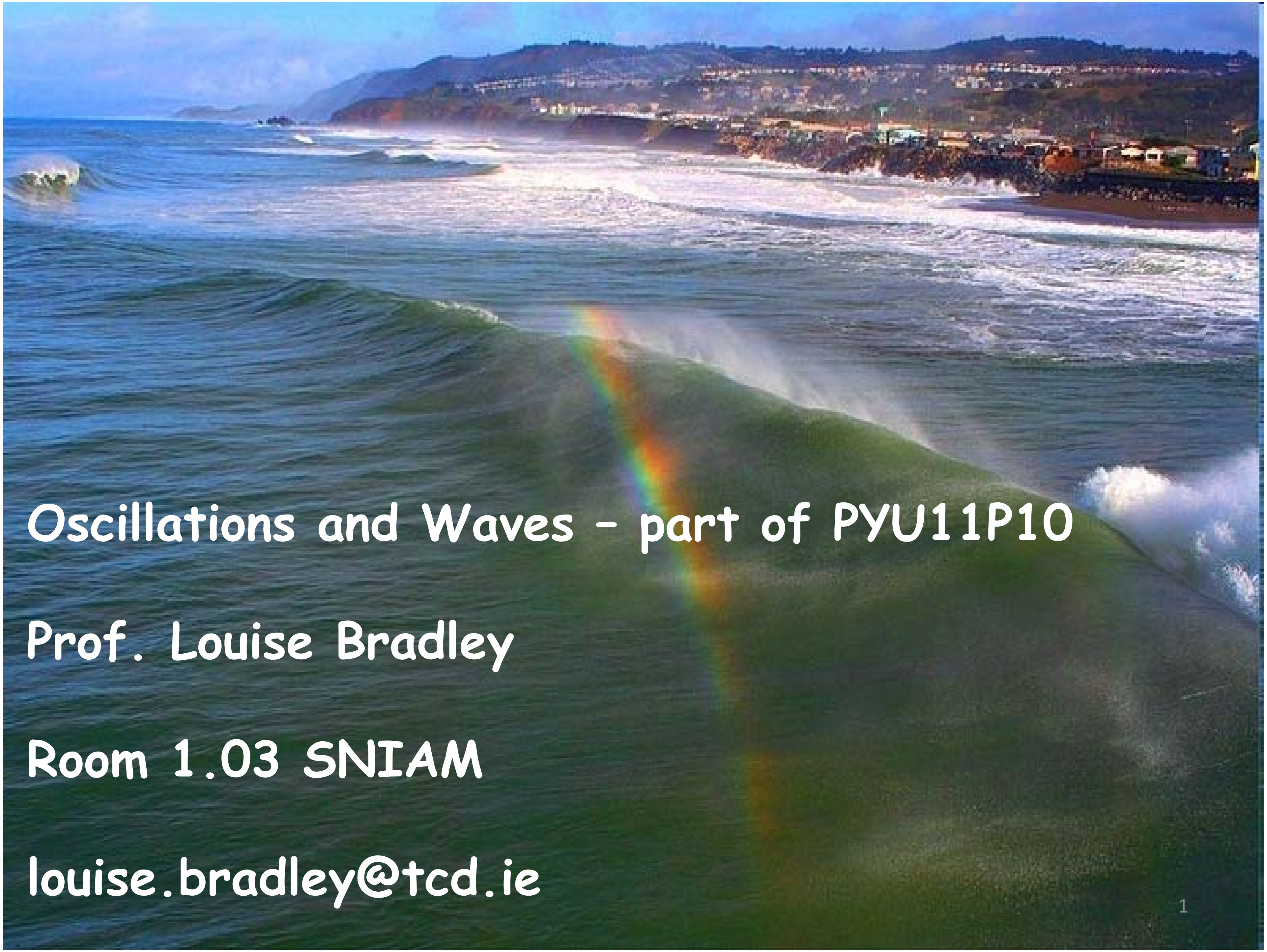
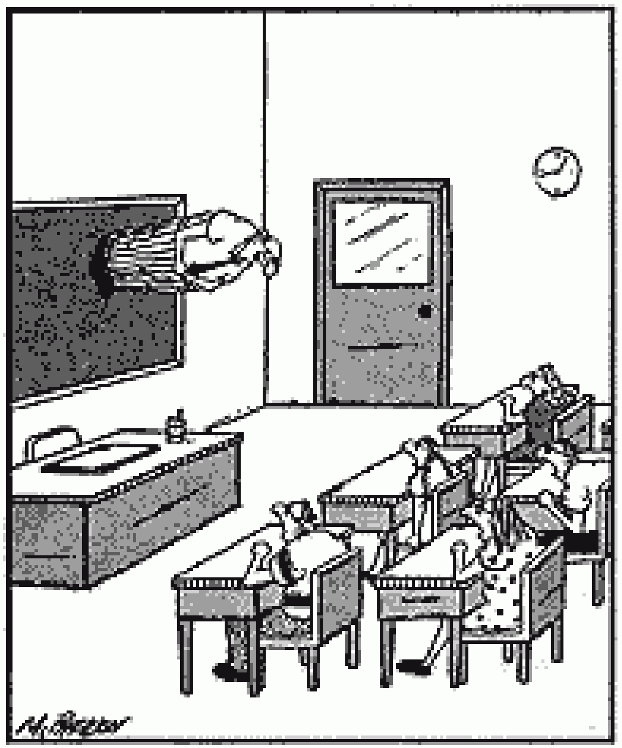

Oscillations and Waves – part of PYU11P10
Prof. Louise Bradley
Room 1.03 SNIAM
louise.bradley@tcd.ie

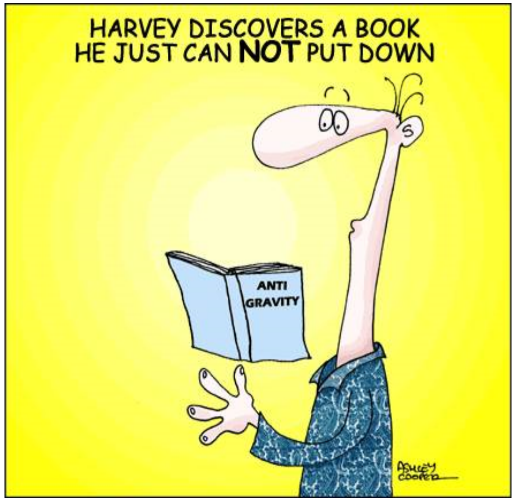
Syllabus

http://www.tcd.ie/Physics/undergraduate/modules/jf/py1p10.php



"Good morning, and welcome to The Wonders of Physics."

Sears and Zemansky's University Physics with modern physics by Young and Freedman



Other course supports

Quiz at back of lecture notes

Tutorials - in lectures

Small Group Tutorials

On-line Mastering Physics

Call in to see me!

Course Notes: https://tcd.blackboard.com

Objectives for the course

- Mathematically describe oscillations
- See how oscillations link to waves
- Apply the description to mechanical waves and concepts of wave energy
- Superposition of waves
- Understand properties of electromagnetic waves
- Apply principles of superposition to interference and diffraction of light waves

Part One : Waves

Vibrations: half a billion times per second

Vibrations: 100s of times per second

Jan 17, 2005

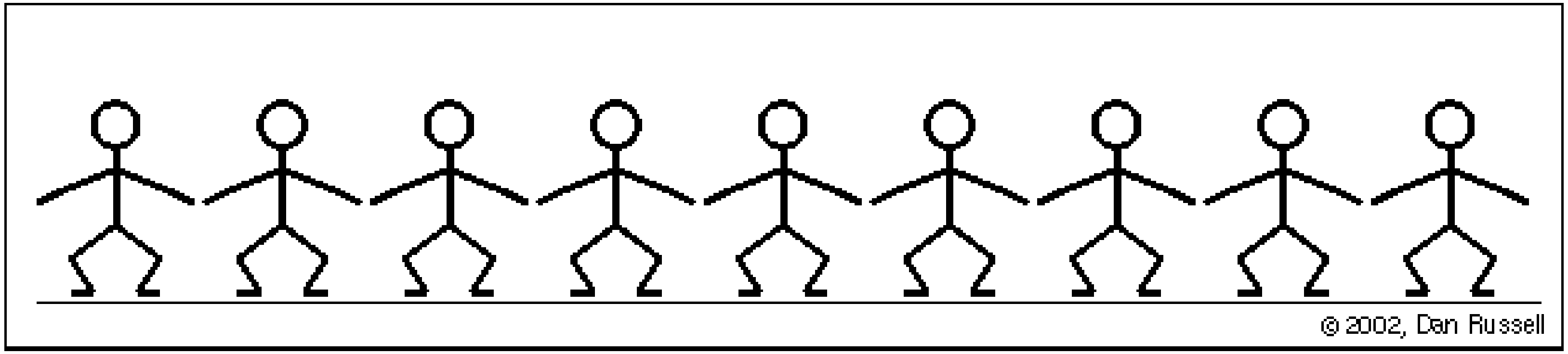
Hanshin, Japan

Vibrations/oscillations and waves are fundamental across physics – at all length scales

Gravitation
Propagation of Earthquakes
Radio and Visible EM waves
Sound

Description of matter:
Quantum mechanics – wave/particle duality
Electron waves
High energy physics – String theory
Elementary particles described by strings: quarks, leptons, Higgs boson…

Applications?



What's a wave?

A wave is a disturbance from equilibrium that travels, or propagates, from one region of space to another

Mechanical Waves → Travel through a medium (solid, liquid or gas)

Electromagnetic Waves → Able to travel in a vacuum: Non-mechanical

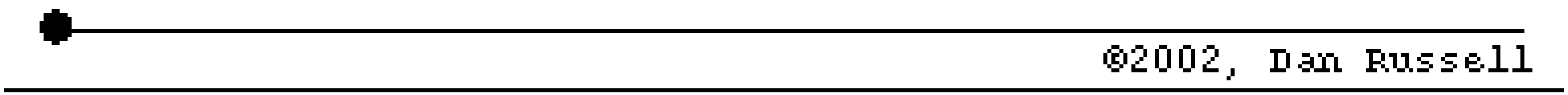
Wave-like behaviour of atomic and sub atomic particles…

- (Quantum Mechanics)… don't worry… not on the exam

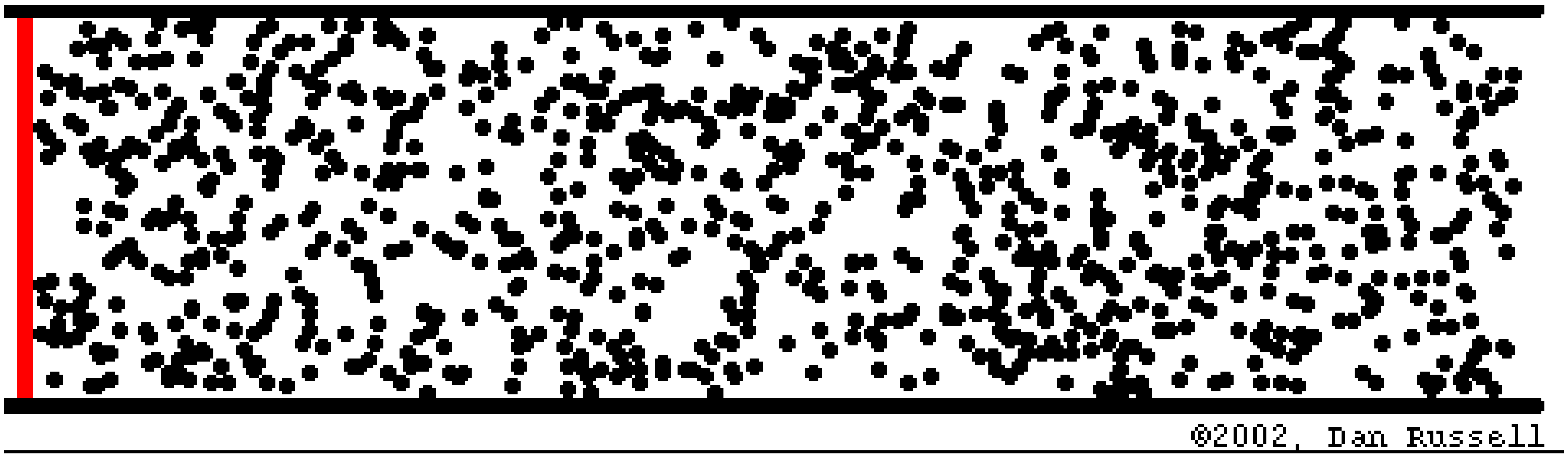
Waves – A universal phenomenon

Mechanical Waves

A **wave pulse** is a disturbance that moves through a medium.



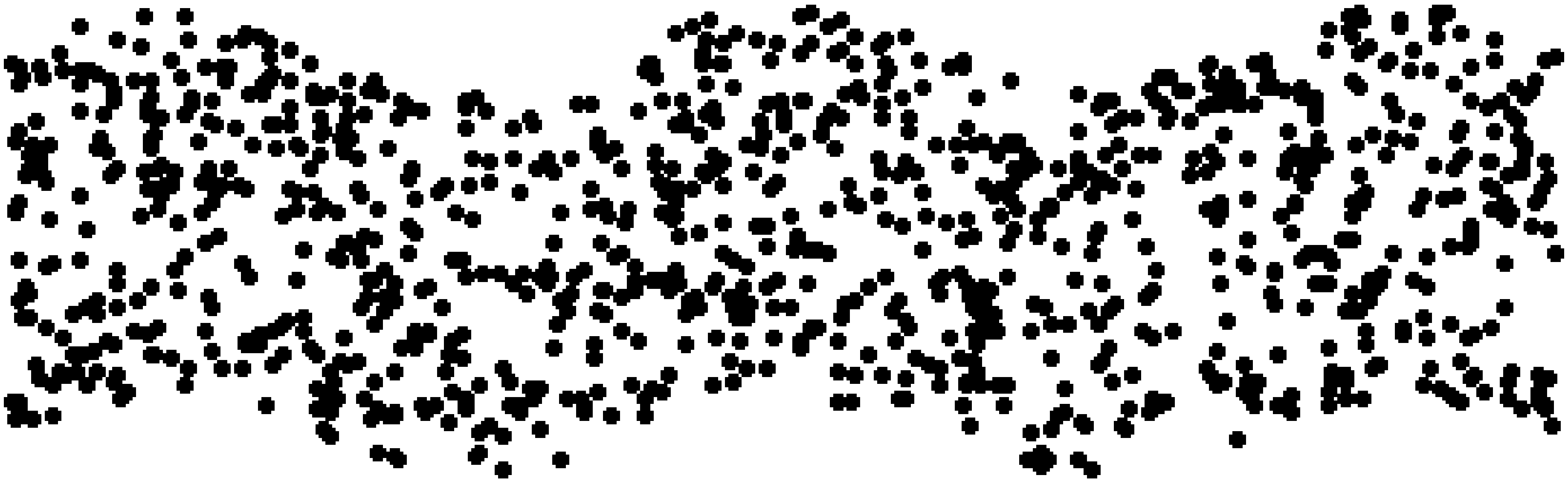
Transverse



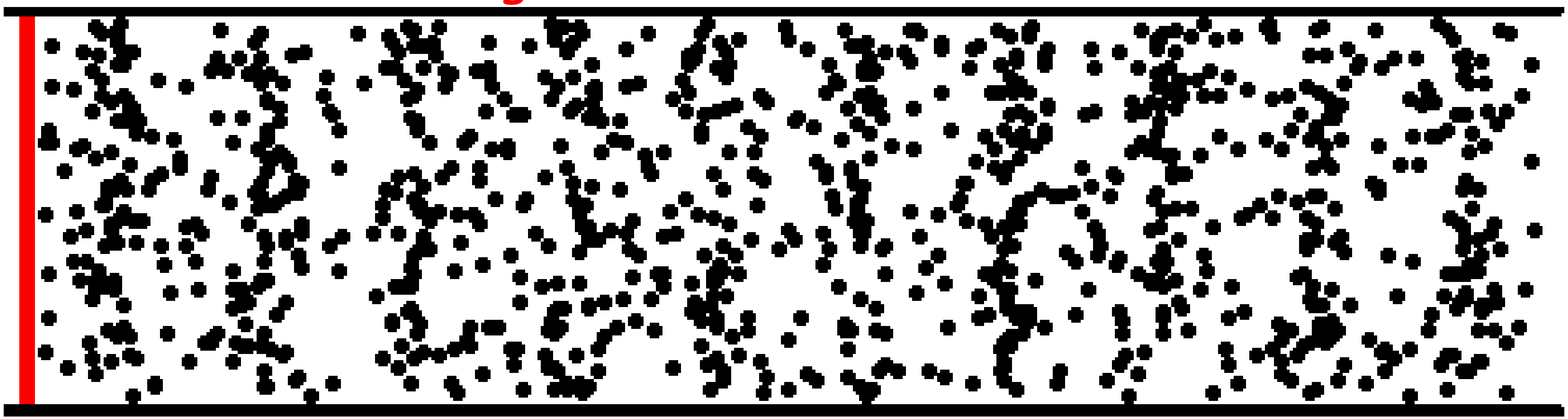
Longitudinal

Periodic Wave

Transverse



Longitudinal



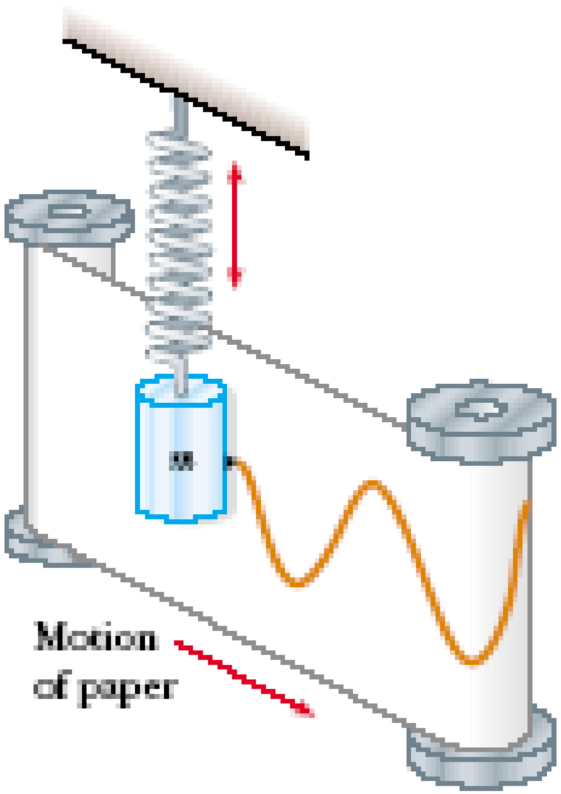
Observations:

Every element of the medium is oscillating

The medium is not flowing in the transverse direction

$\longrightarrow$ only the disturbance is

$\longrightarrow$ Need to be able to describe an oscillation to describe a wave



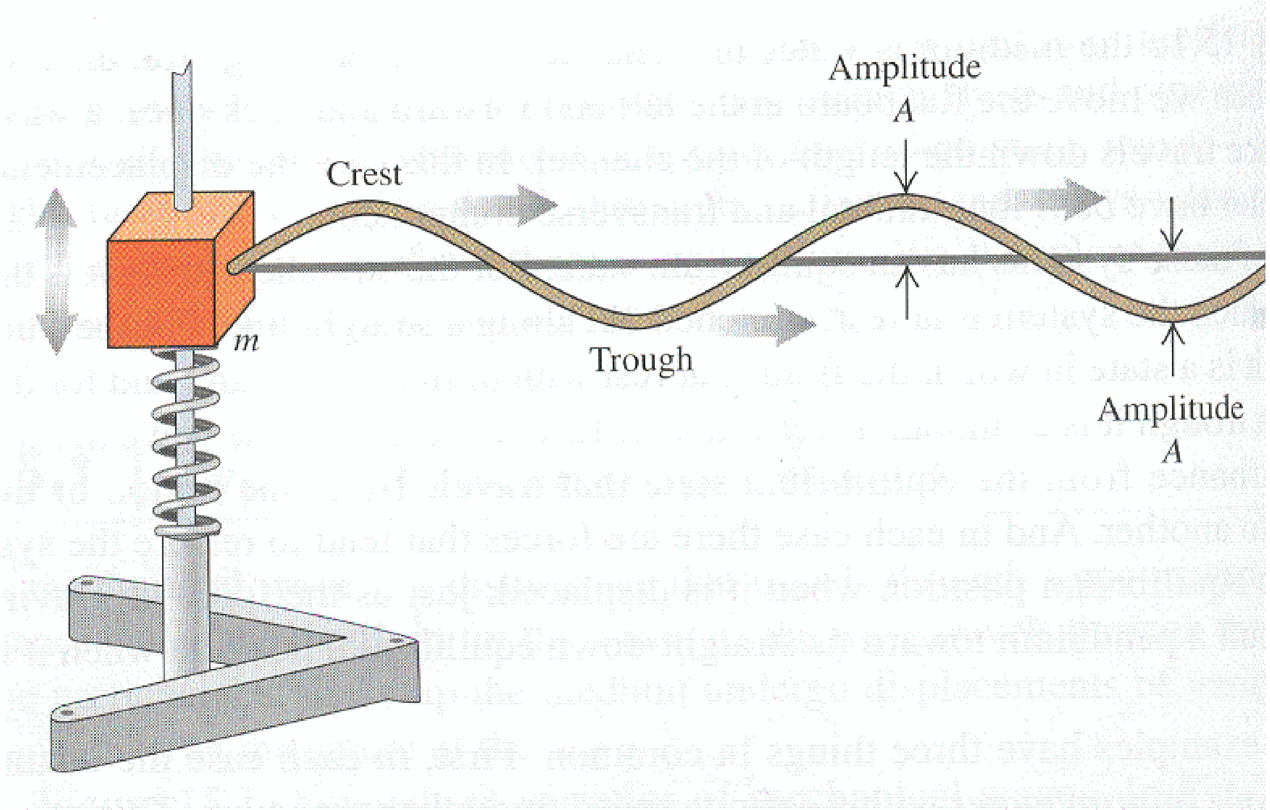
Look at a classic oscillator

Observation:

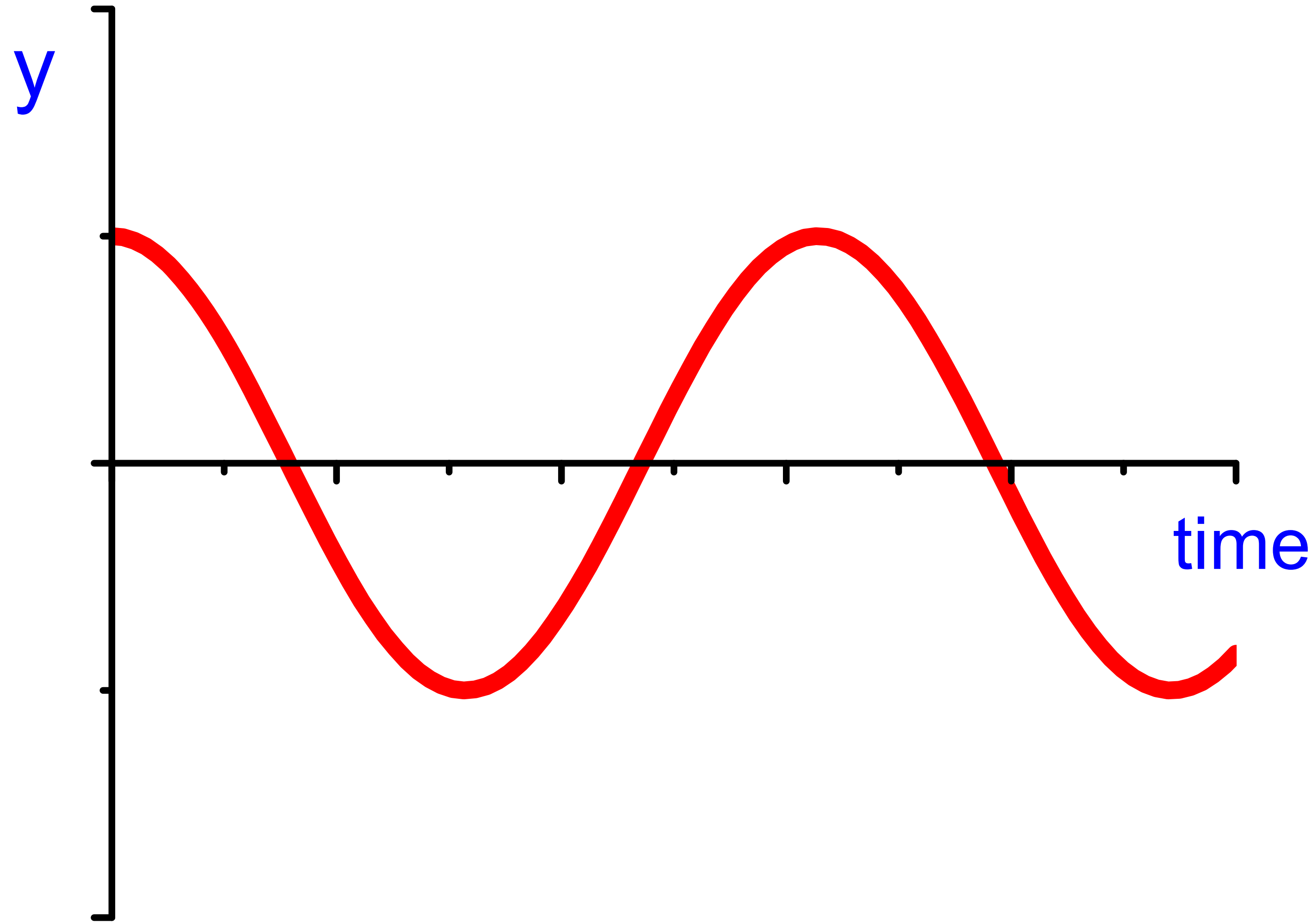
Small amplitude vibrations are always sinusoidal. This sort of vibration is called simple harmonic motion.

http://www.walter-fendt.de/html5/phen/springpendulum_en.htm

Periodic oscillation acts as a source for a periodic wave.



Pick a point on the rope and plot its position as a function of time



Every element of the medium has the same oscillation behaviour as the source

Periodic Motion

Young and Freedman
Chapter 14
Periodic Motion
Read Sections 14.1 and 14.2

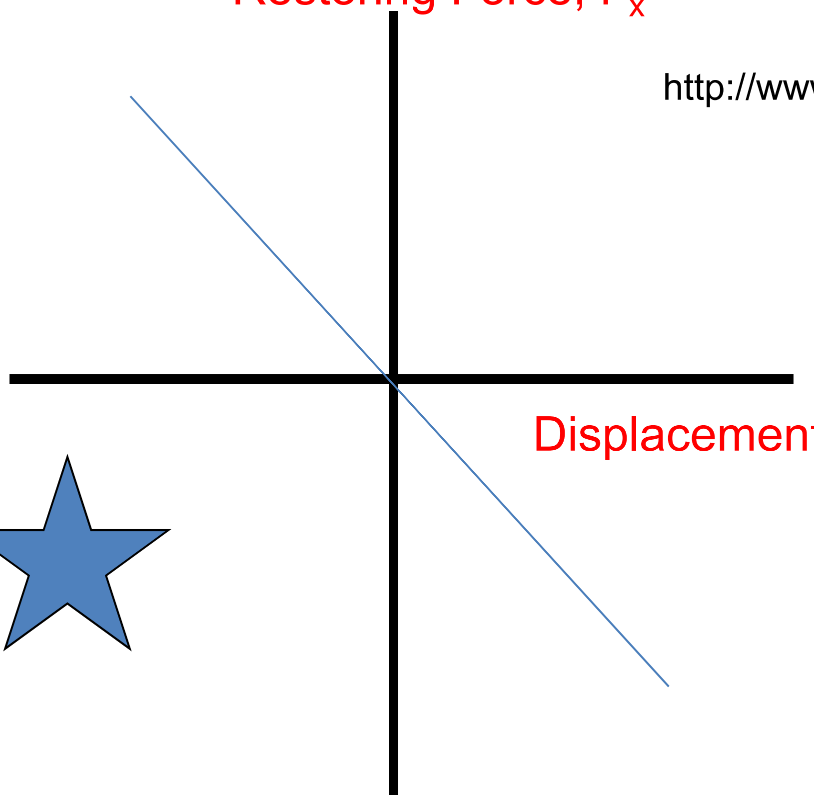
- Describe oscillations and do calculations

Things we need to find out

- What is the relationship between net force and displacement for a body undergoing simple harmonic motion?

- What is the equation of a wave travelling in the x direction as a function of time?

The simplest kind of oscillation occurs when the restoring force F_x is directly proportional to the displacement from equilibrium x, called Simple Harmonic Motion



http://www.walter-fendt.de/html5/phen/springpendulum_en.htm

For a spring:

$$F_x = -kx$$

Hooke's Law
Ch. 6

Which of the following will increase the period of oscillation?

A. Stiffer spring – higher spring constant, k
B. Heavier mass
C. Larger Amplitude

A body undergoing Simple Harmonic Motion is called a Harmonic Oscillator

How does linear F-x graph give rise to sinusoidal motion?

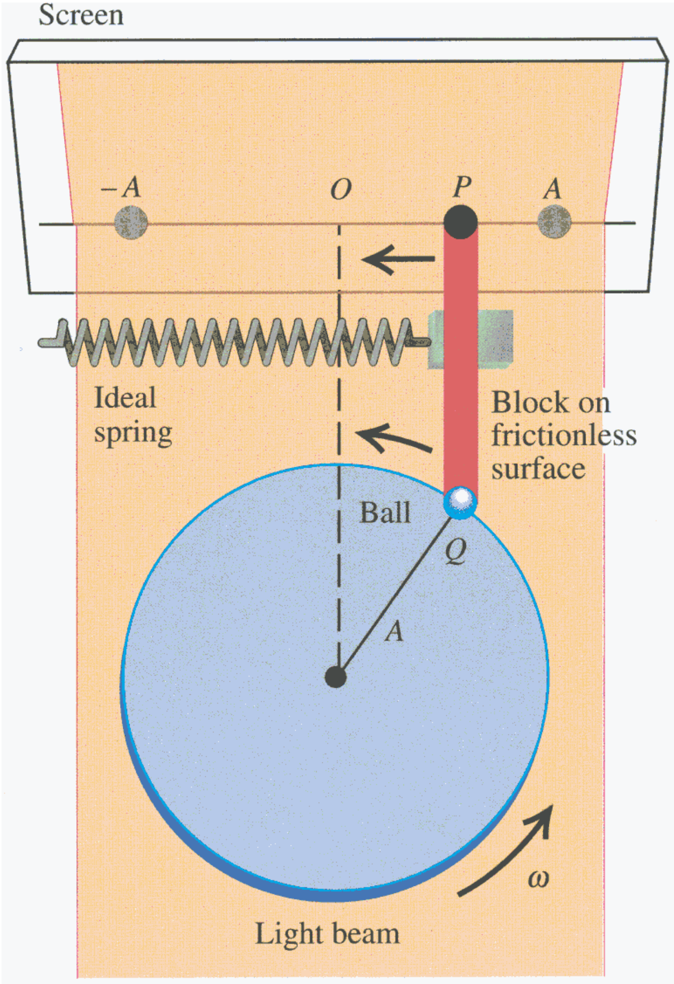
How can we express the displacement, x, as a function of time?

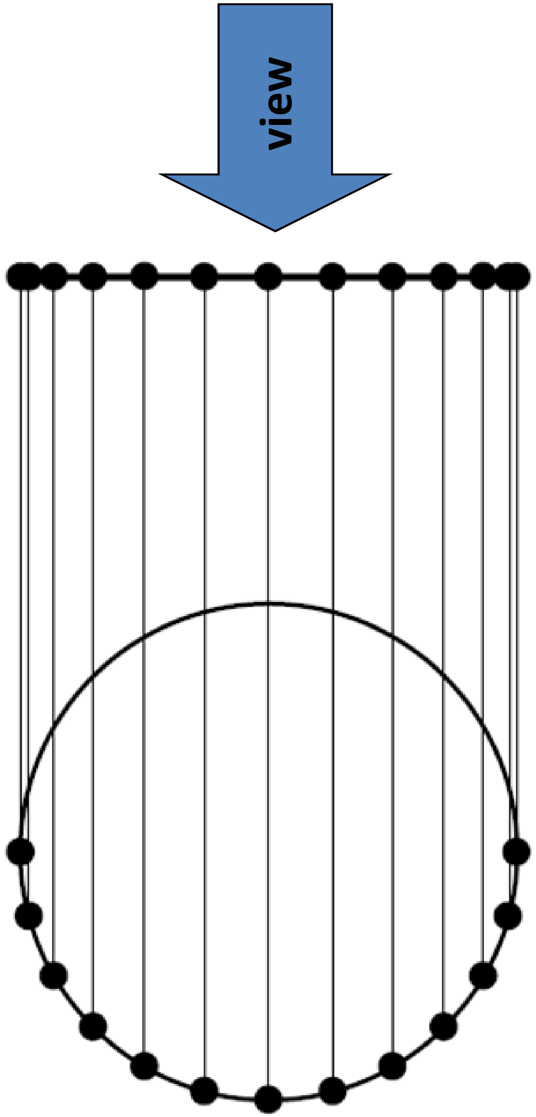
We know the second derivative must satisfy

$$F_x = ma_x = -kx$$

$$\frac{d^2x}{dt^2} = -\frac{k}{m}x$$

Observation:





An object that is in SHM has motion that is identical to circular motion projected down to one dimension.

SHM is projection of uniform circular motion onto a diameter

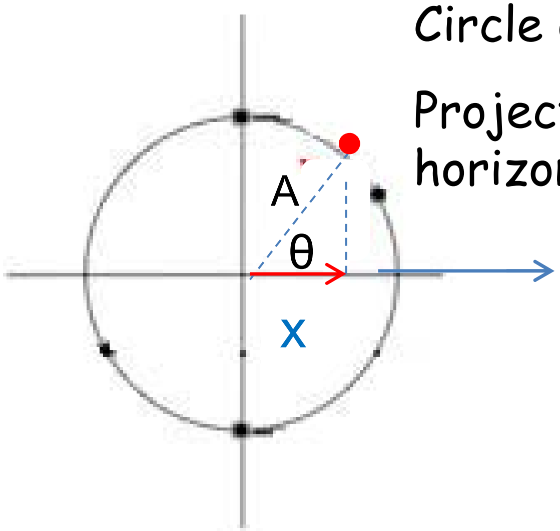
http://surendranath.org/GPA/Oscillations/PhaseGraph/PhaseGraph.html

Period, T: the time for one cycle (SI unit seconds)

Frequency, f: number of cycles per unit time. $f = \frac{1}{T}$

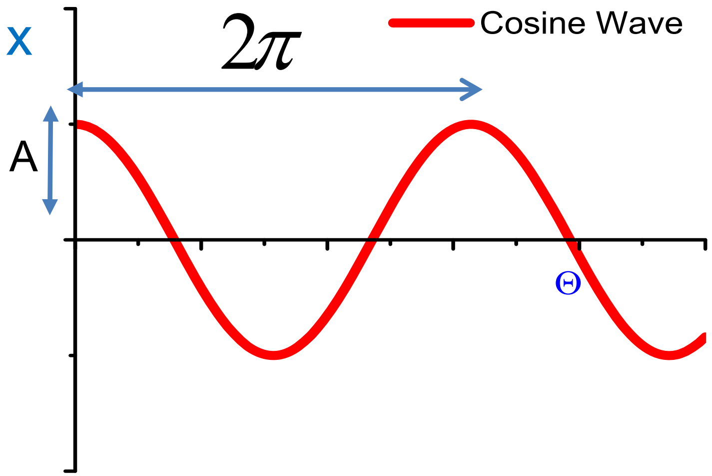
Angular frequency, ω: $\omega = 2\pi f$

The example in the slide above projects onto the horizontal axis x



Circle of radius A

Projection onto horizontal-axis x=ACos(θ)



To make this a function of time:

One full cycle is 2π and takes one period , T, in time

$$\frac{\theta}{2\pi} = \frac{t}{T}$$

$$\boxed{x = ACos(\omega t)}$$

$$\theta = 2\pi \frac{t}{T} = 2\pi f t$$

$$\boxed{\omega \equiv 2\pi f}$$

ω is the angular frequency

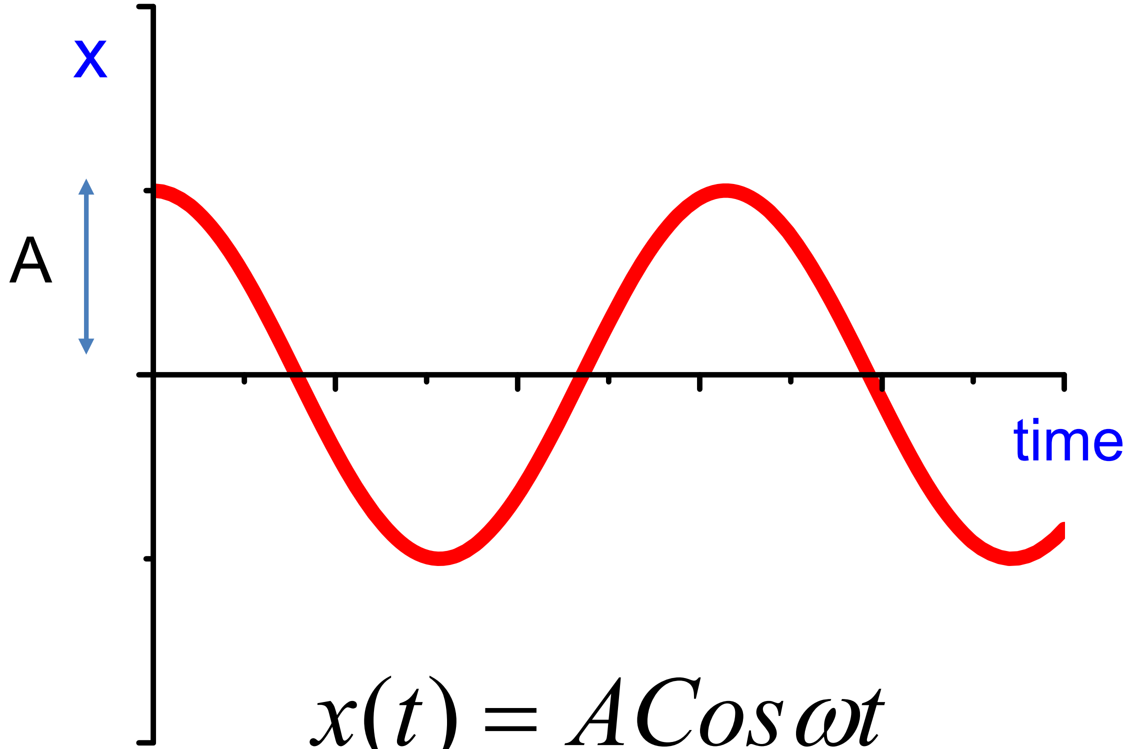
$$\theta = \omega t$$

Waves: transverse wave – reference circle

http://surendranath.org/GPA/Waves/TWRC/TWRC.html

Displacement, x

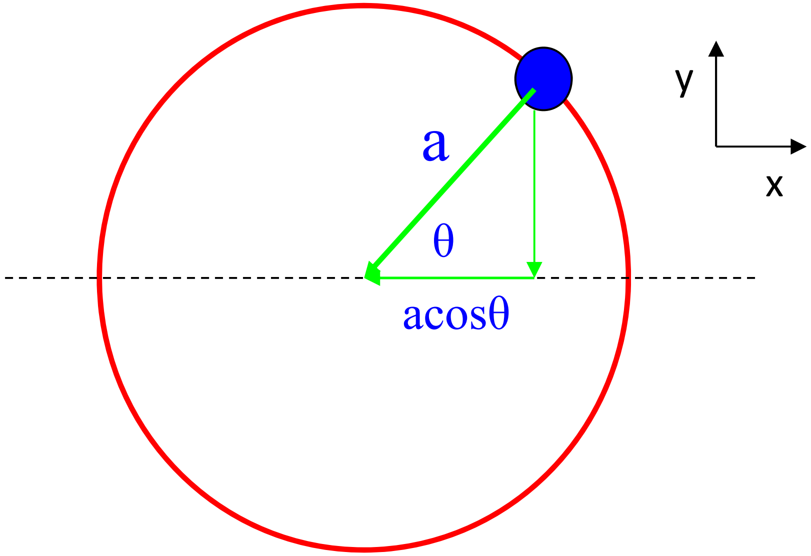
Amplitude, A: the maximum displacement



$$x(t) = A Cos\, \omega t$$

For object with circular motion (with speed v and radius r)

$$a = \frac{v^2}{r}$$



x-component of acceleration

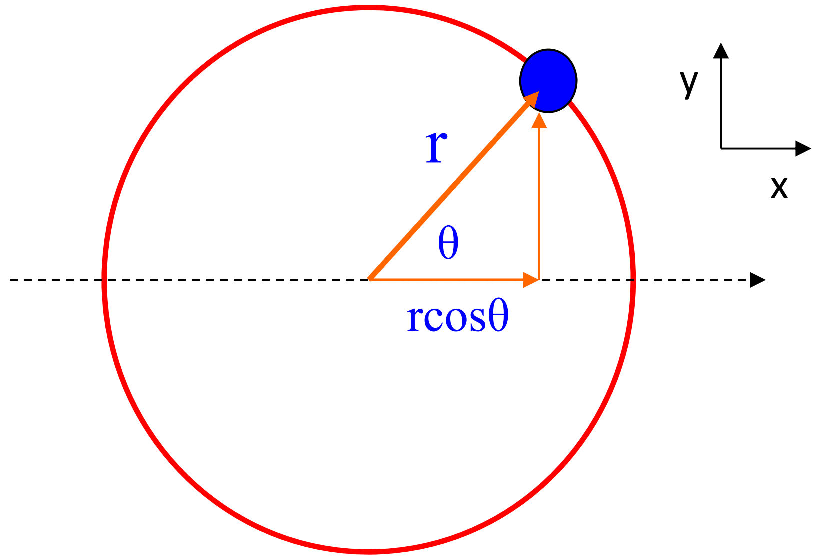
$$\vec{a}_x = -\frac{v^2}{r} \cos\theta$$

Apply Newton's 2nd law; F = ma (mind the minus)

$$\vec{F}_x = -ma_x = -\frac{mv^2}{r} \cos\theta$$

$$v = circumference / period = 2\pi r / T$$

$$F_x = -\frac{4\pi^2 mr}{T^2}\cos\theta$$



but $r.\cos\theta = x$

$$\boxed{\therefore\ F_x = -\frac{4\pi^2 m}{T^2}x}$$

Note: have recovered the condition for SHM

$$-\frac{4\pi^2 m}{T^2}x = -kx$$

where $k = \dfrac{4\pi^2 m}{T^2}$ so $\boxed{T = 2\pi\sqrt{\dfrac{m}{k}}}$

A body that undergoes simple harmonic motion is called a harmonic oscillator & has a period of…

$$\boxed{T = 2\pi\sqrt{\frac{m}{k}}}$$

When the restoring force is directly proportional to the displacement from equilibrium the oscillation is called simple harmonic motion

For our mass oscillating along the y-axis at the end of a spring we have

$$y = A\cos\omega t$$

Can show is a solution of $F_y = m\dfrac{d^2y}{dt^2} = -ky$

$y = A\cos\omega t$ = *The displacement as a function of time*

$\dfrac{dy}{dt} = -\omega A\sin\omega t$ = v_y *The velocity as a function of time*

$\dfrac{d^2y}{dt^2} = -\omega^2 A\cos\omega t$ = a_y *The acceleration as a function of time*

$$-m\omega^2 A\cos\omega t = -kA\cos\omega t$$

$$m\omega^2 = k$$

$$\omega^2 = \frac{k}{m}$$

$$\omega = 2\pi f$$

$$f = \frac{1}{T}$$

$$T = 2\pi\sqrt{\frac{m}{k}}$$

As we had found before

A 40.0 N force stretches a vertical spring 0.250 m.

(a) What mass must be suspended from the spring so that the system will oscillate with a period of 1.00 s?

(b) If the amplitude of the motion is 0.050 m and the period is that specified in part (a), where is the object and in what direction is it moving 0.35 s after it has passed the equilibrium position, moving downward? What is the displacement from the equilibrium position? The spring was stretched downward at t=0.

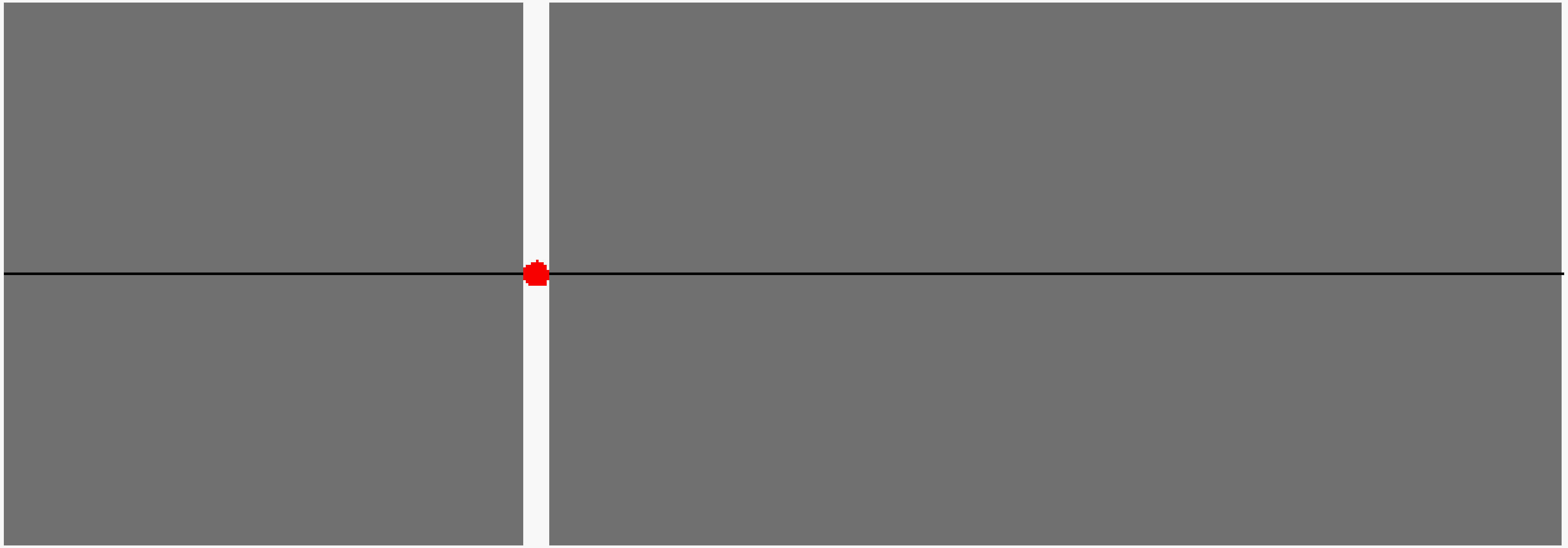
(c) What force magnitude and direction does the ***spring*** exert on the object when it is 0.030 m below the equilibrium position, moving upward?

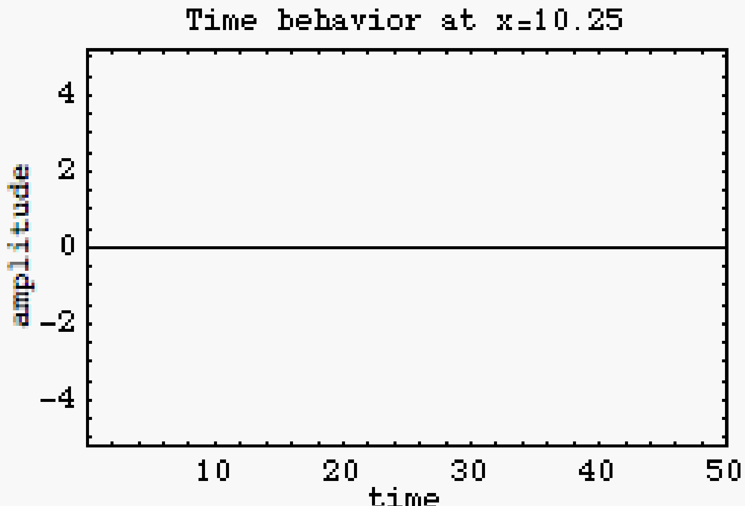
For you:
See Young and Freedman Section 14.3

Plot
(a) Displacement versus time over one period
(b) Velocity versus time over one period
(c) Acceleration versus time over one period
(d) Potential energy versus time over one period
(e) Kinetic energy versus time over one period
(f) The total energy versus time

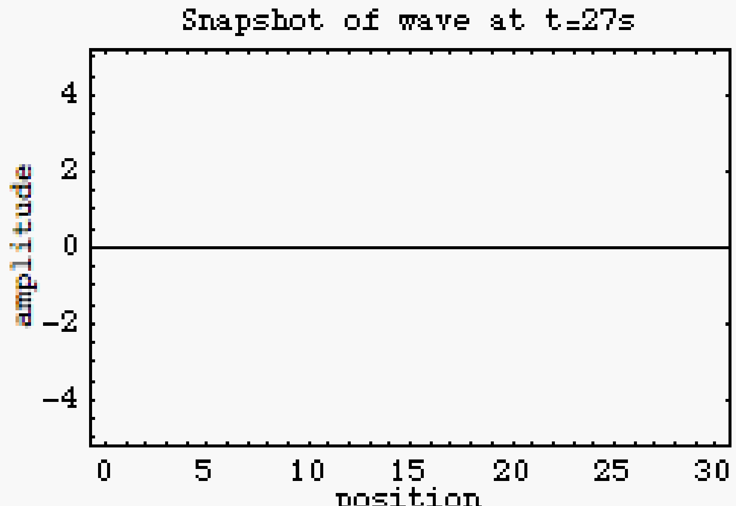
Describing a Wave
Young and Freedman
Chapter 15
Mechanical Waves
Read Sections 15.1 15.2 and 15.3

- *Using the relationship between frequency, speed and wavelength*
- *Using and Interpreting the mathematical expression for a sinusoidal sine wave*

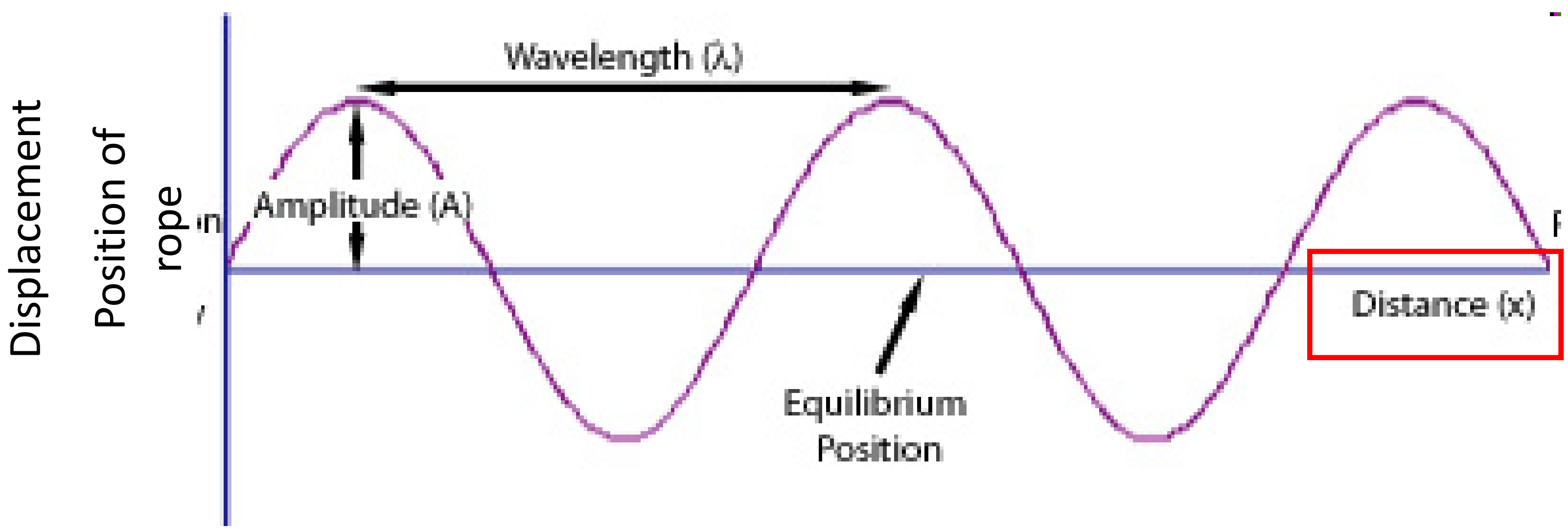


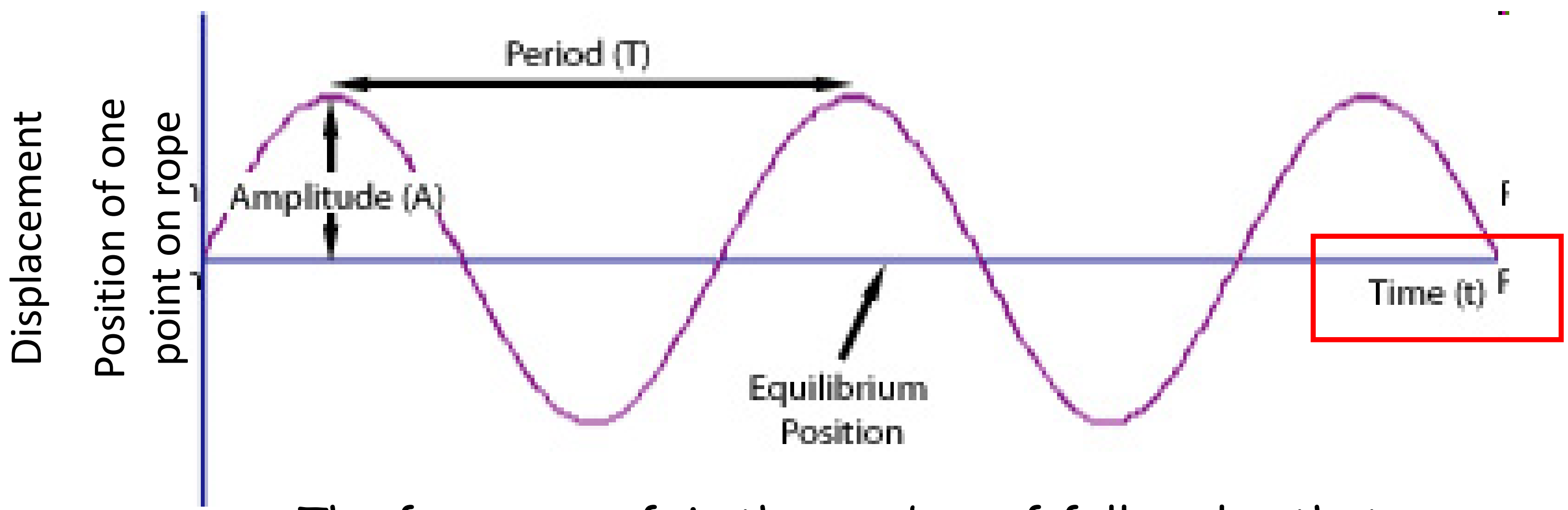


$$\boxed{y(t) = A\cos(\omega t)}$$



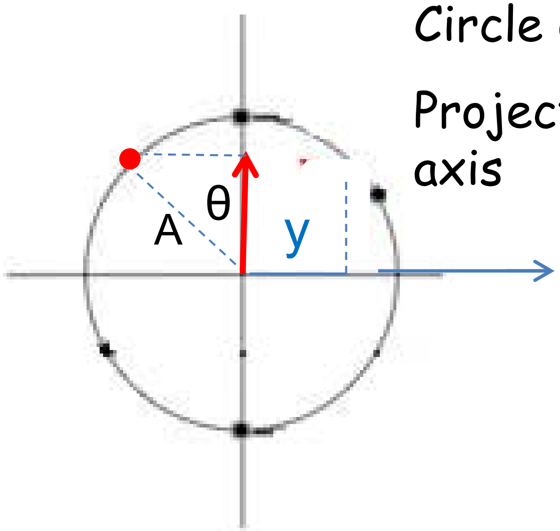
$$\boxed{y(x) = A\cos(kx)}$$





The frequency, f, is the number of full cycles that occurs in one second.

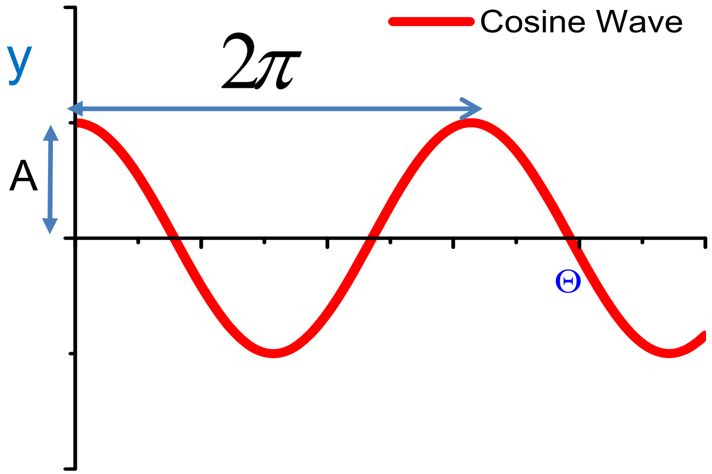
$\boxed{f = (1/T)\ [Hz]\ )}$



Circle of radius A

Projection onto vertical-axis

y=ACos(θ)



To make this a function of time:

One full cycle is 2π and takes one period , T, in time

$$\frac{\theta}{2\pi} = \frac{t}{T}$$

$$y(t) = ACos(\omega t)$$

$$\theta = 2\pi\frac{t}{T} = 2\pi ft$$

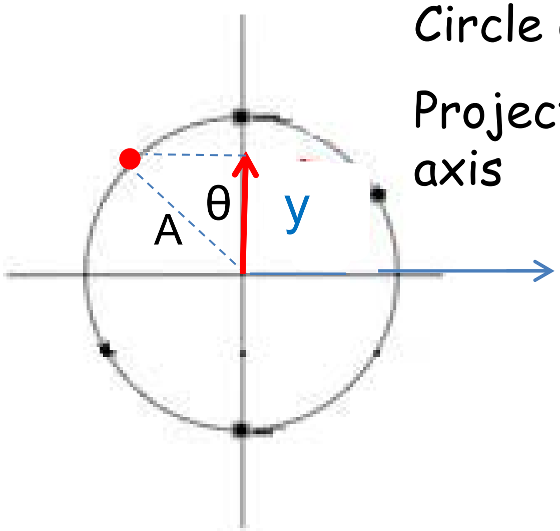
$$\boxed{\omega \equiv 2\pi f}$$

ω is the angular frequency

$$\theta = \omega t$$

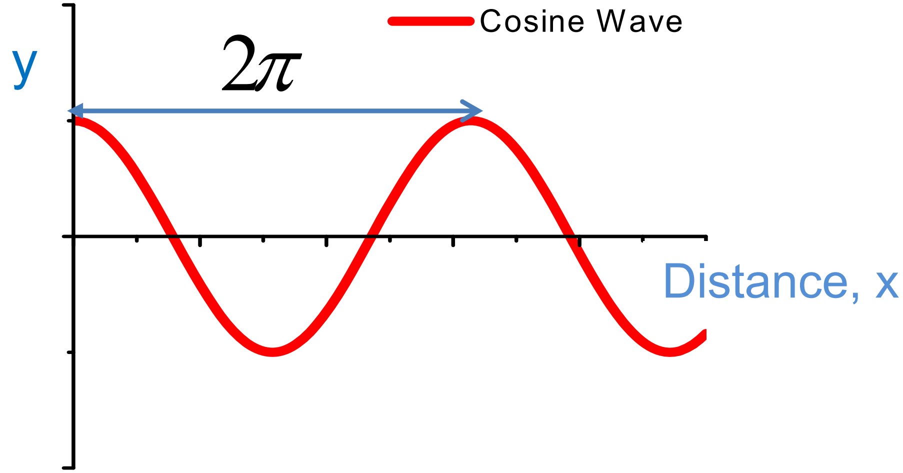
Waves: transverse wave – reference circle

http://surendranath.org/GPA/Waves/TWRC/TWRC.html



Circle of radius A

Projection onto vertical-axis y=ACos(θ)



To make this a function of distance:

One full cycle is 2π and over a distance of 1 wavelength, λ

$$\frac{\theta}{2\pi} = \frac{x}{\lambda}$$

$$\theta = 2\pi \frac{x}{\lambda}$$

$$\boxed{k \equiv \frac{2\pi}{\lambda}}$$

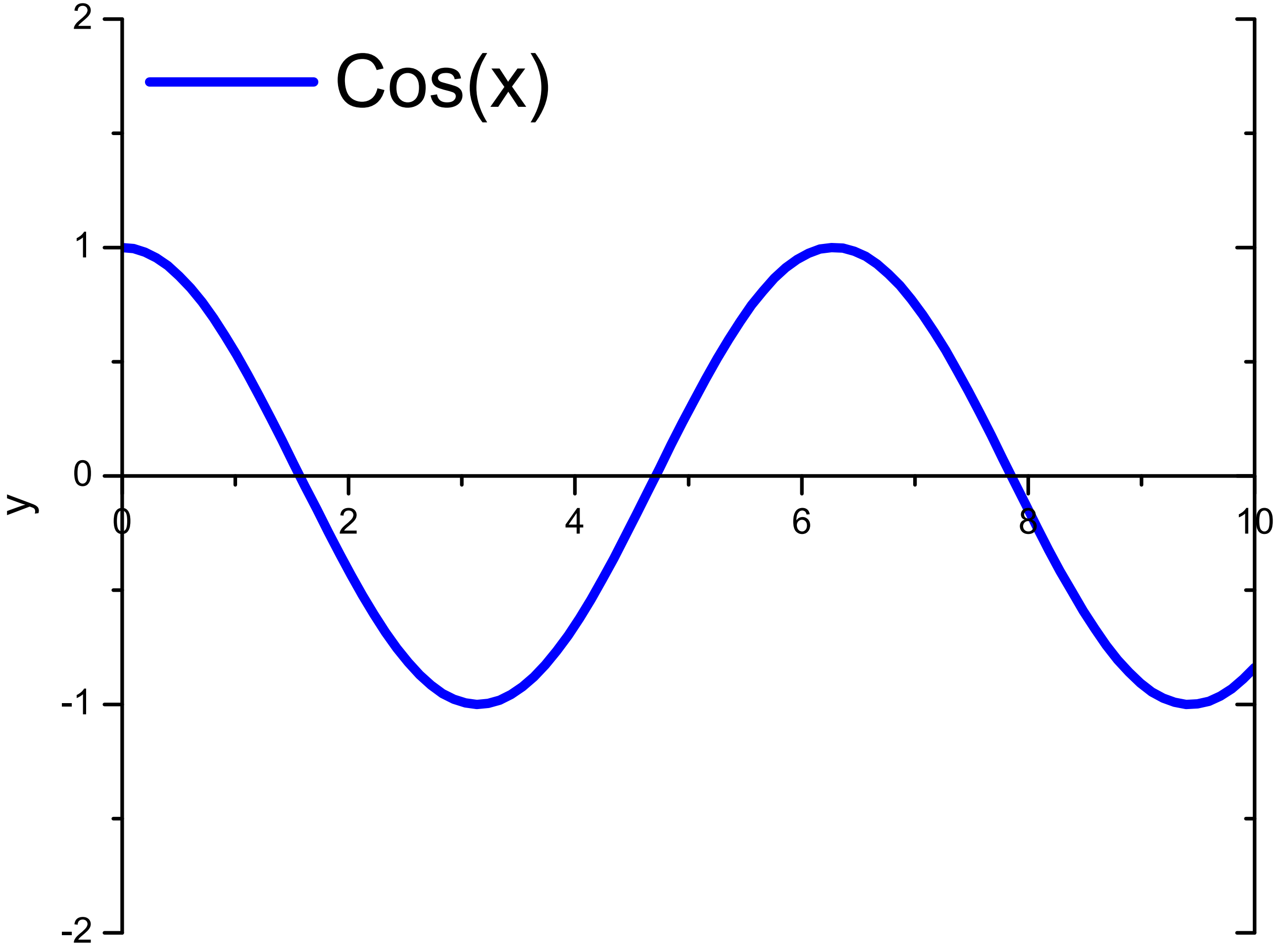
$$\theta = kx$$

$$\boxed{y(x) = ACos(kx)}$$

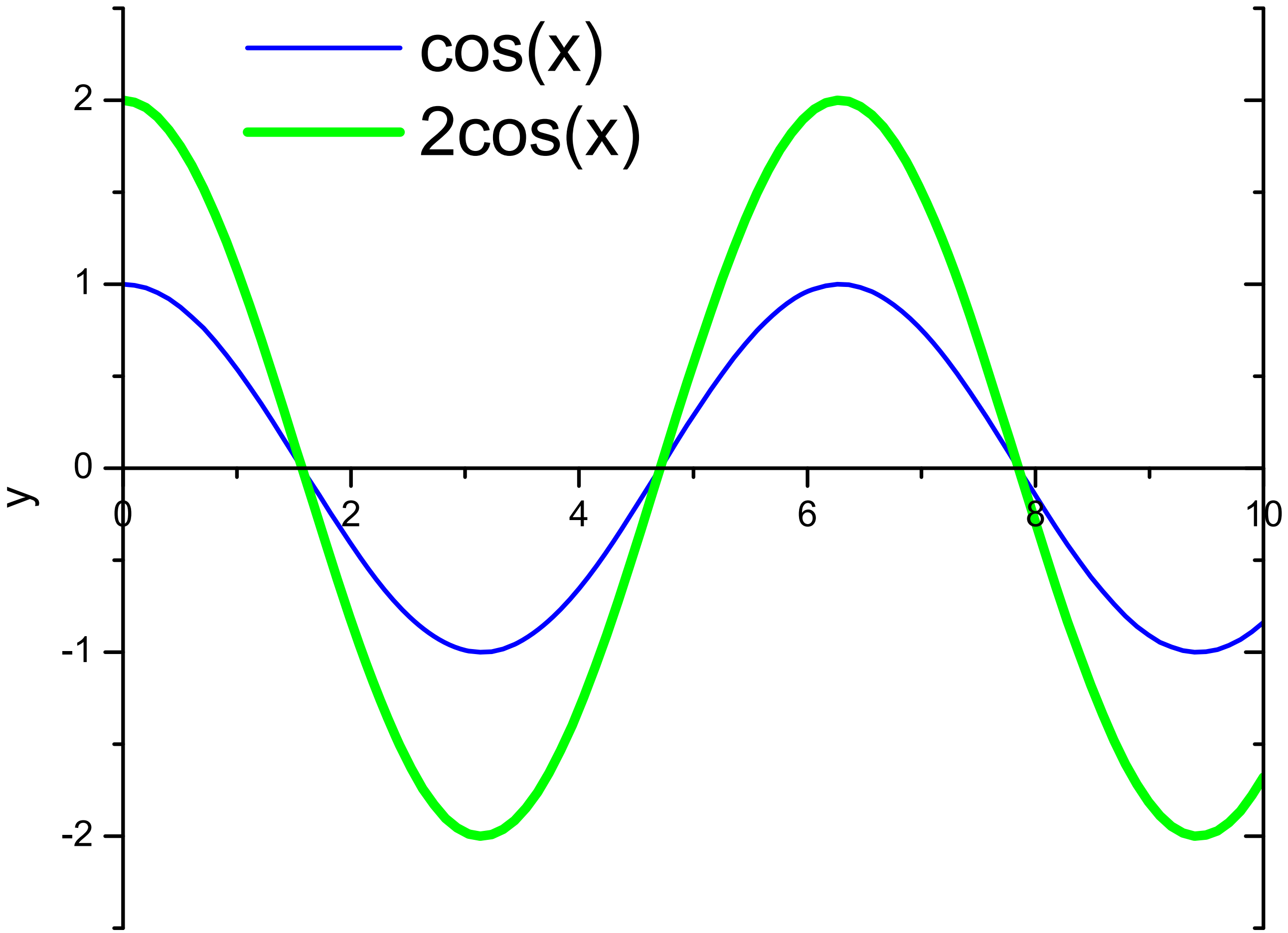
k is the wavenumber

http://surendranath.org/GPA/Waves/TWRC/TWRC.html

$$y = \cos(x)$$

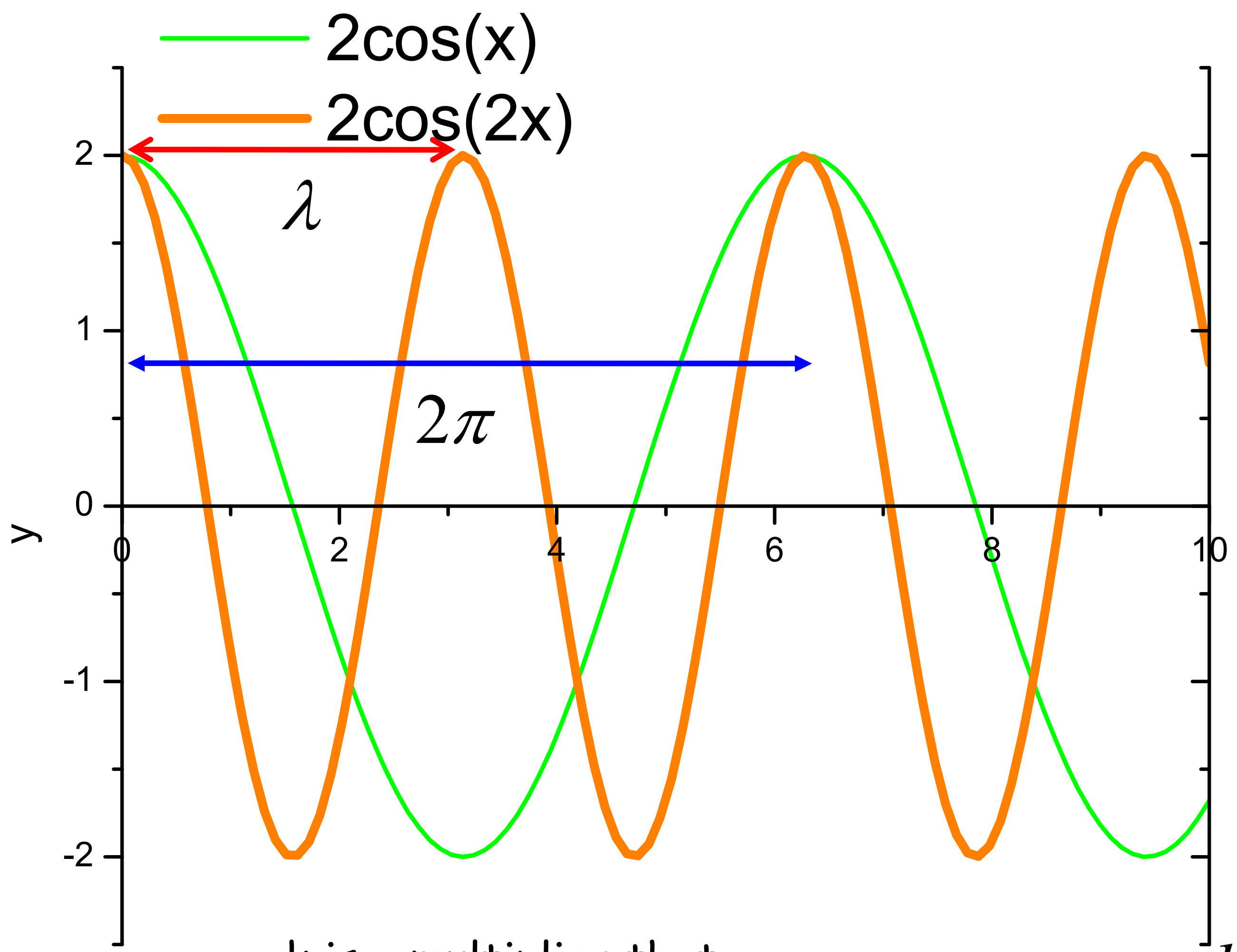


$$\boxed{y = A\cos(x)}$$



$$y = A\cos(2x)$$

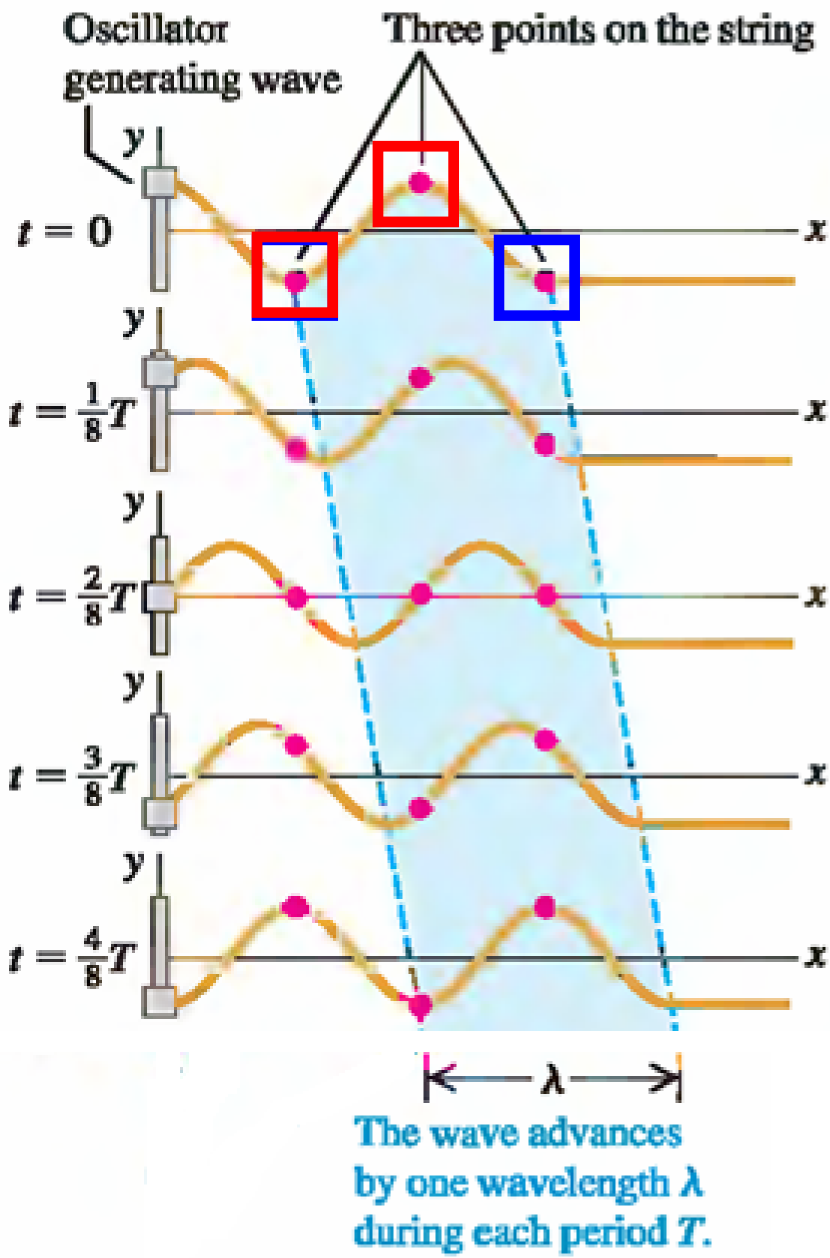
For cos(2x) the repetition length, the wavelength, is halved, $2\lambda = 2\pi$



k is a multiplier that changes wavelength

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

Phase



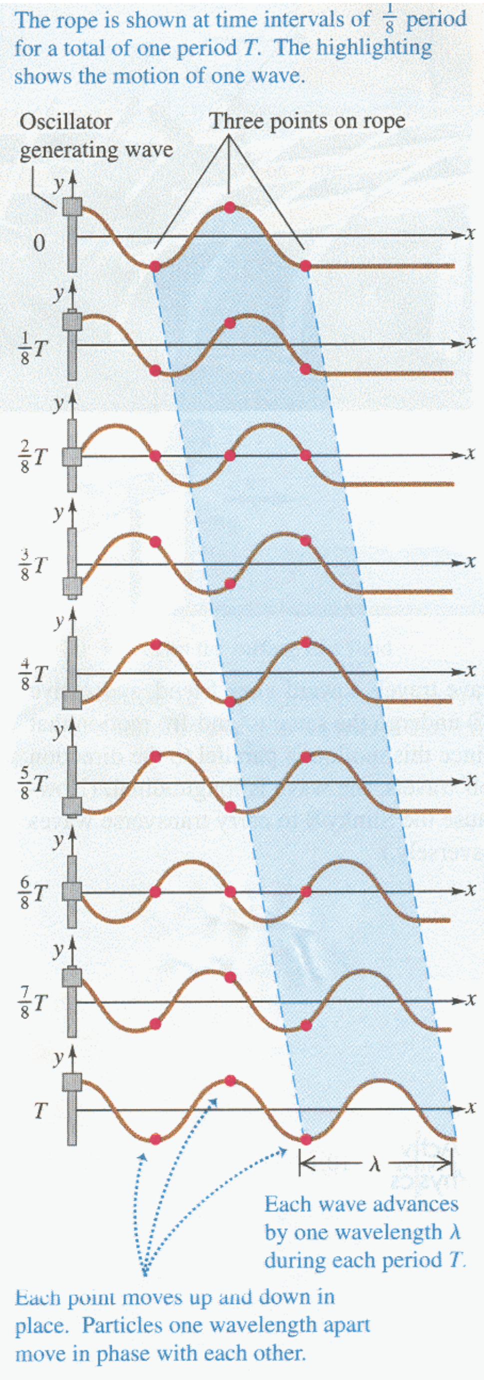
In Phase

Out of Phase

Particles one wavelength apart move in phase with one another

The wave moves a distance of one wavelength λ in time of one period T

$$\boxed{velocity\ , v = \frac{\text{distance}}{\text{time}} = \frac{\lambda}{T} = f\lambda}$$

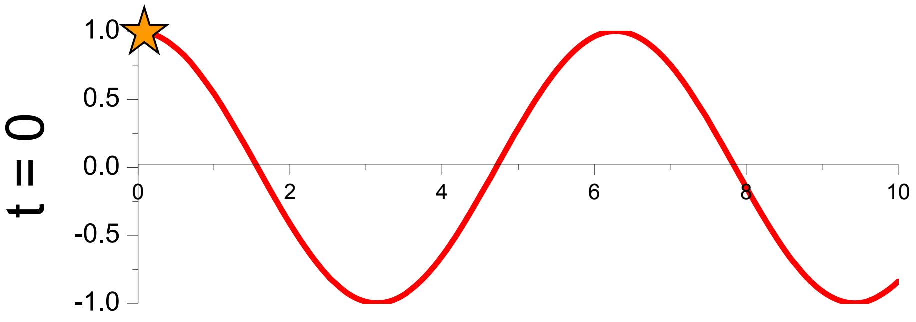


Mathematical Description of a Wave… $\boxed{y(x,t) = A\cos(kx - \omega t)}$

- the travelling wave…

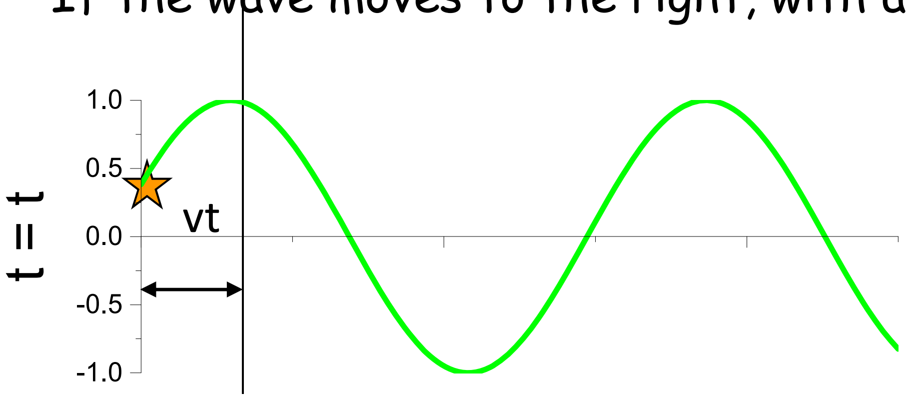
At $t = 0$, the wave can be described as

$$y(x,0) = A\cos(kx)$$



$$y(x,0) = A\cos\left(\frac{2\pi}{\lambda}x\right)$$

If the wave moves to the right, with a velocity v, then after time t :



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

So, the wave has moved to the right a distance of *vt* in time *t*

Note the wavefunction is of the form *f(x-vt)* indicating the movement is to the right. If it were to the left, it would be *f(x+vt)*

$$velocity, v = \frac{\text{distance}}{\text{time}} = \frac{\lambda}{T} = f\lambda$$

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

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

Shows the periodic nature of y in both space and time

i.e. at any given time, t, if we take a snap-shot of the wave, then y will have the same values at $x, x + \lambda, x + 2\lambda$

and, at any given position x (at which a single element of the wave is undergoing SHM) the values of y are the same at times $t, t + T, t + 2T$

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

This can be simplified further, by defining

Angular wave number, or wave number $k \equiv \dfrac{2\pi}{\lambda}$

Angular frequency $\omega \equiv \dfrac{2\pi}{T} = 2\pi f$

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

Wave function doesn't depict the physical wave, but rather it's a graph of the **displacement about the equilibrium** in space and time

$$\boxed{y(x,t) = A\cos\left(kx - \omega t\right)}$$

Velocity of a particle in wave at point x:

Transverse Velocity, v_y

$$\boxed{\Rightarrow v_y(x,t) = \frac{\partial y\left(x,t\right)}{\partial t} = \omega A\sin\left(kx - \omega t\right)}$$

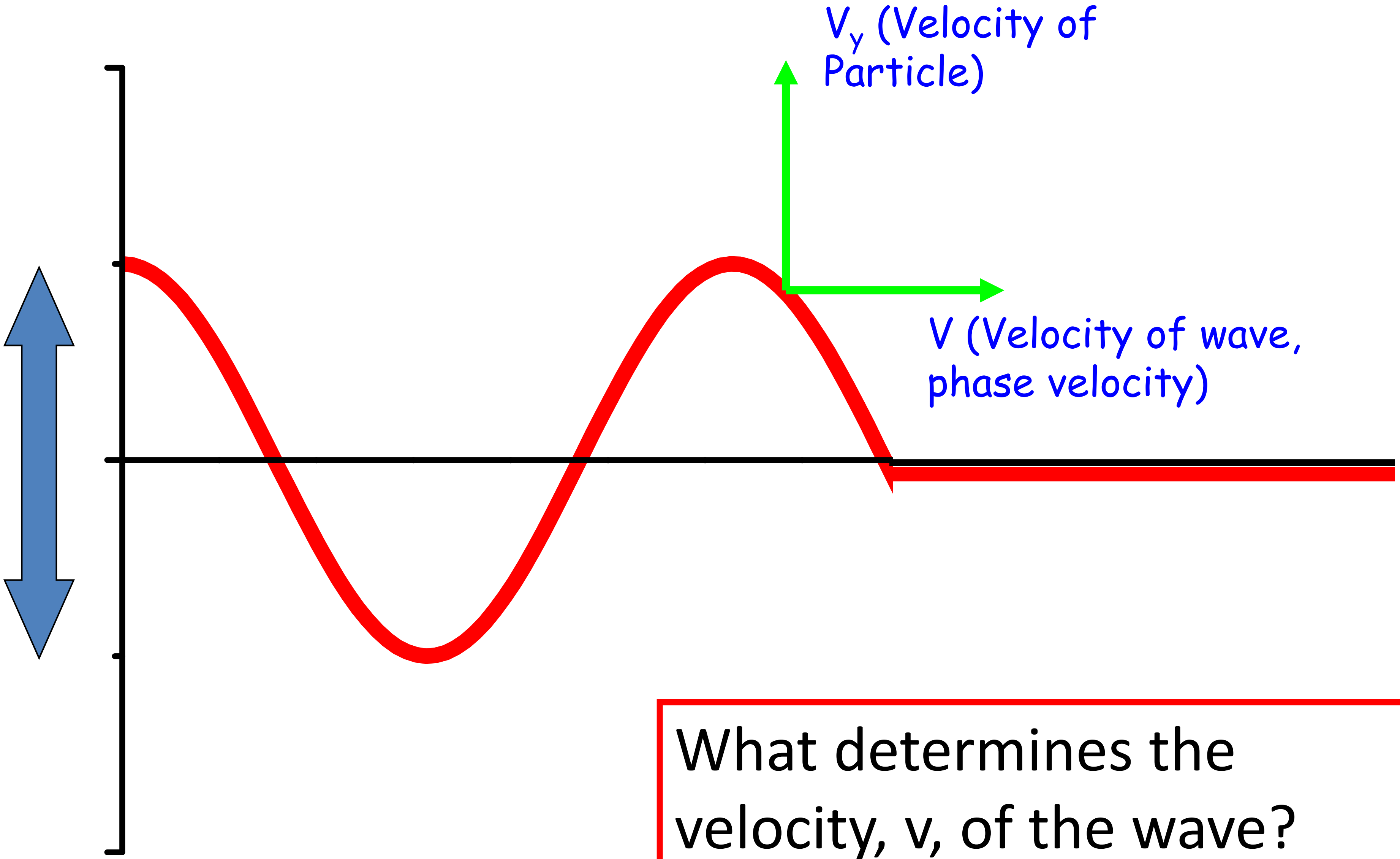
Acceleration of a particle in wave at point x:

Transverse Acceleration, a_y

$$\boxed{a_y(x,t) = \frac{\partial v(x,t)}{\partial t} = -\omega^2 A\cos(kx - \omega t)}$$

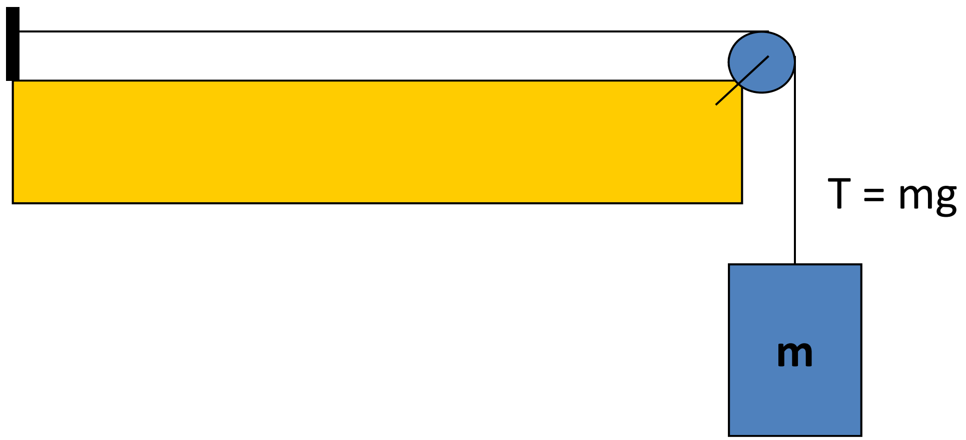
Each particle in the wave is undergoing SHM

For a single position, x constant, we have the same equations as for a mass on a spring



What determines the velocity, v, of the wave?

Speed of Transverse Wave on String



$$v_{wavepulse} = \sqrt{\frac{Tension}{mass\ per\ unit\ length\ of\ the\ string}}$$

$$\boxed{v_W = \sqrt{\frac{T}{\mu}}}$$

A travelling wave is described by

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

A travelling wave with an amplitude of 2.0 cm is set up on a rope, of mass 0.50 kg and length 10 m, by oscillating the end of the rope up and down at a frequency of 10 Hz. Determine the tension that must be applied to the rope to have a speed of 25 m/s. Quantify each of the parameters in the expression for the travelling wave.

Energy in Wave Motion

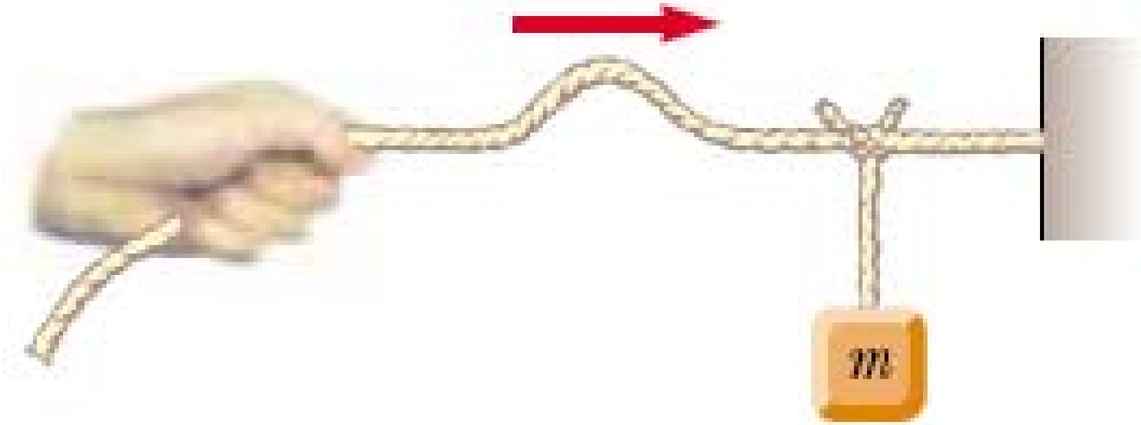
Mechanical Waves

Young and Freedman
Chapter 15
Mechanical Waves
Read Section 15.5 – uses a different approach

- *Calculating the speed of a wave on a string and the rate at which mechanical waves transport energy*

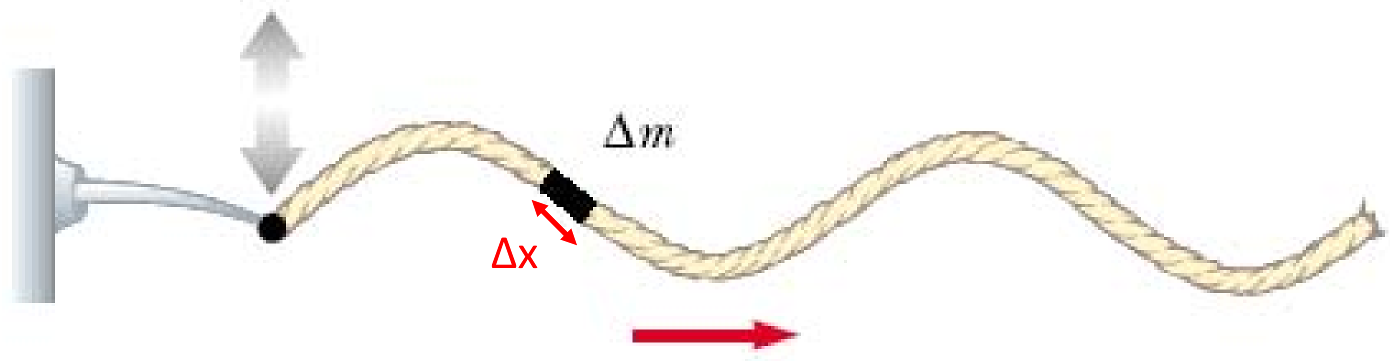
Energy in Wave Motion

Energy in Wave Motion



(a)

Energy in Wave Motion



Energy of this little bit: $$\Delta E_K = \frac{1}{2}(\Delta m)v_y^2$$

If string has mass per unit length, μ, then mass of little bit is: $$\Delta m = \mu \Delta x$$

$$\therefore \Delta E_K = \frac{1}{2}(\mu \Delta x)v_y{}^2$$

$$\text{As } \Delta x \rightarrow 0 \qquad dE_K = \frac{1}{2}(\mu dx)v_y{}^2$$

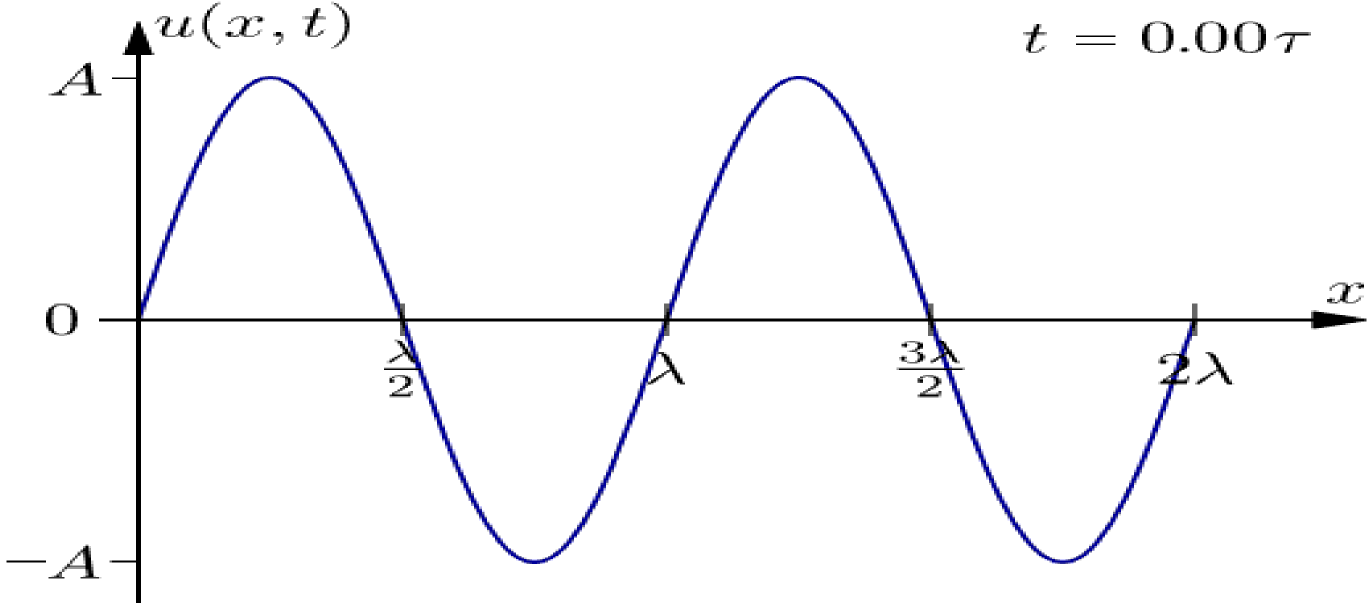
We know what the transverse speed of a wave is:

$$\boxed{\Rightarrow v_y(x,t) = \omega A \sin(kx - \omega t)}$$

$$\therefore dE_K = \frac{1}{2}\mu\left[\boxed{\omega A \sin(kx - \omega t)}\right]^2 dx$$

$$\Rightarrow dE_K = \frac{1}{2}\mu\omega^2 A^2 \sin^2(kx - \omega t)dx$$

$$dE_K = \frac{1}{2}\mu\omega^2 A^2 \sin^2(kx - \omega t)dx$$

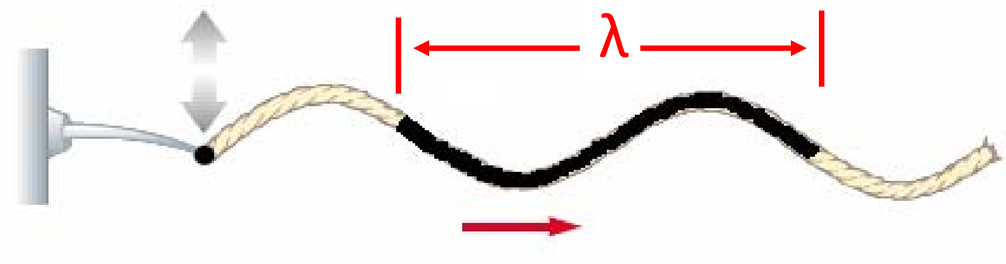


If we take a freeze frame (at t = 0) -

$$\Rightarrow dE_K = \frac{1}{2}\mu\omega^2 A^2 \sin^2(kx)dx$$

$$dE_K = \frac{1}{2}\mu\omega^2 A^2\, sin^2(kx)dx$$

Want energy for all the little bits – we integrate (over one wavelength – how long is a piece of sting?)



$$\Rightarrow E_{K_\lambda} = \int dE_K = \int_0^\lambda \frac{1}{2}\mu\omega^2 A^2 \sin^2(kx)dx$$

$$= \frac{1}{2}\mu\omega^2 A^2 \int_0^\lambda \sin^2(kx)dx$$

Remember?

$$\int_0^{\lambda} \sin^2(kx)dx = \int_0^{\lambda} \frac{1}{2}[1-\cos(2kx)]dx$$

$$E_{K_\lambda} = \frac{1}{2}\mu\omega^2 A^2 \left[\frac{1}{2}x - \frac{1}{4k}\sin(2kx)\right]_0^{\lambda}$$

$$E_{K_\lambda} = \frac{1}{2}\mu\omega^2 A^2 \left[\frac{1}{2}\lambda\right] = \boxed{\frac{1}{4}\mu\omega^2 A^2 \lambda}$$

$$E_{K_\lambda} = \boxed{\frac{1}{4}\mu\omega^2 A^2 \lambda}$$

And don't forget the potential energy (worked out similarly)

$$E_{P_\lambda} = \boxed{\frac{1}{4}\mu\omega^2 A^2 \lambda}$$

$$\therefore E_{Total_\lambda} = \boxed{E_K} + \boxed{E_P} = \frac{1}{2}\mu\omega^2 A^2 \lambda$$

Energy of the Wave in one wavelength

Power of the wave, P

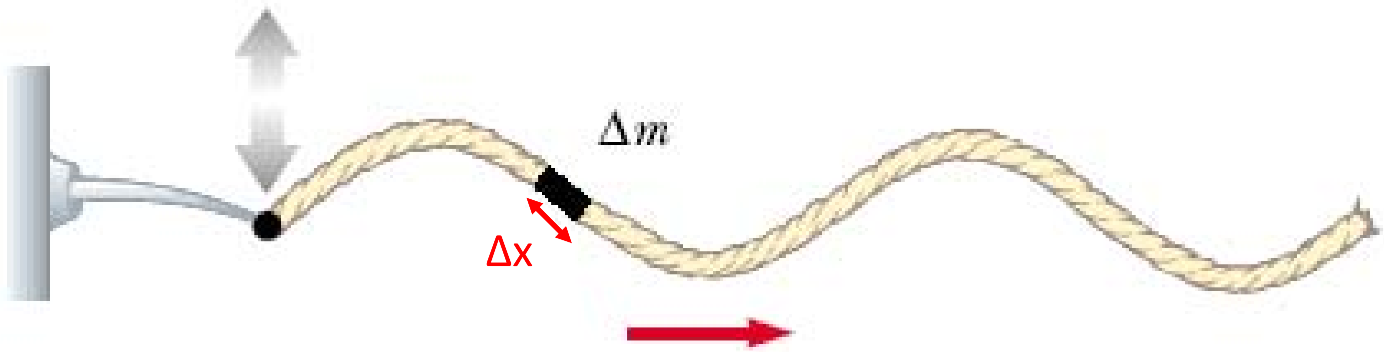
Power is the rate of energy transfer

$$\text{Power} = \frac{\Delta E}{\Delta t} = \frac{E_{Tot_\lambda}}{T}$$

$$P = \frac{E_{Tot_\lambda}}{T} = \frac{\frac{1}{2}\mu\omega^2 A^2 \lambda}{T} = \frac{1}{2}\mu\omega^2 A^2 \boxed{\left(\frac{\lambda}{T}\right)}$$

$$P = \frac{1}{2}\mu\omega^2 A^2 v$$

The Potential Energy



Potential Energy of this little bit:

$$\Delta E_P = \frac{1}{2} k_{spring} y^2$$

k_{spring} is the spring constant

$$T = 2\pi \sqrt{\frac{\Delta m}{k_{spring}}}$$

$$k_{spring} = \omega^2 (\Delta m) = \omega^2 \mu \Delta x$$

$$\therefore \Delta E_P = \frac{1}{2} \omega^2 (\mu \Delta x) y^2$$

For you: Show that

$$E_{P_\lambda} = \frac{1}{4} \mu \omega^2 A^2 \lambda$$

15.69

A sinusoidal wave travels on a string. The string has length 8.00 m and mass 6.00 g. The wave speed is 30.0 m/s and the wavelength is 0.200 m.

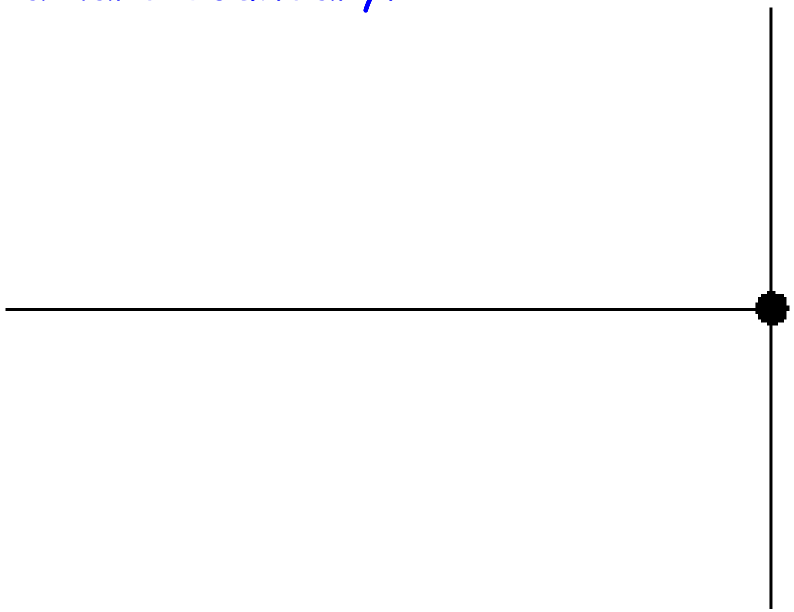
a) If the wave is to have an average power of 50.0 W, what must be the amplitude of the wave?
b) For this same string if the amplitude and wavelength are to be the same as part(a), what is the average power for the wave if the tension is increased such that the wave speed is doubled?

Superposition of Mechanical Waves
Young and Freedman
Chapter 15
Mechanical Waves
Read Sections 15.6 and 15.7

- *Describing what happens when mechanical waves overlap*
- *Properties of standing waves and how to analyse them*

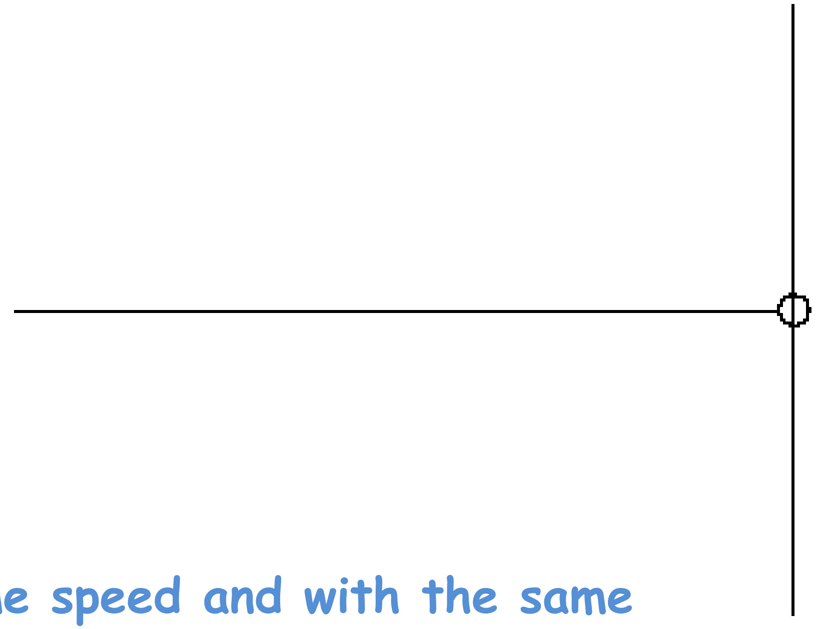
Up to now, we've thought of wave pulse as

What happens if it comes to a hard boundary?



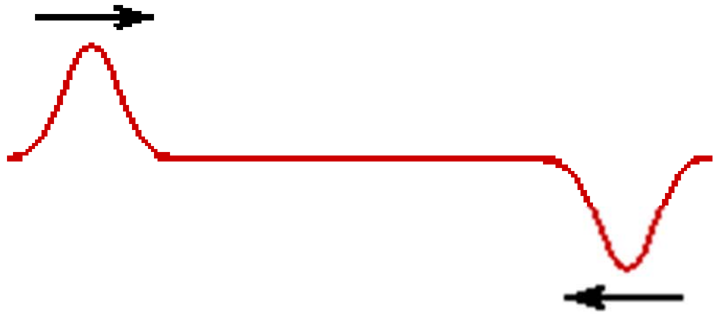
Result: a pulse traveling at the same speed and with the same amplitude but in the opposite direction with opposite polarity

What happens if it comes to a *soft* boundary?



Result: a pulse traveling at the same speed and with the same amplitude and the same polarity but in the opposite direction

These are called boundary conditions



The total displacement of the string at any point is the algebraic sum of the displacements due to the individual pulses at that point - principle of superposition

Principle of superposition - the linear sum.

$$y(x,t) = y_1(x,t) + y_2(x,t)$$

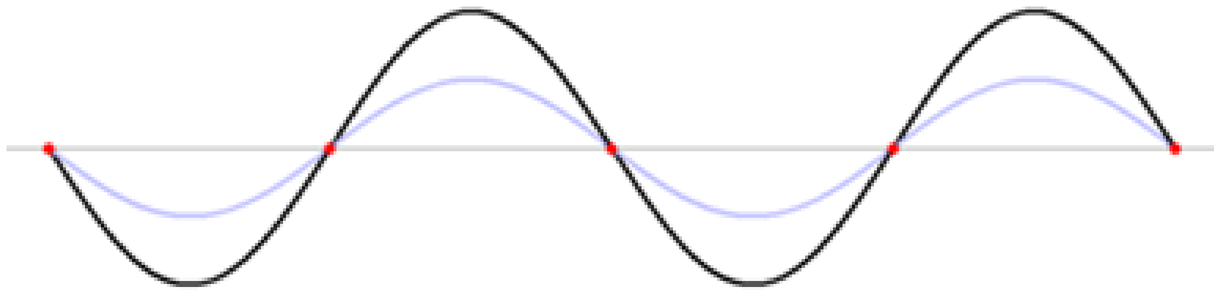
So, how would a sinusoidal wave reflect from a boundary?

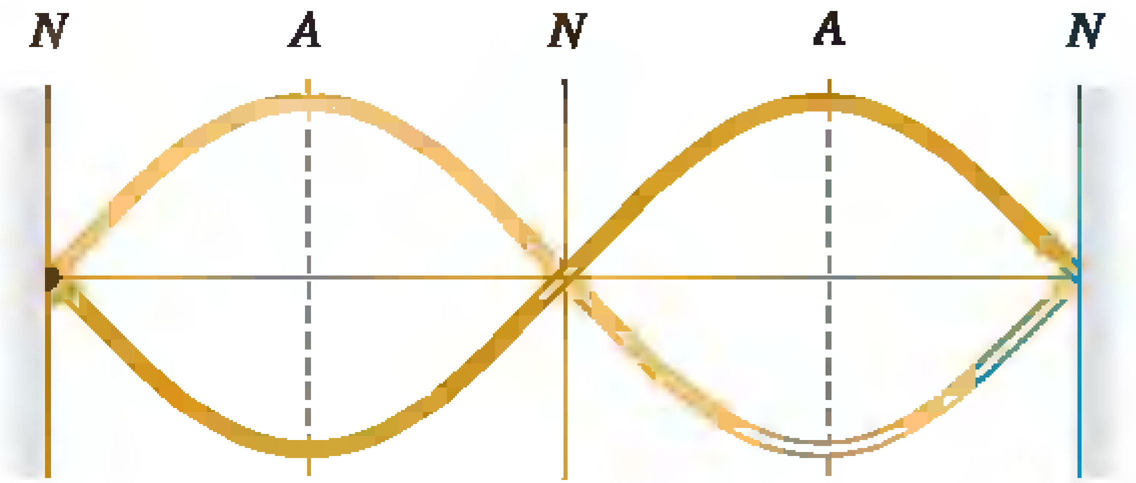
Travelling wave – amplitude remains the same and the wave pattern moves.

Here – the result is that the wave pattern stays the same – **standing wave**

http://www.walter-fendt.de/ph14e/stwaverefl.htm

Standing Wave

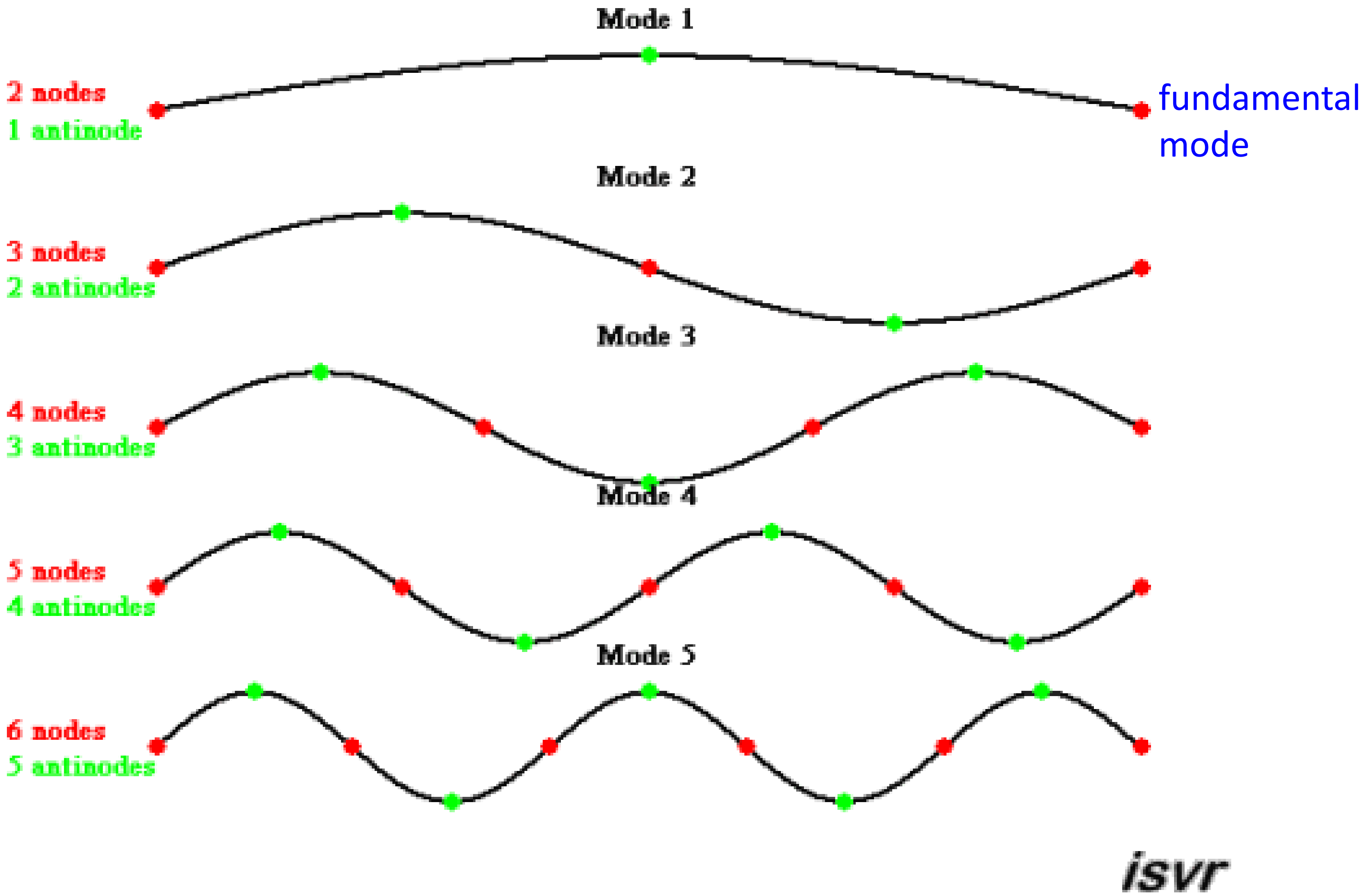




Nodes: places of no displacement

Antinodes: where amplitude of motion is greatest

Each vibration pattern is called a mode



We see here a harmonic series of the fundamental mode

Mathematical Description of a Standing Wave

$$y_1(x,t) = A\cos(kx - \omega t)$$

+

$$y_2(x,t) = -A\cos(kx + \omega t)$$

=

$$y(x,t) = y_1(x,t) + y_2(x,t)$$
$$\Rightarrow A\left[\cos(kx - \omega t) - \cos(kx + \omega t)\right]$$

Note the two sign changes

One for the change in direction on reflection and the other assumes a fixed boundary

$$\boxed{\cos(a \pm b) = \cos a \cos b \mp \sin a \sin b}$$

$$y(x,t) = 2A\sin(kx)\sin(\omega t)$$

$$\Rightarrow \boxed{A_{SW}\ \sin(kx)}\boxed{\sin(\omega t)}$$

$A_{SW} = 2A_{incident\ Wave}$

At each instant;
shape of wave is
sinusoidal

Wave shape, which
stays the same,
oscillates up & down

Where are the nodes?

$$\sin kx = 0$$

$$kx = n\pi,\ n = 0,1,2,\ldots$$

$$k = \frac{2\pi}{\lambda} \Rightarrow x = \frac{n\lambda}{2},\ n = 0,1,2,\ldots$$

The nodes are every $\lambda/2$ apart

For a string of fixed length L, it can have

$$L = \frac{\lambda_1}{2},\quad \frac{2\lambda_2}{2},\quad \frac{3\lambda_3}{2},\quad \ldots$$

$$L = \frac{n\lambda_n}{2},\ n = 1,2,3,\ldots$$

$$\lambda_n = \frac{2L}{n}$$

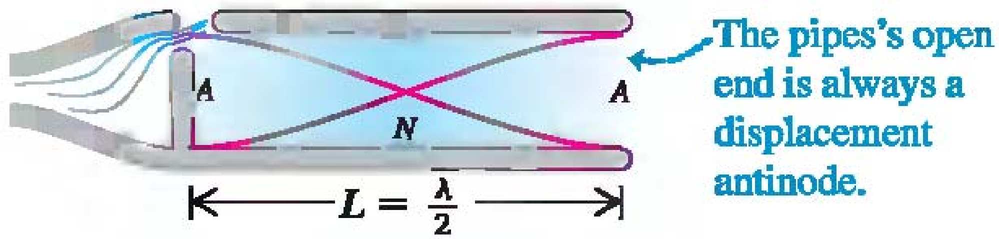
f_1 is the fundamental
f_n are the harmonics

$$v = f_n\lambda_n \Rightarrow f_n = n\frac{v}{2L} = nf_1$$

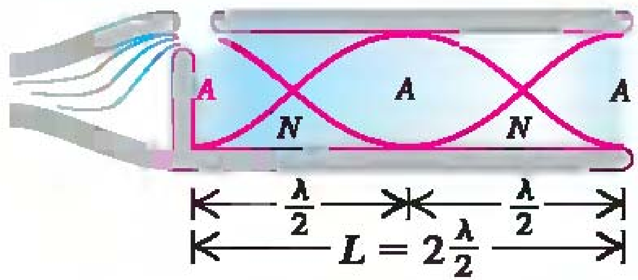
What about Longitudinal Standing Waves?, Organ Pipe

Open BOTH ends

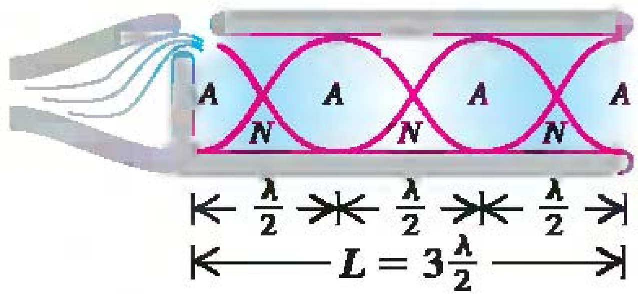
(a)
Fundamental: $f_1 = \frac{v}{2L}$



(b)
Second harmonic: $f_2 = 2\frac{v}{2L} = 2f_1$



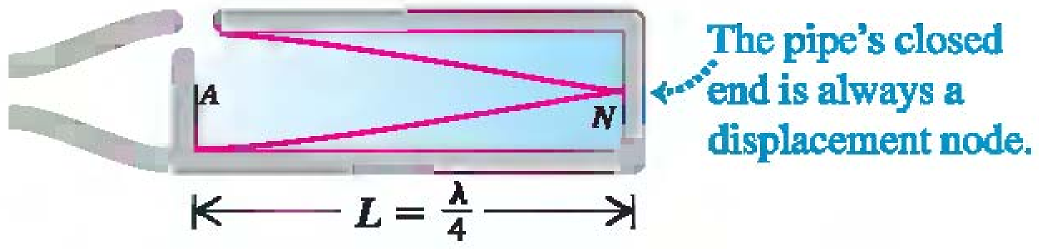
(c)
Third harmonic: $f_3 = 3\frac{v}{2L} = 3f_1$



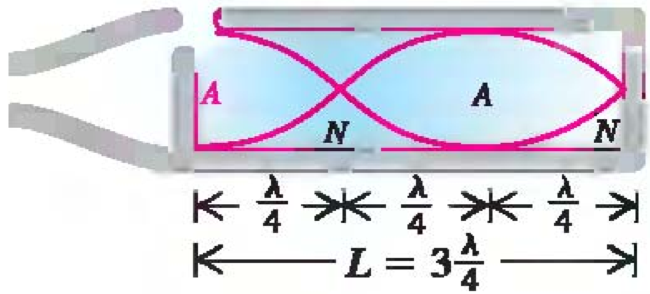
http://www.walter-fendt.de/ph14e/stlwaves.htm

Open at one end only → Only odd harmonics allowed

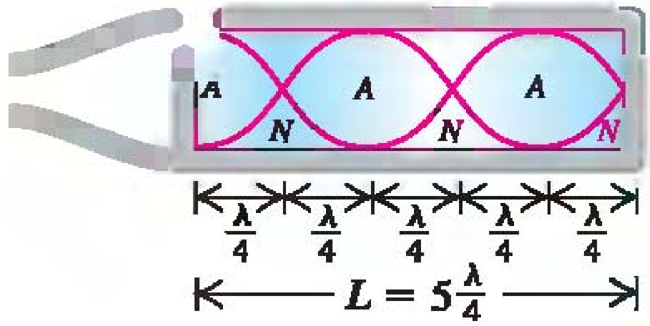
(a)
Fundamental: $f_1 = \frac{v}{4L}$



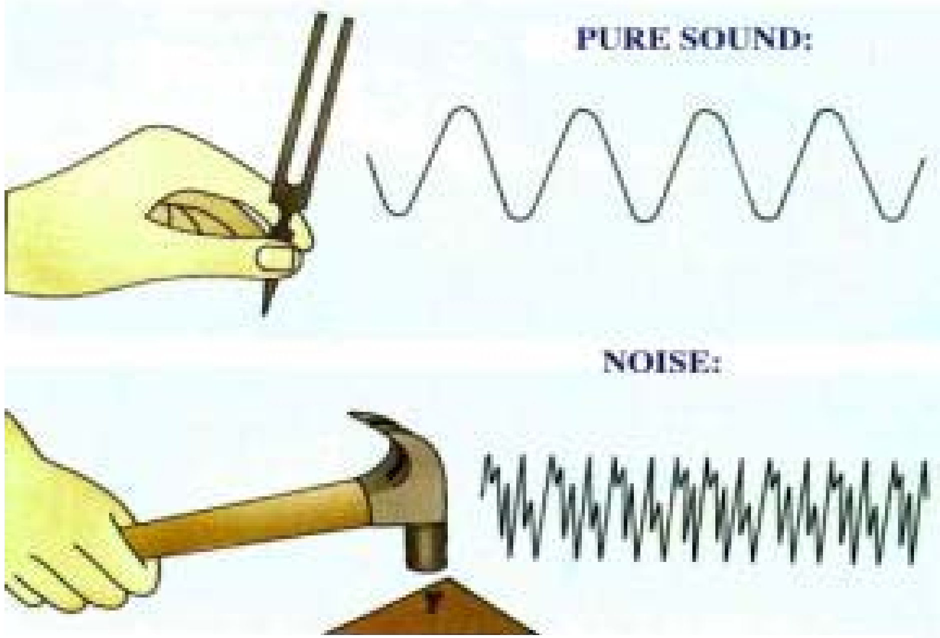
(b)
Third harmonic: $f_3 = 3\frac{v}{4L} = 3f_1$



(c)
Fifth harmonic: $f_5 = 5\frac{v}{4L} = 5f_1$

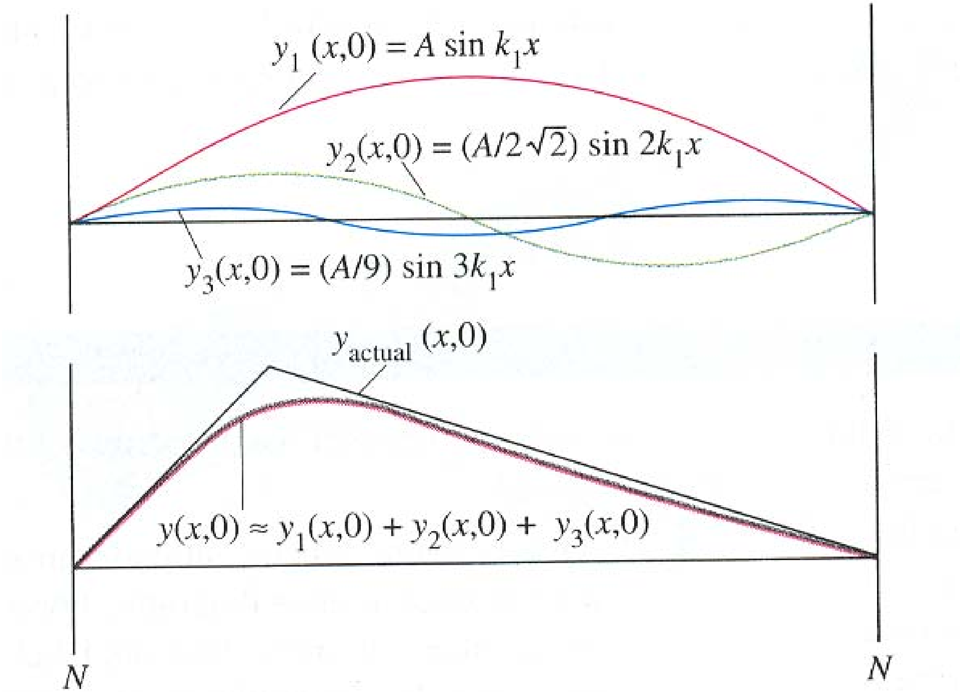


How do we make musical sounds



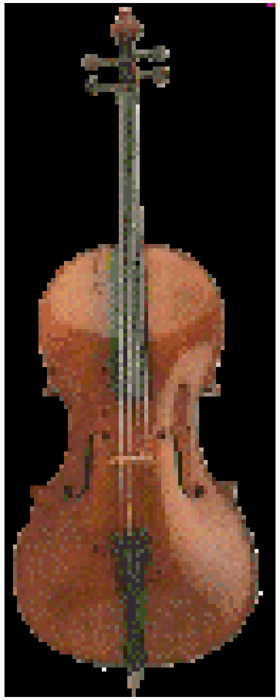
http://www.acoustics.salford.ac.uk/feschools/waves/guitarFullvideo.htm

Harmonic Content

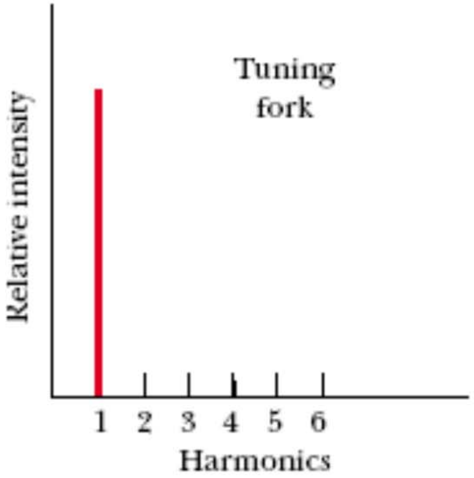


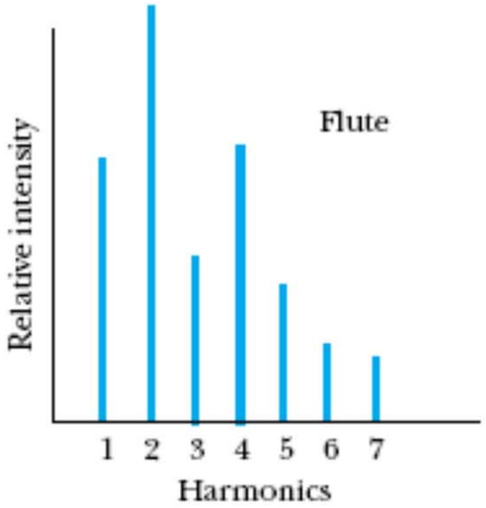
The standing wave produced when a guitar string is plucked is represented by the sum of three sine waves, corresponding to the fundamental and the next two harmonics.
A better fit is obtained as more harmonics are included.
These harmonics correspond to the harmonic content.
The sum of sinusoidal functions representing a complex function is called a Fourier series.
Square Waves?

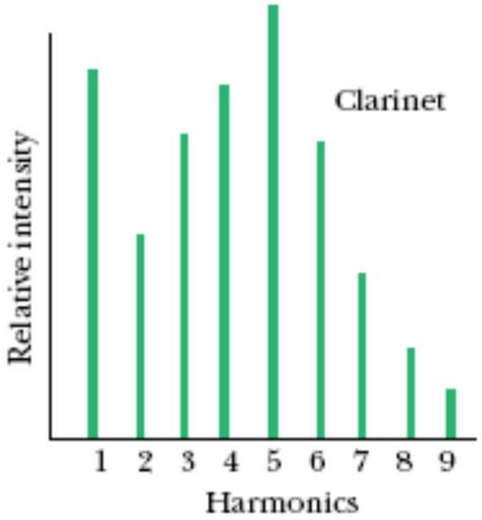
What do we hear?



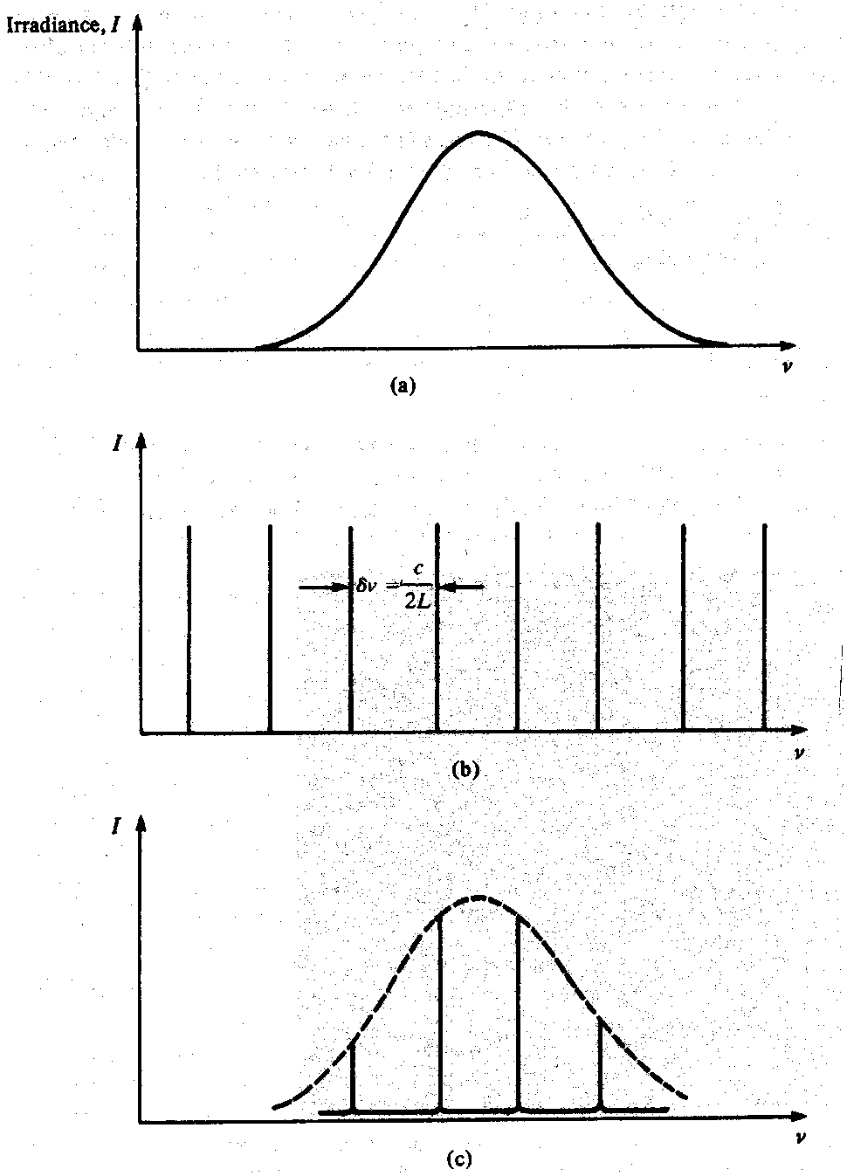
Different instrument, different sounds…

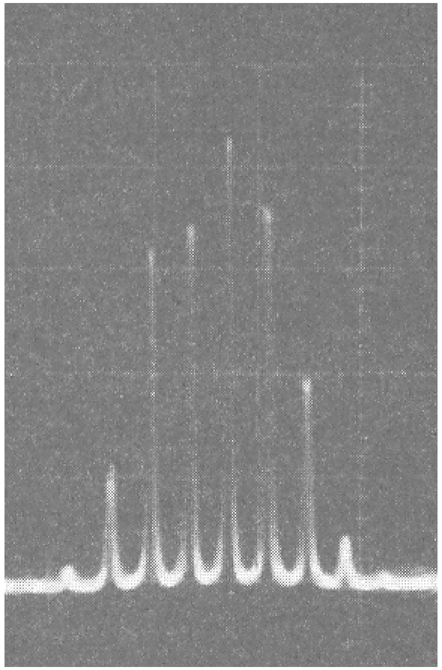






HeNe Laser





Determine the fundamental frequency for a 42.5 cm long pipe, open at one end and closed at the other. A taut string has a mass of 2 g, a length of 4.0 m and is under a tension of 5120 N. Determine which of the harmonics of the pipe, if any, are resonant with the harmonics of the string. [The speed of sound in air is 340 m/s]

Quick Quiz 16.1 In a long line of people waiting to buy tickets, the first person leaves and a pulse of motion occurs as people step forward to fill the gap. As each person steps forward, the gap moves through the line. Is the propagation of this gap (a) transverse (b) longitudinal?

Quick Quiz 16.2 Consider the "wave" at a baseball game: people stand up and shout as the wave arrives at their location, and the resultant pulse moves around the stadium. Is this wave (a) transverse (b) longitudinal?

Quick Quiz 16.3 A sinusoidal wave of frequency f is traveling along a stretched string. The string is brought to rest, and a second traveling wave of frequency $2f$ is established on the string. The wave speed of the second wave is (a) twice that of the first wave (b) half that of the first wave (c) the same as that of the first wave (d) impossible to determine.

Quick Quiz 16.4 Consider the waves in Quick Quiz 16.3 again. The wavelength of the second wave is (a) twice that of the first wave (b) half that of the first wave (c) the same as that of the first wave (d) impossible to determine.

Questions 1

1. Why is a pulse on a string considered to be transverse?
2. How would you create a longitudinal wave in a stretched spring? Would it be possible to create a transverse wave in a spring?
3. By what factor would you have to multiply the tension in a stretched string in order to double the wave speed?

6. If you shake one end of a taut rope steadily three times each second, what would be the period of the sinusoidal wave set up in the rope?

Answers 1

?

Questions 2

8. Consider a wave traveling on a taut rope. What is the difference, if any, between the speed of the wave and the speed of a small segment of the rope?
9. If a long rope is hung from a ceiling and waves are sent up the rope from its lower end, they do not ascend with constant speed. Explain.
10. How do transverse waves differ from longitudinal waves?
11. When all the strings on a guitar are stretched to the same tension, will the speed of a wave along the most massive bass string be faster, slower, or the same as the speed of a wave on the lighter strings?
12. If one end of a heavy rope is attached to one end of a light rope, the speed of a wave will change as the wave goes from the heavy rope to the light one. Will it increase or decrease? What happens to the frequency? To the wavelength?

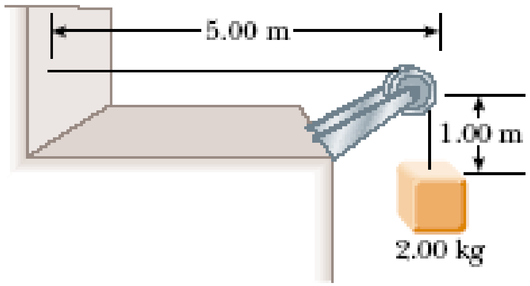
Answers 2

?

Example 16.3 A Sinusoidally Driven String

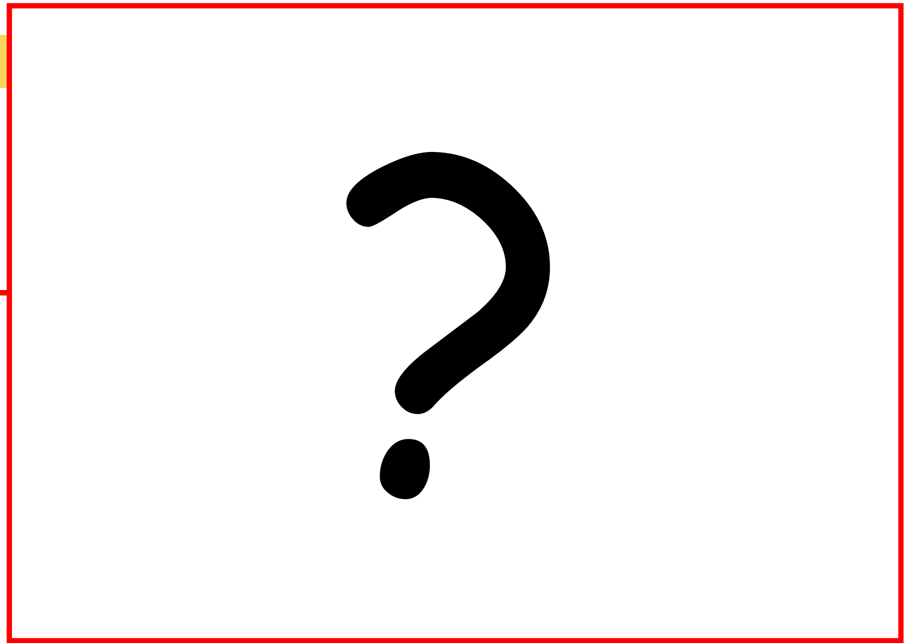
The string shown in Figure 16.10 is driven at a frequency of 5.00 Hz. The amplitude of the motion is 12.0 cm, and the wave speed is 20.0 m/s. Determine the angular frequency ω and wave number k for this wave, and write an expression for the wave function.

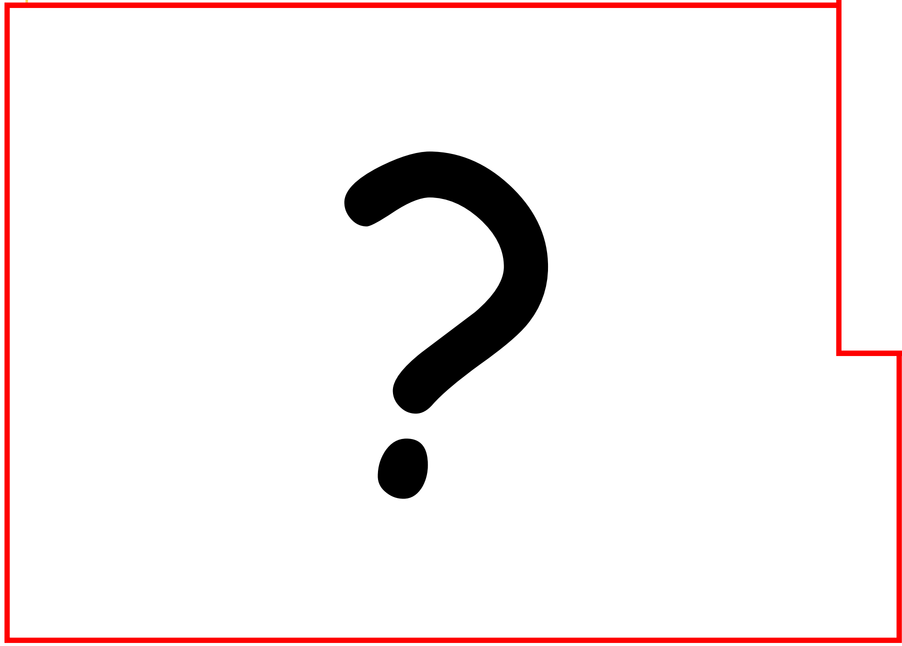
A uniform cord has a mass of 0.300 kg and a length of 6.00 m (Fig. 16.12). The cord passes over a pulley and supports a 2.00-kg object. Find the speed of a pulse traveling along this cord.



Example 16.6 Power Supplied to a Vibrating String

A taut string for which $\mu = 5.00 \times 10^{-2}$ kg/m is under a tension of 80.0 N. How much power must be supplied to the string to generate sinusoidal waves at a frequency of 60.0 Hz and an amplitude of 6.00 cm?

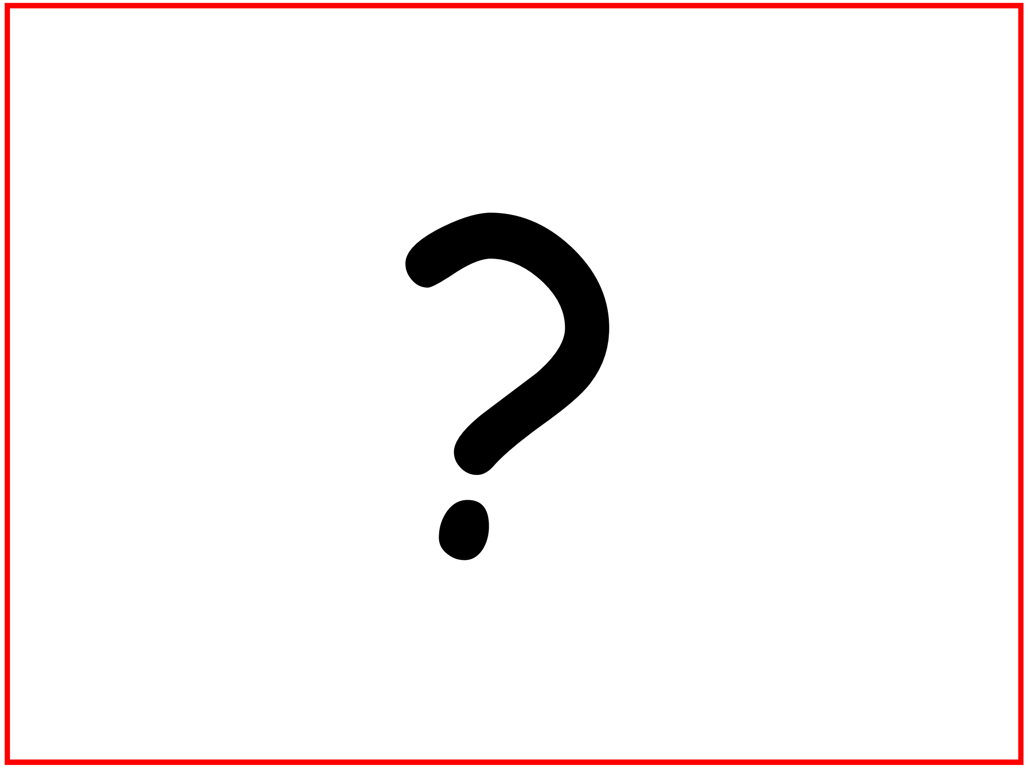




13. A sinusoidal wave is described by

$$y = (0.25 \text{ m}) \sin(0.30x - 40t)$$

where x and y are in meters and t is in seconds. Determine for this wave the (a) amplitude, (b) angular frequency, (c) angular wave number, (d) wavelength, (e) wave speed, and (f) direction of motion.



$\boxed{1.}$ Does the phenomenon of wave interference apply only to sinusoidal waves?

2. As oppositely moving pulses of the same shape (one upward, one downward) on a string pass through each other, there is one instant at which the string shows no displacement from the equilibrium position at any point. Has the energy carried by the pulses disappeared at this instant of time? If not, where is it?

9. Explain why your voice seems to sound better than usual when you sing in the shower.

10. What is the purpose of the slide on a trombone or of the valves on a trumpet?

11. Explain why all harmonics are present in an organ pipe open at both ends, but only odd harmonics are present in a pipe closed at one end.

20. If you inhale helium from a balloon and do your best to speak normally, your voice will have a comical quacky quality. Explain why this "Donald Duck effect" happens. *Caution*: Helium is an asphyxiating gas and asphyxiation can cause panic. Helium can contain poisonous contaminants.

3. Can two pulses traveling in opposite directions on the same string reflect from each other? Explain.

$\boxed{4.}$ When two waves interfere, can the amplitude of the resultant wave be greater than either of the two original waves? Under what conditions?

?

?

Example 18.2 Formation of a Standing Wave

Two waves traveling in opposite directions produce a standing wave. The individual wave functions are

$$y_1 = (4.0 \text{ cm}) \sin(3.0x - 2.0t)$$
$$y_2 = (4.0 \text{ cm}) \sin(3.0x + 2.0t)$$

where x and y are measured in centimeters.

(A) Find the amplitude of the simple harmonic motion of the element of the medium located at $x = 2.3$ cm.

(B) Find the positions of the nodes and antinodes if one end of the string is at $x = 0$.

(C) What is the maximum value of the position in the simple harmonic motion of an element located at an antinode?

Example 18.6 Wind in a Culvert

A section of drainage culvert 1.23 m in length makes a howling noise when the wind blows.

(A) Determine the frequencies of the first three harmonics of the culvert if it is cylindrical in shape and open at both ends. Take $v = 343$ m/s as the speed of sound in air.

(B) What are the three lowest natural frequencies of the culvert if it is blocked at one end?

(C) For the culvert open at both ends, how many of the harmonics present fall within the normal human hearing range (20 to 20 000 Hz)?