PHYS 13300 (Waves, Optics, and Heat) Problem Sets

Steven Labalme

August 11, 2021

Contents

1 Mechanical Waves

8/9: 1) Young and Freedman (2019): Problem 15.9.

Which of the following wave functions satisfies the wave equation?

(a) $y(x,t) = A\cos(kx+\omega t)$.

(b) $y(x,t) = A\sin(kx+\omega t)$.

(c) $y(x,t) = A(\cos kx + \cos\omega t)$.

(d) For the wave of part (b), write the equations for the transverse velocity and transverse acceleration of a particle at point x.

2) Young and Freedman (2019): Problem 15.26.

A fellow student with a mathematical bent tells you that the wave function of a traveling wave on a thin rope is $y(x,t) = (2.30\,\text{mm})\cos[(6.98\,\text{rad/m})x + (742\,\text{rad/s})t]$. Being more practical, you measure the rope to have a length of 1.35 m and a mass of 0.003 38 kg. You are then asked to determine:

(a) Amplitude.

(b) Frequency.

(c) Wavelength.

(d) Wave speed.

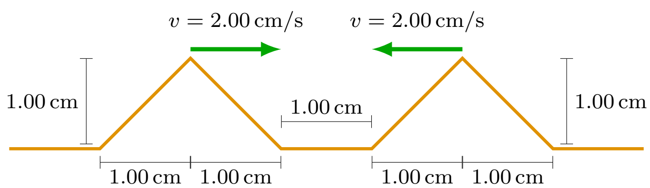
(e) Direction the wave is traveling.

(f) Tension in the rope.

(g) Average power transmitted by the wave.

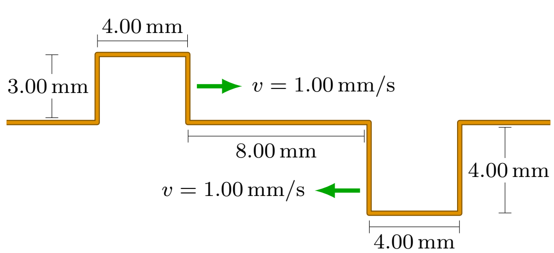
3) Young and Freedman (2019): Problem 15.30.

Interference of Triangular Pulses. Two triangular wave pulses are traveling toward each other on a stretched string as shown below. Each pulse is identical to the other and travels at 2.00 cm/s. The leading edges of the pulses are 1.00 cm apart at $t=0$. Sketch the shape of the string at $t=0.250$ s, $t=0.500$ s, $t=0.750$ s, $t=1.000$ s, and $t=1.250$ s.



4) Young and Freedman (2019): Problem 15.32.

Interference of Rectangular Pulses. The below figure shows two rectangular wave pulses on a stretched string traveling toward each other. Each pulse is traveling with a speed of 1.00 mm/s and has the height and width shown in the figure. If the leading edges of the pulses are 8.00 mm apart at $t=0$, sketch the shape of the string at $t=4.00$ s, $t=6.00$ s, and $t=10.0$ s.



5) Young and Freedman (2019): Problem 15.34.

   Adjacent antinodes of a standing wave on a string are 15.0 cm apart. A particle at an antinode oscillates in simple harmonic motion with amplitude 0.850 cm and period 0.075 0 s. The string lies along the $+x$-axis and is fixed at $x = 0$.

   (a) How far apart are the adjacent nodes?

   (b) What are the wavelength, amplitude, and speed of the two traveling waves that form this pattern?

   (c) Find the maximum and minimum transverse speeds of a point at an antinode.

   (d) What is the shortest distance along the string between a node and an antinode?

6) Young and Freedman (2019): Problem 15.64.

   A strong string of mass 3.00 g and length 2.20 m is tied to supports at each end and is vibrating in its fundamental mode. The maximum transverse speed of a point at the middle of the string is 9.00 m/s. The tension in the string is 330 N.

   (a) What is the amplitude of the standing wave at its antinode?

   (b) What is the magnitude of the maximum transverse acceleration of a point at the antinode?

7) A harmonic wave travels down a string in the $+x$ direction. At position $x = 0$ and time $t = 0$, the following is observed: the displacement of the string is +1.0 cm, the transverse velocity is −2.0 cm/s, and the transverse acceleration is $-4.0\,\mathrm{cm/s^2}$.

   (a) What is the frequency of the wave?

   (b) What is the amplitude of the wave?

8) A long, uniform rope of length L hangs vertically. The only tension in the rope is that produced by its own weight.

   (a) Show that, as a function of the distance y from the lower end of the rope, the speed of a transverse wave pulse on the rope is $\sqrt{gy}$.

   (b) How much time does it take for a wave pulse to travel from one end of the rope to the other?

9) Using continuity conditions on a string, we derived the relative amplitudes for transmitted and reflected waves at a boundary. Show that the average power of the *transmitted* wave plus the average power of the *reflected* wave is equal to the average power of the *incident* wave. (Otherwise, energy would not be conserved.)

2 Sound and Light

8/12: 1) Young and Freedman (2019): Problem 15.25.

A jet plane at takeoff can produce sound of intensity $10.0\,\mathrm{W/m^2}$ at $30.0\,\mathrm{m}$ away. But you prefer the tranquil sound of normal conversation, which is $1.0\,\mathrm{\mu W/m^2}$. Assume that the plane behaves like a point source of sound.

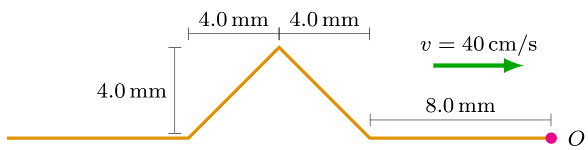
(a) What is the closest distance you should live from the airport runway to preserve your peace of mind?

(b) What intensity from the jet does your friend experience if she lives twice as far from the runway as you do?

(c) What power of sound does the jet produce at takeoff?

2) Young and Freedman (2019): Problem 15.28.

Reflection. A wave pulse on a string has the dimensions shown in the following figure at $t = 0$. The wave speed is $40\,\mathrm{cm/s}$.



(a) If point O is a fixed end, draw the total wave on the string at $t = 15\,\mathrm{ms}$, $20\,\mathrm{ms}$, $25\,\mathrm{ms}$, $30\,\mathrm{ms}$, $35\,\mathrm{ms}$, $40\,\mathrm{ms}$, and $45\,\mathrm{ms}$.

(b) Repeat part (a) for the case in which point O is a free end.

3) Young and Freedman (2019): Problem 16.24.

The fundamental frequency of a pipe that is open at both ends is $524\,\mathrm{Hz}$.

(a) How long is the pipe?

If one end is now closed, find the new fundamental's

(b) Wavelength;

(c) Frequency.

4) Young and Freedman (2019): Problem 16.35.

Two loudspeakers, A and B, are driven by the same amplifier and emit sinusoidal waves in phase. Speaker B is $12.0\,\mathrm{m}$ to the right of speaker A. The frequency of the waves emitted by each speaker is $688\,\mathrm{Hz}$. You are standing between the speakers, along the line connecting them, and are at a point of constructive interference. How far must you walk toward speaker B to move to a point of destructive interference?

5) Young and Freedman (2019): Problem 16.50.

The siren of a fire engine that is driving northward at $30.0\,\mathrm{m/s}$ emits a sound of frequency $2\,000\,\mathrm{Hz}$. A truck in front of this fire engine is moving northward at $20.0\,\mathrm{m/s}$.

(a) What is the frequency of the siren's sound that the fire engine driver hears reflected from the back of the truck?

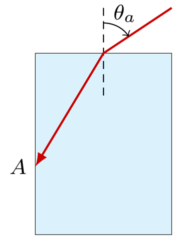
(b) What wavelength would this driver measure for these reflected sound waves?

6) Young and Freedman (2019): Problem 16.62.

A bat flies toward a wall, emitting a steady sound of frequency $1.70\,\mathrm{kHz}$. This bat hears its own sound plus the sound reflected by the wall. How fast should the bat fly in order to hear a beat frequency of $8.00\,\mathrm{Hz}$.

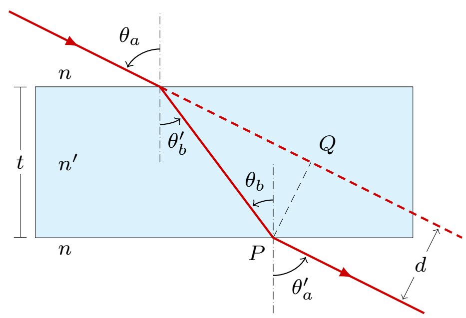
7) Young and Freedman (2019): Problem 33.39.

A ray of light is incident in air on a block of a transparent solid whose index of refraction is n. If $n = 1.38$, what is the *largest* angle of incidence θ_a for which total internal reflection will occur at the vertical face (point A in the below figure)?



8) Young and Freedman (2019): Problem 33.52.

Light is incident in air at an angle θ_a on the upper surface of a transparent plate, the surfaces of the plate being plane and parallel to each other.



(a) Prove that $\theta_a = \theta'_a$.

(b) Show that this is true for any number of different parallel plates.

(c) Prove that the lateral displacement d of the emergent beam is given by the relationship

$$d = t \cdot \frac{\sin(\theta_a - \theta'_b)}{\cos\theta'}$$

where t is the thickness of the plate.

(d) A ray of light is incident at an angle of 66.0° on one surface of a glass plate 2.40 cm thick with an index of refraction of 1.80. The medium on either side of the plate is air. Find the lateral displacement between the incident and emergent waves.

9) An airplane has a defective speedometer. In order to figure out how fast the plane is flying, the pilot (an aspiring opera singer) leans out the window and sings “middle C” (a note of frequency 262 Hz) at a mountain looming ahead. The echo off the mountain is heard by the pilot as “middle A” (frequency 440 Hz). How fast is the plane flying?

References

Young, H. D., & Freedman, R. A. (2019). *University physics with modern physics* (Fifteenth). Pearson Education.