PHY1033C **Fall 2017**

Lecture W9

Waves

1. What is a wave?

Have you been in a crowd making a stadium wave during a football game? Reflect the moment when the wave was coming to you. What did you do? You watch the wave moving and carefully timed to raise yourself from the seat and down back to your seat. You had to coordinate your motion and timing with the people near you in particular on the side the wave was coming. The scenes is spectacular. On the other side of the stadium, you can clearly see the wave circling around the stadium. But there is one interesting and puzzling aspect in this. How could you make something moving when no one actually moved along that direction? You were just moving up and down in a coordinated fashion. Then is the stadium wave just visual illusion?

There are many phenomena similar to the stadium wave. A raindrop on a calm lake makes a ripple moving outward in a circular shape. This ripple moves through a leaf on the water surface, which suggests that actually water does not move out but must be moving only up and down. Imagine there is a long rope on the ground. Pick up one end and give a jerk up and down. You have probably done this before. The bump you created moves along the rope. The rope itself does not move long the direction. If you swing the rope up and down continuously, a periodic train of waves moves along.

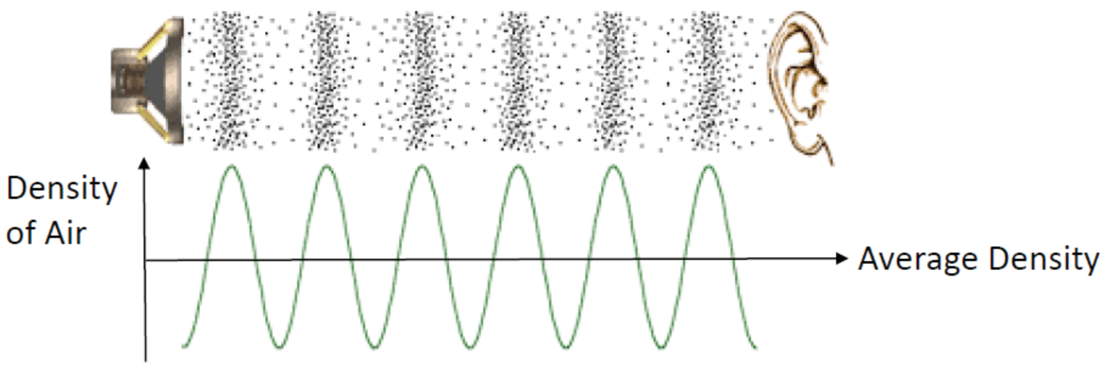

FIG. 1: A snapshot of a sound wave propagating through air. The small dots indicate gas molecules and the graph shows the modulation of particle number density in space. The density oscillates above and below the average density. Adopted from the internet.

There are many waves which we cannot see with naked eyes. Sound is a wave that clearly propagates through air from the source–vocal cords or a loud speaker. What is the nature of sound? If you take a snapshot of the gas molecules while a sound wave propagates through air, it will look like Fig. 1. Sound is simply modulation of density of air (pressure) along the propagating direction. Actually the train of wiggles will move to the right in time. Let's focus on the fixed position between the ear and the speaker. As the wiggles move through the space, the local density of air also oscillates in time. There are periodic oscillations in space and time simultaneously. The distance of one oscillation in space is called the wavelength (ℓ_w) of the wave. The number of oscillation in one second at a fixed position is called frequency (f) of the wave. The pitch of sound is determined by the frequency. For example, middle A note is 440 Hz, meaning local air density oscillates 440 times in one second. The same note one octave higher has 880 Hz frequency. Every octave higher doubles the frequency.

When you walk, there are also two quantities that specify the walk: he length of each step and how fast you make steps. The former is basically the wavelength of your walk and the latter is the frequency. Now you see the speed of your walking is simply the multiplication of the step size (wavelength) and the number of steps in one second (frequency). That applies exactly to waves. The speed of wave (v_w) is simply the multiplication of the wavelength and the frequency:

$$v_w = f \cdot \ell_w.$$

Q1 Why the density of molecule is directly related to gas pressure? Can you use the ideal gas law to answer this question?

Light is a wave, too. But it is a special wave quite different from conventional waves that we discussed so far. Light can propagate through empty space where no matter is present. Then what is oscillating or making a coordinated motion? Light is fluctuating electromagnetic field. You can visualize fluctuating electric and magnetic field lines in space in a similar fashion as wiggling ropes. Light also should obey the relationship given above. For example, the wavelength of a red light is 650 nm (650×10^{-9} m) and 461 THz (461×10^{12} Hz).

Q2 Given the frequency and wavelength of a red light, calculate the speed of light using the wave relationship.

From all these examples, we can conclude that a wave is a coordinated motion of matter or constituent particles. There are a few important principles that all waves share:

- Waves move at a constant speed that is determined by the physical properties of medium: even in air the speed of sound differs for different air temperatures. At room temperature the speed of sound is about 340 m/s.
- Waves carry energy along: it is possible to deliver energy through waves without actually transporting matter of constituent particles!
- Waves obey a superposition principle: If two or more waves arrive simultaneously at the same place, the resulting effect is simply the sum of the effects of all waves.

Q3 In air, the speed of sound is 340 m/s. The middle A note is a wave with 440 Hz frequency. What is the wavelength of this note?

Q4 Is the wavelength of the same note one octave higher longer or shorter than that of middle A?

Figure 2 shows how the superposition principle works. Two bumps with different amplitudes on a rope are generated from both ends of the rope and propagate in the opposite directions. Most of the time each bump is well isolated. But they will pass through each other at some point of time and location and two waves occupy the same position at the same time. When that happens, the resulting effect is simply the addition of the amplitudes as shown in the figure. After crossing each wave just propagate as if nothing happened. The middle diagrams of Fig. 2 show the result of superposition when two waves pass by each other. You can clearly see the difference between (a) and (b). Play with the simulation at https://www.geogebra.org/m/dJrTcxYd.

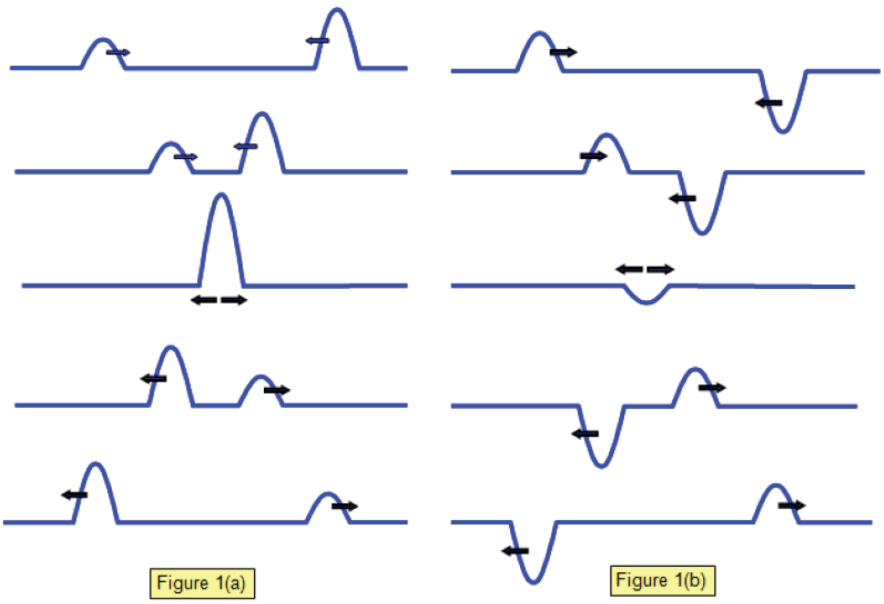

FIG. 2: Interference pattern made by two sources. The red lines are the constructive interference. In other words, when you place a microphone on a red line, strong sound will be detected. However, on a blue line, the destructive interference cancels two waves. Adopted from the internet.

2. Interference of Waves

Let us do some simulation (http://www.falstad.com/ripple/). There are three drop down menus and four sliding bars. Select "Single Source", "Sound", and "COlor Scheme 1" and slide down the "Simulation Speed". The sound source is located at the top radiating sound waves radially. The light (dark) color indicates high (low) pressure. You can clearly see the periodic pattern in space. The distance between the adjacent high pressure point is the wavelength. Place the mouse at a fixed point. Then you also see the light and dark region pass the point. The time between the consecutive light (dark) is the frequency. Now select "Two Sources". They are identical sound source radiating waves of same frequency and wavelength. There are two waves every point and the pattern of the resulting waves are quite interesting. The patter is generated because of superposition! Suppose you are placing a microphone (mouse) at a certain location to listen to the sound wave. No oscillation in time, no sound! Do you see the location that no sound would be detected by the microphone? There are four lines stretched outward from the middle point of the sources along which no oscillations. So if you place a microphone at any point on the lines, you will not detect any sound. This is the destructive interference. The identical sound waves produced by two sources are canceled each other along the lines.

Q3 Vary "Source Frequency" and observe the pattern of the lines of destructive interference. Did you notice that increasing frequency makes the wavelength shorter? As you increase the frequency how the destructive interference lines evolve?

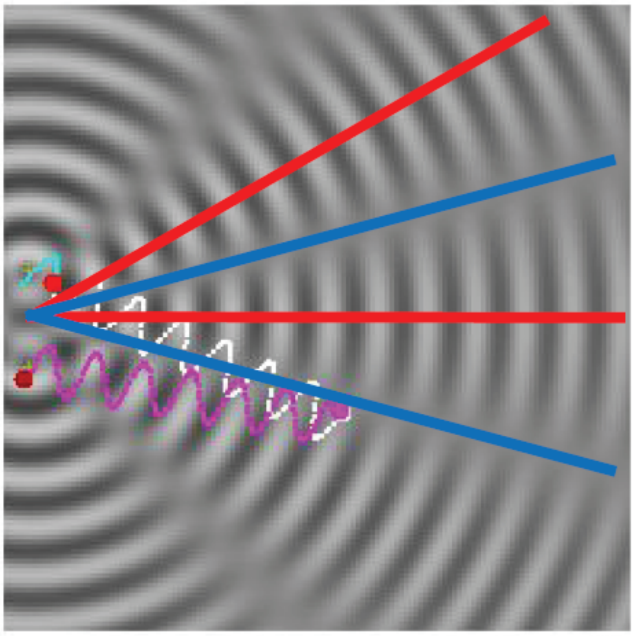

FIG. 3: Superposition of two pulse waves. Adopted from the internet.

The angle between the lines is decreasing as you increase the frequency, and consequently more lines appear. There is a specific relationship between the angle, separation of two sources, and the wavelength. So using this relationship, we can extract one with the knowledge of two others. We will use this to measure the wavelength of light in Lab: In actual experiment it is much easier to locate a constructive interference (bright) spot rather than a destructive (dark) spot.