Chapter 20 Homework

Due: 8:00am on Tuesday, January 19, 2010

Note: To understand how points are awarded, read your instructor's Grading Policy.

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A Vibrating String

An oscillator creates periodic waves on a stretched string.

Part A

If the period of the oscillator doubles, what happens to the wavelength and wave speed?

Hint A.1 **How to approach the problem**

Hint not displayed

Hint A.2 **Find the frequency**

Hint not displayed

Hint A.3 **Find the wave speed**

Hint not displayed

Hint A.4 **Wavelength relation**

Hint not displayed

ANSWER:

- (selected) The wavelength doubles but the wave speed is unchanged.
- The wavelength is halved but the wave speed is unchanged.
- The wavelength is unchanged but the wave speed doubles.

Correct

Part B

If the amplitude of the oscillator doubles, what happens to the wavelength and wave speed?

ANSWER:

- (selected) Both wavelength and wave speed are unchanged.
- The wavelength doubles but the wave speed is unchanged.
- The wavelength is unchanged but the wave speed doubles.

Correct

As you have discovered, when waves travel along a string, the wave speed remains unchanged, unless the properties of the string are changed. The wavelength can be varied only by changing the frequency, or alternatively the period, of the oscillator that creates the waves.

Properties of Ocean Waves

A fisherman notices that his boat is moving up and down periodically, owing to waves on the surface of the water. It takes a time of 2.80 s for the boat to travel from its highest point to its lowest, a total distance of 0.700 m. The fisherman sees that the wave crests are spaced a horizontal distance of 5.60 m apart.

Part A

How fast are the waves traveling?

Hint A.1 **How to approach the problem**

Calculate the period of the ocean waves, using the fisherman's observations. Then, use the period and wavelength to calculate the speed of the waves.

Hint A.2 **Calculate the period of the waves**

Calculate the period T of the ocean waves.

Hint A.2.1 **Definition of period**

The period of a wave is the time it takes for one full wavelength to pass a particular point. This is also the time it takes to go from one crest to the next, or from one trough to the next.

Express your answer in seconds using three significant figures.

ANSWER: T = 5.60 s *Correct*

Hint A.3 **Equation for the speed of a wave**

The speed of a wave is given by $v = f\lambda$, where f is the frequency of the waves and λ = 5.60 m is the wavelength. The frequency is simply the reciprocal of the period, or $f = 1/T$.

Express the speed v in meters per second using three significant figures.

ANSWER: v = 1.00 $\mathrm{m/s}$ *Correct*

Part B

What is the amplitude A of each wave?

Hint B.1 **Definition of amplitude**

Hint not displayed

Express your answer in meters using three significant figures.

ANSWER: A = 0.350 m *Correct*

The fisherman does not simply move up and down as the waves pass by. In fact, the motion of the fisherman will be roughly circular with both upward and forward components (with respect to the direction of the wave) as the wave rises and downward and backward components as the wave falls. The water that comprises the ocean wave itself moves in this same way. Thus, an ocean wave is not a purely transverse wave; it also has a *longitudinal* component.

Find the Wavelength

Assume the following waves are propagating in air.

Part A

Calculate the wavelength λ_1 for gamma rays of frequency f_1 = 5.80×10^{21} Hz.

Hint A.1 **How to set up the problem**

Recall the formula $c = \lambda f$.

Express your answer in meters.

ANSWER: λ_1 = **5.17×10^{-14}** m
Correct

Part B

Now express this gamma-ray wavelength in nanometers.

Hint B.1 **Relation between meters and nanometers**

Hint not displayed

Express your answer in nanometers.

ANSWER: λ_1 = **5.17×10^{-5}** nm
Correct

Part C

Calculate the wavelength λ_2 for visible light of frequency f_2 = 5.25×10^{14} Hz.

Hint C.1 **How to set up the problem**

Hint not displayed

Express your answer in meters.

ANSWER: λ_2 = **5.71×10^{-7}** m
Correct

Part D

Now express this visible wavelength in nanometers.

Hint D.1 **Relation between meters and nanometers**

Hint not displayed

Express your answer in nanometers.

ANSWER: λ_2 = **571** nm
Correct

The Hearing of a Bat

Bats are mainly active at night. They have several senses that they use to find their way about, locate prey, avoid obstacles, and "see" in the dark. Besides the usual sense of vision, bats are able to emit high-frequency sound waves and hear the echo that bounces back when these sound waves hit an object. This sonar-like system is called echolocation. Typical frequencies emitted by bats are between 20 and 200 kHz. Note that the human ear is sensitive only to frequencies as high as 20 kHz.

A moth of length 1.0 cm is flying about 1.0 m from a bat when the bat emits a sound wave at 80.0 kHz. The temperature of air is about 10.0$^\circ\mathrm{C}$. To sense the presence of the moth using echolocation, the bat must emit a sound with a wavelength equal to or less than the length of the insect.

The speed of sound that propagates in an ideal gas is given by

$$v = \sqrt{\frac{\gamma RT}{M}},$$

where γ is the ratio of heat capacities ($\gamma = 1.4$ for air), T is the absolute temperature in kelvins (which is equal to the Celsius temperature plus 273.15$^\circ\mathrm{C}$), M is the molar mass of the gas (for air, the average molar mass is $M = 28.8 \times 10^{-3}\ \mathrm{kg/mol}$), and R is the universal gas constant ($R = 8.314\ \mathrm{J \cdot mol^{-1} \cdot K^{-1}}$).

Part A

Find the wavelength λ of the 80.0-kHz wave emitted by the bat.

Hint A.1 **Relating wavelength, frequency, and speed of a wave**

In periodic waves, the speed at which the wave pattern travels is given by

$$v = \lambda f,$$

where λ is the wavelength and f is the frequency of the wave.

Hint A.2 **Find the speed of sound in air**

Find the speed of sound v in air at $10.0^\circ\mathrm{C}$.

Express your answer in meters per second.

ANSWER: v = 338 $\mathrm{m/s}$
Correct

Express your answer in millimeters.

ANSWER: λ = 4.23 mm
Correct

Part B

Will the bat be able to locate the moth despite the darkness of the night?

ANSWER:
- yes
- no

Correct

Part C

How long after the bat emits the wave will it hear the echo from the moth?

Hint C.1 **How to approach the problem**

After emitting the high-frequency sound, the bat waits for any echoes coming back from possible obstacles. Therefore the time needed to locate an obstacle depends on the speed of sound and the distance of the obstacle from the bat.

Hint C.2 **Find the time needed for the sound wave to reach the moth**

How long does it take the sound wave to reach the moth?

Express your answer in milliseconds to three significant figures.

ANSWER: 2.96 ms
Correct

The time elapsed from the emission of the sound to the detection of its echo is the time the sound wave takes to travel 1 m and back.

Express your answer in milliseconds to two significant figures.

ANSWER: 5.9 ms
Correct

Surface Waves

The waves on the ocean are surface waves: They occur at the interface of water and air, extending down into the water and up into the air at the expense of becoming exponentially reduced in amplitude. They are neither transverse nor longitudinal. The water both at and below the surface travels in vertical circles, with exponentially smaller radius as a function of depth.

Both empirical measurements and calculations beyond the scope of introductory physics give the propagation speed of water waves as

$$v = \sqrt{\frac{g}{k}},$$

where $g = 9.8\ \mathrm{m/s^2}$ is the magnitude of the acceleration due to gravity and k is the wavenumber.

This relationship applies only when the following three conditions hold:

1. The water is several times deeper than the wavelength.
2. The wavelength is large enough that the surface tension of the waves can be neglected.
3. The ratio of wave height to wavelength is small.

The restoring force (analogous to the tension in a string) that restores the water surface to flatness is due to gravity, which explains why these waves are often called "gravity waves."

Part A

Find the speed v of water waves in terms of the wavelength λ.

Hint A.1 **Definition of k**

Hint not displayed

Express the speed in terms of g, λ, and π.

ANSWER: $v = \sqrt{\frac{\lambda g}{2\pi}}$
Correct

Part B

Find the speed v of a wave of wavelength $\lambda = 8.0\ \mathrm{m}$.

Give your answer in meters per second to a precision of two significant figures.

ANSWER: $v(\lambda = 8\ \mathrm{m})$ 3.5 m/s
Correct

Part C

Find the period T for a wave of wavelength λ.

Hint C.1 **Formula for T**

Express T in terms of constants like g and π and any *two* of the following kinematic parameters used to characterize traveling wave propagation: the angular frequency ω, the frequency f, the wavelength λ, and the velocity v.

ANSWER: T = ***Answer not displayed***

Express the period in terms of π, λ, and g.

ANSWER: $T = \frac{\lambda}{\sqrt{\frac{(g \cdot \lambda)}{2\pi}}}$
Correct

Part D

On the East Coast of the United States, the National Weather Service frequently reports waves with a period of 4.0 s. Find the wavelength λ and speed v of these waves.

Hint D.1 **Relationship between wavelength and period**

Hint not displayed

Express your answers numerically as an ordered pair separated by a comma. Give an accuracy of two significant figures.

ANSWER: λ, v = **25,6.25** m, m/s
Correct

Part E

On the West Coast of the United States, the National Weather Service frequently reports waves (really swells) with a period of 15 s. Find the wavelength λ and speed v of these waves.

Express your answers numerically as an ordered pair separated by a comma. Give an accuracy of two significant figures.

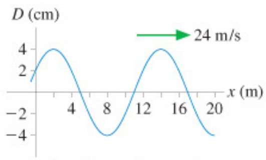
ANSWER: λ, v = **350,23** m, m/s
Correct

Conceptual Question 20.5

Part A

What is the amplitude of the traveling wave in the figure?

Express your answer using two significant figures.



Snapshot graph at $t = 0$ s

ANSWER: A = **4.0** cm
Correct

Part B

What is the wavelength of the traveling wave in the figure?

Express your answer using two significant figures.

ANSWER: λ = **12** m
Correct

Part C

What is the frequency of the traveling wave in the figure?

Express your answer using two significant figures.

ANSWER: f = **2.0** Hz
Correct

Part D

What is the phase constant of the traveling wave in the figure?

Express your answer in terms of constant π.

ANSWER: ϕ_0 = **0.524** rad
Correct

Problem 20.2

The wave speed on a string is 154 $\mathrm{m/s}$ when the tension is 73.0 N.

Part A

What tension will give a speed of 181 $\mathrm{m/s}$?

ANSWER: **101** N
Correct

Problem 20.29

The intensity of electromagnetic waves from the sun is $1.4\ \mathrm{kW/m^2}$ just above the earth's atmosphere. Eighty percent of this reaches the surface at noon on a clear summer day. Suppose you think of your back as a 35.0 cm × 52.0 cm rectangle.

Part A

How many joules of solar energy fall on your back as you work on your tan for 0.800 hr?

ANSWER: **5.87×10^5** J
Correct

Conceptual Question 20.11

One physics professor talking produces a sound intensity level of 52 dB.

Part A

It's a frightening idea, but what would be the sound intensity level of 100 physics professors talking simultaneously?

ANSWER: β = **72** dB
Correct

Doppler Shift

Learning Goal: To understand the terms in the Doppler shift formula.

The Doppler shift formula gives the frequency $f_{\rm L}$ at which a listener L hears the sound emitted by a source S at frequency $f_{\rm S}$:

$$f_{\rm L} = f_{\rm S}\frac{v + v_{\rm L}}{v + v_{\rm S}},$$

where v is the speed of sound in the medium, $v_{\rm L}$ is the velocity of the listener, and $v_{\rm S}$ is the velocity of source.

Part A

The velocity of the source is positive if the source is ______________. Note that this equation may not use the sign convention you are accustomed to. Think about the physical situation before answering.

Hint A.1 **Relating the frequency and the source velocity**

Hint not displayed

ANSWER:

- ○ traveling in the +*x* direction
- ○ traveling toward the listener
- ◉ traveling away from the listener

Correct

Part B

The velocity of the source is measured with respect to the ________.

ANSWER:

- ◉ medium (such as air or water)
- ○ listener

Correct

Part C

The velocity of the listener is positive if the listener is _____________.

Hint C.1 **Relating the frequency and the listener's velocity**

Hint not displayed

ANSWER:

- ○ traveling in the +*x* direction
- ◉ traveling toward the source
- ○ traveling away from the source

Correct

Part D

The velocity of the listener is measured with respect to the ________.

ANSWER:

- ○ source
- ◉ medium

Correct

Here are two rules to remember when using the Doppler shift formula:

1. Velocity is measured *with respect to the medium.*
2. The velocities are *positive* if they are in the direction from the *listener to the source.*

Part E

Imagine that the source is to the right of the listener, so that the positive reference direction (from the listener to the source) is in the $+\hat{x}$ direction. If the listener is stationary, what value does f_L approach as the source's speed approaches the speed of sound moving to the right?

ANSWER:

- ○ 0
- ◉ $\frac{1}{2}f_S$
- ○ $2f_S$
- ○ It approaches infinity.

Correct

Part F

Now, imagine that the source is to the left of the listener, so that the positive reference direction is in the $-\hat{x}$ direction. If the source is stationary, what value does f_L approach as the listener's speed (moving in the $+\hat{x}$ direction) approaches the speed of sound?

ANSWER:

- ◉ 0
- ○ $\frac{1}{2}f_S$
- ○ $2f_S$
- ○ It approaches infinity.

Correct

Basically in this case the listener doesn't hear anything since the sound waves cannot catch up with him or her.

Part G

In this last case, imagine that the listener is stationary and the source is moving toward the listener at the speed of sound. (Note that it is irrelevant whether the source is moving to the right or to the left.) What is f_L when the sound waves reach the listener?

ANSWER:

- ○ 0
- ○ $\frac{1}{2}f_S$
- ○ $2f_S$
- ◉ It approaches infinity.

Correct

This case involves what is called a sonic boom. The listener will hear no sound ($f_L = 0$) until the sonic boom reaches him or her (just as the source passes by). At that instant, the frequency will be infinite. There is no time between the passing waves--they are literally right on top of each other. That's a lot of energy to pass by the listener at once, which explains why a sonic boom is so loud.

The Doppler Effect on a Train

A train is traveling at 30.0 $\mathrm{m/s}$ relative to the ground in still air. The frequency of the note emitted by the train whistle is 262 Hz.

Part A

What frequency $f_{approach}$ is heard by a passenger on a train moving at a speed of 18.0 $\mathrm{m/s}$ relative to the ground in a direction opposite to the first train and approaching it?

Hint A.1 **How to approach the problem**

Hint not displayed

Hint A.2 **Doppler shift equations for moving source or observer**

Hint not displayed

Hint A.3 **Doppler equations when both the source and the listener are in motion**

Hint not displayed

Hint A.4 **Determine the appropriate signs**

Hint not displayed

Express your answer in hertz.

ANSWER: $f_{approach}$ = **302** Hz

Correct

Part B

What frequency f_{recede} is heard by a passenger on a train moving at a speed of 18.0 $\mathrm{m/s}$ relative to the ground in a direction opposite to the first train and receding from it?

Hint B.1 **How to approach the problem**

Hint not displayed

Hint B.2 **Doppler shift equations for moving source or observer**

Hint not displayed

Hint B.3 **Doppler equations when both the source and the listener are in motion**

Hint not displayed

Hint B.4 **Determine the appropriate signs**

Hint not displayed

Express your answer in hertz.

ANSWER: $f_{\rm recede}$ = **228** Hz
Correct

Score Summary:

Your score on this assignment is 99.8%.
You received 69.87 out of a possible total of 70 points.