We will begin lecture 18 by doing two demonstrations of RESONANCE in SHM. We will then move to the topic of WAVES, as presented in Chapters 16 and 17 of our text. After learning the necessary DEFs, we will apply the ideas learned in Chapters 1-7 to this new problem. I have chosen to cover waves at this time because the idea of waves is closely connected to the idea of Simple Harmonic Motion (SHM). However, understanding some aspects of wave motion requires knowledge of FLUIDS and of THERMODYNAMICS, topics which we are saving for the end of the course; as a result, we must skip some topics in waves. We will omit sections 16.3-4 and 16.6, which mainly relate to wave speed; however, wave speed is frequently a topic covered by the MCATs, so you may want to mark these sections for independent study after we have covered fluids and thermodynamics. Wave speed is usually covered in 113 lab.

Let's begin with some basic definitions.

DEFs A MECHANICAL TRAVELING WAVE is a disturbance in some medium that carries energy away from a source. If the disturbance is periodic (i.e. repetitive), then the wave is a PERIODIC TRAVELING WAVE. If the disturbance is not only periodic, but also simple harmonic, then the wave is a HARMONIC TRAVELING WAVE. The DIRECTION OF PROPAGATION of the wave is the direction of energy movement. The SPEED of PROPAGATION (v), also known as the WAVE SPEED, is the speed with which energy moves away from the source.

There are several points of emphasis in the above DEFs. Traveling waves transport ENERGY. The "source" of the wave is the source providing the energy; the energy moves away from the source with speed v in the direction of propagation. The word "mechanical" distinguishes the waves we discuss in 111 from electromagnetic waves, which will be discussed in 112. The "medium" is simply the material through which the wave travels; for example, sound waves can travel through air, water, human tissue (as in the case of ultrasound), etc. The motion of the source doesn't have to be periodic (for example, the complex sound wave created by a car crash would not be periodic), but most useful waves are due to periodic sources -- it is primarily those that we will study. Here are several addition definitions which apply to periodic waves.

DEFs The FREQUENCY (f) of a periodic wave is the frequency of the source of the wave. The PERIOD (T) of a periodic wave is the period of the source. The WAVELENGTH (λ) of a periodic wave is the distance, in meters, traveled by the wave during one period of the source, i.e.

$$\lambda \equiv vT$$

The AMPLITUDE of a periodic wave at location $\mathbf{r}$ is defined in terms of the motion of the particle which is located at position $\mathbf{r}$ (the particle at $\mathbf{r}$ is a part of the medium through which the wave is traveling); the AMPLITUDE at location $\mathbf{r}$ is the maximum distance of that particle away from its equilibrium position.

Of the above DEFs, probably only AMPLITUDE is difficult to grasp. If the wave is harmonic, then the point at $\mathbf{r}$ is undergoing SHM; the AMPLITUDE of the wave at $\mathbf{r}$ is just the amplitude of the SHM of the particle at $\mathbf{r}$. We must specify the location $\mathbf{r}$ because wave amplitude generally decreases with distance from the source; the exception is for a wave in an ideal 1D medium (for example, a stretched string which doesn't get hotter while vibrating).

If you are to understand waves, it is vital that you develop an accurate mental picture of wave motion. There are two primary types of wave motion, which I will define below. There is an internet simulation for each type which will help you to get the mental picture that you will need. Please look at the simulations and then reread the above DEFs for periodic waves, so that you have a good understanding of each DEF. We will run both of these simulations during lecture, where you will get a chance to ask questions.

DEF In a TRANSVERSE WAVE, the particles of the medium are displaced $\perp$ to the direction of propagation of the wave.

A simulation of a harmonic transverse traveling wave on an infinitely long string can be found at

http://www.ngsir.netfirms.com/englishhtm/TwaveA.htm

The source is on the left, but is not shown -- you could imagine the source to be a hand that is shaking the end of the string up and down. The amplitude of this wave, once it is established everywhere on the piece of string that you see, is the same at all points on the string. The key idea for this transverse wave is that the particles move up and down, while the energy moves to the right.

DEF In a LONGITUDINAL WAVE, the particles of the medium move back and forth parallel to the direction of propagation of the wave.

A simulation of a harmonic longitudinal traveling wave on an infinitely long slinky can be found at

http://www.ngsir.netfirms.com/englishhtm/Lwave.htm

In this simulation, the wave is already established when the simulation begins. The source is at the bottom of the page, but is not shown -- you could imagine the source to be a hand that is shaking the end of the slinky back and forth. The horizontal lines represent the rungs of the slinky. To see that energy is moving upward on the page, use the "whiten rarefaction option". The key idea for this longitudinal wave is that the particles of the medium move back and forth (but never get anywhere), while the energy moves away from the source.

To see clearly that the rungs of the slinky are just moving back and forth, "highlight a point" and then turn on the "Y-t graph" for your selected point.

Here are two more DEFs for longitudinal waves.

DEFs For a longitudinal wave, the regions in which the particle density is high (i.e. higher than the average particle density for the medium) are called CONDENSATIONS; the regions in which the particle density is low (i.e. lower than the average particle density for the medium) are called RAREFACTIONS.

You should easily be able to identify the condensations and rarefactions in the simulated longitudinal wave. Longitudinal waves are especially important for us because of the following DEF.

DEF SOUND WAVES are longitudinal waves in a material; i.e. waves in which the atoms of the material move back and forth parallel to the direction of propagation of the wave.

I must emphasize that sound waves do NOT have to audible. The human ear can detect sound waves with frequencies as low as about 20 Hz, and as high as about 20 kHz. Longitudinal waves with frequencies below 20 Hz are called INFRASOUND, and longitudinal waves with frequencies above 20 kHz are called ULTRASOUND. Sound waves are sometimes called pressure waves, or density waves, because of the condensations and rarefactions.

Since our emphasis in Chapter 16 will be on the energy carried by waves, we will finish this reading with some energy-related DEFs. Remember that the energy is coming from the source of the wave, and that energy is continuously being carried away from the source by the wave.

DEF The POWER OF THE SOURCE (P_S) is the rate at which energy is carried away from the source by the wave. The units of P_S are Watts (W), i.e. J/s.

As the energy moves away from the source, it appears in the medium as mechanical energy of particles (usually atoms), i.e. as the KE of the moving particles plus PE_S of the particles, where the "springs" are usually the atomic "springs" that connect adjacent particles (as in the picture on page 282 of our textbook -- for sound waves in air, this statement requires some special comments, which I will make in lecture). (Since the particles are very small, we can usually ignore ΔPE_G for the particles.) Each particle of the medium is continuously receiving energy from adjacent particles nearer the source, and continuously passing energy to adjacent particles farther from the source -- that is how the energy manages to continuously move away from the source. How can we describe, and quantify, this passing energy? The answer to this question is the concept of INTENSITY.

DEF The INTENSITY (I) of a wave at a location $\mathbf{r}$ is the energy per second per unit area passing through a small test area $\perp$ to the direction of propagation and located at $\mathbf{r}$. The units of I are (J/s)/m^2 or W/m^2.

Intensity is one of the more difficult concepts in 111, but it is vitally important concept both in 111 and 112. It is worth spending some extra time making sure that you understand this idea. Figure 16.25 on page 464 of our textbook may help you to visualize the "test area" described in the DEF. Intensity is a meaningful concept only for waves in 3D. For 1D waves, we can simply talk about the energy per second passing any point in the 1D medium; (the per unit area part would make no sense). During lecture 18, we will do examples with the rate of energy transport in both 2D (where intensity is not meaningful) and in 3D.

Humans detect sound waves with intensities as low as about 10^{-12} W/m^2 and up to about 1-10 W/m^2 without pain (see the table in your text on page 465). This is an remarkably wide range of intensities, 12-13 orders of magnitude! Because this range is so very wide, a logarithmic scale is more convenient for practical use. The accepted logarithmic scale is defined by:

DEF For a given sound intensity I, the SOUND INTENSITY LEVEL (β) is

$$\beta \equiv \log(\frac{I}{10^{-12}\ \mathrm{W/m^2}}) \qquad \text{in units of Bels (B)}$$

Bels is a dimensionless unit.

So, for example, if the intensity is 10^{-10} W/m^2, 100 times the minimum audible intensity, the intensity level is 2 Bels. Actually, you almost never see the unit of Bels; the unit of one-tenth of a Bel, i.e. a deciBel (dB), is much more popular and tends to be the unit used on commercial sound level meters. 2 Bels would be 20 dB. We don't really care about this unit in physics class, but its use is ubiquitous, so you should be introduced to it here. I will give you one HW problem in which you must convert from intensity level to intensity, but you will not have to do this conversion on our test. Here is how to convert from intensity in W/m^2 to intensity level in dB, and vice versa:

$$\beta\ (\text{in dB}) = (10\ \text{dB}) \log(\frac{I}{10^{-12}\ \mathrm{W/m^2}}),\ \text{and}$$

$$I = (10^{-12}\ \mathrm{W/m^2}) \cdot 10^{(\beta/10)} \quad (\beta\ \text{in dB})$$

Our final topic in lecture 18 will be the Doppler Effect, which is a change in the observed frequency of a wave due to a moving source or a moving observer. We will figure out the equation for the Doppler effect by using our knowledge of motion and our DEFs for waves, and you will experience a demonstration of the effect.