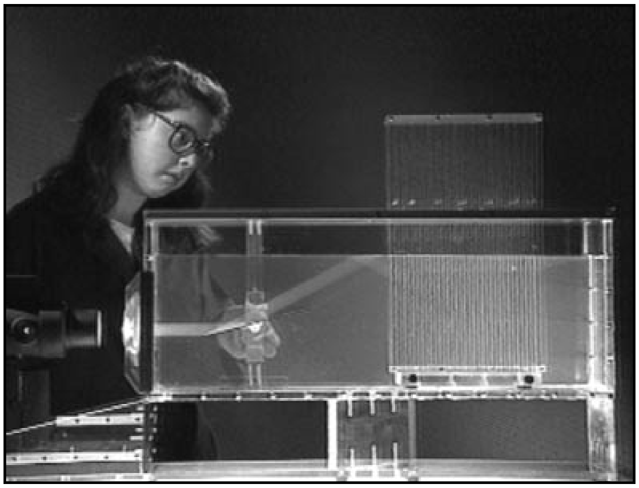

Figure 1

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† Sutton, *Demonstration Experiments in Physics,* Demonstration L-35, Critical Angle and Total Internal Reflection.
Freier and Anderson, *A Demonstration Handbook for Physics,* Demonstrations Od-1, Refraction at the Surface of Water, and Oe-1, Critical Angle.

Critical Angle / Total Internal Reflection / Script

We'll use this water tank and a parallel beam of light to demonstrate total internal reflection.

A chemical in the water fluoresces when the light strikes it, showing the path of the beam. This mirror reflects the beam up to the surface of the water at any angle we choose.

When the beam strikes the surface straight on, very little of the light is reflected.

At a shallower angle, more of the light is reflected but most still passes out into the air, as shown by this thread screen. Notice the misalignment between the beam in water and the beam in air.

At a still shallower angle, the beam is refracted so much that it becomes parallel to the surface. This is known as the critical angle situation.

If the beam hits the surface at an angle shallower than the critical angle, all the light is reflected back at the surface and none crosses through. This is known as total internal reflection.

Equipment

1. Long, narrow tank of water with a small quantity of antifreeze mixed throughout and a lens mounted on its exterior end face, along with a beam mask and its carrier.
2. Carbon arc without its lens.
3. Rotating mirror mounted inside the tank—we used magnetic control.
4. Thread screen that sits inside the tank and extends about the water an appropriate distance.
5. Appropriate power for the carbon arc.

Demo 22-12 Silver Soot Ball

A ball covered with soot, which is stark black in color, is inserted into a tank of water. Due to the inability of the water to "wet" the soot, light undergoes total internal reflection at the water/air interface adjacent to the soot ball, and the soot ball appears to be bright silver![†] This surprising effect is shown in *Figure 1*.

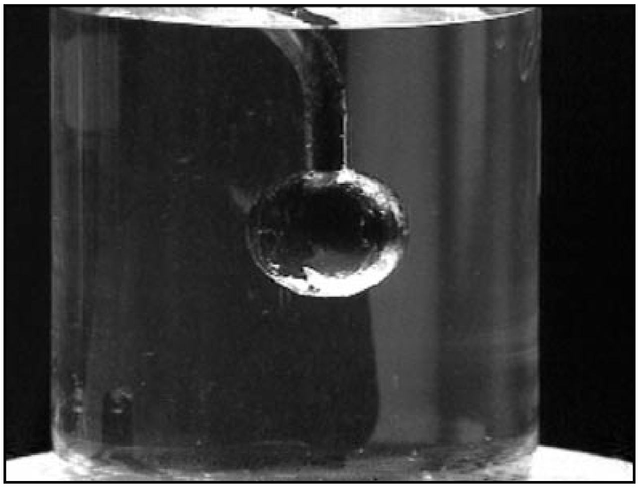

Figure 1

[†] Sutton, *Demonstration Experiments in Physics,* Demonstration L-39, "Mystery Ball."
Freier and Anderson, *A Demonstration Handbook for Physics,* Demonstration Oe-3, Black Ball Turns Silver.

Silver Soot Ball / Script

This metal ball on a stick has been heavily coated with soot. If we dip the ball into a beaker of water, the soot traps air close to the surface. Total internal reflection of light at the water/air interface makes the ball appear silver when it's underwater.

Equipment

1. Metal ball thickly covered with soot (source: a poorly adjusted oil lamp), and its support rod.
2. Clear container of water.
3. Source of light.

Demo 22-13 Light Pipes

A laser beam is shined into the end of a long, curved plastic rod. Due to total internal reflection, the light remains within the plastic rod, only emerging at the opposite end.[†] The apparatus is shown in *Figure 1*.

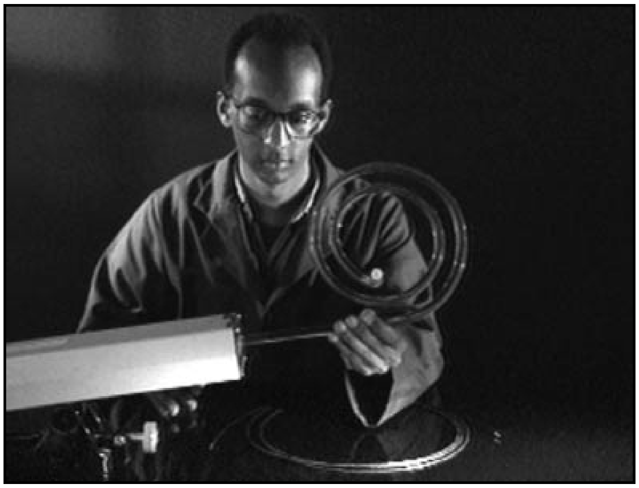

Figure 1

[†] Freier and Anderson, *A Demonstration Handbook for Physics,* Demonstration Oe-7, Light Pipe.

Light Pipes / Script

Fiber optics cables such as these have revolutionized communications. Here is a larger version of a fiber optics cable, known as a light pipe.

When we shine light in one end of the pipe, much of the light comes out the other end despite the bends in the pipe.

The light is totally internally reflected at the inner surface of the pipe and is thus channelled through the pipe from one end to the other.

Equipment

1. Fiber optics cable with its cover trimmed back.
2. Laser.
3. Acrylic plastic light pipe with optically polished ends.
4. AC power.

Demo 22-14 Optical Path in Fibers

A thin rectangular bar of plastic, doped with a dye to make the light more visible, is used to illustrate the path of a light ray inside an optical fiber.[†] Each total internal reflection and the full path of the laser beam are clearly visible in this video, as also shown in *Figure 1*.

Figure 1

[†] Sutton, *Demonstration Experiments in Physics,* Demonstration L-37, Total Internal Reflection at Glass-air Interface.

Optical Path in Fibers / Script

These acrylic tubes will be used to show the type of total internal reflection which makes fiber optics communications possible.

When a laser beam is aimed into the end of this tube, the beam bounces off the walls and is guided along the length of the tube, emerging from the far end.

The laser beam can also be guided along this curved tube.

Real fiber optics cables can bend around corners without losing any of the light passing along them.

Equipment

1. Commercially available optical signal path demonstrator.
2. Laser.
3. AC power.

Demo 22-15 Laser Waterfall

A laser beam is directed through a tank of water and into the nipple out of which the water flows. The laser beam undergoes total internal reflection in the water jet, following the water down into the collection tank and illuminating that tank, as shown in *Figure 1*.[†]

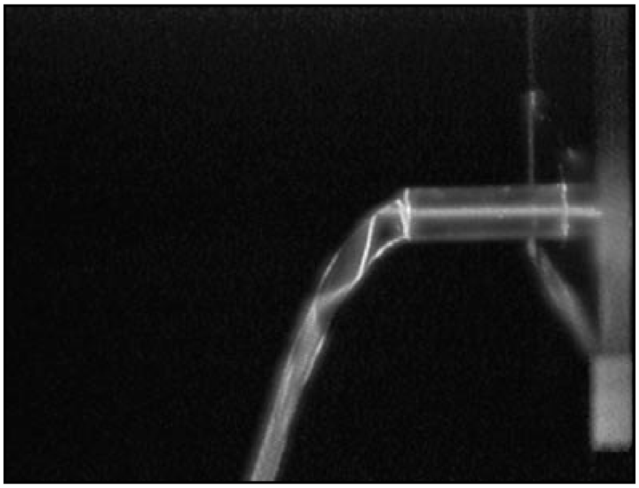

Figure 1

[†] Sutton, *Demonstration Experiments in Physics,* Demonstration L-36, Illuminated Fountain.

Laser Waterfall / Script

We now demonstrate total internal reflection of laser light in a water jet.

A laser is aligned such that its light passes through a water tank and into a tube at the bottom of the tank.

Powdered coffee cream has been added to the water to make the laser beam more visible.

When the stopper is removed, water squirts out of the tank into the container below. The laser beam is reflected internally and follows the water jet into the tank.

In this closeup view we can see the internal reflections of the laser beam in the water jet.

Equipment

1. A clear water tank with a stoppered outlet near the bottom opposite an optically flat wall.
2. Supply of water mixed with a small quantity of powdered coffee creamer.
3. Catch tank.
4. Laser.
5. AC power.

CHAPTER 60

LENSES

Demo 22-16 Real Image Formation

Two double convex lenses are used to focus light from an object onto an image screen.[†] For a given distance between the source and the screen, the video demonstrates that there are two positions of the lens that will provide a focus of the object on the screen: one position produces an image with magnification less than unity, the other, as shown in *Figure 1*, provides an image larger than the object. A distance scale marked off in units of 10 cm provides the scale for comparing the object and image positions and for determining the focal length of the lenses.

Figure 1

[†] Sutton, *Demonstration Experiments in Physics,* Demonstration L-47, Image Formation by Lenses.

A convex lens can project a real image of an object on a screen.

We'll use this setup to look at the images produced with different lenses.

This lens has a relatively long focal length and will focus a real image on the screen only at a long distance from the object.

It will also focus a sharp image when it is approximately that distance from the screen.

This lens has a shorter focal length, and can focus closer to the object.

If we move it to approximately that same difference from the screen, it produces another sharp image.

Equipment

1. Optical bench.
2. Double convex lens.
3. Lens clamp.
4. Translucent screen.
5. Light source with an orientation mask.
6. Three optical bench clamps.
7. Second double convex lens of differing focal length.
8. AC power for the light source.

Demo 22-17 Lens Magnification

Two focusing plano-convex lenses are positioned in front of a backlighted grid to illustrate their magnification. The magnification is observed in the video as the lenses are moved back and forth in front of the grid. Each lens is viewed from the side to compare the curvatures of the lenses, which are responsible for their magnifications. The magnifications are compared in the video, as shown in *Figure 1*, for the two lenses at the same distance in front of the grid. The lens with the shorter focal length is at the left. Finally, the magnification of less than one of a diverging lens is demonstrated. An animated segment explains the ray optics for these situations.

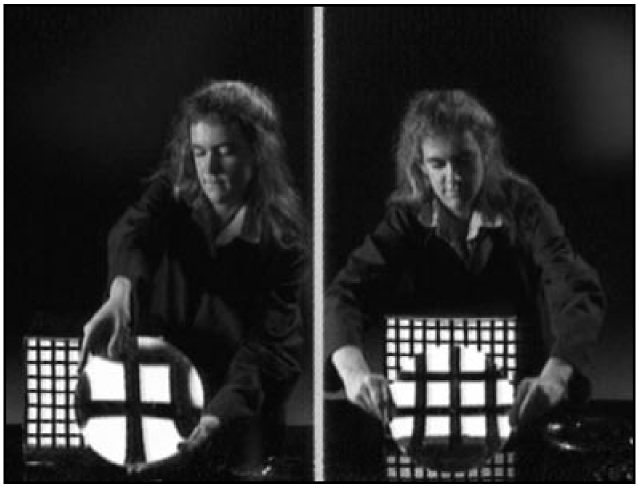

Figure 1

Lens Magnification / Script

Magnifying glasses are commonly used for enlarging print. We'll use these two large magnifying lenses and a back lit grid to demonstrate enlargement by a single lens.

When this large plano convex lens is held against the grid, the image seen through the lens is only slightly magnified.

If we move it out farther from the grid, the magnification increases.

This plano convex lens has a shorter focal length than the last lens because its surface curves more sharply.

If we place both lenses at the same distance from the grid, the lens with the shorter focal length gives a greater magnification.

Here is a plano concave lens with one surface that curves inward. This lens magnifies by a factor less than one producing an image which is smaller than the object.

This animation shows how the light from one square of the grid is bent inward by the convex lens making the square appear larger to the camera because it appears as if the light is coming from these positions. If we move the lens farther out, the square appears even larger.

Equipment

1. Rear illuminated translucent cross grid.
2. Two large plano-convex lenses of two different focal lengths.
3. Plano-concave lens.
4. Light bulb and lamp socket base.
5. AC power.

Demo 22-18 Ray Tracing with Lenses

A light box is used with several incoming parallel rays to trace the rays through focusing and defocusing lenses and to observe the focal properties of the lenses. A plano-convex lens focuses parallel rays to a point as shown in *Figure 1*, and is compared with a similar lens with a shorter focal length. A concave lens defocuses parallel rays such that they appear to come from a single point. Combining the concave and the convex lenses with the same radius of curvature, so their effects cancel, is also shown in the video.

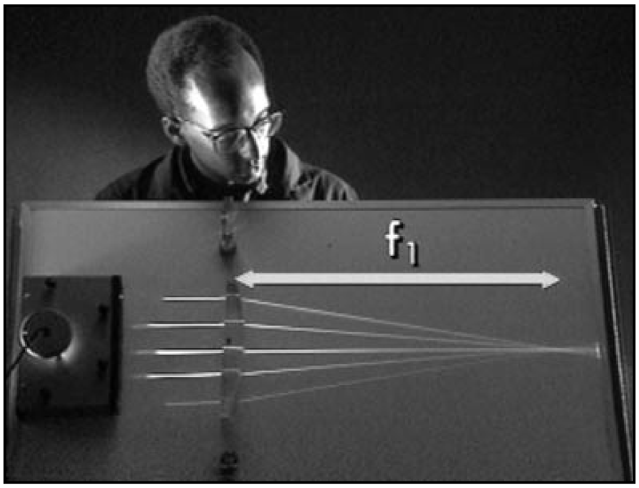

Figure 1

Ray Tracing with Lenses / Script

We'll use this light box and a set of large acrylic lenses to show how light beams are focused by various lenses.

Here is a convex lens with a relatively long focal length.

This convex lens has a shorter focal length.

This concave lens has the same focal length as the second convex lens, but spreads the beams instead of focusing them.

If we place these two lenses together, their effects cancel and the beams pass through unchanged.

Equipment

1. Optics board setup with multiple parallel rays.
2. Plastic plano-convex lens with a long focal length.
3. Transparent support bracket.
4. Another plano-convex lens with a shorter focal length.
5. Plano-concave lens whose focal length matches that of number 4 above.
6. Transformer.
7. AC power.

Demo 22-19 Fresnel Lens

A Fresnel lens is a thin lens constructed in a large number of segments such that light rays entering and exiting the lens do so at the same angles as a normal thick lens. The geometry of such a lens is shown in *Figure 1*, which is taken from a graphics section in the video that describes Fresnel lens construction. Thus Fresnel lenses can be made much thinner and lighter than standard lenses. The operation of Fresnel lenses is also illustrated in the video.

Fresnel invented this type of lens for use in lighthouses. They are also used as the field lenses in overhead projectors and in optically programmed traffic signals, and diverging Fresnel lenses are used for wide-angle viewing on trucks and vans.

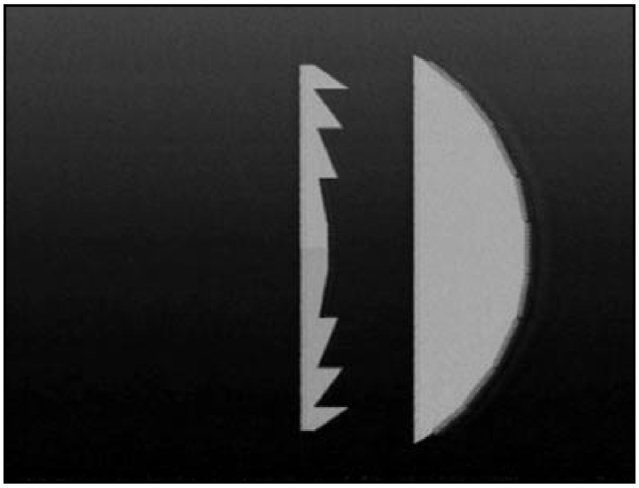

Figure 1

Fresnel Lens / Script

Here is a device known as a Fresnel lens. The lens magnifies objects seen behind it much like an ordinary lens, even though it is only a millimeter thick.

A series of concentric grooves in the lens provide the magnifying power. Each groove is cut to an angle which depends on the radius of the groove as this enlarged drawing of a side view shows. Each of the concentric grooves is cut to the same angle that the surface of a normal plano-concave lens would have at the same radius.

The Fresnel lens provides the same magnifying power as an ordinary glass lens but with much less weight.

Equipment

1. The same illuminated grid and light source described in Demonstration 22-17.
2. Fresnel lens.
3. Large plano-convex lens.

Demo 22-20 Fillable Air Lenses

Hollow convex and concave lenses inserted into water function opposite to normal glass lenses in air. A double concave air lens is shown in the video to focus light under water, as seen in *Figure 1*, but to defocus light when filled with water and used in air. A double convex air lens under water defocuses light, but when it is filled with water and used in air it focuses the light.

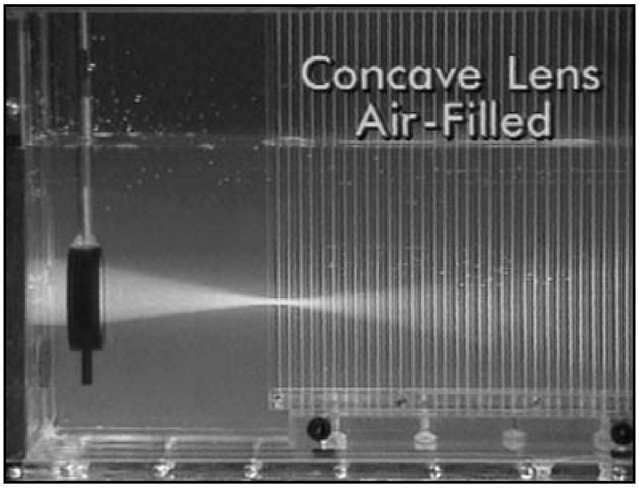

Figure 1

This is a pair of hollow lenses, with thin plastic faces and air in between, as shown in this diagram.

If we place this hollow concave lens and a beam of light, the light is only slightly affected.

If we insert the lens into a beam which is passing through this tank of water, the air filled concave lens now brings the beam to a focus at a point close to the lens.

What will happen if we allow the lens to fill with water?

When the lens is filled with water, it no longer focuses the beam of light.

What will happen if we insert the water-filled lens back into the beam of light in air?

The lens now spreads the beam.

Here is the same sequence repeated with a hollow convex lens.

Equipment

1. Fillable air lenses—one double convex, one double concave.
2. Supply of water.
3. Thread screen.
4. Multiple ray mask.
5. Light source.
6. Tank of water.
7. Tank thread screen.
8. Beam mask.
9. Light source.
10. Appropriate power for the two light sources.

Demo 22-21 Spherical Aberration

A lens that has a spherical shape will exhibit spherical aberration; the position at which parallel light rays focus is closer to the lens for rays further away from the optic axis.† When a stop is placed over the outer part of the lens and the distance between the lens and the image slightly adjusted, the aberration is significantly reduced, as shown in *Figure 1*.‡ If a stop is placed on the center of the lens, leaving the outer part of the lens open, and the position of the lens again adjusted, the image is again clearer than that with the entire lens open, as nicely shown in the video.

Figure 1

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† Sutton, *Demonstration Experiments in Physics,* Demonstration L-49, Chromatic and Spherical Aberration.
Freier and Anderson, *A Demonstration Handbook for Physics,* Demonstration Oh-1, Aberration.

‡ Freier and Anderson, *A Demonstration Handbook for Physics,* Demonstration Oh-2, Improving an Image with a Stop.

Spherical Aberration / Script

When lenses are ground with their faces spherical, they can not bring a light beam to a perfect focus.

We can see the effect of that on image formation using this object, lens, and screen. We'll first bring the image to the best possible focus using the entire lens.

Now we'll block off the outer portions of the lens with this mask.

The image appears slightly fuzzy, but we can bring it to a sharp focus by moving the lens slightly away from the object.

Now we'll block off the center of the lens instead of the outer half. The image is now very fuzzy, but can be sharpened by moving the lens closer to the object.

Notice that this image is not as good as the image obtained with the center of the lens.

Equipment

1. Optical bench.
2. Light source with an orientation mask.
3. Plano-convex spherical lens.
4. Mask for the lens to block the light passing through the outer regions of the lens.
5. Mask for the lens to block the light passing through the center region of the lens.
6. Translucent screen.
7. Lens clamp.
8. Three optical bench clamps.
9. Power for the light source.

Demo 22-22 Chromatic Aberration

Because of dispersion of the colors of light at the interface between the air and the glass lens surface, a single lens produces some chromatic aberration.[†] Light from a group of pinholes is focused onto a screen, exibiting chromatic aberration. When a compound lens is used in place of the original simple lens, the chromatic aberration can be eliminated, as shown in the video and explained in a nice graphics section.

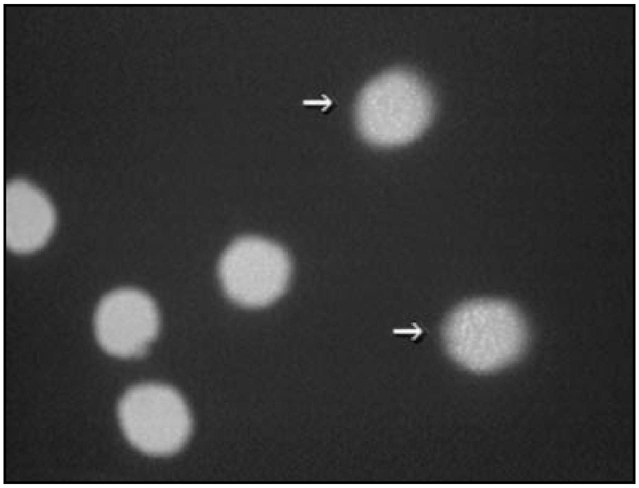

Figure 1

[†] Sutton, *Demonstration Experiments in Physics,* Demonstration L-49, Chromatic and Spherical Aberration.
Freier and Anderson, *A Demonstration Handbook for Physics,* demonstration Oj-9, Chromatic Aberration in a Lens.

We'll use this ordinary glass lens to demonstrate chromatic aberration. This plate has a number of small holes drilled in it, which are lit from the back with a strong white light.

When a lens is placed in front of the plate to cast an image of the holes onto this screen, the colors have separated in the image of each hole. This separation is called chromatic aberration. Notice that the separation is greater for the holes nearest the edge.

If this concave lens, made of a different type of glass, is added to the first lens and the combination refocused,

the images are free of chromatic aberration.

This animation shows how different colors of light are brought to a focus of different points by a simple lens. Here is the effect of adding a corrective lens made of glass with a different index of refraction.

Equipment

1. Chromatic lens pair.
2. Lens clamp that can easily accommodate the pair, or just one of the pair.
3. Mask with holes drilled through it in some desired design.
4. Light source.
5. Screen.
6. Power for the light source.

Demo 22-23 Astigmatism

On-axis astigmatism occurs when the shape of the lens has both a spherically symmetric and a cylindrically symmetric component, so that the focal length in two perpendicular planes is different. In this demonstration such a lens is created by combining a spherical and a cylindrical lens. The focal properties of this "lens" are experimentally investigated using a movable screen, as seen in *Figure 1*, and an animation further illustrates the effect.

This type of astigmatism is commonly found in the eye lens. A different type of astigmatism, called off-axis astigmatism, occurs when the lens is focusing non-paraxial rays.

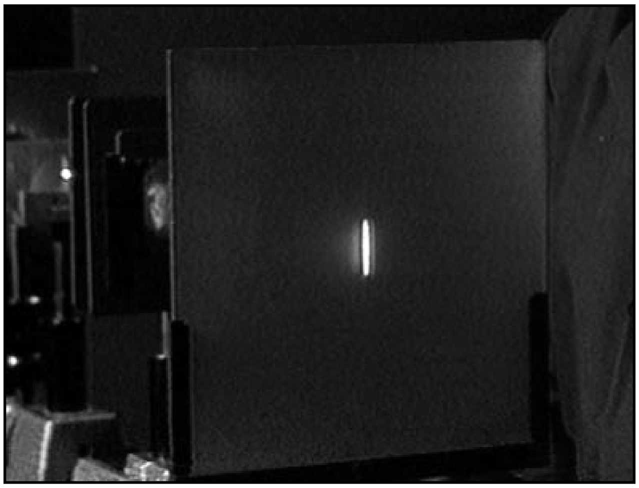

Figure 1

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† Sutton, *Demonstration Experiments in Physics,* Demonstration L-51, Astigmatism and Distortion.

This optical equipment will be used to illustrate on-axis astigmatism.

Light coming through this circular hole is focused by this spherical lens to form a circular image on this ground glass screen.

If a cylindrical lens, which focuses in the vertical direction, is inserted adjacent to the original spherical lens, the horizontal focus remains virtually unchanged, but the vertical focus is closer to the lens, as can be seen by moving the screen closer to the lens. If a single lens such as that of the human eye exhibits this problem, the lens is said to be astigmatic.

By moving the ground glass screen we can follow the light after it leaves the lens, passes the vertical focus, a horizontal line, passes the horizontal focus, a vertical line, and continues to grow larger.

This illustration of astigmatism shows the outer rays from a point source as they pass through an astigmatic lens. Its vertical focal length is shorter than its horizontal focal length, so the cone of light reaches its vertical focus, then its horizontal focus, then grows larger just as the real light cone.

Viewed from 45 degrees, the focus seems to lie between the vertical and the horizontal foci.

Equipment

1. Light source.
2. Beam mask.
3. Circular hole.
4. Spherical lens.
5. Ground glass screen.
6. Cylindrical lens.
7. All of the above are mounted on an optical bench with the appropriate clamps.
8. Power for the light source.

Demo 22-24 Off-Axis Distortion

Off-axis distortion, or coma, occurs when the axis along which the light is being viewed is at a large angle from the optic axis of the lens. In this case the rays from an object using different parts of the lens fail to focus as in the case where they are more nearly coaxial. This demonstration uses a plano-convex lens on an optical board to focus parallel light rays. When the lens is rotated so that the rays are no longer paraxial, off-axis distortion occurs, as seen in *Figure 1*.

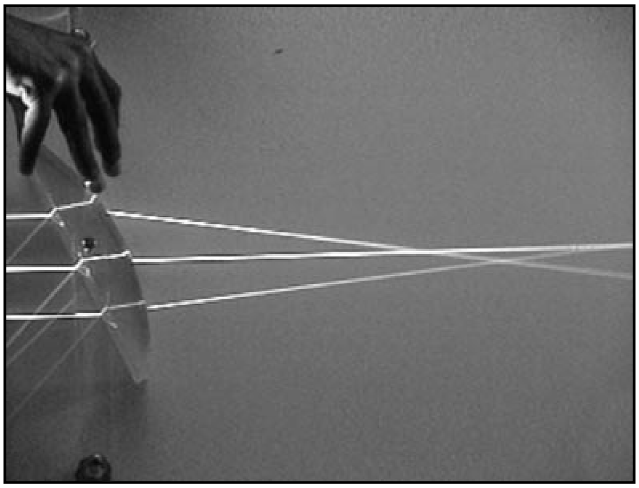

Figure 1

Off-Axis Distortion / Script

When light beams enter a lens parallel to the axis of the lens, the beams are brought to focus at a single point. When the lens is tipped so that its axis is angled to the light beams, they no longer focus at a single point. This is known as off-axis distortion, or coma.

Equipment

1. Optics board setup with three parallel beams of light.
2. Plano-convex lens, with its mounting bracket.
3. Transformer.
4. AC power.