BIG PICTURE IDEAS

#1) *Weight*: Weight is synonymous with (or the same as) the force of gravity.

#2) *The Force of Friction*: The two types of friction between two surfaces are static friction and kinetic friction.

#3) *Newton's Three Laws:* Newton's Three Laws are about the motion of objects.

#4) *Free Body Diagrams or Force Diagrams:* Free Body Diagrams show all the forces which act on objects.

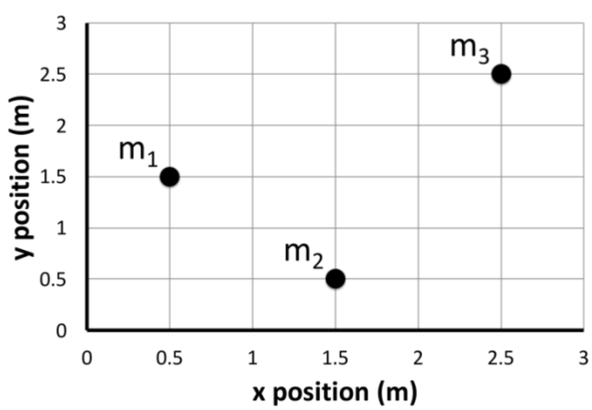
Topic 2.1 – Systems and Center of Mass

1) A collection of objects is called a system.
2) Objects are treated as having no internal structure.
3) A collection of particles in which the particles have little or no interaction are treated as an object.
4) The center of mass of a system of particles can be found using the equation: $\vec{x}_{cm} = \dfrac{\sum m_i \vec{x}_i}{\sum m_i}$
5) The displacement, velocity, and acceleration of a system all refer to the center of mass of the system.
6) The y-position center of mass of this three-particle system where $m_1 = 1$ kg, $m_2 = 2$ kg, and $m_3 = 3$ kg, is:

$$\vec{y}_{cm} = \frac{\sum m_i \vec{y}_i}{\sum m_i} = \frac{m_1 y_1 + m_2 y_2 + m_3 y_3}{m_1 + m_2 + m_3}$$

$$\Rightarrow \vec{y}_{cm} = \frac{(1)(1.5) + (2)(0.5) + (3)(2.5)}{(1) + (2) + (3)}$$

$$\Rightarrow \vec{y}_{cm} = 1.\overline{6}m \approx 1.67m$$



Topic 2.2 – Forces and Free Body Diagrams

1) All forces are vectors, not scalars. That means all forces have both magnitude and direction.
2) All forces are the result of an interaction between two objects.
3) An object cannot exert a force on itself.
4) Free Body Diagrams show all the forces acting on an object. Examples of vectors which are never in free body diagrams are displacement, velocity, acceleration, momentum, impulse, angular momentum, torque, etc.
5) All the forces drawn in a free body diagram start at the center of mass of the object or system.

Topic 2.2 – Forces and Free Body Diagrams (continued)

6) Five steps to help solve any free body diagram problem are:
   a) Draw the free body diagram.
   b) Break forces into components.
   c) Redraw the free body diagram.
   d) Sum the forces.
   e) Sum the forces in a direction which is perpendicular to the direction in step 4.
7) On the AP Physics Exam, we should never break forces into components in our initial free body diagram.
8) The force normal caused by a surface is always perpendicular to the surface and pushes away from that surface.

Topic 2.3 – Newton's Third Law

1) 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.
2) The equation form of Newton's Third Law is: $\vec{F}_{12} = -\vec{F}_{21}$ or $\vec{F}_{\text{A on B}} = -\vec{F}_{\text{B on A}}$
3) Forces internal to a system do not change the motion of the center of mass of the system.
4) When looking at the force of tension in a rope, string, cable, chain, or something similar:
   a) If the rope is ideal, it has negligible mass and does not stretch.
   b) The magnitude of the force of tension in an ideal rope is the same at all points in the rope.
   c) If the rope does not have negligible mass, the force of tension may not be the same at all points in the rope.
   d) The force of tension is always parallel to the direction of the rope, wire, string, or cable.
5) An ideal pulley has negligible mass and rotates around its center of mass with negligible friction.

Topic 2.4 – Newton's First Law

1) Newton's First Law, which is also called the Law of Inertia states that … 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.
2) Newton's First Law can only be verified from an inertial reference frame.
   a) The acceleration of an inertial reference frame is zero.

Topic 2.5 – Newton's Second Law

1) Newton's Second Law is an equation. That equation is $\vec{a}_{sys} = \frac{\sum \vec{F}}{m_{sys}}$ or $\sum \vec{F} = m\vec{a}$

2) The units for force are newtons which, in base S.I. units are $\frac{kg \cdot m}{s^2}$.
   a) A simple way to remember this is using Newton's Second Law.
3) 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.
4) An object in translational equilibrium has zero net force acting on it. Due to Newton's Second Law, this means the acceleration of the object is zero; therefore, the object is either at rest or moving with a constant velocity.
5) The phrase "unbalanced forces" refers to a situation where the net force exerted on a system is not equal to zero.
6) The acceleration of an object is always in the same direction as the net force on the object.
7) If an object is accelerating, the net force acting on the object cannot be zero.
8) 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.

Topic 2.6a – Gravitational Force

1) The interaction between an object with mass and another object with mass is described by the gravitational force.♦
   a) To be clear, because all forces are interactions between two objects, the gravitational force is always between two objects.
2) The magnitude of the gravitational force exerted on a mass in a gravitational field is determined using the equation $F_g = mg$
3) The gravitational force exerted on a mass in a gravitational field is in the same direction as the gravitational field.
4) The magnitude of the gravitational field is determined by taking the weight or force of gravity of the object and dividing it by its mass. $g = \frac{F_g}{m}$
   a) Gravitational field is defined in unit 2b.
5) The direction of the force of gravity acting on the object is always towards the center of mass of the planet or down.
6) 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.

♦ The terms "gravitational force" and "force of gravity" mean the same thing.

Topic 2.6a – Gravitational Force (continued)

a) Five examples of contact forces are: force of tension, force of friction, force normal, force applied, and the spring force.

7) Inertial mass is the measure of an object's inertia or a measure of its resistance to acceleration.

a) Inertial mass is the mass in Newton's Second Law which is: $\sum \vec{F} = m\vec{a}$ or $\vec{a} = \frac{\sum \vec{F}}{m}$

8) Gravitational mass is the mass used to determine the force of gravity, or weight, of an object.

a) Gravitational mass is the mass in the gravitational force equation which is: $F_g = mg$

9) Inertial mass and gravitational mass are mathematically equivalent. This has been experimentally verified.

Topic 2.7 – Kinetic and Static Friction

1) The direction of the force of friction always parallel to the surface, always opposes sliding motion, and is independent of the direction of the force applied.

2) The equation for the force of kinetic friction is: $F_{kf} = \mu_k F_N$

3) The equation for the force of static friction is: $F_{sf} \leq \mu_s F_N$

4) The maximum force of static friction which would prevent an object from sliding on a surface is: $F_{sf_{max}} = \mu_s F_N$

5) For two surfaces, the coefficient of kinetic friction is almost always less that the coefficient of static friction.

6) The force of friction does not depend on the size of the surface area of contact between the two surfaces.

7) Before summing the forces on an object on an incline, typically we will break the force of gravity into its components into directions which are parallel and perpendicular to the incline.

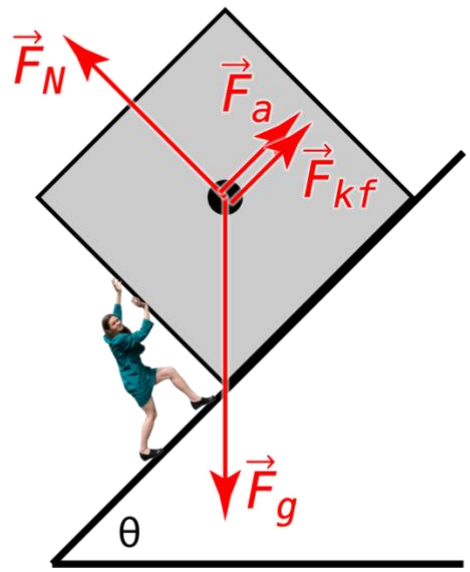
8) The force of gravity perpendicular to an incline equals mass times acceleration due to gravity times the cosine of the incline angle. $F_{g_\perp} = mg\cos\theta$

9) The force of gravity parallel to an incline equals mass times acceleration due to gravity times the sine of the incline angle.
$F_{g_\parallel} = mg\sin\theta$

a) The force of gravity parallel to an incline is always directed down the incline.

Topic 2.7 – Kinetic and Static Friction (continued)

10) The very large block on the incline shown to the right is being lowered down the incline at a constant velocity by the person. The person is pushing on the block, up and parallel to the incline. On the center of mass of the block, draw and label all the forces acting on the block with proportionally correct vector lengths.
(In other words, make sure the force vector lengths are correct relative to one another.)



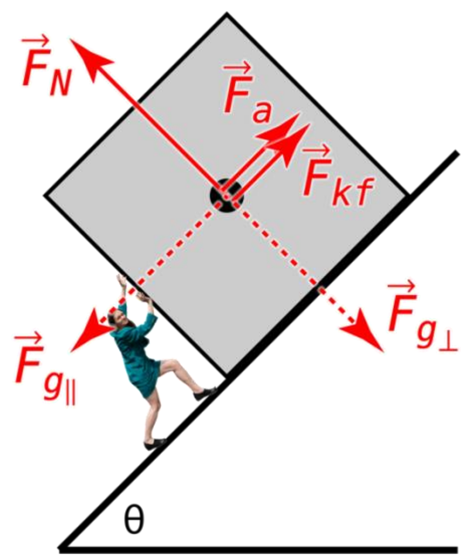
We know the force of friction is kinetic because the block is sliding relative to the incline. We know the direction of the force of kinetic friction because it is parallel to the incline and opposes the sliding motion of the block, therefore, because the block is moving down the incline, the force of kinetic friction is up the incline.

Remember to not break forces into components on answers!

Notes on how to draw vector lengths:

- Because the block is moving at a constant velocity, the acceleration of the block is zero in all directions, therefore the net force acting on the block in all direction equals zero.
- When I redraw the free body diagram with the components of the force of gravity, it is easier to see that the net force in the perpendicular direction is zero: $\sum F_{\perp} = F_N - F_{g_{\perp}} = 0$
  - And the net force in the parallel direction is zero:

$$\sum F_{\parallel} = F_a + F_{kf} - F_{g_{\parallel}} = 0$$



- We do not know the relative lengths of F_a and F_{kf} , however, we do know that the two, when added together, have the same magnitude as $F_{g_{\parallel}}$:

$$\Rightarrow F_a + F_{kf} = F_{g_{\parallel}}$$

  - In other words, you can draw F_a and F_{kf} with pretty much any length you want to as long as the lengths of F_a and F_{kf} add up to the length of $F_{g_{\parallel}}$.