AP Physics
Full Review

Past Exam Breakdown

1. Energy (25%)
2. Dynamics/Newton's Law (20%)
3. Kinematics (17%)
4. Rotational Motion (16%)
5. Momentum (14%)
6. Circular Motion/Gravitation (5%)
7. Simple Harmonic Motion (3%)

Key:

Important Idea

Vocab

Sub-definition

Formulas

Kinematic Equations

$v = v_0 + at$ no Δx

$\Delta x = v_0 t + \frac{1}{2}at^2$ no v

$v^2 = v_0^2 + 2a\Delta x$ no t

$\Delta x = \bar{v}t = \frac{1}{2}(v + v_0)t$ no a

$\Delta x = vt - \frac{1}{2}at^2$ no v_0

$$v = v_0 + at$$

$$v^2 = v_0^2 + 2a\Delta x$$

$$\Delta x = v_0 t + \frac{1}{2}at^2$$

Motion Graphs

- In a **position graph**, velocity is the slope
- In a **velocity graph**, acceleration is the slope & the area under is displacement
- In an **acceleration graph**, the area under the line is velocity

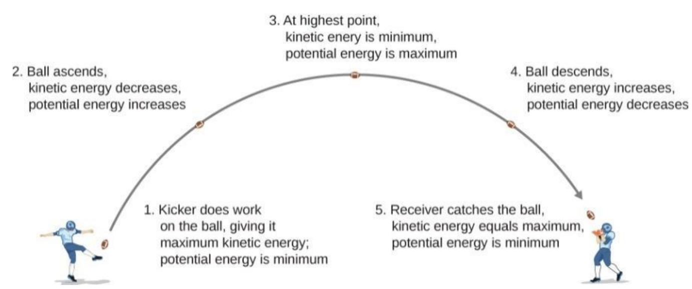
Basic Formulas

- Acceleration=Δv/Δt
- V=d/t
- Vavg=V1+V2/2

Projectile Motion

The basics:

- Horizontal motion: velocity, displacement, time
- Vertical motion: initial velocity, final velocity, displacement, time, acceleration
- Horizontal time=vertical time
- Apply kinematic equations to fill in vertical quantities and then use those to find horizonal quantities
- At the highest point, t=-Voy/-g



Involving an angle:

- Break it down by horizontal and vertical components
- Use kinematics
- Apply the average velocity equation to find missing horizontal quantities (v=d/t)

- If up to the right, sine is for vertical and cosine for horizontal
- Horizontal range: Voy^2xsin2(-)/g where (-) is theta

Forces

Newton's Laws

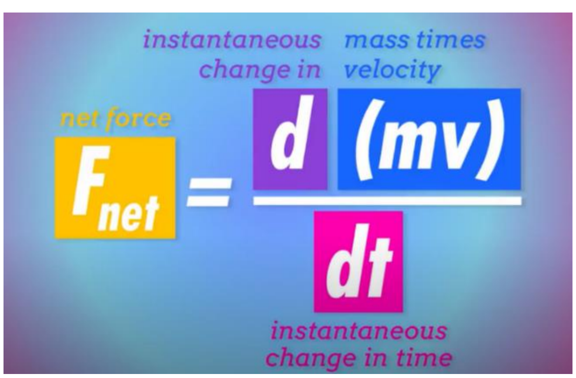
1. If a center of mass is at rest, it'll remain at rest unless acted upon by a net force (a moving center of mass will maintain a constant velocity unless acted upon by a net force)
2. The acceleration of an object/system is equal to the net force acting upon it divided by its mass (a=fnet/m)
3. Every action has an equal and opposite reaction (action-reaction requires 2 forces from 2 objects acting on each other)

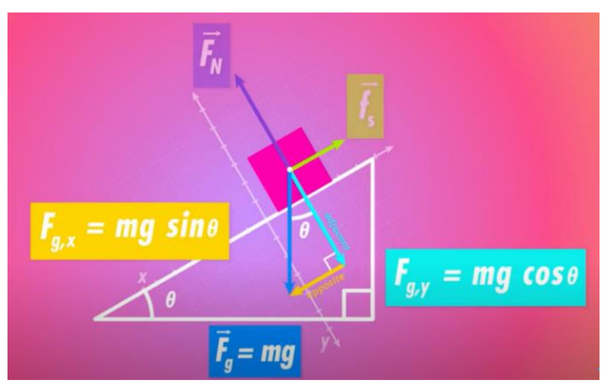
Equilibrium

- Static Equilibrium: occurs when the net force on a MOTIONLESS object/system is 0
- Dynamic Equilibrium: occurs when the net force on a MOVING object/system is 0 (no acceleration though, must have a constant velocity)
- If it's not moving or at a constant rate, all forces are balanced

Normal Force & Friction

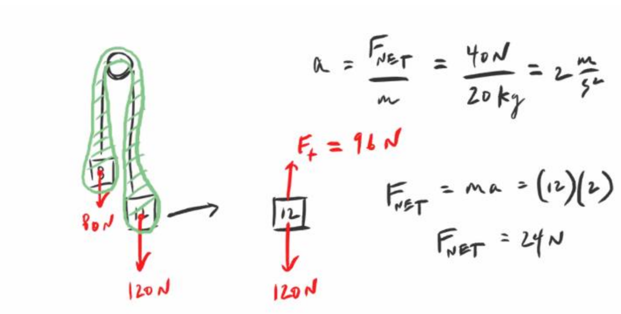
- Normal force acts perpendicular to the surface applying it (Fg=mg)
- Friction force acts parallel to the surface applying it (s stops it from moving, k slows it)
    - Static friction (Fs): acts on motionless object; magnitude/direction will always be whatever keeps the object from moving (Fs≤Ms x Fn); static friction will oppose the applied force until it reaches the max (then kin)
    - Kinetic friction (Fk): acts on moving objects once the static friction threshold has been passed; direction is always opposite the direction the object is moving (Fk=Mk x Fn) where M is the coefficient of friction
    - Sine makes it slide, cosine keeps it close (cos into the ramp, sine down it)

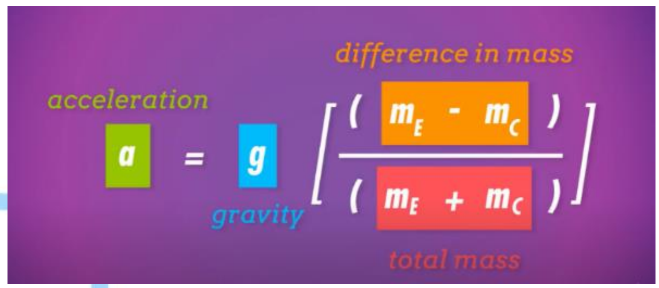


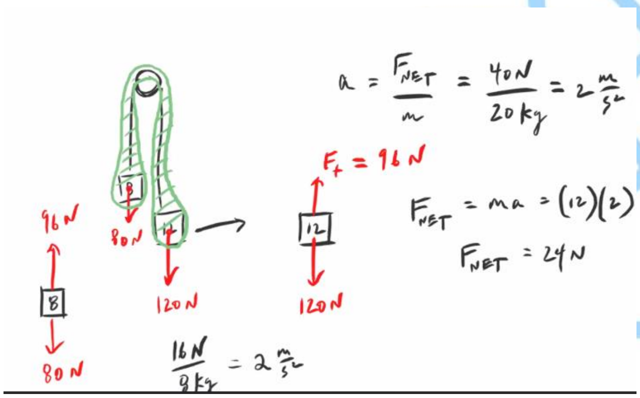


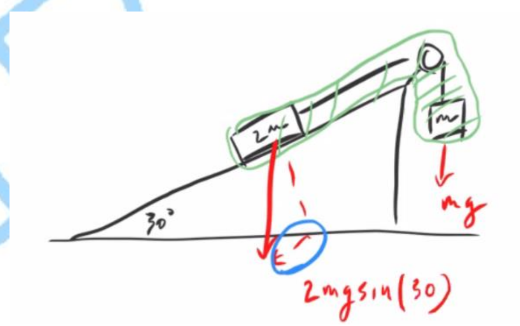
Atwood Machines

- Two masses hanging from a massless string with a massless/frictionless pulley
- Tension is consistent in the string and accelerations are always equal
- Considered a system (python method!), gravity is all that will accelerate it
- Fnet=ma=Tg-T=ma-T which means T=mg-ma
- If m1+m2m the system is in equilibrium (d or s) but if not, it accelerates
- Newton’s third law: a=Fnet/m
- The downwards force of one block minus the net force would give you the force of tension









*if an object is sliding or traveled a distance down (like on a ramp), the velocity at the bottom can be found with v=root of 2gh

*if going down a frictionless ramp, Mk=h/x

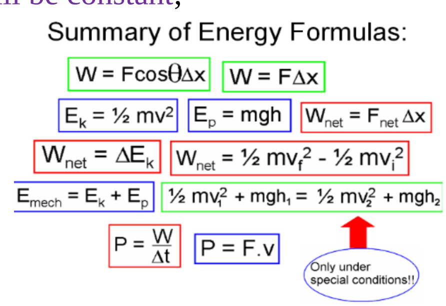
Mechanical Energy

Work

- Work (w) is the mechanical transfer of energy to or from an object/system by pushing or pulling; occurs when a force is applied and displaces an object/system
- Scalar quantity
- Formula: W=Fdcos(-) or KEf-KEi
- Positive work: adds mechanical energy to the system; occurs when a component of the applied force and displacement are in the same direction (Θ is between 0 and 89)
- Negative work: takes mechanical energy from the system; occurs when the applied force and displacement aren't in the same direction (Θ is between 91 and 180)
- Work that is perpendicular to the direction of intended motion does zero work
- Work is the area under a force by position graph

Energy

- Kinetic Energy: the energy of motion, measured in Joules (J); changes in kinetic energy require work! K=1/2mv^2 (if KE is doubled, velocity increases by a factor of root 2)
- Potential Energy: energy an object COULD have if released into motion, measured in Joules (J)
    - Gravitational Potential Energy (Ug)- energy attributed to an object/system based on its location in a gravitational field (Ug=mgh)
      -if no friction, 1/2v^2=gh b/c mass cancels out
    - Elastic Potential Energy (Us)- energy attributed to an object/system based on its contact with a stretched or compressed spring (Us=1/2kx^2)
- Conservation of Energy: the total energy of an isolated system will be constant; mechanical energy will always be conserved in the absence of friction; work is always required to increase or decrease total mechanical energy
- Blocks on ramps: steeper-faster; the height says they'll have the same velocity at the end (steepness affects time, height affects final velocity and Δx if becoming a projectile)
- Mk=Ff/Fn



Power

- Power (P) is the rate at which energy changes state
- Scalar quantity measured in watts (W), 1 W=1J/s
- Multiply watts by time to get joules if constant rate
- P=F x v or P=W/t so P=Fd/t or P=FvcosΘ

Momentum (tendency to remain in motion, always conserved)

Impulse (J)

- Impulse is the change in momentum
- Impulse is the area under a force by time graph
- $I=f\Delta t$ or $I=\Delta(mv)$
- So it follows that f x t = m x change in v

Elastic Collisions

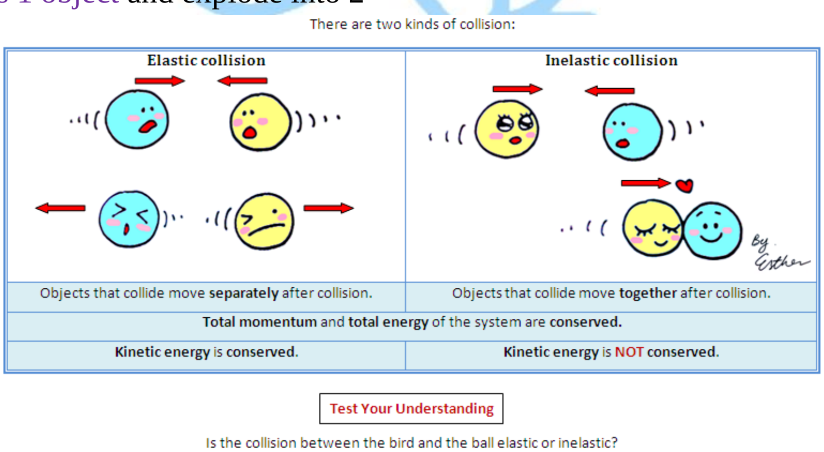
- Elastic collisions conserve the momentum and kinetic energy of the system
- They bounce off each other
- Law of Conservation of Momentum: the total momentum of an isolated system is constant because it's unchanged by inner events
- For elastic collisions, $P1i+P2i=P1f+P2f$

Inelastic Collisions

- They conserve momentum (p in a system is always conserved) but do not conserve kinetic energy
- Objects begin seperately, collide, and frequently stick together if perfectly inelastic

Explosions

- They conserve momentum but not kinetic energy
- They start as 1 object and explode into 2



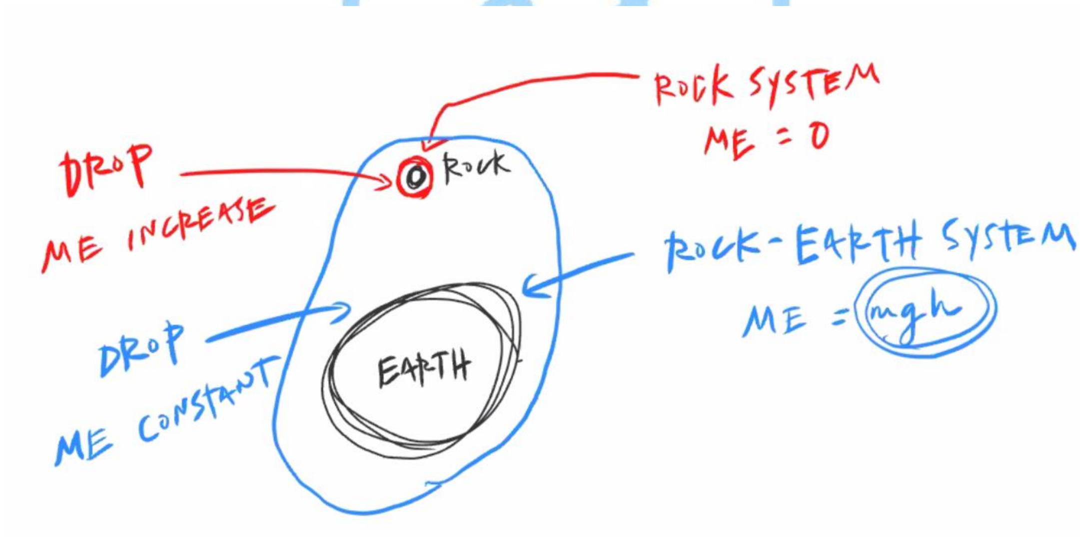
Center of Mass

- The center of mass is essentially where something would balance on a fulcrum

- It can be calculated by establishing a point (where x=0) then multiplying each massive part's distance from that times it's mass. Add those values together and divide by the total mass (shown below where the center of mass is 2)

Closed vs Open Systems

- If energy is changed by something outside of the objects in question, it is open
- Closed systems conserve energy
- If losing energy to the surroundings (taking from the objects that classify system) it means it's open
- Friction=means it's open / mechanical energy is conserved in the absence of friction



Circular Motion & Gravitation

The basics

- Uniform circular motion is the motion of an object moving along a circular path at a constant speed

- Tangential speed is constant
- Tangential velocity is not constant (+ and -)
- Tangential velocity is always TANGENT to the circular path

Centripetal Acceleration & Force

- Centripetal acceleration is directed towards the center of a circular path that turns an object but does NOT change its speed
    - Like regular acceleration, it is measured in m/s^2
    - It is a vector
    - Centripetal acceleration can be solved with: $Ac=v^2/r$ (v being tangential velocity)
- Centripetal force is the force that produces the centripetal acceleration necessary to turn an object; the net force going into the middle of the circle (could be Fn, Fg, etc)
    - It is perpendicular to motion so it can’t do work ($\cos 90=0$)
    - Like regular forces, it is measured in Newtons
    - It is a vector
    - Do not label on free body diagrams
    - Centripetal force is centripetal acceleration times mass or $Fc=m \times (v^2/r)$ or $Fc=mw^2r$ / if an object’s going in a circle on a rope, $Ft-Fg=Fc$
    - If a planet is in orbit, gravitational force is the centripetal force so $GMm/R^2=mv^2/R$ (ref pg 322 in big book)

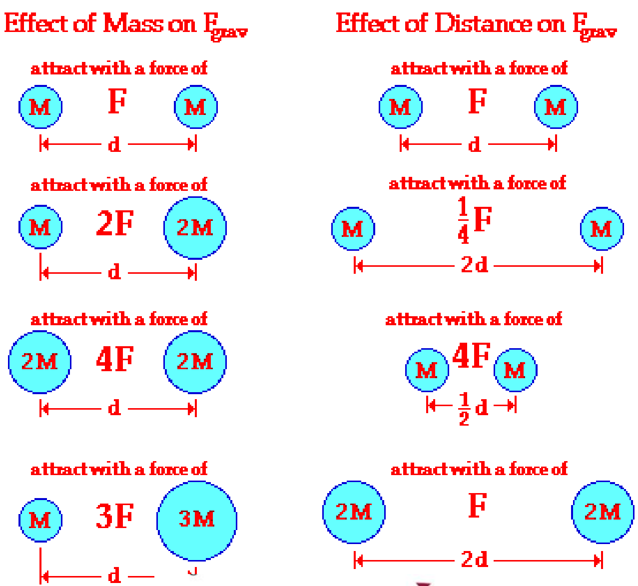
Gravity

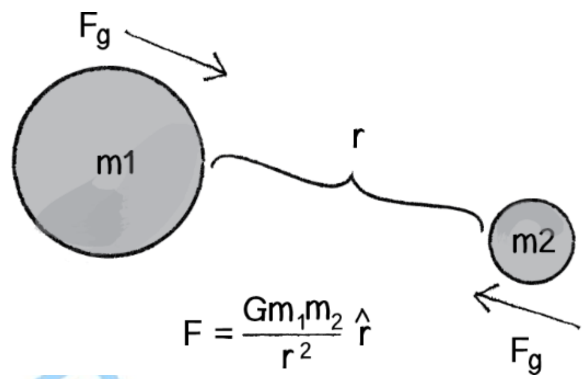
- Newton’s Law of Universal Gravitation: The gravitational force exerted between 2 objects is directly proportional to the mass of each; it is also inversely proportional to the squared distance between the objects’ centers of mass! Or, and far more simply, $Fg=Gm1m2/r^2$ (if distance between particles is 2x, the force decreases by factor of 4)
    - $G=6.67e^{-11}$ (gravity constant)
    - Fg (the force of gravity) also refers to the strength of the field
- Gravitational field (g): The invisible field that surrounds any mass and applies a force on any other object with mass
    - Always directed toward center of mass
    - Gravitational strength is directly related to the gravitational constant (by planet) and the mass of the source (the bigger the mass it’s coming from, the stronger)
    - Gravitational strength is inversely related to the squared distance from the source (the farther, the weaker)
    - Gravitational field strength: $g=GM/r^2$ (on earth that’s the 9.81 number I think)
- Gravitational potential energy: find the GPE between 2 objects/systems using $Ug=Gm1m2/r$

- Earth's radius: 6.37 x 10^6
- Earth's mass: 5.973 x 10^24
- G=6.67e^-11
- So, if it involves earth, Ug=(6.671E^-11)(5.973E^24)(m2)/6.37E^6

Orbits:

- For one orbit/revolution, v=2πr/T and since Ac=v^2/r, then Ac=4π^2r/T^2
- Also Fc=mv^2/r so for 1 revolution, Fc=4 π^2mr/T^2





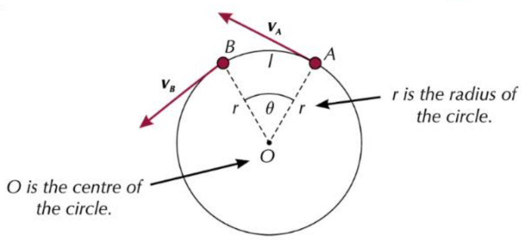
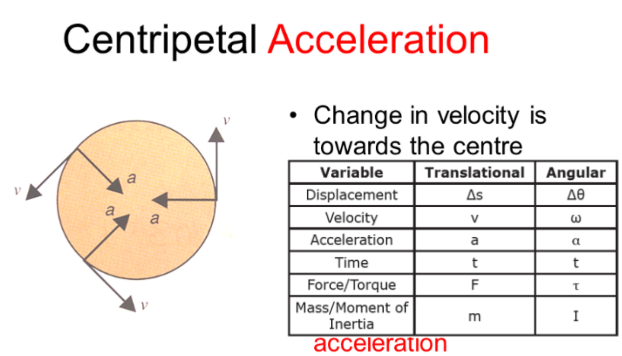


Figure 2: *A ball travelling in a circular path travels through angle θ when it moves from point A to point B.*



Variable	Translational	Angular
Displacement	Δs	Δθ
Velocity	v	ω
Acceleration	a	α
Time	t	t
Force/Torque	F	τ
Mass/Moment of Inertia	m	I

<u>Rotational Motion</u>

Rotational Quantities

- Types of motion:
  - Translational motion: the whole object moves across a trajectory
  - Angular motion: rotation (every point moves along a circle)
  - Combination motion: rotating while traveling a trajectory (has both rotational kinetic energy and kinetic energy)
- Angular Velocity (ω): the # of radians an object rotates in a certain time; every point on a rotating rigid body has the same angular velocity (w=angle of rotation/time)

- Angular velocity is the area under an angular velocity by time graph

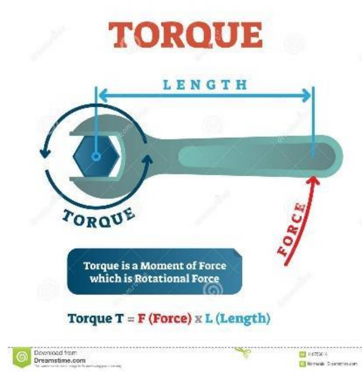
- Angular Acceleration (fish-looking thing): the rate at which a rotating object's angular velocity is changing with respect to time (aa=change in angular velocity/time or torque/inertia)
  - Angular acceleration is the slope of an angular velocity by time graph
  - AA is constant with constant torque
- Translational quantities are the rotational analog times the radius

Translational motion		Rotational motion	
Displacement	dr	Angular displacement	$d\phi$
Velocity	$\mathbf{v} = dr/dt$	Angular velocity	$\boldsymbol{\omega} = d\phi/dt$
Acceleration	$\mathbf{a} = dv/dt$	Angular acceleration	$\boldsymbol{\alpha} = d\omega/dt$
Mass	M	Moment of inertia	$I = \int \rho \lvert\hat{\omega}\times\mathbf{r}\rvert^2 \, dV$
Force	$\mathbf{f} = M\mathbf{a}$	Torque	$\boldsymbol{\tau} \equiv \mathbf{r}\times\mathbf{f} = I\,\boldsymbol{\alpha}$
Work	$W = \int \mathbf{f}\cdot d\mathbf{r}$	Work	$W = \int \boldsymbol{\tau}\cdot d\boldsymbol{\phi}$
Power	$P = \mathbf{f}\cdot\mathbf{v}$	Power	$P = \boldsymbol{\tau}\cdot\boldsymbol{\omega}$
Kinetic energy	$K = M v^2/2$	Kinetic energy	$K = I\omega^2/2$

Translational	Rotational
$v = v_0 + at$	$\omega = \omega_0 + \alpha t$
$\Delta x = v_0 t + \frac{1}{2}at^2$	$\Delta\theta = \omega_0 t + \frac{1}{2}\alpha t^2$
$v^2 = v_0^2 + 2a\Delta x$	$\omega^2 = \omega_0^2 + 2\alpha\Delta\theta$

Torque

- Torque is the rotational analog to force
- Torque is required in order to change an object's angular velocity
- Torque is a vector that uses the Newton-meter unit
- Solved with T=Frsin(-) and T=Iaa where r is the length of the lever and theta is the angle between the force and arm (max at 90 degrees)
  - The lever arm is the perpendicular distance from the axis of rotation/revolution to the line of the applied force
  - Only the force component perpendicular to the lever arm can affect torque
  - Negative torque goes clockwise and positive torque goes counter-clockwise
  - Net torque is proportional to impulse
  - Any force coming from the center of an object will not apply torque
  - Net torque is the slope of angular momentum by time graph
  - If torque is constant, so is angular acceleration
  - If net torque is 0, net force is 0 and vice a versa

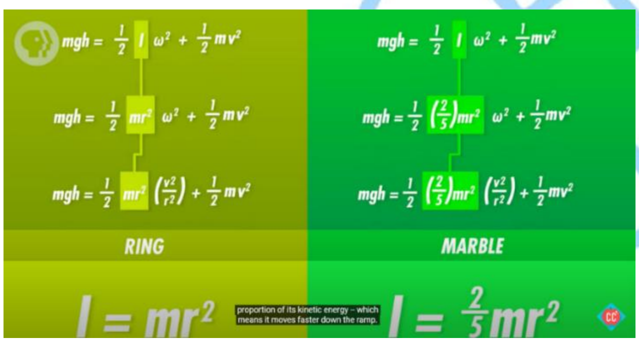


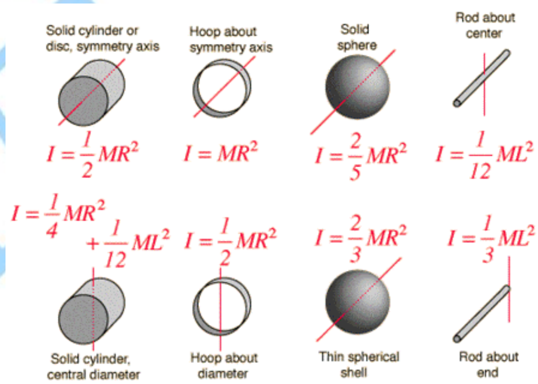
Equilibrium

- Rotational equilibrium occurs when the net torque on an object is zero (like a balance)
- Static equilibrium is when an object is at rest, 0 net force and 0 net torque
    1. Pick an axis/pivot that removes an unknown
    2. Determine the torque created by each force
    3. Determine the sign of each torque around the pivot point
    4. Write the equations for Fnet=0 and Tnet=0
    5. Solve the equations

Inertia

- Moment of inertia: a measure of how easily an object can rotate
    - Rotation is dependent on mass distribution
    - Standard unit is kgm^2
    - Inertia is the slope of a torque by angular acceleration graph
- Newton's 2nd Law for Rotation: an object that experiences a net torque about the axis of rotation undergoes an angular acceleration
    - Solved with aa=Tnet/I (moment of inertia) so smaller inertia, greater aa
- Inertia has a quadratic relationship with r^2 and a linear relationship with mass
- When inertia increases, the angular velocity decreases
- Inertia formulas:





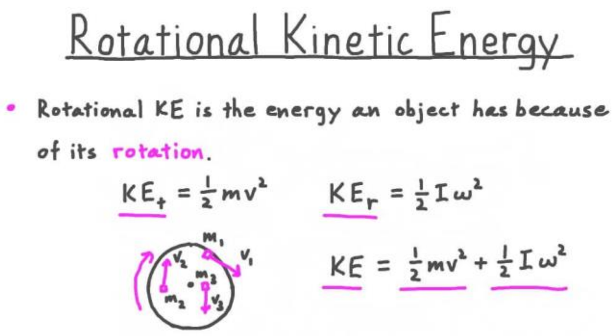
Angular Momentum:

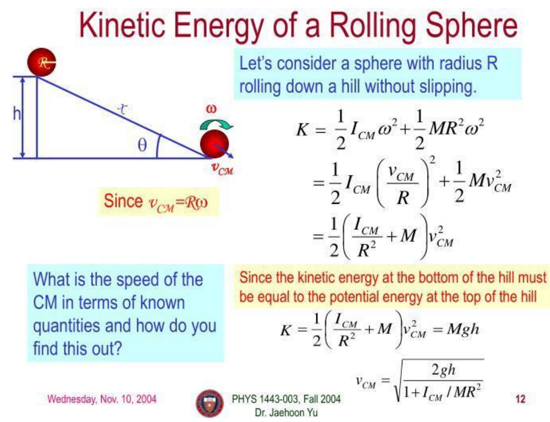
- Angular momentum (L): the momentum attributed to the rotation of an object
- A change in angular momentum requires a torque applied over a time interval
- Angular momentum can be solved by multiplying inertia and angular velocity (L=IW) and the change can be determined by multiplying torque and time (ΔL=Tt)
- Conservation of Angular Momentum: the angular momentum of a rotating object/system subject to no external torque is conserved

Rotational Kinetic Energy:

- RKE is the KE of a rotating object…self-explanatory
- The total KE is always more than a nonrotating object at the same speed

- If an object is rotating AND has a linear displacement, part of its energy is KE and part is RKE. Thus, a rotating object will always take longer to travel down an incline when compared to a sliding one (the sliding one doesn't have to split energy)
- RKE is solved with Krot=1/2Iw^2 or Krot=1/2I(v/r)^2
- Rotating object on a trajectory- Ug=Ktrans+Krot or Ktotal=1/2mv^2+1/2Iw^2





Simple Harmonic Motion

The basics

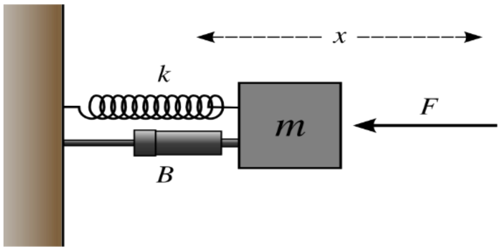
- Simple harmonic motion is an example of periodic motion where the restoring force (see definition below) is directly proportional to the distance stretched or compressed
- Amplitude: the initial displacement (how far it's pushed back)
- Period (T): measured in s, the time required for a system to complete 1 revolution (2πr)
- Frequency (f): measured in Hertz (Hz), it's the # of revolutions/cycles in a unit of time; F=1/T
- Handy dandy table!

	Max location	Min location
Elastic potential energy	Amp	Eq
Spring force	Amp	Eq
Acceleration	Amp	Eq

Kinetic energy	Eq	Amp
Speed	Eq	Amp

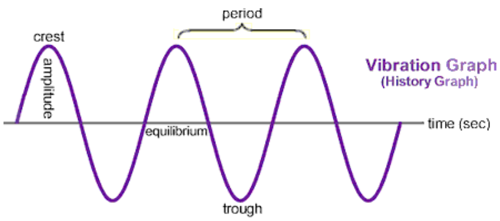
Hooke's Law

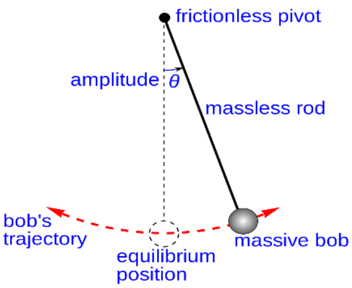
- Hooke's Law states the restoring force is qual to the spring constant times the displacement from equilibrium, aka Fs=kx (k is slope of Fs by x graph)
- Equilibrium: the position where the spring/mass-spring system experiences 0 net force
- Spring constant (k): measured in N/m, it qualitatively means tightness and quantitatively means the amount of force needed to stretch it 1m
- Restoring force: it pushes a stretched/compressed object towards equilibrium
- Max speed at equilibrium where all energy is KE and min speed at amplitude when all energy is PE
- Spring energy: Us=1/2kx^2 or PE=1/2kA^2 (a is amp)



Periods:

- Mass-spring systems: systems consisting of a massive object that's attached to one end of a spring; Ts=2π(square root of m/k) (frequency would be 1/2π x root of k/m)
- Pendulum: a system of a massive object (the bob) suspended by a string/rod; Tp=2π(square root of l/g) where l is the length of the pendulum and g is gravity's a (frequency would be 1/2π x root of g/l)
- Impacts of other variables:
    - Period is affected by m an5d k but not by x, the extra stretch is compensated for by extra energy
    - Double the spring constant (k), f goes up by root 2
    - Half the length (l), divides period (T) by root 2
    - If angular momentum (L) increases, period (T) increases (slower)





Waves

Parts of Transverse Waves

- Crests are points of maximum vertical displacement above the horizontal
- Troughs are points of maximum vertical displacement below the horizontal
- One wavelength is measured as the distance between 2 adjacent crests or troughs
- Amplitude is the maximum displacement from the horizontal to either a crest or trough

Period and Frequency

- The time it takes for one complete vertical oscillation is called the period (T)
- The number of cycles it completes in one second is called frequency (f)
- Period and frequency are inverses of each other
  - $T = \frac{1}{f}$ and $f = \frac{1}{T}$
- To find the speed of a wave:
  - distance = rate × time
  - wavelength = speed × period
  - **$v = f\lambda$**

Wave Speed on a Stretched String

- **Speed of a transverse wave on a stretched spring: $v = \sqrt{\frac{F_T}{\mu}}$**
  - Linear mass density (μ) mass of string/length of string

- F_T is force due to tension

Big Wave Rules

- Rule #1: The speed of a wave is determined by the type of wave and the characteristics of the medium, not by the frequency
- Wave Rule #2: When a wave passes into another medium, its speed changes, but its frequency does not

Superposition of Waves

- When 2 or more waves meet and overlap (interfere), the displacement at any point of the medium is equal to the algebraic sum of the displacement due to the individual waves
- Constructive interference: occurs when 2 waves with both positive or negative displacement overlap and the combined wave has a displacement of a greater magnitude than either one of the individual waves
- Destructive interference: waves that have opposite displacements meet and the combined wave has a magnitude less than each of the individual waves
- In Phase: waves combine and crest meets crest, trough meets trough, then constructive interference occurs
- Out of Phase: waves combine and crest meets trough and trough meets crest, meaning that destructive interference is occurring

Standing Waves

- Combination of 2 waves moving in opposite directions. Also known as stationary waves o Nodes and antinodes always alternate, are equally spaced,

and the distance between the 2 is equal to 1⁄2 a wavelength

- $L = n(\frac{1}{2}\lambda)$

o L=length of string o Length of string must be a multiple of $\frac{1}{2}\lambda$ to form a standing wave o n is an integer known as the harmonic number

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

o This is the equation for the wavelength of a standing wave

- Harmonic frequencies equation: $f_n = \frac{nv}{2L}$

Sound Waves

- Are produced by the vibration of an object which cause pressure variations in the medium of relevance
- Compressions: when molecules are closer together in a medium (high pressure)
- Rarefactions: when molecules are further apart (low pressure)
- Sound waves are longitudinal and move parallel to the direction of wave propagation
- Sound waves speed equation: $v = \sqrt{\frac{B}{\rho}}$

o density = p

o B = bulk modulus (medium that is easily compressed(gas) has a low bulk modulus while liquids and solids tend to have a higher bulk modulus)

Beats • A beat has occurred each time a wave constructively interferes

- The number of beats/second is known as beat frequency

o Equation for beat frequency: $f_{beat} = |f_1 - f_2|$ o Unit: Hz

Resonance for Sound Waves

- Resonant wavelengths and frequencies for a closed tube: $\{ \lambda_n = \frac{4L}{n},\ f_n = n\frac{v}{4L}$ for any odd integer n
- Resonant wavelengths and frequencies for an open tube: $\{ \lambda_n = \frac{2L}{n},\ f_n = n\frac{v}{2L}$ for any integer n

The Doppler Effect

- Change in frequency of a wave in relation to a detector which is moving relative to the wave source

- If the detector is moving toward the source, higher frequencies are detected and waves are emitted at a higher rate
- If the source is moving toward the detector, then detector receives shorter wavelengths and higher frequencies

Electric Forces and Fields

Electric Charge

- Basic Components of Atoms: protons, neutrons, and electrons
- Electrons circle the nucleus which is made up of nucleons (protons and electrons)
- An atom is held together by the electromagnetic force, which helps in allowing the electrons to orbit the nucleus
- Electric charge allows protons (positively charged) and electrons (negatively charged) to attract
- Most atoms contain an equal number of protons and electrons which causes the electric charge to be 0 because the negative charges cancel out the positive charges
- Ionization must occur to charge matter (negatively or positively) because this creates an imbalance in the number of protons and electrons
    - o Ex:

      Removing electrons = positive charge

      Adding electrons = negatively charged

• Charge is conserved and net charge (total amount of charge) cannot be created or

destroyed

• Elementary charge (e) is the basic unit of electric charge and is the magnitude of charge

on an
electron/proton

• Charge of an ionized atom must be a who number (n) multiplied with e because charge

can only be manipulated by variations of the quantity of e (n=1,2,3....)

• Charge is quantized, so the charge of a particle or object is denoted by q

Equation: $q = n(\pm e)$

Coulomb's Law

• Coulomb's Law is defined by the equation: $F_E = k\ ^{q_1 q_2}$

$_{r^2}$ o F_E represents electric force. A negative F_E is an attraction between charges and a positive F_E is repulsion o q_1 and q_2 represent particle charges o r represents the distance between 2 charges

o k is a constant. In a vacuum or air, it is known as Coulomb's constant with a value of $k_0 = 9\times 10^9\ N \times\ ^{m^2}\ C^2$

*force vectors point toward each other for attraction and away for repulsion

• Permittivity of free space is a constant denoted by ε0 which equals: $8.85\times\ ^{10^{-12}}\ C^2$

$N\times m^2$ o k_0 is usually written in terms of this constant o k_0 in terms of ε_0 is: $k_0 = {}^{1}$

$4\pi\varepsilon_0$

• $F_E = {}^{1}$

$4\pi\varepsilon_0 \times\ ^{q_1 q_2}$

$_{r^2}$ would then be the equation for Coulomb's Law for the force between 2 point charges

Superposition

• Net electric field produced at any point by a system of charges is equal to the vector sum of all individual fields, produced by each charge at this point

o $E = E_1 + E_2 + \ldots + E_n = \sum E_i\ {}_{n\ i-1}$

n = total number of charges in the system

units: Newtons (N)

The Electric Field

- Similarly to how a gravitational field created by Earth provides a gravitational force to any mass in the field, the presence of a charge creates an electric field in the space that surrounds it
- $E = \frac{F_{on\ q}}{q}$

qr^2

qr^2

qr^2

  - o $F_{on\ q}$ is the force the test charge experiences o q is the test charge
  - o E the resulting electric field vector
- If the source charge is positive, field vectors point away (remember: positive=repulsion)
- If the source charge is negative, field vectors point towards it (remember: negative=attraction)
- Force and the electric field decrease as they get further away from the charge (indicated by smaller arrows/vectors)
- Field lines determine strength of field:
  - o Dense: stronger field
  - o Sparse: weaker field

- Electric field vectors can be added like any other vectors
  - o Ex: If there were 2 source charges (+Q and -Q) their fields would combine:

    $E_{total} = E_1 + E_2$ (form of superposition)
    If done in various positions in space, these two equal but opposite charges will

form a pair called electric dipole

Note how the arrows move
away from positive source and
towards negative source

- The force generated on a charge that is
  an electric field is shows by the equation: $F = qE$

*When finding the acceleration of particles, work done on a particle during collisions, speed of particles, and time, use the big 5 kinematic equations along with the new ones to find your answers

Direct Current Circuits

Electric Current

- If electrons move randomly, there is no net movement, which means no current
- River, Current analogy: A current is like a river. In the river, water is moving at some rate and in a current, electric charge is moving at some rate
- Drift Speed (v_d): average velocity of charged particles
- Current is measured by how much charge crosses a plane per unit time: $I_{avg} = \frac{\Delta Q}{\Delta t}$
  - o charge/time = Coulomb's/second = 1 ampere (A)
  - o 1 C/s = 1 A
- The direction of the current is taken to be the direction that positive charge carriers would move o Ex: if electrons drift to the right, the current is moving towards the left

Resistance

- River, Resistance analogy: Resistance would be the part of the river that zigzags/increases length, providing resistance to the flow of water
- (Ohm's Law) Resistance equation: $R = {}^{V}{}_{I}$
    - I = current
    - V = voltage (potential difference)
    - Unit: volts/amp = 1 ohm (Ω, omega) = 1 Ω
    - Only works if resistor is already connected to other elements in circuit
- Alternative Formula: $R = \rho L/A$
    - L = length of resistor
    - A = cross sectional area
    - ρ is a property called resistivity (measures how difficult for current to flow through it). Good conductors such as metal have low resistivity and insulators such as rubber have high resistivity

Voltage

- River, Voltage analogy: A river cannot flow if it is flat. Rivers flow from high to low ground. Voltage is the mountain that gives the river the height it needs to flow.
- Voltage is what creates currents
- A circuit usually gets voltage from a battery

Electric Circuits

- If a current always travels in the same direction through the pathway, it is known as a direct current
- Voltage must provide an electromotive force(emf) to drive the flow of charge
    - Emf is not a force, instead it is the work done per unit charge, measured in volts

Journey of Charge Through a Circuit

- Charge starts at the positive terminal of a battery and enters a wire and is pushed through by the electric field
- It then encounters resistance by the atoms and free electrons
- The resistance causes some of the electrical potential energy to turn into heat
- Then the voltage must do positive work on the charge to keep current going
- The charge then moves from negative to positive terminal and the journey starts again in the circuit

Energy and Power

- Rate electrical energy is transferred: $P = IV$
    - o $V = IR$ (equation we discussed previously)
    - o $P = IV = I(IR) = I^2R$
    - o $P = IV = \frac{V}{R} \times V = \frac{V^2}{R}$

Circuit Analysis

- Resistors are symbolized by
- Batteries are symbolized by:
    - o Longer line represents positive (higher potential) terminal and shorter represents negative (lower potential) terminal
- Basic Circuit Diagram:

Combination of Resistors

- Series (one after another):

- Parallel (side-by-side):

- Can be applied to more than one (not just 2) resistor in series: $R_s = \sum_i R_i$
- Can be applied to more than one (not just 2) resistor in parallel: $\frac{1}{R_p} = \sum_i \frac{1}{R_i}$

Kirchhoff's Rules

- First Law (Junction/Node rule): The total current that enters a junction must equal the total current that leaves the junction
- Second Law (Loop Rule): The sum of potential differences (positive and negative) that traverse any closed loop in a circuit must be zero
    - o When going across a resistor in the same direction as the current. The potential drops by IR
    - o When going across a resistor in the opposite direction from the current, the potential increases by IR
    - o When going from the negative to the positive terminal of a source of emf, the potential increases by V
    - o When going from the positive to the negative terminal of a source of emf, the potential decreases by V