One-Dimensional Motion Review

IMPORTANT QUANTITIES

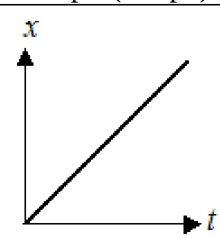
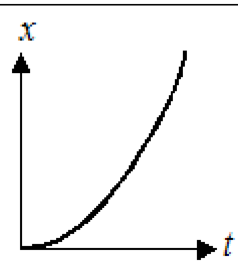
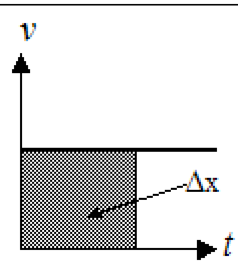
Name	Symbol	Units
Time	t	Seconds
Position	$\mathbf{x}$	Meters
Length Distance	ℓ d	Meters

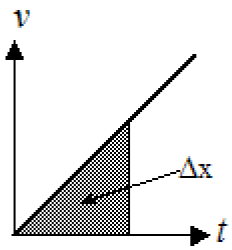
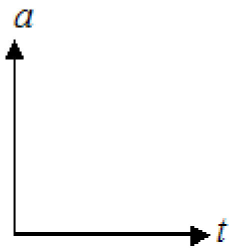
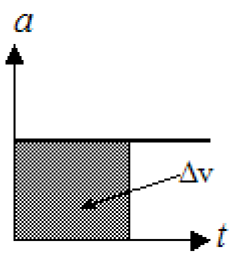
Name	Symbol	Units	Basic Equation
Velocity	$\mathbf{v}$	m/s	$\mathbf{v} = \frac{\Delta \mathbf{x}}{\Delta t}$
Speed	v	m/s	$v = \frac{\Delta \ell}{\Delta t}$
Acceleration	$\mathbf{a}$	m/s^2	$\mathbf{a} = \frac{\Delta \mathbf{v}}{\Delta t}$
Gravity on Earth	$\mathbf{g}$	m/s^2	$\mathbf{g} = 9.8\ m/s^2$ (Down)

IMPORTANT EQUATIONS

Name	Equation	Given?	Notes
Position as a function of time, constant velocity.	$\mathbf{x} = \mathbf{v}_0 t + \mathbf{x}_0$	No	Use if there is no acceleration (meaning the velocity is constant).
Position as a function of time, constant acceleration.	$\mathbf{x} = \frac{1}{2}\mathbf{a}t^2 + \mathbf{v}_0 t + \mathbf{x}_0$	Yes	Use if there is an acceleration, and time is involved in the problem, but no mention is made of final velocity.
Velocity as a function of time, constant acceleration.	$\mathbf{v} = \mathbf{a}t + \mathbf{v}_0$	Yes	Use if there is an acceleration and time in involved in the problem, no mention is made of position.
Velocity in terms of position and acceleration.	$v^2 = 2a(x - x_0) + v_0^2$	Yes	Use if there is an acceleration, final and initial velocities are involved as well as final and initial position, but **<u>no mention is made of time</u>**.

IMPORTANT GRAPHS

Name	Graph (Shape)	Notes
Position vs. Time (Constant Velocity)		**THE SLOPE OF A POSITION VS. TIME GRAPH IS VELOCITY.** Because velocity is constant, the slope is constant. This makes the graph a straight line.
Position vs. Time (Constant Acceleration)		**THE SLOPE OF A POSITION VS. TIME GRAPH IS VELOCITY.** Because the slope increases, the velocity increases. The shape of a position vs. time graph is a **<u>parabola</u>** for constant acceleration.
Velocity vs. Time (Constant Velocity)		**THE SLOPE OF A VELOCITY VS. TIME GRAPH IS ACCELERATION.** Because the slope is zero, acceleration is zero if velocity is constant. Constant velocity means constant *y*-value, so velocity vs. time for constant velocity is a flat line. **THE AREA UNDER A VELOCITY VS. TIME GRAPH REPRESENTS A *<u>CHANGE</u>* IN POSITION.**

Velocity vs. Time (Constant Acceleration)		**THE SLOPE OF A VELOCITY VS. TIME GRAPH IS ACCELERATION.** Because the acceleration is constant, the slope is constant. Constant slope means a straight line. **THE AREA UNDER A VELOCITY VS. TIME GRAPH REPRESENTS A <u>*CHANGE*</u> IN POSITION.**
Acceleration vs. Time (Constant Velocity)		**THE AREA UNDER AN ACCELERATION VS. TIME GRAPH REPRESENTS A <u>*CHANGE*</u> IN VELOCITY.** Since velocity is constant, there is no acceleration. The graph of zero is a horizontal line at $y = 0$, which means there is no area which means that there is no change in velocity.
Acceleration vs. Time (Constant Acceleration)		**THE AREA UNDER AN ACCELERATION VS. TIME GRAPH REPRESENTS A <u>*CHANGE*</u> IN VELOCITY.** Since acceleration is constant, the *y*-value of the graph is a constant, which makes a flat line.

IMPORTANT CONCEPTS

- Speed is the <u>magnitude</u> of velocity. Two cars, one traveling 60 mph north and the other 60 mph south, have the <u>same speed</u> but <u>different velocities</u>.
- Acceleration is a change in velocity. Since velocity is a vector, an object experiences an acceleration if <u>either its speed or its direction changes</u>.
- Only use the equation $v = \frac{\Delta x}{\Delta t}$ if speed is constant or you are asked for <u>average speed</u>!
- Only use the equation $a = \frac{\Delta v}{\Delta t}$ if acceleration is constant or you are asked for <u>average acceleration</u>! Note that this equation can never be used at the same time as $v = \frac{\Delta x}{\Delta t}$.
- Any object is considered to be in free-fall if gravity is the only force acting on it.

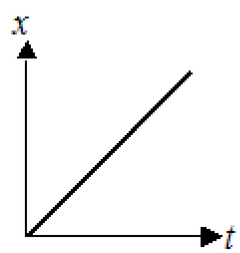
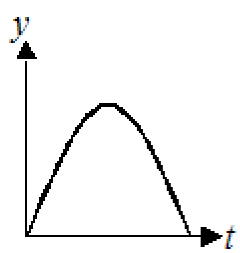
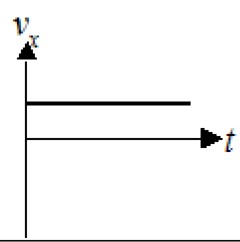
Big concept: Use kinematics whenever you have two of the following and are asked for a third: position, velocity, time, and acceleration.

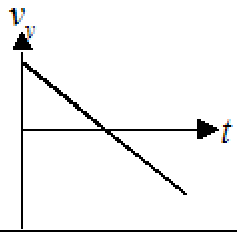
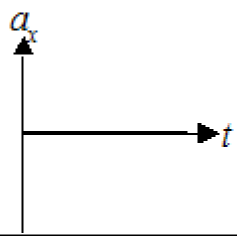
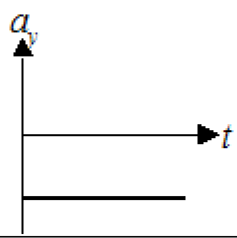
Projectile Motion Review

IMPORTANT EQUATIONS

Name	Equation	Given?	Notes
Horizontal Component of Initial Velocity	$v_{0x} = v_0 \cos\theta$	No	The *x*-component of anything is magnitude times cosine of the angle.
Vertical Component of Initial Velocity	$v_{0x} = v_0 \sin\theta$	No	The *y*-component of anything is magnitude times sine of the angle.
Horizontal Distance as a Function of Time	$x = v_{0x}t + x_0$	No	Constant velocity in the horizontal direction.
Vertical Height as a Function of Time	$y = -\frac{1}{2}gt^2 + v_{0y}t + y_0$	No	Constant acceleration in the vertical direction.
The x-component of velocity is constant.	$v_x = v_{0x}$	No	Constant velocity in the horizontal direction.
Y-component of velocity as a function of time.	$v_y = -gt + v_{0y}$	No	Constant acceleration in the vertical direction.
Maximum Horizontal Range	$R = \frac{v_0^2}{g}\sin 2\theta$	No	Only true on flat surfaces (when $y = y_0$). Note that maximum range occurs when angle is 45.
Maximum Height	$H = \frac{v_0^2}{2g}\sin^2\theta + y_0$	No	Note that maximum height occurs when angle is 90.

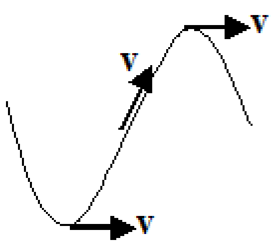
IMPORTANT GRAPHS

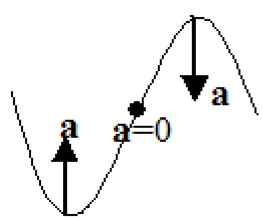
Name	Graph (Shape)	Notes
Horizontal Position vs. Time		Remember that, in the horizontal direction, the motion is constant velocity. This makes the graph of x vs. t a line with slope v_{0x}.
Vertical Position (Height) vs. Time		In the vertical direction, the motion is constant acceleration, making the graph a parabola. The acceleration is downward, so the parabola opens downward.
Horizontal Velocity vs. Time		Remember that, in the horizontal direction, the motion is constant velocity. This makes the graph of v_x vs. t a flat line with value v_{0x}.

Vertical Velocity vs. Time		In the vertical direction, the motion is constant acceleration, making the graph a line. The acceleration is –9.8 m/s^2, so the line has a constant negative slope of –9.8.
Horizontal Acceleration vs. Time		The motion in the horizontal direction is constant velocity, which automatically makes acceleration zero.
Vertical Acceleration vs. Time		The motion in the vertical direction is constant acceleration. The acceleration is –9.8 m/s^2, so the flat line has a constant negative value of –9.8.

IMPORTANT CONCEPTS

- An object in free fall has only the force due to gravity acting on it.
- If an object is in free fall, it has an acceleration of 9.8 m/s^2 downward, even if it is at the peak of its arc. <u>They always try to trick you on this concept!</u>
- The speed of an object in projectile motion is highest at the bottom of its path. The speed is slowest at the peak (though it may not be zero!). This is because the object's potential energy is the most at its peak, so its kinetic energy is least.
- The direction of velocity at a certain point is always <u>tangent to the path</u> that an object travels.
- The direction of acceleration at a certain point is always <u>toward the center of the circle</u> made by the curvature of the path.





Forces and Newton's Laws Review

IMPORTANT QUANTITIES

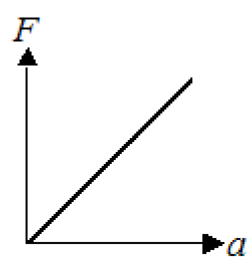
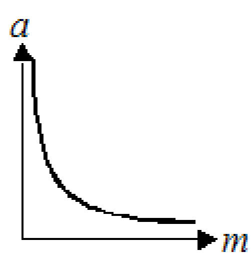
Name	Symbol	Units	Basic Equation
Force	$\mathbf{F}$	N	$\mathbf{F} = m\mathbf{a}$
Tension Force	$\mathbf{F_T}$	N	None
Weight Force	$\mathbf{F_W}$	N	$\mathbf{F}_W = m\mathbf{g}$
Mass	m	kg	None
Spring Constant	k	N/m	None

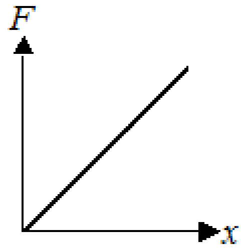
Name	Symbol	Units	Basic Equation
Normal Force	$\mathbf{F_N}$	N	None
Friction Force	$\mathbf{F_f}$	N	$F_f = \mu F_N$
Spring Force	$\mathbf{F_S}$	N	$\mathbf{F}_S = -k\mathbf{x}$
Coefficient of Friction	μ	None	None

IMPORTANT EQUATIONS

Name	Equation	Given?	Notes
Newton's Second Law (The most important equation in all of physics!)	$\sum \mathbf{F} = m\mathbf{a}$	Yes	For a single force, $\mathbf{F} = m\mathbf{a}$. However, for several forces, it is the **<u>vector sum</u>** of all forces equal mass times acceleration.
Newton's Second Law in terms of components.	$\sum F_x = ma_x$ $\sum F_y = ma_y$	No	If you have a problem taking place in 2D, then you need to create a sum-of-all forces equation for the components in each individual dimension.
Perpendicular Component of Weight on an Inclined Plane	$F_\perp = mg\sin\theta$	No	Usually equal to the normal force on an object on an inclined plane.
Parallel Component of Weight on an Inclined Plane	$F_\parallel = mg\cos\theta$	No	Usually equal to the force "down the plane" of an object on an inclined plane.

IMPORTANT GRAPHS

Name	Graph (Shape)	Notes
Force vs. Acceleration (for a constant mass)		Slope is mass.
Acceleration vs. Mass (for a constant force)		As mass increases, acceleration decreases

Force vs. Displacement of a spring		Slope is spring constant *k*.

IMPORTANT CONCEPTS

- Newton's First Law: If the net force on an object is zero (all forces balance), it will move with constant velocity in a straight line. Likewise, if an object travels with constant velocity in a straight line, the net force on the object is zero. <u>Note that an object can be in motion even if it has no net force</u>.
- Newton's Third Law: If object A exerts a force on object B, then object B must exert an equal force (but opposite in direction) on A. Note that <u>action-reaction pairs are always on different objects</u> (they always try to trick you into saying otherwise on the exam). Note also that, since they are on different objects, <u>action-reaction pairs cannot cancel out</u>.
- Weight force is always directed <u>down</u>.
- Only a surface can exert normal force. If there is no surface in the problem, there is no normal force. The normal force is perpendicular (normal) to the surface.
- Only a rope or string can exert tension force. If there is no rope or string in the problem, there is no tension force.
- Normal and tension forces have <u>no basic equations</u>. They can only be found by setting up a statement of Newton's Second Law, and then solving for them.
- A rope exerts the same tension force at both ends, even if it is set through a pulley.
- A scale does not measure mass or weight. It measures the <u>normal force it exerts</u>.
- The negative sign in the spring-force equation only represents that the spring force is always opposite to the displacement of the spring.
- Friction is always parallel to the plane, directed to oppose <u>relative motion</u>. This does not necessarily mean that it is in the opposite direction as velocity. A box in the back of a pick-up truck has friction that prevents it from sliding off of the truck, but that friction is in the same direction as the velocity of the truck.
- Two types of friction: Static friction acts when the object is not sliding on the surface. Kinetic friction acts when the object is sliding on the surface. Both types of friction have separate coefficients of friction, often labeled μ_s and μ_k. Note that $0 < \mu_k < \mu_s < 1$.
- MAJOR NOTE ON FRICTION: The force of friction is $F_f = \mu F_N$. But for static friction, the friction force could be ***<u>less</u>*** than this! This formula only gives the maximum possible static friction!

Big concept: Use forces you are asked to solve for a force or find an object's acceleration.

Circular Motion Review

IMPORTANT QUANTITIES

Name	Symbol	Units	Basic Equation
Period	T	Sec	None
Angular Frequency	ω	Rad/s	$\omega = \frac{2\pi}{T} = 2\pi f$
Centripetal Force	$\mathbf{F_c}$	N	$F_c = m\frac{v^2}{r} = m\omega^2 r$

Name	Symbol	Units	Basic Equation
Frequency	f	Hz	$f = \frac{1}{T}$
Centripetal Acceleration	$\mathbf{a_c}$	m/s^2	$a_c = \frac{v^2}{r} = \omega^2 r$

IMPORTANT EQUATIONS

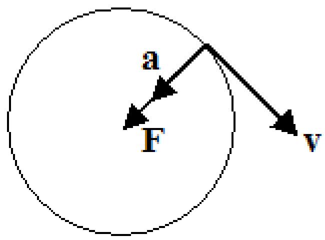
Name	Equation	Given?	Notes
Newton's Second Law for Circular Motion	$\sum F = ma_c = m\frac{v^2}{r} = m\omega^2 r$	No	If the problem involves any sort of circular motion, then you set the sum of all forces equal to the centripetal force. Remember that forces toward the inside of the circle are positive, and forces toward the outside are negative!
Distance as a function of time.	$2\pi r = vT$	No	Distance around a circle is equal to velocity times time for one circle.
Relationship between Velocity and Angular Frequency.	$v = \omega r$	No	On a rotating disk (like a merry-go-round), things farther from the center go faster.

IMPORTANT CONCEPTS

- When an object travels in a circle, the <u>velocity is always directed tangent to the circle</u>.
- When an object travels in a circle, the <u>acceleration and net force are always directed toward the center of the circle</u>.
- On a merry-go-round, people at different distances from the center have different velocities. The farther from the center, the faster an object goes. However, every object has the same ω.
- <u>Centripetal force does not exist on its own</u> the way that other forces (weight, gravity, friction, tension, normal) exist. Centripetal force must be provided by one (or more) of these other forces. Examples:
  - When an object is in orbit, its centripetal force is provided by gravity. $m\frac{v^2}{r} = \frac{GMm}{r^2}$
  - When a penny lies on a rotating turntable, its centripetal force is provided by friction: $m\frac{v^2}{r} = \mu F_n$
  - When a ball is swung (horizontally) on a rope, its centripetal force is provided by tension: $m\frac{v^2}{r} = F_T$
  - When you are standing in a round, spinning room, the walls of the room spin and make you go in a circle. Since the walls are surfaces, the centripetal force is provided by normal force: $m\frac{v^2}{r} = F_N$
  - When an electron (negative charge) orbits a proton (positive charge), the electric force causes the object to move in a circle: $m\frac{v^2}{r} = \frac{kqQ}{r^2}$
  - When a charge q travels through a magnetic field, the magnetic field exerts a force that causes the charge to move in a circle: $m\frac{v^2}{r} = qvB$

- When you swing a mass on the end of a rope in a vertical circle, both weight and tension contribute to centripetal force:
  - Bottom of the circle: $m\frac{v^2}{r} = F_T - mg$ (Weight is away from the center)
  - Top of the circle: $m\frac{v^2}{r} = F_T + mg$ (Weight is away from the center)
  - Side of the circle: $m\frac{v^2}{r} = F_T$ (Weight is tangent to the circle, and so does not contribute)

Consider an object moving counterclockwise:



If you have a circular motion problem, you must set the sum of all forces equal to $\frac{mv^2}{r}$. The sign of each force is important:

- If the force is directed toward the center of the circle, then put it as POSITIVE in the sum-of-all-forces expression.
- If the force is directed away from the center of the circle, then put it as NEGATIVE in the sum-of-all-forces expression.
- If the force is tangent to the circle, then OMIT it in the sum-of-all-forces expression.
- If the force makes an angle with the center of the circle, you must use components—get the component of the force that is toward the center of the circle.

Work, Energy, and Power Review

IMPORTANT QUANTITIES

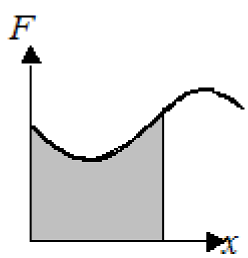
Name	Symbol	Units	Basic Equation
Work	W	J	$W = \mathbf{F} \bullet \mathbf{x}$
Kinetic Energy	K	J	$K = \frac{1}{2}mv^2 = \frac{p^2}{2m}$
Potential Energy (Spring)	U_s	W	$U_s = \frac{1}{2}kx^2$

Name	Symbol	Units	Basic Equation
Energy	E	J	None
Potential Energy (Gravity)	U_g	J	$U_g = mgh$
Power	P	W	$P = \frac{W}{t}$

IMPORTANT EQUATIONS

Name	Equation	Given?	Notes
Work done by Friction (also energy lost to friction)	$W_f = F_f x$	No	Friction takes some energy out of the system. Note that energy lost to friction becomes heat, so sometimes this is referred to as thermal energy.
Conservation of Energy	$\sum E_i = \sum E_f$	No	The sum of all different energies before equals the sum of all different energies after. These could be kinetic, potential, thermal, etc. energies.
Power in terms of Force and Velocity	$P = \mathbf{F} \bullet \mathbf{v}$	Yes	Note that dot products imply that you are multiplying the two vectors and the "cosine of the angle between them".

IMPORTANT GRAPHS

Name	Graph (Shape)	Notes
Force vs. Displacement	 (Could be anything)	The area under a force vs. displacement graph is work.

IMPORTANT CONCEPTS

- NO WORK IS DONE IF FORCE IS PERPENDICULAR TO DISPLACEMENT, OR IF FORCE IS PERPENDICULAR TO VELOCITY.
- USE ENERGY EQUATIONS IF YOU ARE ASKED FOR VELOCITY IN TERMS OF POSITION, OR POSITION IN TERMS OF VELOCITY!
- Note that work is a dot product, so you are multiplying force, distance, and the cosine of the angle between them.
- Work is a transfer of energy from one form to another. If energy goes from kinetic to potential, potential to kinetic, kinetic to thermal, kinetic to another object's kinetic, etc., work was done.
- A force does positive work if the force is in the same direction as displacement. Likewise a force does negative work if the force is opposite displacement.
- A force does positive work if the potential energy related to that force decreases. Likewise, a force does negative work if the potential energy related to that force decreases.
- A force does positive work if the kinetic energy of the object increases.

- <u>Potential energy increases</u> if an object is forced to do "the opposite of what it wants to do." Likewise, potential energy decreases if an object is allowed to do "what it wants to do."
    - Objects want to fall down. So raising an object up increases its potential energy.
    - Springs don't like to be stretched or compressed. Therefore, compressing or stretching a spring (away from its equilibrium position) increases its potential energy.
    - Objects in space want to attract each other due to gravity. Therefore, moving objects apart in space increases their potential energy.
    - Like charges want to move away from each other. Therefore, pushing like charges near each other increases their potential energy.
    - Opposite charges want to move toward each other. Therefore, pulling opposite charges apart increases their potential energy.
    - Like poles of magnets want to move away from each other. Therefore, pushing like poles near each other increases their potential energy.
    - Opposite poles of magnets want to move toward each other. Therefore, pulling opposite poles apart increases their potential energy.

Example:
I lift a book from a low shelf to a high shelf. I do positive work because the force I exert (up) is in the same direction as displacement (up), and my potential energy decreases because I had to burn calories to lift the book. On the other hand, gravity did negative work because the force of gravity (down) was opposite the direction as displacement (up), and gravitational potential energy increased.

NO WORK IS DONE ON AN OBJECT IN ANY UNIFORM CIRCULAR MOTION (the speed doesn't change, so no work is done because no energy is transferred). THIS INCLUDES A CHARGE CIRCLING IN A MAGNETIC FIELD OR A PLANET IN CIRCULAR ORBIT.

Big concept: Use energy whenever are given a position and asked for a velocity, OR given a velocity and asked for a position.

Momentum Review

IMPORTANT QUANTITIES

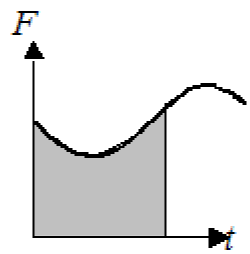
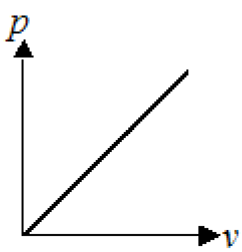
Name	Symbol	Units	Basic Equation
Momentum	**p**	kg•m/s	$\mathbf{p} = m\mathbf{v}$

Name	Symbol	Units	Basic Equation
Impulse	**J**	kg•m/s	$\mathbf{J} = \Delta\mathbf{p} = \mathbf{F}\Delta t$

IMPORTANT EQUATIONS

Name	Equation	Given?	Notes
Conservation of Momentum	$\sum \mathbf{p}_i = \sum \mathbf{p}_f$	No	Use if you are given any problem dealing with a collision. Keep in mind that momentum is a vector, so if an object travels backwards, then it has negative momentum.

IMPORTANT GRAPHS

Name	Graph (Shape)	Notes
Force vs. Time	 (Could be anything)	The area under a force vs. time is equal to impulse. This impulse represents the change in the momentum of the object the force is applied to. If there is a collision of two objects, the impulse is applied to both objects, but in opposite directions (Newton's Third Law).
Momentum vs. Velocity		Slope is mass of the object.

IMPORTANT CONCEPTS

- USE CONSERVATION OF MOMENTUM WHENEVER THERE IS ANY KIND OF COLLISION! DO NOT USE CONSERVATION OF ENERGY!
- An <u>elastic</u> collision is one in which <u>no energy is lost</u> to heat or deformation. In these problems, you must also set up a conservation of energy equation.
- An <u>inelastic</u> collision is one in which <u>some kinetic energy is lost</u> during the collision, but the objects may not stick together. In other words, total kinetic energy before the collision is more than total kinetic energy after the collision.
- A <u>perfectly inelastic</u> collision is one in which the two objects <u>stick together</u>. The most possible energy is lost to heat and deformation during a perfectly inelastic collision.
- DON'T ASSUME that you know that a collision is elastic or inelastic unless you are told.
- DON'T ASSUME that the objects stick together unless you are told.
- When setting up a conservation of momentum equation, remember that a velocity is <u>negative</u> if the object is moving <u>to the left</u> (or down).

Big concept: Use momentum to solve collision problems!

Simple Harmonic Motion Review

IMPORTANT QUANTITIES

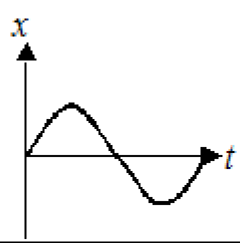
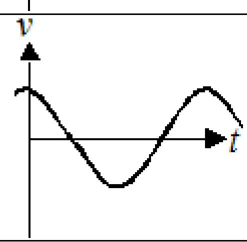
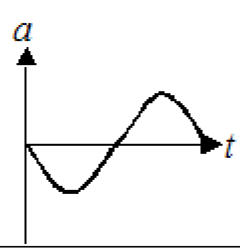
Name	Symbol	Units	Basic Equation
Amplitude	A	m	None

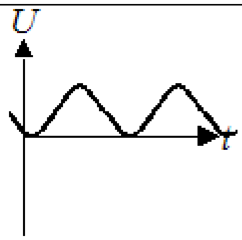
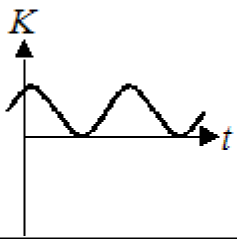
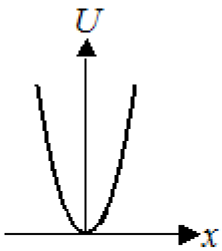
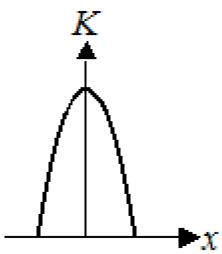
Name	Symbol	Units	Basic Equation
Spring Constant	k	N/m	$F_s = kx$

IMPORTANT EQUATIONS

Name	Equation	Given?	Notes
Period of a Spring-Mass Oscillator	$T = 2\pi\sqrt{\frac{m}{k}}$	Yes	A larger mass will make the period longer, but a stiffer spring will make the period shorter.
Period of a Pendulum	$T = 2\pi\sqrt{\frac{\ell}{g}}$	Yes	The mass at the end of the pendulum does not affect period. A longer string results in a longer periood.
Angular Frequency of a Spring-Mass Oscillator	$\omega = \sqrt{\frac{k}{m}}$	No	Don't memorize this. Instead remember the above equation for period and know that $\omega = \frac{2\pi}{T}$.
Maximum Displacement of a Spring-Mass Oscillator	$x_{\max} = A$	No	Maximum displacement occurs at the endpoints of oscillation.
Maximum Velocity of a Spring-mass Oscillator	$v_{\max} = A\omega$	No	Maximum velocity occurs at the equilibrium point.
Maximum Acceleration of a Spring-mass Oscillator	$a_{\max} = A\omega^2$	No	Maximum acceleration occurs at the endpoints.
Total Energy for a Spring-Block Oscillator	$E_{tot} = \frac{1}{2}mv^2 + \frac{1}{2}kx^2 = \frac{1}{2}kA^2$	No	Total energy is constant throughout the entire oscillation, but "trades off" between kinetic and potential.

IMPORTANT GRAPHS

Name	Graph (Shape)	Notes
Position vs. Time		Displacement varies sinusoidally with time. The highest peak is $x = A$, and the lowest trough is $x = -A$.
Velocity vs. Time		Velocity varies sinusoidally with time. The highest peak is $v = A\omega$, and the lowest trough is $v = -A\omega$.
Acceleration vs. Time		Acceleration varies sinusoidally with time. The highest peak is $a = A\omega^2$, and the lowest trough is $a = -A\omega^2$.

Potential Energy vs. Time		The maximum potential energy is $U_{max} = \frac{1}{2}kA^2$, and only occurs at the points $x = A$ and $x = -A$.
Kinetic Energy vs. Time		The maximum kinetic energy is $K_{max} = \frac{1}{2}kA^2$, and only occurs at the point $x = 0$.
Potential Energy vs. Displacement		PAY ATTENTION TO THE AXES! THIS HAS DISPLACEMENT ON THE HORIZONTAL!
Kinetic Energy vs. Displacement		

IMPORTANT CONCEPTS

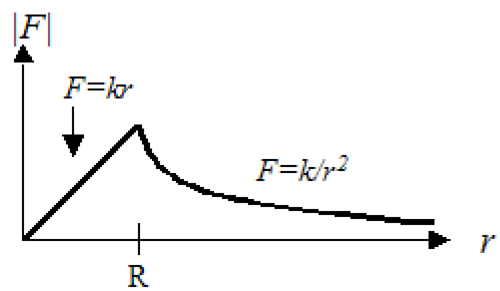
- Simple harmonic motion is the constant exchange of potential and kinetic energy from one form to another.
- Maximum speed and maximum kinetic energy both occur at the equilibrium point. They are zero at the endpoints.
- Maximum force, acceleration, and potential energy occur at the endpoints. They are all zero at the equilibrium position.
- The force of a spring is $F_s = kx$. On the AP exam chart, it says $\mathbf{F}_s = -k\mathbf{x}$. The concept-carrying negative indicates that force is directed opposite the displacement of the spring.

Gravitation Review

IMPORTANT EQUATIONS

Name	Equation	Given?	Notes
Gravitational force between two masses in space	$F_G = -\frac{GmM}{R^2}$	Yes	The two masses are *m* and *M*. The constant *G* is always given. *R* is the distance of the two objects from center-to-center. Note that the force is negative because it always attracts—gravity never repels.
Gravitational potential energy of two masses in space	$U_G = -\frac{GmM}{R}$	Yes	The potential energy goes down (becomes more negative) when the two objects get closer together (what they want to do).
Acceleration of gravity (gravitational field) of an object	$g = \frac{F_G}{m} = \frac{GM}{R^2}$	No	
Escape Velocity	$v_{esc} = \sqrt{\frac{2GM}{R}}$	No	In order to escape a planet of mass *M* (from a distance *R*), set kinetic energy equal to potential energy and solve.

IMPORTANT GRAPHS

Name	Graph (Shape)	Notes
Magnitude of gravitational force on an object as a function of distance from a planet of radius *R*.		Note that when the object is inside the planet, the force increases linearly as the object nears the surface. However, once the object is outside of the planet, the force decreases as $1/r^2$.

IMPORTANT CONCEPTS

- For circular orbits, the closer the orbiting object is to the massive object, the faster it goes, and the shorter the period of orbit.
- In order to analyze a circular orbit, set centripetal force equal to gravitational force.
- When an object is in circular orbit, NO WORK IS DONE!

Fluid Dynamics Review

IMPORTANT QUANTITIES

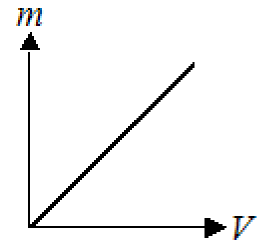
Name	Symbol	Units	Basic Equation
Density	ρ	kg/m^3	$\rho = \frac{m}{V}$
Fluid Flow	Φ	m^3/s	$\Phi = \frac{V}{t}$

Name	Symbol	Units	Basic Equation
Pressure	P	Pa N/m^2	$P = \frac{F}{A}$

IMPORTANT EQUATIONS

Name	Equation	Given?	Notes
Force of Buoyancy	$F_B = \rho_w V g$	Yes	Buoyancy force is always directed up. ρ_w is the density of water, not the object floating/sinking. V is the volume of water displaced by the floating/sinking object (the volume of the object that is below the water level).
Absolute Pressure	$P = P_0 + \rho g y$	Yes	Pressure increases as you go deeper in the water (increasing y). The density of water is ρ. P_0 is the air pressure at the surface of the water.
Gauge Pressure	$P_G = P - P_0 = \rho g y$	No	Gauge pressure is just the difference between your absolute pressure and the surface pressure.
Fluid Flow	$\Phi = Av$	No	Fluid flow is the volume of water that flows through an area A per unit time. The larger the area, the more water flows through. The faster the water, the more water flows through.
Fluid Flow Continuity	$A_1 v_1 = A_2 v_2$	Yes	Because water cannot be created or destroyed, the same amount of water that passes through one surface must also pass through another in the same pipe.
Bernoulli's Equation	$P_1 + \rho g h_1 + \frac{1}{2}\rho v_1^2 =$ $P_2 + \rho g h_2 + \frac{1}{2}\rho v_2^2$	Yes	When a fluid, such as water or air, flows with some velocity, its pressure decreases.

IMPORTANT GRAPHS

Name	Graph (Shape)	Notes
Mass vs. Volume		Slope is density.

IMPORTANT CONCEPTS

- Density is mass per unit volume.
- Pressure is force per unit area.
- When an object floats, buoyancy is equal to weight. When an object sinks, buoyancy is less than weight.
- An object that is less dense than water will float. An object that is denser than water will sink.
- The buoyancy force occurs because the fluid exerts pressure on all parts of the object, but the parts of the object at lower depths has more pressure exerted on it.
- A fluid exerts pressure in all directions.
- When pressure is exerted on a surface, the force is normal (perpendicular) to the surface.
- All points in a fluid with equal depth have equal pressure.
- Absolute pressure is atmospheric pressure plus pressure in the fluid at depth.
- Gauge pressure is just pressure in the fluid at depth, NOT considering the atmospheric pressure.
- When a fluid moves, it exerts less pressure. The faster it moves, the less pressure it exerts.

Given: An object of total volume V_T floats in water. The volume of water displaced (in other words, the volume of the object below the water level) is V_w. Determine the density of the object.

If the object floats, then buoyancy is equal to weight: $\rho_w V_w g = mg$

However, the mass of the object itself is equal to its density times its total volume: $m = \rho V_T$

Subsitute: $\rho_w V_w g = \rho V_T g$

Cancel g and solve: $\rho_w \dfrac{V_w}{V_T} = \rho$

Thermodynamics Review

IMPORTANT QUANTITIES

Name	Symbol	Units	Basic Equation
Number of Moles	n	Mol	
Temperature	T	Kelvin	
Heat	Q	Joules	
Coefficient of linear expansion.	α	1/K	

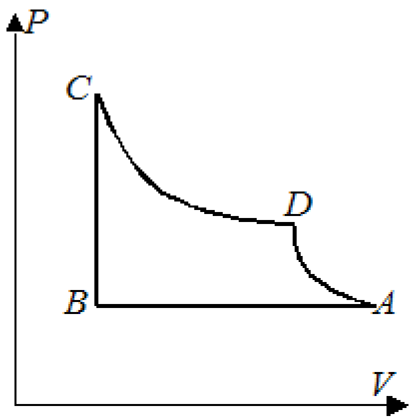
Name	Symbol	Units	Basic Equation
Number of Molecules	N	None	
Thermal Energy	U	Joules	
Work	W	Joules	
Root-mean-square velocity	v_{rms}	m/s	

IMPORTANT EQUATIONS

Name	Equation	Given?	Use If…
Thermal expansion of an object.	$\ell = \alpha \ell_0 \Delta T$	Yes	When an object is heated, it expands. The expansion is the product of "coefficient of linear expansion", its original length, and the change in temperature.
First Law of Thermodynamics	$\Delta U = \Delta Q + \Delta W$	Yes	Heat transferred into a system is positive, heat transferred out of a system is negative. Work done on a system is positive, work done by a system is negative.
Work done on/by a system	$W = -P \cdot \Delta V$	Yes	Work is done on a system (positive work) if its volume decreases. Work is done by a system (negative work) if volume increases.
Ideal Gas Law	$PV = nRT$ $PV = NkT$	Yes No	Relates pressure and volume of a gas to the number of particles and temperature.
Relationship between Avogadro's Number, Boltzmann's Constant, and the Ideal Gas Law Constant	$N_A k = R$	No	All of these constants are given on your constant sheet. But they may ask you about the relationship between them.
Internal Energy of a Monatomic Gas	$U = \frac{3}{2} nRT$ $U = \frac{3}{2} NkT$ $U = \frac{3}{2} PV$	No	
Average Kinetic Energy of a Single Particle	$K = \frac{3}{2} kT$	Yes	
Heat Engine Equations	$Q_H - Q_C = W$ $e = \left\lvert \frac{W}{Q_H} \right\rvert$ $e = \frac{T_H - T_C}{T_H}$	No Yes Yes	The work done by an engine is the difference in the amount of heat it takes from the "hot" reservoir and dumps into the "cold" reservoir. The efficiency of an engine is the ratio of work done to heat taken from the "hot reservoir". Note that efficiency is only 100% if the "cold reservoir" temperature is absolute zero.
Root-Mean-Square Velocity of Particles	$v_{rms} = \sqrt{\frac{3RT}{M}} = \sqrt{\frac{3kT}{\mu}}$	Yes	Remember that molecular mass M is the atomic weight of the gas in <u>grams</u>.

Rate of Heat Transfer Through a Solid Object	$H = \frac{kA\Delta T}{L}$	Yes	Heat is energy. So rate of heat transfer is rate of energy transfer, which is therefore power, measured in watts. The thermal conductivity *k* depends on the substance the solid is made of. The cross-sectional area is *A*, and *L* is the length of the object. Note that no heat flows unless there is a difference in temperature ΔT.

IMPORTANT GRAPHS

Name	Graph (Shape)	Notes
Pressure-Volume (PV) Diagram		The transition from A to B is called <u>isobaric</u>, because pressure does not change. The transition from B to C is called <u>isovolumetric</u>, because volume does not change. NO WORK is done during an isovolumetric transition. The transition from C to D is called <u>isothermal</u>, because temperature does not change. Notice that isotherms are curved toward the origin. The transition from D to A is called <u>adiabatic</u>, because no heat is transferred in or out of the system. Adiabats look the same as isotherms, but are steeper. If you go clockwise around this loop, you have a <u>heat engine</u>, because it does work. If you go counterclockwise, you have a <u>refrigerator</u>, because work is done on it. The work done by it or on it is equal to the area of the loop.

IMPORTANT CONCEPTS

- The assumptions of the ideal gas model: All gasses are monatomic and have zero radius.
- The motion of gas molecules causes temperature. The hotter the gas, the faster the gas molecules move around.
- Pressure is caused when the atoms collide with the walls of the container.
- The work done by a gas is equal to the area underneath the transition on a PV diagram. Work is positive (done on a system) if the transition is to the left (lower volume). Work is negative (done by a system) if the transition is to the right (higher volume).
- The second law of thermodynamics says that entropy is always increasing.

Waves Review

IMPORTANT QUANTITIES

Name	Symbol	Units	Basic Equation
Wavelength	λ	Meters	

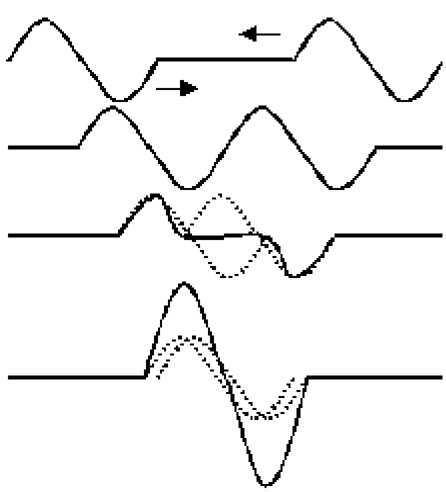
Name	Symbol	Units	Basic Equation
Intensity	I	W/m^2	

IMPORTANT EQUATIONS

Name	Equation	Given?	Notes
Relationship between frequency, wavelength, and velocity of a wave.	$v = \lambda f$	Yes	
Intensity of sound/light from a source.	$I = \dfrac{P}{4\pi r^2}$	No	This equation gives intensity of light or sound a distance r from a source emitting at total power P.
Power absorbed by a surface from sound/light.	$P = IA$	No	When sound or light of intensity I strikes a surface (such as an eardrum or the ground), the surface absorbs power P depending on its area A.
Harmonic wavelengths of a string fixed at both ends.	$\lambda = \dfrac{2L}{n}$	No	
Beat frequency	$f_B = f_2 - f_1$	No	Beats are heard when two tones of close frequencies are played together. The frequency of the beats is the difference in frequencies of the tones.

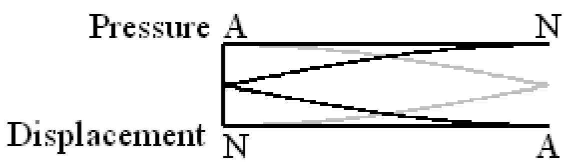
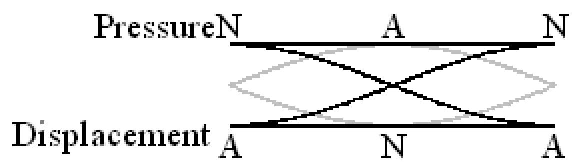
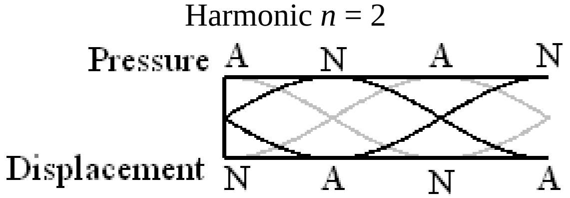
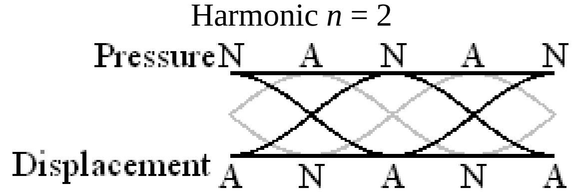
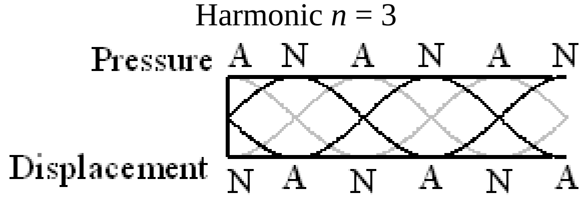
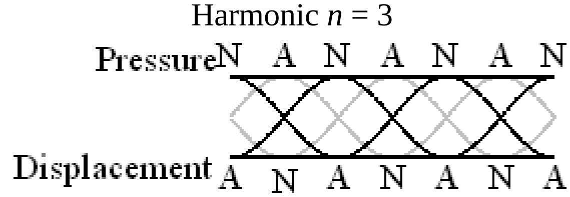
IMPORTANT CONCEPTS

- Doppler effect – When an object approaches you, the frequency of the sound/light it emits is shifted upward. This means that a fire truck sounds higher-pitch when it approaches you, and that a galaxy looks more blue when it approaches you.
- When an object moves away from you, the frequency of the sound/light it emits is shifted downward. This means that a fire truck sounds lower-pitch when it moves away from you, and that a galaxy looks more red when it moves away from you.
- A sequence to show interference. Constructive interference occurs when two waves create a bigger wave, and destructive interference occurs when two waves make a smaller wave.



- Open and closed pipe ends: In a pipe, there are:
  - Pressure nodes (where the pressure does not ever change)
  - Pressure antinodes (where the pressure changes a lot)
  - Displacement nodes (where the molecules never move)
  - Displacement antinodes (where the molecules move a lot)
- The standing wave inside of a pipe must obey these rules:
  - Where there is a displacement node, there is a pressure antinode (and vice versa).
  - Where there is a displacement antinode, there is a pressure node (and vice versa).
  - Two nodes must be separated by an antinode.
- The boundary conditions of air in a pipe are as follows:
  - At a closed end, there must be a pressure antinode and a displacement node (molecules can't move against a wall).
  - At an open end, there must be a pressure node (to match outside air pressure) and a displacement antinode.

Consider a pipe of length L. Putting all of these rules together, we get harmonics that look like this:

<table>
<tr><th>PIPE OPEN AT ONE END</th><th>PIPE OPEN AT BOTH ENDS</th></tr>
<tr><td>Harmonic $n = 1$

Number of wavelengths in pipe: 1/4
Wavelength: $\lambda = 4L$</td><td>Harmonic $n = 1$

Number of wavelengths in pipe: 1/2
Wavelength: $\lambda = 2L$</td></tr>
<tr><td>Harmonic $n = 2$

Number of wavelengths in pipe: 3/4
Wavelength: $\lambda = 4L / 3$</td><td>Harmonic $n = 2$

Number of wavelengths in pipe: 1
Wavelength: $\lambda = L$</td></tr>
<tr><td>Harmonic $n = 3$

Number of wavelengths in pipe: 5/4
Wavelength: $\lambda = 4L / 5$</td><td>Harmonic $n = 3$

Number of wavelengths in pipe: 3/2
Wavelength: $\lambda = 2L / 3$</td></tr>
<tr><td>Harmonic n
Number of wavelengths in pipe: $(2n - 1) / 4$
Wavelength: $\lambda = 4L / (2n - 1)$</td><td>Harmonic n
Number of wavelengths in pipe: $2 / n$
Wavelength: $\lambda = 2L / n$</td></tr>
</table>

Note: Pressure is the gray sine curve and displacement is the black sine curve.

Optics Review

IMPORTANT QUANTITIES

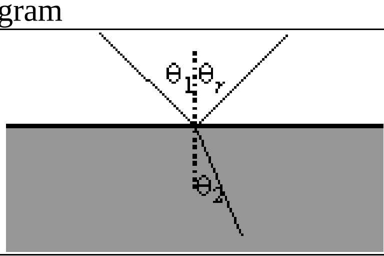
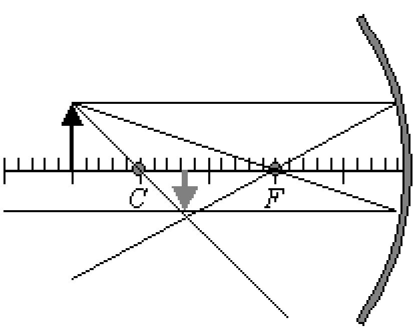
Name	Symbol	Units	Basic Equation
Index of Refraction	n	None	$n = \frac{c}{v}$
Magnific-ation	M	None	

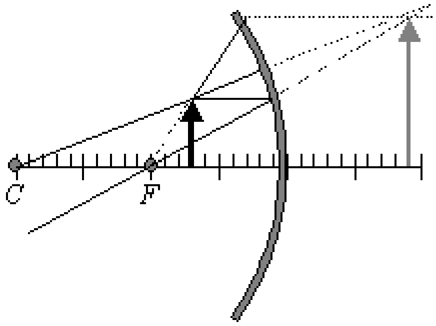
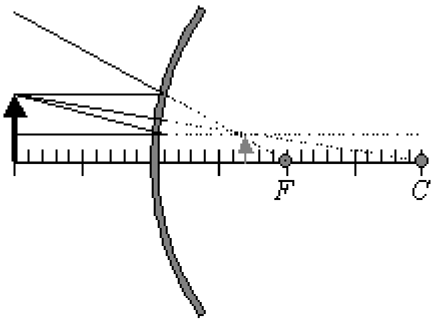
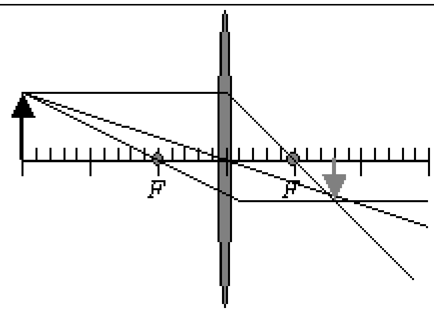
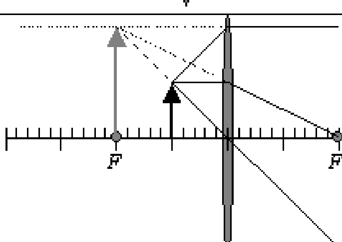
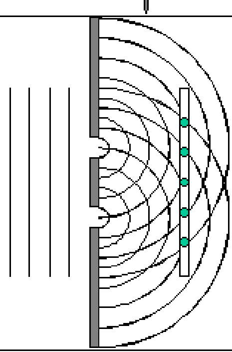
Name	Symbol	Units	Basic Equation
Focal Length	f	meters	

IMPORTANT EQUATIONS

Name	Equation	Given?	Notes
Snell's Law	$n_1 \sin\theta_1 = n_2 \sin\theta_2$	Yes	Law of refraction. Remember that angle is measured from the normal to the surface.
Object and image distance equation	$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$	Yes	Remember that focal length is negative for converging lenses and convex mirrors.
Magnification	$M = \frac{h_i}{h_o} = -\frac{d_i}{d_o}$	Yes	Magnification is negative if the object is real and inverted, but positive if the object is virtual and upright.
Critical Angle for Total Internal Reflection	$\sin\theta_c = \frac{n_2}{n_1}$	Yes	Total internal reflection occurs only when light goes from a high-*n* medium to a lower-*n* medium.
Focal length of a mirror.	$f = \frac{R}{2}$	Yes	The focal length of a mirror is half the radius of curvature.
Location of the *m*th diffraction maximum.	$x = \frac{m\lambda L}{d}$ $d\sin\theta = m\lambda$	Yes	The distance from the central maximum to the *m*th bright spot depends on distance between the slits *d* and the distance from the slits to the screen *L*, and wavelength of the light λ.

IMPORTANT RAY DIAGRAMS

Diagram	Notes
	A ray of light is incident on a surface with angle θ_1. Part of the ray is reflected at angle θ_r, equal to θ_1. The other part of the ray is transmitted through the surface at angle θ_2. In this case, the index of refraction of the gray material is greater than that of the white material.
	A concave mirror. The principal rays that must be drawn for a mirror are as follows: • Draw a ray perfectly horizontal. When it reflects from the mirror, it will go through the focal point. • Draw a ray through the focal point. When it reflects, it will be perfectly horizontal. • Draw a ray through the center. When it reflects, it will go through the center again. The image in this case is real (since actual light rays meet there) and inverted.

	A concave mirror. The principal rays that must be drawn for a mirror are as follows: • Draw a ray perfectly horizontal. When it reflects from the mirror, it will go through the focal point. • Draw a ray through the focal point. When it reflects, it will be perfectly horizontal. • Draw a ray through the center. When it reflects, it will go through the center again. Since the object is closer to the mirror than the focal point, virtual rays must be drawn from the reflected rays. The image in this case is virtual (since only virtual light rays meet there) and upright.
	A convex mirror. The principal rays that must be drawn for a mirror are as follows: • Draw a ray perfectly horizontal. Its virtual reflection will go through the focal point. • Draw a ray towards the focal point. Its virtual ray will be perfectly horizontal. • Draw a ray towards the center. Its virtual ray will go through the center. The image in this case is virtual (since only virtual light rays meet there) and upright.
	A converging lens, with the object farther than the focal point from the lens. The principal rays that must be drawn for a lens are as follows: • Draw a ray perfectly horizontal. The refracted ray will go through the far focal point. • Draw a ray through the near focal point. Its refracted ray will be perfectly horizontal. • Draw a ray through the center of the lens. It will not be refracted. The image in this case is real (since actual light rays meet there) and inverted.
	When the object is closer to the converging lens than the focal length of the lens, virtual rays must be drawn backwards from the real rays. Where the virtual rays meet there is a virtual, upright image.
	Diffraction occurs when a wave encounters two or more slits. When the wave passes through the slits, the wave-fronts a no longer parallel but circular in shape. In places where crest meets crest or trough meets trough, constructive interference causes a bright spot to appear. In places where crest meets trough, a dark spot appears because of destructive interference.

IMPORTANT CONCEPTS

- If M is positive, object is virtual and upright. If M is negative, image is real and inverted.
- A concave mirror and a converging lens have positive focal length.
- A convex mirror and a diverging lens have negative focal length.
- Diffraction is a phenomenon that waves (especially light waves) exhibit when they alternately constructively and destructively interfere with one another.

Electrostatics Review

IMPORTANT QUANTITIES

Name	Symbol	Units	Basic Equation
Charge	Q, q	Coulombs	
Electric Potential (Voltage)	V	Volts	$V = \frac{\text{Energy}}{\text{Charge}}$

Name	Symbol	Units	Basic Equation
Electric Field	$\mathbf{E}$	N/C or V/m	$\mathbf{E} = \frac{\mathbf{F}}{q}$

IMPORTANT EQUATIONS

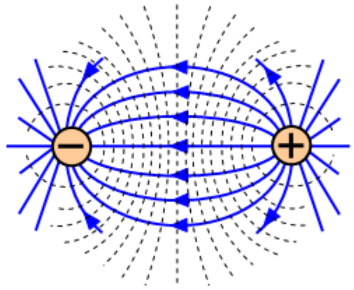
Name	Equation	Given?	Notes
Force on a charge in an electric field.	$\mathbf{F} = q\mathbf{E}$	Yes	Use this equation when you have a single charge in an electric field.
Potential energy of a charge in a potential field.	$U = qV$	Yes	Use this equation when you have a single charge in a potential field.
Potential difference between two points in an electric field.	$\Delta V = -\mathbf{E} \bullet \Delta \mathbf{x}$	Yes	The negative sign means that if you move with the electric field, you go down in voltage, since electric field always points toward lower-voltage places.
Force on two **<u>point</u>** charges.	$F = \frac{kqQ}{r^2} = \frac{qQ}{4\pi\varepsilon_0 r^2}$	Yes	If the sign of the force is negative, the objects attract, but repel of sign is positive. **<u>Only use for two point charges!</u>**
Potential energy of two **<u>point</u>** charges.	$U = \frac{kqQ}{r} = \frac{qQ}{4\pi\varepsilon_0 r}$	Yes	Two objects that repel will have positive potential energy. Remember that objects always want to go to lower potential energy. **<u>Only use for two point charges!</u>**
Electric field created by a single **<u>point</u>** charge.	$E = \frac{F}{q} = \frac{kQ}{r^2} = \frac{Q}{4\pi\varepsilon_0 r^2}$	No	The electric field points away from positive charges and toward negative charges.
Electric potential created by a single **<u>point</u>** charge.	$V = \frac{U}{q} = \frac{kQ}{r} = \frac{Q}{4\pi\varepsilon_0 r}$	Yes	Positive charges create positive potentials around them.
Force experienced by a charge in an electric field	$F = qE$	Yes	Positive charges experience force in the direction of field. Negative charges experience force opposite the direction of the field.
Work done on a charge when it is moved through an electric potential.	$W = \Delta U = q\Delta V$	No	Positive charges always feel force toward regions of lower potential.

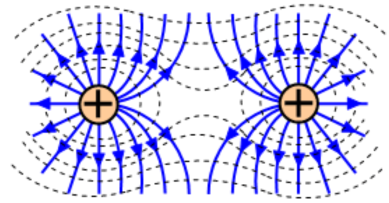
IMPORTANT CONCEPTS

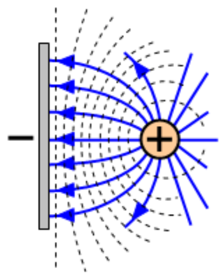
- Remember that a conductor is a material that allows charges to freely flow inside. An insulator is a material where charges are held fixed in place.
- THE ELECTRIC FIELD INSIDE ANY CONDUCTOR IS ALWAYS ZERO.
- ANY EXCESS CHARGE ON A CONDUCTOR WILL BE ON THE SURFACE OF THE CONDUCTOR, NONE INSIDE.
- Positive charges feel a force in the direction of electric field. Negative charges feel a force opposite the direction of the electric field.
- Electric field points in the direction a positive charge wants to go. Therefore, electric field lines point from positive to negative charge.

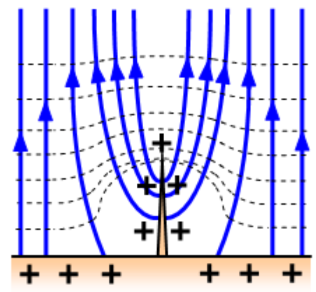
- Parallel plates create uniform electric fields if equal and opposite charges are placed on the plates.

Examples with electric field lines (electric potential lines are dashed):





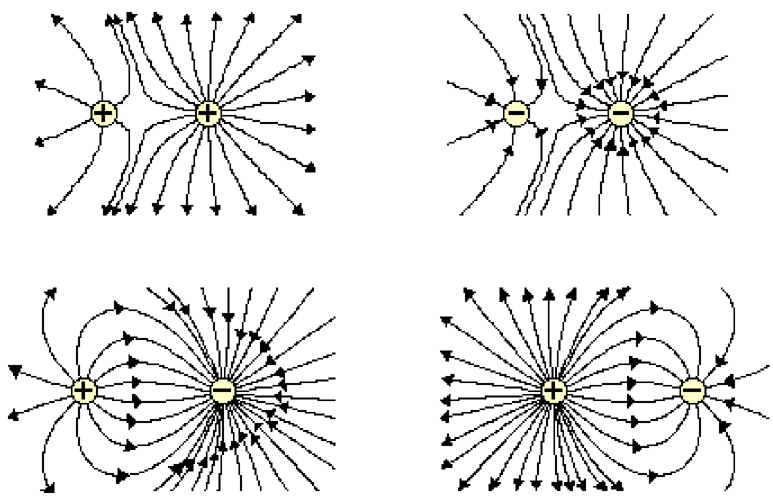




(resourcefulphysics.org)

The first are two unlike charges. The second are two like charges. The third is a charge and a plate. The fourth is a plate of charge with a "rod" sticking out.

Electric Field Line Patterns for Objects with Unequal Amounts of Charge



Circuits Notes

Four important quantities in circuit analysis

- Voltage – Symbol *V*, measured in Volts [V = J/C] – This is what "pushes" the charge to go around the circuit. It is analogous to pressure in a water pipe or in air. If there is are high- and low-pressure regions in the atmosphere, wind blows from high to low pressure. Just as a <u>difference</u> in pressure causes the flow of air, a <u>difference in voltage</u> causes the flow of electric charge.
- Current – Symbol *I*, measured in Amps [A = C/s] – This is the flow of charge, the amount of charge that passes by a given point in a certain amount of time.
- Resistance – Symbol *R*, measured in Ohms [Ω = V/A] – A measure of how much a circuit element resists the flow of charge. It is the ratio of voltage applied (how much "push") to current that results. An element that requires more "push" to accomplish a certain current will have more resistance. When you pedal your bicycle, you are delivering power to the wheels, but the bicycle resists your pedaling force. In the same sense, when electric power is delivered to a device, the device will resist the flow of current.
- Power – Symbol *P*, measured in Watts [W = J/s] – The amount of energy delivered to an object per unit time.

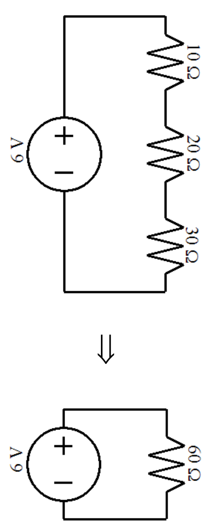
Important formulas

$R = \frac{\rho \ell}{A}$	The resistance of a resistor depends on three things: • The length of the wire ℓ. The longer the wire, the more resistance in the wire. • The "thickness of the wire", quantified by its cross-sectional area *A*. The thicker the area, the less the resistance (remember that wide straws are easier to drink out of). • The substance the resistor is made out of, quantified by the "resistivity" ρ of the substance. Substances with greater resistivity are better resistors/insulators and poorer conductors.
$V = IR$	Whenever a current passes through a resistor, there is a difference in voltage across the resistor. Before the resistor, there is higher voltage, but after the resistor there is lower voltage. Ohm's law relates the current through the resistor to the voltage difference across it.
$P = IV = I^2 R = \frac{V^2}{R}$	The power expended across the resistor is the product of current and voltage. If you remember, $P = Fv$, where *F* is force on and *v* is velocity of an object. But now we don't have a force pushing an object, we have a voltage pushing charges. Likewise we don't have *v*, the motion of the object, we have *I*, the motion of the charge.
$Q = CV$	The charge stored on one side of a capacitor is equal to the product of its capacitance and the voltage difference across it.
$C = \frac{\kappa \varepsilon_0 A}{d}$	For a specific parallel-plate capacitor, the capacitance depends on three things: • The area of the plates *A*. The bigger the plates, the bigger the capacitance. • The distance between the plates *d*. The farther apart, the less capacitance. • The material placed between the plates, quantified by the "relative permittivity" of the material κ. If nothing is between the plates, $\kappa = 1$. Otherwise, κ depends on how much the molecules between the plates are polarized (water has a high κ).
$U = \frac{1}{2} C V^2 = \frac{Q^2}{2C}$	The energy stored in a capacitor of capacitance *C* at a given voltage or with a certain amount of charge.

Circuits – Kirchoff's Circuit Laws

Current Law ("Junction Rule" or "Node Rule")	At any junction of wires, the total current into the junction equals the total current out. Could also be stated as: The total current into a junction equals zero, if current out is taken as negative.
Voltage Law ("Loop Rule")	When traveling around any loop in a circuit, the total voltage increase is equal to the total voltage decrease. Could also be stated as: The total voltage increase around any loop equal zero, if voltage decreases are taken as negative.

Analyzing Circuits – Series Circuits



Elements are "in series" if there are no junctions between them. Every element in series has the same current, but can have different voltages. Resistors in series can be combined into a single resistor R_S by simply adding the resistances:

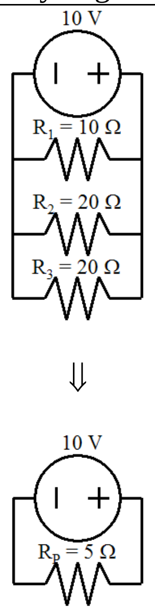
$$R_S = \sum_i R_i$$

The combined series resistance is always greater than any of the original resistors.

How to analyze a series circuit (using the example to the left):

1. Create an "equivalent circuit" that consists of the voltage source and the one combined resistor. In this case, the equivalent resistance is 60 Ω.
2. Get the current through the battery. In this case, it is 0.1 A.
3. Remember the rule that elements in series have the same current, and go back to the original circuit.
4. The battery is in series with all resistors, so all resistors have 0.1 A of current through them. Now use $V = IR$ on each resistor to get the voltage on each resistor.

Analyzing Circuits – Parallel Circuits



Elements are "in parallel" they are connected on both sides to the same two nodes. Every element in parallel has the same voltage, but can have different currents. Resistors in parallel can be combined into a single resistor R_P by adding the reciprocal of the resistances, then taking the reciprocal of the result:

$$\frac{1}{R_P} = \sum_i \frac{1}{R_i}$$

The combined parallel resistance is always less than any of the original resistors.

How to analyze a parallel circuit (using the example to the left):

1. Create an "equivalent circuit" that consists of the voltage source and the one combined resistor. In this case, the equivalent resistance is 5 Ω.
2. Get the current through the battery. In this case, it is 2 A.
3. Remember the rule that elements in parallel have the same voltage, and go back to the original circuit.
4. The battery is in parallel with all resistors, so all resistors have 10 V voltage difference across them. Now use $V = IR$ on each resistor to get the current on each resistor.

Complete Analysis of Above Two Circuits:

Series (note that current is the same in series)

	R	I	V	Current Dir.
Source	–	0.1	6	Up
R_1	10	0.1	1	Down
R_2	20	0.1	2	Down
R_3	30	0.1	3	Down

Parallel (note that voltage is the same in parallel)

	R	I	V	Current Dir.
Source	–	2	10	Right
R_1	10	1	10	Left
R_2	20	0.5	10	Left
R_3	20	0.5	10	Left

Remember these rules when traveling around a loop in a circuit:

- If you cross a resistor WITH the current, the voltage is a drop equal to IR. If you cross a resistor AGAINST the current, the voltage is a rise equal to IR.
- If you cross a battery going from + to –, the voltage of the battery is a drop. If you cross a battery going from – to +, the voltage of the battery is a rise.

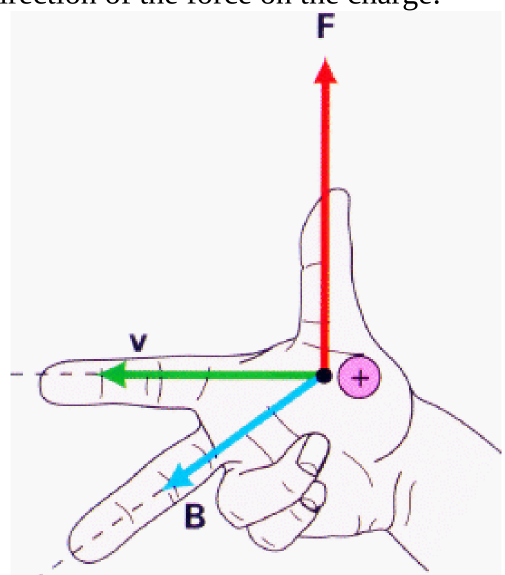
Magnetism Review

IMPORTANT QUANTITIES

Name	Symbol	Units	Basic Equation
Magnetic Field	$\mathbf{B}$	Teslas	
Electro-motive Force (emf)	ε	Volts	

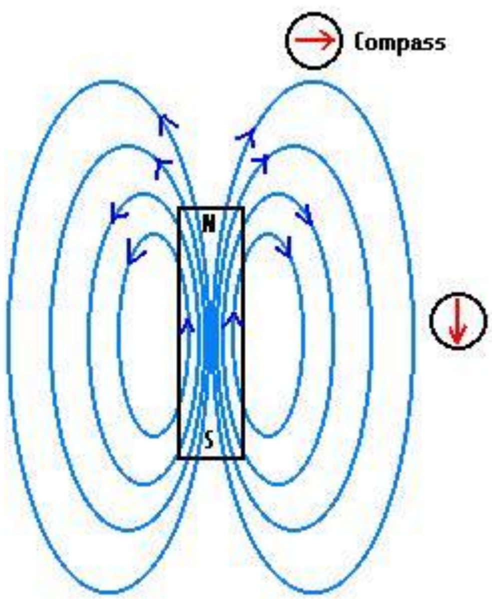
Name	Symbol	Units	Basic Equation
Magnetic Flux	Φ	Webers	$\Phi = \mathbf{B} \bullet \mathbf{A}$

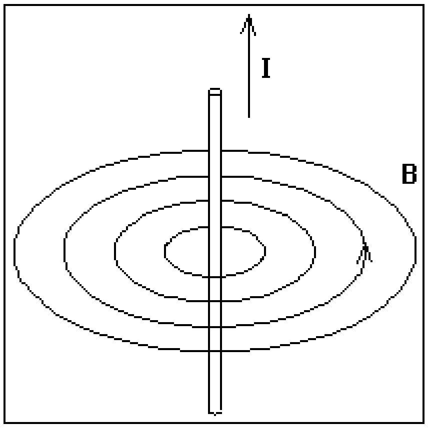
IMPORTANT EQUATIONS

Name	Equation	Given?	Notes
Force on a moving charge in a magnetic field.	$\mathbf{F} = q\mathbf{v} \times \mathbf{B}$	Yes	Use the right-hand rule to determine the direction of the force on the charge:  Use your left-hand, or reverse the direction of the force if the charge is negative.
Force on a current-carrying wire in a magnetic field.	$\mathbf{F} = \mathbf{I}\ell \times \mathbf{B}$	Yes	Use the right-hand rule to determine the direction of the force on the wire. The rule is the same as the force on a charge, but replace **v** with **I**.
Magnetic field created by a current-carrying wire, a distance *r* from the wire.	$B = \dfrac{\mu_0 I}{2\pi r}$	Yes	Use the right-hand rule to determine the direction of circulation of the magnetic field: 1. Put your thumb in the direction of the current. 2. Your fingers will curl in the direction of circulation of the field.
Magnetic Flux through a loop of wire.	$\Phi = \mathbf{B} \bullet \mathbf{A}$	Yes	

EMF created by a changing magnetic flux.	$\varepsilon = -\frac{\Delta\Phi}{\Delta t}$	Yes	Use the left-hand rule (left hand because there is a negative in the equation) to determine the direction of the induced current. 1. Put your thumb in the direction of the magnetic field flowing through the loop. 2. Reverse the direction of your thumb if the flux is decreasing. 3. Your fingers will curl in the direction of the induced current. **<u>If there is more than one loop, multiply EMF by the number of loops!</u>**
Induced EMF in a bar of length *l* moving with velocity *v* through a magnetic field *B*.	$\varepsilon = Blv$	Yes	The bar moving through the magnetic field acts like a battery of voltage ε. The positive side of the battery is the side where positive charges inside the bar are forced by the magnetic force.

DIAGRAMS OF MAGNETIC FIELD LINES





IMPORTANT CONCEPTS

- A COMPASS PLACED IN A MAGNETIC FIELD WILL ORIENT ITSELF SO THAT NORTH IS IN THE DIRECTION OF THE FIELD.
- Force is always perpendicular to both magnetic field and velocity/current.
- When a charge travels in a magnetic field, it travels in a circle because force is always perpendicular to velocity. To find the radius of the circle it travels in, set centripetal force equal to magnetic force.

  $$m\frac{v^2}{r} = qvB$$
- When a charge travels through a magnetic field, NO WORK IS DONE ON IT (since force and velocity are always perpendicular).
- REMEMBER THAT INDUCED EMF ALWAYS OPPOSES WHATEVER INDUCED IT!

Atomic and Nuclear Physics Review

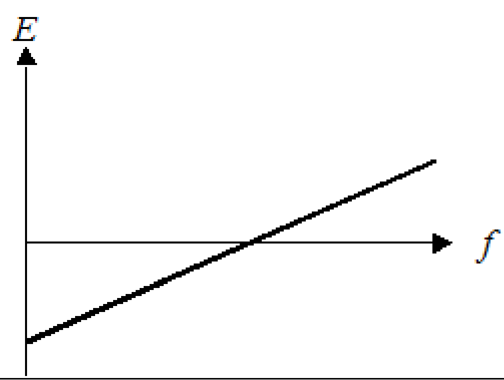
IMPORTANT QUANTITIES

Name	Symbol	Units	Basic Equation
Work Function	ϕ	Joules	

IMPORTANT EQUATIONS

Name	Equation	Given?	Notes
Photoelectric Effect Stopping Voltage	$K = hf - \phi$ $qV = hf - \phi$	Yes	The kinetic energy of an electron that is ejected by a photon of frequency *f* from a material of work function ϕ. Remember that the work function is the amount of energy required to remove one electron.
Energy of a photon	$E = hf = \frac{hc}{\lambda}$	Yes	Energy of a photon depends only on its frequency. Intensity of light depends on number of photons.
Momentum of a photon	$p = \frac{h}{\lambda} = \frac{E}{c} = \frac{hf}{c}$	Yes	Higher frequency photons have higher momentum.
Relationship between frequency and momentum for photons.	$c = \lambda f$	Yes	The speed of light is $c = 3 \times 10^8$ m/s.
De Broglie wavelength of a massive particle	$\lambda = \frac{h}{p} = \frac{h}{mv}$	Yes	The faster or more mass a particle has, the shorter its wavelength.
The energy released when a certain amount of mass is converted to energy.	$E = \Delta m \cdot c^2$ 1 amu $\leftrightarrow$ 931 MeV	Yes	The change in mass during a nuclear reaction turns into energy.

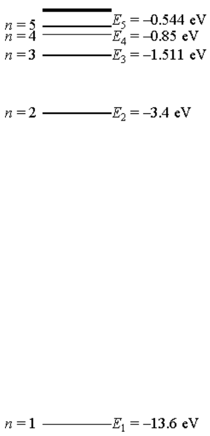
IMPORTANT GRAPHS

Name	Graph (Shape)	Notes
Graph of energy vs. frequency for the photoelectric effect		Slope is Planck's constant, *h*. Y-intercept is the work function, ϕ.

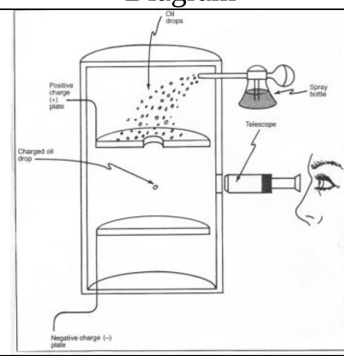
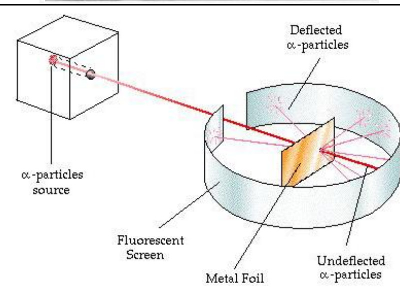
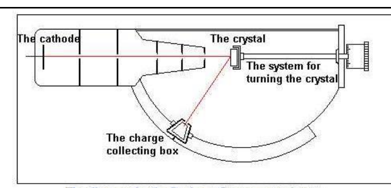
IMPORTANT CONCEPTS

- In a photoelectric effect problem, if you are ever asked for stopping voltage, REPLACE KINETIC ENERGY WITH *qV*.
- Three types of radioactive decay:
  - Alpha decay – nucleus ejects an alpha particle, which is 2 protons and 2 neutrons (helium nucleus)
  - Beta decay – neutron in the nucleus turns into a proton (stays in nucleus) and an electron (beta particle) that is ejected from the atom.
  - Gamma decay – nucleus in an excited state ejects a gamma ray (very high energy) photon. No other change in the nucleus.
- <u>Fusion</u> is where two small nuclei join into a larger nucleus. Only elements lighter than iron can fuse.

- <u>Fission</u> is where one large nucleus breaks into two or more smaller nuclei. Only elements heavier than iron can fizzle.
- In the notation ${}^{56}_{26}\mathrm{Fe}$, 26 is the number of protons (charge), and 56 is the number of protons and neutrons (mass). In a nuclear reaction, both numbers have to be conserved: ${}^{2}_{1}\mathrm{H} + {}^{2}_{1}\mathrm{H} \rightarrow {}^{3}_{2}\mathrm{He} + {}^{1}_{0}\mathrm{n}$
- During a nuclear reaction, mass disappears and turns into energy. To find that energy, find the difference of mass before and after the reaction, and use $E = \Delta m \cdot c^2$ or (1 amu $\leftrightarrow$ 931 MeV).



- Electrons can only be in certain energy levels in an atom. No electron can be "between" energy levels.
- When an electron is in the lowest level, it is said to be in the "ground state".
- When an electron is in a level above the ground state, it is in an "excited state".
- Electrons in the excited state can (and will) drop any number of levels. If an electron drops energy levels, it ejects a single photon whose energy is equal to the ***difference*** in energy levels the electron dropped.
- If the atom is irradiated with photons, the electron can absorb a photon energy to jump up to a higher energy level. It can only do this if the photon energy is exactly equal to the energy difference between the two levels that it jumps.
- If the electron reaches the level of 0 eV or above, it is freed from the atom.

Experiment	Explanation	Diagram
Millikan Oil-Drop	Oil drops are given an electric charge, and are then set in a space where there is an electric field that exerts an upward force on the charge. The electric field is varied so that the oil drop hangs in place ($mg = qE$). Solving for q, Millikan saw that all charges were multiples of the number 1.6×10^{-19}, so this is the charge on an electron.	
Rutherford Scattering	Alpha particles were shot at a piece of gold foil. Many of the particles were repelled back the direction from which they came. The conclusion was that the alpha particles were "bouncing" off of a very heavy, tiny and dense nucleus in the gold atoms.	
Davisson Germer	Electrons are shot at a crystalline nickel target. The electrons that bounced off of the nickel target created a diffraction pattern when they were detected. Since electrons created a diffraction pattern, they (and all matter) are actually waves.	 The diagram for the Davisson-Germer experiment.
Photoelectric Effect	When light strikes a metal surface, electrons are ejected from the metal. The kinetic energy of the photons depends on the frequency of the light, and the number of electrons ejected depends on the intensity (brightness) of the light. Since this is the case, light comes in packets of energy called photons.