Name: Richard Francis Kelly Date of Degree: August 5, 19

Institution: Oklahoma State University Location: Stillwater, Oklaho

Title of Study: SUGGESTIONS AND DEMONSTRATIONS FOR A UNIT ON WAVE THEORY FOR A HIGH SCHOOL PHYSICS CLASS

Pages in Study: 30

Major Field: Natural Science

Scope of Study: This report contains a partial development of a unit on wave theory with emphasis on the basic similarities of all wave motion. Some of the topics which are included in the unit are: simple harmonic motion, transverse and longitudinal waves, Huygens' Principle, diffraction and interference, reflection, refraction, polarization, and Doppler effect. Demonstrations are given which will aid in the teaching of these topics and emphasis is placed on the use of a variety of demonstrations from the various types of wave motion. The report also gives suggestions about some of the methods of presentation which can be used with certain topics.

Findings and Conclusions: Since this report has not been used in the actual teaching situation, the conclusions reached are only the desired results which the writer feels should be aimed for in the teaching of the unit. One of the advantages of teaching wave theory by this method is the saving of time as a result of unification of the material. Another desired outcome would be that the students would have a clearer understanding of the interrelationship between the various sections of physics and would see physics as a unified science. The writer feels that this unification of material which has been done in this report needs to be done in other areas of physics.

ADVISER'S APPROVAL James H. Zant

SUGGESTIONS AND DEMONSTRATIONS FOR A UNIT ON WAVE THEORY FOR A HIGH SCHOOL PHYSICS CLASS

By

RICHARD FRANCIS KELLY

Bachelor of Science
University of Nebraska
Lincoln, Nebraska
1955

Submitted to the faculty of the Graduate School of
the Oklahoma State University
in partial fulfillment of the requirements
for the degree of
MASTER OF SCIENCE
August, 1961

SUGGESTIONS AND DEMONSTRATIONS FOR A UNIT ON WAVE THEORY FOR A HIGH SCHOOL PHYSICS CLASS

Report Approved:

____
Report Adviser

____

____
Dean of the Graduate School

ACKNOWLEDGMENTS

I wish to express my appreciation to Dr. D. L. Rutledge for his many suggestions and helpful criticisms that guided me in the preparation of this report. I also wish to thank Dr. James H. Zant and the National Science Foundation for making this year of study possible.

TABLE OF CONTENTS

LIST OF FIGURES

CHAPTER I

INTRODUCTION

The high school physics course content has increased greatly in the past twenty years with the addition of such topics as television, electronics, and nuclear energy and this increase has created a physics course which contains more material than it is possible to teach in a one-year program. This situation has caused some physics teachers to omit certain sections of the course and there has been no general agreement as to which sections should be omitted. The result of this is that many students leave a physics course with the idea that each section of physics is independent and they also may feel that certain sections are less important because they were not studied.

While it is realized that there is no simple solution to this problem, a partial solution might be to unify certain areas of physics. At the present time, the high school physics students study, at various times during the course, sound waves, light waves, heat waves, radio waves, and other types of waves. This procedure results in using too much time and, too often, the students fail to see any connection between the various types of wave motion studied.

The purpose of this report shall be the development of a unit on wave motion which will study all types of waves but will emphasize the similarities of the various wave motions. For example, there is no need to spend time studying the reflection and refraction of light waves and then study the reflection and refraction of sound waves; instead, reflection and refraction will be studied as phenomena applicable to all forms of wave motion.

Although it is impossible to make a complete listing of all the material to be covered in the unit, the following principles and concepts are considered to be the more important.

1. Simple harmonic motion
2. Graphical study of sine waves
3. Transverse and longitudinal waves
4. Wavelength, frequency, and velocity of waves
5. Wave fronts
6. Huygens' Principle
7. Diffraction
8. Interference
9. Reflection
10. Refraction
11. Polarization
12. Doppler effect

It is not necessary that the topics be taken up exactly in the order listed; however, each of the first six topics is basic and must be covered before a study of the other concepts is possible. This report shall present a brief treatment of the basic principles and a more detailed presentation of the other concepts.

One of the desired outcomes of this unit would be the saving of time as a result of the unification of the material; however, a more important outcome would be that a student would see the interrelationship between the various parts of physics and would think of physics as a unified science.

CHAPTER II

SUGGESTED CLASSROOM PRESENTATION OF BASIC WAVE CONCEPTS

Simple Harmonic Motion

An understanding of simple harmonic motion is necessary because, in many cases, a wave motion is produced as a result of simple harmonic motion, for example, the sound waves produced by a vibrating tuning fork. In the study of simple harmonic motion, the following terms will be used and the students should have a clear understanding of their meaning; displacement, amplitude, period, and frequency.

Simple harmonic motion is defined as motion in which the force on a particle is proportional to the displacement from the equilibrium position and this can be expressed by the formula,

Force = -constant x displacement

The minus sign indicates that the force is opposite to the direction of displacement and therefore, the force tends to return the particle to the equilibrium position. Another way of describing simple harmonic motion is by using a particle which is moving in a circle at uniform speed. The projection of this particle on any diameter will be an example of simple harmonic motion and this can be demonstrated by the shadow projection of circular motion. A wheel with a handle on the rim is placed perpendicular to a screen and rotated with uniform speed and as the handle moves uniformly in a circle, its shadow will execute simple harmonic motion (5,127).

Another very simple demonstration of simple harmonic motion is to place a steel bar, about one meter long, in a clamp and allow it to vibrate horizontally while viewing it end on. The visibility of the motion can be increased if the end of the bar is painted so that it will contrast with the background (5,130). An interesting modification of this demonstration is to give the bar both horizontal and vertical displacement and the resulting motion will give Lissajous figures, which will be relatively simple if the ratio of width to thickness of the bar is a small integer (5,131). Other demonstrations of simple harmonic motion include; observation of a tuning fork under stroboscopic illunination, vibration of a mass suspended by a vertical spring, and motion of a simple pendulum.

Graphical Study of Sine Waves

The principle of superposition states that, when two waves interact, the resultant displacement of any point is the sum of the displacements produced by each wave separately (3,211) and the students can use this principle to find the resultant wave when two or more waves are moving along the same line.

First, consider two waves of the same frequency in the same plane, which are in phase; then, consider the two waves 180° out of phase; and then consider the two waves out of phase by any angle. Next, consider the same cases, except use waves which have different frequencies. The instructor should demonstrate all of these cases on the blackboard making the drawings as accurate as possible.

The case of two waves which are vibrating at right angles should be studied by using some type of three-dimensional model, such as two boards at right angles on which are traced the two waves and then indicate the position in space of the resultant wave. The instructor should emphasize that Lissajous figures are the result of looking at this resultant wave end on. Specific examples of wave motion in which there are two waves acting at the same time include circularly polarized light and the motion of a material particle in a sound field.

Transverse and Longitudinal Waves

In transverse waves, the particles which transmit the wave move perpendicular to the direction of propagation of the wave; while, in longitudinal waves, the particles move parallel to the direction of motion of the wave. By means of a long flexible spring, such as a 'Slinky' which is obtainable at the local toy store, both types of waves can be demonstrated. The 'Slinky' is laid on the floor and one end is given a sideways motion; the resulting wave will be a transverse wave. If several turns of the 'Slinky' are pulled together and then released quickly, the resulting motion will be a longitudinal wave. Both waves should be demonstrated in two ways, with both ends free and with one end fixed. The students should pay particular attention to the differences between the two cases and should look for changes in amplitude, wavelength, or phase.

A more permanent type of wave machine (Figure 1) can be constructed out of a series of pendulums which are hung from a horizontal bar and are on pivots so that they can be swung in the same plane or in parallel planes. Collars are placed on the rods of the pendulums so that they may be connected by rubber bands and the collars may be moved up or down to show various degrees of coupling. To show transverse waves, arrange the pivots so that all of the pendulums will swing in parallel planes and, for longitudinal waves, arrange the pivots so that all of the pendulums will swing in the same plane (5,144).

In discussing transverse and longitudinal waves, the following terms might be used to describe them and therefore the students should know the meaning of these words: crest, through, compression, and rarefaction. At this point, as throughout the teaching of the unit, the teacher should emphasize the basic similarities of all wave motion and yet should use sufficient concrete examples to clearly illustrate such dissimilarities as do exist. For example, the types of waves which are transverse or which are longitudinal should be clearly identified.

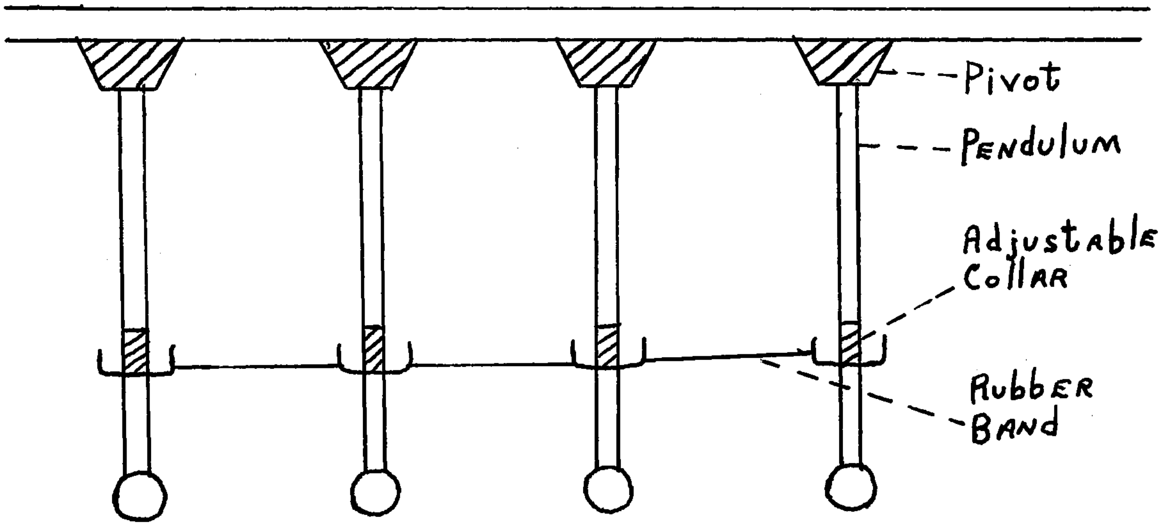

Figure 1. Wave Machine

Wavelength, Frequency, and Velocity of Waves

In this section, the students should learn the definitions of wavelength, amplitude, and frequency and should be able to describe them in terms of either transverse or longitudinal waves. The relationship between the waves and the source which produced them should be pointed out. The frequency of the wave is the same as the frequency of the source.

The basic formula which relates wavelength, frequency, and velocity

velocity = frequency x wavelength

should be studied and various examples considered. For example, by knowing the assigned frequency of a radio station and the velocity of radio waves, it is a simple matter to find the wavelength of this particular radio wave.

While it is not always desirable for students to memorize word-for-word definitions, the following are taken from White (6,201) and are very clear and concise. The wavelength is the distance between two similar points on any two consecutive waves; the amplitude is the maximum value of the displacement; the frequency is the number of waves passing any given point per second. As with any definitions, it is important that the student have an understanding of all words used in the definition.

Wave Fronts and Huygens' Principle

When waves spread out from some source, a surface is produced which contains particles in the same phase of vibration; such a surface is called a wave front (4,186). In many cases, a source will send out waves in all directions and the resulting wave front is described as spherical; however, as the radius of a spherical wave front becomes large, the wave front becomes almost plane.

As a spherical wave front travels outward from a source, the intensity of the wave decreases rapidly. The relative intensities of two waves at different distances from the source are inversely proportional to the squares of the distances from the source (4,186). This can be demonstrated easily using an ordinary light bulb and a light meter or a loudspeaker and a sound-measuring device.

Huygens' Principle states that each point on a wave front may be considered as a secondary source of waves with the same velocity as the primary wave and a line tangent to all of the secondary waves will give a wave front of the primary source (4,599). This principle should be illustrated by blackboard construction for both spherical and plane waves and the student should be able to construct a new wave front from any given type of wave front. Huygens' Principle can be demonstrated using a ripple tank and several sources (5,154).

After the study of this section and periodically throughout the unit, the instructor should check that the students have an understanding of the basic ideas and have certain abilities. The students should understand simple harmonic motion, wavelength, amplitude, frequency, and wave fronts. They should be able to find the resultant wave from two given waves, to describe tranverse and longitudinal waves, to use the formula, velocity = frequency x wavelength

and to construct new wave fronts using Huygens' Principle.

CHAPTER III

SUGGESTED CLASSROOM PRESENTATION OF VARIOUS WAVE PHENOMENA

Diffraction and Interference

Diffraction and interference are interrelated and therefore, they should be studied at the same time. Interference is produced by the interaction of two separate waves and may be constructive, when the two waves reinforce each other, or destructive, when they tend to cancel each other. Diffraction is nothing more than the interference of waves from adjoining points on a wave front (3,314). The term diffraction is generally used to describe the pattern produced by a single slit while interference is usually used to describe the pattern produced by two or more slits.

Diffraction by a single slit can be demonstrated quickly and easily to the entire class using a single-filament lamp and pieces of photographic plate with very narrow slits on them. The pieces of photographic plate are prepared by exposing them to light, developing them, and then making the slits using a straight edge and a razor blade. Place the single-filament lamp on the demonstration desk; then pass out the pieces of photographic plate to the students and when the students observe the lamp through the slit, the diffraction pattern will be very evident (3,235). If pieces of fine-mesh wire are used in place of the photographic plates, the students will observe diffraction in two directions at the same time.

Another method of demonstrating diffraction is by the use of a ripple tank, which is essentially a shallow tray filled with water and which has a mechanical vibrator as a source of waves (5,149). To demonstrate diffraction, place some barrier, with an opening in the middle, across the tank and observe the pattern formed. With the ripple tank, it is very easy to change the size of the opening and observe the effect this produces on the diffraction pattern. In explaining the diffraction pattern to the students, it is important to emphasize how the relationship between the size of the opening and the wave length of the wave will affect the diffraction pattern. If the aperture is very large compared to the wave length, the diffraction is practically neglible (3,295).

Diffraction effects can be obtained without the use of a slit source. Diffraction around a small circular object can be demonstrated using a point source of light, a coin, and a screen. To obtain the point source of light, the beam of light from a projector is focused by a lens on a small hole in a screen and this hole then serves as a point source. Place the coin directly in front of the point source and observe its geometric shadow on the screen. In the center of the shadow will be a bright spot which is due to the constructive interference of all waves from the edge of the coin;

since they have all traveled the same distance, they will arrive at the center in phase (5,400). In doing this demonstration, it is necessary to be very precise in the placing of the coin. If it is placed slightly out of line, a dark spot will be found instead of a bright spot.

Diffraction can also be demonstrated with sound waves using a whistle, a spherical mirror, a screen, and a sensitive flame. Place the whistle at the focus of the spherical mirror so that the sound waves will be plane waves; then place the screen between the whistle and the flame and slowly move the screen sideways. The flame will respond to the sound while still in the geometric shadow (5,176).

In studying interference patterns, the first demonstration should be the observation of a single-filament lamp through a double slit on a photographic plate. If the top of the lamp is covered by colored cellophane and the bottom is covered by a different color of cellophane, the effect of different wavelengths can easily be shown to the students (3,235).

Demonstrations of interference can also be performed with the ripple tank and by using sound waves. The demonstration using the ripple tank is identical to the diffraction demonstration except that two openings are used. When using sound waves, a plane sound wave is sent toward a screen with two parallel slits and the region on the other side in investigated with a sensitive flame or some other detecting device (5,177).

Another method of demonstrating interference or diffraction is by the use of microwaves which are radio waves of a few centimeters wavelength. Microwave experiments have four main advantages; wavelengths can be measured with a meter-stick; the apparatus is simpler than optical equipment; the adjustments are less critical; and the effects are more evident (1,290). A microwave transmitter and receiver are available from several of the scientific supply houses.

To demonstrate interference, a coupling loop with two secondary sources (dipoles) is attached to the microwave transmitter. The secondary sources are clamped to a meter-stick on a wooden optical bench and the two dipoles are oriented the same so that the waves will leave in phase. Set the sources 50 centimeters apart at shoulder height and locate the points of minimum intensity to each source. The difference in the distances from any point of minimum intensity to the two sources should be an odd number of half-wavelengths. If one dipole is then rotated 180° , the sources will be out of phase and the interference pattern should shift correspondingly (1,291).

Another type of interference which should be studied is the interference due to thin air films and a demonstration of Newton's rings will illustrate the principles involved. A plano-convex lens is placed with its curved side touching a plane piece of glass and light is projected through the lens and this light is reflected from the plane piece of glass. The reflected light is then collected and focused on a screen producing a pattern which is a series of alternating light and dark rings (5,397). The center spot is dark due to the automatic phase shift of the reflected ray at the air-to-glass surface (3,268). This automatic phase shift can be demonstrated with the 'Slinky' by having one end fixed.

While studying interference, the instructor should bring out some of the practical uses of interference; such as the use of the Michelson interferometer to accurately determine the length of the standard meter or the use of a thin air film to determine if a surface is optically flat. If two optically flat surfaces are separated by a small wedge, the interference fringes produced will be straight; but if there is any distortion in the surfaces, there will be a corresponding distortion in the fringes.

In order to emphasize the basic similarities of the various wave types, the instructor should assign applicable readings and problems from the various sections of the text. All of these readings and problems should deal with the same phenomena but utilize data and information from different kinds of waves.

Reflection

Reflection of waves from plane and curved surfaces should be studied by both the wave front method and the ray method. The wave front method has the advantage that it gives a clearer picture of what is actually happening; while the ray method has the advantage of being simpler to use even when considering complex cases.

The wave front method may be illustrated by considering a simple case, such as reflection of the wave from a point source at a plane surface (Figure 2). From the point source (S), construct several arcs which represent the wave front at various positions; then construct an arc (C) which is tangent to the plane surface. Using Huygens' Principle, construct a secondary wave front (C') and at the point of tangency (E) swing the arc in the direction of the source. The reflected wave front must contain the two points (D&F) where the secondary wave crosses the plane surface and it must be tangent to the arc constructed at the point of tangency (E). Therefore, the curve (DE'F) represents the reflected wave front. The wave front method becomes complex when considering any case except a very simple one and it is not recommended that all cases of reflection be studied by this method; however, this method should be illustrated at least once.

The ray method of treating reflection has been the traditional method for many years because of its simplicity. This method is based on the law of reflection which states that the angle of incidence is equal to the angle of reflection; however, it should be emphasized to the students that the angles of incidence and reflection must be measured from the normal to the surface. For illustrating the ray method, consider a point source and a curved surface and from the point, draw any ray to the surface. Construct a normal at the point of contact and then construct the angle of reflection which will determine the direction of the reflected ray.

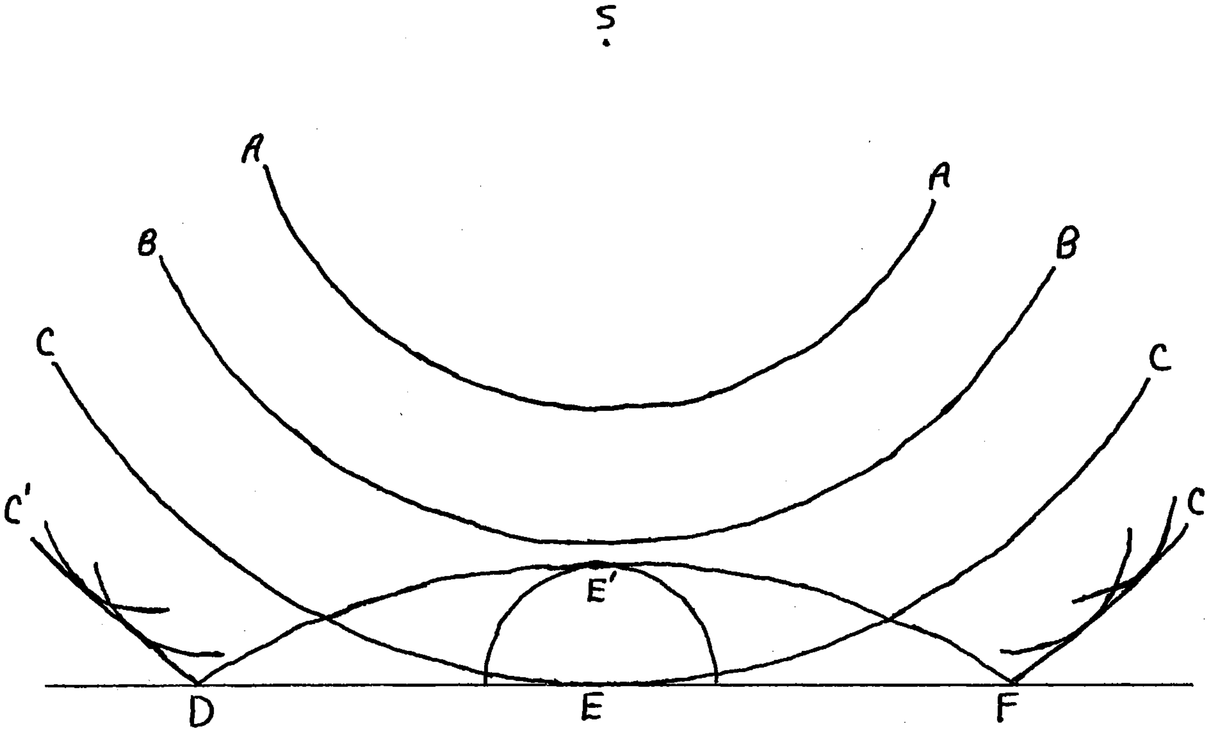

Figure 2. Reflection by the Wave Front Method

The student should be made aware of the relationship between rays and wave fronts. Any ray which leaves a source is perpendicular to the wave front from the same source; in other words, rays are radii of circular wave fronts. Therefore, it is possible when given two rays, which originated at the same source, to determine where the source is located or appears to be located, in the case of a virtual source.

Actual demonstrations of the reflection of a wave can be done using the wave machine if a rod at one end is fixed and by using the ripple tank and placing a properly shaped obstacle in the path of the waves. Reflection can also be demonstrated with light waves, sound waves, and microwaves.

An interesting and unusual demonstration based on reflection can be performed using a large concave mirror, a flower, and a box which is open on one side (Figure 3). The flower is hung upside down in the box and placed at the center of curvature of the mirror with the open side of the box facing the mirror; then the apparatus is enclosed so that a person viewing the demonstration will view it at the proper angle. A person looking in the mirror will see a real image of the flower located on the top of the box. This image will look so life-like that the observer will be unable to distinguish it from a real flower (6,315).

Refraction

Refraction of waves occurs when a wave leaves one medium and enters a second where the velocity of the wave is different. As with reflection, refraction should be studied by

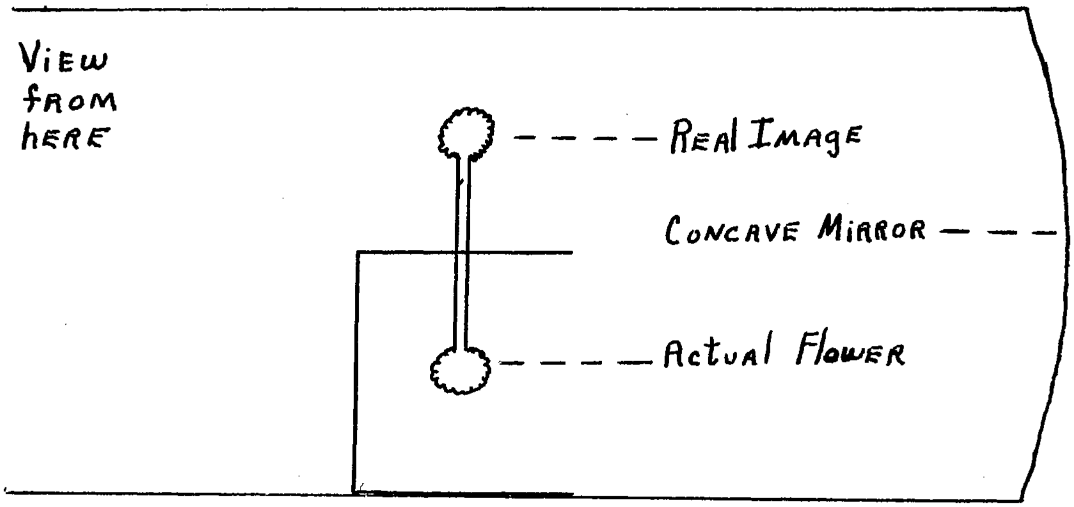

Figure 3. Demonstration of Reflection

both the wave front method and the ray method, using the wave frong method for cases of refraction of a plane wave at a plane surface and the ray method for spherical waves at plane or spherical surfaces.

To illustrate the wave front method, consider a plane wave (ABC) which strikes a plane surface at some angle of incidence (Figure 4). Using Huygens' construction, determine the position of a secondary wave (B'C') in the first medium and also swing an arc into the second medium from the point of contact (A) of the primary wave with the plane surface. The ratio of the radii of the arcs used must be the same as the ratio of the velocities of the wave in the two media. From the point of intersection (B') of the secondary wave and the plane surface, construct a tangent (A'B') to the arc in the second medium. This tangent (A'B') will represent the wave front in the second medium.

The ray method of construction is based upon the law of refraction, usually called Snell's law, which states that the ratio of the sine of the angle of incidence to the sine of the angle of refraction is equal to the ratio of the velocities in the two media (4,533).

Illustrating the ray method for a single ray striking a plane surface should be done first, since all other cases can then be done by merely repeating the same procedure for all of the rays involved. Consider a ray (AB) striking a plane surface at some angle (Figure 5) and construct the normal (NB) at the point of contact (B); then, using the point

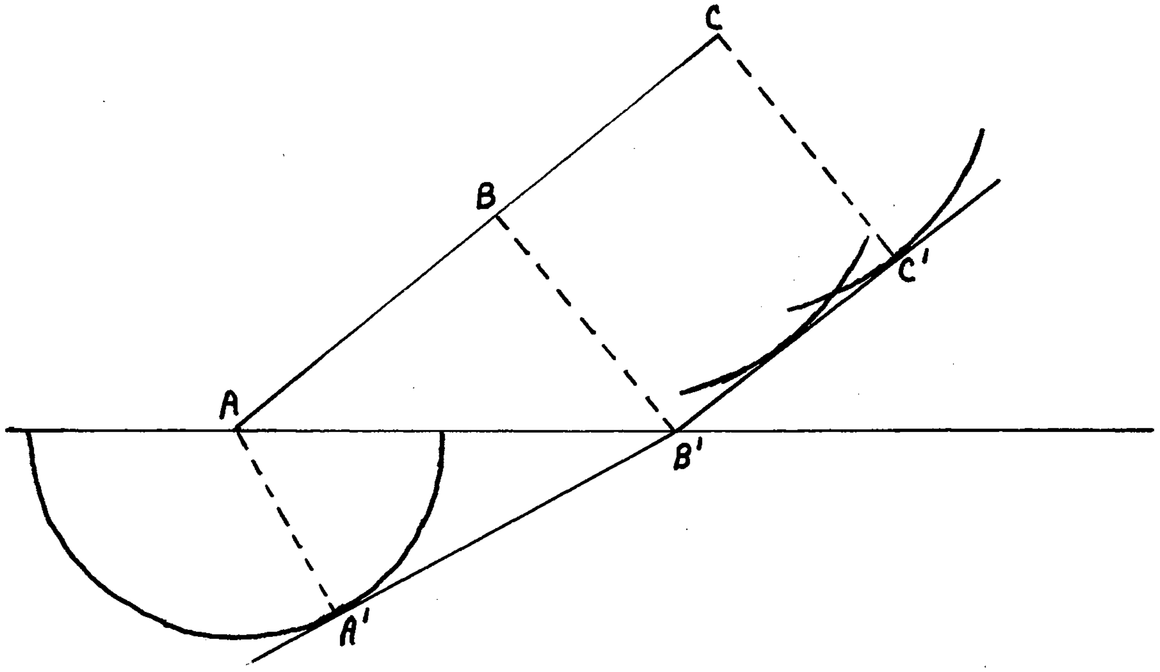

Figure 4. Refraction by the Wave Front Method

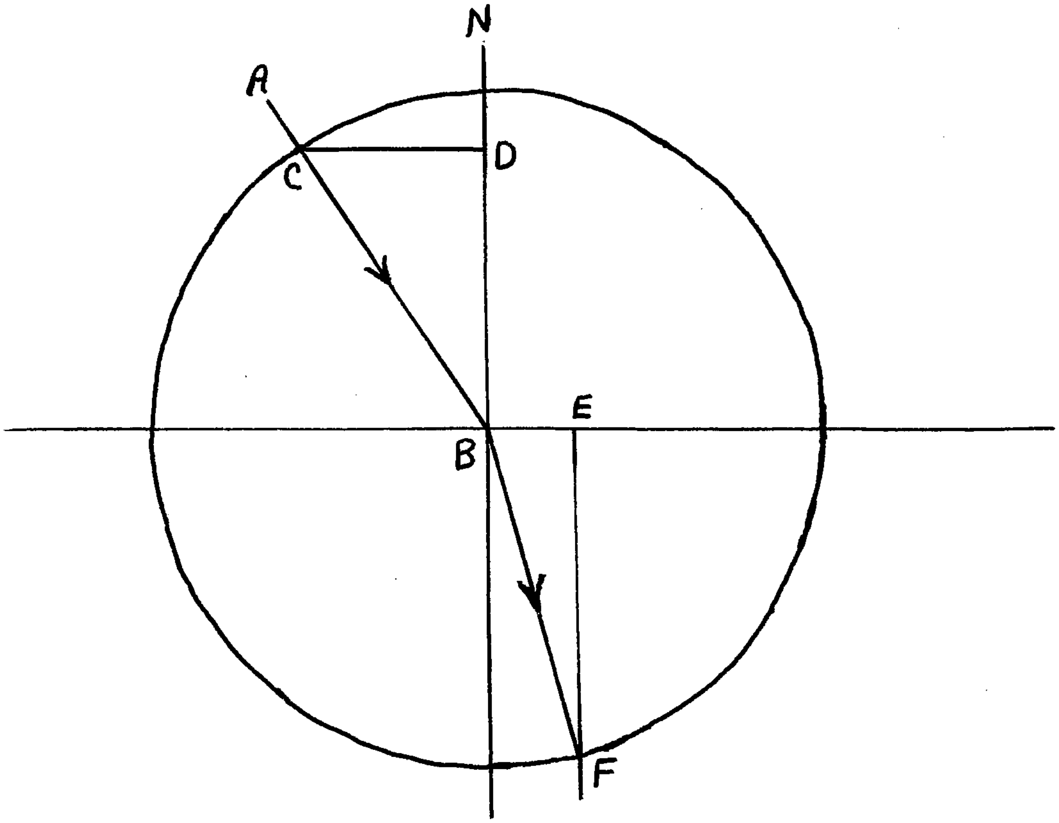

Figure 5. Refraction by the Ray Method

of contact (B) as the center, construct a circle of unit radius. From the point of intersection (C) of the incident ray and the circle, construct (CD) perpendicular to the normal (NB); (CD) represents the sine of the angle of incidence. Since the ratio of the velocities is known, the sine of the angle of refraction can be determined from Snell's law. This distance (BE) is laid off on the line representing the plane surface and a perpendicular (EF) is constructed which extends into the second medium until it crosses the circumference of the circle. A line (BF) from the center of the circle to this point of intersection will represent the path of the ray in the second medium.

The instructor should consider many different cases of refraction, in some cases changing the ratio of the velocities and in other cases changing the shape of the surface and the shape of the wave. One special case that should be considered is the case where the angle of incidence exceedes the critical angle and there is total reflection instead of refraction.

Many different cases of refraction of actual waves may be shown by use of the ripple tank. Obstacles of any shape, such as lenses or prisms, are made of clear glass and submerged just below the surface, so that a shallower layer of water lies in the path of the wave; then a low-frequency wave is set up in the tank and passed over the obstacle (5,154). Refraction can also be shown by light waves using lenses and prisms and by sound waves using a gas such as carbon dioxide as the refracting medium.

Some interesting demonstrations of refraction of microwaves can be performed using microwave apparatus described by Hull (2,563). A 60° prism, 10 inches on a side, is constructed from 1/4-inch plywood and filled with paraffin, which gives the prism an index of refraction of 1.47. Another 60° prism composed of parallel metal plates will have an index of refraction, less than one, given by the formula,

$$n = (1 - (d/2b)^2)^{1/2}$$

where d is the wavelength and b is the distance between the plates. When using the parallel plate prism, the electric vector of the microwaves must be parallel to the plates of the prism.

Polarization

Polarization is a phenomena which is characteristic of transverse waves and therefore, the student must have a good understanding of transverse waves before studying polarization. One important concept that the student must have is that in a single transverse wave, the vibration may be in many different directions and yet be perpendicular to the direction of motion of the wave. A simple way to describe this is to consider an end-on view of a wave as a circle and then any diameter of this circle would represent a possible plane of vibration. A transverse wave of this type is called an unpolarized wave because any plane of vibration is equally probable; but if the plane of vibration is limited to one particular angle, then the wave is described as plane polarized. In some cases, certain planes of vibration have a greater probability of occurring than other planes of vibration and the wave is described as partially polarized.

The most common example of a transverse waves is a light wave and therefore, the study of polarization will essentially be a study of the polarization of light; however, the instructor should emphasize that the results would be true for any transverse wave.

The simplest demonstration of polarization is by using a polarizing film, such as polaroid film, which has the property of absorbing some of the vibrations but permitting other vibrations to be transmitted; and the light which is transmitted is nearly plane polarized. If two sheets of polaroid film are held so that the direction of transmission of one is perpendicular to the direction of transmission of the other, then the light which is polarized by the first sheet will not be transmitted by the second sheet.

A single sheet of polaroid film can be used to analyze light to determine if it is unpolarized, plane polarized, or partially polarized. View the light through the polaroid film through an angle of at least 90° ; if there is no change in intensity, the light is unpolarized; if there is a complete lack of transmission of light at some point, the light is plane polarized; if there is merely a decrease or an increase in the intensity, the light is partially polarized.

Polarization of light by reflection can be demonstrated using a glass plate, a source of unpolarized light, and a sheet of polaroid film. If the unpolarized light is reflected from the glass plate and analyzed using the polaroid film, it will be found that the reflected ray is partially polarized; but if the angle of incidence is approximately 57°, the analysis of the reflected ray will reveal that it is plane polarized. The particular angle of incidence at which the reflected ray is plane polarized is called the polarizing angle (6,349). A study of the refraction at this angle of incidence will reveal that the angle between the reflected ray and the refracted ray is 90° ; this condition is necessary for the reflected ray to be plane polarized and the result is known as Brewster's law (6,349).

An interesting demonstration (Figure 6) can be performed which illustrates the polarization of light due to scattering from fine particles (3,506). The equipment needed is a source of light (S), a lens (L), a piece of polaroid film (F), a glass tank (T) about two feet long, a large plane mirror (M), hyposulfite of soda, and concentrated sulfuric acid. The tank is filled with clear water and the source is placed at one end and the lens is used to obtain a parallel beam of light through the tank. The mirror is placed above the tank at an angle of 45° so that the students may have a view of the top of the tank at the same time that they view the side of the tank. The piece of polaroid film is placed between the lens and the tank and then the hyposulfite of soda (20 grams per gallon of water) is dissolved in the water and about two milliliters of acid is added. The chemical reaction will produce fine sulfur particles which will cause the scattering

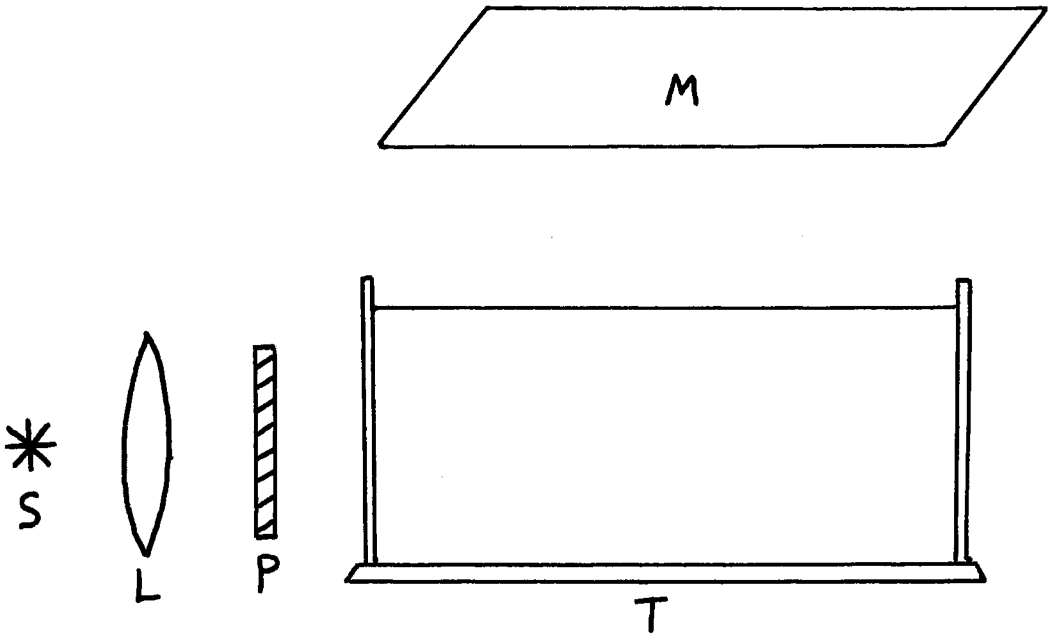

Figure 6. Polarization by Scattering

and polarization of the beam of light. If the polaroid film is rotated, the students will see the beam in the mirror and then in the tank. Polarization can also be demonstrated using radio waves (5,456) and using microwaves (1,301).

Doppler Effect

The Doppler effect is an apparent change in the frequency of a source due to the relative motion of the source and an observer. In the past, this effect has been studied in the high school physics course in relation to sound waves; unfortunately, the students were generally not made aware that it is equally true for any type of wave.

The following symbols will be used in the next two paragraphs; V = velocity of the wave motion; v = velocity with which the observer is approaching the source or the source is approaching the observer; n = true frequency of the wave; n' = apparent frequency of the wave; L = wavelength; L' = wavelength (apparent); t = period of the source.

First consider the case of the stationary source and an observer moving toward it. In one second, the observer will receive all of the waves in a distance $(V + v)$; as compared to receiving all the waves in a distance V if he was standing still. The ratio of the apparent frequency to the true frequency will be the same as the ratio of the number of waves received; therefore,

$$n'/n = (V + v)/V$$

When the observer is moving away from the source, v is negative (4,215).

In the case of a stationary observer and a source moving toward him, the shape of the waves will be changed. If the source is at rest, $L = Vt$; but if the source is moving, each wave will be shortened by a distance vt and $L' = Vt - vt$. Since the frequency is inversely proportional to the wavelength,

$$L/L' = n'/n = V/(V - v)$$

When the source is moving away from the observer, v is negative (4,216).

An actual demonstration of the Doppler effect can be done with the ripple tank by moving the source horizontally and observing that the waves in front become closer together, while those behind spread farther apart (5,154). An even simpler demonstration is to attach a whistle to a string and swing it rapidly in a circle. The rise and fall of the pitch as it approaches and recedes from the class will be evident (5,191).

While it is impossible to demonstrate the Doppler effect with light waves, the instructor should explain that the motion of the stars relative to the earth can be determined by their change in color, which corresponds to a change in frequency due to the Doppler effect. The Doppler effect is also used in certain types of radar.

In this chapter, some demonstrations have been given which will help to give the students an understanding of certain wave phenomena. There are many more demonstrations which can be used and the instructor should use as many other demonstrations as possible because the students will understand a concept better if a demonstration is presented along with the explanation of the concept. Throughout the unit, the instructor should use the text and other available books as sources of student assignments to increase the students' information about the various wave phenomena. These assignments should be carefully correlated with the particular wave phenomena which is being studied. At the end of this unit, the instructor should test the students' understanding of the material and, if there are any areas of weakness, these areas should be studied again, repeating some of the same demonstrations and adding new demonstrations when possible.

CHAPTER IV

SUMMARY

In this unit, the material presented has been considered as separate topics; however, the student should be made aware that in actual practice the situation is never as simple as in theory. For example, a wave may undergo reflection, refraction, and polarization, all at the same time.

There are certain difficulties which a high school physics teacher may encounter when attempting to use some of the ideas in this report. One major problem might be the lack of certain equipment needed for the demonstrations. Some of the equipment, such as a ripple tank, can easily be constructed at a low cost; however, items such as the microwave transmitter or receiver are expensive items and the cost is sometimes prohibitive. In such cases, the instructor should attempt to devise other demonstrations, using available equipment, that will illustrate the principle being studied.

Another problem that might arise would be the lack of certain previous courses by the students. In the report, the presentations of the wave front method and the ray method are based on basic principles and constructions of geometry; if the students have not had this course, the presentations will have little meaning to them. As in all teaching situations, the instructor should examine the background of the students

BIBLIOGRAPHY

1. *The Lloyd William Taylor Manual of Advanced Undergraduate Experiments in Physics.* Ed. Thomas B. Brown. Reading, Mass.; Addison-Wesley, 1959.

2. Hull, Gordon F., Jr. 'Microwave Experiments and Their Optical Analogs.' *American Journal of Physics*, XVII (1949), 559-566.

3. Jenkins, Francis A. and Harvey E. White. *Fundamentals of Optics.* 3rd ed., New York: McGraw-Hill, 1957.

4. Smith, Alpheus W. *Elements of Physics.* 5th ed., New York: McGraw-Hill, 1948.

5. Sutton, Richard M. *Demonstration Experiments in Physics.* New York: McGraw-Hill, 1938.

6. White, Harvey E. *Physics - An Exact Science.* New York: D. Van Nostrand, 1959.

VITA

Richard Francis Kelly

Candidate for the Degree of

Master of Science

Report: SUGGESTIONS AND DEMONSTRATIONS FOR A UNIT ON WAVE THEORY FOR A HIGH SCHOOL PHYSICS CLASS

Major Field: Natural Science

Biographical:

Personal Data: Born at Schuyler, Nebraska, April 29, 1933, the son of Frank and Helen Kelly.

Education: Attended grade school in Schuyler, Nebraska; graduate from Schuyler High School in 1951; received Bachelor of Science degree from the University of Nebraska, with a major in Education, in June, 1955.

Professional experience: Taught at Blair High School in Blair, Nebraska from September, 1957 to June, 1960; attended a National Science Foundation Academic Year at Oklahoma State University from September, 1960, to August, 1961.