Frequency, Period, and Wavelength

Frequency, period, and wavelength are three interrelated phenomena.

- *Frequency*

  How *frequently* an event occurs.

- *Period*

  The *period* of time required to complete an event.

- *Wavelength*

  The distance (*length*) that that a wave of a given frequency travels during one complete cycle of the event.

Imagine a tube filled with ten miniature ping pong balls. Each ball is one inch in diameter. (A standard ping pong ball is about 1.5 inches in diameter, but using a ball that is exactly one inch in diameter simplifies the mathematical calculations.)

Figure 1. Ten Balls in a Ten-inch Tube

When the ball at one end of the tube is tapped, it taps the adjacent ball, initiating a chain of events that causes a wave to travel to the end of the tube. To simplify the mathematics, we will assume that the movement of each ball takes one-tenth of a second (0.1 seconds). Therefore, a wave will take one second to travel to the end of a tube filled with ten balls. When the wave reaches the end of the tube, the end ball will rebound, causing the wave to travel back to the other end of the tube.

Once *cycle* of the wave can be defined as the time that it takes the wave make the round trip to the end of the tube and back again. In this case, the period of time required to complete one cycle is two seconds. This time could also be expressed as $1/30^{th}$ minute.

If the *period* of time required to complete one cycle is $1/30^{th}$ minute, we can deduce that it would be possible to complete 30 complete cycles in one minute. The *frequency* of the wave could therefore be expressed as 30 cycles per minute. Thus, the period of the wave is inversely related to the frequency.

This relationship is common sense. It is logical that more trips can be completed when a shorter distance is traveled. For example, a tube five inches long would be filled with five balls. It would therefore take 1 second to make a complete round trip in a tube that is half the length of the first tube. The period of the wave could be expressed as $1/60^{th}$ minute. If it takes $1/60^{th}$ minute to complete one cycle (i.e., round trip), it would therefore be possible to complete 60 cycles in one minute.

Figure 2. Five Balls in a Five-inch Tube

These relationships between distance traveled and period hold for other contexts as well. For example, if a person completed the 100-meter dash in 15 seconds, then they would be likely to complete the 50-meter dash in about half that amount of time.

Everyday experience tells us that it takes a longer amount of time to travel a longer distance. If it takes five minutes to walk to school, a complete round trip would take ten minutes. If it is possible to make a round trip in 10 minutes (i.e., $1/6^{th}$ hour), then it is possible to make six round trips in an hour. Thus the relationship for frequency, period, and distance holds for everyday events as well as for movement of a wave.

The same relationships for a wave take longer to understand because they are not observed on a daily basis in this context. Although a wave – movement of energy through a medium – is more abstract, the same relationships among frequency, period, and distance traveled hold true regardless of whether the event is movement of a wave through a medium or a walk to school.

A wave transmitted through the medium of air affects many particles. While it is not possible to directly visualize air molecules, Styrofoam bits suspended in a Plexiglas tube allow visualization of the wave. The Styrofoam bits are denser at some points along the tube and less dense at other points. The density of the Styrofoam at different points is the result of rarefaction and compression caused by the wave traveling through the air. This method for visualizing waves traveling through air was first devised by the German physicist August Kundt in the nineteenth century.

Figure 3. A sound wave traveling through Styrofoam suspended in a tube.

At the beginning of the twentieth century another German physicist, Heinrich Rubens, devised another way to visualize the rarefaction and compression created by a wave travelling through air in a tube. He drilled a series of holes in the top of a copper tube. The flames from natural gas flowing through the tube were higher at nodes of higher density.

Figure 4. A Reubens tube can be used to visualize areas of high and low pressure.

The movement of a wave through a cloud of particles can also be simulated with a computer. The principle is the same as for the tube filled with ping pong balls. The longer the tube, the longer the wave takes to travel the length of the tube.

Figure 5. A wave traveling through particles in a tube.

Thus, the longer the tube, the longer the period of time that it takes the wave to travel the length of the tube.

This phenomenon can also be demonstrated with a physical tube. An acoustic wave in a tube has characteristics that are similar to mechanical waves. Sound travels at a rate of about a thousand feet per second. (The precise speed of sound is 1,125 feet per second at sea level when the temperature is 68 degrees.) Therefore the wavelength of a 100 Hz sound would be 11.25 feet (i.e. 1,125 feet per second divided by 100 Hz). Consequently, the resonant frequency of an open-ended 11 foot tube would be approximately 50 Hz (dictated by the time required for the sound wave to travel to the end of the tube and back again).

Figure 6. Measuring the amplitude of a sound wave traveling through a tube.

When the frequency of a pure tone tune is matched to the length of a tube, the intensity of the tone measured by a sound level meter is greatest at this point. This is another way of saying that the intensity of the tone is greatest when the wavelength of the tone matches the length of the tube that the wave is traveling through.