Flipping Physics Lecture Notes:
AP Physics 1 - Unit 2a Review – Newton's Laws and Forces – Exam Prep
http://www.flippingphysics.com/ap-physics-1-unit-2a-review.html

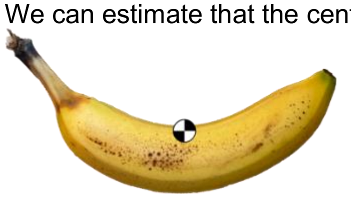
This lecture is a free part of my AP Physics 1 Ultimate Review Packet. If you find this video useful, I suggest you invest in the rest of the packet.

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:
  - $\vec{v}_{cm} = \frac{\sum m_i \vec{v}_i}{\sum m_i}$ & $\vec{a}_{cm} = \frac{\sum m_i \vec{a}_i}{\sum m_i}$

Center of Mass of an Object with Shape:

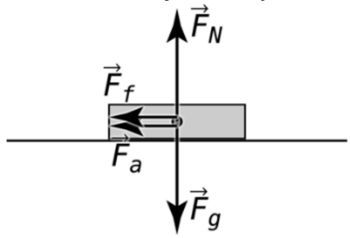
- An object is a collection of particles which have little to no interaction with one another.
  - An object is treated as having no internal structure.
- Because finding the center of mass of an object with shape requires calculus, center of mass problems which involve objects in AP Physics 1 should only include uniform density objects with obvious centers of mass or center of mass we can estimate. For example:
  - The center of mass of a uniform density sphere is right in its center.
  - The center of mass of a uniform density rectangular box is right in its center.
  - We can estimate that the center of mass of a banana is roughly here:



- I go through several examples of Center of Mass problems in my video "Center of Mass - AP Physics 1: Kinematics Review Supplement".

Forces:

- All forces are vectors; they have both magnitude and direction.
- All forces are the result of an interaction between two objects. Always!
  - An object cannot exert a force on itself!
- Free Body Diagrams show all the forces acting on an object.
  - Only force vectors should be in free body diagrams.
    - Vector which you might be tempted to put in a free body diagram, however, you should never put this in a free body diagram: displacement, velocity, acceleration, momentum, impulse, angular momentum, torque, etc.
  - 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 five steps to help solve any free body diagram problem are:
  1) Draw the free body diagram.
  2) Break forces into components.
  3) Redraw the free body diagram.
  4) Sum the forces.
  5) Sum the forces in a direction which is perpendicular to the direction in step 4.

- The force normal caused by a surface is always perpendicular to the surface and pushes away from that surface.
- Force of tension is in a rope, string, cable, chain, or something similar.
  - If the rope is ideal, it has negligible mass and does not stretch.
  - The force of tension in an ideal rope has the same magnitude at all points in the rope.
    - If the rope does not have negligible mass, the force of tension may not be the same at all points in the rope.
  - The force of tension is always parallel to the direction of the rope, wire, string, or cable.
- Contact forces are the result of the interaction of one object touching another object and result from electric forces between the atoms of the objects.
  - Five examples of contact forces are: force of tension, force of friction, force normal, force applied, and the spring force.

<u>Newton's First Law:</u>

- "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."
  - Students often forget
    - objects in motion will remain at a *constant velocity*, not just in motion.
    - That it is unless acted upon by "a net, external force", not just "a force".
- This is often called the Law of Inertia.
  - Inertia is the tendency of an object to resist a change in state of motion.
    - More simply, inertia is the tendency of an object to resist acceleration.
- Newton's First Law is only valid when measurements are taken from an inertial reference frame.
  - The acceleration of an inertial reference frame is zero.
  - On the AP Physics 1 exam, all reference frames are assumed to be inertial, unless otherwise stated.

<u>Newton's Second Law:</u>

- On the AP Physics equation sheet: $\vec{a}_{sys} = \frac{\sum \vec{F}}{m_{sys}}$
- Expressed how I usually use it: $\sum \vec{F} = m\vec{a}$
  - They are the same equation rearranged.
- The units we typically use for forces are newtons.

- $\sum \vec{F} = m\vec{a} \Rightarrow N = \frac{kg \cdot m}{s^2}$
- When using Newton's Second Law we always have to identify the object or system on which we are summing the forces and the direction in which we are summing the forces.
- Because force and acceleration are vectors, the acceleration of an object is always in the same direction as the net force on the object.
- When an object is in translational equilibrium the net force on the object equals zero.
  - Translational equilibrium means the object is either at rest or moving at a constant velocity because the acceleration of the object equals zero.
    - $\sum \vec{F} = 0 = m\vec{a} \Rightarrow \vec{a} = 0$
  - If an object is at rest, there could be forces acting on the object from other objects, however, the net force acting on the object is zero.

<u>Newton's Third Law:</u>

- Newton's Third Law states that for every force object one exerts on object two, object two exerts an equal but opposite force on object one.
  - $\vec{F}_{12} = -\vec{F}_{21}$ or $\vec{F}_{\text{A on B}} = -\vec{F}_{\text{B on A}}$
  - These two forces act simultaneously.
- Forces internal to a system do not change the motion of the center of mass of the system.

<u>The Gravitational Force:</u>

- The interaction between an object with mass and another object with mass is described by the gravitational force.
  - Realize "gravitational force", "force of gravity", and "weight" mean the same thing.
  - To be clear, because all forces are interactions between two objects, the gravitational force is always between two objects.
- The magnitude of the gravitational force exerted on a mass in a gravitational field is determined using the equation $F_g = mg$.
  - The gravitational force exerted on a mass in a gravitational field is in the same direction as the gravitational field.
    - The term "gravitational field" will be well defined a bit later.
      - More specifically in my [next AP Physics 1 review video](#).
    - In Free Fall $a_y = -g$ and $F_g = mg$, the "*g*" symbols are the same.
  - The direction of the force of gravity on the object is always towards the center of mass of the planet; down.
  - The two objects interacting in this gravitational force equation are the object and the planet causing the gravitational field.
- Inertial mass is the measure of an object's inertia or a measure of its resistance to acceleration.
  - Inertial mass is the mass in Newton's Second Law: $\vec{a} = \frac{\sum \vec{F}}{m}$ or $\sum \vec{F} = m\vec{a}$
- Gravitational mass is the mass used to determine the force of gravity, or weight, of an object.
  - Gravitational mass is the mass is the gravitational force equation: $F_g = mg$
- Inertial mass and gravitational mass are mathematically equivalent.
  - This has been experimentally verified.

The Force of Friction:

- The direction of the force of friction:
  - Is always parallel to the surface
  - always opposes sliding motion
  - is independent of the direction of the force applied
- The equation for the force of friction as given on the equation sheet is: $\left|\vec{F}_f\right| \leq \mu \left|\vec{F}_N\right|$
  - The coefficient of friction, μ:
    - is a ratio of the maximum force of friction and the force normal:

      $$\left|\vec{F}_f\right| \leq \mu \left|\vec{F}_N\right| \Rightarrow \mu = \frac{\left|\vec{F}_{f_{\max}}\right|}{\left|\vec{F}_N\right|}$$
    - has no units
    - cannot be negative
    - typical value are between and 2
    - is experimentally determined
  - For Kinetic Friction: $F_{kf} = \mu_k F_N$
    - Kinetic friction is when the two surfaces are sliding relative to one another.
  - For Static Friction: $F_{sf} \leq \mu_s F_N$
    - 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 maximum force of static friction which would prevent an object from sliding on a surface is:
      - $F_{sf_{\max}} = \mu_s F_N$
  - For two surfaces, the coefficient of static friction is almost always more than the coefficient of kinetic friction.
    - It takes more force to put an object into motion than it takes to keep an object moving.
- The force of friction does not depend on the size of the surface area of contact between the two surfaces.

Force on Objects on Inclines:

- Before summing the forces on an object on an incline, typically we will break the force of gravity into its components which are parallel and perpendicular to the incline.
- The force of gravity perpendicular: $F_{g_\perp} = mg\cos\theta$
- The force of gravity parallel: $F_{g_\parallel} = mg\sin\theta$
  - The force of gravity parallel to an incline is always directed down the incline.