I. SPEED AND PROPERTIES

Like waves, light exhibits the properties of reflection and refraction. In addition, light also displays polarization, dispersion, scattering, and color. Reflection is the return of incident light from a surface. Refraction occurs when light is bent when passing from one medium into another, or as it passes through a nonuniform medium. In **polarization**, light vibrates in a single plane. The splitting of a beam of light through a prism is called **dispersion**. **Scattering** accounts for the red sunrises and sunsets with blue midday skies. Color is a property of frequency and wavelength.

SECTION OBJECTIVES

Read these objectives to learn what you should be able to do when you have completed this section.

1. Relate the history of measuring the speed of light;
2. Solve problems involving the velocity, wavelength, and frequency of light;
3. Solve problems involving the index of refraction of light, and
4. Explain polarization, dispersion, and scattering.

VOCABULARY

Study these words to enhance your learning success in this section.

angle of incidence	mirage
angle of reflection	normal
angle of refraction	polarization
dispersion	scattering
index of refraction	total internal reflection
looming	

Note: All vocabulary words in this LIFEPAC appear in **boldface** print the first time they are used. It you are unsure of the meaning when you are reading, study the definitions given.

SPEED

Light travels at the ultimate speed. Nothing known travels faster than light in the vacuum of space. Because light has wave characteristics, light was thought to require a material medium. When no matter could be detected in space, a propertyless substance, *ether*, was postulated as filling all space. Subsequent experiments have disproved the existence of ether in space, and have shown that the wave type of which light is a part needs no material medium.

History. It is difficult to know who the first individual was to attempt to measure the speed of light (some of the ancients thought that light was instantaneous), but Galileo is the first on written record to attempt it. He and an assistant carried lanterns to two hills a known distance apart. As his assistant uncovered his lantern, he was to start a clock. When Galileo saw his assistant's lamp, he was to uncover his own lamp. The clock would be stopped when the assistant saw the light that Galileo uncovered. Man's reaction time is much slower than the speed of light and the experiment was a failure, except to prove that the speed of light is indeed very fast.

In 1676 Olaus Roemer, a Danish astronomer, proposed to measure the speed of light using large distances in order that reaction time should not be a crucial factor. He observed that the satellites (moons) of Jupiter were eclipsed at regular intervals by the planet. He timed the revolutions of several of its moons and discovered that when the earth was near Jupiter, the eclipses occurred 11 minutes earlier than expected; and when the earth was farthest in its orbit, they occurred 11 minutes later because light had to pass from Jupiter across the earth's orbit to the observer. An error was inherent because the diameter of the earth's orbit was not accurately known. Accurate data yields $16\frac{1}{3}$ minutes for light to cross earth's orbit and not the 22 minutes that Roemer found. The diameter of the earth's orbit is $2.94 \cdot 10^{11}$ m; therefore,

$$v = {}^{d}/_{t}$$

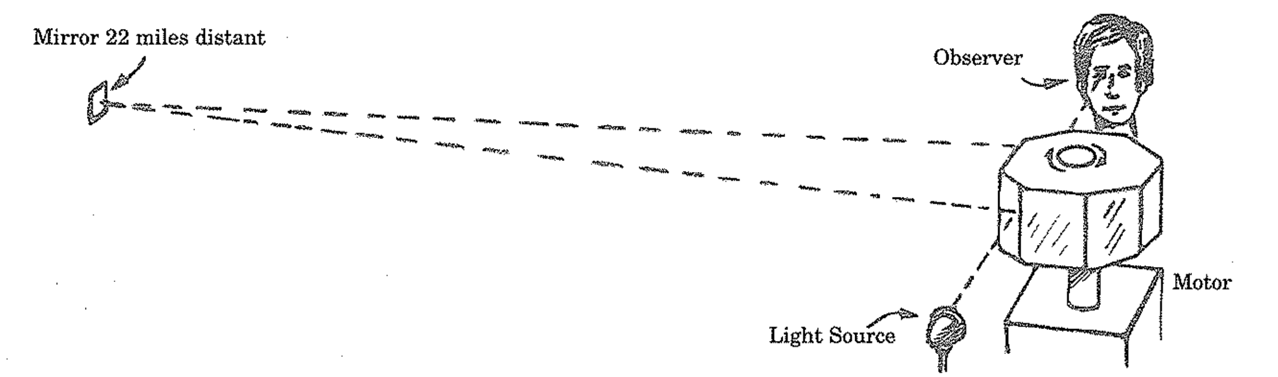
$$= \frac{2.94 \cdot 10^{11} \text{ m}}{980 \text{ sec}}$$

$$= \frac{3 \cdot 10^{8} \text{ m}}{\text{sec.}}$$

The letter *c* denotes the velocity of light in a vacuum.

$$c = 3 \cdot 10^{8}\ {}^{m}/_{sec}$$

In 1848 Fizeau calculated the speed of light over a short distance. The most famous of all the speed of light experiments was performed in 1880 by Albert Michelson by bouncing flashes of light from an octagonal (8-sided) mirror to a plane mirror 22 miles away. The reflected light returned to the rotating mirror. When an observer saw the reflected light in the rotating mirror, the time for the light to travel 44 miles was equal to the time for the mirror to turn $^{1}/_{8}$ of a revolution. Michelson calculated the speed of light to be 186,364 $^{mi}/_{sec}$. In 1907 he received the Nobel prize for this experiment becoming the first American physicist to receive this prize The speed of light is usually rounded to 186,000 $^{mi}/_{sec}$, or $1.86 \cdot 10^{5}\ {}^{mi}/_{sec}$, which is equivalent to $3 \cdot 10^{8}\ {}^{m}/_{sec}$.



Prepare a report.

1.1 In 1677 Christiaan Huygens advocated a wave model for light, which was a radical concept for that day. Prepare a report on the life and revolutionary theories of this man. Submit a five-page, double-spaced, handwritten report for evaluation.

Score ____________
Adult check ____________
Initial Date

Answer these questions.

1.2 If Galileo's experiment did not measure the speed of light, what did it measure; and what did it prove concerning the speed of light?

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1.3 What symbol is used to denote the velocity of light in a vacuum, and what is its speed in a vacuum in $^{m}/_{sec}$ and $^{mi}/_{sec}$?

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1.4 What is the significance of the Michelson experiment of 1880?

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Measurement. With means now available to measure the speed of light, light was discovered to travel fastest in a vacuum and slower through a material medium. In water the speed of light is 2.25 • 10^8 m/sec, and in glass it is about 2.0 • 10^8 m/sec (this figure varies depending on the composition of the glass). Nothing discovered travels faster than light in a vacuum; high energy particles can travel faster than light in water, however.

Complete this activity.

1.5 If an unknown, transparent substance existed in which the speed of light were to be measured, comment on what you would expect the results to show.

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PROPERTIES

Under varying circumstances light exhibits some unexpected properties. Only the ones that are readily observable will be studied. For the purpose of study, a *ray* is the vector that describes the direction of light transmission. A ray describes the movement of a wave and is therefore perpendicular to a wave front.

Reflection. When a particle, such as a ball, hits a wall at any given angle, the particle reflects along a path that forms the same angle with the wall as did the incident path. In Science LIFEPAC 1204, wave fronts at a reflecting barrier were shown to have the same consistent relationship.

Try this investigation. You will study the angles that light makes as it is incident on a mirror.

These supplies are needed:

mirror	ruler
pencil	protractor
flashlight	ball bearing
sheet of paper	

Follow these directions and answer the questions. Put a check in the box when each step is completed.

❑ 1. Shine a pencil-thin beam of light on a mirror perpendicular to its surface.

1.6 How does the light reflect? _______________________

1.7 How does the relationship of incident to reflected ray relate to the reflection of water waves moving perpendicular to a barrier?

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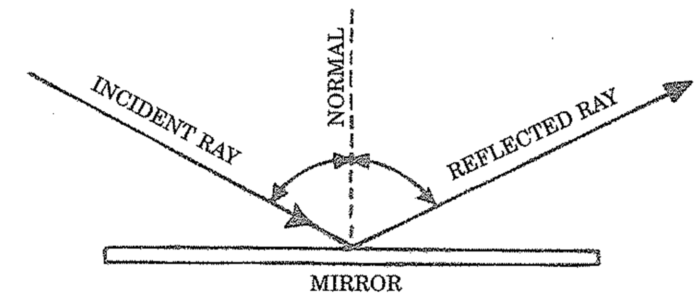
❑ 2. Shine a pencil-thin beam of light on a mirror standing on a sheet of paper on the table (or floor) so that you can mark the incident ray and reflected ray.

❑ 3. Mark a line on the paper representing the reflective surface. (The reflective surface of a mirror is usually the back edge.)

❑ 4. Draw a dashed line perpendicular to the mirror surface at a point where the incident and reflected ray meet. This perpendicular is called a **normal** to the surface.

❑ 5. Measure the angles between the rays and the normal. The **angle of incidence** is the angle formed by the incident ray and the normal to the surface. The angle formed by the reflected ray and normal is called the **angle of reflection** (r).



1.8 What is the angle of incidence? _______________________

1.9 What is the angle of reflection? _______________________

❑ 6. Repeat for several different angles.

1.10 What appears to be the relationship between the angle of incidence and angle of reflection?

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1.11 In Science LIFEPAC 1204 what was the relationship for these two angles made by the reflection of waves in a ripple tank? _______________________

❑ 7. Roll a ball bearing so that it hits a fixed, hard surface (a metal plate) at several angles (including head-on). Observe the way in which the ball bearing reflects.

1.12 What generalization can you make about how a ball bearing reflects from a wall?

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1.13 Have you proved that light can only behave like a wave?

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Refraction. Like refraction of water waves, refraction of light is a bending as it passes from one medium to another (or through a nonuniform medium). The angle of incidence is measured from the normal, as mentioned in Step 5. The **angle of retraction** is the angle between the refracted ray and the normal that is drawn to the surface at the point of incidence.

Answer this question.

1.14 As water waves went from a high-velocity medium (deep water) to a low-velocity medium (shallow water), did the wave speed up or slow down? (Refer to Science LIFEPAC 1204.)

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Draw a line perpendicular to the wave front indicating the direction of the incident waves and continue it to the line denoting the boundary. Draw a normal to the edge there and measure the angle of incidence. Now do likewise with the refracted waves, draw another normal if convenient, and measure the angle of refraction.

Answer this question.

1.15 Is the angle of incidence (high-velocity medium) larger than the angle of refraction (low-velocity medium)? ______________________________

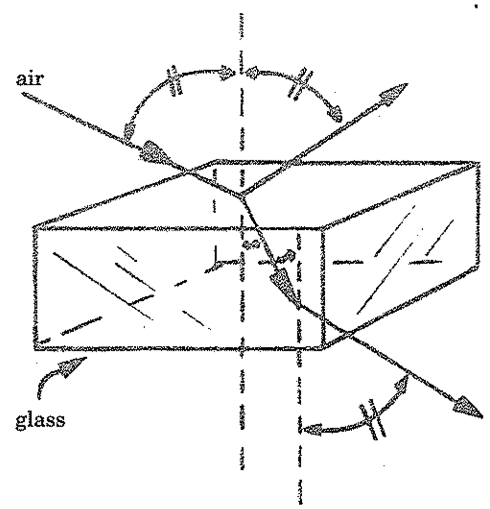
Try this investigation. You will investigate the refraction of light through glass.

These supplies are needed:

- cube of glass (or a thick piece window glass)
- protractor
- pen light

Follow these directions and answer the questions. Put a check in the box when each step is completed.

❑ 1. Shine a thin pencil beam of light at the flat smooth surface of glass.



❑ 2. Draw a line representing the incident beam of light that strikes the glass surface at an angle.

❑ 3. Note where the light emerges from the glass and mark that place. The line from where the light entered the glass to where it left is the refracted ray.

❑ 4. Measure the angle of incidence and angle of refraction.

1.16 Which is the high-velocity medium, air or glass? ______________________________

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1.17 What is the angle of incidence? ______________________________

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1.18 What is the angle of refraction? ______________________________

1.19 What happens to the angle of light as it goes from a high-velocity medium to a low-velocity medium? ______________________________

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1.20 As light goes from air to glass, does it bend toward or away from the normal?

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Try this investigation. Now you will do a similar experiment with a ball bearing.

These supplies are needed:

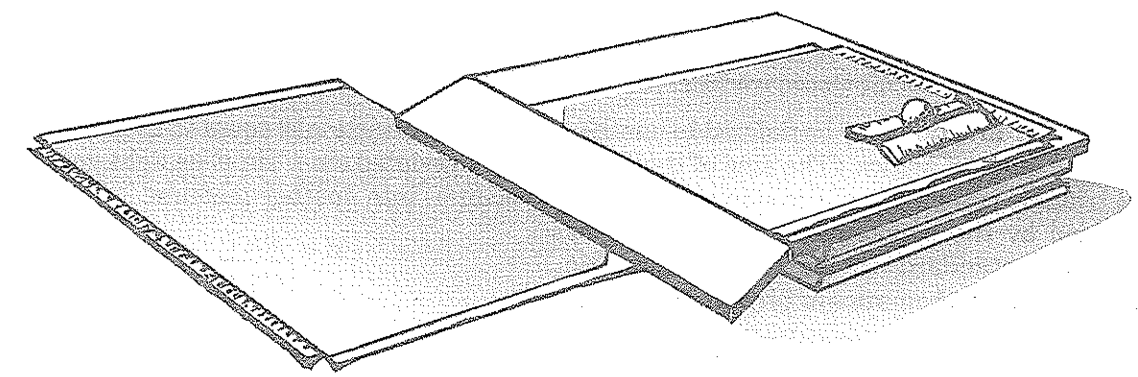
- steel ball bearing ($^1/_2$" diameter or larger)
- 2 sheets of paper
- 2 sheets of fresh carbon paper
- cardboard ramp
- incline (grooved ruler)
- protractor

Follow these directions and answer the questions. Put a check in the box when each step is completed.

❑ 1. Construct a flat elevated surface with a ramp sloping to a table.

❑ 2. Place a sheet of carbon paper and plain paper face to face on the elevated and lower surfaces.

❑ 3. Roll the ball bearing down grooved ruler on to the elevated surface so that it continues to roll down the ramp and to the table.



The ball bearing should mark the plain paper with carbon as it rolls.

❑ 4. Draw a normal where the ball leaves the upper surface and another normal at the table surface where the ball left the ramp.

❑ 5. Measure the angles of the ball path to the normals.

1.21 Where is the speed of the ball bearing the greatest, on the elevated surface or at the table surface? ______________________________

1.22 What happens to the angles of incidence and refraction as the ball bearing goes from the low-velocity medium to the high-velocity medium? ______________________________

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1.23 After comparing your answers to 1.15, 1.19 and 1.22, does light behave like a wave or a particle? ______________________________

Having observed that light does indeed behave like a wave, you will proceed to discover that the relationship between the angle of incident and the angle of refraction depends upon the velocities of light in both mediums.

The **index of refraction** (n) is the ratio of the speed of light in a vacuum (c) to its speed in the medium (v).

$$n = {}^c/_v$$