Geometrical Optics

Advanced Placement Physics B
Mr. DiBucci

The Reflection of Light: Mirrors

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The Reflection of Light: Mirrors

PREVIEW

In this chapter the reflection of light from mirrors is discussed. You will see how reflections are formed by plane and spherical mirrors, how to construct ray diagrams for reflecting surfaces, and how to determine magnification.

QUICK REFERENCE

Important Terms

Wave fronts
Surfaces on which all points of a wave are in the same phase of motion.

Rays
Lines that are perpendicular to the wave fronts and point in the direction of the velocity of the wave.

Law of reflection
For light that reflects off a smooth surface, (a) the incident ray, the reflected ray, and the normal to the surface all lie in the same plane, and (b) the angle of reflection equals the angle of incidence.

Virtual image
An image from which rays of light do not actually come, but only appear to do so.

Real image
An image from which rays of light actually emanate.

Plane mirror
A flat reflecting surface which forms an upright, virtual image that is located as far behind the mirror as the object is in front of the mirror. In addition, the heights of the image and the object are equal.

Spherical mirror
A reflecting surface that has the shape of a section from the surface of a sphere.

Principal axis
The straight line drawn through the center of curvature and the middle of the mirror's surface.

Paraxial rays
Rays that lie close to the principal axis.

Radius of curvature
The distance from the center of curvature to the mirror.

Focal point
A point on the principal axis where paraxial rays that are parallel to the principal axis converge after being reflected from a concave mirror. For a convex mirror, it is the point on the principal axis from which such rays appear to emanate.

Focal length
The distance from the focal point to the middle of the mirror.

Magnification
The ratio of the image height to the object height.

Equations

The **focal length** of a **concave mirror**

$$f = \frac{1}{2}R \qquad (25.1)$$

The **focal length** of a **convex mirror**:

$$f = -\frac{1}{2}R \qquad (25.2)$$

The **mirror equation**:

$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f} \qquad (25.3)$$

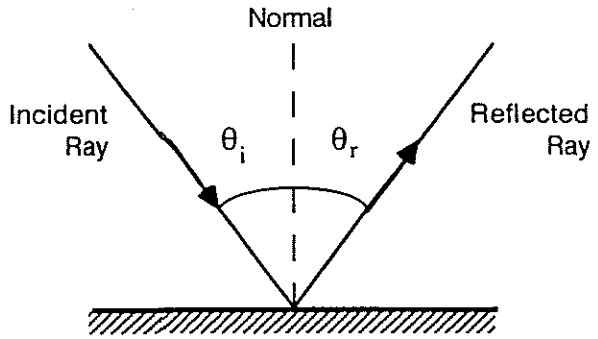
The magnification equation:

$$m = \frac{\text{Image height}}{\text{Object height}} = -\frac{d_i}{d_o} \qquad (25.4)$$

DISCUSSION OF SELECTED SECTIONS

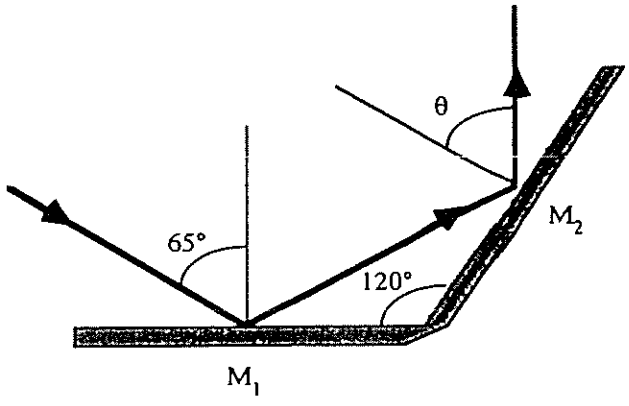
25.2 The Reflection of Light

Suppose a ray of light is incident on a flat, reflecting surface, such as the mirror shown in the diagram. The angle of incidence θ_i is the angle that the incident ray makes with respect to the normal to the surface. The angle of reflection θ_r is the angle that the reflected ray makes with the normal. The **law of reflection** states that the incident ray, the reflected ray, and the normal to the surface all lie in the same plane, and the angle of reflection equals the angle of incidence.



Example 1

Two plane mirrors are separated by 120°, as the drawing illustrates. If a ray strikes mirror M_1, at a 65° angle of incidence, at what angle θ does it leave mirror M_2?



The ray leaves M_1 at an angle of 65° with respect to the normal, or 90° - 65° = 25° with respect to the plane of M_1. The first reflected ray therefore strikes M_2 at an angle of 180° - (120° + 25°) = 35° with respect to the plane of M_2. The second angle of incidence is 90° - 35° = 55°. Finally, the angle of reflection from M_2, θ, is equal to the angle of incidence for mirror M_2, which is just θ = 55°.

HELPFUL SUGGESTIONS

1. It is important to remember the sign conventions that are used with the mirror equation and the magnification equation. These conventions apply to both concave and convex mirrors:

Object distance

d_o is + if the object is in front of the mirror (real object).
d_o is - if the object is behind the mirror (virtual object).

Image distance

d_i is + if the image is in front of the mirror (real image).
d_i is - if the image is behind the mirror (virtual image).

Focal length

f is + for a concave mirror.
f is - for a convex mirror.

Magnification

m is + for an image that is upright with respect to the object.
m is - for an image that is inverted with respect to the object.

EVERYDAY PHYSICS

1. The side view mirror on the passenger side of most cars reads "Caution, objects are closer than they appear". What does this tell you about the type of mirror being used for these side view mirrors?

2. Set up two pocket mirrors at right angles to one another and place a small object between them. You'll see three objects in the mirrors. Change the angle of the mirrors and see how many images you can obtain. Notice what happens when the mirrors are nearly facing one another.

3. Convex and concave mirrors are quite commonly found in everyday situations. Makeup mirrors use concave mirrors to provide magnified images of one's face. Store security systems usually employ large convex mirrors which allow large areas of the store to be seen as a single compact image. As you will see in chapter 26, concave mirrors are used in a type of telescope known as a reflecting telescope.

Quiz answers

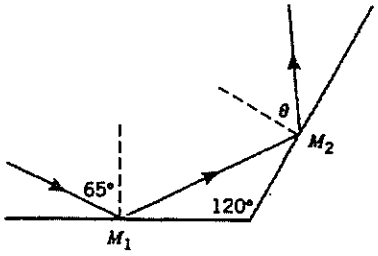
1. a	5. a	9. b
2. c	6. c	10. a
3. d	7. d	11. d
4. b	8. c	12. d

Practice Problem 6

Type of Mirror	Radius of Curvature	Focal Length	Object Distance	Image			Magnif.
				Distance	Real?	Inverted?	
Concave	20.0 cm	+10.0 cm	+6.67 cm	-20.0 cm	NO	NO	+ 3.0
Plane	——	——	+45 cm	-45 cm	NO	NO	+ 1.0
Convex	50.0 cm	- 25.0 cm (-26.25)	+5.0 cm	-4.2 cm	NO	NO	+ 0.84
Concave	38 cm	+19 cm	+25 cm	+75 cm	YES	YES	- 3.0
Concave	40.0 cm	+20.0 cm	+13.3 cm	-40.0 cm	NO	NO	+ 3.0
Convex	30.0 cm	-15.0 cm	+30.0 cm	-10.0 cm	NO	NO	+0.33
Concave	30.0 cm	+15.0 cm	+16.7 cm	+150 cm	YES	YES	- 9.0

Section 25.2 The Reflection of Light, Section 25.3 The Formation of Images by a Plane Mirror

1. **ssm** Two plane mirrors are separated by 120°, as the drawing illustrates. If a ray strikes mirror M_1 at a 65° angle of incidence, at what angle θ does it leave mirror M_2?



2. Review Conceptual Example 1 before attempting this problem. A person whose eyes are 1.70 m above the floor stands in front of a plane mirror. The top of her head is 0.12 m above her eyes. (a) What is the height of the shortest mirror in which she can see her entire image? (b) How far above the floor should the bottom edge of the mirror be placed?

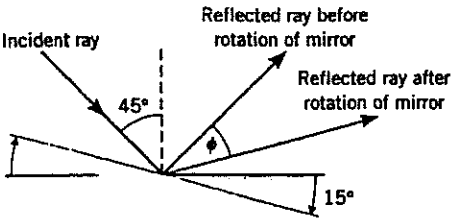
3. A person stands 3.6 m in front of a wall that is covered floor-to-ceiling with a plane mirror. His eyes are 1.8 m above the floor. He holds a flashlight between his feet and manages to point it at the mirror. At what angle of incidence must the light strike the mirror so the light will reach his eyes?

Skip 4. Review Conceptual Example 2. Suppose that in Figure 25.9b the two perpendicular plane mirrors are represented by the $+x$ and $+y$ axes of an x, y coordinate system. An object is in front of these mirrors at a point whose coordinates are $x = +2.0$ m and $y = +1.0$ m. Find the coordinates that locate each of the three images.

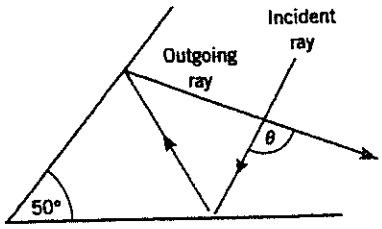
5. **ssm www** Two diverging light rays, originating from the same point, have an angle of 10° between them. After the rays reflect from a plane mirror, what is the angle between them? Construct one possible ray diagram that supports your answer.

6. Suppose you walk with a speed of 0.90 m/s toward a plane mirror. What is the speed of your image *relative to you*, when your velocity is (a) perpendicular to the mirror and (b) at an angle of 50.0° with respect to the normal to the mirror?

*7. A ray of light strikes a plane mirror at a 45° angle of incidence. The mirror is then rotated by 15° into the position shown in red in the drawing, while the incident ray is kept fixed. (a) Through what angle ϕ does the reflected ray rotate? (b) What is the answer to part (a) if the angle of incidence is 60° instead of 45°?



8. The drawing shows two plane mirrors that intersect at an angle of 50°. An incident light ray reflects from one mirror and then the other. What is the angle θ between the incident and outgoing rays?



9. **ssm** A lamp is twice as far in front of a plane mirror as a person is. Light from the lamp reaches the person via two paths: it strikes the mirror at a 30.0° angle of incidence and reflects from the mirror before reaching the person. It also travels directly to the person without reflecting. Find the ratio of the travel time along the reflected path to the travel time along the direct path.

1) 55°
2) 0.91 m, 0.85 m
3) 14°
4) See manual
5) 10°
6) 1.8 m/s, 1.2 m/s
7) 30°, 30°
8) 100°
9) 1.73

Section 25.4 Spherical Mirrors, Section 25.5 The Formation of Images by Spherical Mirrors

10. A 2.0-cm-high object is situated 15.0 cm in front of a concave mirror that has a radius of curvature of 10.0 cm. Using a ray diagram drawn to scale, measure (a) the location and (b) the height of the image. The mirror must be drawn to scale.

11. Repeat problem 10 for a concave mirror with a focal length of 20.0 cm, an object distance of 12.0 cm, and a 2.0-cm-high object.

12. The image of a very distant car is located 12 cm behind a convex mirror. (a) What is the radius of curvature of the mirror? (b) Draw a ray diagram to scale showing this situation.

13. **ssm** Repeat problem 10 for a convex mirror with a radius of curvature of 1.00×10^2 cm, an object distance of 25.0 cm, and a 10.0-cm-high object.

14. Repeat problem 10 for a concave mirror with a focal length of 7.50 cm, an object distance of 11.0 cm, and a 1.0-cm-high object.

15. A plane mirror and a concave mirror ($f = 8.0$ cm) are facing each other and are separated by a distance of 20.0 cm. An object is placed 10.0 cm in front of the plane mirror. Consider the light from the object that reflects first from the plane mirror and then from the concave mirror. Using a ray diagram drawn to scale, find the location of the image that this light produces in the concave mirror. Specify this distance relative to the concave mirror.

Section 25.6 The Mirror Equation and the Magnification Equation

16. The focal length of a concave mirror is 17 cm. An object is located 38 cm in front of this mirror. Where is the image located?

17. **ssm www** When viewed in a spherical mirror, the image of a setting sun is a virtual image. The image lies 12.0 cm behind the mirror. (a) Is the mirror concave or convex? Why? (b) What is the radius of curvature of the mirror?

18. Review Conceptual Example 7 as background for this problem. An object is located 20.0 cm in front of a mirror. If the mirror is a plane mirror, the image distance would be $d_i = -20.0$ cm. However, the mirror is convex. Verify that the larger the radius of the mirror is, the closer the image distance is to the value of -20.0 cm. Do this by calculating the image distance for a radius of (a) 118 cm and (b) 1210 cm.

19. A concave mirror ($R = 64.0$ cm) is used to project a transparent slide onto a wall. The slide is located at a distance of 38.0 cm from the mirror, and a small flashlight shines light through the slide and onto the mirror. The setup is similar to that in Figure 25.19*a*. (a) How far from the wall should the mirror be located? (b) The height of the object on the slide is 1.20 cm. What is the height of the image? (c) How should the slide be oriented, so that the picture on the wall looks normal?

20. A clown is using a concave makeup mirror to get ready for a show and is 27 cm in front of the mirror. The image is 65 cm *behind* the mirror. Find (a) the focal length of the mirror and (b) the magnification.

21. **ssm** The image behind a convex mirror (radius of curvature = 68 cm) is located 22 cm from the mirror. (a) Where is the object located and (b) what is the magnification of the mirror? Determine whether the image is (c) upright or inverted and (d) larger or smaller than the object.

22. A person is viewing the image of a mountain produced by a concave mirror. The mountain is 4100 m high, and the height of the image is -3.2 cm (the minus sign means that the image is inverted relative to the object). The image is located 25 cm in front of the mirror. How far (in meters) is the mountain from the mirror?

23. Convex mirrors are being used to monitor the aisles in a store. The mirrors have a radius of curvature of 4.0 m. (a) What is the image distance if a customer is 15 m in front of the mirror? (b) Is the image real or virtual? (c) If a customer is 1.6 m tall, how tall is the image?

24. A dentist's mirror is placed 2.0 cm from a tooth. The *enlarged* image is located 5.6 cm behind the mirror. (a) What kind of mirror (plane, concave, or convex) is being used? (b) Determine the focal length of the mirror. (c) What is the magnification? (d) How is the image oriented relative to the object?

25. **ssm www** A small postage stamp is placed in front of a concave mirror (radius = R), such that the image distance equals the object distance. (a) In terms of R, what is the object distance? (b) What is the magnification of the mirror? (c) State whether the image is upright or inverted relative to the object. Draw a ray diagram to guide your thinking.

*26. (a) Where should a diamond ring be placed in front of a concave mirror, such that the image is twice the size of the ring? There are two answers, depending on whether the image is upright or inverted. Express your answers in terms of the radius of curvature R. (b) Draw ray diagrams to confirm your answers.

*27. An object is placed in front of a convex mirror, and the size of the image is one-third that of the object. What is the ratio d_o/f of the object distance to the focal length of the mirror?

*28. An object is placed a distance d_o in front of a mirror whose focal length is f. The magnification is m. Derive an expression for d_o in terms of f and m.

29. **ssm** An object is located 14.0 cm in front of a convex mirror, the image being 7.00 cm behind the mirror. A second object, twice as tall as the first one, is placed in front of the mirror, but at a different location. The image of this second object has the same height as the other image. How far in front of the mirror is the second object located?

30. A concave mirror has a focal length of 30.0 cm. The distance between an object and its image is 45.0 cm. Find the object and image distances assuming that (a) the object lies beyond the center of curvature and (b) the object lies within the focal point.

See next page for Answers

10) 7.5cm, 1cm

11) 30 cm Behind mirror, 5cm

12) 24cm

13) 16.7cm Behind Mirror, 6.67cm

14) 23.6 In Front
2.14cm Inverted

15) 10.9cm

16) +31cm

17) convex, 24.0cm

18) -14.9cm, -19.4cm

19) 200cm, -6.3cm

20) 46cm, 2.4

21) 62cm, 0.35, upright, smaller

22) 3.2×10^{4}m

23) -1.8m, virtual, 19cm

24) Concave, 3.1cm
2.8, upright

25) -1 Inverted

26) R/4, 3R/4

27) -2

28) $d_o = \frac{f(m-1)}{m}$

29) 42cm

30) 90cm, 45cm

Name: Per: Date:

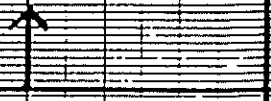
In the following diagrams, use the reasoning strategy for ray-tracing to locate the image.

- State if it is upright or inverted
- State if it is magnified, real or virtual

Concave mirror

F

Concave mirror



F

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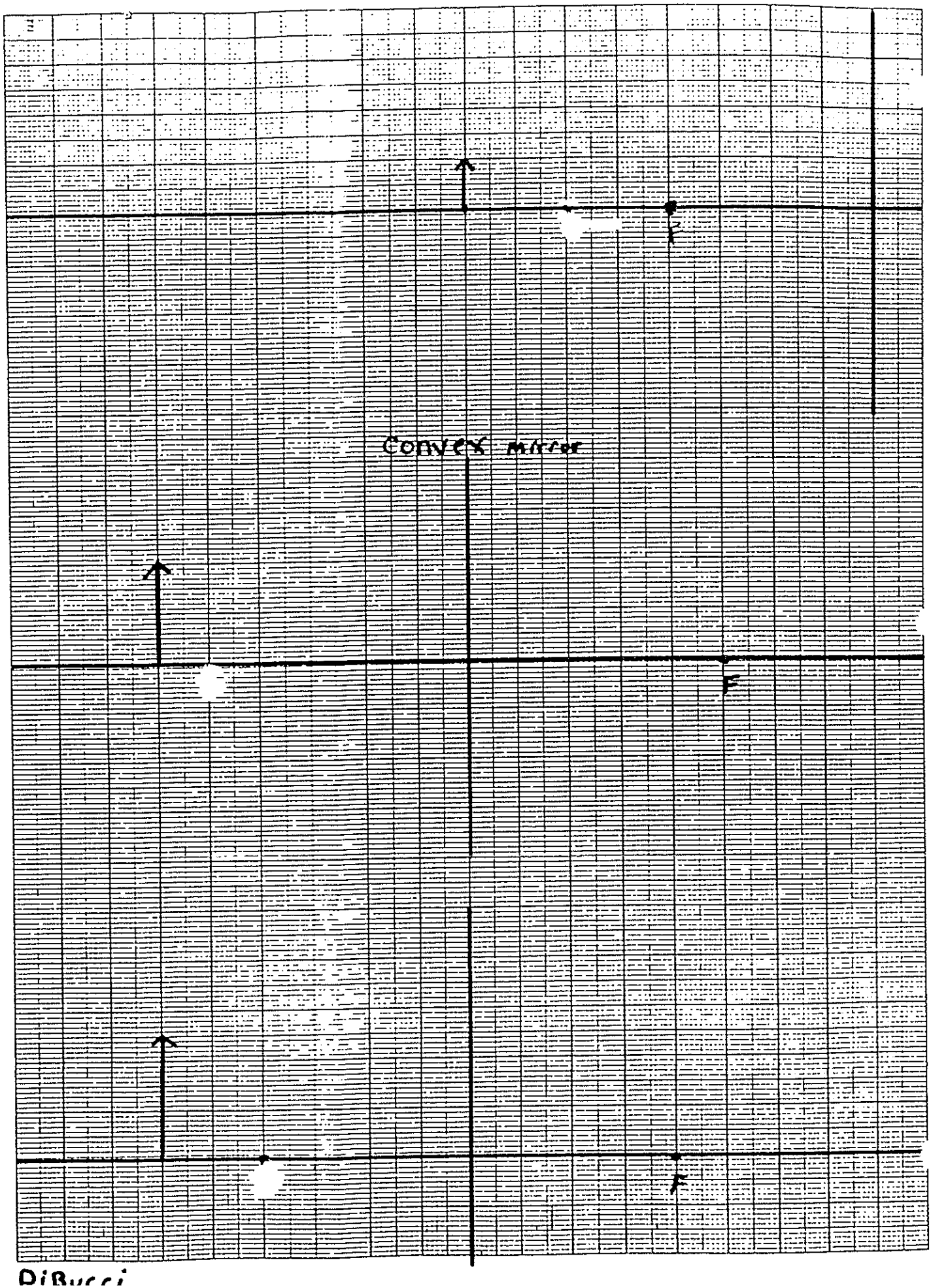
Concave



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Mirrors and the Reflection of Light DiBucci

MULTIPLE CHOICE

1. If you stand 2.0 m in front of a plane mirror, how far away would you see the image of yourself?

a) 1.0 m
b) 2.0 m
c) 4.0 m
d) 8.0 m

2. Plane mirrors produce images which

a) are always smaller than the actual object.
b) are always larger than the actual object.
c) are always the same size as the actual object.
d) could be smaller, larger, or the same size as the actual object, depending on the placement of the object.

3. A laser beam strikes a plane's reflecting surface with an angle of incidence of 37ø. What is the angle between the incident ray and the reflected ray?

a) 37ø
b) 74ø
c) 45ø
d) 90ø

4. How far are you from your image when you stand 0.75 m in front of a vertical plane mirror?

a) 0.75 m
b) 1.5 m
c) 3.0 m
d) None of the above.

5. A plane mirror forms an image that is

a) real and upright.
b) virtual and upright.
c) real and upside down.
d) virtual and upside down.

6. The angle of incidence

a) must equal the angle of reflection.
b) is always less than the angle of reflection.
c) is always greater than the angle of reflection.
d) may be greater than, less than, or equal to the angle of reflection.

7. How fast do you approach your image when you approach a vertical plane mirror at a speed of 2 m/s?

a) 1 m/s
b) 2 m/s
c) 4 m/s
d) None of the above.

8. An object is located 2.6 m in front of a plane mirror. The image formed by the mirror appears to be

a) 1.3 m in front of the mirror.
b) on the mirror's surface.
c) 1.3 m behind the mirror's surface.
d) 2.6 m behind the mirror's surface.

9. A concave mirror with a radius of 20 cm creates a real image 30 cm from the mirror. What is the object distance?

a) 20 cm
b) 15 cm
c) 7.5 cm
d) 5.0 cm

10. When a person stands 40 cm in front of a cosmatic mirror (concave mirror), the erect image is twice the size of the object. What is the focal length of the mirror?

a) 27 cm
b) 40 cm
c) 80 cm
d) 160 cm

11. A person's face is 30 cm in front of a concave shaving mirror. If the image is an erect image 1.5 times as large as the object, what is the mirror's focal length?

a) 20 cm
b) 50 cm
c) 70 cm
d) 90 cm

12. An object is placed 15 cm from a concave mirror of focal length 20 cm. The object is 4.0 cm tall. How tall is the image?

a) 1.0 cm
b) 2.0 cm
c) 8.0 cm
d) 16 cm

13. An object is placed 15 cm from a concave mirror of focal length 20 cm. The object is 4.0 cm tall. Where is it located?

a) 12 cm
b) 15 cm
c) 60 cm
d) 120 cm

14. A spherical concave mirror has a radius of curvature of 50 cm. How far from the mirror is the focal point located?

a) 25 cm
b) 50 cm
c) 75 cm
d) 100 cm

15. A light ray, traveling parallel to a concave mirror's axis, strikes the mirror's surface near its midpoint. After reflection, this ray

a) again travels parallel to the mirror's axis.
b) travels at right angles to the mirror's axis.
c) passes through the mirror's center of curvature.
d) passes through the mirror's focal point.

16. A light ray, traveling obliquely to a concave mirror's axis, crosses the axis at the mirror's center of curvature before striking the mirror's surface. After reflection, this ray

a) travels parallel to the mirror's axis.
b) travels at right angles to the mirror's axis.
c) passes through the mirror's center of curvature.
d) passes through the mirror's focal point.

17. A negative magnification for a mirror means

a) the image is inverted, and the mirror is concave.

b) the image is inverted, and the mirror is convex.
c) the image is inverted, and the mirror may be concave or convex.
d) the image is upright, and the mirror is convex.
e) the image is upright, and the mirror may be concave or convex.

18. Which of the following is an accurate statement?

a) A mirror always forms a real image.
b) A mirror always forms a virtual image.
c) A mirror always forms an image larger than the object.
d) A mirror always forms an image smaller than the object.
e) None of the above is true.

19. Sometimes when you look into a curved mirror you see a magnified image (a great big you!) and sometimes you see a diminished image (a little you). If you look at the bottom (convex) side of a shiny spoon, what will you see?

a) You won't see an image of yourself because no image will be formed.
b) You will see a little you, upside down.
c) You will see a little you, right side up.
d) You will see a little you, but whether you are right side up or upside down depends on how near you are to the spoon.
e) You will either see a little you or a great big you, depending on how near you are to the spoon.

20. If you stand in front of a convex mirror, at the same distance from it as its radius of curvature,

a) you won't see your image because there is none.
b) you won't see your image because it's focused at a different distance.
c) you will see your image and you will appear smaller.
d) you will see your image and you will appear larger.
e) you will see your image at your same height.

21. If you stand in front of a convex mirror, at the same distance from it as its focal length,

a) you won't see your image because there is none.
b) you won't see your image because it's focused at a different distance.
c) you will see your image and you will appear smaller.
d) you will see your image and you will appear larger.
e) you will see your image at your same height.

22. If you stand in front of a concave mirror, exactly at its center of curvature,

a) you won't see your image because there is none.
b) you won't see your image because it's focused at a different distance.
c) you will see your image and you will appear smaller.
d) you will see your image and you will appear larger.
e) you will see your image at your same height.

23. If you stand in front of a concave mirror, exactly at its focal point,

a) you won't see your image because there is none.
b) you won't see your image because it's focused at a different distance.
c) you will see your image, and you will appear smaller.
d) you will see your image and you will appear larger.
e) you will see your image at your same height.

24. A light ray, traveling obliquely to a concave mirror's surface, crosses the axis at the mirror's focal point before striking the mirror's surface. After reflection, this ray

a) travels parallel to the mirror's axis.
b) travels at right angles to the mirror's axis.
c) passes through the mirror's center of curvature.
d) passes through the mirror's focal point.

25. An object is placed at a concave mirror's center of curvature. The image produced by the mirror is located

a) out beyond the center of curvature.
b) at the center of curvature.
c) between the center of curvature and the focal point.
d) at the focal point.

26. An object is positioned between a concave mirror's center of curvature and its focal point. The image produced by the mirror is located

a) out past the center of curvature.
b) at the center of curvature.
c) between the center of curvature and the focal point.
d) at the focal point.

27. An object is situated between a concave mirror's surface and its focal point. The image formed in this case is

a) real and inverted.
b) real and erect.
c) virtual and erect.
d) virtual and inverted.

28. An object is 47.5 cm tall. The image is 38.6 cm tall, and 14.8 cm from the mirror. How far is the object from the mirror?

a) 124 cm
b) 47.6 cm
c) 18.2 cm
d) 12.0 cm

29. An object is 14 cm in front of a convex mirror. The image is 5.8 cm behind the mirror. What is the focal length of the mirror?

a) -4.1 cm
b) -8.2 cm
c) -9.9 cm
d) -20 cm

30. An image is 4.0 cm behind a concave mirror with focal length 5.0 cm. Whare is the object?

a) 2.2 cm in front of the mirror.
b) 2.2 cm behind the mirror.
c) 9.0 cm in front of the mirror.
d) 1.0 cm behind the mirror.

31. A object is 12 cm in front of a concave mirror, and the image is 3.0 cm in front of the mirror. What is the focal length of the mirror?

a) 15 cm
b) 7.9 cm
c) 2.4 cm
d) 1.3 cm

32. An object is 10 cm in front of a concave mirror with focal length 3 cm. Where is the image?

a) 13 cm from the mirror
b) 7.0 cm from the mirror
c) 4.3 cm from the mirror
d) 3.3 cm from the mirror

33. Light arriving at a concave mirror on a path through the focal point is reflected

a) back parallel to the axis.

b) back on itself.
c) through the focal point.
d) through the center of curvature.

34. Light arriving at a concave mirror on a path parallel to the axis is reflected

a) back parallel to the axis.
b) back on itself.
c) through the focal point.
d) through the center of curvature.

35. If the radius of curvature of the concave mirror is r, the focal length is

a) 2r
b) r
c) r/2
d) Cannot be determined from the information given.

36. A single concave spherical mirror produces an image which is

a) always virtual.
b) always real.
c) real only if the object distance is less than f.
d) real only if the object distance is greater than f.

37. A single convex spherical mirror produces an image which is

a) always virtual.
b) always real.
c) real only if the object distance is less than f.
d) real only if the object distance is greater than f.

38. A convex spherical mirror has a focal length of -20 cm. An object is placed 10 cm in front of the mirror on the mirror's axis. Where is the image located?

a) 20 cm behind the mirror.
b) 20 cm in front of the mirror.
c) 6.7 cm behind the mirror.
d) 6.7 cm in front of the mirror.

39. A concave spherical mirror has a focal length of 20 cm. An object is placed 10 cm in front of the mirror on the mirror's axis. Where is the image located?

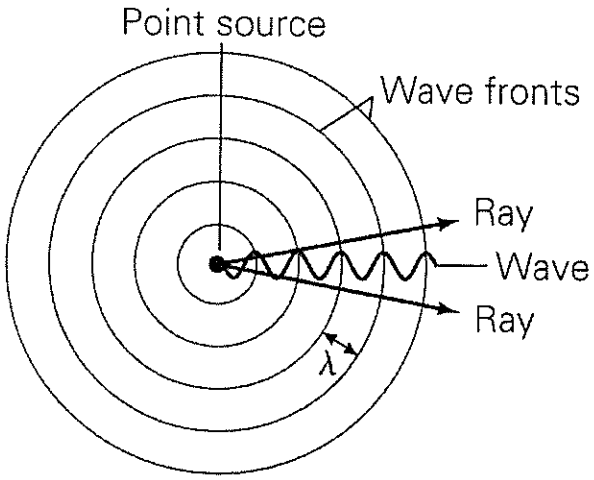
a) 20 cm behind the mirror.
b) 20 cm in front of the mirror.
c) 6.7 cm behind the mirror.
d) 6.7 cm in front of the mirror.

40. A convex spherical mirror has a focal length of -20 cm. An object is placed 30 cm in front of the mirror on the mirror's axis. Where is the image located?

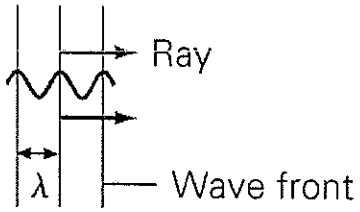
a) 12 cm in front of the mirror.
b) 60 cm behind the mirror.
c) 60 cm in front of the mirror.
d) None of the above.

ANSWER KEY FOR TEST mirrors

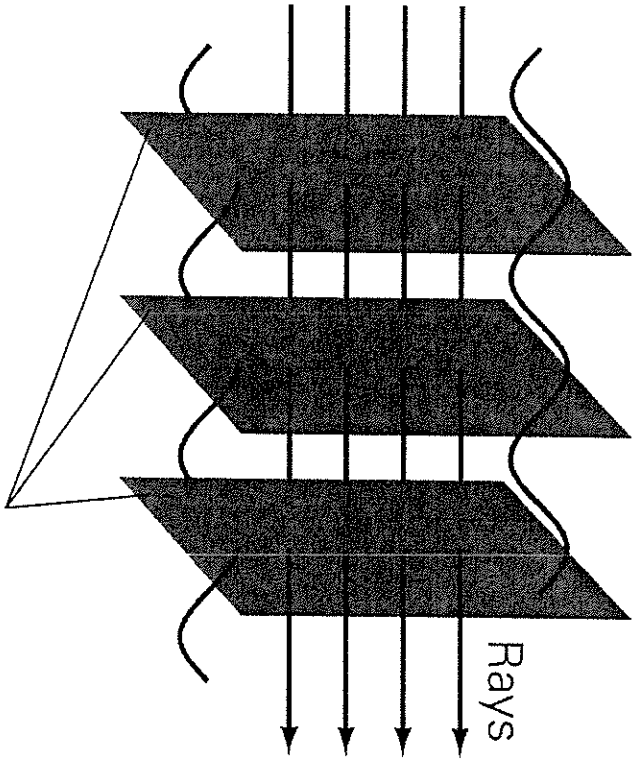
1. c
2. c
3. b
4. b
5. b
6. a
7. c
8. d
9. b
10. c
11. d
12. d
13. c
14. a
15. d
16. c
17. c
18. e
19. c
20. c
21. a
22. e
23. a
24. a
25. b
26. a
27. c
28. c
29. c
30. a
31. c
32. c
33. a
34. c
35. c
36. d
37. a
38. c
39. a
40. d

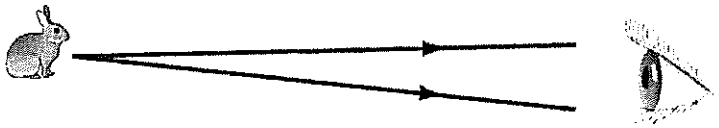


(a)

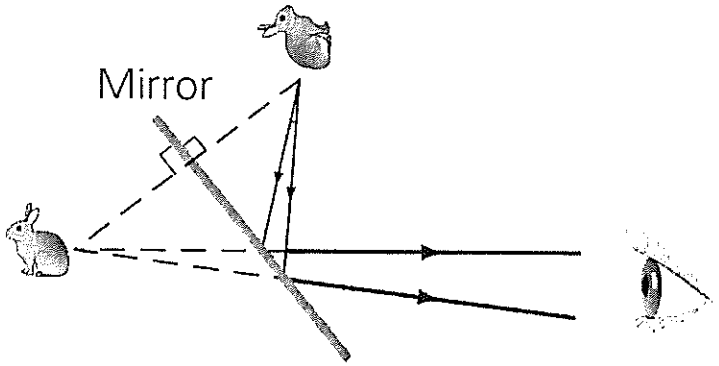


(b)

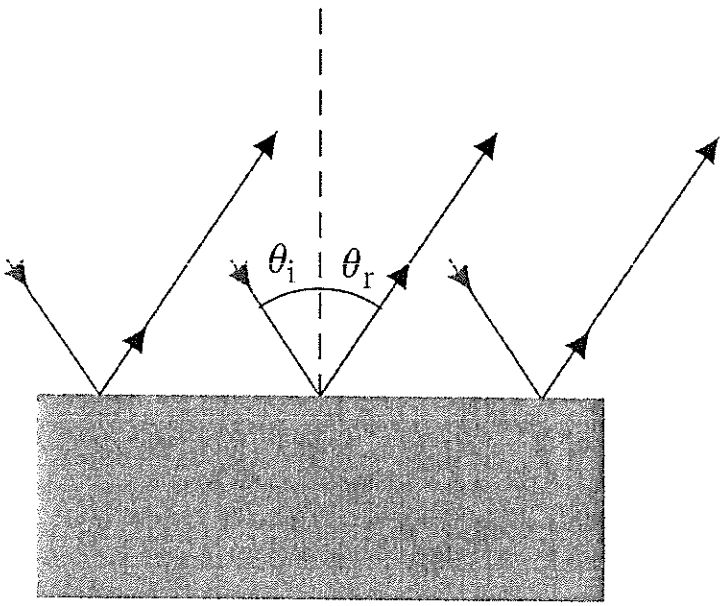




(a)



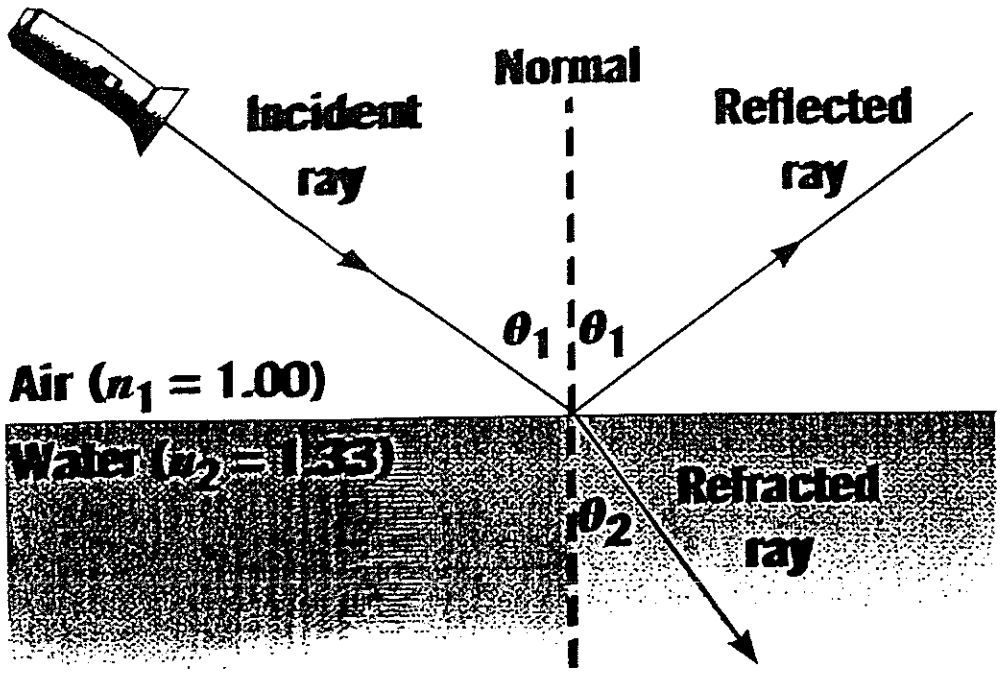
(b)



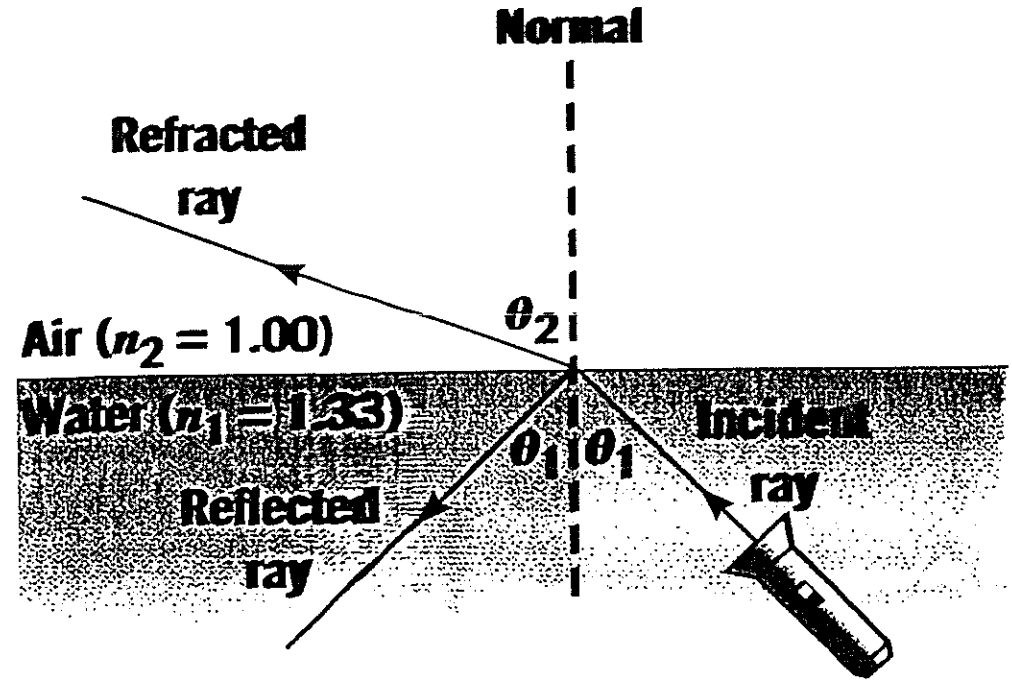
Specular (regular) reflection (diagram)

The Refraction of Light: Lenses and Optical Instruments

Mr. DiBucci



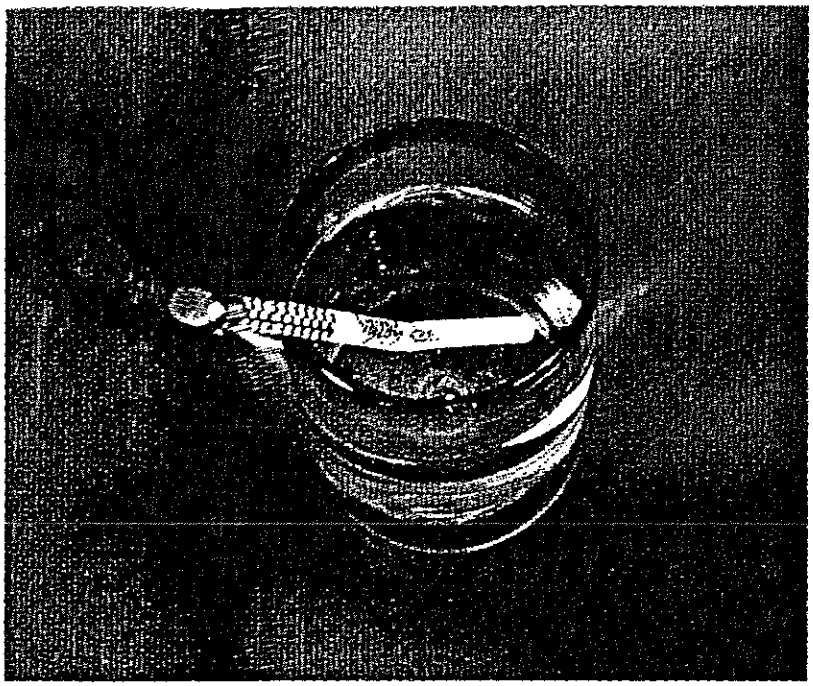
(*a*)



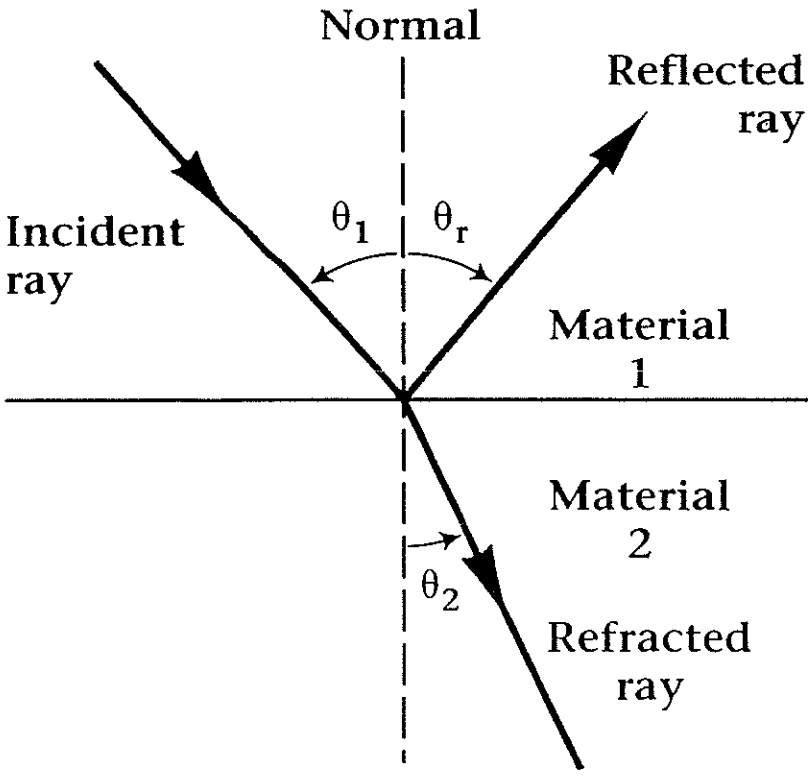
(*b*)

FIGURE 26-2

113. Refraction of light at a boundary: Snell's law. (Fig. 22.7)



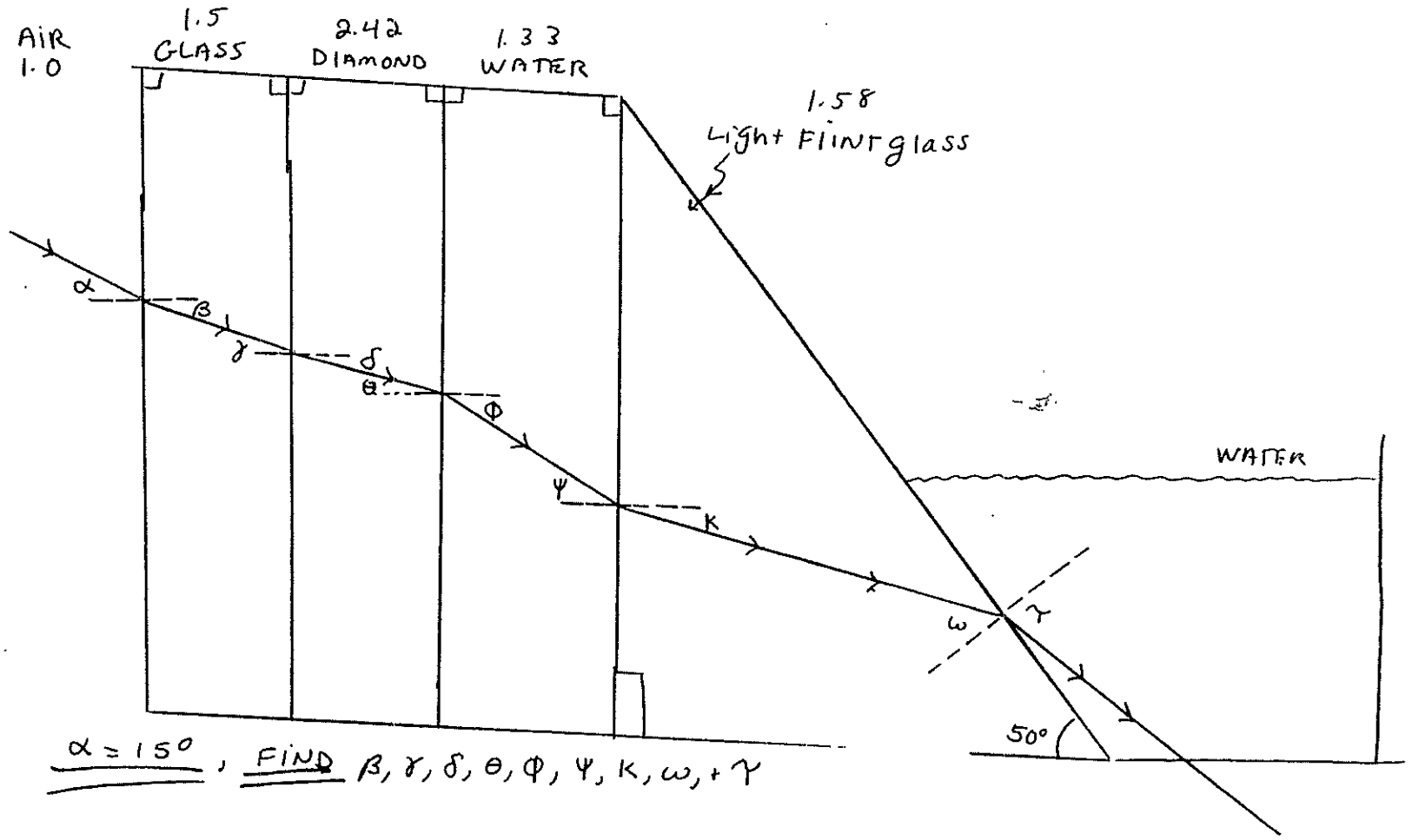
(a)



(b)

NAME _____

DIBUCCI



$\alpha = 15^\circ$, FIND $\beta, \gamma, \delta, \theta, \Phi, \Psi, K, \omega, +\gamma$

5. Fill-in the following table for a single lens. Include the appropriate signs on ALL numbers.

Lens Type	focal length	object distance	image distance	magnification	real/virtual	inverted/upright
converging	25 cm	15 cm				
converging		22 cm	+22 cm			
diverging			12 cm	0.50		
diverging	11 cm		5 cm			
	8 cm		18 cm			inv

6. Two converging lenses with focal lengths 15 cm and 25 cm are placed 18 cm apart. An object is located 8.0 cm to the left of the 15 cm focal length lens. Where is the final image formed?

7. A converging lens is used to read the small print in a contract. The lens is held 9.0 cm from the print and produces a magnification of + 2.5. What is the focal length of the lens?

8. A camera is supplied with a 35.0 mm focal length lens. A 2.00 m tall man stands 16.0 m from the camera and has his picture taken. What is the size of the image of the man that the lens produces on the film?

Practice Problem 5

Lens Type	focal length	object distance	image distance	magnification	real / virtual	inverted / upright
converging	+ 25 cm	+ 15 cm	-38 cm	+2.5	V	up
converging	+11 cm	+ 22 cm	+22 cm	-1.0	R	inv
diverging	-24 cm	+24 cm	- 12 cm	+ 0.50	V	up
diverging	- 11 cm	+9.2cm	-5 cm	+0.54	V	up
converging	+ 8 cm	+14 cm	+18 cm	-1.3	R	inv

Section 26.1 The Index of Refraction

1. **ssm** What is the speed of light in benzene?

2. Light travels at a speed of 2.201×10^8 m/s in a certain substance. What substance in Table 26.1 could this be? Use 2.998×10^8 m/s for the speed of light in a vacuum.

3. Find the ratio of the speed of light in diamond to the speed of light in ice.

4. The frequency of a light wave is the same when the light travels in ethyl alcohol as it is when it travels in carbon disulfide. Find the ratio of the wavelength of the light in ethyl alcohol to that in carbon disulfide.

5. **ssm www** A glass window ($n = 1.5$) has a thickness of 4.0×10^{-3} m. How long does it take light to pass perpendicularly through the plate?

6. The speed of light is 1.25 times larger in material A than it is in material B. Determine the ratio n_A/n_B of the refractive indices of these materials.

*7. In a certain time, light travels 3.50 km in a vacuum. During the same time, light travels only 2.50 km in a liquid. What is the refractive index of the liquid?

*8. A flat sheet of ice has a thickness of 2.0 cm. It is on top of a flat sheet of crystalline quartz that has a thickness of 1.1 cm. Light strikes the ice perpendicularly and travels through it and then through the quartz. In the time it takes the light to travel through the two sheets, how far (in cm) would it have traveled in a vacuum?

1) 2×10^8 m/s
2) ethyl Alcohol
3) 0.5411
4) 1.198
5) 2×10^{-11} s
6) 0.800
7) 1.40
8) 4.3 cm

Table 26.1 **Index of Refraction[a] for Various Substances**

Substance	Index of Refraction, n
Solids at 20 °C	
Diamond	2.419
Glass, crown	1.523
Ice (0 °C)	1.309
Sodium chloride	1.544
Quartz	
Crystalline	1.544
Fused	1.458
Liquids at 20 °C	
Benzene	1.501
Carbon disulfide	1.632
Carbon tetrachloride	1.461
Ethyl alcohol	1.362
Water	1.333
Gases at 0 °C, 1 atm	
Air	1.000 293
Carbon dioxide	1.000 45
Oxygen, O_2	1.000 271
Hydrogen, H_2	1.000 139

[a] Measured with light whose wavelength in a vacuum is 589 nm.

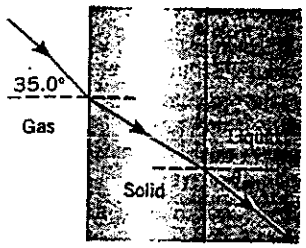
Section 26.2 Snell's Law and the Refraction of Light

9. **ssm** A light ray in air is incident on a water surface at a 43° angle of incidence. Find (a) the angle of reflection and (b) the angle of refraction.

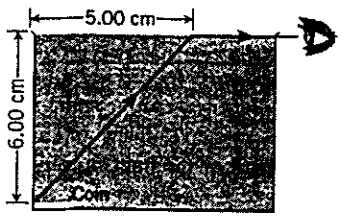
10. A layer of oil ($n = 1.45$) floats on an unknown liquid. A ray of light shines from the oil into the unknown liquid. The angles of incidence and refraction are, respectively, 65.0° and 53.0°. What is the index of refraction of the unknown liquid?

11. A ray of light is propagating in water and strikes a plate of fused quartz. The angle of refraction in the quartz is measured to be 36.7°. What is the angle of incidence?

12. Refer to Conceptual Example 7 as an aid in understanding this problem. The drawing shows a ray of light traveling through a gas ($n = 1.00$), a solid ($n = 1.55$), and a liquid ($n = 1.55$). At what angle θ does the light enter the liquid?



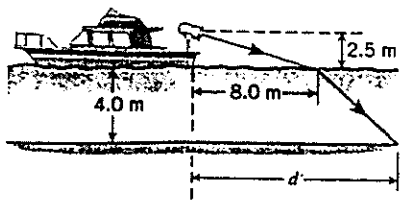
13. **ssm** The drawing shows a coin resting on the bottom of a beaker filled with an unknown liquid. A ray of light from the coin travels to the surface of the liquid and is refracted as it enters into the air. A person sees the ray as it skims just above the surface of the liquid. How fast is the light traveling in the liquid?



14. Amber ($n = 1.546$) is a transparent brown-yellow fossil resin. An insect, trapped and preserved within the amber, appears to be 2.5 cm beneath the surface, when viewed directly from above. How far below the surface is the insect actually located?

15. A beam of light impinges from air onto a block of ice at a 60.0° angle of incidence. Assuming that this angle remains the same, find the percentage by which the angle of refraction changes when the ice turns to water, and state whether the change is an increase or a decrease.

16. A spotlight on a boat is 2.5 m above the water, and the light strikes the water at a point that is 8.0 m horizontally displaced from the spotlight (see the drawing). The depth of the water is 4.0 m. Determine the distance d, which locates the point where the light strikes the bottom.



***17.** **ssm** **www** In Figure 26.7, suppose that the angle of incidence is $\theta_1 = 30.0°$, the thickness of the glass pane is 6.00 mm, and the refractive index of the glass is $n_2 = 1.52$. Find the amount (in mm) by which the emergent ray is displaced relative to the incident ray.

***18.** A silver medallion is sealed within a transparent block of plastic. An observer in air, viewing the medallion from directly above, sees the medallion at an apparent depth of 1.6 cm beneath the top surface of the block. How far below the top surface would the medallion appear if the observer (not wearing goggles) and the block were under water?

***19.** Refer to Figure 26.5*a* and assume the observer is nearly above the submerged object. For this situation, derive the expression for the apparent depth: $d' = d(n_2/n_1)$, Equation 26.3. *(Hint: Use Snell's law of refraction and the fact that the angles of incidence and refraction are small, so tan $\theta \approx$ sin θ.)*

***20.** Review Conceptual Example 4 as background for this problem. A man in a boat is looking straight down at a fish in the water directly beneath him. The fish is looking straight up at the man. They are equidistant from the air/water interface. To the man, the fish appears to be 2.0 m beneath his eyes. To the fish, how far above its eyes does the man appear to be?

***21.** **ssm** A small logo is embedded in a thick block of crown glass ($n = 1.52$), 3.20 cm beneath the top surface of the glass. The block is put under water, so there is 1.50 cm of water above the top surface of the block. The logo is viewed from directly above by an observer in air. How far beneath the top surface of the water does the logo appear to be?

***22.** A beaker has a height of 30.0 cm. The lower half of the beaker is filled with water and the upper half is filled with oil ($n = 1.48$). To a person looking down into the beaker from above, what is the apparent depth of the bottom?

9) 31°
10) 1.64
11) 40.8°
12) 21.7°
13) 1.92×10^8 m/s
14) 3.9 cm
15) 2% decrease
16) 12.1 m
17) 1.19 mm
18) 2.1 cm
19) $d' = \left(\frac{n_2}{n_1}\right)d$
20) 2.7 m
21) 3.23 cm
22) 21.4 cm

Section 26.3 Total Internal Reflection

24. A ray of light is traveling in glass and strikes a glass/liquid interface. The angle of incidence is 58.0°, and the index of refraction of glass is $n = 1.50$. (a) What must be the index of refraction of the liquid such that the direction of the light entering the liquid is not changed? (b) What is the largest index of refraction that the liquid can have, such that none of the light is transmitted into the liquid and all of it is reflected back into the glass?

25. **ssm** One method of determining the refractive index of a transparent solid is to measure the critical angle when the solid is in air. If θ_c is found to be 40.5°, what is the index of refraction of the solid?

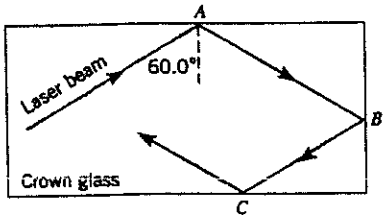
26. Light is propagating from diamond into crown glass. a) Find the critical angle. (b) Is there a critical angle for light propagating from crown glass into diamond? If so, find its value.

27. A glass block ($n = 1.60$) is immersed in a liquid. A ray of light within the glass hits a glass–liquid surface at a 65.0° angle of incidence. Some of the light enters the liquid. What is the smallest possible refractive index for the liquid?

28. A point source of light is submerged 2.2 m below the surface of a lake and emits rays in all directions. On the surface of the lake, directly above the source, the area illuminated is a circle. What is the maximum radius that this circle could have?

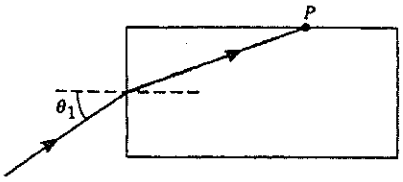
29. **ssm** A person is sitting in a small boat in the ocean. A shark is swimming under water at a depth of 4.5 m. When the shark is beyond a certain distance (measured horizontally) from the boat, the shark cannot be seen. Assume that the person's eyes are very near the surface of the water and find that distance.

30. The drawing shows a crown glass slab with a rectangular cross section. As illustrated, a laser beam strikes the upper surface at an angle of 60.0°. After reflecting from the upper surface, the beam reflects from the side and bottom surfaces. (a) If the glass is surrounded by air, determine where part of the beam first exits the glass, at point *A*, *B*, or *C*. (b) Repeat part (a), assuming that the glass is surrounded by water.



31. Three materials, *A*, *B*, and *C*, have refractive indices n_A, n_B, and n_C. The materials are in the form of parallel plates and are stacked on top of one another with *A* on the bottom and *B* in the middle. A ray of light originates in material *A* and strikes the *A*–*B* surface with an angle of incidence θ_A. It is observed that the light penetrates into material *B* only when θ_A is less than 50.0° and penetrates into material *C* only when θ_A is less than 30.0°. Find n_B/n_A and n_B/n_C.

*32. The drawing shows a crystalline quartz slab with a rectangular cross section. A ray of light strikes the slab at an incident angle of $\theta_1 = 34°$, enters the quartz, and travels to point *P*. This slab is surrounded by a fluid with a refractive index *n*. What is the maximum value of *n* such that total internal reflection occurs at point *P*?



24) 1.5, 1.27

25) 1.54

26) 38.9° No critical Angle

27) 1.45

28) 2.5m

29) 5.1m

30) 49.5, B, A

31) 0.766, 1.53

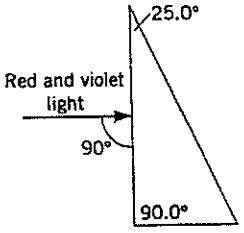
32) 1.35

Section 26.5 The Dispersion of Light: Prisms and Rainbows

41. **ssm** A beam of sunlight encounters a plate of crown glass at a 45.00° angle of incidence. Using the data in Table 26.2, find the angle between the violet ray and the red ray in the glass.

42. Yellow light strikes a diamond at a 45.0° angle of incidence and is refracted when it enters the diamond. Blue light strikes a piece of flint glass and has the same angle of refraction as does the yellow light in the diamond. See Table 26.2 for data. What is the angle of incidence of the blue light?

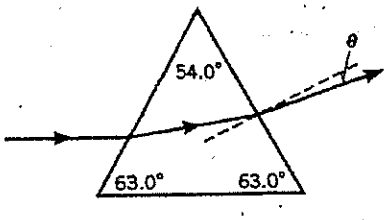
43. Horizontal rays of red light ($\lambda = 660$ nm, in vacuum) and violet light ($\lambda = 410$ nm, in vacuum) are incident on the flint-glass prism shown in the drawing. See Table 26.2 for any necessary data. What is the angle of refraction for each ray as it emerges from the prism?



44. Violet light and red light travel through air and strike a block of plastic at the same angle of incidence. The angle of refraction is 30.400° for the violet and 31.200° for the red light. The difference between the indices of refraction is $n_V - n_R = 0.0400$, where n_V and n_R are the indices of refraction of the violet and red light, respectively. Delaying any rounding off of calculations until the very end, find (a) n_V and (b) n_R.

***45.** **ssm** This problem relates to Figure 26.19 which illustrates the dispersion of light by a prism. The prism is made from flint glass (see Table 26.2), and its cross section is an equilateral triangle. The angle of incidence for both the red and violet light is 60.0°. Find the angles of refraction at which the red and violet rays emerge into the air from the prism.

***46.** Refer to Conceptual Example 7 as background material for this problem. The drawing shows a horizontal beam of light that is incident on an ice prism. The base of the prism is also horizontal. The prism ($n = 1.31$) is surrounded by oil whose index of refraction is 1.48. Determine the angle θ that the exiting light makes with the normal to the right face of the prism.



41) 0.35°
42) 29.5°
43) 44.6°, 45.9°
44) 1.73, 1.69
45) 52.7°, 56.2°
46) 20.4°

DiBucci

Section 26.6 Lenses, Section 26.7 The Formation of Images b Lenses, Section 26.8 The Thin-Lens Equation and the Magni cation Equation

(Note: When drawing ray diagrams, be sure that the object height h_o is much smaller than the focal length f of the lens or mirror. This ensures that the rays are paraxial rays.)

•**47.** A figurine is placed 15.0 cm in front of a converging le ($f = 40.0$ cm). Using a ray diagram drawn to scale, find (a) t image distance and (b) the magnification.

48. When a diverging lens is held 13 cm above a line of print, in Figure 26.30, the image is 5.0 cm beneath the lens. What is t focal length of the lens?

49. **ssm** A macroscopic (or macro) lens for a camera is usual a converging lens of normal focal length built into a lens barr that can be adjusted to provide the additional lens-to-film distan needed when focusing at very close range. Suppose that a mac lens ($f = 50.0$ mm) has a maximum lens-to-film distance 275 mm. How close can the object be located in front of the len

50. A tourist takes a picture of a mountain 14 km away using camera that has a lens with a focal length of 50 mm. She thi takes a second picture when the mountain is only 5.0 km awa What is the ratio of the height of the mountain's image on the fil for the second picture to its height on the film for the first pictur

51. A converging lens ($f = 12.0$ cm) is held 8.00 cm in fro of a newspaper. Find (a) the image distance and (b) tl magnification.

52. A diverging lens has a focal length of -25 cm. (a) Find tl image distance when an object is placed 38 cm from the len (b) Is the image real or virtual?

53. **ssm** An object is located 30.0 cm to the left of a convergir lens whose focal length is 50.0 cm. (a) Draw a ray diagram t scale and from it determine the image distance and the magnifica tion. (b) Use the thin-lens and magnification equations to verif your answers to part (a).

54. A diverging lens has a focal length of -32 cm. An object placed 19 cm in front of this lens. Calculate (a) the image distanc and (b) the magnification. Is the image (c) real or virtual, (d) up right or inverted, and (e) enlarged or reduced in size?

55. A camera is supplied with two interchangeable lense whose focal lengths are 35.0 and 150.0 mm. A woman whos height is 1.80 m stands 8.00 m in front of the camera. What is th height (including sign) of her image on the film, as produced b (a) the 35.0-mm lens and (b) the 150.0-mm lens?

•**56.** A camper is trying to start a fire by focusing sunlight onto piece of paper. The diameter of the sun is 1.39×10^9 m and it mean distance from the earth is 1.50×10^{11} m. The camper is us ing a converging lens whose focal length is 10.0 cm. (a) What i the area of the sun's image on the paper? (b) If 0.530 W of sun light pass through the lens, what is the intensity of the sunlight a the paper?

*•**57.** **ssm** An object is 18 cm in front of a diverging lens that ha a focal length of -12 cm. How far in front of the lens should the object be placed so that the size of its image is reduced by a factor of 2.0?

*•**58.** An object is in front of a converging lens ($f = 0.30$ m). The magnification of the lens is $m = 4.0$. (a) Relative to the lens, in what direction should the object be moved so that the magnification changes to $m = -4.0$? (b) Through what distance should the object be moved?

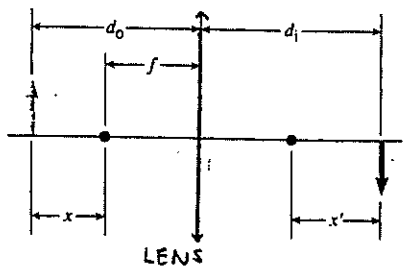
*•**59.** **ssm www** The moon's diameter is 3.48×10^6 m and its mean distance from the earth is 3.85×10^8 m. The moon is being photographed by a camera whose lens has a focal length of 50.0 mm. (a) Find the diameter of the moon's image on the slide film. (b) When the slide is projected onto a screen that is 15.0 m from the lens of the projector ($f = 110.0$ mm), what is the diameter of the moon's image on the screen?

*•**60.** From a distance of 72 m, a photographer uses a telephoto lens ($f = 300.0$ mm) to take a picture of a charging rhinoceros. How far from the rhinoceros would the photographer have to be to record an image of the same size using a lens whose focal length is 50.0 mm?

*••**61.** The equation

$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$$

is called the *Gaussian* form of the thin-lens equation. The drawing shows the variables d_o, d_i, and f. The drawing also shows the distances x and x', which are, respectively, the distance from the object to the focal point on the left of the lens and the distance from the focal point on the right of the lens to the image. An equivalent form of the thin-lens equation, involving x, x', and f, is called the *Newtonian* form. Show that the Newtonian form of the thin-lens equation can be written as $xx' = f^2$.



*••**62.** A converging lens ($f = 25.0$ cm) is used to project an image of an object onto a screen. The object and the screen are 125 cm apart, and between them the lens can be placed at either of two locations. Find the two object distances.

47) -24cm, 1.6
48) -8.1cm
49) 61.1mm
50) 2.8
51) -24cm, $+3.0$
52) -15cm
53) -75cm, $+2.5$ -75cm, $+2.5$cm
54) -12cm, $+.63$, virtual, upright, reduced
55) -7.9×10^{-3}m, -3.44×10^{-2}m
56) 6.74×10^{-7} m^2, 7.86×10^5 W/m^2
57) 48cm
58) Away from lens, 0.15 m
59) 4.52×10^{-4}m, 6.12×10^{-2}m
60) 12 m
61) } NOT SO FAST! see MR. DiBucci's
62) } solutions!

The Eye

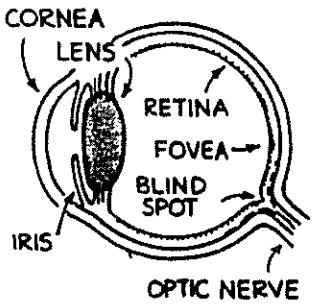


Fig. 30–18 The human eye.

In many respects the human eye is similar to the camera. The amount of light that enters is regulated by the **iris**, the colored part of the eye which surrounds the opening called the **pupil**.* Light enters through the transparent covering called the **cornea**, passes through the pupil and lens, and is focused on a layer of tissue at the back of the eye—the **retina**—that is more sensitive to light than any artificial detector made. Different parts of the retina receive light from different directions.

The retina is not uniform. There is a small region in the center of our field of view at which we have the most distinct vision. This spot is called the *fovea*. Much greater detail can be seen here than at the side parts of the eye.

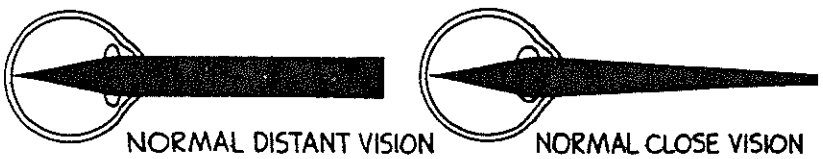
There is also a spot in the retina where the nerves carrying all the information run out. This is the *blind spot*. You can demonstrate that you have a blind spot in each eye if you hold this book at arm's length, close your left eye, and look at the circle in Figure 30–19 with only your right eye. You can see both the circle and the X at this distance. If you now move the book slowly toward your face, with your right eye still fixed upon the circle, you'll reach a position about 20 to 25 cm from your eye where the X disappears. To establish the blind spot in your left eye, close your right eye and similarly look at the X with your left eye so that the circle disappears. With both eyes opened, you'll find no position where either the X or circle disappears because one eye "fills in" the part of the object to which the other eye is blind. It's nice to have two eyes.

* The hole of the pupil usually looks black because light is going in but not coming out. Sometimes in flash photos, the light from the flashbulb enters the eye at just the right angle to reflect off the retina at the back of the eye. That's why flash photographs sometimes show the pupils to be pinkish.

Fig. 30–19 For the blind spot experiment.

In both the camera and the eye, the image is upside down, and this is compensated for in both cases. You simply turn the camera film around to look at it. Your brain has learned to turn around images it receives from your retina!

A principal difference between a camera and the human eye has to do with focusing. In a camera, focusing is accomplished by altering the distance between the lens and the film. In the human eye, most of the focusing is done by the cornea, the transparent membrane at the outside of the eye. Adjustments in focusing of the image on the retina are made by changing the thickness and shape of the lens to regulate its focal length. This is called *accomodation* and is brought about by the action of the *ciliary muscle*, which surrounds the lens.



Name _____ Per. ____ date _____

Converging and Diverging Lenses
DiBucci

Directions:

1. For each of the following lenses make an accurate ray diagram to locate the image. Record the image distance and magnification factor. State if it is a real, virtual, magnified reduced, upright or inverted image.

2. Use the thin lens equation to calculate the image distance and magnification factor.
Show your work for each one on the page provided.

2. Verify that the results from part 1 are the same as part 2.

Helpful information to be used with the lens equation:

REASONING STRATEGY

Summary of Sign Conventions for Lenses

Focal length

f is + for a converging lens.

f is − for a diverging lens.

Object distance

d_o is + if the object is to the left of the lens (real object), as is usual.

d_o is − if the object is to the right of the lens (virtual object).*

Image distance

d_i is + for an image (real) formed to the right of the lens by a real object.

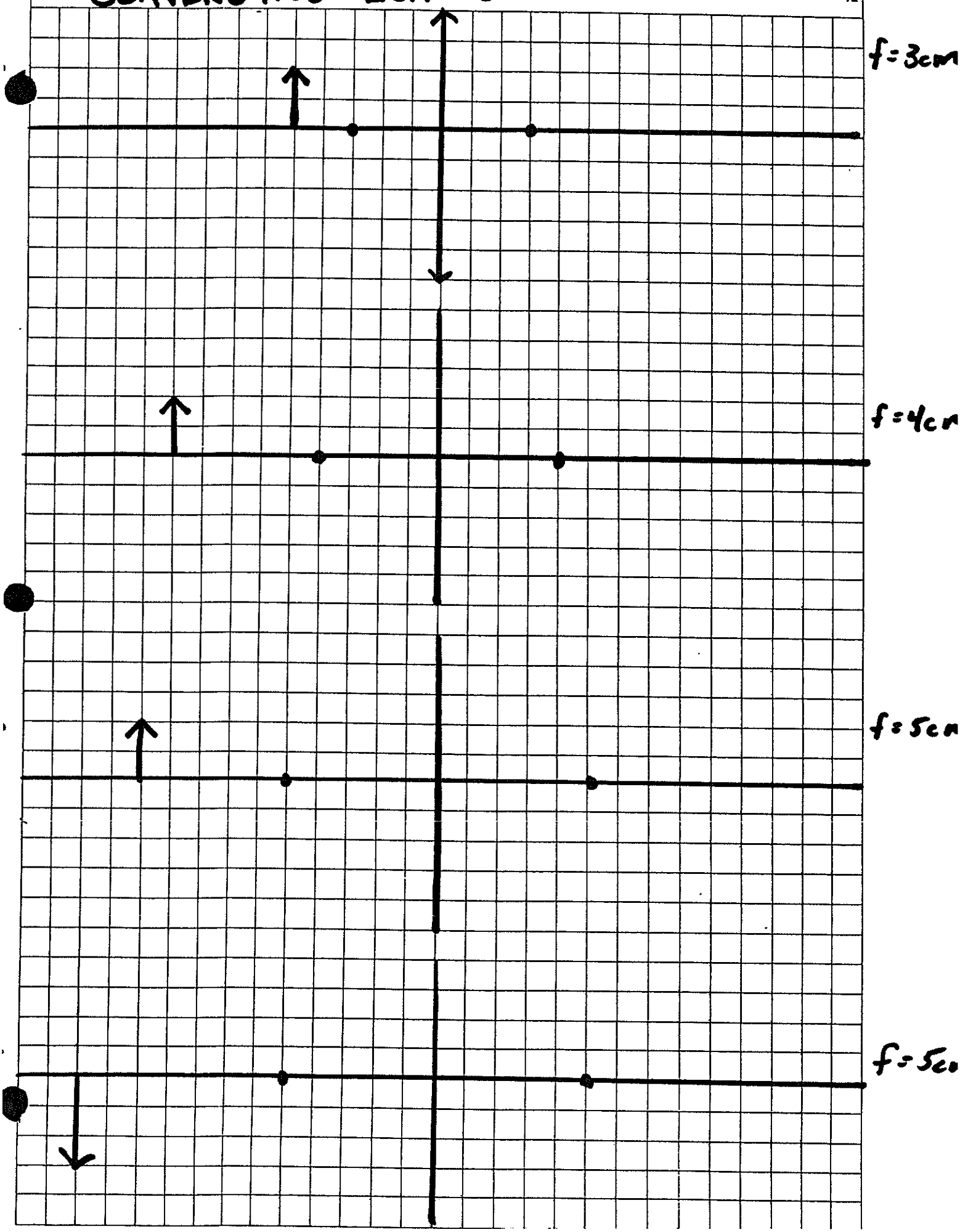
d_i is − for an image (virtual) formed to the left of the lens by a real object.

Magnification

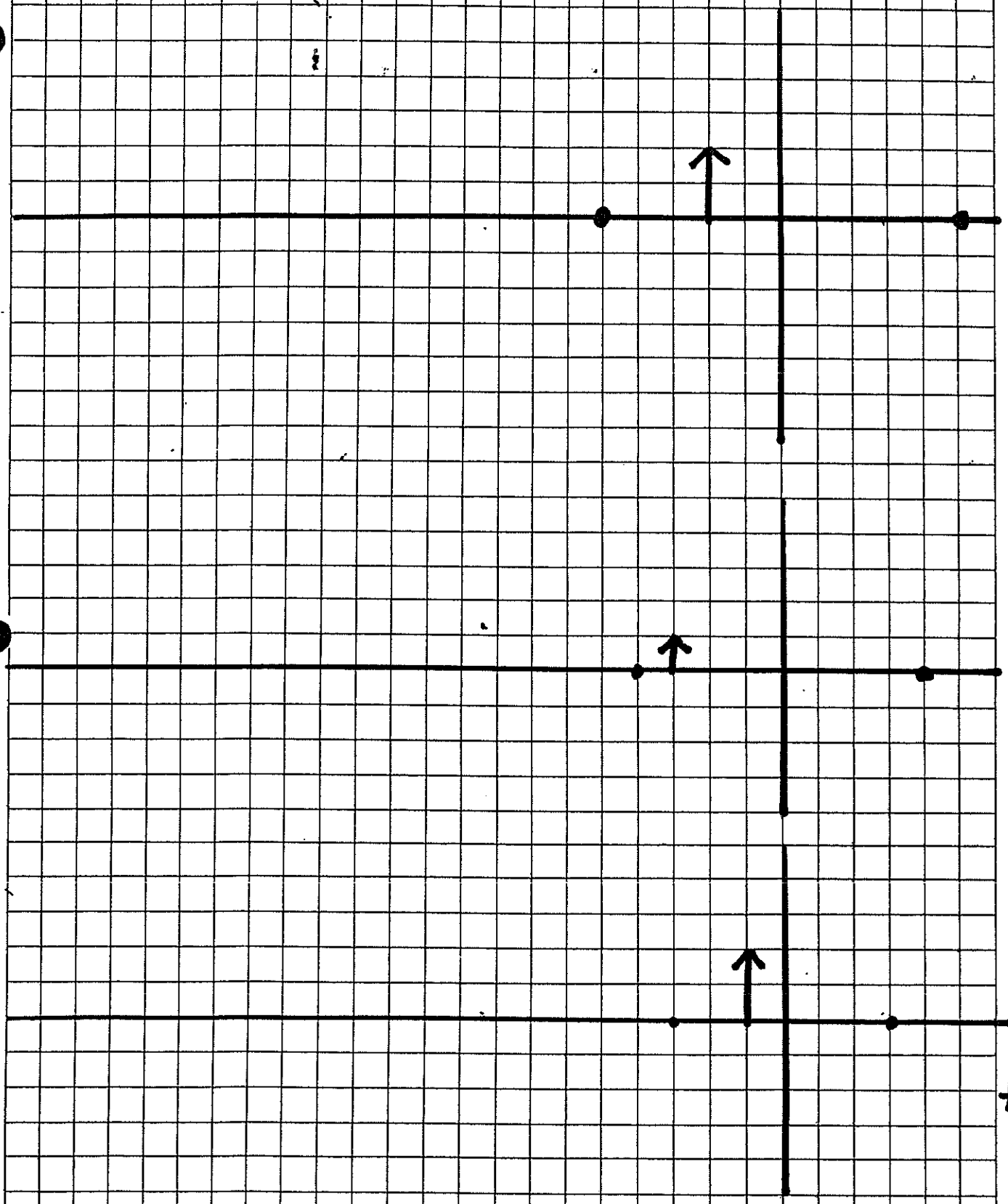
m is + for an image that is upright with respect to the object.

m is − for an image that is inverted with respect to the object.

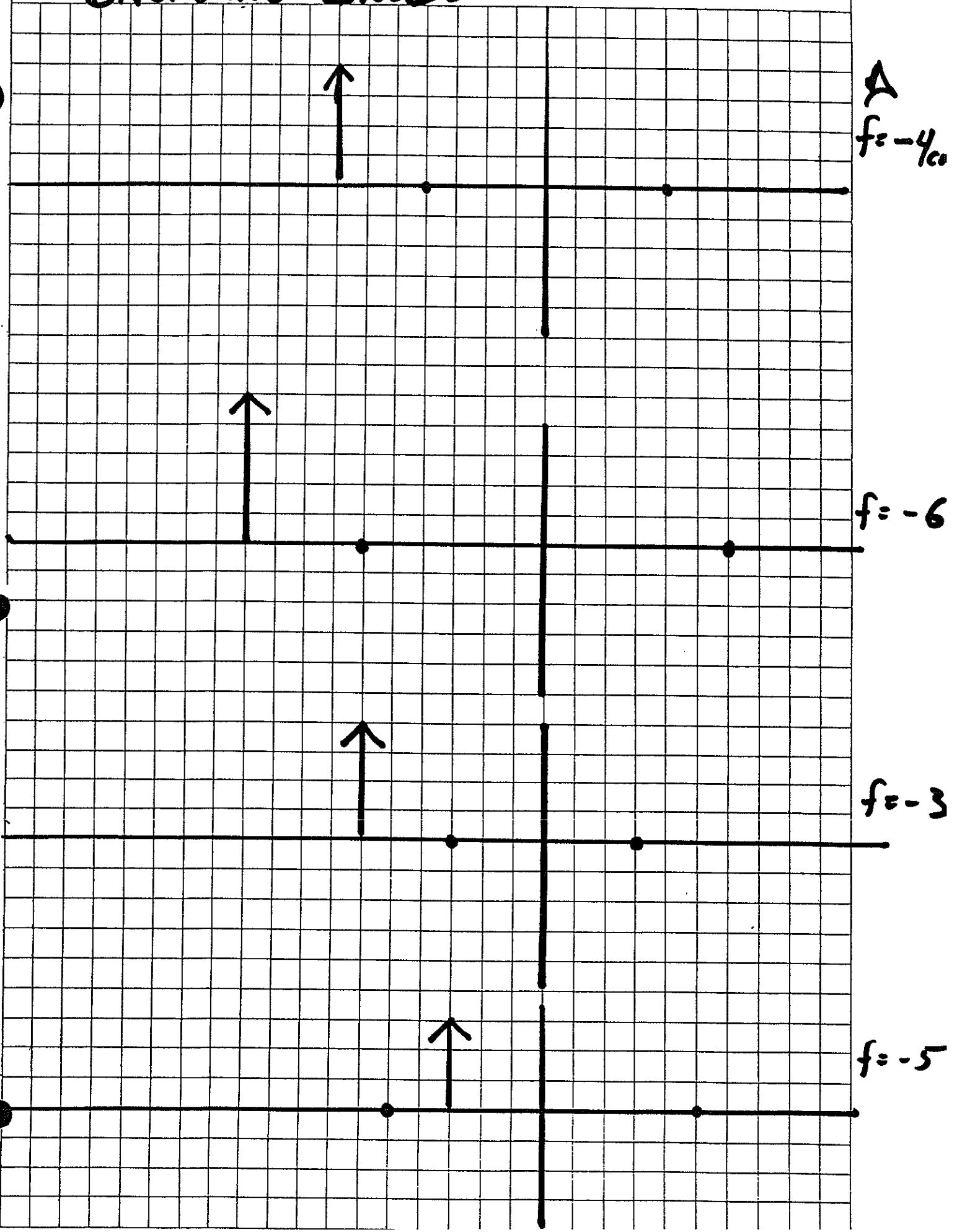
NAME CONVERGING Lenses EXPERIMENT NO. 72



NAME CONVERGING Lenses EXPERIMENT NO. 72



NAME DIVERGING LENSES EXPERIMENT NO. 72



Name _____ Per. ____ date _____

Converging and Diverging Lenses
DiBucci

W.S. #2

Directions:

1. For each of the following lenses make an accurate ray diagram to locate the image. Record the image distance and magnification factor. State if it is a real, virtual, magnified reduced, upright or inverted image.

2. Use the thin lens equation to calculate the image distance and magnification factor.
Show your work for each one on the page provided.

2. Verify that the results from part 1 are the same as part 2.

Helpful information to be used with the lens equation:

REASONING STRATEGY

Summary of Sign Conventions for Lenses

Focal length

f is + for a converging lens.

f is − for a diverging lens.

Object distance

d_o is + if the object is to the left of the lens (real object), as is usual.

d_o is − if the object is to the right of the lens (virtual object).*

Image distance

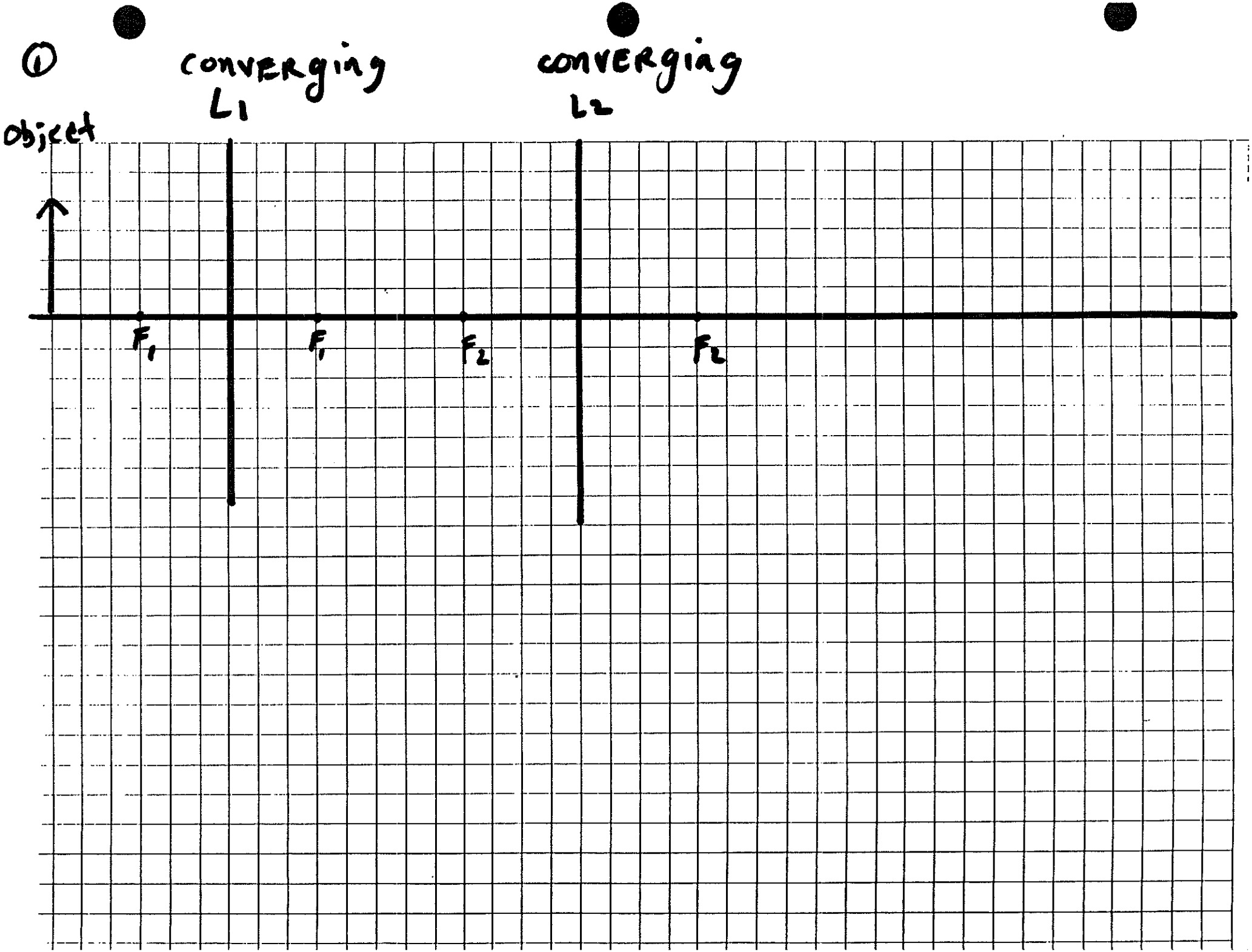
d_i is + for an image (real) formed to the right of the lens by a real object.

d_i is − for an image (virtual) formed to the left of the lens by a real object.

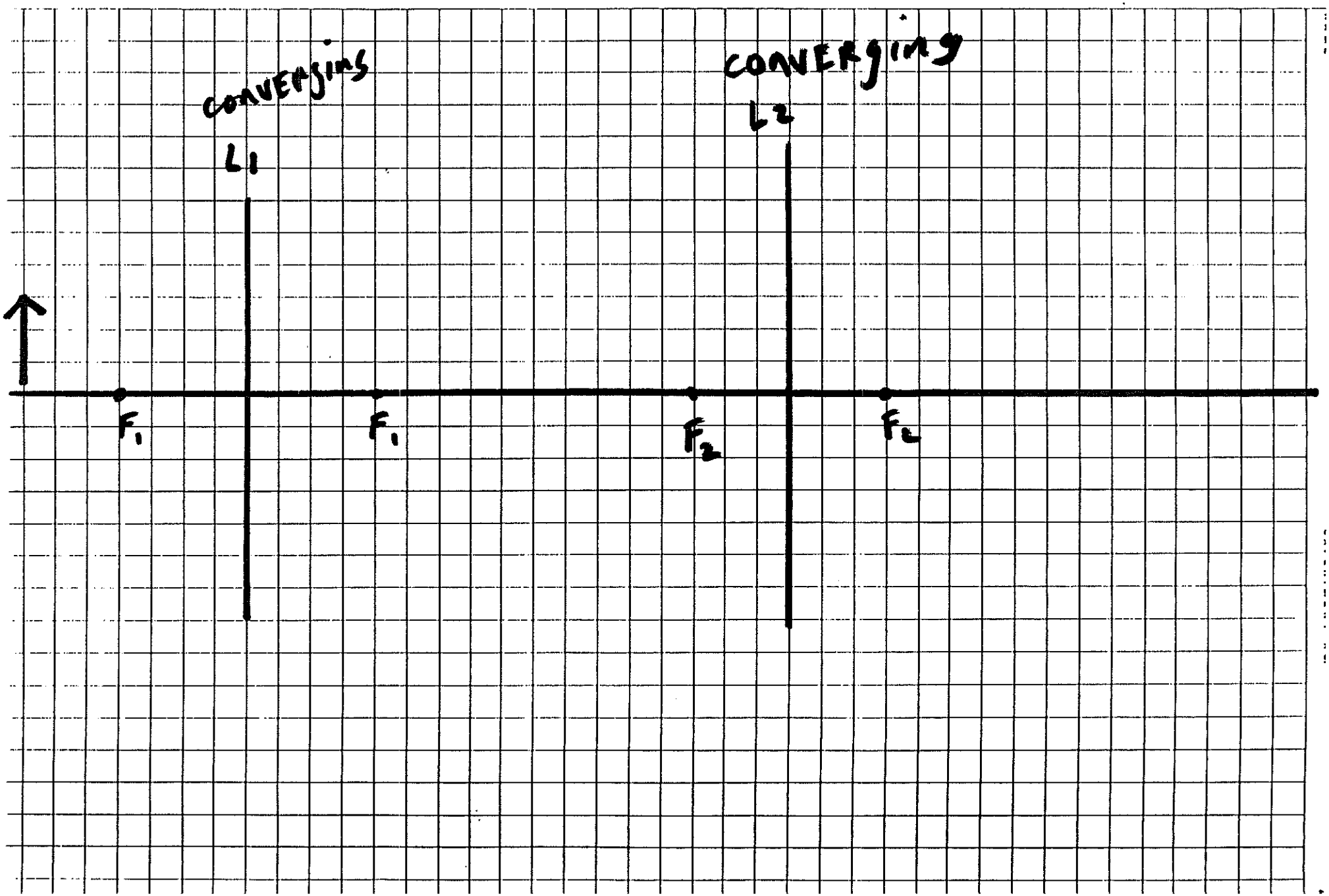
Magnification

m is + for an image that is upright with respect to the object.

m is − for an image that is inverted with respect to the object.


①
converging
L_1
converging
L_2
object
F_1
F_1
F_2
F_2

(2)



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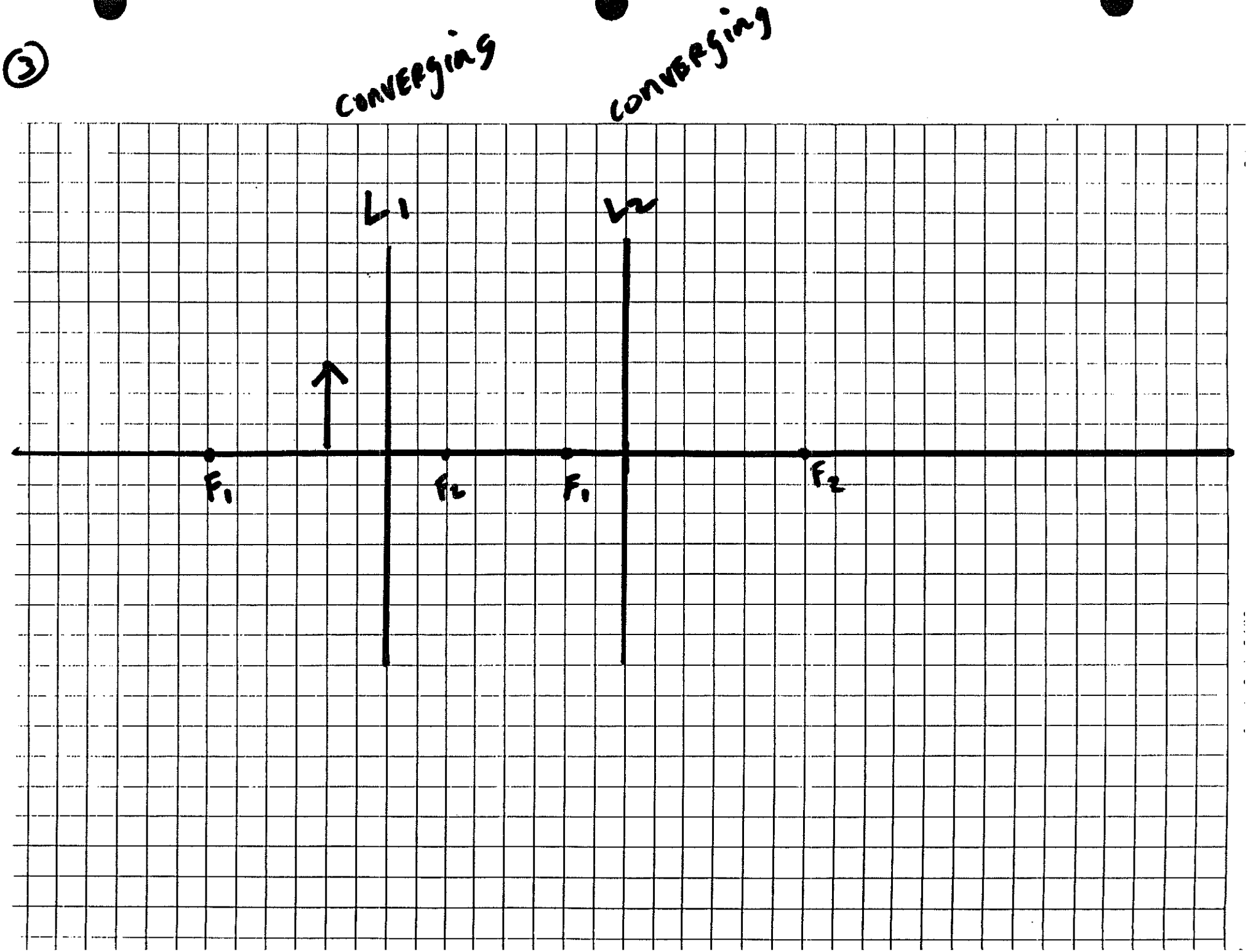
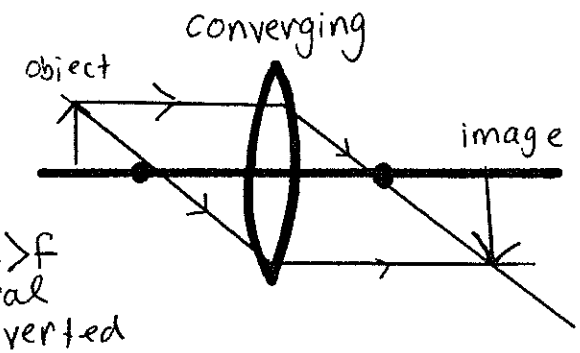
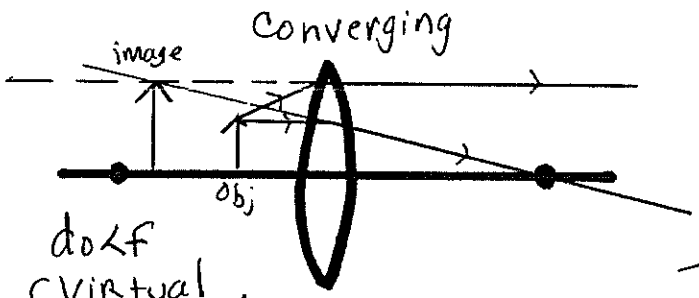


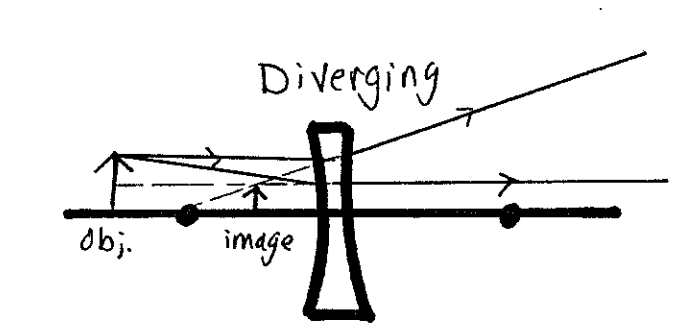
Lenses



$d_o > f$
{ Real
{ inverted

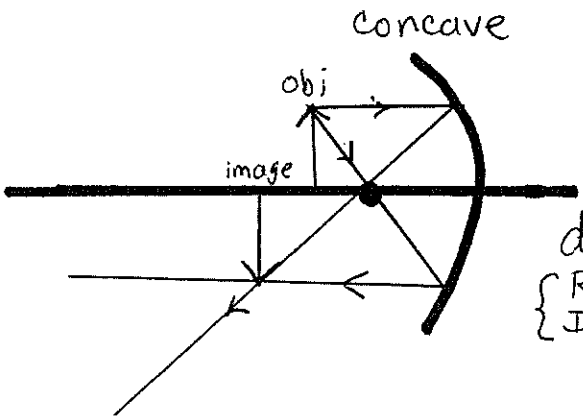


$d_o < f$
{ virtual
{ magnified
{ upright

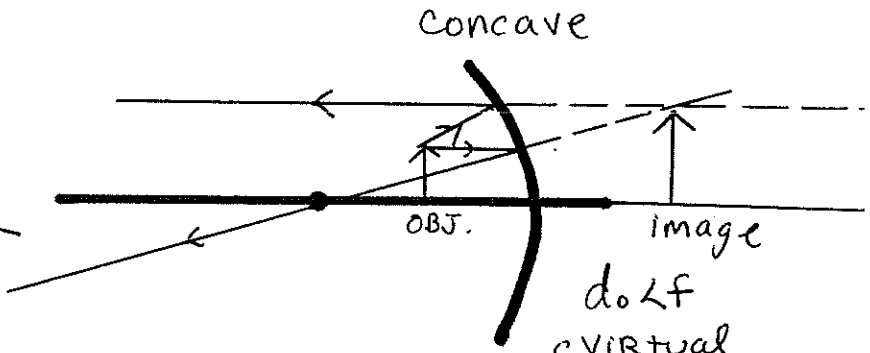


{ Virtual
{ Reduced

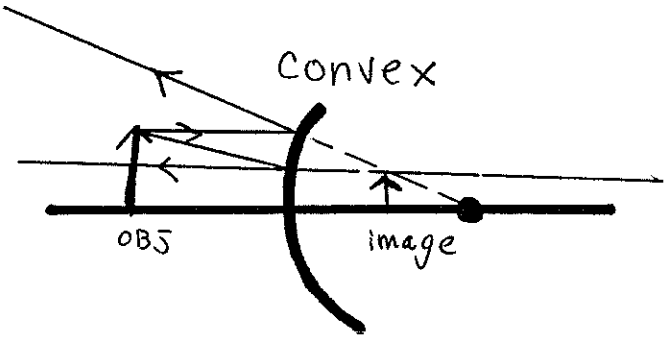
Mirrors



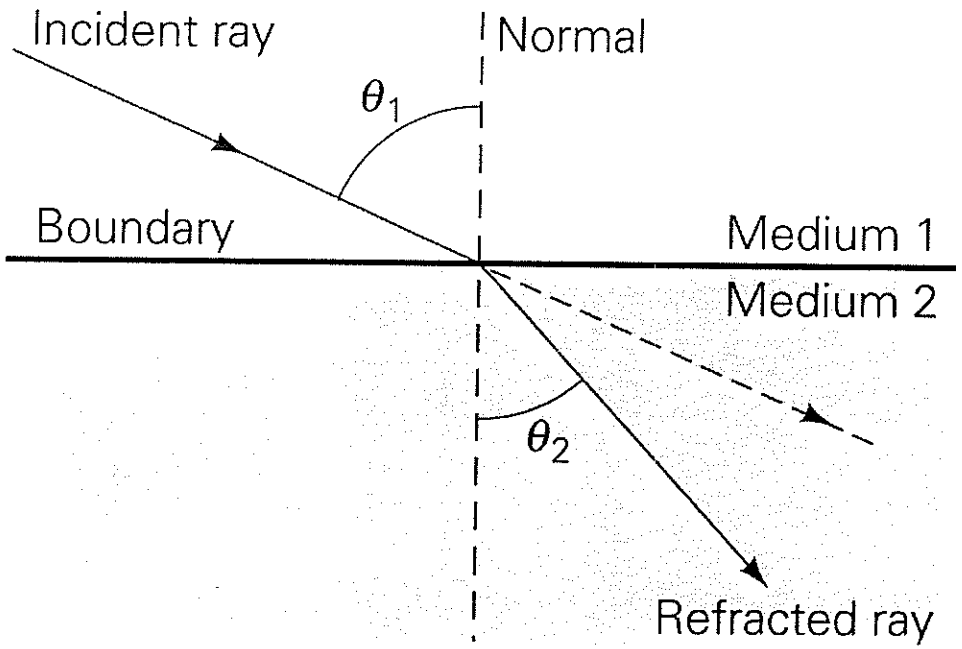
$d_o > f$
{ Real
{ Inverted

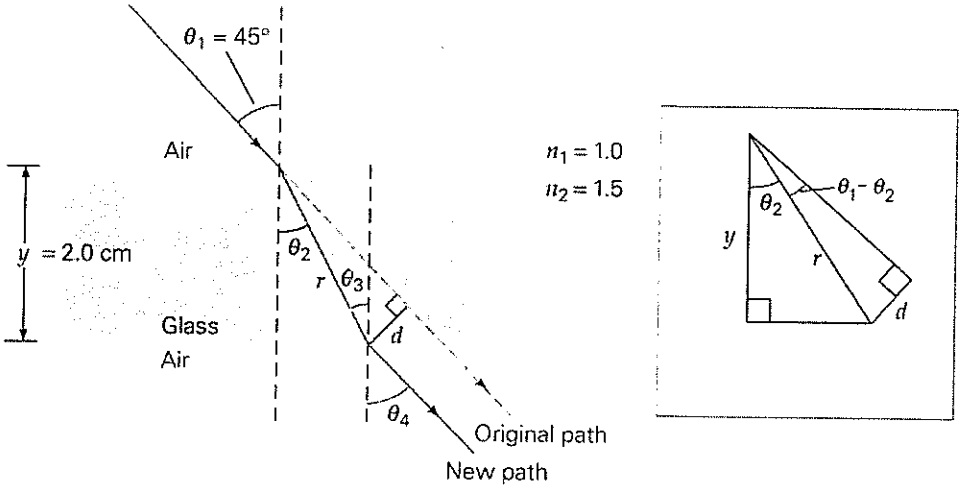


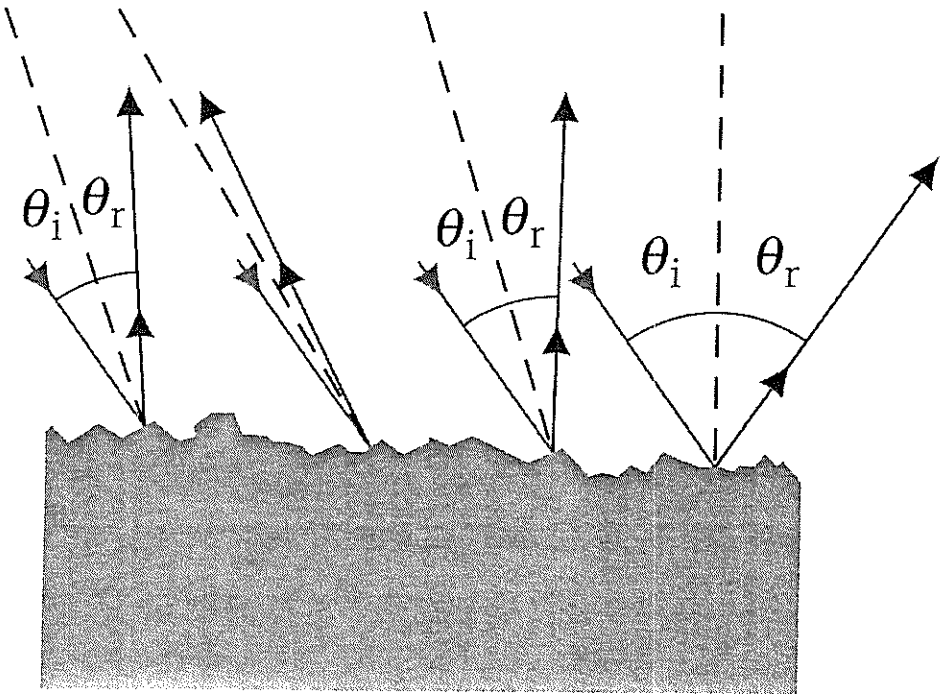
$d_o < f$
{ virtual
{ magnified
{ Upright

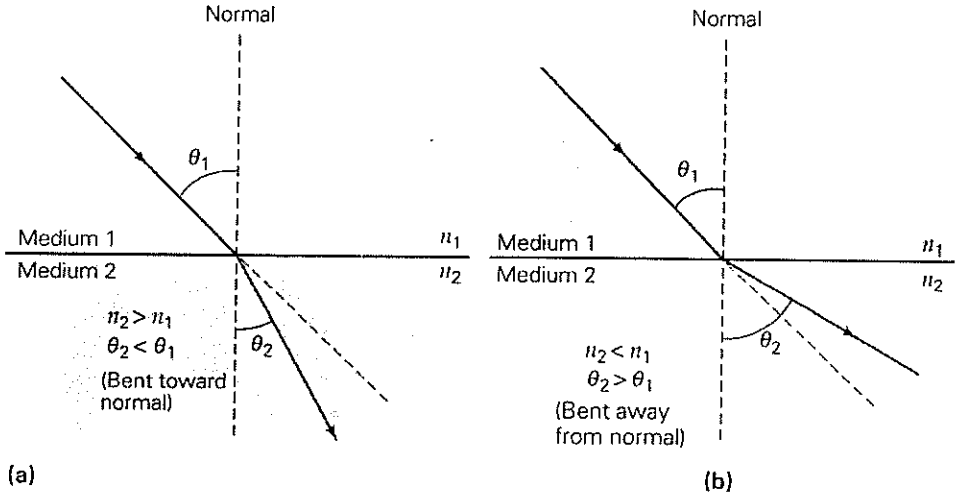


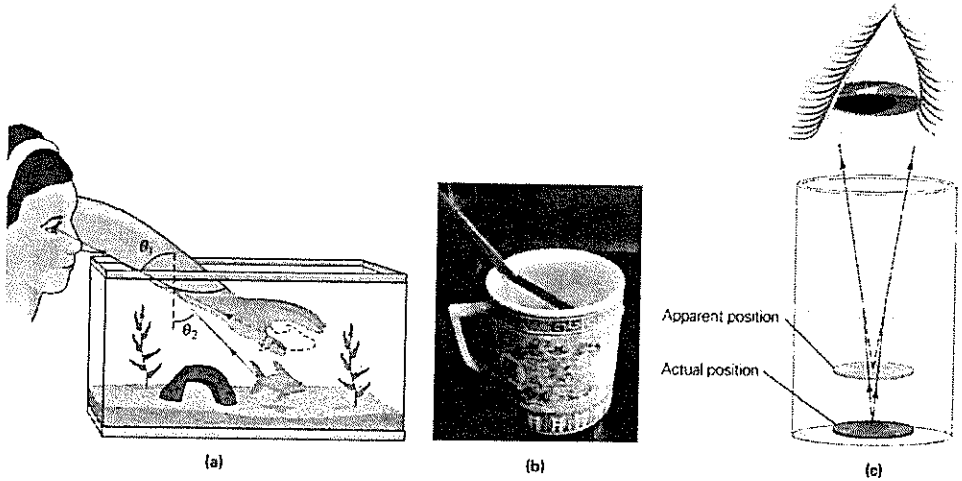
{ Virtual
{ REDuced.

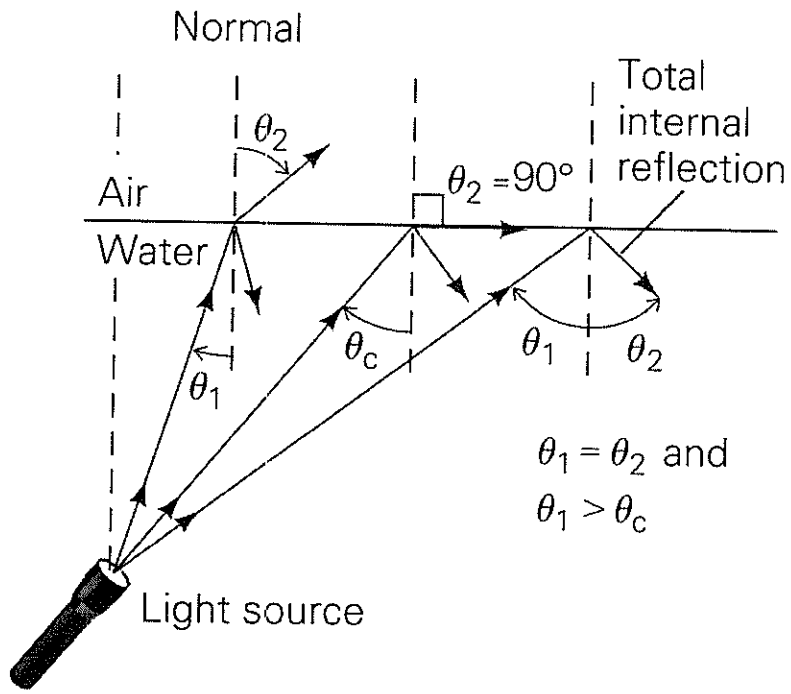


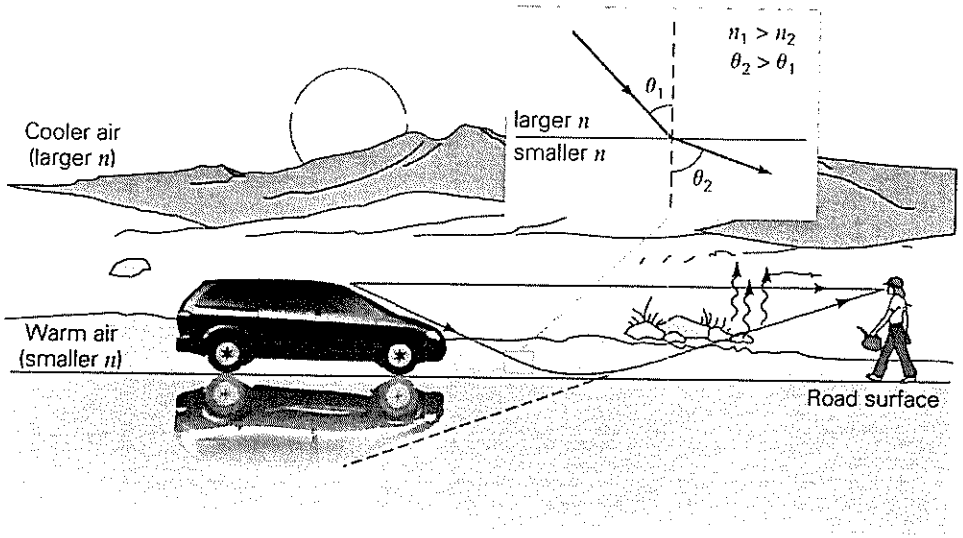


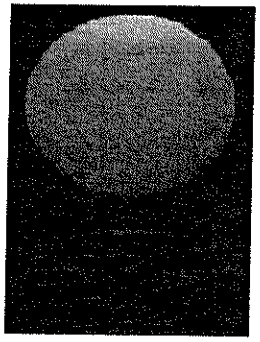








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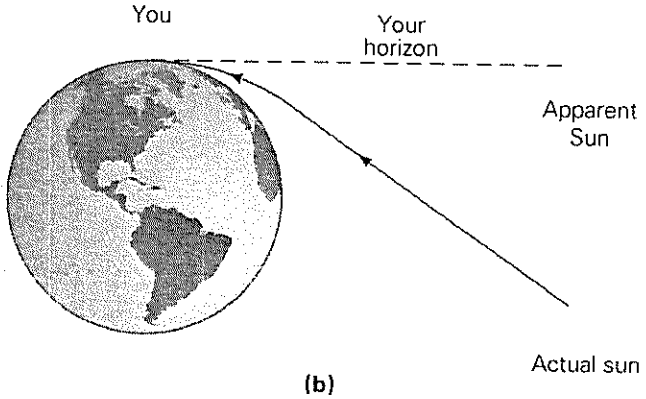

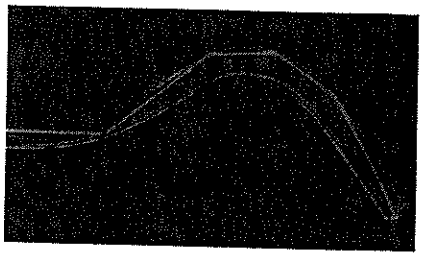

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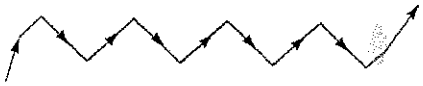

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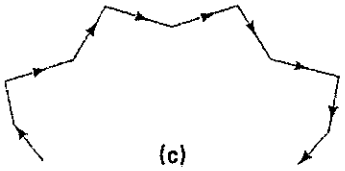

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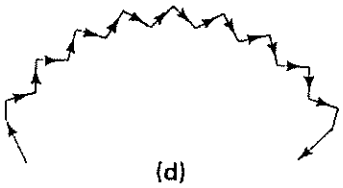
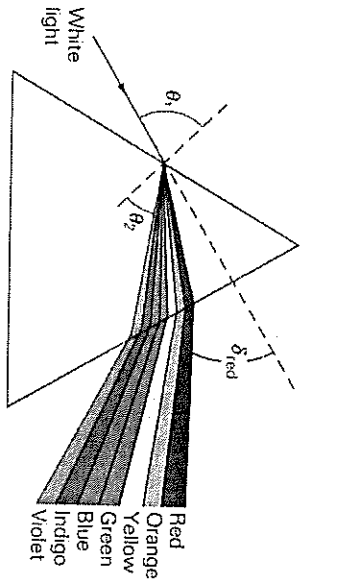
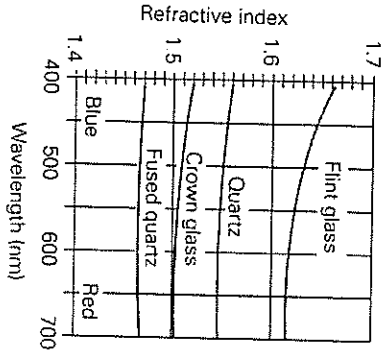


(d)





NAME _____ PER. _____

MIRROR : LENS REVIEW SHEET

1 Complete the following table. As an example, the first row of the table shows a completed set of data.

	Type of Mirror	Radius of Curvature	Focal Length	Object Distance	Image			Magnif.
					Distance	Real?	Inverted?	
A	Concave	20.0 cm	+10.0 cm	+6.67 cm	-20.0 cm	NO	NO	+ 3.0
B	Plane	——	——	+45 cm				
C		50.0 cm		+5.0 cm				+ 0.84
D					+75 cm			- 3.0
E			+20.0 cm		-40.0 cm			
F	Convex				-10.0 cm			0.33 (sign?)
G	Concave	30.0 cm			+150 cm			

2. Fill-in the following table for a single lens. Include the appropriate signs on ALL numbers.

	Lens Type	focal length	object distance	image distance	magnification	real/virtual	inverted/upright
A	converging	25 cm	15 cm				
B	converging		22 cm	+22 cm			
C	diverging			12 cm	0.50		
D	diverging	11 cm		5 cm			
E		8 cm		18 cm			inv