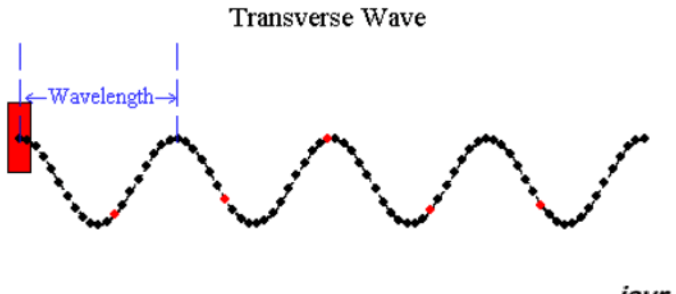
PHY131H1F - Class 22

Today:

- Today, we start the **last chapter** of this course: Ch.14 on Waves
- Wave Properties
- Waves on a string
- Wave Power and Intensity
- Sound Waves



Animation from http://resource.isvr.soton.ac.uk/spcg/tutorial/tutorial/Tutorial_files/Web-basics-nature.htm

Announcements

```
BILL: Ah. Music lover, eh?
BRIDE: He's fond of music.
BILL: Aren't we all?
```

- Next semester I'll be teaching PHY207H1S "Physics of Music" for the first time.
- The Practicals Coordinator for PHY131, Dr. Sealfon, has arranged a musical demonstration for Wednesday morning at 11:10am. It will consist of about 10 minutes of choir and organ music, with some Fast Fourier Transform software to illustrate the overtones present in a large theatre like Convocation Hall.

Learning Catalytics Question 1

The constant, k, introduced in Section 14.2 on Wave Math is

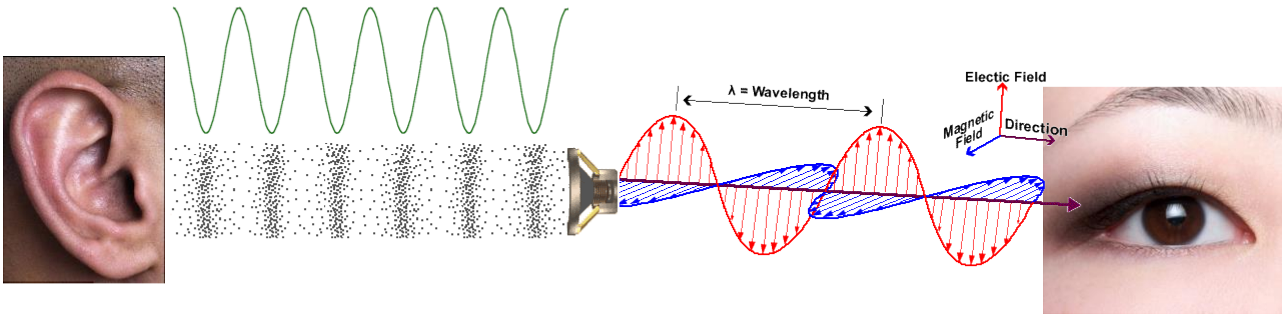
A. The Boltzman's constant, with units: J/K.

B. The Coulomb constant, with units: $\mathrm{N\ m^2/c^2}$.

C. The spring constant, with units: N/m.

D. The wave number, with units: rad/m.

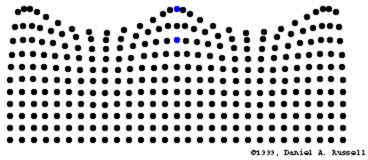
Last day I asked



- Two of the five senses depend on **waves** in order to work: which two?
- Answer: Sight and Sound!
- Sound is a pressure wave which travels through the air.
- Light is a wave in the electric and magnetic fields.

Chapter 14. Wave Motion

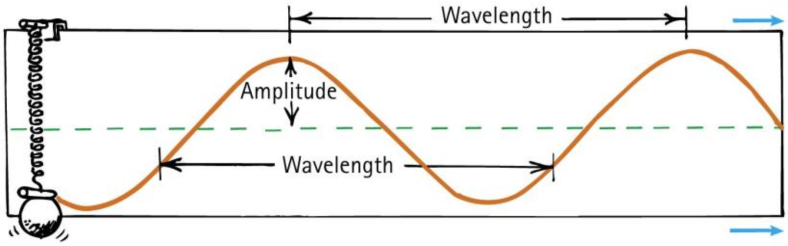
- A *vibration* is a periodic linear motion of a particle about an equilibrium position.
- When many particles vibrate and carry energy through space, this is a *wave.* A wave extends from one place to another.
- Examples are:
  - water waves
  - light, which is an electromagnetic wave
  - sound



[image from https://webspace.utexas.edu/cokerwr/www/index.html/waves.html ©1999 by Daniel A. Russell]

Amplitude and Wavelength

- Amplitude
  - distance from the midpoint to the crest or to the trough
- Wavelength
  - distance from the top of one crest to the top of the next crest, or distance between successive identical parts of the wave



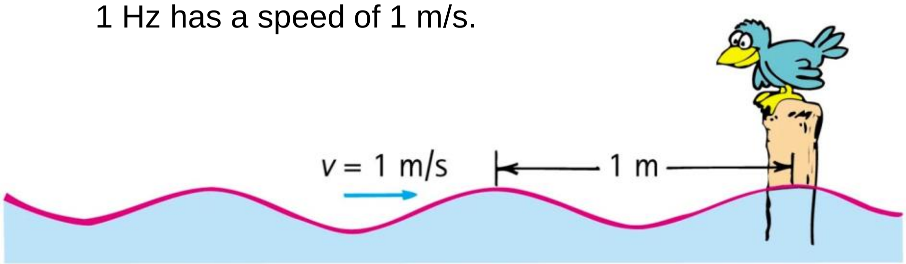
Wave speed

- Describes how fast a disturbance moves through a medium
- Related to frequency and wavelength of a wave

  Wave speed = frequency × wavelength

Example:

- A wave with wavelength 1 meter and frequency of 1 Hz has a speed of 1 m/s.

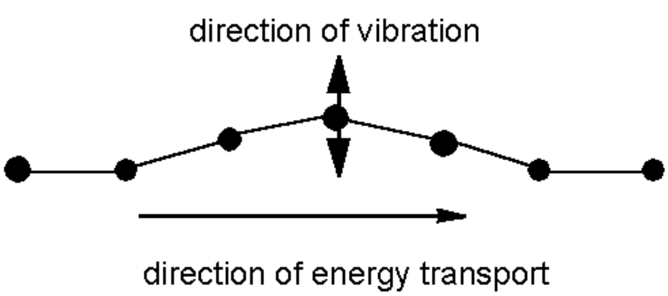


Transverse waves

- Medium vibrates perpendicularly to direction of energy transfer
- Side-to-side movement

  Example:

  - Vibrations in stretched strings of musical instruments

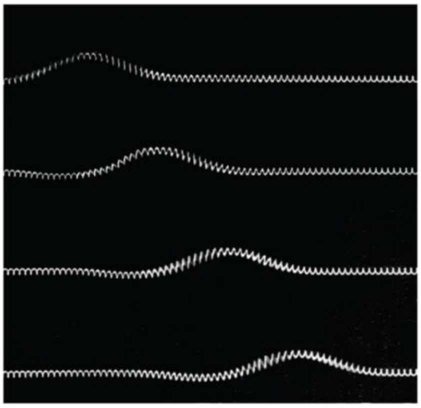


[image from http://www.maths.gla.ac.uk/~fhg/waves/waves1.html]

Transverse waves

The speed of transverse waves on a string stretched with tension F is:

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



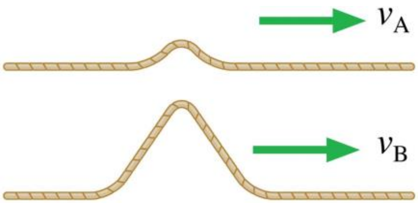
Where μ is the string's mass-to-length ratio, also called the **linear density**:

$$\mu = \frac{m}{L}$$

Units: [kg/m]

Learning Catalytics Question 2

These two wave pulses travel along the same stretched string, one after the other. Which is true?



A. $v_A > v_B$

B. $v_B > v_A$

C. $v_A = v_B$

D. Not enough information to tell.

Pre-class 22 Quiz from This Morning

2. multiple choice

You are generating traveling waves on a stretched string by wiggling one end. If you suddenly begin to wiggle more rapidly without appreciably affecting the tension, you will cause the waves to move down the string

A. faster than before.

B. slower than before.

C. at the same speed as before.

Learning Catalytics Question 3

For a wave pulse on a string to travel twice as fast, the string tension must be

A. Increased by a factor of 4.
B. Increased by a factor of 2.
C. Decreased to one half its initial value.
D. Decreased to one fourth its initial value.
E. Not possible. The pulse speed is always the same.

Pre-class 22 Quiz from This Morning

1. numerical

Waves travel along a 100-m length of string which has a mass of 55 g and is held taut with a tension of 75 N. What is the speed of the waves?

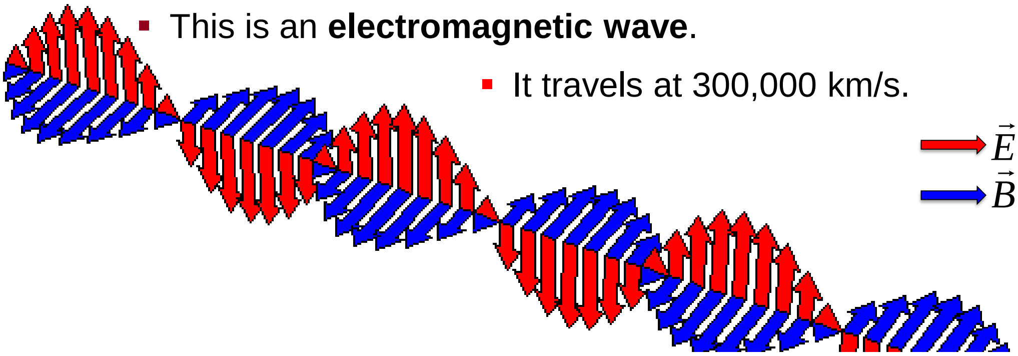
[Enter the number of the answer only. Use units of m/s.]

370:

Example.
An 80 kg climber hangs from a rope, 20 m below a rocky overhang. The rope has a linear density of 37 g/m. Approximately how long would it take a transverse pulse to travel the length of the rope from the climber to the overhang?

Transverse Waves
Maxwell's Theory of Electromagnetic Waves

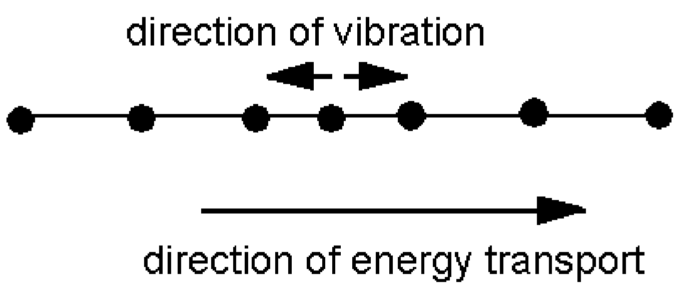
- A changing electric field creates a magnetic field, which then changes in just the right way to recreate the electric field, which then changes in just the right way to again recreate the magnetic field, and so on.
- This is an **electromagnetic wave**.
- It travels at 300,000 km/s.



Longitudinal waves

- Medium vibrates parallel to direction of energy transfer
- Backward and forward movement consists of
  - compressions (wave compressed)
  - rarefactions (stretched region between compressions)

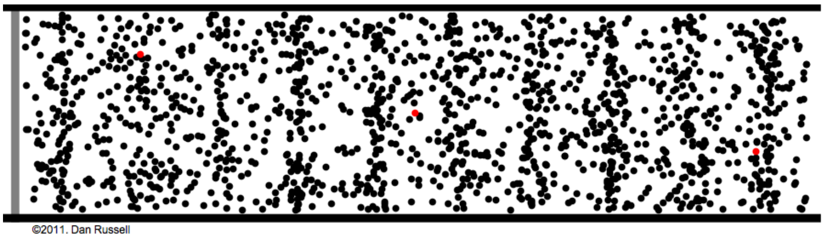
  Example: sound waves in solid, liquid, gas



[image from http://www.maths.gla.ac.uk/~fhg/waves/waves1.html]

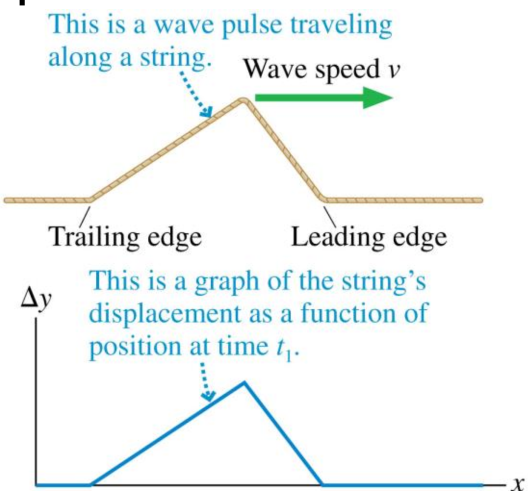
Longitudinal Waves

- Sound is a longitudinal wave.
- Compression regions travel at the speed of sound.
- In a compression region, the density and pressure of the air is higher than the average density and pressure.



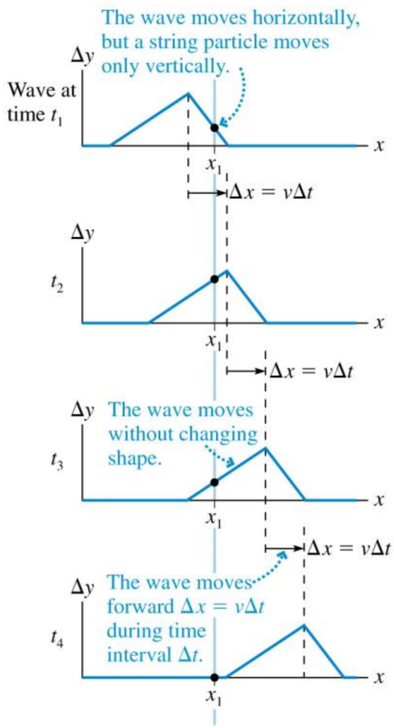
Snapshot Graph

- A graph that shows the wave's displacement as a function of position at a single instant of time is called a **snapshot graph**.
- For a wave on a string, a snapshot graph is literally a picture of the wave at this instant.



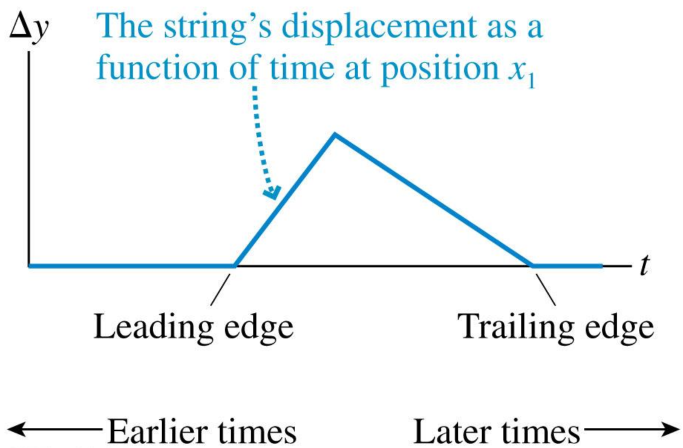
One-Dimensional Waves

- The figure shows a sequence of snapshot graphs as a wave pulse moves.
- These are like successive frames from a movie.
- Notice that the wave pulse moves forward distance $\Delta x = v\Delta t$ during the time interval Δt.
- That is, the wave moves with *constant speed.*



History Graph

- A graph that shows the wave's displacement as a function of time at a single **position** in space is called a **history graph.**
- This graph tells the history of that particular point in the medium.
- Note that for a wave moving from left to right, the shape of the history graph is *reversed* compared to the snapshot graph.



The Mathematics of Sinusoidal Waves

$y = A\cos(kx - \omega t)$ is a sinusoidal wave traveling in the $+x$ direction.

$y = A\cos(kx + \omega t)$ is a sinusoidal wave traveling in the $-x$ direction.

- The *angular frequency* of the wave is omega:

$$\omega = 2\pi f = \frac{2\pi}{T}$$

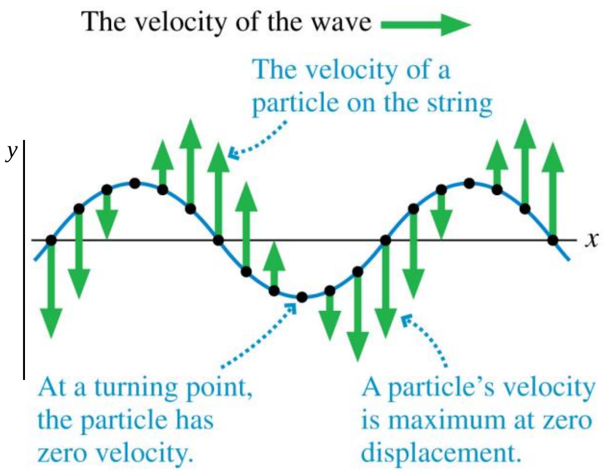
- The *wave number* of the wave is k:

$$k = \frac{2\pi}{\lambda}$$

This wave travels at a speed: $v = \frac{\omega}{k}$.

Wave Motion on a String

- Shown is a snapshot graph of a wave on a string with vectors showing the velocity of the string at various points.
- As the wave moves along x, the velocity of a particle on the string is in the y-direction.

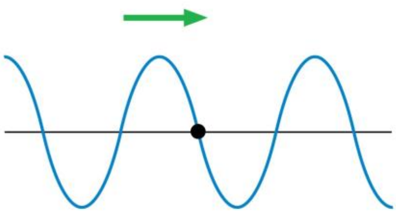


$$y = A\cos(kx - \omega t)$$

$$v_y = \frac{\partial y}{\partial t} = A\omega\sin(kx - \omega t)$$

Learning Catalytics Question 4

A wave on a string is traveling to the right. At this instant, the motion of the piece of string marked with a dot is



A. Up.

B. Down.

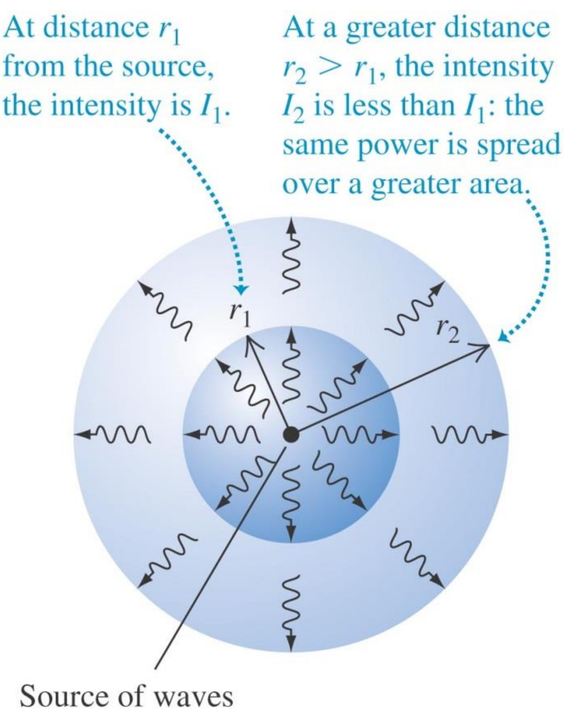
C. Right.

D. Left.

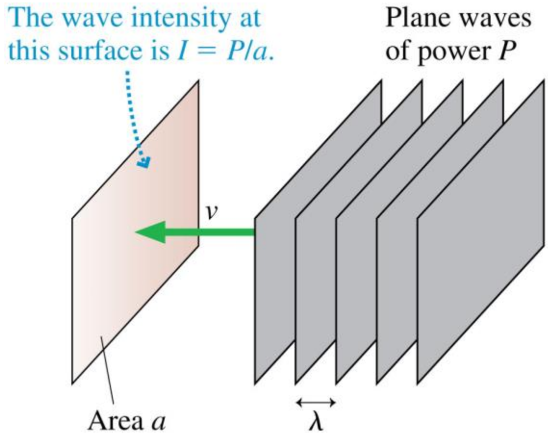
E. Zero. Instantaneously at rest.

Wave intensity

- The *intensity* of a wave is the average power it carries per unit area.
- If the waves spread out uniformly in all directions and no energy is absorbed, the intensity I at any distance r from a wave source is inversely proportional to r^2.



Power and Intensity



- When plane waves of power P impinge on area a, we define the **intensity** I to be:

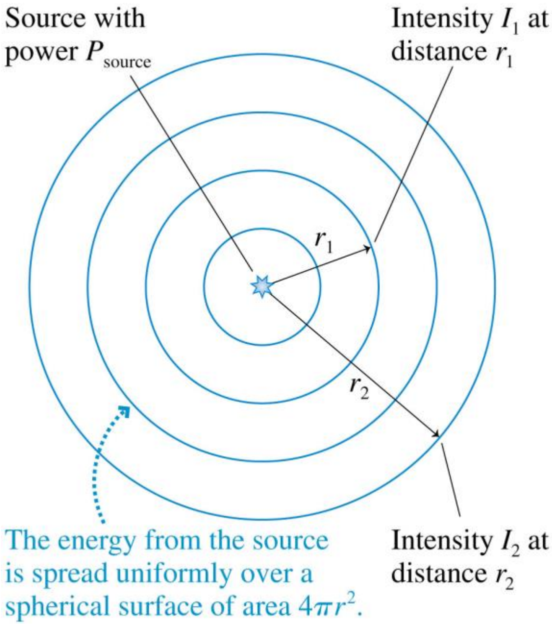
$$I = \frac{P}{a} = \text{power-to-area ratio}$$

Example 20.9.
A laser pointer emits 1.0 mW of light power into a 1.0 mm diameter laser beam. What is the intensity of the laser beam?

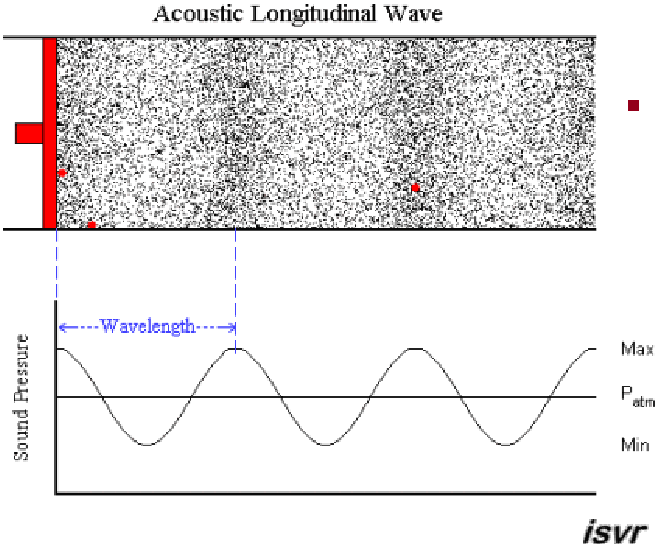
Intensity of Spherical Waves

- If a source of spherical waves radiates uniformly in all directions, then the power at distance r is spread uniformly over the surface of a sphere of radius r.
- The intensity of a uniform spherical wave is:

$$I = \frac{P_{\text{source}}}{4\pi r^2}$$



Sound Waves



- A sound wave in a fluid is a sequence of compressions and rarefactions.

Animation from http://resource.isvr.soton.ac.uk/spcg/tutorial/tutorial/Tutorial_files/Web-basics-nature.htm

Pre-class 22 Quiz from This Morning

3. multiple choice

What characteristic of sound determines the "pitch" of a musical note?

A. amplitude

B. wavelength

C. frequency

D. phase

E. intensity

Sound Waves

- For air at room temperature (20°C), the speed of sound is $v_{sound} = 343$ m/s.
- Your ears are able to detect sinusoidal sound waves with frequencies between about 20 Hz and 20 kHz.
- Low frequencies are perceived as "low pitch" bass notes, while high frequencies are heard as "high pitch" treble notes.
- Sound waves with frequencies above 20 kHz are called *ultrasonic* frequencies.
- Oscillators vibrating at frequencies of many MHz generate the ultrasonic waves used in ultrasound medical imaging.

Image from http://www.weblocal.ca/uc-baby-3d-ultrasound-brampton-on.html

Before Class 23 on Wednesday

- If you haven't done it, please check your utoronto email, respond to the course_evaluations email and evaluate us!
- Please read up to the end of Section 14.7 of Chapter 14 on Waves, and/or watch the Preclass 23 Video
- We are skipping section 14.8 on Doppler Shift for this course.
- Something to think about over the weekend:
- What is a "Standing Wave"?
- NOTE: We will be meeting right here, 11:10am-12:00pm on Thursday for the last class of the semester!