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Chapter 7

WAVES

The concept of waves was as dominant in physics in the 1800's and 1900's as the concept of particles was in the two preceding centuries. A familiar example of a wave is provided by a long row of upright dominos. If the first domino is tipped over, it pushes the domino in front of it, which in turn pushes the next one, and so on, until all the dominos have been knocked down. We have a disturbance that can propagate quite far, even though each domino moves very little.

We can generate a different kind of waves by holding one end of a long horizontal rope, whose other end is fastened to a support. By flipping our hand up and down, we can cause a series of ripples to snake their way toward the other end of the rope. The way we flip our hand determines the shape of the ripples or waves we generate. A wave shape of particular interest is the so-called *sinusoidal* wave depicted in **Figure 7.1**.

Note that, from instant to instant, it is different points on the rope that are at maximum up, or down, displacement. What we see is not a stationary pattern, but one that snakes its way along the rope at some speed. These waves are said to be "transverse", because each segment of the rope is displaced in a direction perpendicular to the direction of propagation.

Depending on how we move our hand, we may or may not generate ripples that lie all on a single plane, vertical or otherwise. If we do, we say that we are generating "polarized" transverse waves.

Ripples on a water surface

More complex patterns occur when waves propagate on a plane, or in all directions in space. If a small pebble, for instance, is dropped on a very calm pond, it creates a disturbance that propagates radially in all directions on the water surface, generating a circular pattern of spreading ripples.

If, instead of a small pebble, we drop a long, thin stick, we get a different pattern called a "line wave". The disturbance now propagates in the direction perpendicular to the stick. Instead of spreading concentric circles, we see spreading parallel lines resembling ocean breakers rolling onto a beach.

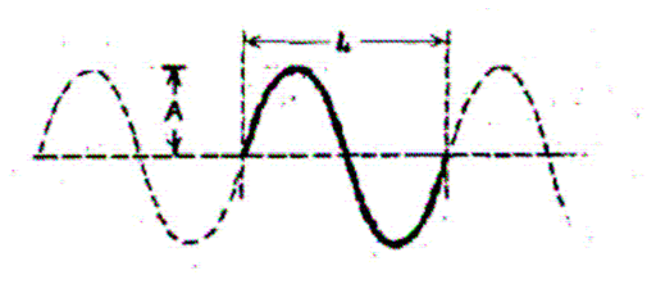

Figure 7.1 - A sinusoidal wave

The curve above displays what happens, at one particular instant, at all points along the line of wave propagation, the rope in our example. (The same curve can be seen also as representing what happens, at one particular point, at subsequent instants of time.)

We see a series of waves, each consisting of a crest above, and a trough below, the base line. The maximum displacement A, above or below the line, is called the amplitude of the wave.

The distance L between any two corresponding points of two consecutive waves is called the wavelength. It defines a cycle that is repeated again and again. Points that are one wavelength apart have identical displacements. Points that are half a wavelength apart have equal but opposite displacements.

The number of waves generated per second is called the frequency. (This is the number of up-and-down ripples we generate in one second by flipping our hand.) Depending on its magnitude, frequency is expressed in Hertz, cycles per second, kiloHertz (thousands of Hertz), megaHertz (millions of Hertz), etc.

The speed of propagation is the distance traveled by the waves in one second. It is equal to the length of a single wave (the wavelength) times the number of waves generated per second (the frequency)
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Interference and Diffraction

Two phenomena that are most characteristic of the behavior of waves are "interference" and "diffraction".

Since waves have ups and downs, two waves acting on the same point(s) can cancel or reinforce one another, a phenomenon known as "interference". Consider two identical sinusoidal waves (remember Figure 7.1). If they exactly overlap one another, or are displaced from one another by a whole number of wavelengths, their interference will create a combined wave whose crests are twice as high, and whose troughs are twice as low. On the other hand, if two identical sinusoidal waves are displaced by half a wavelength, or an odd number of half wavelengths, they will completely cancel one another.

Diffraction, on the other hand, is the spreading of waves around obstacles, as illustrated in **Figure 7.2**. An interesting combination of diffraction and interference patterns that will be of importance later is shown in **Figure 7.3**.

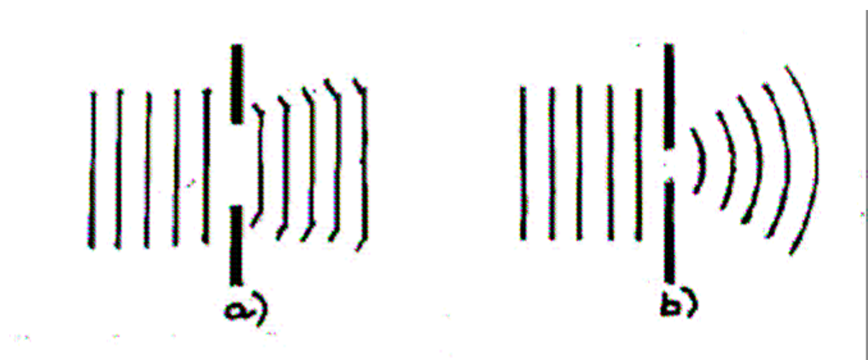

Figure 7.2 - Diffraction of line waves

a) On a water surface, a train of parallel line waves approaches from the left a barrier with an opening. If the size of the opening is sufficiently larger than the wavelength of the approaching waves, the waves generated on the other side of the barrier are also line waves of the same wavelength but with a slight rounding at the edges.

b) As the size of the opening becomes smaller and smaller, relative to the wavelength of the oncoming waves, the rounding becomes more and more pronounced, until the waves generated on the other side of the barrier become semicircular waves with the same frequency and wavelength as the oncoming line waves.

Standing Waves

In addition to *traveling* waves such as those considered so far, there are also *standing* waves, which oscillate in place without traveling. Consider, for instance, a taut guitar string whose end points are fixed. If the string is plucked at its midpoint, it will start vibrating. The result is a single standing half-wave. The amplitude of the up-and-down oscillations is largest at the center; it decreases on either side as we go toward the two fixed end points.

A peak gradually turns into a valley, which then gradually turns into a peak, and so on, as the string vibrates. By plucking the string at other appropriate points, we can generate standing waves displaying two, three or more half-waves.

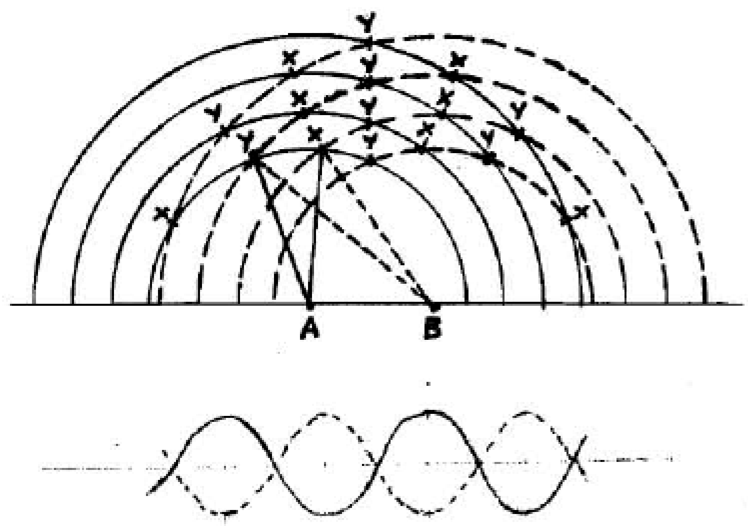

Figure 7.3. Diffraction and interference of identical waves

On a water surface, two suitably small openings A and B create on the other side of a barrier two identical sets of diffraction waves, which interfere with one another.

There are points of zero displacement, such as those marked X, where the waves from A and B always cancel one another. (In the lower part of the figure, we see two waves that have equal but opposite displacements and thus cancel one another.) There are points of maximum displacement, such as those marked Y, where the two waves always reinforce one another to double their values (whether up or down).