Flipping Physics Lecture Notes:
AP Physics 1 Exam Cram: Full Curriculum in 30 Minutes

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Unit 1: Kinematics

Vectors and Scalars:

- Vectors have magnitude and direction.
- Scalars have magnitude only.

Displacement, Velocity, and Acceleration:

- The distance an object travels is the length of the path taken between initial and final position.
- An object's displacement is the straight-line distance between the object's initial and final position.
  - Displacement is the change in position of an object.
    - $\Delta\vec{x} = \vec{x}_f - \vec{x}_i$
  - If an object stops at the same place it started, it has a displacement of zero.
  - Displacement is a vector. Distance is a scalar.
    - The distance an object travels will always be greater than or equal to the magnitude of the displacement of the object.
- The equation for average velocity is: $\vec{v}_{\text{avg}} = \frac{\Delta\vec{x}}{\Delta t}$
  - Velocity is a vector.
  - If the time interval over which the average velocity is taken is very small, then the velocity is considered to be instantaneous velocity. That is, the velocity at a specific time, rather than the velocity over a time period.
- The equation for average acceleration is: $\vec{a}_{\text{avg}} = \frac{\Delta\vec{v}}{\Delta t}$
  - Acceleration is a vector.
  - If the time interval over which the average acceleration is taken is very small, then the acceleration is considered to be instantaneous acceleration. That is, the acceleration at a specific time, rather than the acceleration over a time period.
- When the acceleration of an object does not change, we can use the uniformly accelerated motion or UAM equations. These are also often called the kinematics equations.
  - There are 5 UAM variables and 4 UAM equations. If you know 3 of the UAM varaibles, you can determine the other 2. That leaves you with … 1 Happy Physics Student!
  - These three are on the equation sheet:
    - $v_x = v_{x0} + a_x t$
    - $v_x^2 = v_{x0}^2 + 2a_x(x - x_0)$
    - $x = x_0 + v_{x0} + \frac{1}{2}a_x t^2$

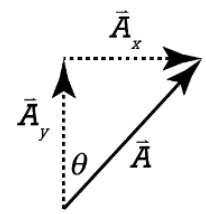
- This UAM equation is not on the equation sheet:
  - $\Delta x = \frac{1}{2}(v_x + v_{x0})\,t$
- All of these equations assume the initial time is zero.

Motion Graphs:

- The slope of a position vs. time graph is velocity.
- The slope of a velocity vs. time graph is acceleration.
- The area between the curve and the horizontal time axis on a velocity vs. time graph is change in position.
- The area between the curve and the horizontal time axis on an acceleration vs. time graph is change in velocity.
- Area above the horizontal axis is positive and area below the horizontal axis is negative.

Two-Dimensional Motion:

- Break, or resolve, vectors into their component vectors:



$$\sin\theta = \frac{\text{opposite}}{\text{hypotenuse}} = \frac{A_x}{A} \Rightarrow A_x = A\sin\theta$$

$$\cos\theta = \frac{\text{adjacent}}{\text{hypotenuse}} = \frac{A_y}{A} \Rightarrow A_y = A\cos\theta$$

  - Be careful, theta will not always be with the horizontal, therefore, the x-component will not always use cosine.
- The only force acting an object is the gravitational force and the object is near the surface of the Earth, the object is in projectile motion:
  - $a_y = 10\ m/s^2$ down ; can use UAM equations in y-direction.
  - $a_x = 0$; can use constant velocity equation in x-direction.

Relative Motion:

- The description of the motion of an object changes depending on the frame of reference of the person observing the motion.
- Combining the motion of an object and the motion of an observer in a reference frame involves vector addition.

Unit 2: Force and Translational Dynamics

Center of Mass of a System of Particles:

- The equation on the equation sheet for the center of mass of a system of particles is:

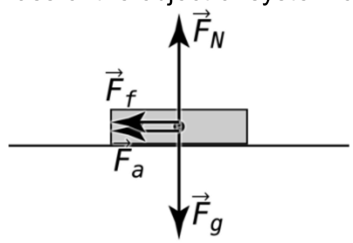
$$\vec{x}_{cm} = \frac{\sum m_i \vec{x}_i}{\sum m_i}$$

  - I find some students understand the equation when I express it this way instead:

$$\vec{x}_{cm} = \frac{m_1\vec{x}_1 + m_2\vec{x}_2 + \ldots}{m_1 + m_2 + \ldots}$$

  - The x could also be y or z, depending on which direction the center of mass is defined in.
  - The position, x, is relative to a zero point which could be the origin; however, it could be defined as elsewhere.
- This equation could also refer to the velocity and acceleration of the center of mass of a system of particles:
  - $\vec{v}_{cm} = \frac{\sum m_i \vec{v}_i}{\sum m_i}$ & $\vec{a}_{cm} = \frac{\sum m_i \vec{a}_i}{\sum m_i}$

Forces:

- All forces are vectors; they have both magnitude and direction.
- All forces are the result of an interaction between two objects. Always!
- Free Body Diagrams show all the forces acting on an object.
  - Only force vectors should be in free body diagrams.
  - All forces start at the center of mass of the object or system.
  - If there are two or more forces acting in the same direction on an object, those forces still start at the center of mass of the object or system offset from one another.
    - For example: 

  - Never break forces into components in a free body diagram answer on an AP Physics exam. If you need to break forces into components, redraw that free body diagram elsewhere on the exam.
- The force normal caused by a surface is always perpendicular to the surface and pushes away from that surface.
- Force of tension in a rope, or something similar, is always parallel to the direction of the rope and a pull.

Newton's First Law:

- "An object at rest will remain at rest and an object in motion will remain at a constant velocity unless acted upon by a net, external force."
  - This is often called the Law of Inertia because inertia is the tendency of an object to resist acceleration.

Newton's Second Law:

- On the AP Physics reference sheet: $\vec{a}_{sys} = \frac{\sum \vec{F}}{m_{sys}}$ or $\sum \vec{F} = m\vec{a} \Rightarrow N = \frac{kg \cdot m}{s^2}$
- When the net force on an object equals zero, the object is in translational equilibrium. That means the object is either at rest or moving at a constant velocity because the acceleration of the object equals zero.
  - $\sum \vec{F} = 0 = m\vec{a} \Rightarrow \vec{a} = 0$

Newton's Third Law:

- Newton's Third Law states that for every force object 1 exerts on object 2, object 2 exerts a force on object 1 that is equal in magnitude and opposite in direction.
  - $\vec{F}_{12} = -\vec{F}_{21}$ or $\vec{F}_{\text{A on B}} = -\vec{F}_{\text{B on A}}$
  - These two forces act simultaneously.

The Gravitational Force:

- The magnitude of the gravitational force exerted on a mass in a gravitational field is determined using the equation $F_g = mg$.
  - The direction of the force of gravity on an object is always towards the center of mass of the planet; down.

The Force of Friction:

- The direction of the force of friction:
  - is always parallel to the surface
  - always opposes sliding motion
  - always independent of the direction of the force applied
- For Kinetic Friction: $F_{kf} = \mu_k F_N$
  - Kinetic friction is when the two surfaces are sliding relative to one another.
- The coefficient of friction, μ, has no units, cannot be negative, is experimentally determined
- For Static Friction: $F_{sf} \leq \mu_s F_N \Rightarrow F_{sf_{max}} = \mu_s F_N$
  - Static friction is when the two surfaces are not sliding relative to one another.
  - The force of static friction adjusts in an attempt to keep the two surfaces from sliding relative to one another.
- The force of friction does not depend on the size of the surface area of contact between the 2 surfaces.

Universal Gravitation and Gravitational Field:

- The equation for the magnitude of the gravitational force using Newton's Law of Universal Gravitation is: $\left|\vec{F}_g\right| = \frac{Gm_1m_2}{r^2}$
  - r is not the radius. r is the distance between the centers of mass of the two objects.
  - The gravitational force is always directed along a line connecting the centers of mass of the two objects and is always directed toward the other mass.
- The local gravitational field on a planet, little g, is nearly constant on the surface of the planet.
- The magnitude of the gravitational field can be found by setting the two equations for gravitational force equal to one another.
  - $$F_g = m_{\text{object}}g = \frac{Gm_{\text{object}}m_{\text{planet}}}{r^2} \Rightarrow g = \frac{Gm_{\text{planet}}}{\left(R_{\text{planet}}\right)^2}$$

The Spring Force:

- An ideal spring force is proportional to its displacement from equilibrium position.
- The equation for the spring force is called Hooke's law and it is: $\vec{F}_s = -k\Delta\vec{x}$
- The direction of the spring force is always toward equilibrium position.
  - The negative in Hooke's law represents that the spring force and the displacement of the object from equilibrium position are opposite in direction.
- The magnitude of the slope of a graph of spring force vs. displacement from equilibrium position is the spring constant; y = mx + b.

Circular Motion:

- The linear velocity of an object moving along a circular path is called tangential velocity which is always directed perpendicularly to the radius describing the path and parallel to the path itself.
- An object moving along a circular path, must have a centripetal acceleration which is always directed inward toward the center of the circle.
  - The reason an object moving along a circular path must have a centripetal acceleration is because the direction of the tangential velocity of the object is always changing.
  - Centripetal acceleration equals the square of tangential speed divided by radius.
    - $$a_c = \frac{{v_t}^2}{r}$$
- The time it takes an object which is moving along a circular path at a constant speed to complete one circle is defined as the period, T.
  - The number of revolutions completed by the object per second is defined as frequency, f. $T = \frac{1}{f}$

- Centripetal force is the net force in the in direction which causes the centripetal acceleration of the object in toward the center of the circle.
  - $\sum \vec{F}_{in} = m\vec{a}_c$
    - The centripetal force is not a new force
    - The centripetal force is never in a free body diagram.
    - The direction "in" is positive and the direction "out" is negative.

Unit 3: Work, Energy, and Power

Translational Kinetic Energy:

- An object whose center of mass is moving has translational kinetic energy: $KE = \frac{1}{2}mv^2$

Work:

- Work is the amount of mechanical energy transferred into or out of a system.
  - $W = Fd\cos\theta$
- The work done by a conservative force on a system is independent of the path of the object.
  - Two examples of conservative forces are the gravitational force and the spring force.
- The work done by a nonconservative force on a system does depend on the path.
  - Two examples of nonconservative forces are the force of friction and the force of air resistance.

Potential Energy:

- The three types of mechanical energy are kinetic energy, gravitational potential energy, and elastic potential energy.
- Potential Energy is the energy stored in a system due to the positions of the objects in the system.
- In a constant gravitational field, the change in gravitational potential energy is: $\Delta U_g = mg\Delta y$
- A single object cannot have potential energy.
- The general form for the gravitational potential energy which exists between two objects with mass is: $U_g = -\frac{Gm_1m_2}{r}$
  - The location of zero gravitational potential energy in this equation is where the two objects are infinitely far away from one another.
    - This is why the general form of gravitational potential energy is always negative.
- The equation for elastic potential energy is: $PE_e = U_e = \frac{1}{2}kx^2$
- Work and Energy are scalars. This means Work, Kinetic Energy, Gravitational Potential Energy, and Elastic Potential Energy do not have direction, they have magnitude only.

Conservation of Energy:

- A system with only one object in it can only have kinetic energy.
- Any changes to the types of energies in a system are balanced by equivalent changes of other types of energies in the system or by a transfer of energy into or out of the system.

- The total mechanical energy of a system remains the same if there is zero net work done on the system and there is zero work done by nonconservative forces.
  - $ME_i = ME_f$ or $\Delta ME = 0$
- When there is net work done on a system, energy is transferred between the system and its surroundings.
- When friction does work on the system and no external force add or remove energy from the system: $W_{NC} = \Delta ME$
- The Work-Energy Principle is: $W_{\text{net}} = \Delta KE$
  - This equation can be used when work is done by friction on the system and when an external force does work on the system.
- Whenever you are using these equations where mechanical energy remains constant or energy is transferred into or out of a system, in addition to clearly identifying the system, you always have to identify the following 3 things: the initial point, the final point, and the horizontal zero line.

Power:

- Power is the rate at which energy changes with respect to time, by either being transferred into or out of a system or converted from one type of energy to another within a system.
- $P_{\text{avg}} = \frac{\Delta E}{\Delta t} = \frac{W}{\Delta t}$ & $P_{\text{instantaneous}} = Fv\cos\theta$

Unit 4: Linear Momentum

Linear Momentum:

- Linear momentum: $\vec{p} = m\vec{v}$
- Typically, during a collision or explosion, the net external force acting on the object or system is considered to be negligibly small relative to the forces internal to the system.
- During an explosion, forces internal to the system push the objects in the system apart.

Change in Momentum and Impulse:

$$\sum \vec{F} = m\vec{a} = m\left(\frac{\Delta\vec{v}}{\Delta t}\right) = m\left(\frac{\vec{v}_f - \vec{v}_i}{\Delta t}\right) = \frac{m\vec{v}_f - m\vec{v}_i}{\Delta t} = \frac{\vec{p}_f - \vec{p}_i}{\Delta t} \Rightarrow \sum \vec{F} = \frac{\Delta\vec{p}}{\Delta t}$$

- Impulse, J, can be expressed in three different ways:

$$\vec{J} = \Delta\vec{p} = \vec{F}_{\text{avg}}\Delta t = \vec{A}\text{rea "under" F vs. t curve}$$

Conservation of Linear Momentum:

- When the net force acting on a system is zero, the impulse on the system is also zero, and the momentum of the system remains constant because no momentum is added or removed from the system.
  - $\sum \vec{p}_i = \sum \vec{p}_f$
- If the net force acting on a system with several objects in it is zero, the velocity of the center of mass of the system is constant. This is because the change in momentum of the system is zero.
- When the net force on a system is nonzero, the impulse on the system is also zero, so linear momentum does not remain constant because linear momentum is transferred between the system and the environment.

Elastic and Inelastic Collisions:

- Three main types of collisions:
  - Elastic Collisions: the total kinetic energy of the system before the collision is the same as the total kinetic energy after the collision.
  - Inelastic collision: the total kinetic energy of the system decreases during the collision.
  - Perfectly Inelastic Collisions: Inelastic collisions where the objects stick to one another after the collision.
- Most real-world collisions are inelastic collisions.
- During all collisions, because the net external force acting on the system is considered to be negligibly small relative to the internal forces, the linear momentum of the system remains the same.

Unit 5: Torque and Rotational Dynamics

Rotational Kinematics:

- Angular Displacement: $\Delta\theta = \theta_f - \theta_i$
  - Units for angular displacement are degrees, radians, and revolutions.
    - To use angular displacement, and all other angular variables in pretty much any physics equation, it needs to be in radians.
  - 1 revolution = 360° = 2π radians
- Average Angular Velocity: $\omega = \frac{\Delta\theta}{\Delta t}$
- Average Angular Acceleration: $\alpha = \frac{\Delta\omega}{\Delta t}$
- Rigid objects with shape maintain a constant shape as they rotate.
  - All the points in a rigid object go through the same angular displacement during the same time interval, have the same angular velocity, and have the same angular acceleration.
- Uniformly Angularly Accelerated Motion, UαM:
  - Is similar to Uniformly Accelerated Motion, UAM.
  - The UαM equations are valid when the angular acceleration of the object is constant.
- In graphs of rotational motion:
  - The slope of an angular position as a function of time graph is angular velocity.
  - The slope of an angular velocity as a function of time graph is angular acceleration.
  - The area "under" an angular acceleration as a function of time graph is change in angular velocity.
  - The area "under" an angular velocity as a function of time graph is change in angular position or angular displacement.

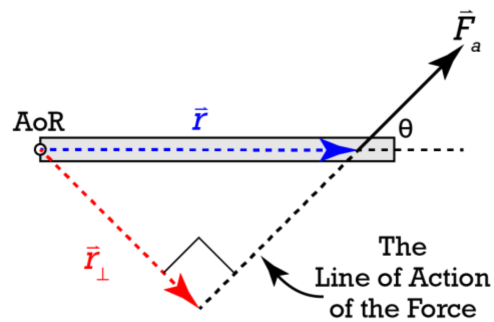
Connecting Linear and Rotational Motion:

- An object moving along a circular path moves through an angular displacement, however, it also moves through a linear distance called arc length. $s = r\Delta\theta$
  - It also has a linear velocity called tangential velocity. $v_t = r\omega$
  - It can also have a linear acceleration called tangential acceleration. $a_t = r\alpha$
    - The directions of tangential velocity and tangential acceleration are tangent to the circular path being traced out by the object and perpendicular to the radius.
  - In order to use each of the three equations relating a linear variable to a rotational variable, the rotational variable needs to be in radians. This is because radians are a dimensionless quantity.

- Centripetal acceleration equals tangential speed squared over radius. It also equals radius times angular speed squared.
- The three different accelerations an object can have in circular motion are angular acceleration, tangential acceleration, and centripetal acceleration.
    - Angular acceleration is the only one of the three which is an angular quantity with units of radians per second squared.
    - Both tangential acceleration and centripetal acceleration are linear accelerations with units of meters per second squared.
        - Tangential acceleration is always in a direction tangent to the circular path being traced out by the object and perpendicular to the radius.
        - Centripetal acceleration is always in a direction perpendicular to the circular path being traced out by the object and in toward the center of the circle along the radius.
            - This means tangential acceleration and centripetal acceleration are always perpendicular to one another.
    - Circular motion cannot exist without centripetal acceleration.
    - Tangential acceleration refers to the change in *magnitude* of the tangential velocity of an object.
    - Centripetal acceleration refers to the change in *direction* of the tangential velocity of an object.
- When a rigid object is rotating, the terms angular displacement, angular velocity, and angular acceleration refer to the whole object, however, the terms arc length, tangential velocity, tangential acceleration, and centripetal acceleration refer to a specific location on the object.

Torque:

- Torque, τ, is the ability of a force to cause an angular acceleration of an object. $\tau = rF\sin\theta$
    - r is the distance from the axis of rotation to the location where the force acts on the object.
    - F is the force causing the torque.
    - θ is the angle between the directions of r and F.
    - $r_\perp$ is called the lever arm which is the perpendicular distance from the axis of rotation to the line of action of the force.



- Torque is a vector. In AP Physics 1 we use clockwise and counterclockwise to indicate the direction of torque.
- When working with torque we draw force diagrams of all the forces acting on an object. The objects are no longer point particles; they are rigid objects with shape. This means we need to indicate in our force diagram where the forces act on the object.

Rotational Inertia:

- Rotational Inertia, I, is a measure of how much an object resists angular acceleration.
- The equation for rotational inertia of a point particle rotating around an axis of rotation is: $I_{\text{point particle}} = mr^2$
    - m is the mass of the point particle.
    - r is the distance between the axis of rotation and the location of the point particle.
- To get the rotational inertia of a system of particles, we add up the rotational inertias of each particle in the system.
    - $I_{\text{system of particles}} = \sum I_i = \sum m_i r_i^2$
- When needed, the equations for rotational inertias of rigid objects with shape will be provided on the AP Physics 1 exam.

- In order to determine the rotational inertia of a particle, a system of particles, or a rigid object with shape, you must first identify the axis of rotation.
- If you have the equation for the rotational inertia of a uniform, rigid object with shape about an axis through its center of mass, you can determine the rotational inertia of that object about another axis which is parallel to the axis through the center of mass by using the Parallel Axis Theorem. $I = I_{CM} + MD^2$
  - I_{CM} is the rotational inertia of the uniform, rigid object with shape about its center of mass.
  - M is the mass of the uniform, rigid object with shape.
  - D is the distance between the two axes.

Rotational Equilibrium and Newton's First Law in Rotational Form:
- When a system is in rotational equilibrium, the angular velocity of the system is constant.
  - $\sum \vec{\tau} = 0 = I\vec{\alpha} \Rightarrow \vec{\alpha} = 0 \Rightarrow \vec{\omega} = \text{contsant}$
- Newton's First Law in Rotational Form is: An object at rest remains at rest, and a rotating object maintains a constant angular velocity, unless acted upon by a net, external torque or the distribution of the mass of the object changes.

Newton's Second Law in Rotational Form:
- $\sum \vec{\tau} = I\vec{\alpha}$
  - From this we can see that the rotational equivalent of force is torque, the rotational equivalent of mass is rotational inertia, and the rotational equivalent of linear acceleration is angular acceleration.
- An object which is at rest and is not rotating is in both translational and rotational equilibrium, this is called static equilibrium.
  - In static equilibrium the net torque about any axis of rotation is equal to zero.
  - Pick an axis of rotation which makes the math easier.

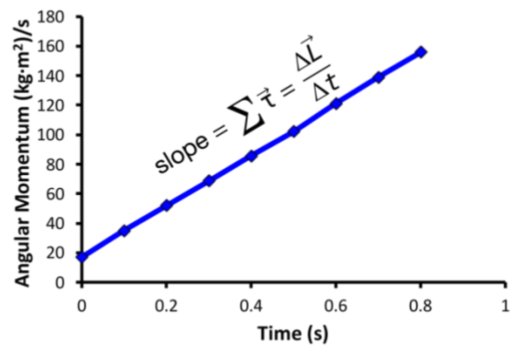
Unit 6: Energy and Momentum of Rotating Systems

Rotational Kinetic Energy:
- Objects whose center of mass is changing location have Translational Kinetic Energy: $KE_{trans} = \frac{1}{2}mv^2$
- Objects that are rotating have Rotational Kinetic Energy: $KE_{rot} = \frac{1}{2}I\omega^2$
- The total kinetic energy of a rigid object is the addition of its rotational kinetic energy about its center of mass and its translational kinetic energy from the linear motion of its center of mass.

Torque and Work:
- A torque can transfer energy into or out of a rigid system if the torque acts over a change in angular position or angular displacement.
- Work done by a constant torque on a rigid system is: $W = \tau\Delta\theta$
- On a graph of torque as a function of angular position, work is the area "under" the curve.

Angular Momentum and Angular Impulse:
- Angular Momentum of a Rigid Object with Shape is: $\vec{L} = I\vec{\omega}$
  - Angular momentum of a rigid object with shape has to be relative to an axis of rotation.

- Angular Momentum of a Point Particle is: $L = rmv\sin\theta$
  - r is the distance from the axis of rotation, or reference point, to the point particle.
  - m is the mass of the particle
  - v is the magnitude of the velocity of the point particle.
  - θ is the angle between r and v.
  - Angular momentum of a point particle has to be relative to an axis of rotation, which is sometimes called a reference line.
  - This equation is for the magnitude of the angular momentum of a point particle.
- Just like linear momentum, angular momentum is a vector; it has both magnitude and direction.
  - In AP Physics 1, we use clockwise and counterclockwise to indicate the direction of angular momentum.
- A different rotational form of Newton's Second Law can be used to find Angular Impulse:
  - $\sum \vec{\tau} = \frac{\Delta \vec{L}}{\Delta t} \Rightarrow \vec{J}_{\text{angular}} = \Delta \vec{L} = \vec{\tau}\Delta t$
- The three things angular impulse is equal to are:
  - $\vec{J}_{\text{angular}} = \Delta \vec{L} = \vec{\tau}\Delta t = \text{Area "Under" } \tau \text{ vs. } t \text{ Curve}$
- On a graph of angular momentum as a function of time, the slope of the curve is the net torque acting on the object.



<u>Conservation of Angular Momentum:</u>

- The total angular momentum of a system remains constant if the net torque acting on the system equals zero. When that occurs, no angular momentum is added or removed from the system.
  - $$\sum \vec{\tau}_{\text{system}} = \frac{\Delta \vec{L}_{\text{system}}}{\Delta t} = 0$$
    $$\Rightarrow \Delta \vec{L}_{\text{system}} = 0 = \vec{L}_{f_{\text{system}}} - \vec{L}_{i_{\text{system}}}$$
    $$\Rightarrow \vec{L}_{f_{\text{system}}} = \vec{L}_{i_{\text{system}}} \Rightarrow \sum \vec{L}_f = \sum \vec{L}_i$$

<u>Rolling:</u>

- A rigid object with shape which is rolling without slipping has equations for the displacement, velocity, and acceleration of its center of mass which are very similar to the circular motion equations for arc length, tangential velocity and tangential acceleration.
  - Circular Motion ⇒ Rolling without Slipping
  - Arc Length: $s = r\Delta\theta \Rightarrow$ Displacement: $\Delta x_{CM} = R\Delta\theta$
  - Tangential Velocity: $v_t = r\omega \Rightarrow$ Velocity: $v_{CM} = R\omega$
  - Tangential Acceleration: $a_t = r\alpha \Rightarrow$ Acceleration: $a_{CM} = R\alpha$
- When an object is rolling without slipping it has both translational and rotational kinetic energies.
- The acceleration of a rigid object with shape rolling without slipping on an incline only depends on three variables: the incline angle, the gravitational field, and the factor in front of MR^2 in the rotational inertia equation.
- When an object is rolling *with* slipping, the equations for rolling *without* slipping are no longer valid. For example, the velocity of the center of mass of an object rolling *with* slipping does *not* equal the radius of the object times its angular velocity.

Motion of Orbiting Satellites:

- In *circular* orbits, the total mechanical energy of the system, the gravitational potential energy of the system, angular momentum of the satellite, and the kinetic energy of the satellite all remain constant.
- In *elliptical* orbits the total mechanical energy of the system and the angular momentum of the satellite remain constant, however, the gravitational potential energy of the system and the kinetic energy of the satellite do not remain constant.
- When a satellite is in a circular orbit or an elliptical orbit around a planet its linear momentum does not remain constant because the direction of its velocity changes, however, the angular momentum of the satellite does not change; the direction of its angular velocity does remain constant.
- Escape velocity is defined as the speed necessary directed away from the surface of a planet such that the final velocity of the object will be zero when the object is an infinite distance from the planet.

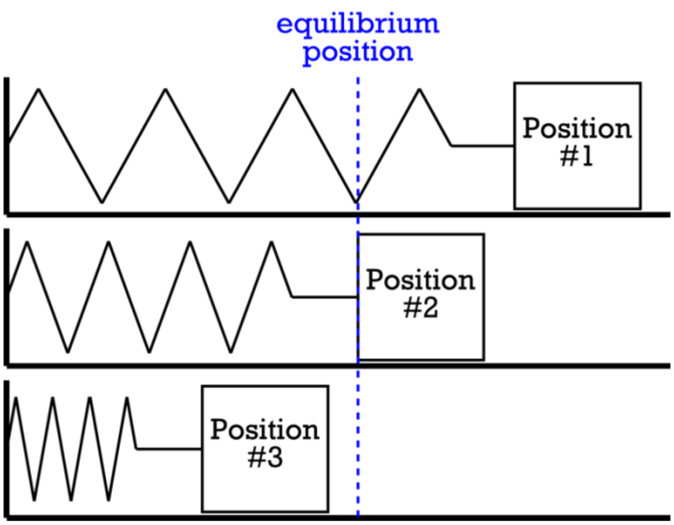
Unit 7: Oscillations

Simple Harmonic Motion:

- Periodic motion is motion which is repeated in equal intervals of time.
- Simple Harmonic Motion is periodic motion which results from a restoring force acting on an object where the magnitude of that force is proportional to the displacement of the object from equilibrium position.
  - Equilibrium position is the location where the net force acting on the object is zero.
  - A restoring force is always directed towards equilibrium position.

Frequency and Period of Simple Harmonic Motion:

- The period of simple harmonic motion, T, is defined as the time it takes to go through one full cycle or oscillation.
- The amplitude of simple harmonic motion, A, is defined as the maximum distance from equilibrium position.
- The following are all examples of the positions the mass-spring system would move through during one full cycle: 1, 2, 3, 2, 1 or 2, 3, 2, 1, 2 or 2, 1, 2, 3, 2 or 3, 2, 1, 2, 3
- Force, acceleration, velocity, and displacement of the mass-spring system for each position are:



a) x_1 = Amplitude; $v_1 = 0$
b) $\|F_{s1}\|$[1] and $\|a_1\|$ are at their maximum
c) F_{s1} and a_1 are directed to the left

d) $x_2 = 0$; $\|v_2\|$ is at its maximum
e) F_{s2} and $a_2 = 0$
f) v_2 is directed to the left or right

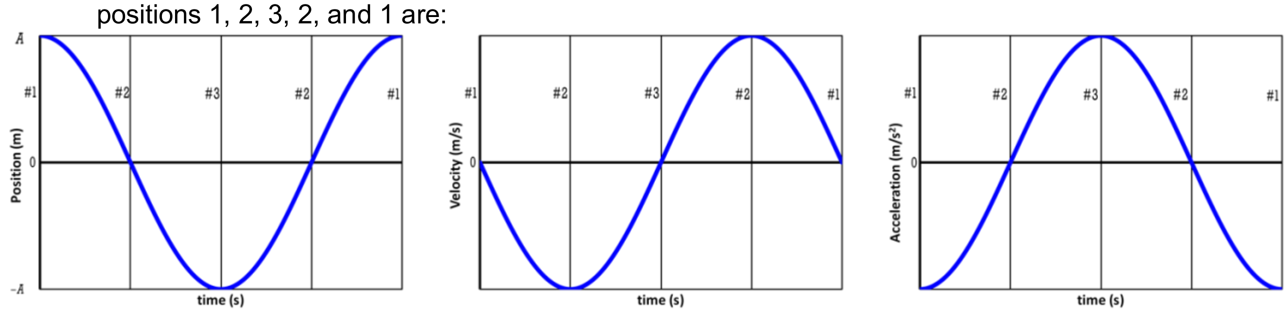
g) x_3 = -Amplitude; $v_3 = 0$
h) $\|F_{s3}\|$ and $\|a_3\|$ are at their maximum
i) F_{s3} and a_3 are directed to the right

[1] Two vertical lines on either side of a variable in physics means "The magnitude of the variable".

- The equation for the period of a mass-spring system is: $T_{\text{mass-spring}} = 2\pi\sqrt{\frac{m}{k}}$
  - The restoring force for a horizontal mass-spring system is the spring force acting on the mass.
- The equation for the period of a simple pendulum is: $T_{\text{pendulum}} = 2\pi\sqrt{\frac{L}{g}}$
  - A simple pendulum is considered to be in simple harmonic motion for small angles.
    - For AP Physics 1 that maximum angle can be as large at 15°.
  - The restoring force for a simple pendulum is the component of the force of gravity acting on the pendulum bob which is tangent to the direction of the motion of the bob.
- Frequency, f, of simple harmonic motion is defined as the number of cycles, or oscillations, per second.

Representing and Analyzing Simple Harmonic Motion:

- An equation which can describe the position of an object in simple harmonic motion is: $x = A\cos(2\pi f t)$
  - The only difference between using cosine and sine in this equation is that they are phase shifted from one another by a magnitude of 90° or $\pi/2$ radians.
  - In other words, when you use cosine the initial position of the object is the amplitude, and when you use sine, the initial position of the object is equilibrium position.
- The graphs of position, velocity, and acceleration of a mass-spring system moving through positions 1, 2, 3, 2, and 1 are:



Energy of Simple Harmonic Oscillators:

- The total mechanical energy of an object in simple harmonic motion is the sum of the kinetic energy and the potential energy of the system.
- The total mechanical energy of an isolated system in simple harmonic motion is constant.
- The total mechanical energy of a horizontal, ideal mass-spring system is: $ME_t = \frac{1}{2}kA^2$
  - It also is: $ME_t = \frac{1}{2}m{v_{max}}^2$
  - $ME_t = \frac{1}{2}kA^2 = \frac{1}{2}m{v_{max}}^2 \Rightarrow kA^2 = m{v_{max}}^2 \Rightarrow v_{max} = \sqrt{\frac{kA^2}{m}} = A\sqrt{\frac{k}{m}}$

Unit 8: Fluids

Density:

- $\text{density} = \frac{\text{mass}}{\text{volume}}$ or $\rho = \frac{m}{V}$

Pressure:

- $P = \frac{F_\perp}{A}$
- Pressure is a scalar.
- The absolute pressure at any point in a fluid is the sum of the pressure at the top of the fluid, P_0 , and the gauge pressure caused by the weight of the vertical column of fluid above that point.
  - $P_{\text{absolute}} = P_0 + \rho g h$
  - $P_{\text{gauge}} = \rho g h$
    - ρ: fluid density
    - g: gravitational field strength
    - h: fluid depth
    - Gauge pressure does not depend on the cross-sectional area of the container holding the fluid.

Fluids and Newton's Laws:

- The buoyant force is equal in magnitude to the weight of the fluid displaced by the object.
- The buoyant force equation is:

$$F_B = m_f g \;\&\; \rho = \frac{m}{V} \Rightarrow m_f = \rho_f V_f \Rightarrow F_B = \rho_f V_f g$$

Fluids and Conservation Laws:

- The continuity equation for ideal fluid flow says that the volumetric flow rate, or cross-sectional area times fluid flow speed, is constant. $A_1 v_1 = A_2 v_2$
  - This is true for ideal fluid flow through a closed volume like a pipe.
- Bernoulli's equation is a description of mechanical energy remaining constant in ideal fluid flow.
  - Bernoulli's equation is: $P_1 + \frac{1}{2}\rho {v_1}^2 + \rho g y_1 = P_2 + \frac{1}{2}\rho {v_2}^2 + \rho g y_2$
- Bernoulli's Principle relates fluid speed and fluid pressure.
  - Assuming the difference in height is negligible, according to Bernoulli's Principle, if fluid speed increases, fluid pressure decreases.
- Torricelli's Theorem can be derived from Bernoulli's equation.
  - Torricelli's Theorem gives the speed of an ideal fluid exiting a large, open reservoir through a small hole.
  - Torricelli's Theorem is: $v = \sqrt{2g\Delta y}$