# Science-1A Lecture: Week-4, Friday, September 4, 2020

This lecture and Chapter 5 of the textbook are about waves. Take a moment to read the short introduction to waves at page 89 of the printed handouts. It is also available at *http://yosemitefoothills.com/Science-1A/Handouts/Week-05/Chapter-5-Notes.pdf* .

All waves share two simple equations given in the Chapter 5 section on page 2 of your Equation Sheet. They are:

$$f=\frac{1}{T} \quad \text{and} \quad v=\lambda f$$

We have already seen the first equation in connection with pendulums. It follows from the definitions of **frequency** *f* and **period** *T* and applies to any periodic motion. Satellite orbits and pendulums have frequencies and periods although they are not waves.

The second equation is specific to waves. In addition to a frequency, waves can have a velocity and wavelength. A wave moves in time as well as space. At a particular location in space, a wave will rise and fall with time with a period of *T*, but at a fixed time a photograph of the same wave will show peaks separated by a distance called its **wavelength** which we represent by the lower-case Greek letter lambda $\lambda$. A wave carries energy in its apparent direction of motion with a **velocity** *v*. By tradition, however, we use the letter *c* rather than *v* to represent the speed of electromagnetic waves in a vacuum. c is close to $3.00\times10^{8}\,\text{m/s}$ as given on the 3rd line of the Chapter 5 section on page 2 of the Equation Sheet. The second equation above is therefore written as $c=\lambda f$ when used with electromagnetic waves.

Watch the following three Crash Course videos. They show lots of important concepts that are relevant to our Science-1A studies.

**Traveling Waves (CC 17) 7 min 44 s**
*https://www.youtube.com/watch?v=TfYCnOvNnFU&list=PL8dPuuaLjXtN0ge7yDk_UA0ldZJdhwkoV&index=18*

The rope demonstration is very easy. I stretched a long rope between secure posts next to the house, and the grand kids were twanging it throughout the afternoon, learning about waves by playing with it. In lab, I stretch a rope diagonally across the room and do the following:

1. Sending a **transverse** pulse wave along it that gets reflected back upside down from the far tie point.
2. Have a student help so pulses can simultaneously be sent from each end to show that they can pass through each other, briefly adding in the middle, a phenomenon called wave **superposition**.
3. Showing that the speed of the wave can be increased by tightening the rope.
4. Periodically shaking one end of the rope at just the right frequencies to set up **standing waves**.
5. Sending a **longitudinal** (compression) wave down the rope by pulling it lengthwise and releasing. The longitudinal wave in a rope is not visible, but could be felt by someone with their hand gently touching the rope near its other end.

A slinky is better able to illustrate longitudinal waves, and very long ones are available. A problem is that they are easy to over stretch and then do not return to their original shape.

Just about everything discussed in this video is relevant to our class except for some of the equations. The ones you need to know about are listed at the top of this page.

Notice the difference between transverse (sideways) waves and longitudinal (compression) waves, ropes, and solids can do both; sound waves are only longitudinal; water waves are a combination; and electromagnetic waves are always transverse.

Waves in a rope carry energy along the rope and only slowly weaken from friction and air resistance. Sound and electromagtic waves from a small source spread out from the source, but get weaker as $1/r^2$ – 3 times as far away has $1/3^2=1/9$ as much energy per unit area (sound intensity). Circular water waves caused by a stone thrown into a pond, spread out along the pond surface and weaken as 1/r – 3 times as far away has 1/3 as much energy per unit length of the perimeter of its circular ripples.

**Sound (CC 18) 9 min 38 s**
*https://www.youtube.com/watch?v=qV4lR9EWGlY&list=PL8dPuuaLjXtN0ge7yDk_UA0ldZJdhwkoV&index=19*
Just about everything in this video is relevant to Science-1A.
Note her use of the expression "picowatt". I hope you will recognize that "pico" is the unit prefix $10^{-12}$ and watt is the unit of power. So picowatt pW is $10^{-12}$ W of power.
I will not test you about the sound intensity unit decibel, but people that work with music use decibels all the time when mixing sounds.

**The Physics of Music (CC 19) 10 min 34 s**
*https://www.youtube.com/watch?v=XDsk6tZX55g&list=PL8dPuuaLjXtN0ge7yDk_UA0ldZJdhwkoV&index=20*
This is all interesting stuff, but you will not be tested on the formulas connecting frequency with length.

I have written a very detailed discussion of waves with pretty pictures that is on pages 90-97 of the printed handouts and also at
*http://yosemitefoothills.com/Science-1A/Handouts/Week-05/Waves.pdf*
This has more than you are expected to absorb, but you should look it over and try to understand the pictures.

These notes talk of the trigonometric sine function, written as sin( ... ), which produces the periodic wave shown in the figures on the first page. Waves evolve in time and travel in space, so the x-axis may either be time *t*, or distance *x*. When it is time, the repetition period of the wave is its period $T=1/f$, and when it is distance, the repetition period is its wavelength $\lambda=v/f$ . Higher frequency means more wiggles in a given time and a shorter wavelength.

A pure sound tone at a frequency of 440 Hz can be heard can be heard by playing
*http://yosemitefoothills.com/Science-1A/Handouts/Week-05/440Hz.mp*3
while double that frequency at 880 Hz is at
*http://yosemitefoothills.com/Science-1A/Handouts/Week-05/880Hz.mp3*

The second page of those notes shows what happens when two waves of nearly the same frequency are present. With sound, the wave pressures add and we hear the combination as a low "beat" frequency. You can hear this by playing the tone at
*http://yosemitefoothills.com/Science-1A/Handouts/Week-05/BeatFrequency.wav*
where one frequency is initially a few Hz below the other, but is gradually increased until it ends up a few Hz above. Where they are the same frequency is called the **zero beat** condition which is used by musicians to tune their instruments to a tuning fork.

Repetitive sounds other than pure tones are produced by a combination of "harmonic" frequencies. How such combinations can produce a "square" wave are discussed on page 4 and can be seen in the animated gif at *http://yosemitefoothills.com/Science-1A/Handouts/Week-05/SquarePlot.gif*

Combining the same frequencies in a different way can produce "triangular" and "sawtooth" waves. These combinations can be seen in the gifs at
*http://yosemitefoothills.com/Science-1A/Handouts/Week-05/TrianglePlot.gif*
and
*http://yosemitefoothills.com/Science-1A/Handouts/Week-05/SawtoothPlot.gif* .

You are not expected to know the material in the remainder of this "Waves" handout, but it is there for those who are curious.

**How Waves Work**

Each part of a wave is driven by a previous part, and then in turn drives the subsequent part. The best way to understand this is to be part of a wave. See for example, a stadium wave shown at
*https://www.youtube.com/watch?v=Gg10qGJ2zCg* .
The speed of this stadium wave depends on how quickly the fans react to their neighbors.

The extra water forming the peak of a water wave comes from the peak before it, but then as it falls down, this extra water flows ahead to raise the water next to it. The troughs are created by the momentum of the falling peaks pushing water below the surface level. A similar behavior happens with pressure in sound waves, and electric and magnetic fields driving each other in electromagnetic waves.

There is a nice video that shows a device that makes waves slow enough to see how the wave moves. It is entitled "Wave Machine Demonstration and is at
*https://www.youtube.com/watch?v=VE520z_ugcU* .

**Shock Waves**

If an object moves faster than the waves it creates, the wave energy piles up to produce a shock wave. This is nicely discussed in the following Ted-ed talk entitled "The Sonic Boom Problem" at
*https://www.youtube.com/watch?v=JO4_VHM69oI*

A comet crashing into Russia near a town created a spectacular visual show. As everyone watched its trail in the sky, its shock wave hit with about a 20 second delay. See the video at
*https://www.youtube.com/watch?v=gRrdSwhQhY0*

The bow wave of a fast moving boat is another kind of shock wave.

The tip of a whip makes its cracking sound because it moves faster than the speed of sound.
*https://www.youtube.com/watch?v=aHlFYHticq4*
The person swinging the whip puts kinetic energy into the thick handle of the whip. That energy travels as a pulse down the whip to less massive parts. Kinetic energy ( $\frac{1}{2} m v^2$ ) is preserved so the less massive parts end moving up faster until the very end moves faster than the speed of sound, making the cracking sound.

We will learn more about waves when we specifically study electromagnetic waves in a few weeks.