Today	**Review for Exam 1**	HW5 redo	HW7
Next Monday.	**Exam 1**		
Wednesday	**Ch 18 Electric Force**		

Administrative:

- HW7 will be graded immediately and available for pick-up about 1.5 hrs after lecture ends.
- HW6 redo and HW7 redo will be accepted until 2pm tomorrow. At that point I will post their solutions for the benefit of folks studying for the test.

Exam 1 Review

- **Format**
  - Short answer
  - No long problem
  - Show work for partial credit
  - Provide your own equation sheet, but it may have *no words* on it.
- **Content**
  - Ch. 10, 16, 17.
    - Material I covered in lecture
    - Problems like my examples
    - Problems like your homework
    - Problems like the lab
    - Particular candidates for the long problems are things that you'd seen in at least two of these three contexts.
    - If the book writes it in a beige box – you better know it. Ex. The Principle of Linear Superposition.
    -

Chapter 10 Simple Harmonic Motion

10.1 The Ideal Spring and Simple Harmonic Motion

- **Essential for Simple Harmonic Motion**
  - **Equilibrium Position**
    - A location where a body feels no net force or torque
  - **Restoring Force**
    - Force or forces that conspire to return a displaced body to its equilibrium position
    - **Linear**
      - The force is, or is approximately, linear in displacement form equilibrium.
  - **Inertia**
      - The tendency of an object to remain in its state of motion unless acted upon by a net force. This allows a body under the influence of a linear restoring force to overshoot the equilibrium position.
- **Hooke's Law:** $\vec{F}_{Sp\rightarrow} = -k_{sp}\Delta\vec{x}$

- Not a fundamental Force, but a mathematical linear approximation for forces that restore a body to Equilibrium**.**
- k_{sp} is the "spring constant" and represents the 'stiffness' of the restoring force. The bigger k_{sp}, the stronger the restoring force for a given displacement.
- Springs in parallel have a greater net stiffness, springs in series have a lower net stiffness.
- This relationship is built upon the approximate linearity of inter-atomic forces in bulk matter. The force – displacement relationship on the atomic level scales up to the macroscopic level. Thus this equation has broad applicability.

10.2 Simple Harmonic Motion

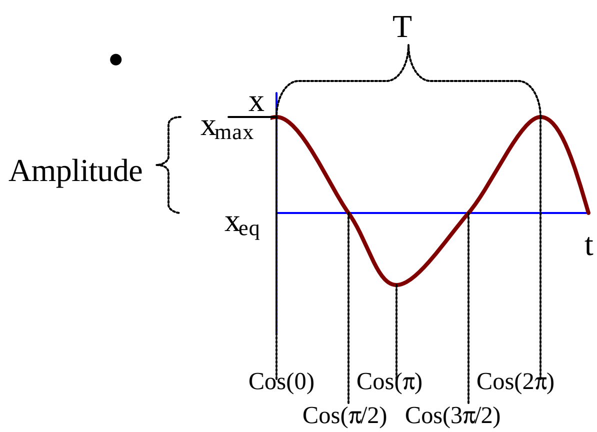
- The repetitive / cyclic motion that results from a linear restoring force. Systems that can execute this type of motion: mass on spring, pendulum, tuning fork, bridge, air, string, sounding board, atoms, …

10.2.1 Displacement

- If the spring force is the only force acting on a body,
- $F_{net} = F_{Sp\rightarrow m}$**,** or expressing both of these in terms of position, x,

  $m\dfrac{d^2}{dt^2}x = -k_{sp}x$**.** This equality is true for $x = x_{\max}\cos(wt)$ where

  $w = \sqrt{\left(k_{sp}/m\right)}$ **= Angular Frequency.**
- **Sinusoidal Motion**
  - Plotting as a function of time:
  -



10.2.1.1 **Period =** T, the period of time it takes for the position to go through one full cycle and return to its initial condition. $T = \dfrac{2p}{w} = 2p\sqrt{\dfrac{m}{k}}$

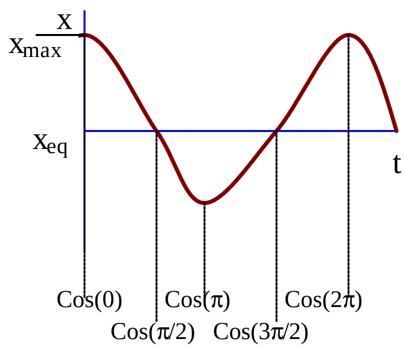
10.2.1.2 **Frequency** = f = 1/T. The inverse of the period. Instead of how many seconds per one cycle (period), how many cycles per one second (frequency).

10.2.1.3 **Amplitude =** the maximum value the function obtains. In the case of displacement, the absolute value of the maximum displacement from equilibrium.

10.2.2 Velocity = $\dfrac{dx}{dt} = -wx_{\max}\sin(wt)$**.** Note: the amplitude of velocity, $v_{max} = \omega x_{max}$.

10.2.3 Acceleration = $\frac{dv}{dt} = \frac{d^2x}{dt^2} = -w^2 x_{\max} \cos(wt) = -w^2 x(t)$**.** Note: the amplitude of acceleration, $a_{max} = \omega^2 x_{max}$.

Be able to identify on the position vs. time plot, where the object is moving the fastest, where it comes to a hault. When it experiences the greatest force, when it experiences no force, when it has executed one full cycle of motion.



10.3 The Pendulum

- **The Three Conditions for simple harmonic motion met**
    - **Equilibrium Position:** hanging straight down
    - **Restoring Force:** Gravitation and tension, easiest to describe in terms of angles and restoring torque: mg *l* sin(θ).
        - **Linear** approximation: mg*l*θ.
    - **Inertia:** Moment of inertia m l^2.

$Ia = t_{gravity}$

- $mr^2 \frac{d^2q}{dt^2} \approx -mgrq$ this gives rise to $q = q_{\max} \cos(wt)$ where

$w = \sqrt{\frac{g}{l}} \Rightarrow T = 2p\sqrt{\frac{l}{g}}$

- Note: the period does not depend on mass, only length.
- Note: as with the mass on a spring, there is a ratio of something to do with the restoring force (g) and something to do with the inertia (l).

10.4 Dampened harmonic Motion

- In reality, the restoring force is seldom the only force interacting with the system. There are usually dissipative forces tapping energy out of the system, ex. friction, drag. These have the effect of shrinking x_{max} through time., so the system oscillates between smaller and smaller extremes until its motion dies away.
- **Critically Dampened =** motion dies away the fastest. **Over dampened =** oddly, applying an even bigger damping force draws the motion out a little longer.

10.5 Driven Harmonic Motion

- Another role that an external force, other than the restoring force, can play is to drive the oscillations. If the driving force is applied at the same frequency of the motion, like a person pushing a swing, the motion grows to its maximum.

10.5.1 Resonance = the situation of a force driving a system at its natural frequency & thus maximizing the oscillations' amplitude.

Chapter 16 Waves and Sound

16.1 The Nature of Waves

- A mass attached to a spring attached to another mass attached to a spring…coupled simple harmonic oscillators. The series of individual mass' oscillations is a wave.

16.1.1 Transverse: the masses can move perpendicular to each other, bobbing up and down out of line consecutively. The sum of these motions can be, for example, waves on the surface of water. The displacements are perpendicular, i.e. *transverse,* to the propagation of the wave down the line.

16.1.2 Longitudinal: the masses can move back and forth toward and away from each other consecutively. The sum of these motions can be, for example, compressions moving through the air as sound. The displacements are parallel, i.e. *longitudinal*, to the propagation of the wave.

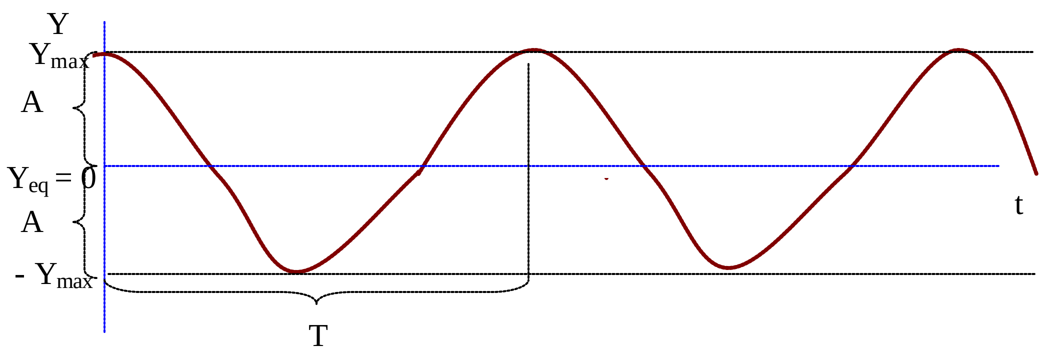
16.1.3 Medium: the material that supports the wave's distortion (ex. a string, or the air for a sound wave).

16.1.4 Front: a point of in the medium where the distortion is taking place.

16.1.5 Wave/Front Speed: v_w the speed with which the front moves through the medium.

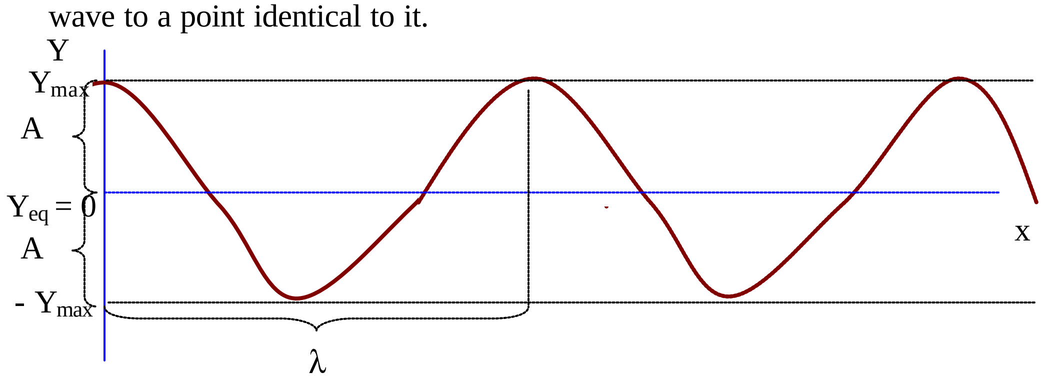
16.2 Periodic Waves

16.2.1 Period: Same as for a single simple harmonic oscillator: the period of time for the system to execute one full cycle of displacement and return to its initial state. For a simple, sinusoidal wave, this is equal to the time for just one piece of the medium to execute one full cycle.

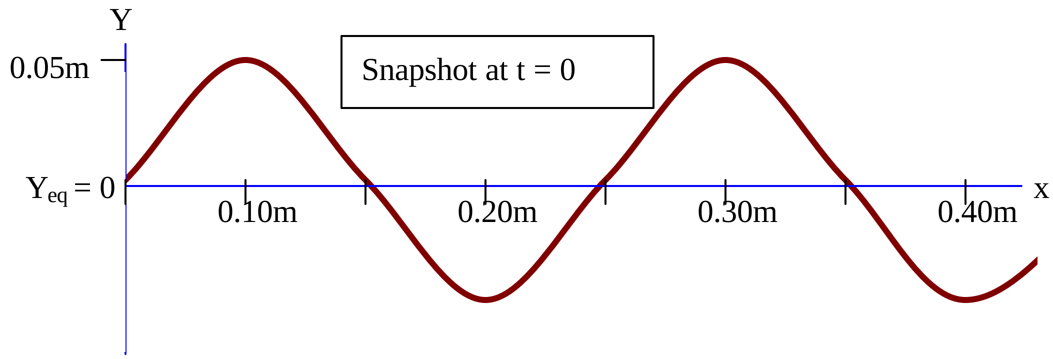


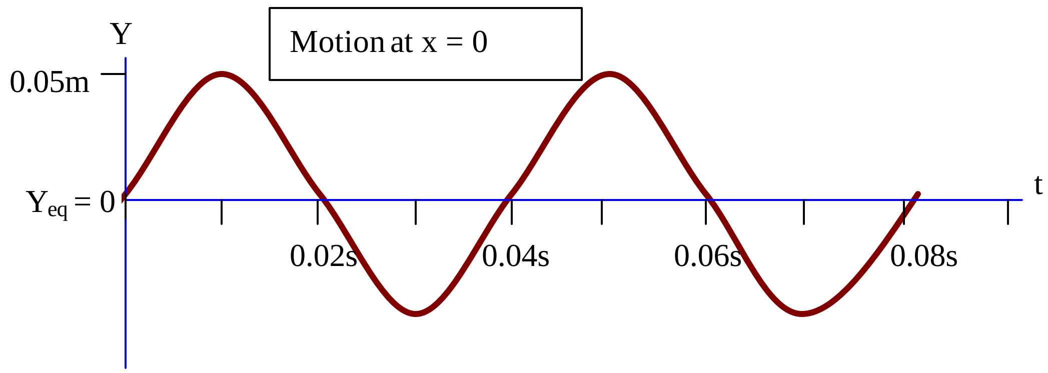
16.2.2 Frequency: 1/T

16.2.3 Wavelength: λ. The "period" in space. The distance along the medium (say, a string) over which one full cycle is supported. The distance from a point in the wave to a point identical to it.



16.2.4 $\mathbf{v_w = \lambda / T = \lambda f}$. Wave speed equals the wavelength over the period.





- The two plots above represent a wave traveling down my favorite wave-demo (the series of long beams). Write the Y position as a function of x and t. In other words, write the basic form of the equation and fill in values for all the constants.

Y(x,t) = ______________________________

16.3 The Speed of a Wave on a String

- Similar to a single simple harmonic oscillator, the rapidity of the motion depends on the square root of something force like (restoring the individual pieces of the medium to equilibrium with their neighbors) over something inertial like (how sluggishly the medium responds to the force).
- $v_w = \sqrt{\dfrac{F}{m/L}}$

16.4 The Mathematical Description of a Wave

- $y(t,x) = Y_{\max} \sin\left(2\pi\left(\dfrac{t}{T} \mp \dfrac{x}{\lambda}\right)\right)$**; -** for moving in the + direction, + for moving in the – direction.
- Be able to do something like Problem 24: Read the period or frequency, wavelength, and amplitude off plots of a wave as a function of time and location.

16.5 The Nature of Sound

- Longitudinal waves through matter in which the distortion that defines a wave pulse is the simultaneous variation in atomic / molecular forces or pressure, dislocation from equilibrium, and density.

16.5.1 Longitudinal Sound Waves

Like a chain of masses bound to each other by springs, where the masses are dislocated by pushing toward and away from each other along the chain. Like in a slinky.

16.5.1.1 **Compression / condensation:** Location along the medium where the particles are pressed together more than usual: increased density / pressure.

16.5.1.2 **Rarefaction :** Locations along the medium where the particles are spread out more than usual: decreased density / pressure.

16.5.2 Frequency of Sound Waves

16.5.2.1 **Pure Tone:** Conveniently, the human ear resolves a complicated sound wave into individual sinusoidal waves (describable by $D(t,x) = D_{\max} \sin\left(2p\left(\frac{t}{T} \mp \frac{x}{l}\right)\right)$ where "D" is for which ever distortion you're following through the air). We call these simple sound waves Pure Tones.

16.5.2.2 **Pitch:** Pure tones are distinguished in the ear by their frequencies, the perception of a sound wave's frequency is a Pitch.

- **Why the ear resolves pitch** (in overly simplistic terms): The ear has a fleet of simple harmonic oscillators that have different natural frequencies. Each oscillator resonates & sends a signal to the brain when it is driven by sound at its natural frequency.

16.5.3 The Pressure Amplitude of a Sound Wave

16.5.3.1 **Pressure Amplitude:** One of the simultaneous distortions that propagate in sound waves is a change in pressure. Pressure amplitude is the maximum pressure change due to a sound wave.

16.5.3.2 **Loudness:** This translates into a pressure on the eardrum & the strength of the force driving the simple harmonic oscillators in our ears & thus the amplitude of their motion. This determines our perception of loudness.

16.6 The Speed of Sound

- The speed of a sound wave, like any other wave, depends on the properties of the medium. Like everything else, it roughly goes like the square root of the ratio of something force like over something inertia like.

16.6.1 Gasses

- In a gas, the speed of sound is roughly the speed with which the particles naturally move. This speed was found in Kinetic Theory to relate to the temperature of the gas and the mass of the particles. More specifically the speed of a sound wave in an ideal gas is
  - $v_W = \sqrt{\frac{gkT}{m}}$
- Be able to use this equation to compare speeds in different media or at different temperatures; use in conjunction with $v_w = \lambda f$ to compare different frequencies given the same wavelengths & different temperatures and/or temperatures.

- **Long Problem:** Say you have an organ pipe that plays middle C (f = 271.9 Hz) when 'breathing' air, molecular mass of 4.80×10^{-25} kg. What note would it play when 'breathing' helium (mass 6.6×10^{-26} kg) instead? Note: air is diatomic and helium is monatomic.

16.7 Sound Intensity

- Rather than discussing the strength of a sound in terms of pressure, we can discuss it in terms of energy transmitted through the wave to a receiver, per time & per area.
- $I = \frac{E}{A \cdot t} = \frac{P}{A}$, here P is for power, not pressure. Units are in $J/(m^2 * s) = W/m^2$

16.7.1 Threshold of Hearing:
The sound intensity below which we cannot hear: $I_o = 10^{-12} W/m^2$ (this is a bit of an over generalization & rounded to a nice number).

16.7.2 Spherically uniform radiation

- Sound radiates outward uniformly in all directions. For a point source or a spherical source, this means that the sound radiates out spherically.
- Given that only so much energy is invested in a wave front, and it travels out radially at a constant speed, the power in the wave front is constant, however, the front itself expands over larger and larger spherical surfaces.
- $I = \frac{P}{4pr^2}$ gives the intensity in terms of the Power of the wave front and the radius of the front (which is a spherical shell).
- Be able to use this equation to compare two situations: Ex. Intensities at different distances for the same wave front.

16.8 Decibels

- Yet another way of describing the strength of a sound wave. Our perception of Loudness does not scale linearly with the pressure amplitude or intensity of the wave.

16.8.1 Sound Intensity Level

- Relative Loudness of sound 2 to 1 $\approx \frac{1}{5} \cdot 10dB \log\left(\frac{I_2}{I_1}\right)$ (using log base 10). This makes it convenient to define the **Sound Intensity Level**: $b \equiv 10dB \log\left(\frac{I}{I_o}\right)$
- **Decibel: dB.** This is a log of a ratio of like quantities, thus it is unitless. We call readings of Sound Intensity Level decibels, or dB's
- ?Be able to put this and the equation for spherically radiating sound together to compare Sound Intensity Levels at different distances from the source?

16.9 The Doppler Effect

- **Moving Source:** When a source moves relative to an observer, the wavelength of the sound waves changes, as each subsequent sound front is emitted from a different location.
  - $l' = l \mp v_s T$ where v_s is the speed of the source. – if the source moves toward the observer and compresses the wave, + if the source moves away from the observer and stretches the wave, no change at all if the source moves perpendicular to the observer.
- **Moving Observer:** When an observer moves relative to the source, the speed with which the sound waves and observer meet is changed.

- $v_w' = v_w \pm v_o$ the effective wave speed is increased if the observer approaches the source, decreased if the observer moves away from the source, not changed for perpendicular motion.

- **Moving Medium: (Not responsible for this case)** Similar to the moving observer, if the wind is blowing, it changes to the speed with which the sound travels from source to observer.

16.9.1 Moving Source, Moving Observer, General Case

- $f' = f\left(\frac{1 \pm \frac{v_o}{v_w}}{1 \mp \frac{v_s}{v_w}}\right)$
  - **Note:** v_o = observer speed, v_s = source's speed, v_w = wave's speed. $+v_o$ for observer moving toward source. - v_s for source moving toward observer, so top sign is toward each other, bottom sign is away from each other.
  - **Hint:** When you forget which sign is which case, appeal to a reasonability check in the most extreme cases– if the source is moving infinitely fast away from you, you never hear a thing, the frequency is 0; if the observer is moving at the speed of sound away from the source, again, the frequency should be 0.

Chapter 17 Linear Superposition and Interference

17.1 The Principle of Linear Superposition

- Two (or more) sources driving disturbance waves through the same medium at the same time. How the resulting motion is determined.

17.1.1 Principle of linear superposition

- When two or more waves are present simultaneously at the same place, the resultant disturbance is the sum of disturbances from the individual waves.
  - Know what this means.

17.2 Constructive and destructive interference

17.2.1 In phase

- Waves are in phase if they maximize or minimize, etc. at the same time at the same place – they're both telling the medium right there to do the same thing.

17.2.2 Constructive interference

- In phase waves add according to the principle of linear superposition to construct an even bigger distortion in the medium than one of them alone would have done. They don't have to be completely in phase to construct – just as long as their distortions have the same sign.

17.2.3 Out of phase

- In the extreme, two waves tell the medium to do the exact opposite thing, ex. one says 'go up' while the other says 'go down'.

17.2.4 Destructive interference

- Out of phase waves add according to the principle of linear superposition to partly or wholly destroy each other – certainly a smaller distortion in the medium than one of them alone would have done. If they are perfectly out of phase and of equal magnitude, this would cause complete cancellation – no distortion at all.

17.2.5 Relative distances from two coherent sources to points of constructive and destructive interference.

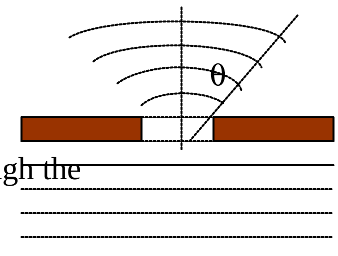
- Points in phase, total constructive interference: $|d1 - d2| = n\ \lambda$, n = 0, 1, 2, …
- Points out of phase, total destructive interference: $|d1 - d2| = (n + ½)\ \lambda$, n = 0, 1, 2, …

17.2.6 Node = Point in space of complete destructive interference, no wave distortion

17.2.7 Anti-node = Point in space of complete constructive interference, maximum wave distortion.

17.3 Diffraction

- Waves passing from a narrow to a broader medium radiate out to eventually fill the full breadth of the medium. This is diffraction. However, it doesn't happen immediately, this leaves dead space behind obstacles. This effect can be mathematically described in terms of the angle of the wave's spread, i.e., the diffraction angle.: θ.



17.3.1 Single slit – first minimum

- the ½ angle of the beam's cone for a slit (ex. water waves moving through the opening of a bay or sound through a rectangular doorway) is related by
  - $\sin q = \frac{l}{D}$

17.3.2 Circular opening – first minimum

- Specifically, the ½ angle of the beam's cone for a *round* window (ex. sound coming through a *round* window or a speaker mouth) is related by
  - $\sin q = 1.22 \frac{l}{D}$

17.4 Beats

- If the medium is being driven by two sources of the exact same frequency, then the points of constructive and destructive interference are stationary in space. However, if the sources have different frequencies, then these points travel through space. To a stationary listener. The effect is the sound oscillates between constructive and destructive interference. This effect is known as beating.

17.4.1 Beat frequency

- The period of time between two waves cycling form in phase, through out of phase, and back to in phase is the least common multiple of the two. Ex. a sound with a 10 ms period and a sound with a 12 ms period are both peaked after 60 ms.
- In terms of frequency, the frequency of the beat is simply the difference of the two source's frequencies. $f_{beat} = | f_2 - f_1 |$

Standing wave

- A standing wave results when two sources drive at equal frequency and amplitude, but off in phase. This happens most often when a wave interacts with its own reflection. Ex. on the torsion wave beam, waves travel to the left, reflect off the end and travel back to the right. The effect is that nodes and anti-nodes are fixed in space.

17.5 Transverse Standing Waves

- **Lab**: With a string anchored at both ends, you could only support wavelengths that fit the condition that a node must be at both ends – integer multiples of half wavelengths could be supported.

17.5.1 Natural frequency

- Given the properties of the medium, the wave speed is predetermined.
- Given the points where the medium is anchored, the possible wavelengths are determined.
- This, with v=λf means that there are only set frequencies at which the medium wants to hold a wave. The lowest one is termed the **natural frequency**. Subsequent ones are termed the **harmonics.**

17.5.2 String fixed at both ends

- Like Lab: Combine the constraints of nodes being at both ends, the possibilities of higher harmonics with nodes symmetrically spaced along the string L = n $\lambda/2$, n = 1,2,3…; v=λf ; and the dependence of wave-speed on the medium $v_w = \sqrt{\frac{F}{m/L}}$.