CENCO Physics

Selective Experiments In Physics

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WAVE PHENOMENA: RIPPLE TANK EXPERIMENTS

OBJECT: To study reflection, refraction, interference, and diffraction by the use of waves produced in a ripple tank and observed with stroboscopic light.

METHOD: A vibrator, whose frequency can be varied, is used to produce waves on the surface of water in a ripple tank having a transparent base. A lamp below the ripple tank has its light intercepted by a rotating disc with slots in it to produce intermittent illumination. The speed of the disc can be varied so that the waves can be made to appear to be at rest. By using various forms of vibrators and boundaries in the ripple tank, reflection, refraction, interference, and diffraction can be observed. From measurements on the interference pattern, the wavelength of the waves can be found.

THEORY: By inserting a probe into the surface of water at a regular rate waves having a transverse component can be produced on the surface. These waves, in shallow water, travel with a speed which depends on the depth of the water and its surface tension. The latter can be made negligible by placing a drop of detergent on the surface of the water, in which case the speed depends only on the depth of the water.

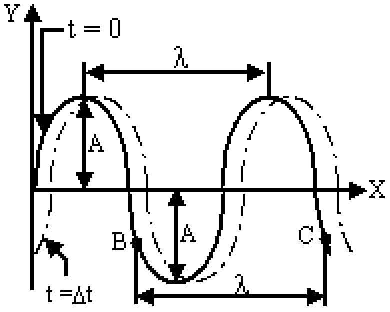

Fig. 1. Transverse wave of amplitude A and wavelength λ, traveling to the right. Dot-dash curve shows wave a short time Δt later than full curve.

Waves are characterized by speed, wavelength, frequency, and amplitude. For the waves on the surface of water in which there are crests and troughs, the *wavelength* λ is the distance between two successive crests or two successive troughs (Fig. 1). The *amplitude* of the transverse component of the wave is the height of a crest or the depth of a trough below the level of the undisturbed water, that is, the amplitude is the maximum vertical displacement of the water. At any position on the water through which waves are traveling, the vertical displacement changes from a crest to a trough and back to the crest. The *period* T of the wave is the time required for a crest to move to the location of the next crest, or more generally, is the time for a particle in a given displacement to return to that same displacement. During the time T a crest travels horizontally a distance of one wavelength λ. The speed v of the wave is the wavelength λ divided by the period T or $v = \lambda / T$. Suppose the period of a wave is 1/5 sec; then at any point there are 5 waves per second passing that point. The number of vibrations per unit time (here 5 per second) is called the *frequency f* of the waves. In general the period T and frequency f are related by the relation $T = 1/f$ or $f = 1/T$. Hence the equation for the speed of a traveling or progressive wave is either

$$v = \frac{\lambda}{T} \quad \text{or} \quad f\lambda \qquad (1)$$

This is a general relationship for all kinds of progressive or traveling waves.

When progressive waves move from a region in which their speed is v_1 to another region in which their speed is changed to v_2, the wavelengths in the two regions differ. Since the frequency f of the waves in the two regions must be the same, both being produced by the same source, it follows that

$$\frac{v_1}{v_2} = \frac{f\lambda_1}{f\lambda_2} = \frac{\lambda_1}{\lambda_2} \qquad (2)$$

If v_1 is larger than v_2, then λ_1 is larger than λ_2. Also if the wavefront enters the region of changed speed at an oblique angle, not only is the wavelength changed but the direction of the wavefront is changed. This change of direction of the wave due to change of speed is called *refraction*.

When traveling or progressive waves strike an obstacle they are thrown back or *reflected*. In the case of spherical waves produced by a point source which strike a plane obstacle, the reflected waves appear to come from a point as far behind the obstacle as the source is in front (Fig. 2). In the region between the source and the plane obstacle, the water is acted on by two waves, viz., the incident waves and the reflected waves, which are traveling in opposite directions. At any point in the region between source and obstacle the resultant displacement of the water is the vector sum of the displacements due to each wave. If at some point the incident wave is producing a crest while at the same instant the reflected wave is producing a trough, the resultant displacement is zero or there is a *node of motion*. On the other hand if a crest from one wave appears at the same point as a crest from the other wave, a crest of double amplitude occurs. *Standing or stationary* waves are set up. These can be observed on a vibrating rope or on the surface of water. In order for such standing waves to be established, the length of the rope, or the distance in the ripple tank between the source and the reflector, must be adjusted to a suitable multiple of a wavelength.

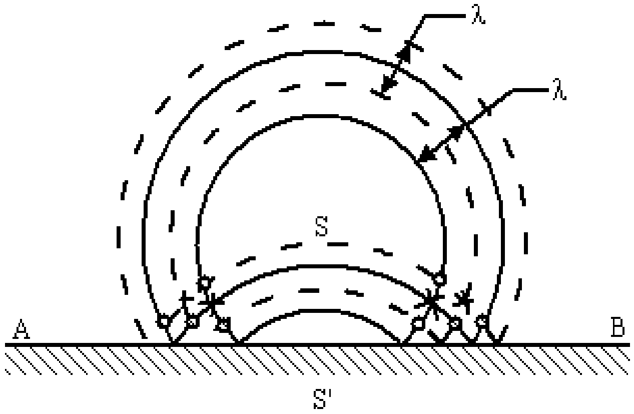

Fig. 2. Point source S sending out circular waves which are reflected by plane AB, giving rise to reflected waves which appear to come from point S', a virtual source. The full lines represent crests, while dashed lines represent troughs. Interface occurs where the incident and reflected waves overlap. Nodes of motion are shown by the circles ○, while positions of maximum amplitude, loops are shown by the crosses +.

An important property of all progressive waves is that they can show the phenomenon of *interference*. Interference in any medium can be produced by traveling waves from two sources having the same frequency and wavelength. Consider for example that the two sources S_1 and S_2 in Fig. 3 are driven by the same vibrator and each produces a crest or trough at the same time, that is, the two sources have the same frequency and are in phase. Consider the effect of these two sources at some point P. These waves travel different distances to the point P, and the difference in distances determines the relative phases of the waves from S_1 and S_2 arriving at P. This path difference is (S_1P - S_2P).

If the waves from S_1 and S_2 start out in phase and if the difference in their path length is some integral multiple n of λ, they will arrive in phase at P. Thus there is maximum displacement or constructive interference at P if

$$\left(S_1P - S_2P\right) = n\lambda \tag{3}$$

Similarly, there is destructive interference at P, or zero displacement, if the path difference is an odd number of half wavelengths; that is, if

$$\left(S_1P - S_2P\right) = \left(2n + 1\right)\lambda/2 \tag{4}$$

The locus of points showing interference is such that (S_1P - S_2P) is some constant distance. If the constant distance is an integral number of wavelengths, constructive interference takes place. The locus of points having (S_1P - S_2P) equal to a constant is a hyperbola with the points S_1 and S_2 as foci.

The wave pattern from the two sources driven by the same agitator is shown in Fig. 3b. In this figure the sources are set apart a distance of 3λ, and the solid-line segments of circles represent the crests while the dot-dash segments of circles represent the troughs at a particular instant. Maximum constructive interference between the two waves occurs at the intersection of two full or two dot-dash wave patterns. The intersection of a full and a dot-dash circle represents a crest from one source and a trough from the other arriving together. This would correspond to complete destructive interference. As the waves from the sources move out, the points of interference move out along the hyperbolic paths. The lines AB and CD show how the points of maximum constructive interference and complete destructive interference move out as time progresses.

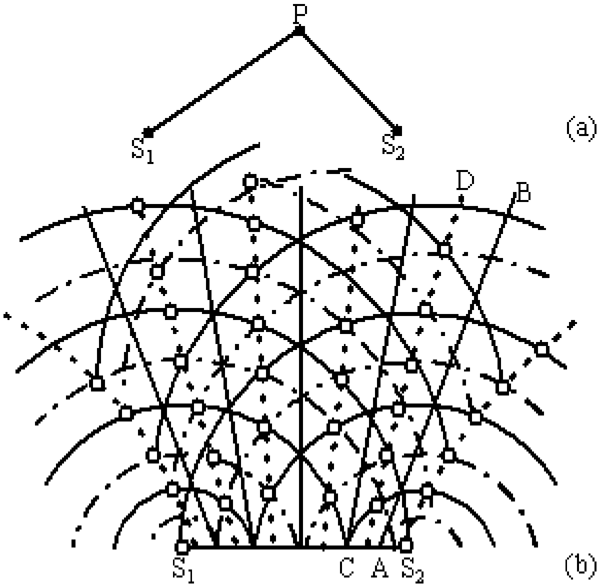

Fig. 3. Interference pattern produced by two sources S_1 and S_2. Maxima or location of constructive interference along the solid lines, AB etc., and minima, or location of destructive interference occur along the dash lines, CD etc.

In order to make the crests and troughs in a traveling wave appear to stand still, intermittent illumination is used. Suppose that a short pulse of light falls on a moving crest at a given point and that the illumination is cut off until the next crest arrives at the point. Then, the continuous action of light being pulsed to illuminate successive crests as they arrive at a particular point creates the illusion of a single stationary crest appearing at the point. This intermittent light can illuminate an area where a number of wavefronts are present and make the wavefronts appear to be stationary. A device for producing regular intermittent illumination is called a *stroboscope*. A common type is that in which alight is placed below one of the slots in a uniformly rotating disc. If the slots are located at equal intervals around the rotating disc, then regularly spaced pulses of light pass through the slots.

The standing waves in the ripple tank which are produced by interference do not need stroboscopic illumination to be seen as stationary, though this may enhance the sharpness of the waves.

If the light from a lamp below the ripple tank passes through the water and onto the ceiling, or by reflection onto the walls, the crests and troughs appear as light and dark portions respectively. The crests of the waves produce a partial focusing effect and give a light region, whereas the troughs spread out the light and give a darker region.

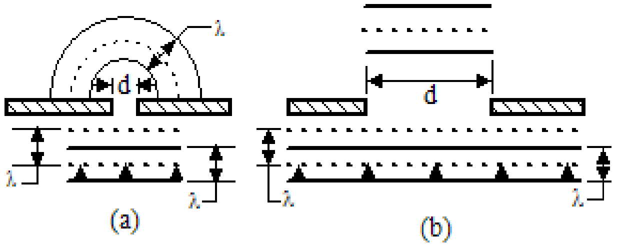

Fig. 4. Diffraction of plane waves through two slits. (a) λ/d large, bending of waves large; (b) λ/d small, bending of waves small.

When the wavefront of a wave is limited either by an obstacle, or a slit in a large obstacle, the wavefront spreads around the obstacle or slit. This phenomenon is known as *diffraction*. The amount of spreading depends on the ratio of λ to the width d of the obstacle or slit. If, λ/d is large, the spreading is large; conversely if, λ/d is small there is little spreading, as shown in Fig. 4.

Fig. 5. Ripple Tank set up for operation.

APPARATUS: The apparatus consists of the ripple tank, Fig. 5, which has a variable speed agitator, a variable speed stroboscope and an adjustable mirror. Also provided is a 20cm diameter watch glass which is the ripple tank, a glass disc, 4 reflectors, 3 microscope slides, 3 extra support springs, and 3 generators which can be attached to the agitator arm. A 6volt 6.5ampere source of *dc* power, such as a storage battery, and a few drops of detergent are required.

PROCEDURE: Set the ripple tank on a level table in a room which can be darkened. Connect the terminals of the *dc* source to the binding posts on the ripple tank assembly, being careful to observe the correct polarity. After cleaning the watch glass of any grease, mount it on the spring supports and pour in clean water until it reaches about one inch from the edge of the watch glass. Put a drop of detergent on the surface of the water so as to reduce the surface tension of the water. Install the single-wire wave generator in the agitator arm and firmly tighten the clamping screw. Place the tip of the wire so that it is in contact with the water. Turn on the switch on the ripple tank assembly and adjust the speeds of the agitator and the stroboscope so that the wave pattern appears stationary. Darken the room. The wave pattern can be seen on the ceiling or on a nearby wall, depending upon the mirror adjustment. To record the pattern place a sheet of paper mounted on a drawing board near the wall.

Note: During the following experiment the speeds of the stroboscope and agitator must be kept constant as nearly as possible. Only very minor changes in the speed control settings should be necessary to keep the wave pattern stationary.

Experimental: ***Part A***. Place the largest reflector in the ripple tank a short distance from the source of the circular waves, and adjust the position of the reflector until an interference pattern is observed. Record the wavelength of the waves and the centers of the incident and reflected waves. These centers should be at equal distances from the mirror. For this to be the case the angle of incidence must be equal to the angle of reflection, see problem 8.

Part B. Remove the reflector and place the circular glass disk in the water near the center of the tank. Observe the change in wavelength occurring when waves in water proceed from deep to shallow water. Draw a diagram of the wavefronts observed.

Replace the single wire generator with the comb-like generator for producing plane waves. Observe the wave pattern with the circular glass disc in the water. Replace the circular glass disc with the microscope slides placed on top of one another, and observe the refraction when the incident wave fronts strike the shallow water at an acute angle. Trace the wave pattern on the drawing board and record the wavelengths in the two media. Calculate the refractive index of the waves which is given by the ratio of the speeds or the ratio of the wavelengths, Eq. (2). Also find the refractive index from the ratio of the sines of the angles of incidence and refraction. Compare the two results.

Part C. Replace the comb-like generator with the two pronged generator, making sure the two prongs are both in contact with the water. An interference pattern is produced by the two similar sources (prongs), as shown in Fig 3b. Trace this pattern on the paper on the drawing board or mark on the paper the positions of the two sources and the positions where constructive and destructive interference occurs. Also make marks so as to obtain the wavelength λ of the waves. Using the interference pattern find the wavelength λ from Eqs. (3) and (4). Another method of producing interference between two sources in phase is that of using the waves emerging from two relatively narrow slits on which a plane wave is incident. Set up the agitator for plane waves. Form a slit system with the three reflectors set parallel to the wavefronts. The narrow reflector should be in the middle with the other two at its sides and with enough space between them to form the desired slits. The size of the slits should be such that the waves which emerge from them are large enough to produce interference. Observe the interference pattern and make measurements for the wavelength as in the experiment above.

Part D. Observe and draw the spreading out of the wavefronts when a plane wave passes through slits of different widths and also around obstacles of various sizes.

Part E. Compare the values obtained for the wavelength in the above experiments. Comment on the differences in these values.

QUESTIONS: 1. A progressive wave has a frequency of 4 vib/sec and a speed of 20cm/sec. Find the wavelength and period of the wave.

2. A point source is producing circular waves in a ripple tank. A stroboscope is adjusted so that the waves appear to be stationary. If the stroboscope is speeded up slightly the waves move. State which direction the waves move, toward or away from the point source and explain the answer.

3. An observer can hear two people talking who are around a corner, but cannot see them. Explain this in physical terms and state what this implies about the wavelengths of light and sound.

4. An interference pattern is produced by two point generators a distance *d* apart. What happens to the nodal lines if a third point source, similar to the other two, is placed midway between the two sources, at a distance of *d/2* from each of the other two sources?

5. Give the reason why it is not possible to observe interference between two independent sources of light.

6., A transverse wave is traveling to the right as shown in Fig. 1. Draw this diagram and on it show the appearance of the wave after a quarter period; after a half period.

7. The equation of a wave, wavelength λ, speed *v*, traveling along the positive *X-axis* is $y = A\sin 2\pi/\lambda(x - vt)$. Plot this equation for *t* = *O* and *t*= *T/4* where *T* is the period of the wave. Verify the fact that this wave is traveling along the positive *X*-axis or to the right. Repeat the above for $y = A\sin 2\pi/\lambda(x + vt)$ and show that this wave is traveling along the negative *X*-axis or to the left.

8. Prove the statement given at the end of the paragraph in Part A.

9. Prove that the refractive index which is equal to the ratio of the sines of the angles of incidence and refraction is also equal to the ratio of the wavelengths in the two media. See the end of the paragraph in Part B.