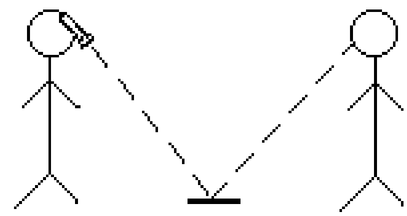
# Light

## PROBLEM PRESENTATION / EXPLORATION

A. Flashlight Geometry

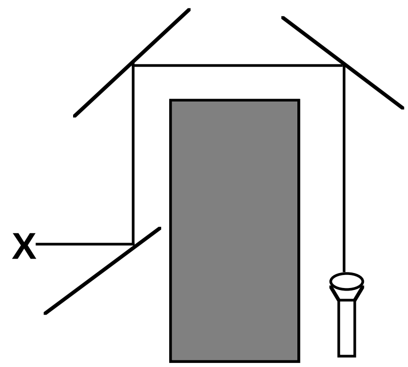
1. Needed for this exercise are two students of the same height, a flashlight, a flat mirror (15 cm x 15 cm), 2 meter sticks, and some masking tape.
2. Have two students stand facing one another 3-4 meters apart next to a blank wall. In between the students place a flat mirror (15 cm x 15 cm) on the floor.
3. With the lights dimmed have student #1 raise the flashlight to "nose-level" and aim it at the mirror. The flashlight bulb should be as close to his/her nose as possible.
4. Where will student #1 have to stand in order that he/she can aim it at the mirror on the floor and have the beam bounce up to student #2's nose?



5. Once this has successfully been done, measure how far each student is standing from the center of the mirror.
6. Repeat this activity with another student kneeling on his knees. Where would student #1 have to stand so that the flashlight beam hits student #3 in the nose?
7. Having studied the pattern involved in the first two cases, where would student #1 have to stand and where would the mirror have to be located to make the flashlight beam hit the intersection of the wall and ceiling? Is there more than one correct solution to this problem? [Yes}

B. **X** Marks the Spot

1. The CHALLENGE is to, with the help of three mirrors, shine a flashlight around an obstacle to hit the spot marked with an X.
2. The materials needed for this CHALLENGE are a penlight flashlight (obviously, if you have a laser, use it), three pocket mirrors (approximately 5 cm x 8 cm), clay or Play Doh®, a shoe box, and a card with a black X on it.
3. The rules are simple:
   a.) Have the students draw a diagram of where they think the mirrors should be placed before they are given the mirrors and other equipment.
   b.) Arrange the three mirrors (all three must be used) in such a way that by aiming the flashlight a beam of light can be bounced around so that it will finally focus on a card with the X in the center. It would probably help to dim the lights in the room.
   c.) The X must be placed on the card and located on the opposite side of the shoe box.
   d.) The beam must be parallel to the table or floor on which the box is placed.
   e.) The clay can be used to support the mirrors while they are being positioned.
   f.) Compare the final solution(s) with the predicted diagrams. One of many possible ways to set this up is sketched in the diagram at the top of the next page.




C. Convex Lens
1. Obtain a magnifying glass, a meter stick, a small candle, and a metal cap from a jar on which to set the candle so that the hot melted wax can be caught.
2. Place the candle, the magnifying lens, and your eye along the meter stick at different positions.
3. The CHALLENGE is to find the relative positions of your eye, the lens, and the candle so that you see:
   a.) an enlarged image of the candle rightside up
   b.) an enlarged image of the candle upside down
   c.) a reduced image of the candle upside down
   d.) an image of the candle having the same size but upside down
4. You have probably noticed that in moving the positions of the candle and the lens that there is a point where the image of the candle gets all blurry. Try to determine how far your eye is away from the lens when it seems the blurriest. Write this down for use later. (Concept Invention, F3)
5. Make sure to record the positions on the meter stick of the candle, the lens, and your eye for cases a, b, c, and d above. (You may require a measuring tape longer than one meter in one or more of the cases. This will depend on what type of lens you are using.)
6. Now, replace a white piece of poster board at the position your eye occupied. In which cases do you see an image projected there? If the image is not sharp, move the lens and/or the poster board to bring it into focus? Is there a case where you can not project the image onto the poster board?

D. Examples of plane (flat), concave and convex mirrors are required for this station. Possible sources of the curved mirrors are shaving or makeup mirrors (concave), circular rearview mirrors used on trucks (convex), some chromed hubcaps (convex), and spoons (concave and convex).
1. Have students look into the various mirrors and note their image.
2. In which mirror(s) can you make your image larger?
3. In which mirror(s) can you make your image smaller?
4. In which mirror)s) can you make your image remain the same size?
5. In which mirror(s) can you make your image appear rightside up?
6. In which mirror(s) can you make your image appear upside down?
7. is there any of these mirrors where you can make your image first be rightside up and then with some adjustment make it appear upside down?

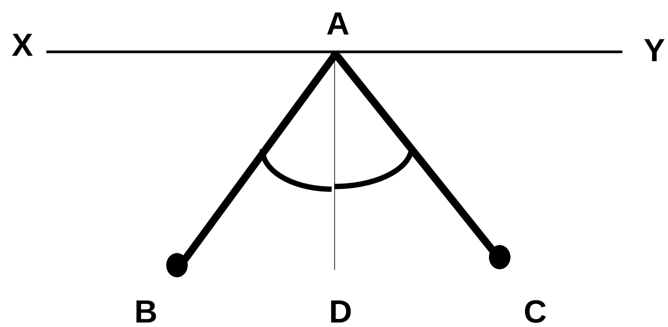
**CLASS RESPONSE / CONCEPT INVENTION**

A. Intuitive Angles
1. Find a volunteer who claims to be a good pool player for this demo.
2. On top of a lab table place a piece of wood approximately 5 cm by 10 cm by 100 cm. Arrange it so that the wide face is perpendicular to the table top.
3. In the middle of the board make a mark.

4. Place rubber ball approximately 100 cm from the mark and 65 cm from the board (Position B).
5. Challenge the "pool player" to roll another rubber ball in such a manner that it first hits the mark on the wood (Position A) and subsequently bounces off and hits the first rubber ball.
6. What positional relationship is operating in this effort? Refer to the drawing below.

B. Angle of Incidence and Angle of Reflection

1.



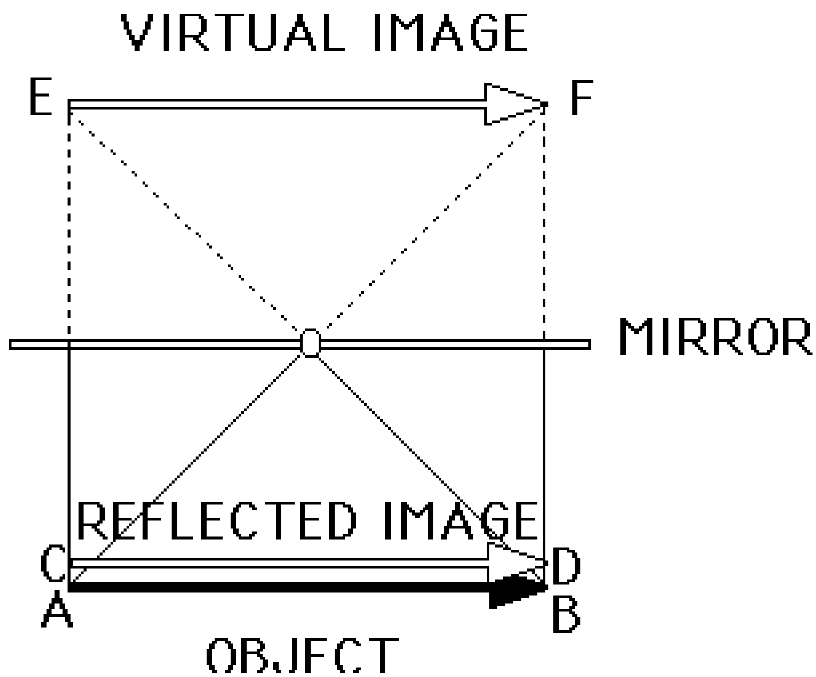

2. The line AD is referred to as the Normal line. It is perpendicular to the line XY.
3. Very likely the "pool player" will be able to articulate that angle BAD must equal angle CAD for a ball thrown from C to hit a ball resting at B.
4. We want to call angle CAD the ANGLE OF INCIDENCE, in other words the angle initially made with the wall and the NORMAL. We want call angle BAD the ANGLE OF REFLECTION, or the angle made with the NORMAL when the ball reflected off the wall.
5. As the "pool player" intuitively knew, ***THE ANGLE OF INCIDENCE EQUALS THE ANGLE OF REFLECTION***.

C. Finding the Angle of Incidence and Angle of Reflection for Visible Light

1. Place a sheet of paper with the long side facing you on the table. Draw a horizontal line across the page and label it XY.
2. Label the midpoint of XY A. Draw a dotted line perpendicular to XY through A. Label the other end of the dotted line D.
3. Draw a line from A to the left corner of the paper. Proceed down this line about 8 cm. from point A and mark a point B.
4. Place a mirror along line XY. Make sure that XY lines up with the back edge of the mirror. Make sure that the mirror remains perpendicular to the paper. You might use some blobs of clay to secure the mirror.
5. Take two pins, stick them on small pieces of clay, and place them on line AB. Make sure the pins remain vertical.
6. Lower your body to the level of the pins. Move your head left and right. Look at the pins toward the mirror, until the front pin covers the back pin and they look like one.
7. Place a pin to the right of the dotted line AD and move it around, until it looks as if it is lined up in the mirror and covers the other two pins. All pins should appear in a straight line. Keep your eyes near the level of the pins. After you line up the three pins, press the third pin down to mark the point. Label it C.
8. Draw a line from A going through point C.
9. Measure angles BAD and CAD. What positional relationship appears to be acting in this case? [The two angles are equal.]

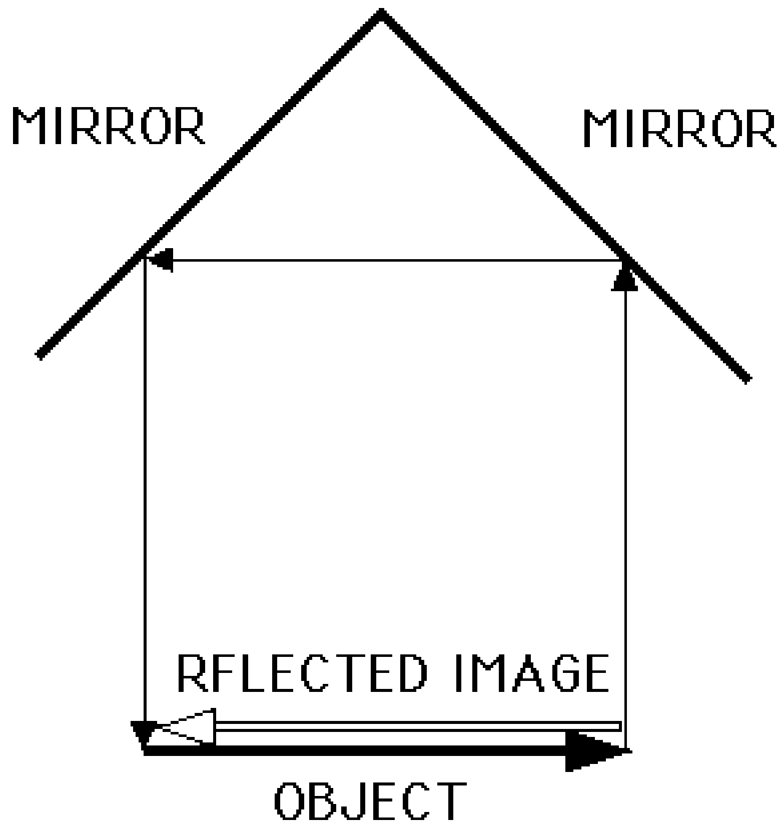
D. Is Your Mirror Telling You the Truth?

1. Do you see the same thing in a mirror that others see when they look at you?
2. Stand in front of a plane mirror. The first thing that you notice is that your image seems to be coming from behind the mirror, even though you know that it isn't. Your image is the same size as you and is right side up, not inverted as in some other kinds of mirrors and lenses.
3. Find a student who parts his/her hair right down the middle. Make a black X with a magic marker on a piece of tape and put it on his/her right cheek.
4. To which cheek will the piece of tape appear to be sticking on his/her image? [Left] If you touch your left ear, your image will be seen touching its right ear.
5. This is because the angle of incidence and angle of reflection are equal for every ray emanating from your face. Every ray bounces off the plane mirror with equal angles of incidence and reflection, but it appears that the ray is emanating from behind the mirror and is turned around so that left is right and right is left.



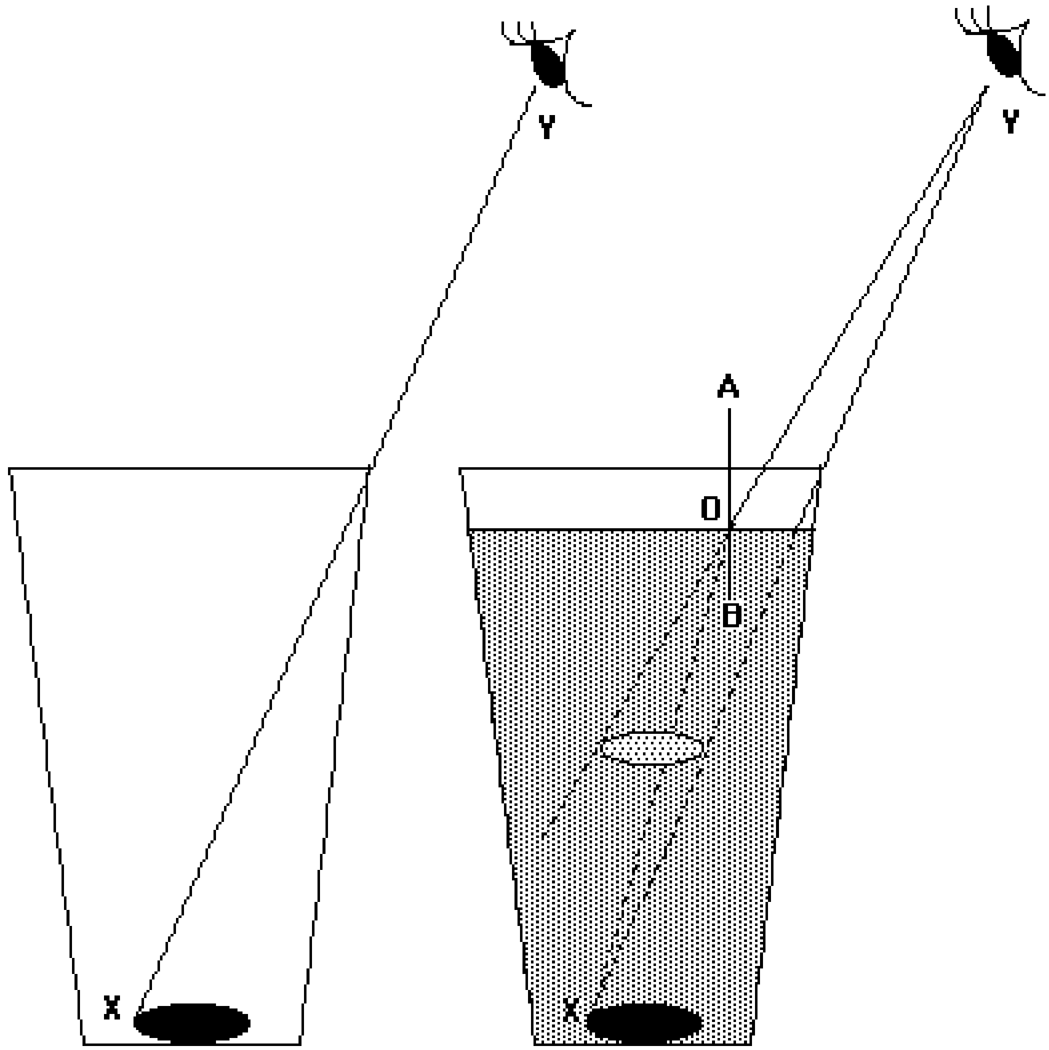

6. The ray coming from point A of the object hits the mirror at O and actually reflects back to D. It appears to our brain, however, to be coming from E beyond the mirror. Likewise the ray coming from the object at B hits the mirror at O and actually reflects back to C. Once again it appears to our brain, that it is coming from F beyond the mirror. Consequently, when we look into a plane mirror the left hand side of the object appears to be behind the mirror on the right and the right hand side of the object appears to be behind the mirror on the left side. In a plane mirror we do not see the reflected image, we see the **Virtual Image**. The virtual image can not be projected on a screen, it is not real, merely virtual. CD is not a real image even though the rays bounce back to this point. Our brain tells us that the image is really at EF, although we know it can't be.
6. To see what others see when they look at you requires two mirrors. Tape two mirrors together so that they hinge at one edge.
7. Place the mirrors perpendicular to each other on the edge of the table. Observe yourself in the two mirrors by looking at the joint corner of the two mirrors.
8. Touch your left ear. Which ear did your image touch? Does this differ from looking into a plane mirror?
9. The light rays are reflected in 90° angles from one mirror to the other and

then back to the eye. With the two mirrors perpendicular to each other, anything on the left of the object is reflected to the right hand side. All points of the object on the left side are seen on the right. Finally, you can see how others see you. Do you like this view any better than what you have been looking at all these years??

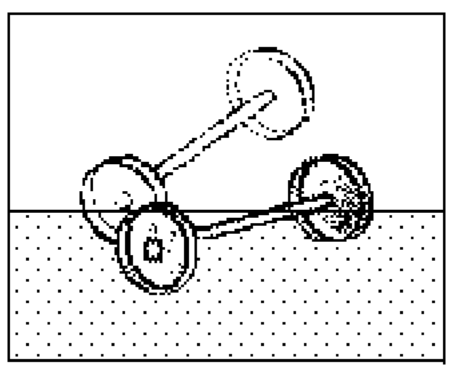



E. Refraction

1. Tape a penny to the inside bottom of an opaque cup (try a Styrofoam® coffee cup) and place it on the table.
2. Move your head down so that the penny just disappears behind the rim of the cup. Hold your head steady so that the penny is still hidden to your eye.
3. Have another student pour water into the cup. What happens? [The penny magically reappears and appears to be floating half-way up from the bottom..]
4. Look at the diagram showing the ray coming from the far edge of the penny. Since the level of your eye was low enough the edge of the cup blocked it from reaching your eye and you can't see the penny.
5. In the second diagram after the water has been added, notice that the eye is in the same location but this time the light ray coming from the far edge of the penny has been bent (refracted) as it passed from the water to the air and on to your eye. The object appears to be located half-way up from the bottom.
6. This is a common phenomenon when light travels from one medium to another medium. This is because the speed of light is different in different media. It was moving slower through the water and faster through the air. It would move fastest in a vacuum.
7. The normal line AB has been drawn in perpendicular to the interface of the water and air. The light bends away from the normal when it speeds up. Notice how angle XOB is smaller than AOY.



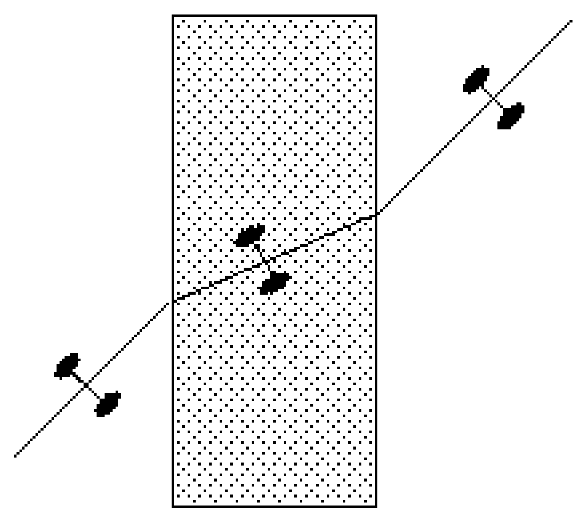

8. To understand how this happens you will need two wheels and an axle. These could come from cannibalizing a toy car, or it could be build with a Tinker Toys® stick and two wheels. Also you will need some sheets of paper, a piece of sandpaper, and a large piece of cardboard.



9. Build a ramp with the piece of cardboard. To the piece of cardboard tape the

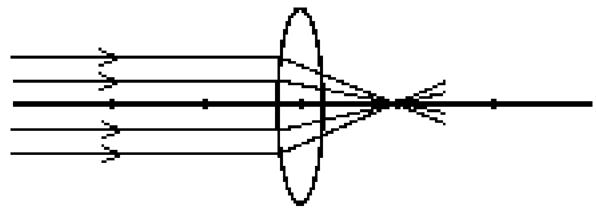
sheet of sandpaper. Tape next to it sheets of paper so that they equal the thickness of the sandpaper. Place the sandpaper/paper boundary at an angle of 45° with the long axis of the cardboard ramp. Now allow the wheels to roll down the ramp. Make sure that they will hit the boundary between the sandpaper and regular paper. Notice what happens when the leading edge of the first wheel hits the different surface. If it is going from paper to sandpaper it will veer one way because its speed is changing (slowing down). If it is going from the sandpaper to the paper it will veer the other way because its speed is changing (speeding up). In the first case it turns toward the normal and in the second case it turns away from the normal until both wheels are on the same surface. At this point the wheels once again continue on a straight path. The angle of the ramp can not be very steep or gravity will wipe out the refraction.

10. Another way to picture this refraction is to envision a pair of toy-cart wheels that can spin independently of one another rolling at some angle other than 90° from a smooth surface onto a patch of grass. Moving from the smooth surface to the grass the leading wheel will slow down and the direction will be changed until the trailing wheel hits the grass. For a while, as long as both wheels are moving on the grass the wheel assembly will move straight. Then, once again the lead wheel will hit the smooth surface on the other side of the patch of grass and will speed up. This will turn the wheel assembly until the trailing wheel also hits the smooth surface. Once again the wheel assembly will move ahead in a straight path.



F. Convex Lenses

1. As light passes through glass it bends (refracts) because for a short time its speed is changed. Depending on the angle at which the light hits the glass and length of its path a ray of light can be bent to different degrees.
2. If parallel rays of light pass through different thicknesses of glass the rays will be bent to different degrees and depending on the shape and thickness of the glass the rays can be made to converge. The distance from the center of the lens to where they converge is known as the focal length of the lens. Measure the focal length of the magnifying glass used in the EXPLORATION phase of this lesson. At the top of the next page is a diagram of a typical converging lens.



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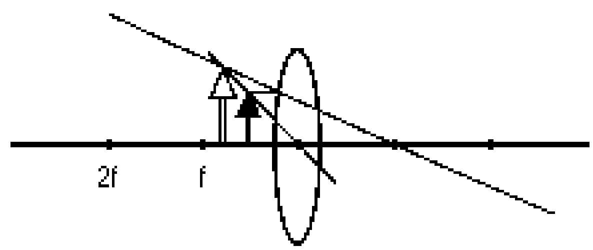
FOCAL LENGTH

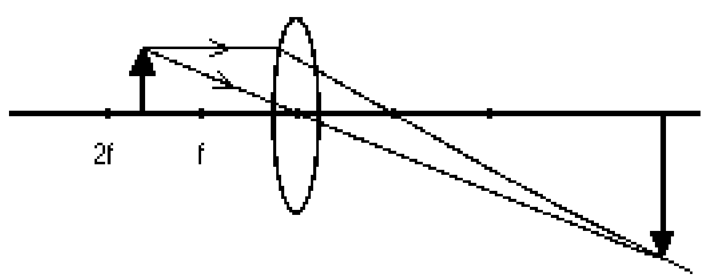
3. Using this focal length set up the lens, the candle and the poster board screen according to the table below.

| Position of Object | Nature of Image | | |
|---|---|---|---|
| | Real or Virtual? | Magnified? | Inverted or Erect? |
| Beyond f | REAL | YES & NO | INVERTED |
| At f | NO IMAGE | ------- | ------- |
| Within f | VIRTUAL | YES | ERECT |

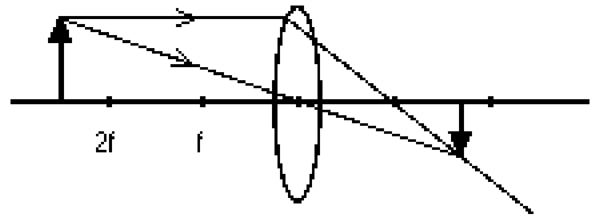
4. Where in relation to the focal length (f) from the lens is the object when the image appears right-side up (erect)?




5. Where in relation to the focal length (f) from the lens is the object when the image appears inverted and larger than the object?

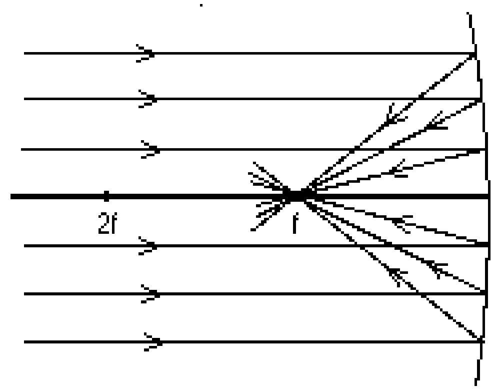



6. Where in relation to the focal length (f) from the lens is the object when the image appears inverted and smaller than the object?




G. Concave Mirrors

1. A mirror reflects light to form an image instead of refracting it as in the case of lenses. All images created by looking into a plane mirror are **VIRTUAL**. This means that you can not project them on to a screen. They appear as though they are coming from behind the mirror.
2. Concave mirrors, such as the inside of the bowl of a spoon, form both virtual images and **REAL** images. Real images can be projected onto a screen.
3. As parallel rays of light hit the surface of a concave mirror they are reflected through the same point in front of the mirror. This point is called the focal point.

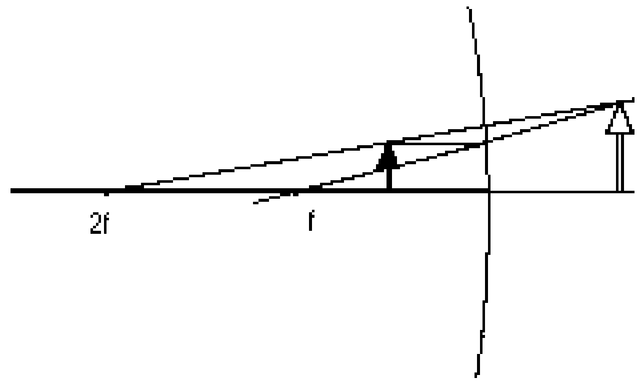



4. As in the case of the convex lens, the distance from the focal point to the center of the mirror is called the focal length of the mirror. Measure the focal length, f, for the mirror used in part D of the EXPLORATION section of this lesson.
5. Instead of the light coming into the mirror in parallel rays form a source such as the sun, put a point source of light right at the focal point of the mirror. What will happen? [This is the principal of how a automobile headlight works. The tiny bulb is put at the focal point and the rays are directed off the reflector parallel to each other resulting in a parallel beam of light instead of light scattered in all directions.

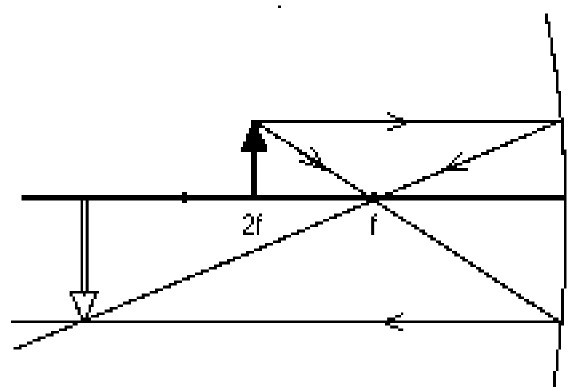
| Position of Object | Nature of Image | | |
|---|---|---|---|
| | Real or Virtual? | Magnified? | Inverted or Erect? |
| Beyond **f** | REAL | YES & NO | INVERTED |
| At **f** | NO IMAGE | ------- | ------- |
| Within **f** | VIRTUAL | YES | ERECT |

6. Arrange the concave mirror and candle as you did in part D of the EXPLORATION section of this lesson. Move the screen to from a sharp image of the candle. Is it real or virtual? smaller or larger than the object? inverted or erect?
7. Using this focal length set up the mirror, the candle and the poster board screen according to the table below.

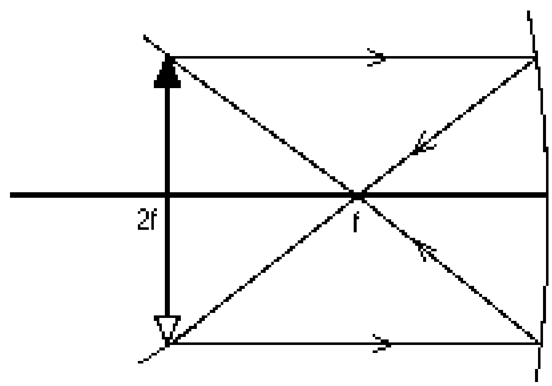
8. Where in relation to the focal length (f) from the mirror is the object when the image appears right-side up (erect)?




9. Where in relation to the focal length (f) from the mirror is the object when the image appears inverted and larger than the object?




10. Where in relation to the focal length (f) from the lens is the object when the image appears inverted and the same size as the object?



H. Convex Mirrors

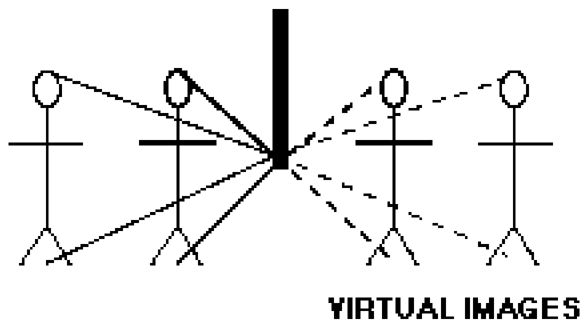
1. A mirror that is curved like the back of a spoon is a convex mirror. The image formed here, like a plane mirror, is always virtual. Is it inverted or erect? Is it larger, smaller, or the same size as the object?
2. Where are convex mirrors used? Why not use a plane mirror for this same purpose? What is the advantage of the convex mirror?

CONCEPT EXTENSION

A. How High Do I Have to Hang a Wall Mirror in Order to See All of Myself Including My Shoes?

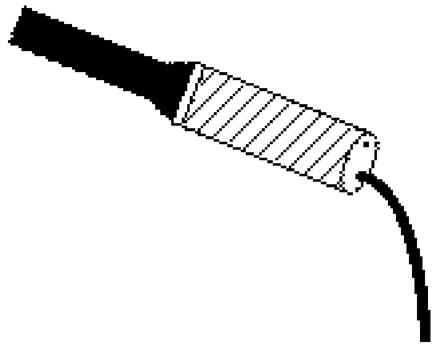
1. Which of the following position(s), A, B, or C could the mirror be hung to allow you to see both your head and your feet at the same time?

2. Let two students hold a mirror against the wall while a third student stands in front of the mirror and attempts to see both her head and feet. The fourth student should measure how high off the floor the mirror would have to be hung to see both head and feet.
3. Would the distance off the floor be different for either the tallest person in class or for the shortest person in class? [Once it was adjusted for the shortest person, everyone else would be able to see both their head and feet without further adjustment.]
4. Would the distance off the floor be different if you stood nearer or farther away from the mirror than for the original determination? [No, see sketch below.]
5. The solution involves the students finding out that the bottom of the mirror must be placed on the wall at least as high as half the height of the shortest student. The rays from the feet must be able to hit at the bottom of the mirror and bounce up to the eyes. Since the angle of incidence and angle of reflection must be equal, the lowest part of the mirror must be halfway between the floor and the student's head. The distance from the student to the mirror is not important. The minimum height is the same.




B. Critical Angle
1. If you swim underwater and look up, you will see some objects above the water. To your surprise you also might see a reflection of an object from in front and underneath you.
2. Against a black background place a deep aquarium. Get a waterproof flashlight and submerge it. Shine the beam of light from the bottom of the aquarium up toward the top surface of the water. Notice what happens to the beam of light. Now change the angle of the beam shining on the underneath surface of the water. When the angle is about 43° from the normal, what happens? (see diagram below)

3. When the angle of incidence is greater than 43° with the normal, light is totally reflected at the boundary of the water and air. This special angle is called the critical angle. It differs for each two adjacent media that the light passes through. For the boundary of glass and air it is about 48°; for the boundary of a diamond and air it is about 24°. This is the principal utilized in fiber optical instruments.
4. Fill a straight glass tube with water. Seal one end with some type of kitchen plastic wrap. Shine a flashlight from one end and look at the other end of the tube. Does light travel down the tube so that you can see it coming out the other end? [Yes] This should be no great surprise since we know that light travels in straight lines. What would happen if you used a curved glass tube? Would you be able to see light coming out of the bottom of the curved tube. [No] Could you design a way to "pour" light so that light would undergo total reflection and finally come out the bottom end?
5. Obtain a tall skinny bottle (some types of olive jars will work). With a nail put a large hole at the edge in the metal lid. Put a smaller hole on the opposite edge. To the bottom of the jar attach a flashlight. Duct tape works well. Wrap some newspaper around the jar so that light doesn't escape out the sides. Fill the jar within about two centimeters of the top, then screw on the lid. Turn the flashlight on. Tilt the jar/flashlight apparatus so that water pours out the hole. If the water is poured out in a darkened room, the light will be contained (because of total reflection) in the curved stream of water. All light hitting the water/air boundary at greater than about 43° will be totally reflected internally over and over until it comes out the end of the stream of water. If you stick your finger into the stream of water, light will fall on it. This will happen if you put your finger in the water near where it comes out of the jar or in the curved part of the stream near the sink.



6. Are there other substances that allow light to travel a curved path by way of total reflection? [A curved piece of Lucite® will work.]

C. Mirages

1. We have seen that refraction occurs because light travels at different speeds through two different media such as air and glass. We also know that light travels at different speeds in a given medium depending on the temperature.
2. Would light traveling through two adjacent regions of the same medium heated to different temperature be refracted? How could this be used to explain the formation of mirages in the desert or on the highways when it is very hot?

D. Predictions

1. Write your name on a note card and prop it up on a table so that it is perpendicular to the table top. You may need to support it with a book or other object. Get a 16 oz or 20 oz plastic soft drink bottle. Rip off the plastic wrapper so that the clear plastic is visible. Fill the bottle with water and set it in front of the note card containing your name. What will you see?
2. Cut the top and bottom off of a plastic 2 L soft drink bottle. This will give you a plastic cylinder about 15 cm tall. Stretch a piece of Saran Wrap® over one end and secure it with a rubber band. Lay your note card down flat on the table and place the cylinder over it. Predict what you will see as you add more and more water to the Saran Wrap.
3. Take another note card and on one side with a red pen write in capital letters COKE. On the other side write with a blue pen in capital letters PEPSI. Place the card on a flat table. Obtain a glass rod with diameter of at least one centimeter. Place the rod over the COKE on one side of the card and then over PEPSI on the other side of the card. Predict what you will see each time. Explain your observations.
[When looking through the rod at the word COKE they will see the same thing that they would without the rod. Looking at the word PEPSI they will see


Because there is a horizontal line of symmetry for each letter in COKE, the top half of COKE and the bottom half are identical, and when reflected from top to bottom look the same as before they were reflected. Since there is not a horizontal line of symmetry in each letter of the word PEPSI, only the E and I will look the same before and after reflection. The other three letters are backwards. See if you can disequilibrate the students into thinking that the different colors are responsible for what they see.]