Unit 3: Newtonian Mechanics – Newton's Laws

OBJECTIVES:

We will continue to reinforce the all topics explored previously.[1]

Big Idea 1: Objects and systems have properties such as mass and charge. Systems may have internal structure.

Enduring Understanding 1.A: The internal structure of a system determines many properties of the system.

> *Essential Knowledge 1.A.5: Systems have properties determined by the properties and interactions of their constituent atomic and molecular substructures. In AP Physics, when the properties of the constituent parts are not important in modeling the behavior of the macroscopic system, the system itself may be referred to as an object.*
>
> > *Learning Objective 1.A.5.1: The student is able to model verbally or visually the properties of a system based on its substructure and to relate this to changes in the system properties over time as external variables are changed.*
> >
> > Learning Objective 1.A.5.2: The student is able to construct representations of how the properties of a system are determined by the interactions of its constituent substructures.
> >
> > Essential Knowledge 5.A.1: A system is an object or a collection of objects. The objects are treated as having no internal structure.

Essential Understanding 1.C: Objects and systems have properties of inertial mass and gravitational mass that are experimentally verified to be the same and that satisfy conservation principles.

> Essential Knowledge 1.C.1: Inertial mass is the property of an object or system that determines how its motion changes when it interacts with other objects or systems.
>
> > Learning Objective 1.C.1.1: The student is able to **design an experiment** for collecting data to determine the relationship between the net force exerted on an object, its inertial mass, and its acceleration.
>
> Essential Knowledge 1.C.2: Gravitational mass is the property of an object or a system that determines the strength of the gravitational interaction with other objects, systems, or gravitational fields.
>
> a. The gravitational mass of an object determines the amount of force exerted on the object by a gravitational field.
>
> b. Near the Earth's surface, all objects fall (in a vacuum) with the same acceleration, regardless of their inertial mass.
>
> Essential Knowledge 1.C.3: Objects and systems have properties of inertial mass and gravitational mass that are experimentally verified to be the same and that satisfy conservation principles.
>
> > Learning Objective 1.C.3.1: The student is able to **design a plan** for collecting data to measure gravitational mass and to measure inertial mass and to distinguish between the two experiments.

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[1] Specific objectives that are repeated here from previous topics are italicized.

Essential Knowledge 1.C.4: In certain processes, mass can be converted to energy and energy can be converted to mass according to $E = mc^2$, the equation derived from the theory of special relativity.[2]

Big Idea 2: Fields existing in space can be used to explain interactions.

Enduring Understanding 2.A: A field associates a value of some physical quantity with every point in space. Field models are useful for describing interactions that occur at a distance (long-range forces) as well as a variety of other physical phenomena.

Essential Knowledge 2.A.1: A vector field gives, as a function of position (and perhaps time), the value of a physical quantity that is described by a vector.

a. Vector fields are represented by field vectors indicating direction and magnitude.

b. When more than one source object with mass *or electric charge* is present, the field value can be determined by vector addition.

c. Conversely, a known vector field can be used to make inferences about the number, relative size, and location of sources.

Essential Knowledge 2.A.2: A scalar field gives, as a function of position (and perhaps time), the value of a physical quantity that is described by a scalar. *This should include electric potential.*

a. Scalar fields are represented by field values.

b. When more than one source object with mass *or charge* is present, the scalar field value can be determined by scalar addition.

c. Conversely, a known scalar field can be used to make inferences about the number, relative size, and location of sources.

Enduring Understanding 2.B: A gravitational field is caused by an object with mass.

Essential Knowledge 2.B.1: A gravitational field $\vec{g}$ at the location of an object with mass m causes a gravitational force of magnitude mg to be exerted on the object in the direction of the field.

a. On Earth, this gravitational force is called weight.

b. The gravitational field at a point in space is measured by dividing the gravitational force exerted by the field on a test object at that point by the mass of the test object and has the same direction as the force.

c. If the gravitational force is the only force exerted on the object, the observed free-fall acceleration of the object (in meters per second squared) is numerically equal to the magnitude of the gravitational field (in N/kg) at that location.

Learning Objective 2.B.1.1: The student is able to apply $\vec{F} = m\vec{g}$ to calculate the gravitational force on an object with mass to calculate the gravitational force on an object with mass m in a gravitational field of strength g in the context of the effects of a net force on objects and systems.

[2] We will revisit this.

Essential Knowledge 2.B.2: The gravitational field caused by a spherically symmetric object with mass is radial and, outside the object, varies as the inverse square of the radial distance from the center of that object.

a. The gravitational field caused by a spherically symmetric object is a vector whose magnitude outside the object is equal to $G\frac{M}{r^2}$.

b. Only spherically symmetric objects will be considered as sources of the gravitational field.

Learning Objective 2.B.2.1: The student is able to apply $g = G\frac{M}{r^2}$ to calculate the gravitational field due to an object with mass M, where the field is a vector directed toward the center of the object of mass M.

Learning Objective 2.B.2.2: The student is able to approximate a numerical value of the gravitational field (g) near the surface of an object from its radius and mass relative to those of the Earth or other reference objects.

Big Idea 3: The interactions of an object with other objects can be described by forces.

Enduring Understanding 3.A.: All forces share certain common characteristics when considered by observers in inertial reference frames.

Essential Knowledge 3.A.2: Forces are described by vectors.

a. Forces are detected by their influence on the motion of an object.

b. Forces have magnitude and direction.

Learning Objective 3.A.2.1: The student is able to represent forces in diagrams or mathematically using appropriately labeled vectors with magnitude, direction, and units during the analysis of a situation.

Essential Knowledge 3.A.3: A force exerted on an object is always due to the interaction of that object with another object.

a. An object cannot exert a force on itself.

b. Even though an object is at rest, there may be forces exerted on that object by other objects.

c. The acceleration of an object, but not necessarily its velocity, is always in the direction of the net force exerted on the object by other objects.

Learning Objective 3.A.3.1: The student is able to analyze a scenario and make claims (develop arguments, justify assertions) about the forces exerted on an object by other objects for different types of forces or components of forces.

Learning Objective 3.A.3.2: The student is able to challenge a claim that an object can exert a force on itself.

Learning Objective 3.A.3.3: The student is able to describe a force as an interaction between two objects and identify both objects for any force.

Learning Objective 3.A.3.4: The student is able to make claims about the force on an object due to the presence of other objects with the same property: mass, electric charge.

Essential Knowledge 3.A.4: If one object exerts a force on a second object, the second object always exerts a force of equal magnitude on the first object in the opposite direction.

Learning Objective 3.A.4.1: The student is able to construct explanations of physical situations involving the interaction of bodies using Newton's third law and the representation of action-reaction pairs of forces.

Learning Objective 3.A.4.2: The student is able to use Newton's third law to make claims and predictions about the action-reaction pairs of force when two objects interact.

Learning Objective 3.A.4.3: The student is able to analyze situations involving interactions among several objects by using free-body diagrams that include the application of Newton's third law to identify forces.

Enduring Understanding 3.B: Classically, the acceleration of an object interacting with other objects can be predicted by using $\vec{a} = \frac{\vec{F}}{m}$.

Essential Knowledge 3.B.1: If an object of interest interacts with several other objects, the net force is the vector sum of the individual forces.

Learning Objective 3.B.1.1: The student is able to predict the motion of an object subject to forces exerted by several objects using an application of Newton's second law in a variety of physical situations with acceleration in one dimension.

Learning Objective 3.B.1.2: The student is able **to design a plan** to collect and analyze data for motion (static, constant, or accelerating) from force measurements and carry out an analysis to determine the relationship between the net force and the vector sum of the individual forces.

Learning Objective 3.B.1.3: The student is able to re-express a free-body diagram representation into a mathematical representation and solve the mathematical representation for the acceleration of the object.

Learning Objective 3.B.1.4: The student is able to predict the motion of an object subject to forces exerted by several objects using an application of Newton's second law in a variety of physical situations.

Essential Knowledge 3.B.2: Free-body diagrams are useful tools for visualizing forces being exerted on a single object and writing the equations that represent a physical situation.

a. An object can be drawn as if it was extracted from its environment and the interactions with the environment identified.

b. A force exerted on an object can be represented as an arrow whose length represents the magnitude of the force and whose direction shows the direction of the force.

c. A coordinate system with one axis parallel to the direction of the acceleration simplifies the translation from the free-body diagram to the algebraic representation.

Learning Objective 3.B.2.1: The student is able to create and use free-body diagrams to analyze the physical situations to solve problems with motion qualitatively and quantitatively.

Essential Knowledge 3.B.3: *This objective deals with restoring force and simple harmonic motion. We will mention restoring force here but won't cover the bulk of this objective until a later unit.*

Enduring Understanding 3.C: At the macroscopic level, forces can be categorized as either long-range (action-at-a-distance) forces or contact forces.

Essential Knowledge 3.C.1: Gravitational force describes the interaction of one object that has mass with another object that has mass.

a. The gravitational force is always attractive.

b. The magnitude of force between two spherically symmetric objects of mass m_1 and m_2 is… $G\frac{m_1 m_2}{r^2}$ where r is the center-to-center distance between the objects.

c. In a narrow range of heights above the Earth's surface, the local gravitational field, g, is approximately constant.

Essential Knowledge 3.C.4: Contact forces result from the interaction of one object touching another object, and they arise from inter-atomic electric forces. These forces include tension, friction, normal, spring, *and buoyant*.

Learning Objective 3.C.4.1: The student is able to make claims about various contact forces between objects based on the microscopic cause of those forces.

Learning Objective 3.C.4.2: The student is able to explain contact forces (tension, friction, normal, buoyant, spring) as arising from inter-atomic electric forces and that they therefore have certain directions.

Enduring Understanding 3.G: Certain types of forces are considered fundamental.

Essential Knowledge 3.G.1: Gravitational forces are exerted at all scales and dominate at the largest distance and mass scales.

Learning Objective 3.G.1.1: The student is able to articulate situations when the gravitational force is the dominant force and when the electromagnetic, weak, and strong forces can be ignored.

Learning Objective 3.G.1.2: The student is able to connect the strength of the gravitational force between two objects to the spatial scale of the situation and the masses of the objects involved and compare that strength to other types of forces.

Essential Knowledge 3.G.2: Electromagnetic forces are exerted at all scales and can dominate at the human scale. (more later)

Essential Knowledge 3.G.3: The strong force is exerted at nuclear scales and dominates the interactions of nucleons.

Learning Objective 3.G.3.1: The student is able to identify the strong force as the force that is responsible for holding the nucleus together.

Big Idea 4: Interactions between systems can result in changes in those systems.

Enduring Understanding 4.A: The acceleration of the center of mass of a system is related to the net force exerted on the system, where $\vec{a} = \frac{\vec{F}}{m}$.

Essential Knowledge 4.A.1: The linear motion of a system can be described by the displacement, velocity, and acceleration of its center of mass.

Learning Objective 4.A.1.1: The student is able to use representations of the center of mass of an isolated two-object system to analyze the motion of the system qualitatively and semi-quantitatively.

Essential Knowledge 4.A.2: The acceleration is equal to the rate of change of velocity with time, and velocity is equal to the rate of change of position with time.

a. The acceleration of the center of mass of a system is directly proportional to the net force exerted on it by all objects interacting with the system and inversely proportional to the mass of the system.

b. Force and acceleration are both vectors, with acceleration in the same direction as the net force.

Learning Objective 4.A.2.1: The student is able to make predictions about the motion of a system based on the fact that acceleration is equal to the change in velocity per unit time, and velocity is equal to the change in position per unit time.

Learning Objective 4.A.2.2: The student is able to evaluate using given data whether all the forces on a system or whether all the parts of a system have been identified. (quantitative)

Learning Objective 4.A.2.3: The student is able to create mathematical models and analyze graphical relationships for acceleration, velocity, and position of the center of mass of a system and use them to calculate properties of the motion of the center of mass of a system.

Essential Knowledge 4.A.3: Forces that systems exert on each other are due to interactions between objects in the systems. If the interacting objects are parts of the same system, there will be no change in the center-of-mass velocity of that system.

Learning Objective 4.A.3.1: The student is able to apply Newton's second law to systems to calculate the change in the center-of-mass velocity when an external force is exerted on the system.

Learning Objective 4.A.3.2: The student is able to use visual or mathematical representations of the forces between objects in a system to predict whether or not there will be a change in the center-of-mass velocity of that system.

GUIDED NOTES

NOTES:

I. **Introduction: The interactions of an object with other objects can be described by forces. Forces are detected by their influence on the motion of an object. All forces share certain common characteristics when considered by observers in inertial reference frames.**

A. _______________

1. A ____________________
2. Symbol:
3. SI Unit:

** A Newton is equal to_____________. From this, what do you think the formula is to determine force on an object?

B. Certain types of ____________ are considered __________________.

1. ________________________________ are ____ and _________________ at the ______________________________________ scales.

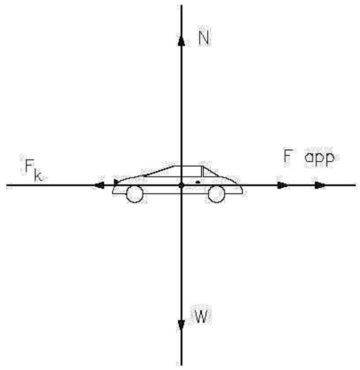
2. ________________________________ are ____ and can _________________ at the ________________scale.

- *What do you think this means?*

3. ________________________________ is ____ and _________________ at the ______________________________________. It _____________ ____________________________ to ____.

<u>Learning Objective 3.G.1.1</u>: The student is able to articulate situations when the gravitational force is the dominant force and when the electromagnetic, weak, and strong forces can be ignored.

C. _______________________________________: A sketch in which all of the external force vectors acting on an object are shown. For example,



II. Contact Forces v. Field Forces

A. At the macroscopic level, forces can be categorized as either long-range (action-at-a-distance) forces or contact forces.

B. _________________________________ result from the interaction of one object ___________________ another object, and they ____ ________________________________. These forces include ________________, _______________, ________________, _______________, and _______________.[3]

C. _________________________________ _________________________________.

1. ***Big Idea 2: Fields existing in space can be used to explain interactions.***

2. **All fundamental forces are field forces.**

3. **A field associates a value of some physical quantity with every point in space.** Field models are useful for describing interactions that occur at a distance (long-range forces) as well as a variety of other physical phenomena. [Click here for an example.]

- A ___________________________ gives as a function of position (and perhaps time) the value of a physical quantity that is described by a vector.

  a. Vector fields are ____ indicating direction and magnitude.

  b. When more than one source object with mass or electric charge is present, the field value ____.

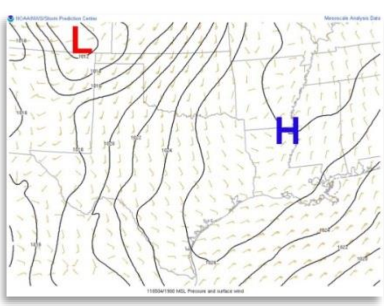
  c. Conversely, a known vector field can be used to make inferences about the number, relative size, and location of ___________. (In other words, _________________________.)

  d. Examples: (next page)

[3] We won't deal with the buoyant force until our unit on fluid mechanics.

- Example 1: An astronaut floats halfway between two moons or essentially equal mass that orbit at different distances between a large planet. Assume the astronaut is close enough to the planet that she is pulled more strongly toward the planet than toward either moon. Draw the vector field at the location of the astronaut as well as at one other location in the field. Also sketch (in a dotted line) the resultant vector field at each of your two locations.

- Example 2: Draw a vector field with three arrows originating at one location. Then generate an inference about the number, relative size, and location of the sources of the field.



- These processes can also be applied to scalar values, such as energy and pressure. For example, a weather pressure map is a scalar field.

III. Gravitational Force and Gravitational Field

A. ___________________________ _____________ describes the interaction of ________________ that has mass _________________________________that has mass.

1. The gravitational force is _________________________________.

2. The magnitude of force between two spherically symmetric objects of mass m_1 and m_2 is…

where…

- $\boldsymbol{G}$ is the gravitational constant equal to $\boldsymbol{6.67\ x\ 10^{-11}\ N \cdot m^2/kg^2}$
- r is the __________________________________ distance between the objects.

3. Examples:

- Example 2: The average center-to-center distance between Earth and the moon is 3.9E8m. The mass of Earth is 5.97E24kg, and the mass of the moon is 7.35E22kg. What is the magnitude of the gravitational force between them?

- Example 3: Describe modifications *to the variables* that would create a stronger gravitational pull between Earth and the moon. What modifications to the variables would weaken the gravitational pull. What is the most effective variable modification you could make to strengthen or weaken the gravitational force?

- Example 4: If two protons were as far apart as the Earth and moon, how would their strong nuclear force compare to the gravitational force? How would the electromagnetic force compare?

B. A _______________________________is _______________________________with mass and describes the _______________ of that field on another object in the field. (See #3 below.)

1. A _____________________________________ at the ________________________ of an ____of _________________________to be _____________________________________in the _________________________ of the field such that

where…

- _____________represents the _________________________, a _____________ that points in the direction of the force.
- _____________represents the gravitational ______________________________. (See #2, below.)
- m is the object's mass.

2. Rewritten we get the formula

On Earth, this gravitational force is called _______________. Therefore, putting the two together, we get that the gravitational field is the weight divided by the object's mass. (See #1.)

3. If the gravitational force is the <u>only</u> force exerted on the object, the observed ____ of the object (in meters per second squared) ____ the magnitude of the ____at that _______________. Therefore on Earth,

4. Example 5: Calculate the gravitational force on a 10kg bunch of bananas dangling from a palm tree on some Caribbean island. Next, calculate the tension force required to keep the banana bunch from falling when a farmer pulls down on the bunch with a force of 50N. Be sure to start with a free-body diagram. Finally, describe the system involved in the problem.

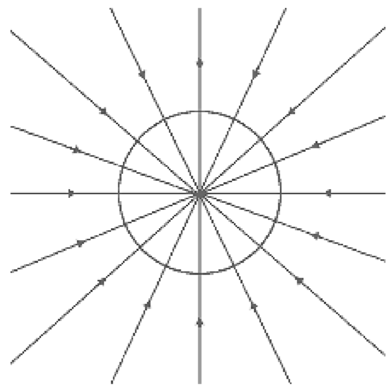
5. Sources of gravitational fields: In this course, we will only consider fields created by spherically symmetrical objects. The gravitational field caused by a spherically symmetric object with mass is radial and outside the object varies as the inverse square of the radial distance from the center of that object such that we also can rewrite the formula for field…

so that

. where…

- _________is considered to be the ________________________the field.
- This last version of the equation is *not* on the formula sheet.

Conceptual breakdown: This represents the strength of a gravitational field created by a mass M at a center-to-center distance r.



Question: Where is the field the strongest/weakest? How does this diagram represent this?

a. <u>Example 6</u>: Calculate the gravitational field created by Earth on its surface. The mass of Earth is 5.97E24kg, and the average radius of Earth is 6.371E6m.

b. <u>Example 7</u>: Approximate a numerical value of the gravitational field on the moon. Moon's mass is 1.2% of Earth's mass, and its radius is 27% of Earth's.

c. Example 8: Approximate a numerical value of the gravitational field near the surface of a denser planet of equal mass to Earth.

6. Final note on gravitational fields: In a narrow range of heights above the Earth's surface, the local gravitational field, g, is approximately constant. For example…

Place	Latitude	Altitude	"g" in m/s^2
North Pole	90^o	0m	9.832
Green Land	70^o	20m	9.825
New York	41^o	38m	9.803
Chicago	42^o	182m	9.803
Denver	40^o	1638m	9.796
Canal Zone	9^o	6m	9.782
Java	6^oSouth	7m	9.782

Why do you think g is greater at the North Pole and less near the equator?[4]

[4] Check out this fun calculator to find the value of g at different locations: http://www.physicsclassroom.com/class/circles/Lesson-3/The-Value-of-g

IV. ____________

A. ____________________________________ have __________________ of ________________________and ________________________that are experimentally verified to be ____________and that satisfy conservation principles.

B________________________ is the __________________of an object or system that __________________ its ________________________when it __________________with ______________________________.

1. Using ______________________________, we can ____________________________ when a ____________________________,

2. **The greater/smaller an object's inertial mass, the more/less force is required to accelerate the object.**

3. Inertial mass can be measured **even in outer space** where gravity is minimal.

C. ___________________________ is the __________________ of an object or a system that ____ with ____.

1. The gravitational mass of an object ____________________________________ ____.

2. **The greater the gravitational mass, the more strongly gravity pulls on the object.**

D. ____.[5]

Both are measured in kg.

- This fact explains why near the Earth's surface, all objects fall (in a vacuum) with the same acceleration, regardless of their inertial mass.

E. ____________________________________: Einstein's theory of special relativity showed that _________ is actually ____________________________________. The amount of energy is equal to the mass multiplied by the speed of light squared according to the famous formula__________________________.

[5] No experiment has proven them to be unequal. Therefore they are considered to be equal.

<u>Big Idea 3</u>: The interactions of an object with other objects can be described by forces.

<u>Big Idea 4</u>: Interactions between systems can result in changes in those systems.

V. ____________________________________

A. Objects ____ that velocity (___________________________) due to being acted on by a ____________________________________

B. ____________________________________: The _________ in which an object ____________________________________[6] because the ___________________ __________________. (**∑F = 0N**)

- Examples at rest…

- Examples in motion…

C. From the learning objectives: *A force exerted on an object is always due to the interaction of that object with another object.* ***An object cannot exert a force on itself.*** *Even though an object is at rest, there may be forces exerted on that object by other objects.* ***The student is able to challenge a claim that an object can exert a force on itself.*** Generate an example to show you can do this.

{From page 60 of the curriculum guide: ***"Internal forces are forces that are exerted between objects in the system, while the external forces are those that are exerted between the system's objects and objects outside of the system. Internal forces do not affect the motion of the center of mass of the system."****}*

[6] **Maintaining velocity means BOTH magnitude and direction.**

VI. ___________________________________

A. When a ____,

____according to the relationship:

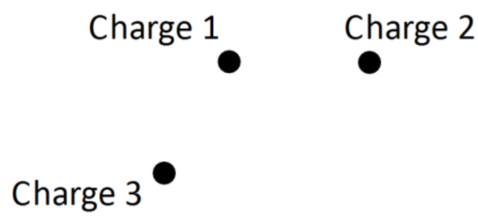
The _________________ of an object, ___________________________________,

is ___________________________________exerted on the object by other objects.

- What do you think is meant by “but not necessarily its velocity?” Write out an explanation of this in a narrative form.

1. Example 9: Two objects at rest become electrically attracted to each other. Object A has a mass of 0.5kg, and Object B has a mass of 0.3kg. They are 0.25m apart. If the force between them is 10.0 N…
   a. What is the acceleration of the center of mass of Object A?
   b. What is the acceleration of the center of mass Object B?
   c. Where will they meet? (Assume they act as particles located at their centers of mass.)
   d. Describe the motion of the center of mass of the *system* as Object A and Object B interact. Justify your answer narratively.

2. <u>Example 10</u>: Three charges, each with a mass of 3E-6kg, exert forces on each other. Charge 1 experiences a force of 2E-3N to the right caused by attraction to Charge 2. Charge 1 also experiences a force of 4E-3N at an angle of 65° above right caused by repulsion from Charge 3. None of the forces is fixed in place.



a. Create a free-body diagram to represent these forces.

b. Predict qualitatively the direction of the acceleration as accurately as you can.

c. Calculate the net force and acceleration of the center of mass of Charge 1.

d. Explain why the center of mass of the *system* does not accelerate even as Charge 1 moves.

e. How can you look at this from an inertial reference frame? A non-inertial reference frame?

B. Special Topic: Types of Forces

1. ____________________________

a. The force ____________________________on a surface ___________________ to the surface.

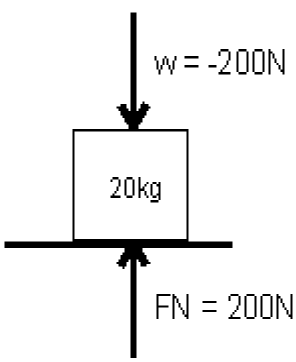
b.

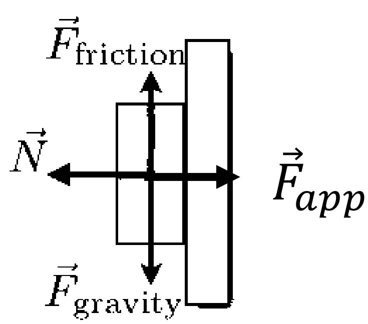
(This is not on the formula sheet.)

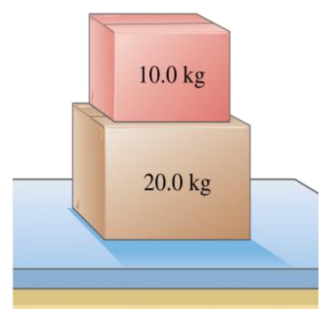
c. When an ________________________ is applied to the object against the surface, the ______________________ of that applied force that is _____________________ to the surface ______________________ to the normal force equation, such that

(This is definitely not on the formula sheet. It's conceptual.)

d. For each of the following situations, qualitatively analyze the normal force on each object.







2. ____________________________

   a. A force _____________________________________an object such as a rope

   b. $\vec{F}_T$ is often found by analyzing free-body diagrams.

   c. Example 11: Two masses hang from a rigid wheel as shown below. Mass 1 is 2kg, and mass 2 is 4kg. The wheel can be assumed to be supported by sturdy attachment from above so that the wheel does not fall.

      a. Which way will the center of mass of the system of the two masses move? Justify your answer.

      b. Draw a free-body diagram for each of the masses as well as for the rigid wheel. (Don't worry yet about how large to make the tension vectors.)

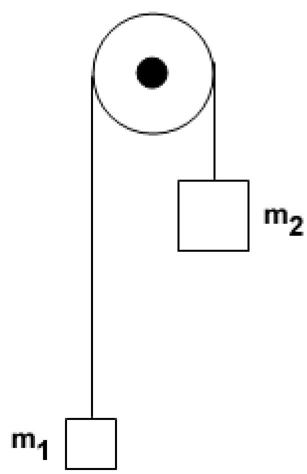
      c. What is the net force on the system of the two masses (ignoring the wheel)?

      d. What must be the acceleration of the center of mass of the system of the two masses as they pass over the wheel?

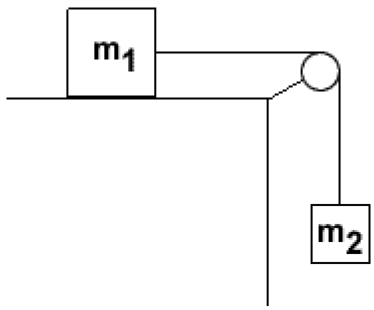
      e. Therefore what is the net force on mass 1? On mass 2?

      f. Therefore what is the tension in the string above mass 1? Above mass 2?

      g. How do the tensions compare? Generate a narrative explanation.



d. Example 12: Two masses are attached across a pulley mounted to the end of a table as shown below. Mass m_1 is 4 times more massive than mass m_2. Repeat all of the previous questions from example 11. Assume that friction is negligible. (You do not need to draw a free-body diagram for the pulley.) *Put all answers in terms of m_2 and g.*



e. <u>Example 13</u>: A child pulls a cord (assume perfectly horizontally) on a train toy that has 4 train cars attached in a row. How does the acceleration of the center of mass of the system compare to the motion of each car? Design a problem to explain why the force accelerating each car is different from the force on every other car, and all are different from the tension force on the cord. Analyze narratively what the effect, if any, the force of one car on the next car has on the motion of the center of mass of the system.

INTERMISSION: If the interacting objects are parts of the same system, there will be no change in the center-of-mass velocity of that system.

B. Special Topic: Types of Forces (continued)

3. ________________

   a. Friction is a force that ________________________to a surface and ________________________.

   b. ________________________

      1.) ________________________________of motion; our concern is with ____ because it tells us how hard we have to push/pull to ____________________________________to move.

      2.) Formula:

      where…

      - ________is the ____, a value that ________________________________of the surfaces.

   c. ________________________

      1.) ________________________________motion.

      2.) Formula:

      where…

      - ________is the ____.

      3.) Specific example: drag (e.g., air resistance)

   d. ________________ friction is ________________ _______________ friction. Therefore it is ________________________to make an object ________ to move ________ to ________ it moving.

Examples on the next page.

e. Examples:

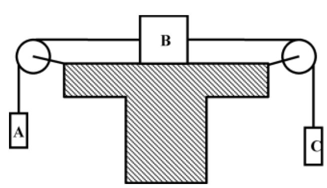
1.) Example 14: Return to example 12. Describe how the situation would change if…

a. The maximum static friction between mass 1 and the table is greater than the weight of mass 2.

b. The maximum static friction between mass 1 and the table is less than the weight of mass 2.

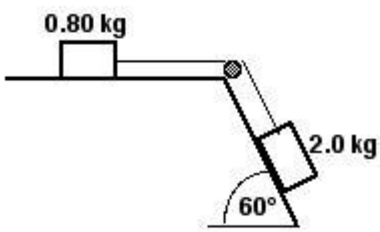
c. Re-answer questions a-g if the coefficient of kinetic friction between mass 1 and the table is 0.2. Assume the system moves. Put all answers in terms of m2 and g.

2.) Example 15: Analyze the situation shown below in which two equal masses, A & C, hang in static equilibrium from mass B via strings that pass over pulleys on a table. What do you think the tension is in the string to the left of mass B? What do you think the tension is in the string to the right of mass B? Justify your answer using mathematical and narrative representations. Then we will test this out in class to see if you are right. ☺



INTERMISSION #2: When an object sits on an inclined surface, there is a component of its weight that is directed downward parallel to the surface. Figure out a general equation that will give you this component in such a situation. You will come up with a very helpful formula that your teacher calls "parallel component of gravity." It is NOT on the formula sheet and is not necessarily going to be recognized by a grader. However, knowing this formula will save you time on a test. (Just be sure to notate carefully what you are doing.)

3.) Example 16: In the situation below, show using free-body diagrams and mathematical analysis what the acceleration of the center of mass of the system would be if the coefficient of static friction between the blocks and the surface is 0.4, and the coefficient of kinetic friction between the blocks and the surface is 0.2. Then explain narratively using full sentences how you could calculate the tension in the string.



C. Special Topic: ________________________

1. Example 17: We have previously examined the motion of falling objects when air resistance was negligible. Now let's consider an object that does experience a meaningful amount of air resistance as it falls. Generate a narrative accompanied by free-body diagrams to explain…

a. What happens to the object's velocity, acceleration, and net force as it *begins* to fall.

b. What happens to the object's velocity, acceleration, and net force as it is midway through its fall.

c. What happens to the object's velocity, acceleration, and net force at a point where the magnitude of the force of air resistance equals the magnitude of the object's weight.

2. When an object falls *in the presence of air resistance*, it no longer free-falls. The upward force of the air resistance reduces downward net force. As the object moves faster and faster, the air resistance builds causing the net downward force to become smaller and smaller. Eventually ____, the ________________________________. The object ________________________and ________________________ whatever ________________ it has attained. This velocity is its maximum falling velocity, called its ________________________.

VII. ____

a. If one object exerts a force on a second object, the ___________________________________ of ________________________________on the first object in the ________________________.

b. Examples:

1. Example 18: A hammer hits a nail, driving the nail into a block of wood.

a. From the perspective of the hammer-nail-wood system, identify all of the forces involved and the results of those forces. Use free-body diagrams as well as narrative representations.

b. Why doesn't this law result in all forces canceling and no acceleration?

- Rule: *Each object ________________only to ________________________________. The hammer experiences a ________________________________from the nail, so the hammer ______________________. The nail experiences a _________________ from the hammer, so it ________________________.*

c. From the perspective of an outside observer looking at the system as a whole, identify all of the forces involved and the results of those forces on the center of mass of the entire system.

- Rule: *Forces ________________ a system can change the motion of the objects within the system but____.*

2. <u>Example 19</u>: Repeat the same questions for a horse-cart-Earth system.

VIII. Example incorporating all of Newton's laws while examining kinematic variables from multiple reference frames for isolated systems with internal structure:

<u>Example 20</u>: A child plays with balls while riding in a compartment of a train car that is moving at 40 m/s in a straight line. She rolls the two balls toward each other in line with the train's motion so that they collide, exerting forces on each other. The red ball has a mass of 0.25 kg, and the yellow ball has a mass of 0.50kg. Relative to the floor of the train, the red ball's velocity just before colliding was 2.2 m/s, while the yellow ball's velocity just before colliding was 1.5 m/s in the opposite direction. The collision takes 0.41 seconds and results in the red ball rolling backward relative to the floor of the train at 1.3 m/s. After the collision the red ball travels 1.4 m before friction stops its motion. Both balls are made of the same material, and the floor is made of the same material throughout the entire car.

1. How much force did the yellow ball exert on the red ball?

2. What was the final velocity of the yellow ball after the collision?

3. What can you discover about the friction on the red ball? Explain semi-quantitatively.

4. Explain semi-quantitatively how you could find the displacement of the yellow ball relative to the floor of the train before the yellow ball stops.

5. So far we have examined the ball's motions relative to an observer in the train car. Consider instead a stationary observer at a train station using superhero vision to watch the balls as the train passes. What would each of the following values look like to this observer?

   a. Initial velocity of each ball

   b. Acceleration of each ball

c. Displacement of each ball after the collision as the balls roll to a stop

d. The motion of center of mass of the ball-ball-train system. (Also analyze how the forces between the balls affect the motion of the center of mass of the ball-ball-train system.)

Wow. We’re done. 👍