Wave Properties
Student Worksheet

Answer the following questions during or after your study of Wave Properties.

1. A person standing 385 m from a cliff claps her hands loudly, only to hear the sound return to her as an echo 2.3 seconds later. What is the speed of sound on this day at her location?

2. A boat traveling in saltwater (speed of sound = 1530 m/s) sends out an ultrasonic signal to the sea floor only to receive the reflected signal 0.23 second later. How deep is the ocean?

3. A particular sonar unit in a fishing boat stops working reliably when the boat is brought from the ocean to a freshwater lake. What is the problem? Should the captain worry about running aground?

4. How are refraction and the speed of wave in different media related?

5. What properties do waves have that particles do not? Can you think of any properties that particles have that waves do not?

6. Why do only very small particles have noticeable wave properties?

7. A wave of amplitude 0.5 m interferes with a wave of amplitude of 0.2m. What is the maximum resultant displacement that may occur? What is the minimum resultant displacement that may occur?

8. A string is rigidly attached to a post. A wave with amplitude of 0.5m is sent down the string. It is reflected off of the post. Assuming the amplitude of the forward wave remains the same upon reflection, what is the displacement when the two waves cross each other? What is this called?

9. A string is free to move in its attachment to a post. A wave with amplitude of 0.5m is sent down the string. It is reflected off of the post. Assuming the amplitude of the forward wave remains the same upon reflection, what is the displacement when the two waves cross each other? What is this called?

10. In attempting to tune a piano, a piano tuner produces a note at 440 Hz. He notices that he hears beats with a frequency of 2 Hz when he strikes the “A” key on the piano. What frequency is the piano key actually producing? Why are there two possibilities?

11. Why can you hear a radio playing around the corner but not see it?

12. What produces a standing wave? What are standing waves characterized by?

13. A horn, when stationary, is heard to produce a tone of A (440 Hz). When the horn is placed on a train, it is heard to make a tone at 435 Hz. What direction is the train moving, relative to the listener?

14. How do police officers use the Doppler Effect to determine whether or not you deserve a ticket?

15. How can the density of a gas be determined from the shape of the spectral lines it produces?

16. How does MOSAIC observe only the ozone from the mesosphere through the 99% of the ozone that lies in the lower atmosphere?

Wave Properties
Teacher Notes

This worksheet is intended to accompany the Wave Properties PowerPoint (Wave Properties.pptx) created as part of Haystack Observatory's RET project on Physics and MOSAIC. The PowerPoint can be used as an in-class presentation, but also could be re-envisioned as a Webquest-type activity of self-directed learning.

This worksheet provides practice solving problems as well as thinking conceptually through the principles of waves.

1. A person standing 385 m from a cliff claps her hands loudly, only to hear the sound return to her as an echo 2.3 seconds later. What is the speed of sound on this day at her location?
   The speed of sound is the total distance traveled by the sound divided by the time elapsed. The total distance is out and back, so 2 x 385 m. v = (2*385) / 2.3 s = **335 m/s**

2. A boat traveling in saltwater (speed of sound = 1530 m/s) sends out an ultrasonic signal to the sea floor only to receive the reflected signal 0.23 second later. How deep is the ocean?
   Again, the distance traveled by the sound is equal to the speed of the sound times the time elapses. The distance is the out and back distance, or two times the distance to the bottom of the ocean from the boat. d = 1530 m/s * 0.23 s = 352 m / 2 = **176 m**

3. A particular sonar unit in a fishing boat stops working reliably when the boat is brought from the ocean to a freshwater lake. What is the problem? Should the captain worry about running aground?
   The speed of sound depends on the medium the sound is traveling through. Sound travels at a different speed in salt water than it does in fresh water. Specifically, sound travels faster in salt water, due to the increased density. That means, then, that the sonar will assume a faster speed than is accurate, leading to an over-reporting of the distance to the bottom of the lake. The captain should be cautious to not run aground, since the actual depth will be less than what the sonar indicates.

4. How are refraction and the speed of wave in different media related?
   Refraction arises because of the change in speed of waves in different media. When a wave travels faster in one medium, it tends to spend more time in it, and waves appear to bend towards the faster medium.

5. What properties do waves have that particles do not? Can you think of any properties that particles have that waves do not?
   Waves can exhibit diffraction and interference, which particles cannot. Particles have a definite mass and momentum, which particles do not.

6. Why do only very small particles have noticeable wave properties?
   Because the de Broglie wavelength of a particle is h/p, and h is a very small number, the wavelength is only appreciable if p (= mv, the momentum of the particle) is very small as well.

7. A wave of amplitude 0.5 m interferes with a wave of amplitude of 0.2m. What is the maximum resultant displacement that may occur? What is the minimum resultant displacement that may occur?
   If the two waves interfere constructively, the amplitude will be **0.7 m**. If the two waves interfere destructively, the amplitude will be **0.3 m**.

8. A string is rigidly attached to a post. A wave with amplitude of 0.5m is sent down the string. It is reflected off of the post. Assuming the amplitude of the forward wave remains the same upon reflection, what is the displacement when the two waves cross each other? What is this called?
   When a wave reflects off a fixed post, it is inverted. So, when the two waves interfere, it will result in **destructive interference**, with **no (0) displacement**.

9. A string is free to move in its attachment to a post. A wave with amplitude of 0.5m is sent down the string. It is reflected off of the post. Assuming the amplitude of the forward wave remains the same upon reflection, what is the displacement when the two waves cross each other? What is this called?
   When a wave reflects off a free boundary, it is not inverted, so when the two waves encounter each other it will result in **constructive interference**, with **amplitude of 1.0 m**.

10. In attempting to tune a piano, a piano tuner produces a note at 440 Hz. He notices that he hears beats with a frequency of 2 Hz when he strikes the "A" key on the piano. What frequency is the piano key actually producing? Why are there two possibilities?
    The piano could be producing either 442 Hz or 438 Hz. The tuner can't be sure which because the frequency of the beat is equal to the absolute value of the difference between the two frequencies. He would need to try a different frequency (441 Hz, for example) and see what happens to the beat frequency (if it becomes 3 Hz or 1 Hz in this example) to determine which frequency the piano is producing.

11. Why can you hear a radio playing around the corner but not see it?
    Sound waves in the audible range have large wavelengths, comparable to the size of a hallway or corner. Both are approximately on the scale of a meter. This allows the sound waves to diffract, or spread out, around the corner. Visible light, however, has a very short wavelength (less than micrometer), and thus, the waves do not diffract around the corner, which is an opening on the scale of meters.

12. What produces a standing wave? What are standing waves characterized by?
    Standing waves are produced by the alternating constructive and destructive interference of a forward wave and its reflection. They are characterized by a stationary pattern with nodes and antinodes.

13. A horn, when stationary, is heard to produce a tone of A (440 Hz). When the horn is placed on a train, it is heard to make a tone at 435 Hz. What direction is the train moving, relative to the listener?
    The train must be **moving away from the listener**, since the frequency detected is less than the frequency emitted. This means the observed wavelength is longer, which occurs when the source and observer are getting further apart.

14. How do police officers use the Doppler Effect to determine whether or not you deserve a ticket?
    Police use radar guns to determine your velocity by using the Doppler effect. The radio waves are emitted from the radar gun, bounce off your car, and return to the radio gun with a Doppler shift due to the relative motion of the car towards the radar gun. This is why police officers often stand still and aim directly at the cars to find speeders.

15. How can the density of a gas be determined from the shape of the spectral lines it produces?
    The broader the spectral line, the denser the gas that produced it. The more narrow the spectral line, the more rarefied the gas.

16. How does MOSAIC observe only the ozone from the mesosphere through the 99% of the ozone that lies in the lower atmosphere?
    MOSAIC looks at a very narrow range of frequencies, and, since the spectral line from the mesosphere is not pressure broadened, it can be detected within the range of the system. The stronger signal from the lower atmosphere is significantly pressure-broadened, and thus, cannot be detected in the narrow frequency range covered by MOSAIC.