PHY 113 A General Physics I
9-9:50 AM MWF Olin 101

Plan for Lecture 34:
Chapter 16 – Physics of wave motion

1. **Examples of wave motion**
2. **What determines the wave velocity**
3. **Properties of periodic waves**

	11/02/2012	Exam	10-13,15		
23	11/05/2012	Fluid mechanics	14.1-14.4	14.8, 14.24	11/07/2012
24	11/07/2012	Fluid mechanics	14.5-14.7	14.39, 14.51	11/09/2012
25	11/09/2012	Temperature	19.1-19.5	19.1, 19.20	11/12/2012
26	11/12/2012	Heat	20.1-20.4	20.3, 20.14, 20.24	11/14/2012
27	11/14/2012	First law of thermodynamics	20.5-20.7	20.26, 20.35	11/16/2012
28	11/16/2012	Ideal gases	21.1-21.5	21.10, 21.19	11/19/2012
29	11/19/2012	Engines	22.1-22.8	22.3, 22.62	11/26/2012
	11/21/2012	*Thanksgiving Holiday*			
	11/23/2012	*Thanksgiving Holiday*			
	11/26/2012	Review	14,19-22		
	11/28/2012	Exam	14,19-22		
30	11/30/2012	Wave motion	16.1-16.6	16.5, 16.22	12/03/2012
31	12/03/2012	Sound & standing waves	17.1-18.8	17.35, 18.35	12/05/2012
	12/05/2012	Review	1-22		
	12/13/2012	Final Exam -- 9 AM			

The phenomenon of wave motion

The wave equation

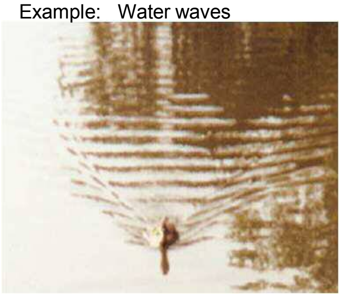
$$y(x,t)$$

Wave variable; position; time

$$\frac{\partial^2 y}{\partial t^2} = c^2 \frac{\partial^2 y}{\partial x^2}$$

- What does the wave equation mean?
- Examples
- Mathematical solutions of wave equation and descriptions of waves

Example: Water waves

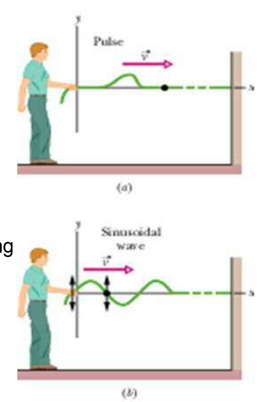


Source: http://www.eng.vt.edu/fluids/msc/gallery/gall.htm

Needs more sophistocated analysis:

Mechanical waves occur in continuous media. They are described by a value (y) which changes in both time (t) and position (x) and are characterized by a wave velocity c: y=y(x-ct) or y=y(x+ct)

Waves on a string:



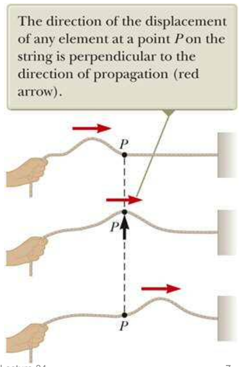
Typical values for c:

3×10^8 m/s light waves

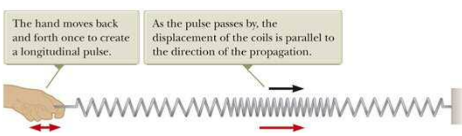
~1000 m/s wave on a string

343 m/s sound in air

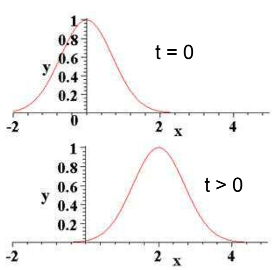
Transverse wave:



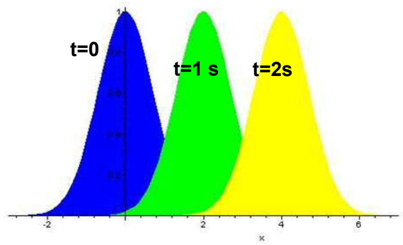
Longitudinal wave:



General traveling wave –



iclicker question:



The figure above shows three snap shots of a transverse wave plotted versus distance (x in meters). The snapshots were taken at t=0s (blue), t=1s (green), and t=2s (yellow). What is the velocity of the wave? (a) 1 m/s (b) 2 m/s (c) 3 m/s (d) 4 m/s (e) 6 m/s

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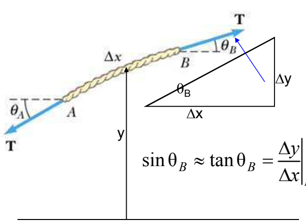
Basic physics behind wave motion --

example: transverse wave on a string with tension T and mass per unit length μ



$$\sin\theta_B \approx \tan\theta_B = \left.\frac{\Delta y}{\Delta x}\right|_B$$

$$m\frac{d^2y}{dt^2} = T\sin\theta_B - T\sin\theta_A$$

$$m \approx \mu\Delta x$$

$$\Rightarrow \mu\Delta x\frac{d^2y}{dt^2} \approx T\left(\left.\frac{\Delta y}{\Delta x}\right|_B - \left.\frac{\Delta y}{\Delta x}\right|_A\right)$$

$$\lim_{\Delta x\to 0}\frac{1}{\Delta x}\left(\left.\frac{\Delta y}{\Delta x}\right|_B - \left.\frac{\Delta y}{\Delta x}\right|_A\right) = \frac{\partial^2 y}{\partial x^2}$$

$$\frac{\partial^2 y}{\partial t^2} = \frac{T}{\mu}\frac{\partial^2 y}{\partial x^2}$$

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The wave equation:

$$\frac{\partial^2 y}{\partial t^2} = c^2\frac{\partial^2 y}{\partial x^2} \qquad \text{where } c \equiv \sqrt{\frac{T}{\mu}} \text{ (for a string)}$$

Solutions: $y(x,t) = f(x \pm ct)$ — function of *any* shape

Note: Let $u \equiv x \pm ct$

$$\frac{\partial f(u)}{\partial x} = \frac{\partial f(u)}{\partial u}\frac{\partial u}{\partial x}$$

$$\frac{\partial^2 f(u)}{\partial x^2} = \frac{\partial^2 f(u)}{\partial u^2}\left(\frac{\partial u}{\partial x}\right)^2 = \frac{\partial^2 f(u)}{\partial u^2}$$

$$\frac{\partial^2 f(u)}{\partial t^2} = \frac{\partial^2 f(u)}{\partial u^2}\left(\frac{\partial u}{\partial t}\right)^2 = \frac{\partial^2 f(u)}{\partial u^2}c^2$$

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Examples of solutions to the wave equation:

Moving "pulse": $y(x,t) = y_0 e^{-(x-ct)^2}$

Periodic wave: $y(x,t) = y_0 \sin\left(k\left(x-ct\right)+\phi\right)$

phase factor

"wave vector"
not spring constant!!!

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

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

$$y(x,t) = y_0 \sin\left(2\pi\left(\frac{x}{\lambda} - \frac{t}{T}\right) + \varphi\right) \qquad \frac{\lambda}{T} = c$$

Periodic traveling waves:

$$y(x,t) = y_0 \sin\left(2\pi\left(\frac{x}{\lambda} - \frac{t}{T}\right) + \varphi\right) \qquad \frac{\lambda}{T} = c$$

phase (radians)

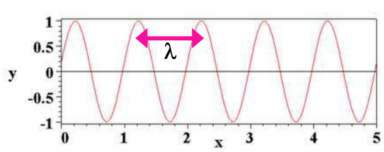
velocity (m/s)

period (s); $T = 1/f$

wave length (m)

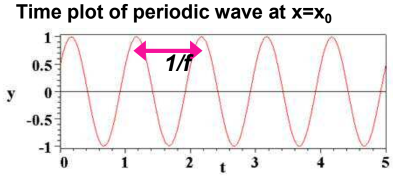
Amplitude

Snapshot of periodic wave at $t=t_0$



f* λ = *c

Time plot of periodic wave at $x=x_0$



Combinations of waves ("superposition")

Note that:

$$\sin A \pm \sin B = 2\sin\left[\tfrac{1}{2}(A \pm B)\right]\cos\left[\tfrac{1}{2}(A \mp B)\right]$$

$$y_{right}(x,t) = y_0 \sin\left(2\pi\left(\frac{x}{\lambda} - \frac{t}{T}\right) + \varphi\right) \qquad y_{left}(x,t) = y_0 \sin\left(2\pi\left(\frac{x}{\lambda} + \frac{t}{T}\right) + \varphi\right)$$

"Standing" wave:

$$y_{right}(x,t) + y_{left}(x,t) = 2y_0 \sin\left(\frac{2\pi x}{\lambda} + \varphi\right)\cos\left(\frac{2\pi t}{T}\right)$$

Summary of wave properties:

Wave speed c depends on the process and/or medium in which wave occurs.

Example: Wave on a string with tension T and mass/length μ: $c = \sqrt{\frac{T}{\mu}}$

Example: Sound wave in air with pressure p and density ρ: $c = \sqrt{\frac{\gamma p}{\rho}}$

Example: Light wave due to coupled electric and magnetic fields:

$c = 2.9979 \times 10^8\, m/s$ (fundamental constant)