# SECTION A – Geometric Optics

1974B3. An object 1 centimeter high is placed 4 centimeters away from a converging lens having a focal length of 3 centimeters.

(a) Sketch a principal ray diagram for this situation.
(b) Find the location of the image by a numerical calculation.
(c) Determine the size of the image.

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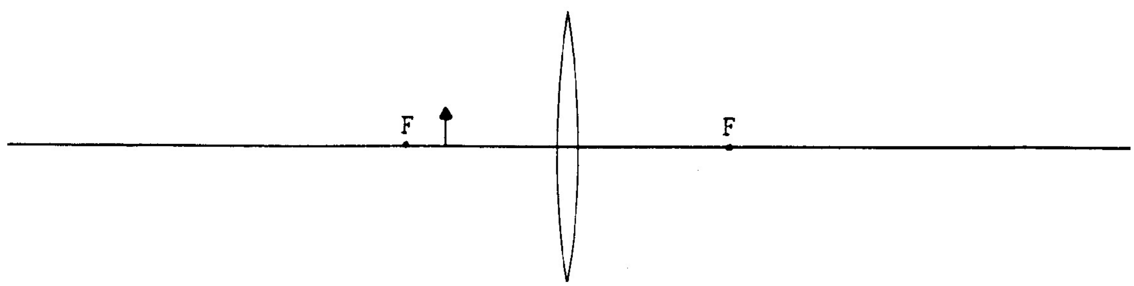


1976B6. An object of height 1 centimeter is placed 6 centimeters to the left of a converging lens whose focal length is 8 centimeters, as shown on the diagram above.

(a) Calculate the position of the image. Is it to the left or right of the lens? Is it real or virtual?
(b) Calculate the size of the image. Is it upright or inverted?
(c) On the diagram, locate the image by ray tracing.
(d) What simple optical instrument uses this sort of object-image relationship?

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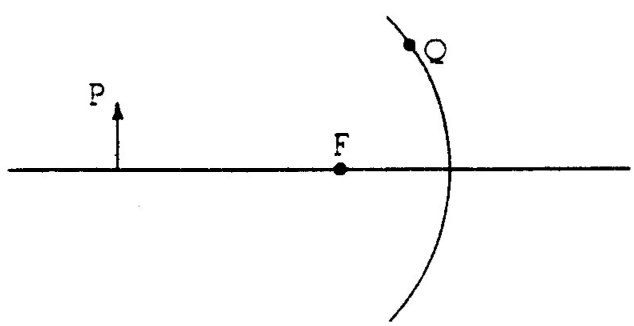


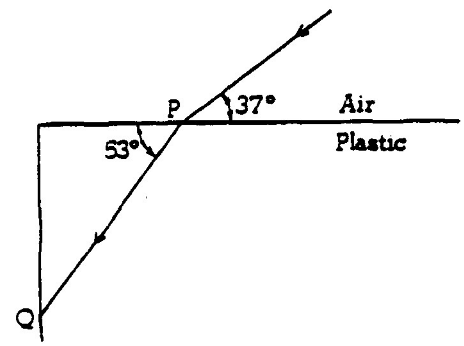

1978B5. An object 6 centimeters high is placed 30 centimeters from a concave mirror of focal length 10 centimeters as shown above.

(a) On the diagram above, locate the image by tracing two rays that begin at point P and pass through the focal point F. Is the image real or virtual? Is it located to the left or to the right of the mirror?
(b) Calculate the position of the image.
(c) Calculate the size of the image.
(d) Indicate on the diagram above how the ray from point P to point Q is reflected, if aberrations are negligible.

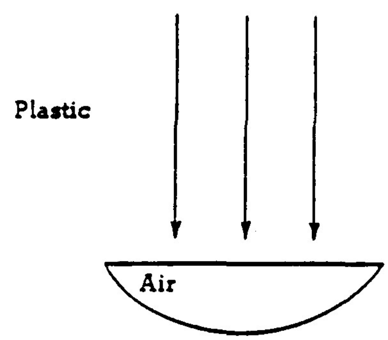
1979B6. A light ray enters a block of plastic and travels along the path shown.

a. By considering the behavior of the ray at point P, determine the speed of light in the plastic.

b. Determine what will happen to the light ray when it reaches point Q, using the diagram to illustrate your conclusion.

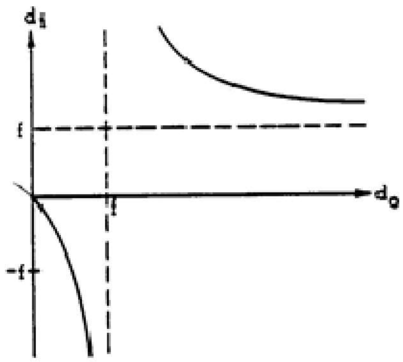



c. There is an air bubble in the plastic block that happens to be shaped like a plano-convex lens as shown below. Sketch what happens to parallel rays of light that strike this air bubble. Explain your reasoning.



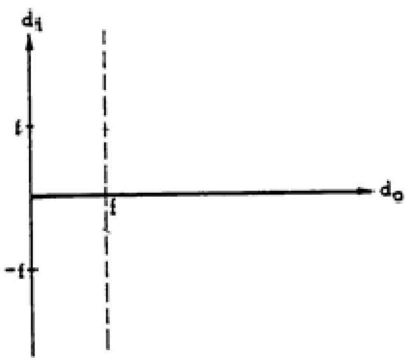
1980B4. In the graphs that follow, a curve is drawn in the first graph of each pair. For the other graph in each pair, sketch the curve showing the relationship between the quantities labeled on the axes. Your graph should be consistent with the first graph in the pair.

(e) $d_i$ = Image Distance (positive to right of lens) for a Thin Convex (converging) Lens of Focal Length $f$



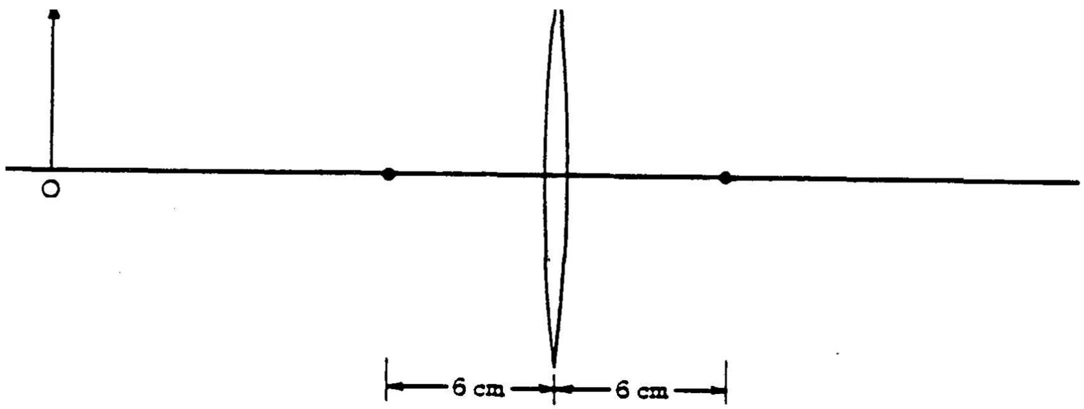

$d_o$ = Object Distance (positive to left of lens) for the Same Lens

$d_i$ = Image Distance (positive to right of lens) for a Thin Concave (diverging) Lens of Focal Length $-f$



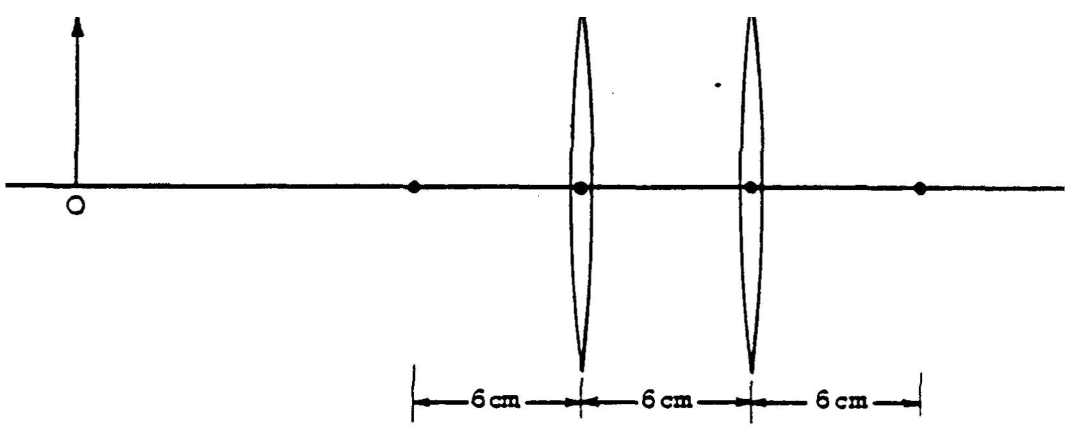

$d_o$ = Object Distance (positive to left of lens) for the Same Lens

1981B5. An object O is placed 18 centimeters from the center of a converging lens of focal length 6 centimeters as illustrated below:



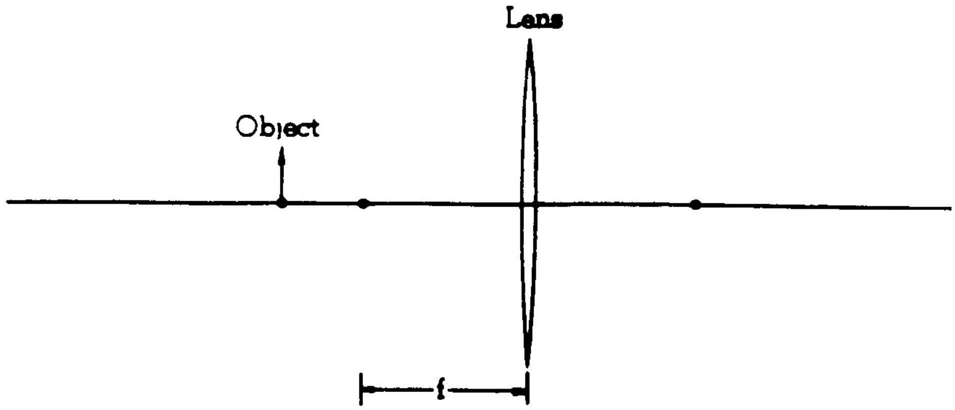

a. On the illustration above, sketch a ray diagram to locate the image.
b. Is the Image real or virtual? Explain your choice.
c. Using the lens equation, compute the distance of the image from the lens.

A second converging lens, also of focal length 6 centimeters is placed 6 centimeters to the right of the original lens as illustrated below.




d. On the illustration above, sketch a ray diagram to locate the final image that now will be formed. Clearly indicate the final image.

1982B6. An object is located a distance 3f/2 from a thin converging lens of focal length f as shown in the diagram below.




a. Calculate the position of the image.
b. Trace two of the principal rays to verify the position of the image.
c. Suppose the object remains fixed and the lens is removed. Another converging lens of focal length $f_2$ is placed in exactly the same position as the first lens. A new real image larger than the first is now formed. Must the focal length of the second lens be greater or less than f ? Justify your answer

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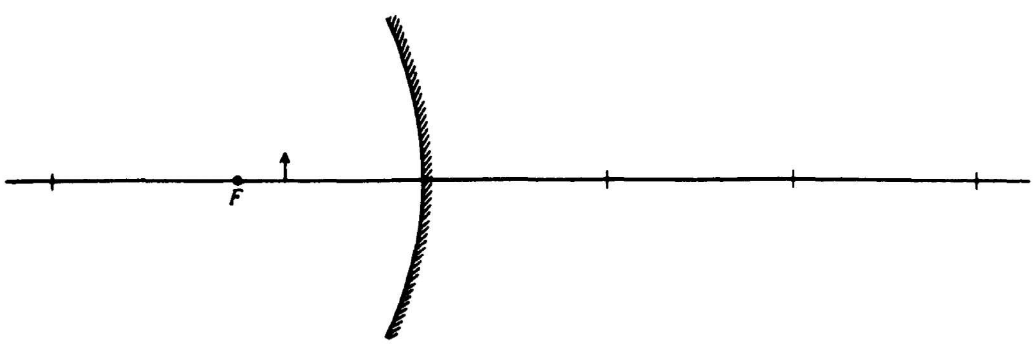


1983B5. The concave mirror shown above has a focal length of 20 centimeters. An object 3 centimeter high is placed 15 centimeters in front of the mirror.
a. Using at least two principal rays, locate the image on the diagram above.
b. Is the image real or virtual? Justify your answer.
c. Calculate the distance of the image from the mirror.
d. Calculate the height of the image.

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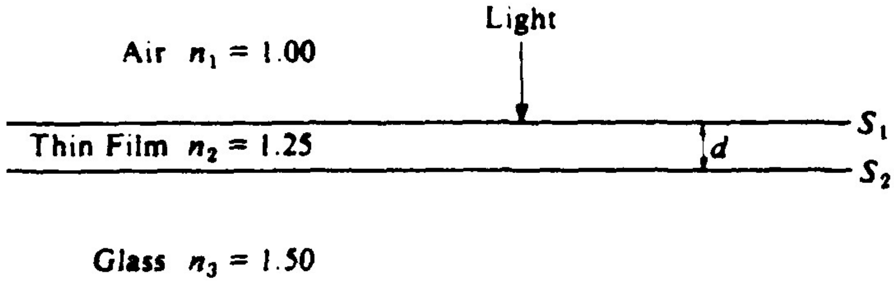
1984B5. The surface of a glass plate (index of refraction $n_3 = 1.50$) is coated with a transparent thin film (index of refraction $n_2 = 1.25$). A beam of monochromatic light of wavelength $6.0 \times 10^{-7}$ meter traveling in air (index of refraction $n_1 = 1.00$) is incident normally on surface $S_1$ as shown. The beam is partially transmitted and partially reflected.




a. Calculate the frequency of the light.
b. Calculate the wavelength of the light in the thin film.

The beam of light in the film is then partially reflected and partially transmitted at surface $S_2$
c. Calculate the minimum thickness $d_1$ of the film such that the resultant intensity of the light reflected back into the air is a minimum.
d. Calculate the minimum nonzero thickness $d_2$ of the film such that the resultant intensity of the light reflected back into the air is a maximum.

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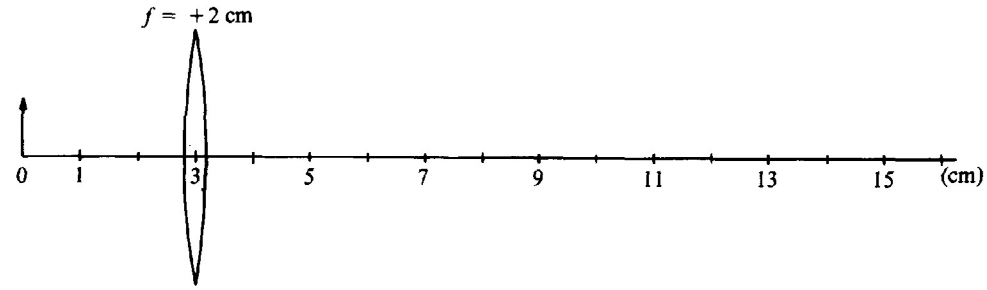
**NOTE: This is a repeat from the physical optics section but has an important new part in it in bold.**

1985B5. Light of wavelength $5.0 \times 10^{-7}$ meter in air is incident normally (perpendicularly) on a double slit. The distance between the slits is $4.0 \times 10^{-4}$ meter, and the width of each slit is negligible. Bright and dark fringes are observed on a screen 2.0 meters away from the slits.
a. Calculate the distance between two adjacent bright fringes on the screen.

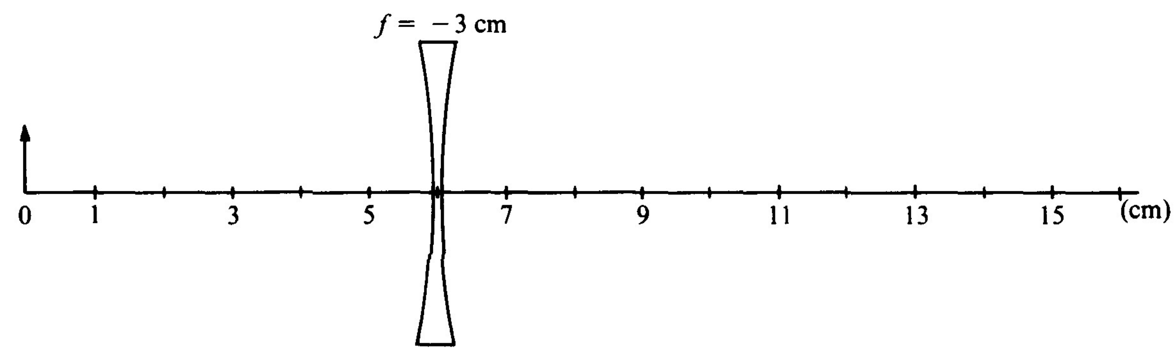
**The entire double-slit apparatus, including the slits and the screen, is submerged in water, which has an index of refraction 1.3.**
**b. Determine each of the following for this light in water.**
**i. The wavelength**
**ii. The frequency**
**c. State whether the distance between the fringes on the screen increases, decreases, or remains the same. Justify your answer.**

1986B6. An object is placed 3 centimeters to the left of a convex (converging) lens of focal length f = 2 cm, as shown below.



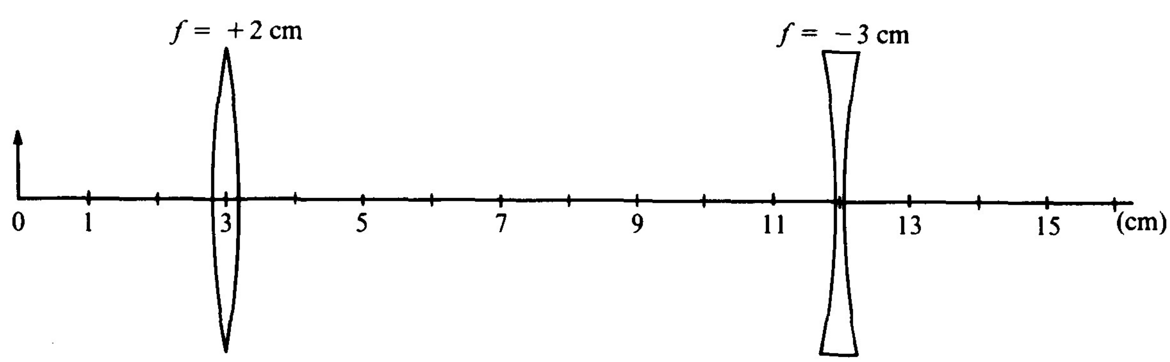

a. Sketch a ray diagram on the figure above to construct the image. It may be helpful to use a straightedge.
b. Determine the ratio of image size to object size.

The converging lens is removed and a concave (diverging) lens of focal length f = –3 centimeters is placed as shown below.



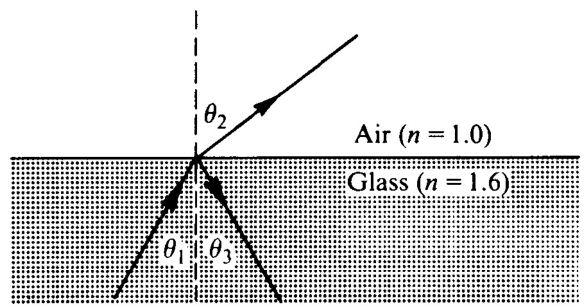

c. Sketch a ray diagram on the figure above to construct the image.
d. Calculate the distance of this image from the lens.
e. State whether the image is real or virtual.

The two lenses and the object are then placed as shown below.




f. Construct a complete ray diagram to show the final position of the image produced by the two-lens system.

1987B5. Light of frequency 6.0 x $10^{14}$ hertz strikes a glass/air boundary at an angle of incidence $\theta_1$. The ray is partially reflected and partially refracted at the boundary, as shown. The index of refraction of this glass is 1.6 for light of this frequency.




a. Determine the value of $\theta_3$ if $\theta_1 = 30°$.
b. Determine the value of $\theta_2$ if $\theta_1 = 30°$.
c. Determine the speed of this light in the glass.
d. Determine the wavelength of this light in the glass.
e. What is the largest value of $\theta_1$ that will result in a refracted ray?

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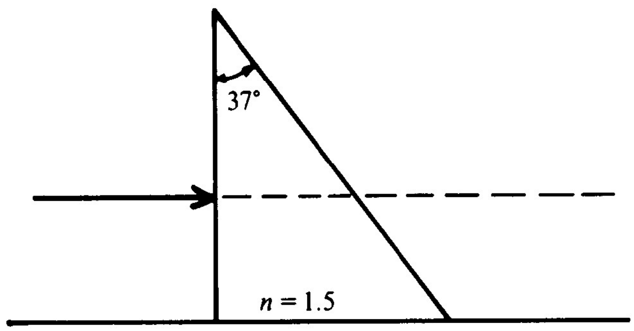



Figure I

1988B5. The triangular prism shown in Figure I above has index of refraction 1.5 and angles of 37°, 53°, and 90°. The shortest side of the prism is set on a horizontal table. A beam of light, initially horizontal, is incident on the prism from the left.

a. On Figure I above, sketch the path of the beam as it passes through and emerges from the prism.
b. Determine the angle with respect to the horizontal (angle of deviation) of the beam as it emerges from the prism.
c. The prism is replaced by a new prism of the same shape, which is set in the same position. The beam experiences total internal reflection at the right surface of this prism. What is the minimum possible index of refraction of this prism?

The new prism having the index of refraction found in part (c) is then completely submerged in water (index of refraction = 1.33) as shown in Figure II below. A horizontal beam of light is again incident from the left.

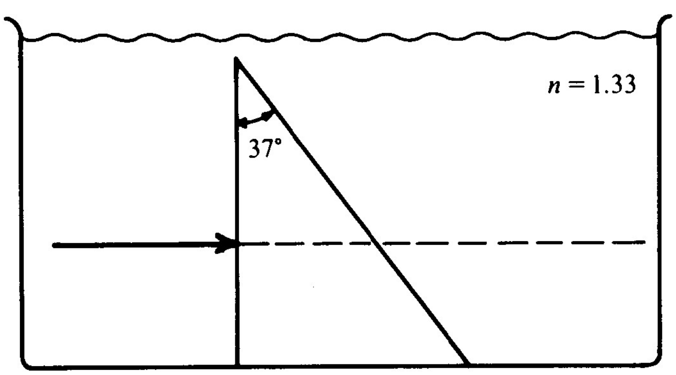
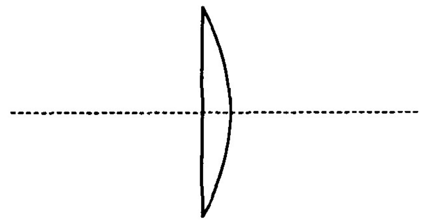



Figure II

d. On Figure II, sketch the path of the beam as it passes through and emerges from the prism.
e. Determine the angle with respect to the horizontal (angle of deviation) of the beam as it emerges from the prism.



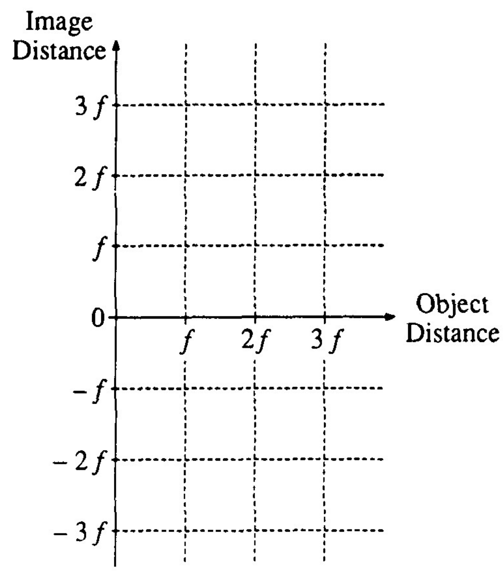
1989B5. The plano-convex lens shown above has a focal length f of 20 centimeters in air. An object is placed 60 centimeters (3f) from this lens.

a. State whether the image is real or virtual.

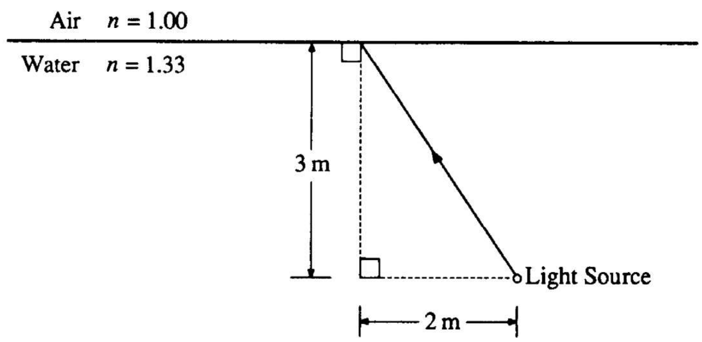
b. Determine the distance from the lens to the image.

c. Determine the magnification of this image (ratio of image size to object size).

d. The object, initially at a distance 3f from the lens, is moved toward the lens. On the axes below, sketch the image distance as the object distance varies from 3f to zero.

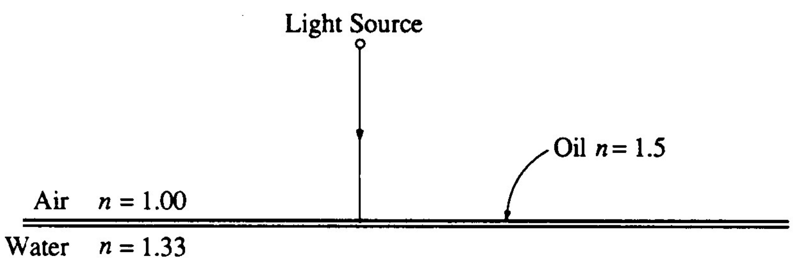



e. State whether the focal length of the lens would increase, decrease, or remain the same if the index of refraction of the lens were increased. Explain your reasoning.



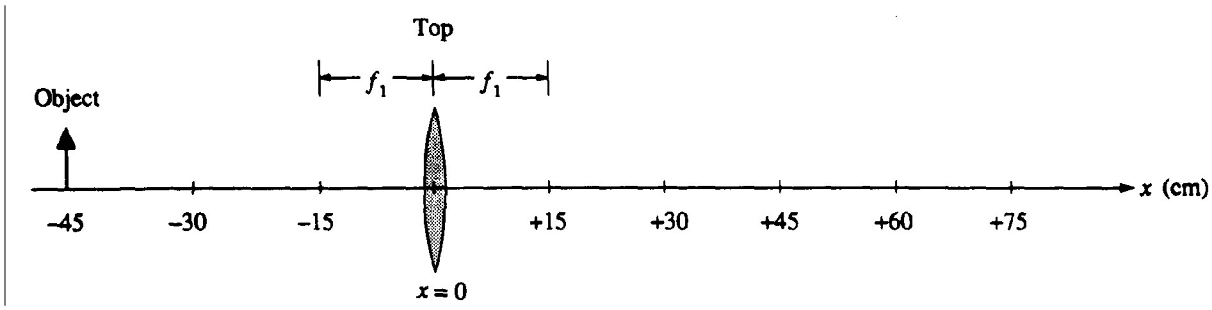

1990B6. A beam of light from a light source on the bottom of a swimming pool 3.0 meters deep strikes the surface of the water 2.0 meters to the left of the light source, as shown above. The index of refraction of the water in the pool is 1.33.

a. What angle does the reflected ray make with the normal to the surface?
b. What angle does the emerging ray make with the normal to the surface?
c. What is the minimum depth of water for which the light that strikes the surface of the water 2.0 meters to the left of the light source will be refracted into the air?



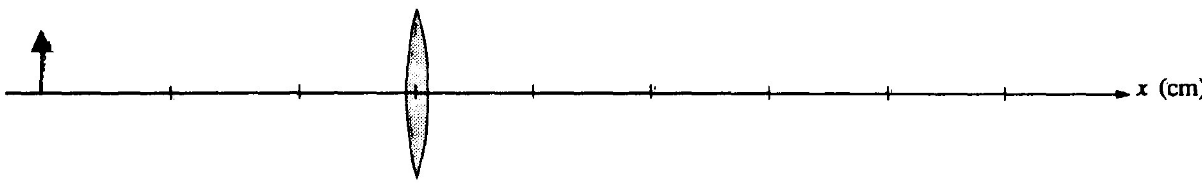

In one section of the pool, there is a thin film of oil on the surface of the water. The thickness of the film is $1.0 \times 10^{-7}$ meter and the index of refraction of the oil is 1.5. The light source is now held in the air and illuminates the film at normal incidence, as shown above.

d. At which of the interfaces (air-oil and oil-water), if either, does the light undergo a 180° phase change upon reflection?
e. For what wavelengths in the visible spectrum will the intensity be a maximum in the reflected beam?




1992B6. A thin double convex lens of focal length f, = + 15 centimeters is located at the origin of the x-axis, as shown above. An object of height 8 centimeters is placed 45 centimeters to the left of the lens.

a. On the figure below, draw a ray diagram to show the formation of the image by the lens. Clearly show principal rays.

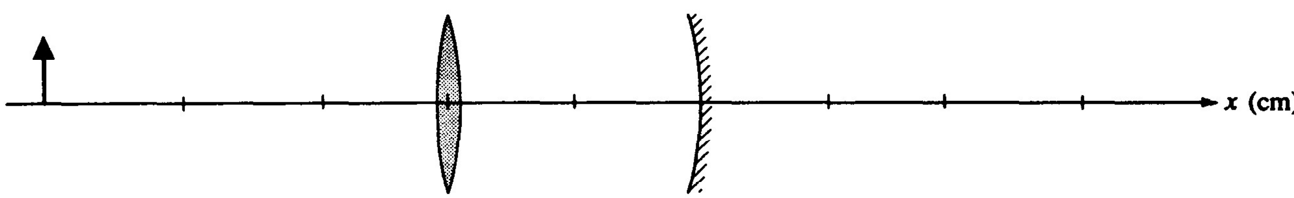



b. Calculate (do not measure) each of the following.
   i. The position of the image formed by the lens
   ii. The size of the image formed by the lens

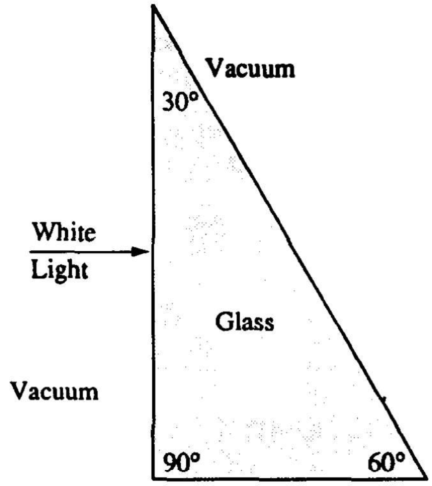
c. Describe briefly what would happen to the image formed by the lens if the top half of the lens were blocked so that no light could pass through.

A concave mirror with focal length $f_2$ = + 15 centimeters is placed at x = + 30 centimeters.

d. On the figure below, indicate the position of the image formed by the lens, and draw a ray diagram to show the formation of the image by the mirror. Clearly show principal rays.



| | Wavelength in Vacuum | Index of Refraction of Glass |
|---|---|---|
| Red Light | 700 nm | 1.5 |
| Blue Light | 480 nm | 1.6 |




1993B4. The glass prism shown above has an index of refraction that depends on the wavelength of the light that enters it. The index of refraction is 1.50 for red light of wavelength 700 nanometers ($700 \times 10^{-9}$ meter) in vacuum and 1.60 for blue light of wavelength 480 nanometers in vacuum. A beam of white light is incident from the left, perpendicular to the first surface, as shown in the figure, and is dispersed by the prism into its spectral components.

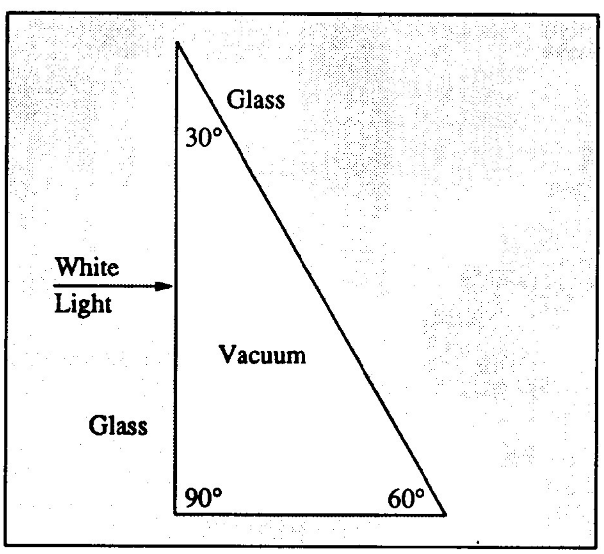
a. Determine the speed of the blue light in the glass.

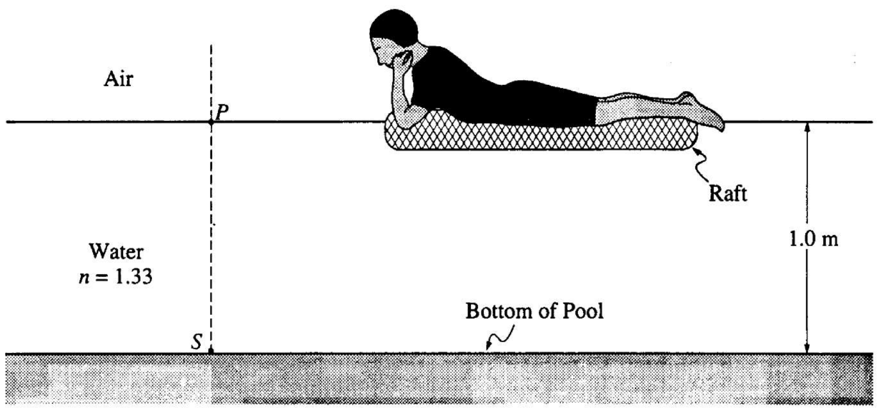
b. Determine the wavelength of the red light in the glass.

c. Determine the frequency of the red light in the glass.

d. On the figure above, sketch the approximate paths of both the red and the blue rays as they pass through the glass and back out into the vacuum. Ignore any reflected light. It is not necessary to calculate any angles, but do clearly show the change in direction of the rays, if any, at each surface and be sure to distinguish carefully any differences between the paths of the red and the blue beams.

e. The figure below represents a wedge-shaped hollow space in a large piece of the type of glass described above. On this figure, sketch the approximate path of the red and the blue rays as they pass through the hollow prism and back into the glass. Again, ignore any reflected light, clearly show changes in direction, if any, where refraction occurs, and carefully distinguish any differences in the two paths.

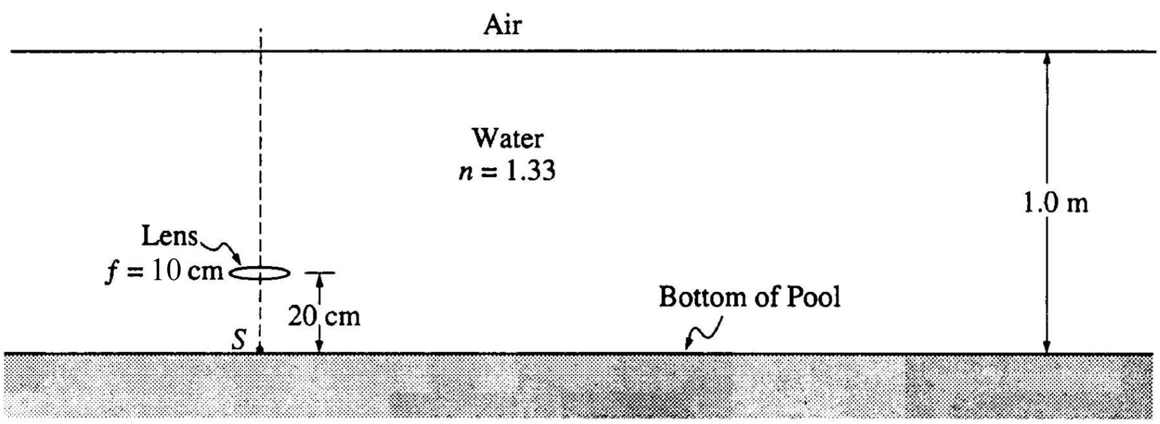





1994B5. A point source S of monochromatic light is located on the bottom of a swimming pool filled with water to a depth of 1.0 meter, as shown above. The index of refraction of water is 1.33 for this light. Point P is located on the surface of the water directly above the light source. A person floats motionless on a raft so that the surface of the water is undisturbed.

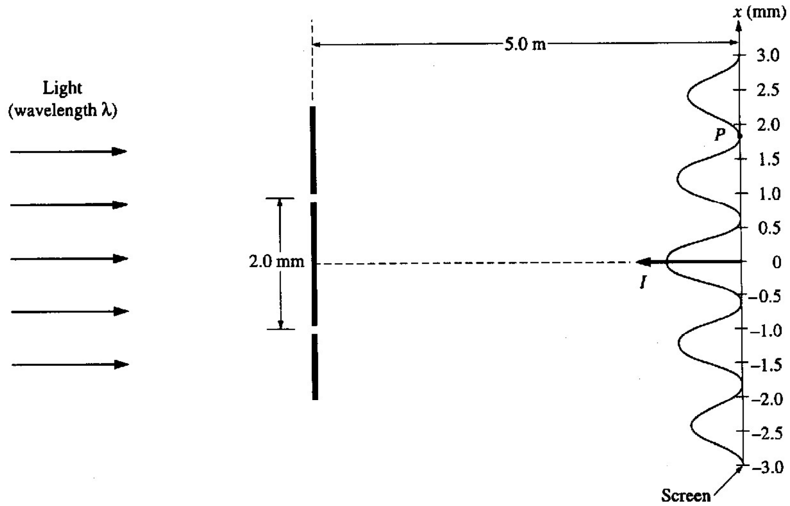
a. Determine the velocity of the source's light in water.
b. On the diagram above, draw the approximate path of a ray of light from the source S to the eye of the person. It is not necessary to calculate any angles.
c. Determine the critical angle for the air-water interface.

Suppose that a converging lens with focal length 10 centimeters in water is placed 20 centimeters above the light source, as shown in the diagram below. An image of the light source is formed by the lens.




d. Calculate the position of the image with respect to the bottom of the pool.
e. If, instead, the pool were filled with a material with a different index of refraction, describe the effect, if any, on the image and its position in each of the following cases.
   i. The index of refraction of the material is equal to that of the lens.
   ii. The index of refraction of the material is greater than that of water but less than that of the lens.

**NOTE: This is a repeat from the physical optics section but has an important new part in it in bold.**




1996B3. Coherent monochromatic light of wavelength λ in air is incident on two narrow slits, the centers of which are 2.0 mm apart, as shown above. The interference pattern observed on a screen 5.0 m away is represented in the figure by the graph of light intensity I as a function of position x on the screen.

a. What property of light does this interference experiment demonstrate?

b. At point P in the diagram, there is a minimum in the interference pattern. Determine the path difference between the light arriving at this point from the two slits.

c. Determine the wavelength, λ, of the light.

d. Briefly and qualitatively describe how the interference pattern would change under each of the following separate modifications and explain your reasoning.

   **i. The experiment is performed in water, which has an index of refraction greater than 1.**

   ii. One of the slits is covered.

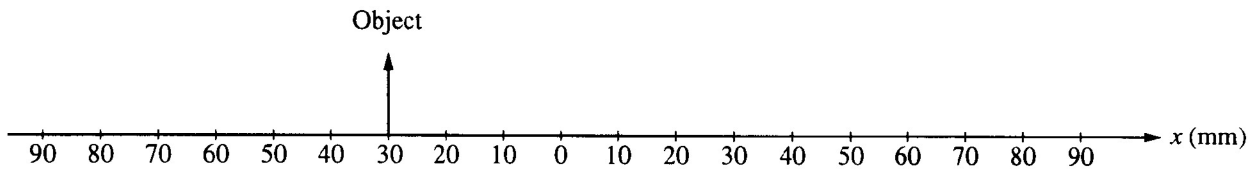
   iii. The slits are moved farther apart.

1997B5. An object is placed 30 mm in front of a lens located at x = 0. An image of the object is located 90 mm behind the lens.

a. Is the lens converging or diverging? Explain your reasoning.

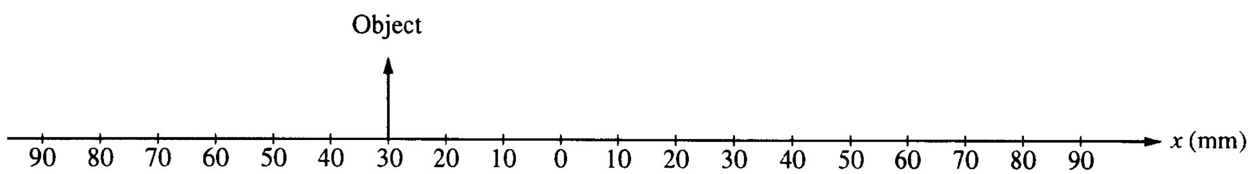
b. What is the focal length of the lens?

c. On the axis below, draw the lens at position x = 0. Draw at least two rays and locate the image to show the situation described above.




d. Based on your diagram in (c), describe the image by answering the following questions in the blank spaces provided.
Is the image real or virtual?_________________
Is the image smaller than, larger than, or same size as the object?________________
Is the image inverted or upright compared to the object?________________

e. The lens is replaced by a concave mirror of focal length 20 mm. On the axis below, draw the mirror at position x = 0 so that a real image is formed. Draw at least two rays and locate the image to show this situation

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1999B6. You are given the following equipment for use in the optics experiments in parts (a) and (b).

A solid rectangular block made of transparent plastic
A laser that produces a narrow, bright, monochromatic ray of light
A protractor
A meterstick
A diffraction grating of known slit spacing
A white opaque screen

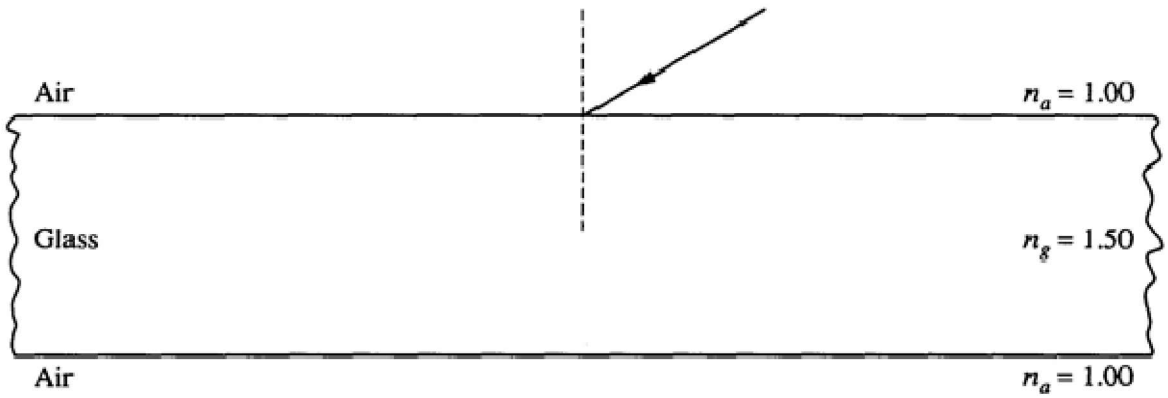
a. Briefly describe the procedure you would use to determine the index of refraction of the plastic. Include a labeled diagram to show the experimental setup. Write down the corresponding equation you would use in your calculation and make sure all the variables in this equation are labeled on your diagram.

b. Since the index of refraction depends on wavelength, you decide you also want to determine the wavelength of your light source. Draw and label a diagram showing the experimental setup. Show the equation(s) you would use in your calculation and identify all the variables in the equation(s). State and justify any assumptions you make.

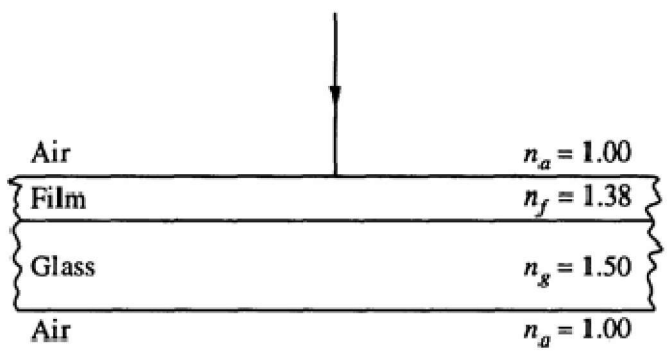
2000B4.

A sheet of glass has an index of refraction $n_g = 1.50$. Assume that the index of refraction for air is $n_a = 1.00$.

a. Monochromatic light is incident on the glass sheet, as shown in the figure below, at an angle of incidence of 60°. On the figure, sketch the path the light takes the first time it strikes each of the two parallel surfaces. Calculate and label the size of each angle (in degrees) on the figure, including angles of incidence, reflection, and refraction at each of the two parallel surfaces shown.




b. Next a thin film of material is to be tested on the glass sheet for use in making reflective coatings. The film has an index of refraction $n_f = 1.38$. White light is incident normal to the surface of the film as shown below. It is observed that at a point where the light is incident on the film, light reflected from the surface appears green ($\lambda$ = 525 nm).

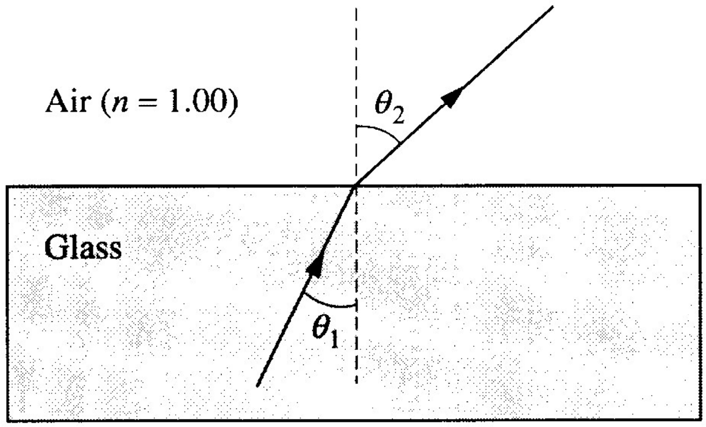



i. What is the frequency of the green light in air?

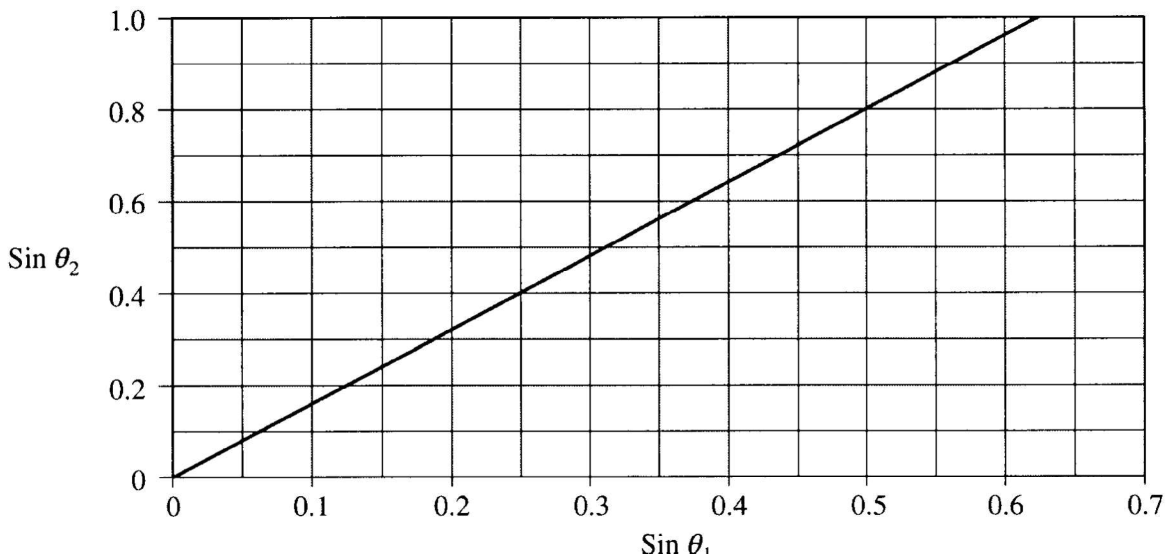
ii. What is the frequency of the green light in the film?

iii. What is the wavelength of the green light in the film?

iv. Calculate the minimum thickness of film that would produce this green reflection.




2001B4. In an experiment, a beam of red light of wavelength 675 nm (in air), passes from glass into air, as shown above. The incident and refracted angles are $\theta_1$ and $\theta_2$ , respectively. In the experiment, angle $\theta_2$ is measured for various angles of incidence $\theta_1$, and the sines of the angles are used to obtain the line shown in the following graph.




a. Assuming an index of refraction of 1.00 for air, use the graph to determine a value for the index of refraction of the glass for the red light. Explain how you obtained this value.

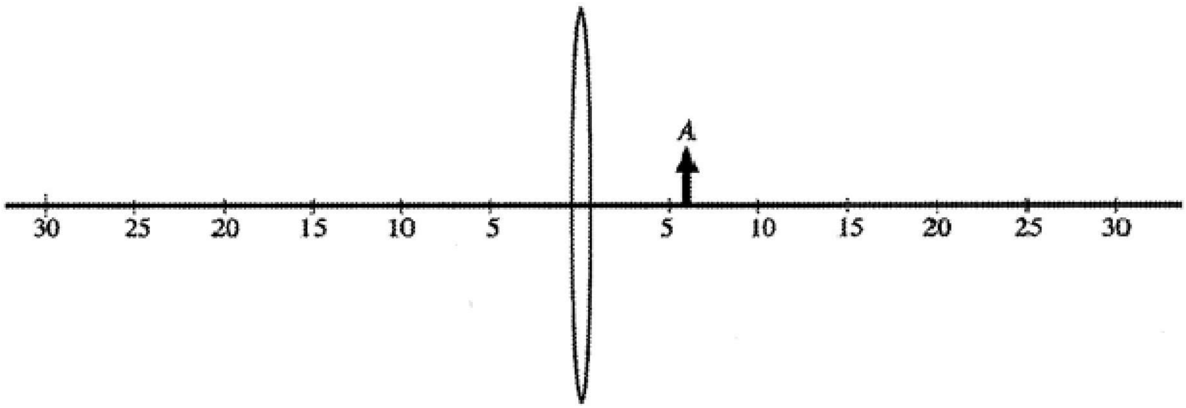
b. For this red light, determine the following.
   i. The frequency in air
   ii. The speed in glass
   iii. The wavelength in glass

c. The index of refraction of this glass is 1.66 for violet light, which has wavelength 425 nm in air.
   i. Given the same incident angle $\theta_1$, show on the ray diagram at the top of the page how the refracted ray for the violet light would vary from the refracted ray already drawn for the red light.
   ii. Sketch the graph of sin $\theta_2$ versus sin $\theta_1$ for the violet light on the figure above that shows the same graph already drawn for the red light.

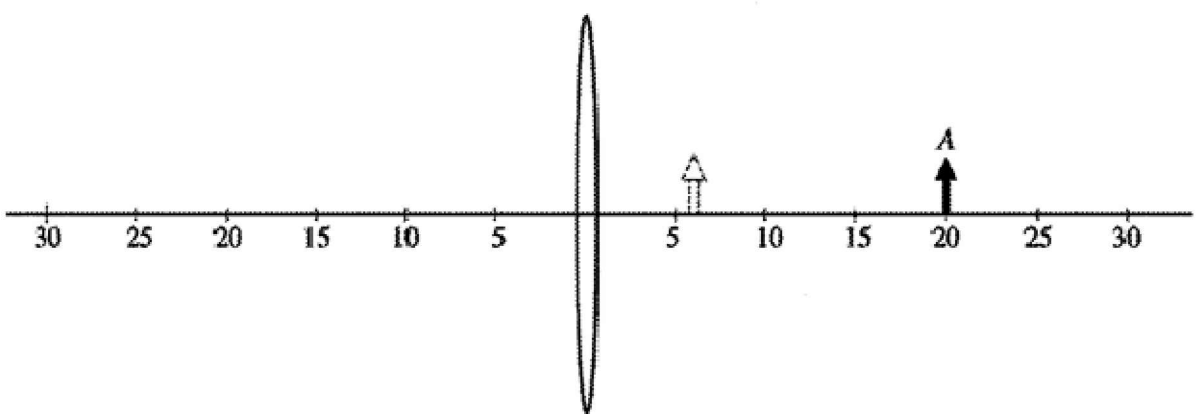
d. Determine the critical angle of incidence $\theta_c$, for the violet light in the glass in order for total internal reflection to occur.

2002B4. A thin converging lens of focal length 10 cm is used as a simple magnifier to examine an object *A* that is held 6 cm from the lens.

(a) On the figure below, draw a ray diagram showing the position and size of the image formed.

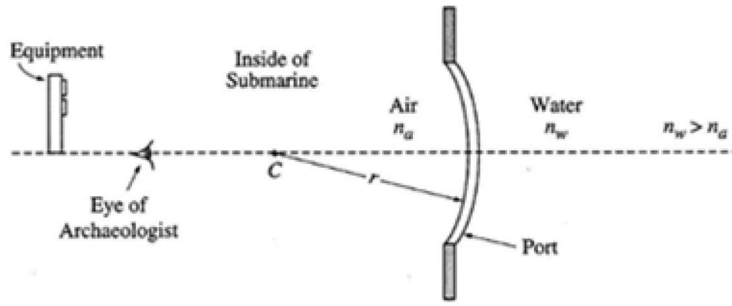



(b) State whether the image is real or virtual. Explain your reasoning.
(c) Calculate the distance of the image from the center of the lens.
(d) Calculate the ratio of the image size to the object size.




(e) The object *A* is now moved to the right from $x = 6$ cm to a position of $x = 20$ cm, as shown above. Describe the image position, size, and orientation when the object is at $x = 20$ cm.

2002B4B. A marine archaeologist looks out the port of a research submarine, as shown. The port is spherically shaped with center of curvature at point $C$ and radius of curvature $r$. It is made of a material that has an index of refraction of $n_w$, the same as the index of refraction of seawater, which is greater than $n_a$, the index of refraction of air. The archaeologist is located to the left of point $C$ and some equipment in the submarine is located behind the archaeologist. The archaeologist can see through the port, but the port also acts as a mirror so the archaeologist can see the reflection of the equipment.




(a) What is the focal length of the mirror?

(b) On the following figure, sketch a ray diagram to locate the position of the image of the equipment formed as a result of the mirror effect.

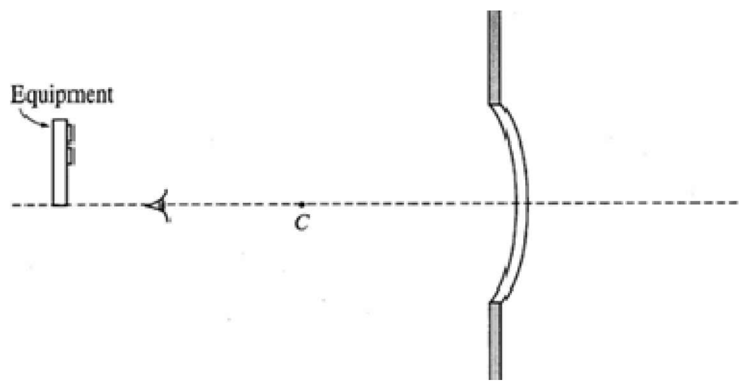
(c) Based on your ray diagram, check the appropriate spaces below to describe the image of the equipment formed as a result of the mirror effect.

i. Image is:____ upright ____ inverted

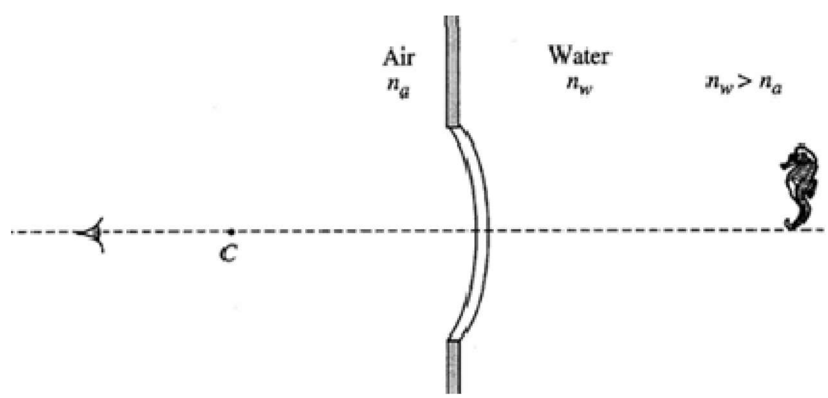
ii. Image is:____ real ____ virtual

iii. Image is:____ larger than the equipment

____ smaller than the equipment




The archaeologist also observes a seahorse located outside the port directly in front of the archeologist. Due to refraction of light at the inner surface of the port, the seahorse does not appear to the archaeologist to be at its actual location.




(d) On the figure above, sketch a ray diagram to locate the position of the image of the seahorse formed by the refraction of light at the port.

(e) Based on your ray diagram, check the appropriate spaces below to describe the image of the seahorse, as seen by the archaeologist, formed by the refraction of light at the port.

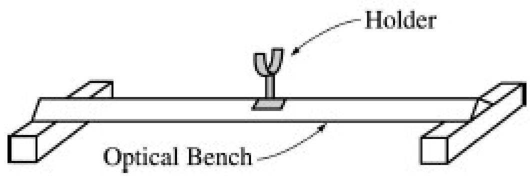
i. Image is:____upright ____ inverted

ii. Image is:____real ____ virtual

iii. Image is:____ larger than the seahorse ____ smaller than the seahorse

2003B4.

In your physics lab, you have a concave mirror with radius of curvature $r$ = 60 cm. You are assigned the task of finding experimentally the location of a lit candle such that the mirror will produce an image that is 4 times the height of the lit candle.




You have an optical bench, which is a long straight track as shown above. Objects in holders can be attached at any location along the bench. In addition to the concave mirror and the lit candle in holders, you also have the following equipment.

____ convex mirror in holder ____ concave lens in holder ____ convex lens in holder
____ meter stick ____ ruler ____ screen in holder

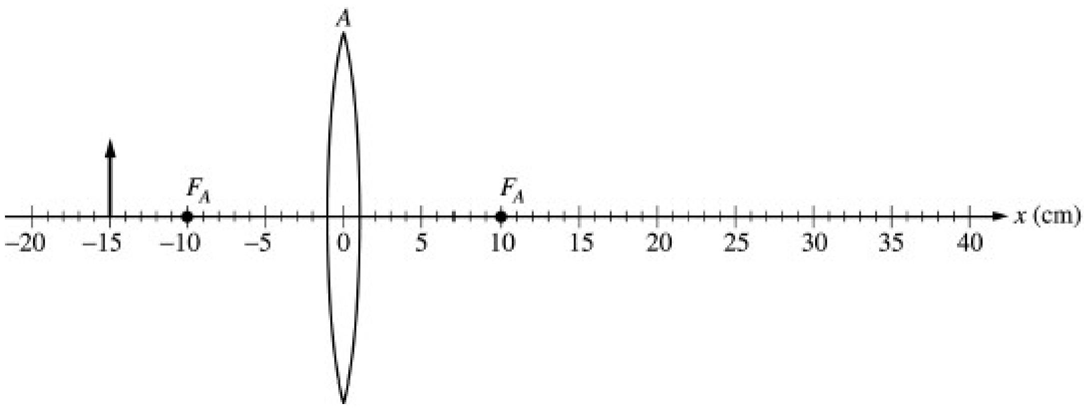
(a) Briefly list the steps in your procedure that will lead you to the location of the lit candle that produces the desired image. Include definitions of any parameters that you will measure.

(b) On the list of equipment before part (a) place check marks beside each additional piece of equipment you will need to do this experiment.

(c) On the scale below, draw a ray diagram of your lab setup in part (a) to show the locations of the candle, the mirror, and the image.

(d) Check the appropriate spaces below to indicate the characteristics of your image.
____ real ____ upright ____ larger than object
____ virtual ____ inverted ____ smaller than object

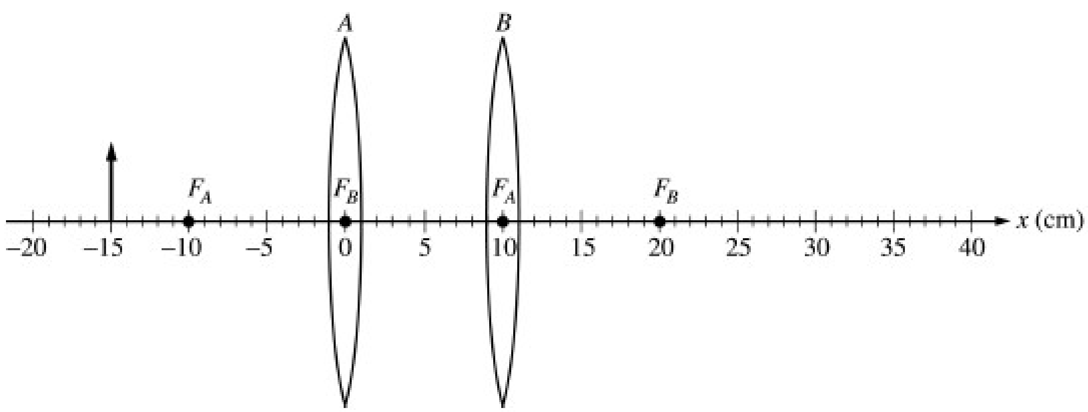
(e) You complete your assignment and turn in your results to your teacher. She tells you that another student, using equipment from the same list, has found a different location for the lit candle. However, she tells both of you that the labs were done correctly and that neither experiment need be repeated. Explain why both experiments can be correct.




B2003B3.

A thin convex lens $A$ of focal length $f_A$ = 10 cm is positioned on an $x$-axis as shown above. An object of height 5 cm, represented by the arrow, is positioned 15 cm to the left of lens $A$.

(a) On the figure above, draw necessary rays and sketch the image produced by lens $A$.
(b) Calculate the location of the image produced by lens $A$.
(c) Calculate the height of the image produced by lens $A$.




A second thin convex lens $B$ of focal length $f_B$ = 10 cm is now positioned 10 cm to the right of lens $A$, as shown above.

(d) Determine the location on the $x$-axis given above of the final image produced by the combination of lenses.
(e) Check the appropriate spaces below to indicate the characteristics of the final image produced by the combination of lenses.

____ inverted ____ larger than the original object
____ upright ____ smaller than the original object

Explain your answers.

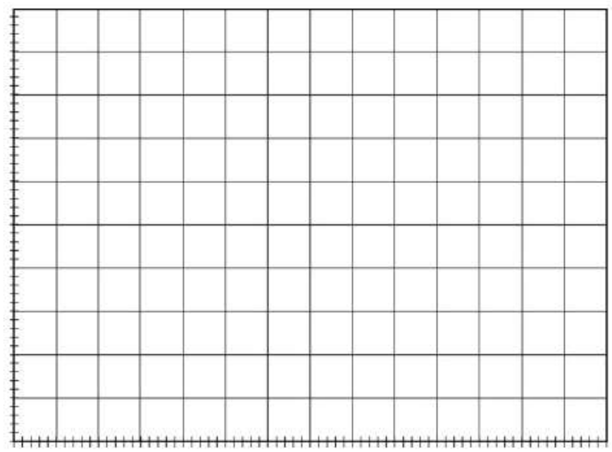
2006B4.

A student performs an experiment to determine the index of refraction $n$ of a rectangular glass slab in air. She is asked to use a laser beam to measure angles of incidence $\theta_i$ in air and corresponding angles of refraction $\theta_r$ in glass. The measurements of the angles for five trials are given in the table below.

| Trial | $\theta_i$ | $\theta_r$ | | |
|---|---|---|---|---|
| 1 | 30° | 20° | | |
| 2 | 40° | 27° | | |
| 3 | 50° | 32° | | |
| 4 | 60° | 37° | | |
| 5 | 70° | 40° | | |

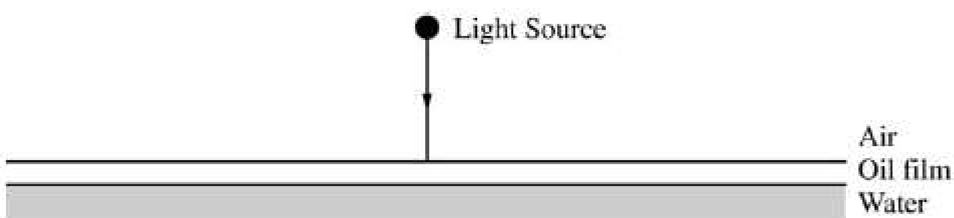
(a) Complete the last two columns in the table by calculating the quantities that need to be graphed to provide a linear relationship from which the index of refraction can be determined. Label the top of each column.

(b) On the grid, plot the quantities calculated in (a) and draw an appropriate graph from which the index of refraction can be determined. Label the axes.



(c) Using the graph, calculate the index of refraction of the glass slab.

The student is also asked to determine the thickness of a film of oil ($n$ = 1.43) on the surface of water ($n$ = 1.33).




Light from a variable wavelength source is incident vertically onto the oil film as shown above. The student measures a maximum in the intensity of the reflected light when the incident light has a wavelength of 600 nm.

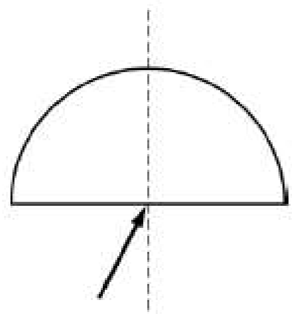
(d) At which of the two interfaces does the light undergo a 180° phase change on reflection?

___The air-oil interface only ___The oil-water interface only

___Both interfaces ___Neither interface

(e) Calculate the minimum possible thickness of the oil film.

B2006B4.



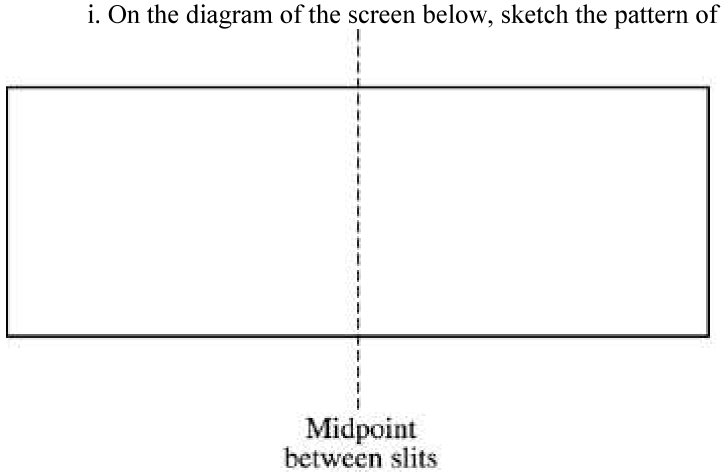
A ray of red light in air ( $\lambda$ = 650 nm ) is incident on a semicircular block of clear plastic ($n$ = 1.51 for this light), as shown above. The ray strikes the block at its center of curvature at an angle of incidence of 27°.

(a) Part of the incident ray is reflected and part is refracted at the first interface.
   i. Determine the angle of reflection at the first interface. Draw and label the reflected ray on the diagram above.
   ii. Determine the angle of refraction at the first interface. Draw and label the refracted ray on the diagram above.
   iii. Determine the speed of the light in the plastic block.
   iv. Determine the wavelength of the light in the plastic block.

(b) The source of red light is replaced with one that produces blue light ($\lambda$ = 450 nm), for which the plastic has a greater index of refraction than for the red light. Qualitatively describe what happens to the reflected and refracted rays.

(c) The semicircular block is removed and the blue light is directed perpendicularly through a double slit and onto a screen. The distance between the slits is 0.15 mm. The slits are 1.4 m from the screen.

   i. On the diagram of the screen below, sketch the pattern of light that you should expect to see.




   ii. Calculate the distance between two adjacent bright fringes

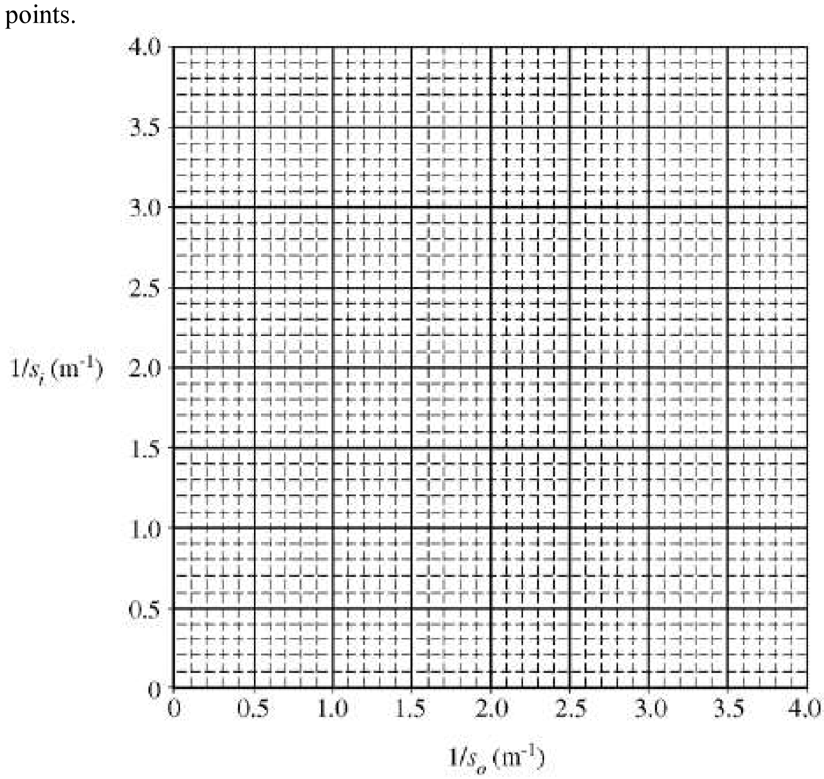
2007B6. You are asked to experimentally determine the focal length of a converging lens.
(a) Your teacher first asks you to estimate the focal length by using a distant tree visible through the laboratory window. Explain how you will estimate the focal length.

To verify the value of the focal length, you are to measure several object distances $s_o$ and image distances $s_i$ using equipment that can be set up on a tabletop in the laboratory.
(b) In addition to the lens, which of the following equipment would you use to obtain the data?
____Lighted candle ____ Candleholder ____ Desk lamp ____ Plane mirror
____ Vernier caliper ____ Meterstick ____ Ruler ____ Lens holder
____ Stopwatch ____ Screen ____ Diffraction grating
(c) On the tabletop below, sketch the setup used to obtain the data, labeling the lens, the distances $s_o$ and $s_i$ , and the equipment checked in part (b).


You are to determine the focal length using a linear graph of $1/s_i$ versus $1/s_o$ . Assume that you obtain the following data for object distance $s_o$ and image distance $s_i$ .

| Trial # | $s_o$ (m) | $s_i$ (m) | $1/s_o$ $(m^{-1})$ | $1/s_i$ $(m^{-1})$ |
|---|---|---|---|---|
| 1 | 0.40 | 1.10 | 2.5 | 0.91 |
| 2 | 0.50 | 0.75 | 2.0 | 1.3 |
| 3 | 0.60 | 0.60 | 1.7 | 1.7 |
| 4 | 0.80 | 0.50 | 1.2 | 2.0 |
| 5 | 1.20 | 0.38 | 0.83 | 2.6 |

(d) On the grid below, plot the points in the last two columns of the table above and draw a best-fit line through the points.



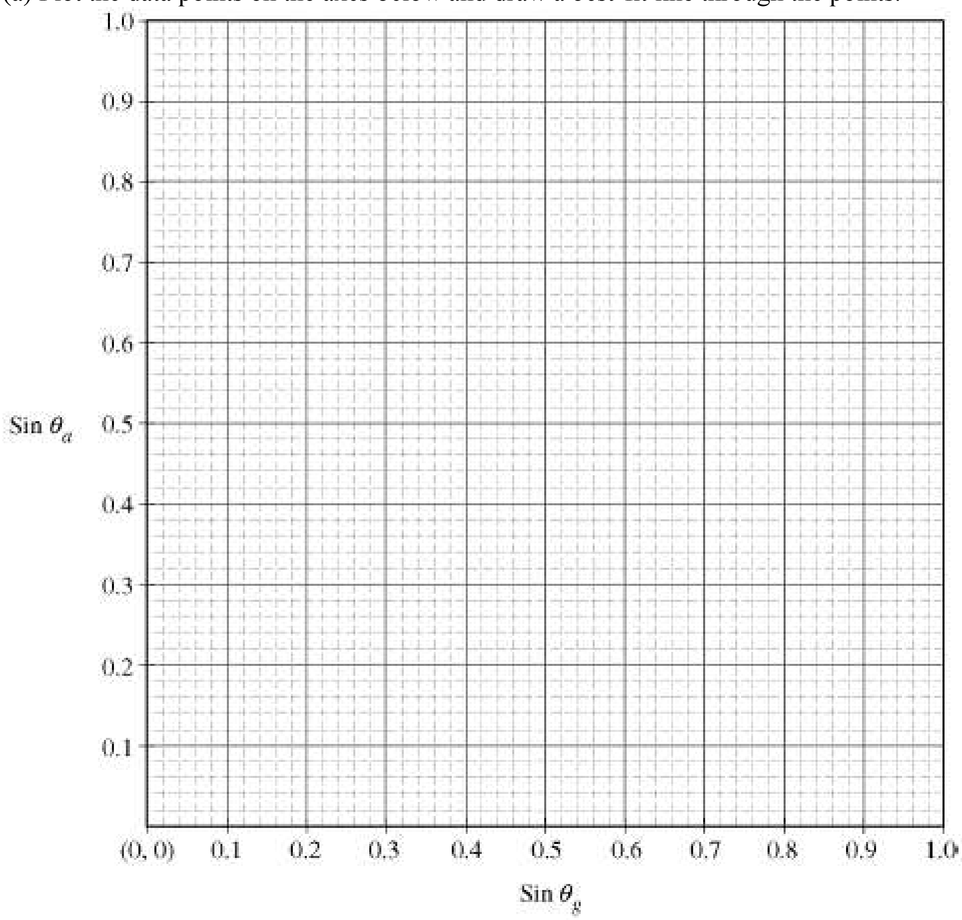

(e) Calculate the focal length from the best-fit line.

B2007B6

A student is asked to determine the index of refraction of a glass slab. She conducts several trials for measurement of angle of incidence $\theta_a$ in the air versus angle of refraction $\theta_g$ in the glass at the surface of the slab. She records her data in the following table. The index of refraction in air is 1.0.

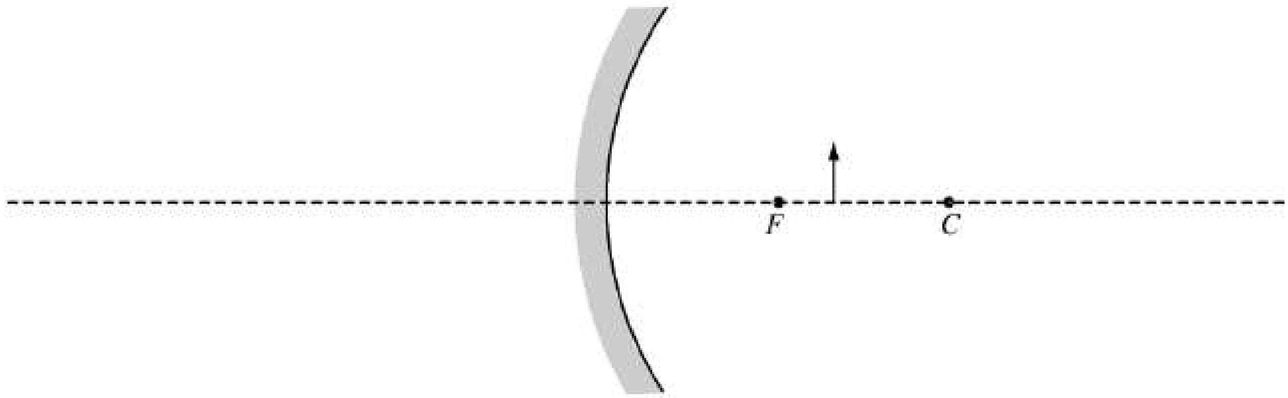
| Trial # | $\theta_g$ (degrees) | $\theta_a$ (degrees) | Sin $\theta_g$ | Sin $\theta_a$ |
|---|---|---|---|---|
| 1 | 5.0 | 8.0 | 0.09 | 0.14 |
| 2 | 15 | 21 | 0.26 | 0.36 |
| 3 | 25 | 39 | 0.42 | 0.63 |
| 4 | 35 | 56 | 0.57 | 0.83 |

(a) Plot the data points on the axes below and draw a best-fit line through the points.




(b) Calculate the index of refraction of the glass slab from your best-fit line.
(c) Describe how you could use the graph to determine the critical angle for the glass-air interface. Do not use the answer to the part (b) for this purpose.
(d) On the graph in (a), sketch and label a line for a material of higher index of refraction.

2008B6.




The figure above shows a converging mirror, its focal point *F*, its center of curvature *C*, and an object represented by the solid arrow.

(a) On the figure above, draw a ray diagram showing at least two incident rays and the image formed by them.

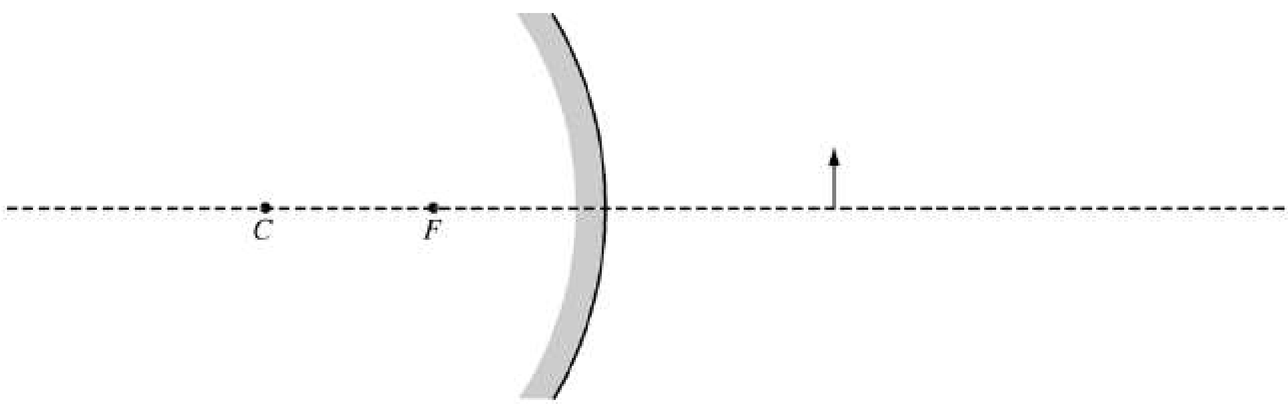
(b) Is the image real or virtual?

____ Real ____ Virtual

Justify your answer.

(c) The focal length of this mirror is 6.0 cm, and the object is located 8.0 cm away from the mirror. Calculate the position of the image formed by the mirror. (Do NOT simply measure your ray diagram.)

(d) Suppose that the converging mirror is replaced by a diverging mirror with the same radius of curvature that is the same distance from the object, as shown below.



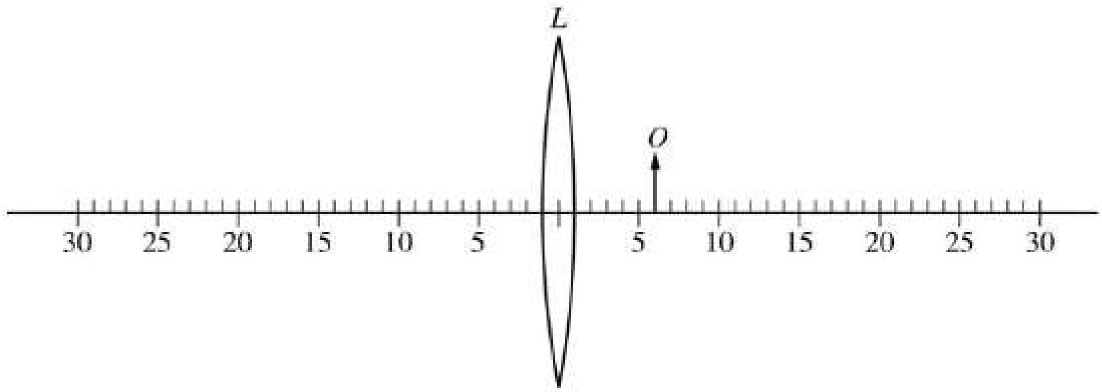

For this mirror, how does the size of the image compare with that of the object?

____ Larger than the object ____ Smaller than the object ____ The same size as the object

Justify your answer.

B2008B6.

A thin converging lens $L$ of focal length 10.0 cm is used as a simple magnifier to examine an object $O$ that is placed 6.0 cm from the lens.



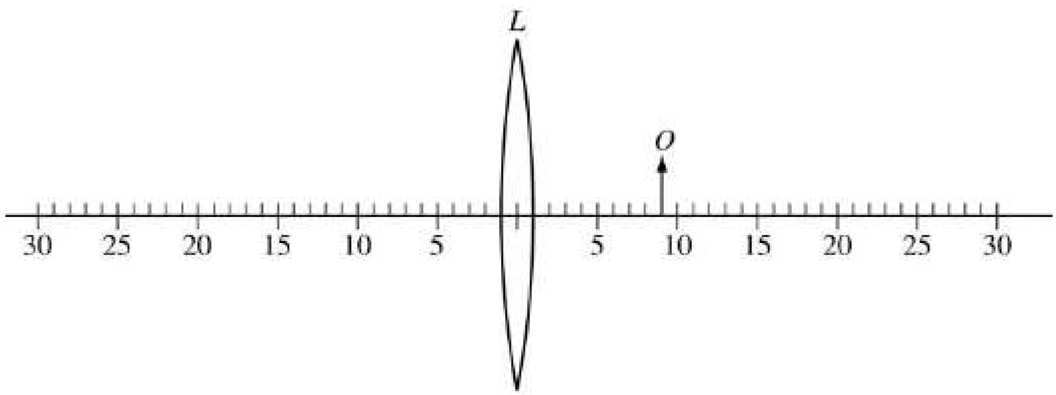

(a) On the figure above, draw a ray diagram showing at least two incident rays and the position and size of the image formed.

(b) i. Indicate whether the image is real or virtual.

____ Real ____ Virtual

ii. Justify your answer.

(c) Calculate the distance of the image from the center of the lens. (Do NOT simply measure your ray diagram.)

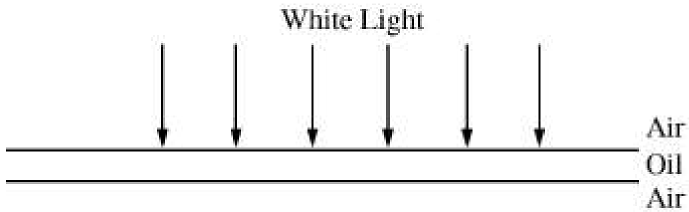



(d) The object is now moved 3.0 cm to the right, as shown above. How does the height of the new image compare with that of the previous image?

____ It is larger. ____ It is smaller. ____ It is the same size.

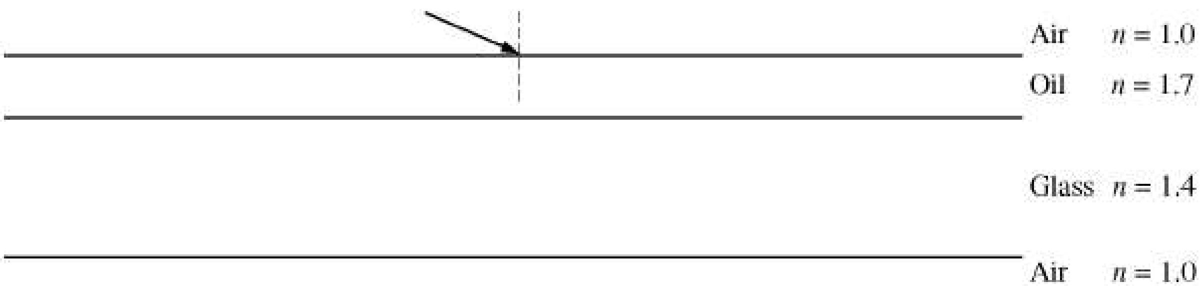
Justify your answer.

B2009B5




A wide beam of white light is incident normal to the surface of a uniform oil film. An observer looking down at the film sees green light that has maximum intensity at a wavelength of $5.2 \times 10^{-7}$ m. The index of refraction of the oil is 1.7.

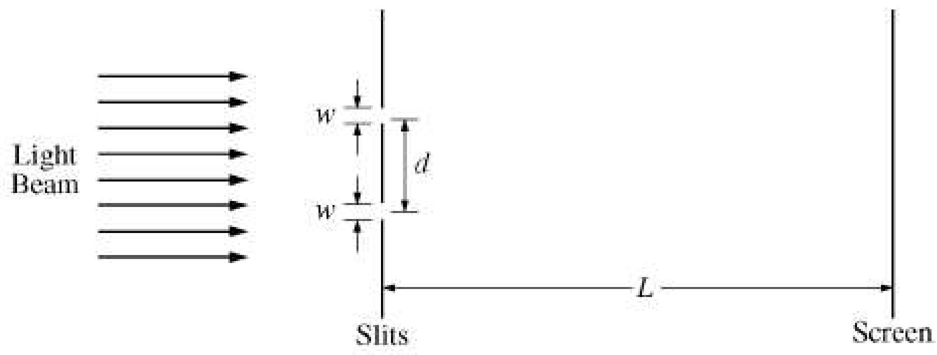
(a) Calculate the speed at which the light travels within the film.
(b) Calculate the wavelength of the green light within the film.
(c) Calculate the minimum possible thickness of the film.
(d) The oil film now rests on a thick slab of glass with index of refraction 1.4, as shown in the figure below. A light ray is incident on the film at the angle shown. On the figure, sketch the path of the refracted light ray that passes through the film and the glass slab and exits into the air. Clearly show any bending of the ray at each interface. You are NOT expected to calculate the sizes of any angles.



**NOTE: This is a repeat from the physical optics section but has an important new part in it in bold.**

2009B6

In a classroom demonstration, a beam of coherent light of wavelength 550 nm is incident perpendicularly onto a pair of slits. Each slit has a width *w* of $1.2 \times 10^{-6}$ m, and the distance *d* between the centers of the slits is $1.8 \times 10^{-5}$ m. The class observes light and dark fringes on a screen that is a distance *L* of 2.2 m from the slits. Your notebook shows the following setup for the demonstration.

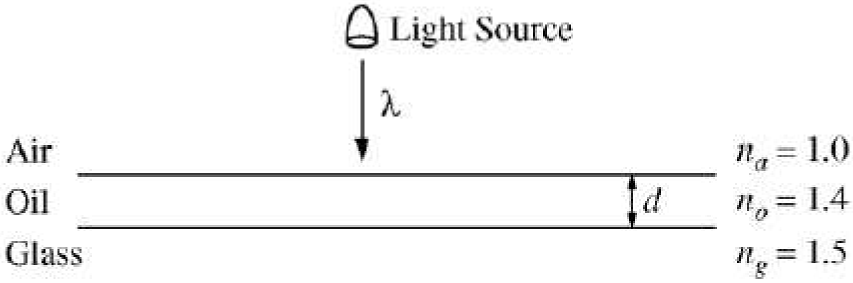



Note: Figure not drawn to scale.

(a) Calculate the frequency of the light.
(b) Calculate the distance between two adjacent dark fringes on the screen.

**The entire apparatus is now immersed in a transparent fluid having index of refraction 1.4.**
**(c) What is the frequency of the light in the transparent fluid?**
**(d) Does the distance between the dark fringes increase, decrease, or remain the same?**
**_____ Increase _____ Decrease _____ Remain the same**
**Explain your reasoning.**

**Supplemental Problem.**




In a classroom demonstration of thin films, your physics teacher takes a glass plate and places a thin layer of transparent oil on top of it. The oil film is then illuminated by shining a narrow beam of white light perpendicularly onto the oil's surface, as shown above. The indices of refraction of air, the oil, and the glass plate are given in the diagram. Standing near the light source, you observe that the film appears green. This corresponds to a wavelength of 520 nm.

(a) Determine each of the following for the green light.

i. The frequency of the light in air

ii. The frequency of the light in the oil film

iii. The wavelength of the light in the oil film

(b) Calculate the minimum thickness of the oil film (other than zero) such that the observed green light is the most intense.

(c) As your teacher changes the angle of the light source, the light you observe from the film changes color. Give an explanation for this phenomenon.