

Portland State University
 General Physics Workshop
 Problem Set 2

Waves on a String and Sound

Equations and Relations:

Speed, wavelength, and frequency of a wave

$$v = \lambda f$$

Speed of a wave of a string:

$$v = \sqrt{\frac{T}{\mu}}$$

F : tension force

Mass per length (string)

$$\mu = m/L$$

Harmonic wave function

$$y(x, t) = A \cos\left(\frac{2\pi}{\lambda}x - \frac{2\pi}{T}t\right)$$

$$k = 2\pi/\lambda \quad \omega = 2\pi/T$$

Intensity as power per area:

$$I = \frac{P}{A}$$

$$I = \frac{P}{4\pi r^2} \quad (\text{point source at a distance } r)$$

Intensity level β ,

$$\beta = 10 \log(I/I_0)$$

$$I_0 = 10^{-12} \text{ W/m}^2$$

Standing waves on a string:

$$f_n = n f_1 = n(v/2L)$$

$$\lambda_n = \lambda_1/n = 2L/n \quad n = 1, 2, 3, \dots$$

Vibrating columns of air – closed at one end

$$f_n = n f_1 = n(v/4L) \quad n = 1, 3, 5, \dots$$

$$\lambda_n = \lambda_1/n = 4L/n$$

Vibrating columns of air – open at both ends

$$f_n = n f_1 = n(v/2L) \quad n = 1, 2, 3, \dots$$

$$\lambda_n = \lambda_1/n = 2L/n$$

L : length of the tube or string

1. When sound waves strike the eardrum, the membrane vibrates with the same frequency as the sound. The highest pitch that typical humans can hear has a period of 50.0 μs . What are the frequency and angular frequency of the vibrating eardrum for this sound?
2. High-frequency sound waves (ultrasound) are used to probe the interior of the body, much as x-rays do. To detect small objects, such as tumors, a frequency of around 5.0 MHz is used. What are the period and angular frequency of the molecular vibrations caused by this pulse of sound?
3. A variable oscillator allows a laboratory student to adjust the frequency of a source to produce standing waves in a vibrating string. A 1.20-m length of string ($\mu = 0.400 \text{ g/m}$) is placed under a tension of 200 N. What frequency is necessary to produce three standing

loops in the vibrating string? What is the fundamental frequency? What frequency will produce five loops?

- *The piano strings that vibrate with the lowest frequencies consist of a steel wire around which a thick coil of copper wire is wrapped. Only the inner steel wire is under tension. What is the purpose of the copper coil?*
4. A piano string of length 1.50 m and mass density 25.0 mg/m vibrates at a (fundamental) frequency of 450.0 Hz.
- What is the speed of the transverse string waves?
 - What is the tension?
 - What are the wavelength and frequency of the sound wave in air produced by vibration of the string? The speed of sound in air at room temperature is 340 m/s.
5. One of the harmonics of a column of air open at both ends has a frequency of 324 Hz and the next higher harmonic has a frequency of 378 Hz.
- What the frequency of the next higher harmonic?
 - What is number, n , of this harmonic?
 - What is the fundamental frequency of the air column?
- *If the length of a guitar string is decreased while the tension remains constant, what happens to each of these quantities?*
- the wavelength of the fundamental*
 - the frequency of the fundamental*
 - the time for a pulse to travel the length of the string*
 - the maximum velocity for a point on the string (assuming the amplitude is the same both times)*
 - the maximum acceleration for a point on the string (assuming the amplitude is the same both times)*
- *A cello player can change the frequency of the sound produced by her instrument by*
- increasing the tension in the string,*
 - pressing her finger on the string at different places along the fingerboard, or*
 - bowing a different string.*
- Explain how each of these methods affects the frequency.*
6. A wave on a string has equation $y(x,t) = (4.0 \text{ mm}) \sin(\omega t - kx)$, where $\omega = 6.0 \times 10^2 \text{ rad/s}$ and $k = 6.0 \text{ rad/m}$.
- What is the amplitude of the wave?

- (b) What is the wavelength?
 - (c) What is the period?
 - (d) What is the wave speed?
 - (e) In which direction does the wave travel?
7. (a) Plot a graph for $y(x,t) = 4.0\text{cm} \sin(378\text{s}^{-1}t - 314\text{cm}^{-1}x)$, where t is in s and x and y are in cm, versus x at $t = 0$ and at $t = \frac{1}{480}$ s. From the plots determine the amplitude, wavelength, and speed of the wave.
- (b) For the same function, plot a graph of $y(x,t)$ versus t at $x = 0$ and find the period of the vibration.
8. During a concert a single singer generates an intensity level of 55dB at a certain location in the concert hall. With the whole choir singing the intensity level is 75dB. Assuming that each singer generates the same intensity level, how many people are in the choir?

Additional Questions

1. Why must astronauts on the surface of the moon communicate with each other by radio? Can they hear another spacecraft as it lands nearby? Can they hear by touching helmets?
2. When an earthquake occurs, the S waves (transverse waves) are not detected on the opposite side of the Earth while the P waves (longitudinal waves) are. How does this provide evidence that the Earth's solid core is surrounded by liquid?
3. Why is it that your own voice sounds strange to you when you hear it played back on a tape recorder, but your friends all agree that it is just what your voice sounds like? [Hint: Consider the media through which the sounds wave travels when you usually hear your own voice.]
4. Is the vibration of a string in a piano, guitar, or violin a sound wave? Explain.
5. Many real estate agents have an ultrasonic rangefinder that enables them to quickly and easily measure the dimensions of a room. The device is held to one wall and reads the distance to the opposite wall. How does it work?