2. Wave Phenomena in Water and Air

PURPOSE AND BACKGROUND

Wave motion is responsible for the propagation of sound. In this laboratory we study various wave characteristics and how they are related to the production and propagation of sound. We will take a look at *reflection*, *refraction*, *interference*, and *diffraction*. A "ripple tank" with water waves is used to simulate the properties of sound waves. A light source at the ripple tank illuminates the waves so that they are visible. For actual sound waves we use a two-speaker system to demonstrate interference.

THEORY AND EXPERIMENT

A wave is a periodic disturbance or fluctuation in a medium about its equilibrium position. We use water waves as a good example. Waves transport energy and can do work. A simple *sine wave* can be used to demonstrate important properties of waves. Figure 1 shows the *displacement* of the vibrating medium (e.g., air, water, or a string) as a function of time. The horizontal axis is time, and the vertical axis is displacement. The equilibrium position is at $y = 0$. The period T is the time for one complete cycle, in other words the time for a system to return to its initial position.

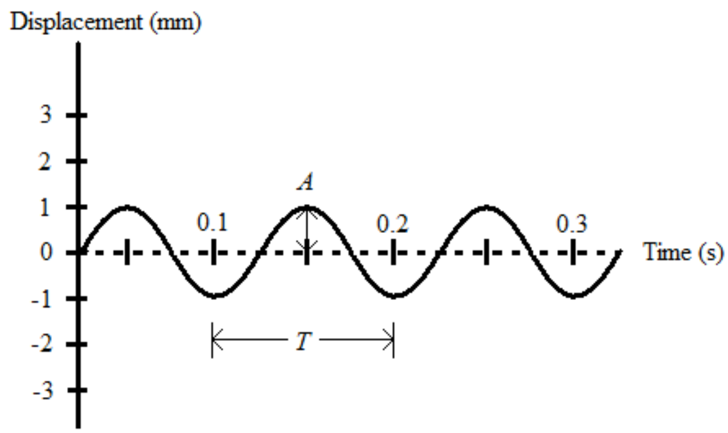

Figure 1: Displacement of the medium (e.g., water) of a wave from equilibrium as a function of time, for a fixed point of observation.

The frequency of oscillation is defined as the inverse of the period, $f = 1/T$.

The physical unit of frequency is *Hertz*, abbreviated Hz. The oscillation in Figure 1 has a period of $T = 0.10$ s and a frequency of $f = 10$ Hz. For water, the molecules move up and down (transversely), while the wave itself travels in a direction perpendicular to the up and down motion. This kind of wave is called a *transverse traveling wave*. The *wavelength* λ is the distance the wave travels during one "up and down" cycle. It is the distance from any one crest to the next nearest crest, or from wave trough to next trough, or between any two corresponding points having the same *phase*—see Figure 2. If we call v the wave speed, then we have

$$v = \frac{\lambda}{T} = f\lambda\,. \tag{1}$$

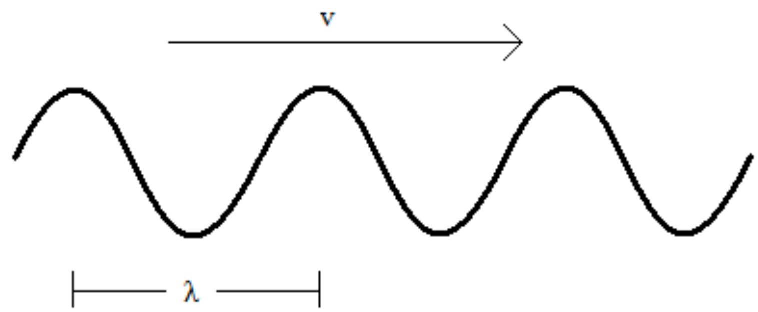

Figure 2: A transverse wave traveling with velocity v and wavelength λ. We see a snapshot at a fixed time with vertical direction showing the displacement of the medium and horizontal direction the position of the wave.

I Wave Velocity

We can use a PASCO ripple tank to produce plane waves in the "strobe light" setting. The direction of the traveling waves is perpendicular to the crests and troughs of the waves.

1. Set the PASCO ripple machine to a frequency setting of $f = 20$ Hz and use the strobe function to snap shot the wave pattern.
2. Trace 6 consecutive wave crests.
3. Measure the length of the consecutive crests and determine the wavelength λ by dviding the length by 5.
4. Use this wavelength λ to calculate the velocity v of the wave.
5. Repeat these steps for $f = 15$ Hz and $f = 25$ Hz and fill in the table.

Wave Velocities

Frequency	5 wavelengths	wavelength λ	velocity v
f=15Hz			
f=20Hz			
f=25Hz			

For waves in shallow water, we can also calculate their velocity using the equation $v = (gd)^{\frac{1}{2}}$, where $g = 9.8m/s^2$ and d is the depth of the water. Calculate the velocities for the three frequencies above. Compare the values for velocity between the two methods of calculation. Consider and discuss sources of error for each of the two methods.

II Reflection

When sound waves hit a barrier such as a wall, some of the sound is reflected (with the rest absorbed by the wall). Waves obey the *law of reflection*. A line drawn perpendicular to a point on the wall is called the "surface normal"—see Figure 3. The angle that the incoming wave makes with the normal is called the *angle of incidence*. The law of reflection states that for a wave approaching a barrier, the wave will be reflected from the surface at an angle equal to the angle of incidence. For the law of reflection to hold, the surface roughness must be small compared to the size of the

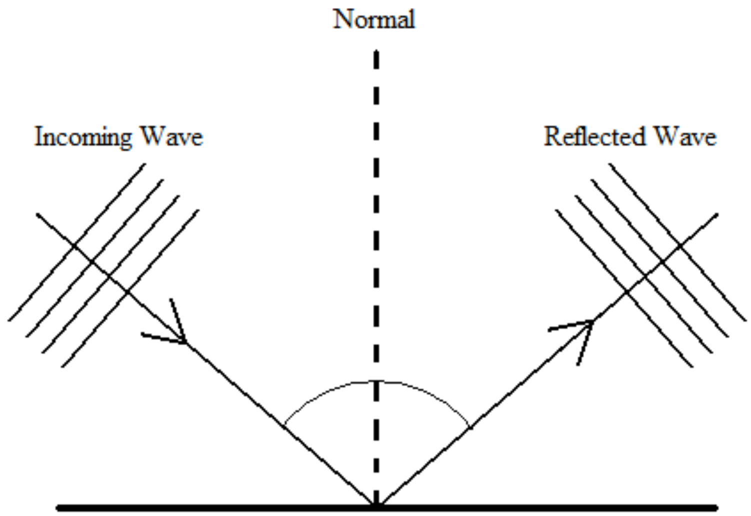

Figure 3: Incoming wave reflected off a smooth surface.

wavelength. In other words, we need a smooth, or optically speaking, a "mirror- like" surface. This is the case in our experiments with the ripple tank.

Reproduce a similar plane wave reflection using the PASCO ripple machine. Using the strobe function, trace the wavefronts before and after reflection.

Questions

1. Use your tracing of the wavefronts and the law of reflection to calculate the incoming and reflected wave angles.

III Interference of Waves

When two or more wave trains move through the same region of space, the waves interfere with each other at any given spot. *Constructive interference* occurs when two waves with the same phase, such as two wave crests, align at the same location. The two amplitudes add together to create a "hotspot" of twice the amplitude and thus a maximum in intensity—see Figure 4.

On the other hand, if the wave crest of one wave meets with a wave trough of another wave, the two waves are completely out-of-phase and suffer *destructive interference*. The resultant amplitude is nearly zero, and so is the wave intensity—again see Figure 4.

Questions

2. Complete the second diagram in Figure 4 showing the interference of two sine waves that are 90 degrees out of phase with one another (i.e., so that the crest of one wave occurs at the zero of the other wave, etc.)

A Interference of Water Waves

We can study the interference maxima and minima with water waves in the "ripple tank" using the wave generator with two small point-like dippers, each producing circular waves. If we space

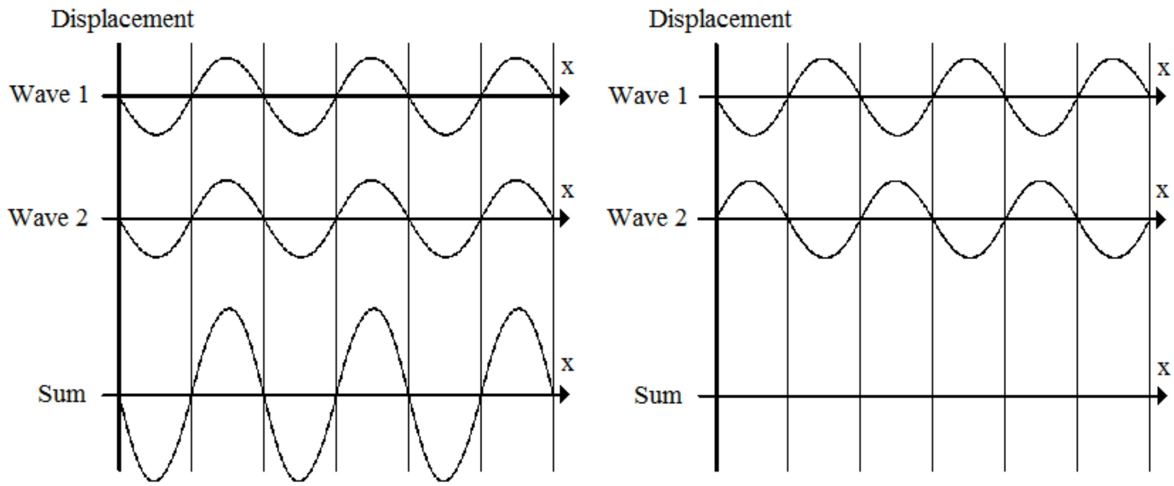

Figure 4: Interference and superposition of two waves. The diagram on the left shows *constructive* interference and on the right *destructive* interference.

the plungers a few wavelengths apart, and choose a frequency between 15 and 20 Hz, we observe the interference pattern similar to that shown in Figure 5. The radial lines correspond to regions of destructive interference where the two circular waves cancel each other out (e.g., at the top black dot in Figure 5). Between those radial lines are regions of constructive interference (e.g., at the bottom black dot in Figure 5).

Questions

3. Suppose we change the frequency of the dippers. Describe how the interference pattern changes. (For example, does increasing the frequency of the dippers increase or decrease the number of radial lines in the interference pattern.)

B Interference of Sound Waves

Sound waves from two speakers behave exactly like the interfering water waves in the ripple tank shown in Figure 5. For interference from the speakers to be clearly audible, the wavelength should be somewhat smaller than the distance between the speakers. By walking in front of the speakers, you can hear the interference maxima (constructive interference) and minima (destructive interference) as you walk.

Questions

4. At the midpoint in front of the speakers (i.e., at the same distance from each speaker) would you hear constructive or destructive interference? Why?

5. Would the number of audible maxima and minima increase or decrease if the frequency is increased?

6. Do you think the interference of sound waves is desirable or undesirable in rooms and concert halls? Why? How would you address such problems?

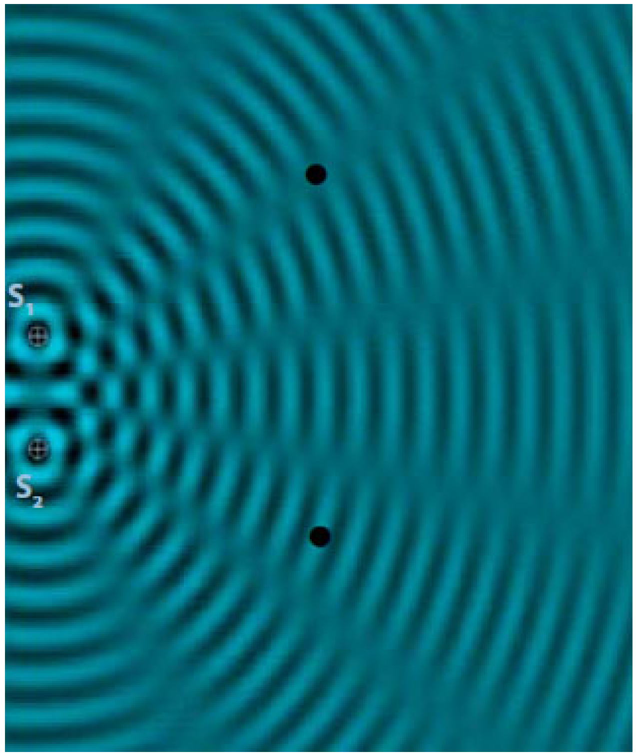

Figure 5: Interference of circular water waves. [Image from `chegg.com`.]

IV Diffraction of Waves

Diffraction is a wave phenomenon with direct applications to sound propagation when there is a barrier, opening, or corner. The effect is pronounced when the wavelength is comparable to the size of the obstacle. In such cases diffraction enables one to hear sound "around corners"—see Figure 6. We all have heard sound from a door opening when we were outside a room but not in the line-of-sight of the sound source inside.

The amount of diffraction depends on the relative size of the wavelength of the waves and the size of the opening or barrier obstructing the passage of the waves. For example, suppose a wave approaches a barrier with a width large compared to the wavelength. Then there is a "shadow" region without waves behind the barrier, as expected. If, however, the wavelength is comparable to the barrier width, the "shadow" region behind the barrier becomes small and waves travel into that region.

P.S. Water waves are an example of *transverse waves*, whereas sound waves are *longitudinal waves*. In the first case the medium (water) oscillates *transversely* to the direction of wave propagation; in the second case (air) the oscillations are *longitudinal* along and against the propagation direction. These differences do not affect the basic study of wave behavior in this laboratory.

Questions

7. For the case of plane waves incident on an opening, sketch the diffracted waves for the case where the wavelength of the waves is small compared to the size of the opening.

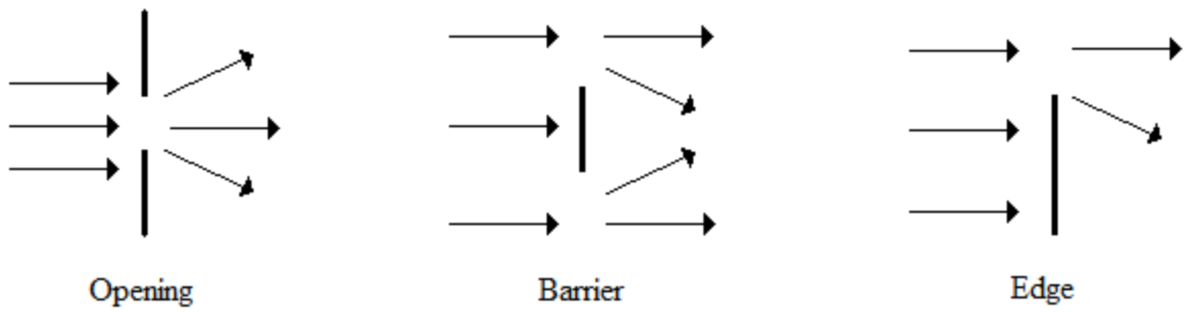

Figure 6: Diffraction of sound waves after passing through an opening, around a barrier, and around an edge.

8. Same as the previous question but for the case where the wavelength of the waves is comparable to the size of the opening.