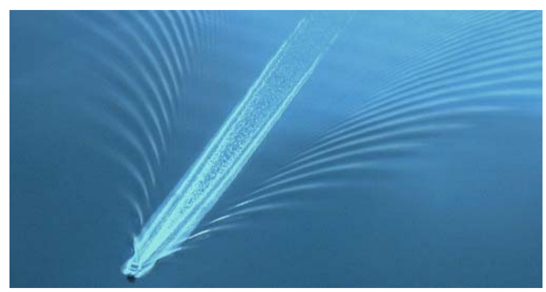
PHYS:1200 LECTURE 21 — VIBRATION, WAVES, AND SOUND (2)

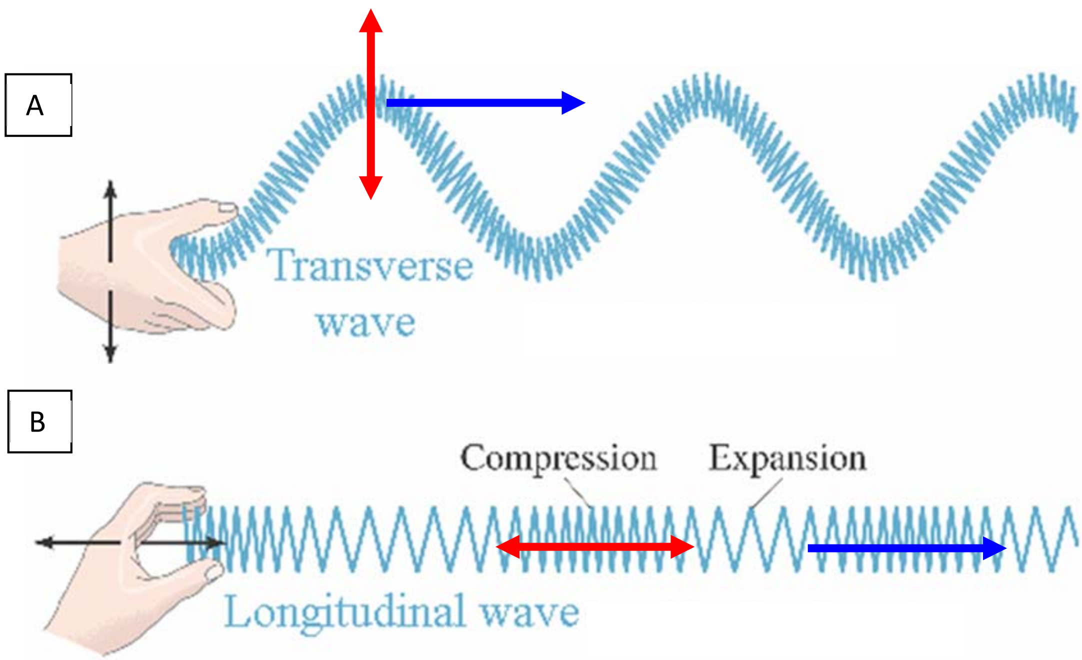
In the last lecture we discussed oscillating systems which involves the periodic motion of an object like, e.g., a pendulum. However, the system as a whole remains at a fixed location. A **wave** is an oscillation accompanied by a transfer of energy that **travels** through space or mass— it is a type of moving oscillation of a medium, or in the case of electromagnetic waves, oscillations of electric and magnetic fields through a vacuum.

21-1. Waves.—When you toss a pebble into a calm pond, ripples move outward from the point where the pebble enters the water surface. The pebble disturbs the water and wave propagate outward. What we actually see in the rearrangement of the water's surface is the motion of the disturbance. **Some of the energy of the motion of the initial disturbance is transferred outwardly in the water. Notice that the wave (disturbance) moves outward but not the water.** When the disturbances reaches a certain position in the water, the water surface rises and falls. Ships moving through the ocean create a disturbance that propagates outward from its sides. **A mechanical wave then is a disturbance that propagates through a medium or through space.**



The water wave is an example of a **mechanical wave** in which a disturbance moves through a material medium. Another common example of a mechanical wave is a sound wave which is a pressure or density disturbance that propagates through a gas, liquid, or a solid. Mechanical waves must have a medium to propagate the disturbance. Light, on the other hand, is the propagation of energy in the form of electric and magnetic fields. Light can propagate through a transparent medium, like glass, but no medium is required. Light is an electromagnetic wave which can propagate through empty space (vacuum). The light that comes to the Earth from the sun, travels through the vacuum of space. We will be concerned in this and the next lecture with mechanical waves. Electromagnetic waves will be discussed later in the course.

Mechanical waves propagate due to the elastic properties of the medium. When you poke your finger in a tank of water, the water pushes back after you remove your finger. Air is also compressible, and this property causes sound waves to propagate. The elastic nature of a string or a spring (its ability to be stretched and then relax) allows waves to propagate along their length. The speed of propagation of the wave depends on the properties of the medium; for example, the speed of sound depends on the ambient pressure and density of a gas, while the speed of propagation of a wave on a string depends on the tension and linear mass density of



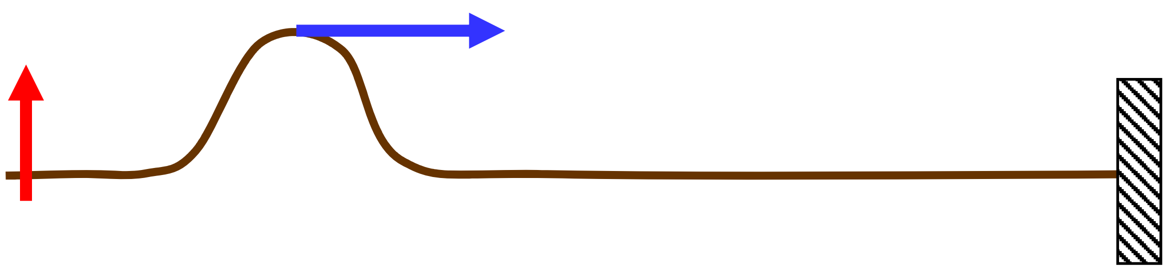
the string. **Waves are important because they are a means of transporting energy from one place to another, without transporting matter.**

21-2. Wave Classifications.—Waves are classified by how they behave in space and in time. A wave may be a **single pulse**, or a **series of pulses** launched at regular intervals of time. A continuous series of waves is called a **harmonic wave**. The spatial classification of waves characterizes the motion of the medium as the disturbance passes. The two broad types of waves are (a) transverse waves and (b) longitudinal waves. The difference between transverse and longitudinal waves can be illustrated by considering disturbances produced on a long spring that has one end fastened to a wall, as shown below.

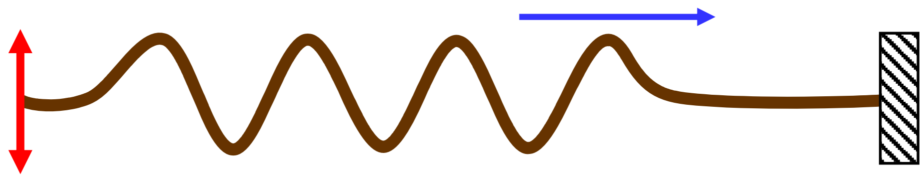
a. Transverse waves.—In a transverse wave (Part A of the figure) the disturbance is produced by jiggling the free end of the spring up and down. The disturbance moves from left to right as indicated by the blue arrow. **When the disturbance reaches a given point along the spring, that part of the spring moves up and down (red arrow) in the direction transverse (at 90 degrees) to the direction of wave propagation.**

b. Longitudinal waves.—In a longitudinal wave (Part B of the figure).the disturbance is produced by pushing or pulling the spring in and out. The disturbance moves from left to right as indicated again by the blue arrow. **When the disturbance reaches a given point along the spring, the coils in that part of the spring move back and forth parallel (longitudinally) to direction in which the wave propagates.** The coils that are bunched together are called the compression of the wave, and the coils that are stretched are called the expansion or rarefaction of the wave.

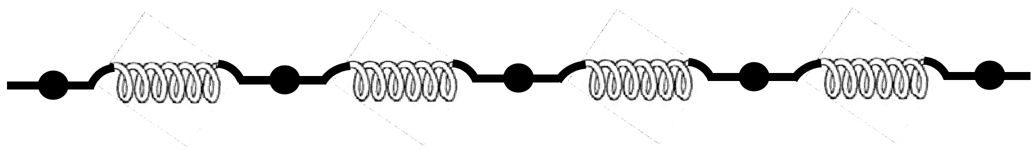
21-3. Transverse Waves on a String.—A long string is attached at one end to a wall and pulled so that it is under some tension. The free end is then given an upward impulse which generates a **transverse wave (disturbance) that propagates to the right**. When the pulse reaches a



particular point along the string, that portion of the string moves up then back down to its original position. The wave (single pulse, in this case), propagates because the disturbance causes the string to be stretched and this stretching of one portion of the string then affects the portion adjacent to it. **The speed of propagation of the wave does not depend on how the pulse is generated, but depends on two properties of the string: the tension in the string, and the linear mass density of the string**. The linear mass density of the string is the total mass of the string divided by its total length. The speed of propagation increases as more tension is applied to the string. The speed of propagation is higher for thin strings (small values of the mass per unit length) and lower for heavy strings (large values of the mass per unit length). If the end of the string is continuously jiggled up and down, a transverse harmonic wave is produced.

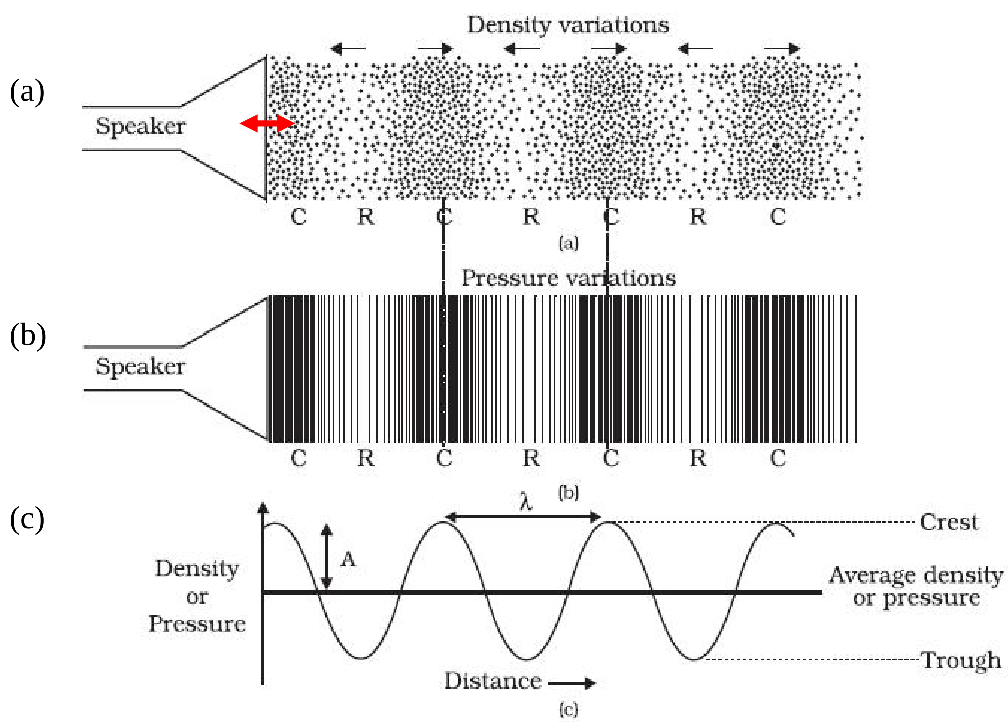


The motion of transverse waves on a string can be analyzed using Newton's 2nd law of motion. Often the behavior of strings can be analyzed using a model in which we think of the string as a series of



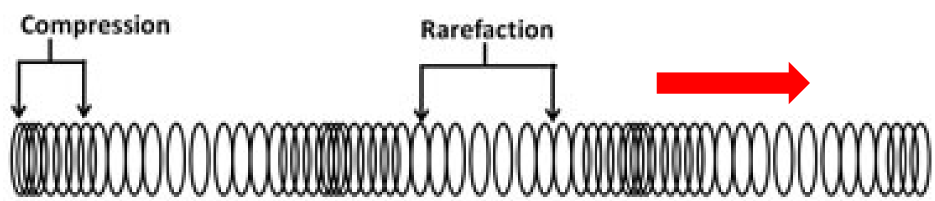
masses connected by springs. The known properties of the springs allows us to represent the elastic properties of the actual string. Models are often used in physics to represent complex systems in a way that can be analyzed more easily. The model system composed of masses and springs is easier to analyze because the masses and springs are discreet (separate), whereas in a string, the mass is distributed continuously.

21-4. Sound Waves.—When you pop a balloon with a pin, a sound wave is produced which propagates outward in all directions. The air in the balloon is at a higher pressure than the air on the outside, and when it is suddenly released, the localized pressure disturbance travels as a sound wave. **Sound waves are longitudinal pressure and density disturbances that propagate in a gas, liquid, or a solid**. The speed of propagation depends on the specific properties of the medium. A loudspeaker attached to the end of a long tube is a good way of generating sound

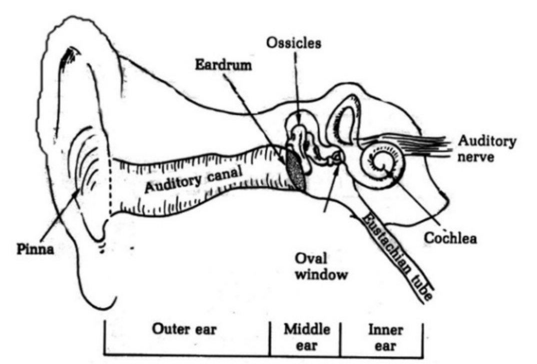


waves (see the figure above). A loudspeaker has a cone (called the diaphragm) made of paper or plastic that is forced to oscillate back and forth when an electrical signal is applied to it. (We will see how this works when we talk about magnetic forces.) The outward movement of the loudspeaker causes the layer of air adjacent to it to be compressed or expanded when it moves inward (part a in the figure). The layer of compressed air molecules responds by pushing on the adjacent layer of air, and this process is then propagated as a wave. The air molecules jiggle back and forth parallel to the direction of wave propagation, so sound is a longitudinal wave. **The disturbance creates a series of compressions (high density regions) and rarefactions (low density regions) in the air.** Like any other gas, pressure and density are directly related to each other, so regions of high density also correspond to high pressure (part b of the figure). Part (c) of the figure is a plot of the pressure variation in the sound wave with distance along the direction of propagation. The pressure is measured relative to its ambient value before the sound wave is present. The wave crests correspond to regions of slightly higher pressure, and the wave troughs correspond to the regions of slightly lower pressure. The figure below shows a longitudinal wave on a long spring. This type of wave bears a close resemblance to a sound wave, since it consists of alternating regions where the coils are bunched together (compressions) and regions where the coils are spread out (rarefactions). Clearly, there is no sound if there is no air; sound does not propagate in a vacuum, as we will demonstrate in class.

*a. The sense of hearing.***—**The human sensation of sound is the physiological response of our ears to a compressional waves in air. The sound waves enter our outer ears and travel through the ear canal to the eardrum. The eardrum, or tympanic membrane, is a highly sensitive membrane that is caused to vibrate when the sound waves impinge upon it. (In fact, the eardrum is sensitive to displacements on the order of the size of an atom! This is why our ears are very sensitive to changes in atmospheric pressure.) A very complicated mechanism in the inner ear



converts the mechanical vibrations into electrical impulses that travel along the auditory nerve to our brain. The normal human ear responds to sound impulses in the frequency range of 30 Hz to 20,000 Hz. Inaudible sound above 20,000 Hz is called ultrasound; sound waves below 30 Hz are referred to as infrasound. As we get older, the upper frequency of audible sound is diminished. This will be dramatically demonstrated in class. Prolonged exposure to very high intensity sound can diminish one's ability to hear high frequencies.



The human ear.

b. The speed of sound.—**The speed of sound (v_s) in dry air at 20 C is 343 m/s** = 1,126 ft/s = 768 mph ≈ 1/5 mile per second. In water sound propagates at 1500 m/s, over four times faster than in air. The speed of sound in solids is even much higher, for example 5000 m/s in copper.

By noting the number of seconds between seeing a lightning flash and hearing the thunder (the sound waves generated by the lightning bolt), one's distance from a lightning strike can be estimated. Since sound travels at roughly 1/5 mile/s, each 5 second delay indicates that the lightning strike was 1 mile away from you. This rule of thumb is called the **5 second rule**. The speed of light is almost a million times higher than the speed of sound, so we see the light almost instantaneously, while the sound waves reach us later.

*c. Sound level, the decibel (dB) scale.***—**The human ear is sensitive to sounds that cover a range of intensities of about 10^{14}! For such a broad range, a **logarithmic scale (the dB scale)** is more convenient. The decibel level is set up so that a barely audible sound (threshold of hearing) has a sound level of 0 dB. The sound level in dB is then measured relative to this threshold. If the actual sound intensity (the amount of sound energy falling on an area of 1 m^2 every second, doubles, the sound level increases by 3 dB. If the sound intensity increases 10 times, the sound level increases by 10 dB. The Richter scale is a logarithmic scale used to quantify the magnitude of earthquakes. For two earthquakes, one of magnitude say 5 and another of magnitude 6, the actual energy involved in the magnitude 6 earthquake is 10 times that of the magnitude 5 earthquake. The difference is very significant.