AP Physics-B **Wave Behavior**

Introduction: There are only two ways by which energy can be transferred between two points. The first method involves the transfer of matter. The second method of energy transfer involves wave motion. All waves transfer energy. The behavior of all waves follows the same general rules of wave behavior. You can understand the behavior of all waves by studying the behavior of a few. In this unit we will concentrate our study on mechanical waves.

A pulse is a disturbance through a medium and a wave is a series of pulses. Most waves are periodic in nature, that is, the disturbances occur at regular intervals. Three physical characteristics are important in characterizing new waves: the wavelength, the frequency, and the wave velocity. One wavelength is the minimum distance between corresponding points on consecutive pulses. The frequency of periodic waves is the rate at which the disturbance repeats itself. Waves travel, or propagate, with a specific velocity. Mechanical waves require a medium (physical stuff) to travel through. The speed of the wave depends on the elastic and inertial properties of the medium.

Behavioral Objectives: Upon completion of the readings and activities of this unit and when asked to respond either orally of on a written test, you will:

- Know that different waves follow the same general behavior.
- Distinguish between a pulse and a wave.
- Distinguish between transverse and longitudinal waves.
- Define wavelength, frequency, and velocity. State the equation showing the relationship among speed, wavelength, and frequency. Solve problems using this equation.
- Relate period to frequency.
- Describe the relationship between the energy content of a wave and its amplitude.
- State the relationship between the speed of a wave and the medium.
- List the major characteristics of the behavior of waves at the boundaries between media. Solve problems involving that behavior.
- Recognize that a change of medium means a change in speed and wavelength.
- State the superposition principle. Define constructive and destructive interference.
- List the requirements for the development of nodes.
- State the law of reflection.
- Relate the behavior of the transmitted wave to the phenomenon of refraction. State the law of refraction.
- Define diffraction.
- Explain the formation of nodal lines.

Textbook Reference: Wilson, Buffa, Lou: Chapter 13 Hecht: Chapter 11

"The essential new thing here is that for the first time we consider the motion of something which is not matter, but energy propagated through matter."

Albert Einstein (1879-1955) and Leopold Infeld (1898-1968)

The Wave Equation: The equation relating the velocity of propagation, wavelength and frequency of a wave describes all waves, where v is for velocity, f or ν (nu) is frequency, and λ (lambda) is wavelength.

$$v = f \cdot \lambda \quad \text{or} \quad v = \lambda \cdot \nu \quad \text{or} \quad v = \lambda / T$$

Exercises:

1.) A wave of a long spring travels 30.0 m in three seconds. What is the speed of the wave? *10 m/s*

2.) Transverse waves traveling along a rope have a frequency of 12 hertz. The waves have a wavelength of 2.4 meters. What is the speed of the wave? *28.8 m/s*

3.) Waves generated along a spring have a wavelength of 0.15 meters and travel at a speed of 0.90 m/s. What is the frequency of the waves? If the frequency if decreased to 0.5 hertz, what is their wavelength? *6 Hz 1.8 m*

4.) A microwave is an electromagnetic wave. Like all electromagnetic waves, they travel through space at a speed of 3.0×10^8 m/s. Determine the wavelength of a microwave which has a frequency of 5.0×10^9 Hz. *0.06 m*

5.) A hiker shouts toward a vertical cliff 685 meters away. The echo is heard 4.00 seconds later.
a.) What is the speed of sound that day? b.) The wavelength of sound is 0.750 m. What is its frequency?
c.) What is the period of the wave? *342.5 m/s 456.7 Hz 0.0022 s*

6.) To obtain waves of longer wavelength, all other conditions being the same, is wave frequency along a rope increased or decreased? Explain!

7.) If a wave generator produces 12 pulses in 3 seconds, what is (a) its period? (b) its frequency? *0.25 s 4 Hz*

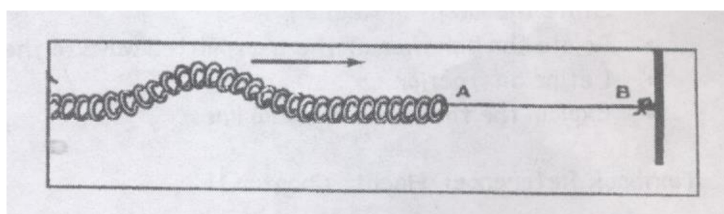
8.) Would you increase or decrease the frequency of the generator in a ripple tank in order to produce waves of greater wavelength?

9.) (a) In a ripple tank, when one pulse is sent every one-tenth second, we find that the wavelength is 3.0 m. What is the speed of propagation? (b) In the same medium, we send two pulses, the second one a half-second after the first. How far apart are they? *30 m/s 15 m*

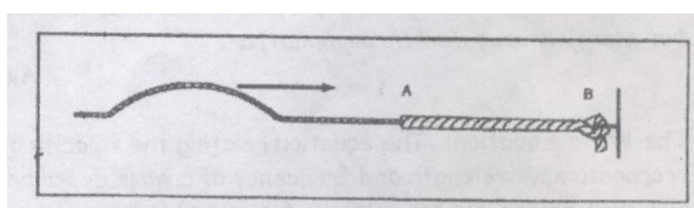
Waves at Boundaries Between Media; Reflection, Transmission, and Refraction: When energy transferred by a wave reaches the boundary to a new medium, energy is partially transmitted into the new medium and partially reflected back through the original medium. The amount of energy either transmitted and/or reflected depends on how different the two media are. Upon reflection, the direction of wave propagation obeys the "Law of Reflection" – The Angle of Incidence is equal to The Angle of Reflection. The Angle of Incidence is measured between the Incident Ray and the Normal Line and The Angle of Reflection is measured between the Normal Line and the Reflected Ray.

10.) A long spring passes along the floor of a room and out a door. A pulse is sent along the spring. After a while, an inverted pulse of almost the same amplitude returns along the spring. Is the spring attached to the wall in the next room, or is it lying loose on the floor?

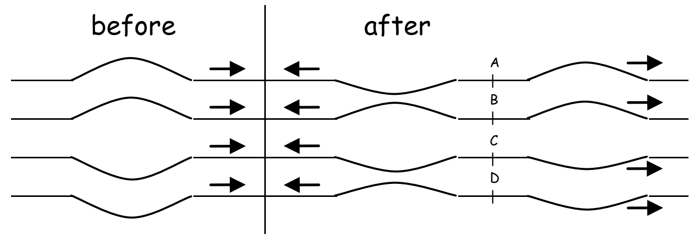
11.) A pulse is sent along a spring as shown in the figure to the right. The spring is attached to a light thread which ends at a wall. a.) Describe the behavior of the pulse when it reaches A. b.) Is the reflected pulse from A upright or inverted? c.) Describe the behavior of the transmitted pulse when it reaches B. d.) Is the reflected pulse from B upright or inverted?



12.) a.) Describe the behavior of the pulse in the figure to the right when it reaches boundary A. b.) Describe the behavior of the transmitted pulse when it reaches boundary B.



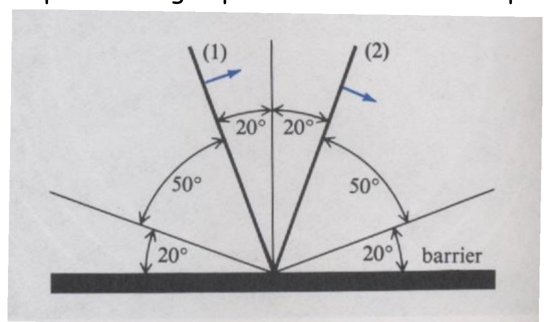
13.) The "before" side of the figure to the right shows a pulse travelling through a medium that is attached to a second medium – although the second medium is not shown on the "before" side of the figure. The "after" side shows both the transmitted pulse in the new medium and the reflected pulse return back through the original medium. Describe the boundaries A, B, C, and D as either more or less rigid.



14.) You send out a pulse at one end of a spring and it returns to you upside down and smaller in size. What can you deduce about the speed of the pulse on a second spring which is attached to the other end of your spring?

15.) When light passes from air to water or vice versa, part of it is reflected. If this situation resembles that of a pulse crossing from one coil spring to another, in which case will you expect the light pulse to be reflected upside down? *air to water*

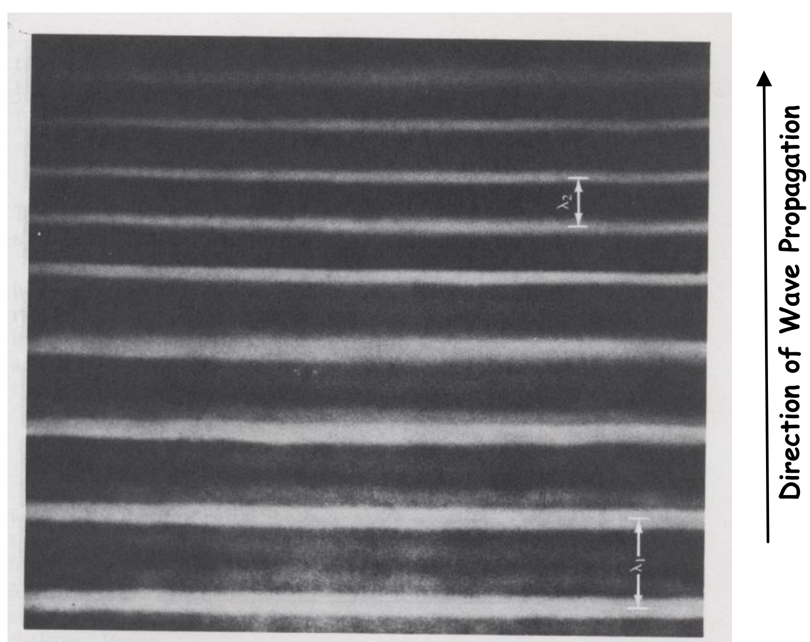
16.) In the figure to the right, the heavy black lines are crests; the arrows represent the direction of propagation of the pulses.
a.) Which is the incident pulse and which is the reflected pulse?
b.) What is the angle of incidence?
(2) – incident, (1) – reflected *70°*



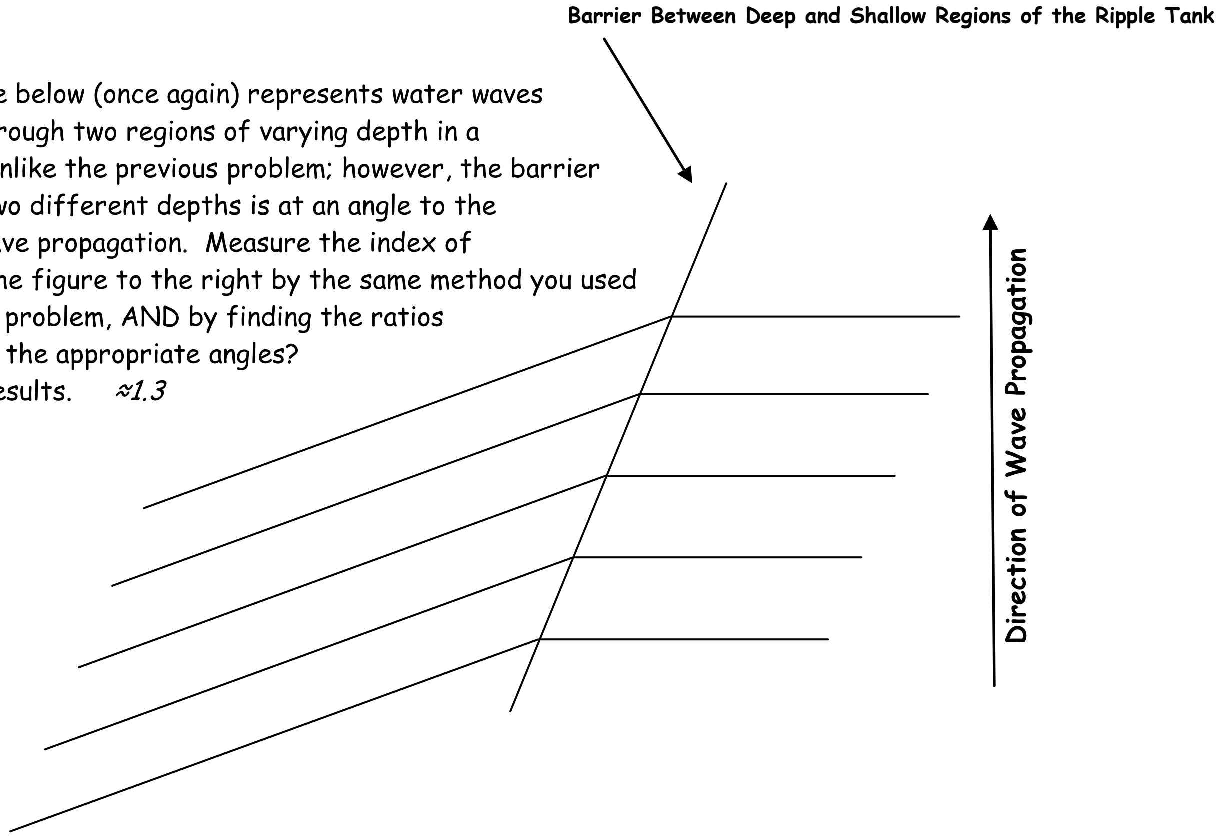
Refraction: If we take a look at a wave that enters a new medium from an "incident" medium, we will observe a change in wave speed according to the elastic and inertial properties of the new medium. Furthermore, this change in wave speed is accompanied by a change in wavelength as the frequency of the waves in both media must remain the same. Insight into just how different the incident and refractive media are is found in a ratio known as the "Index of Refraction." The Index of Refraction (n) is a ratio of the wavelengths of the waves in the incident medium to the wavelengths of the waves in the refractive or new medium. Additionally, it may also be calculated as the ratio of wave speed in the incident medium to the wave speed in the refractive medium – AND - as the ratio of the sine of "The Angle of Incidence" to the sine of "The Angle of Refraction." Recall that the Angle of Incidence is measured between the Incident Ray and the Normal Line. The Angle of Refraction on the other hand is measured between the Refracted Ray and the Normal Line. When wave speed slows down, the direction of propagation bends TOWARD the Normal Line and when wave speed increases, the direction of propagation bends AWAY FROM the Normal Line.

$$n = \frac{\lambda_1}{\lambda_2} = \frac{v_1}{v_2} = \frac{\sin \Theta_i}{\sin \Theta_r}$$

17.) In the figure to the right imagine the waves moving from the region at the bottom of the page toward the region at the top of the page. Where is the boundary between the area of deep to shallow water? b.) What is the index of refraction in passing from the deep to the shallow water? *1.85*



18.) The figure below (once again) represents water waves propagating through two regions of varying depth in a Ripple Tank. Unlike the previous problem; however, the barrier between the two different depths is at an angle to the direction of wave propagation. Measure the index of refraction in the figure to the right by the same method you used in the previous problem, AND by finding the ratios of the sines of the appropriate angles? Compare the results. *≈1.3*



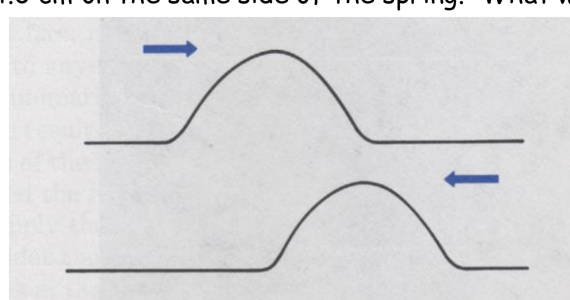
19.) A ripple tank wave passes from a shallow to a deep section with an incident angle of 45° and a refracted angle of 60°. a.) What is the ratio of speed in the two sections? b.) If the wave speed is 25 m/s in the deep section, what is it in the shallow one? *0.816* *20.4 m/s*

Superposition and Interference:

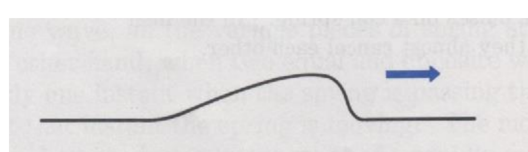
20.) If two pulses traveling toward each other on a coil spring have displacements in the same direction, can they cancel each other when they cross?

21.) Two pulses have maximum displacements of 3.0 cm and 4.0 cm on the same side of the spring. What will be the maximum displacement? *7.0 cm*

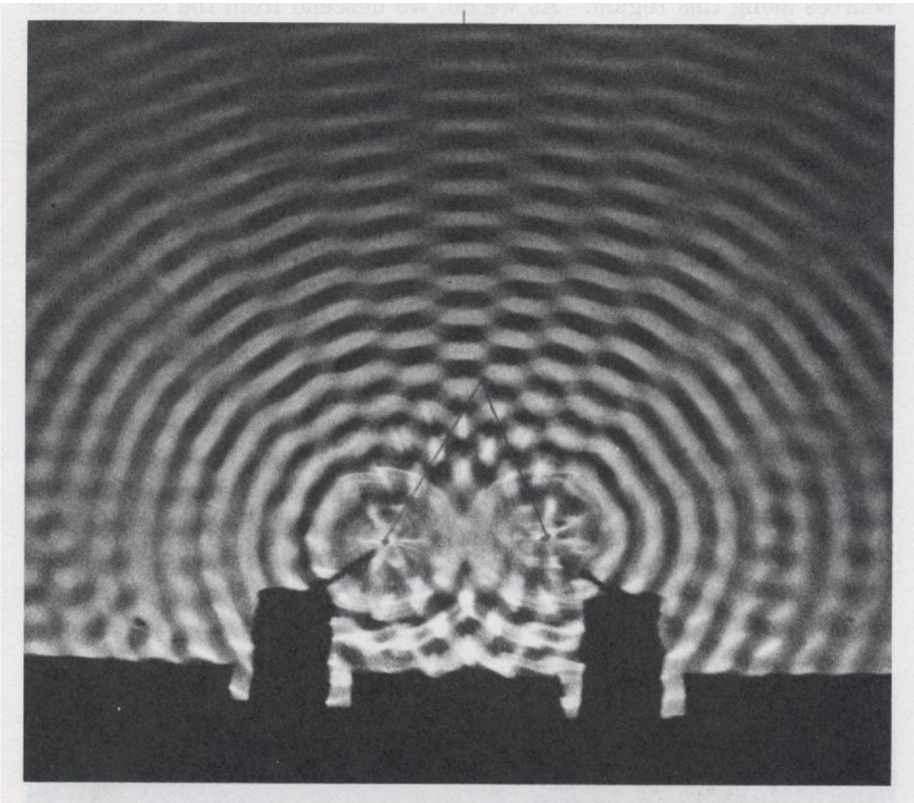
22.) Using the two pulses shown to the right, determine the size and shape of the combined pulse at this moment.



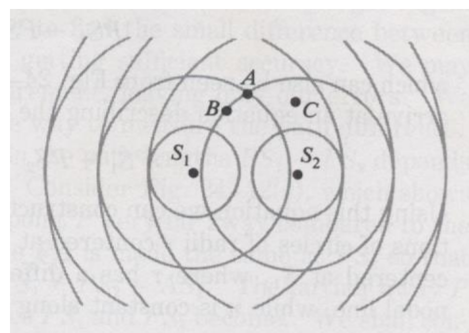
23.) A pulse, shown to the right, is sent along a coil spring toward the right. Draw the pulse traveling to the left that could momentarily cancel the pulse shown.



24.) On the picture below, locate the nodes and antinodes. Locate and mark d, x, and L. Calculate the wavelength.



25.) In the figure to the right, the circles represent the crests of waves produced by sources S_1 and S_2. At which of the points A, B, and C is there a "double crest," a "double trough," or a nodal point?



For Further Study:

Waves on the surface of a lake strike a breakwater that has two small holes "A" and "B" in it, 2.0 m apart. A and B act as new sources of waves, vibrating in phase. A man in a rowboat – at a point 43 meters from the midpoint of a line connecting the sources - notices that he is in calm water. He also notices that there is another region of calm water between him and the central region of heavy wave activity. He is 5.0 m from this central region. What is the wavelength of these waves?   *15.5 cm*