GUIDED NOTES

Unit 4: Newtonian Mechanics – Energy

OBJECTIVES

We will continue to reinforce the concepts explored previously.

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

Essential Understanding 2.E: Physicists often construct a map of isolines connecting points of equal value for some quantity related to a field and use these maps to help visualize the field.

Essential Knowledge 2.E.1: Isolines on a topographic (elevation) map describe the lines of approximately equal gravitational potential energy per unit mass (gravitational equipotential.) As the distance between two different isolines decreases, the steepness of the surface increases. [Contour lines on topographic maps are useful teaching tools for introducing the concept of equipotential lines. Students are encouraged to use the analogy in their answers when explaining gravitational end electrical potential and potential difference.]

Learning Objective 2.E.1.1: The student is able to construct or interpret visual representations of the isolines of equal gravitational potential energy per unit mass and refer to each line as a gravitational equipotential.

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

Enduring Understanding 3.E: A force exerted on an object can change the kinetic energy of the object.

Essential Knowledge 3.E.1: The change in the kinetic energy of an object depends on the force exerted on the object and on the displacement of the object during the time interval that the force is exerted.

a. Only the component of the net force exerted on an object parallel or antiparallel to the displacement of the object will increase (parallel) or decrease (antiparallel) the kinetic energy of the object.

b. The magnitude of the change in the kinetic energy is the product of the magnitude of the displacement and of the magnitude of the component of force parallel or antiparallel to the displacement.

c. The component of the net force exerted on an object perpendicular to the direction of the displacement of the object can change the direction of the motion of the object without changing the kinetic energy of the object. This should include uniform circular motion and projectile motion.

Learning Objective 3.E.1.1: The student is able to make predictions about the changes in kinetic energy of an object based on considerations of the direction of the net force on the object as the object moves.

Learning Objective 3.E.1.2: The student is able to use net force and velocity vectors to determine qualitatively whether kinetic energy of an object would increase, decrease, or remain unchanged.

Learning Objective 3.E.1.3: The student is able to use force and velocity vectors to determine qualitatively or quantitatively the net force exerted on an object and qualitatively whether kinetic energy of that object would increase, decrease, or remain unchanged.

Learning Objective 3.E.1.4: The student is able to apply mathematical routines to determine the change in kinetic energy of an object given the forces on the object and the displacement of the object.

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

Enduring Understanding 4.C: Interactions with other objects or systems can change the total energy of a system.

Essential Knowledge 4.C.1: The energy of a system includes its kinetic energy, potential energy, and microscopic internal energy. Examples should include gravitational potential energy, elastic potential energy, and kinetic energy.

Learning Objective 4.C.1.1: The student is able to calculate the total energy of a system and justify the mathematical routines used in the calculation of component types of energy within the system whose sum is the total energy.

Learning Objective 4.C.1.2: The student is able to predict changes in the total energy of a system due to changes in position and speed of objects or frictional interactions within the system.

Essential Knowledge 4.C.2: Mechanical energy (the sum of kinetic and potential energy) is transferred into or out of a system when an external force is exerted on a system such that a component of the force is parallel to its displacement. The process through which the energy is transferred is called work.

a. If the force is constant during a given displacement, then the work done is the product of the displacement and the component of the force parallel or antiparallel to the displacement.

b. Work (change in energy) can be found from the area under a graph of the magnitude of the force component parallel to the displacement versus displacement.

Learning Objective 4.C.2.1: The student is able to make predictions about the changes in the mechanical energy of a system when a component of an external force acts parallel or antiparallel to the direction of the displacement of the center of mass.

Learning Objective 4.C.2.2: The student is able to apply the concepts of conservation of energy and the work-energy theorem to determine qualitatively and/or quantitatively that work done on a two-object system in linear motion will change the kinetic energy of the center of mass of the system, the potential energy of the systems, and/or the internal energy of the system.

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Big Idea 5: Changes that occur as a result of interactions are constrained by conservation laws.
Enduring Understanding 5.A: Certain quantities are conserved, in the sense that the changes of those quantities in a given system are always equal to the transfer of that quantity to or from the system by all possible interactions with other systems.

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 Knowledge 5.A.2: For all systems under all circumstances, energy, charge, linear momentum, and angular momentum are conserved. For an isolated or a closed system, conserved quantities are constant. An open system is one that exchanges any conserved quantity with its surroundings.

Learning Objective 5.A.2.1: The student is able to define open and closed/isolated systems for everyday situations and apply conservation concepts for energy, charge, and linear momentum to those situations.

Essential Knowledge 5.A.3: An interaction can be either a force exerted by objects outside the system or the transfer of some quantity with objects outside the system.

Essential Knowledge 5.A.4: The boundary between a system and its environment is a decision made by the person considering the situation in order to simplify or otherwise assist in analysis.

Enduring Understanding 5.B: The energy of a system is conserved.

Essential Knowledge 5.B.1: Classically, an object can only have kinetic energy since potential energy requires an interaction between two or more objects.

Learning Objective 5.B.1.1: The student is able to set up a representation or model showing that a single object can only have kinetic energy and use information about that object to calculate its kinetic energy.

Learning Objective 5.B.1.2: The student is able to translate between a representation of a single object, which can only have kinetic energy, and a system that includes the object, which may have both kinetic and potential energies.

Essential Knowledge 5.B.2: A system with internal structure can have internal energy, and changes in a system's internal structure can result in changes in internal energy. (This includes mass-spring oscillators, simple pendulums, charged objects in electric fields, and changes in internal energy when configuration changes.)

Learning Objective 5.B.2.1: The student is able to calculate the expected behavior of a system using the object model (i.e., by ignoring changes in internal structure) to analyze a situation. Then, when the model fails, the student can justify the use of conservation of energy principles to calculate the change in internal energy due to changes in internal structure because the object is actually a system.

Essential Knowledge 5.B.3: A system with internal structure can have potential energy. Potential energy exists within a system if the objects within that system interact with conservative forces.
a. The work done by a conservative force is independent of the path taken. The work description is used for forces external to the system. Potential energy is used when the forces are internal interactions between parts of the system.
b. Changes in the internal structure can result in changes in potential energy.

Learning Objective 5.B.3.1: the student is able to describe and make qualitative and/or quantitative predictions about everyday examples of systems with internal potential energy.

Learning Objective 5.B.3.2: The student is able to make quantitative calculations of the internal potential energy of a system from a description or diagram of that system.

Learning Objective 5.B.3.3: The student is able to apply mathematical reasoning to create a description of the internal potential energy of a system from a description or diagram of the objects and interactions in that system.

Essential Knowledge 5.B.4: The internal energy of a system includes the kinetic energy of the objects that make up the system and the potential energy of the configuration of the objects that make up the system.

a. Since energy is constant in a closed system, changes in a system's potential energy can result in changes to the system's kinetic energy.

b. The changes in potential and kinetic energies in a system may be further constrained by the construction of the system.

Learning Objective 5.B.4.1: The student is able to describe and make predictions about the internal energy of systems.

Learning Objective 5.B.4.2: The student is able to calculate changes in kinetic energy and potential energy of a system using information from representations of that system.

Essential Knowledge 5.B.5: Energy can be transferred by an external force exerted on an object or system that moves the object or system through a distance. This process is called doing work on a system. The amount of energy transferred by this mechanical process is called work. Energy transfer in mechanical or electrical systems may occur at different rates. Power is defined as the rate of energy transfer into, out of, or within a system.

Learning Objective 5.B.5.1: The student is able to **design an experiment** and analyze data to examine how a force exerted on an object or system does work on the object or system as it moves through a distance.

Learning Objective 5.B.5.2: The student is able to **design an experiment** and analyze graphical data in which interpretations of the area under a force-distance curve are needed to determine the work done on or by the object or system.

Learning Objective 5.B.5.3: The student is able to predict and calculate from graphical data the energy transfer to or work done on an object or system from information about a force exerted on the object or system through a distance.

Learning Objective 5.B.5.4: The student is able to make claims about the interaction between a system and its environment in which the environment exerts a force on the system, thus doing work on the system and changing the energy of the system (kinetic energy plus potential energy.)

Learning Objective 5.B.5.5: The student is able to predict and calculate the energy transfer to (i.e., the work done on) an object or system from information about a force exerted on the object or system through a distance.

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NOTES

I. Energy Defined

A. Energy is the ____ (____________________)

1. A __________ value

2. SI Unit: __________, equivalent to __________

B. Open & Closed Systems

1. A ____________________ is ____________________and ____ within the system.

2. An ____________________ can ____________________with the _________________.

3. Open and closed systems can also be analyzed in terms of other conserved quantities, such as momentum and charge, that we'll explore in later units.

C. ______________________________:

1. A ____________________ with ______________________________can have internal energy, and ____can result in ______________________________of internal energy within the system.

2. The internal energy of a system ____of the ____________________that make up the system and the ________________________ of the ____that make up the system.

3. _______________________________is energy ____________________ in a system ____within the system.

a. Details:

1.) This energy can be considered "__________" in that it is not actively causing the object to change at a particular moment in time.

2.) ____of a system can result in ____.

3.) The term "potential energy" is used when _______________________________ ____________________of the system. For example, a bird in a nest has potential energy due to the force of gravity within the bird-Earth system.

b. ____: Energy due to ____________________ relative to a ________________________in a ________________________.

1.) Symbol:

2.) Formula:

where…

a.) m is mass

b.) g is acceleration due to gravity, and…

c.) Δy is height

3.) Example 1: A 25.0 kg dog sleeps on a couch that is 0.550 m tall. What is the system? What is the gravitational potential energy of the dog? What is the internal energy of the system?

4.) ________________

a.) Isolines ____for some quantity ________________________________ (in this case an energy field.) Physicists use these lines to help ________________________________.

b.) ____: Isolines on a topographic (elevation) map describe the lines of approximately equal gravitational potential energy per unit mass (gravitational equipotential.)

1.) As the ________________ between two different isolines ________________, the ________________ of the surface ________________.

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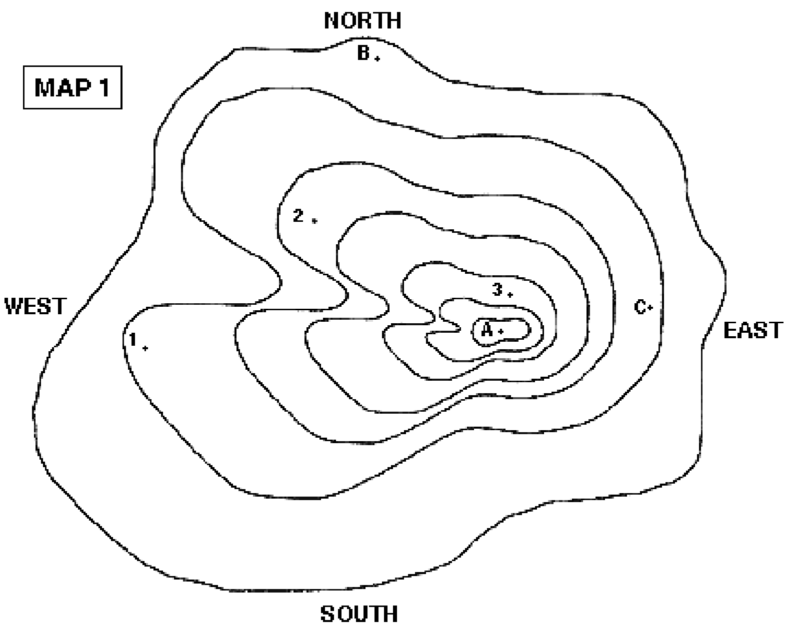
2.) Learning Objective: The student is able to construct or interpret visual representations of the isolines of equal gravitational potential energy per unit mass and refer to each line as a gravitational equipotential….So, try to draw a side view of the mountain whose gravitational potential isolines are shown below. Draw the mountain as viewed from the south.



c. ____: Energy of an ________________________due to its being ______________________________.

1.) Symbol:

2.) Formula:

where…

a.) k is the ___________________ (related to stiffness as measured by ________________________) and

b.) x is the amount the spring is ________________________________ from its ________________position

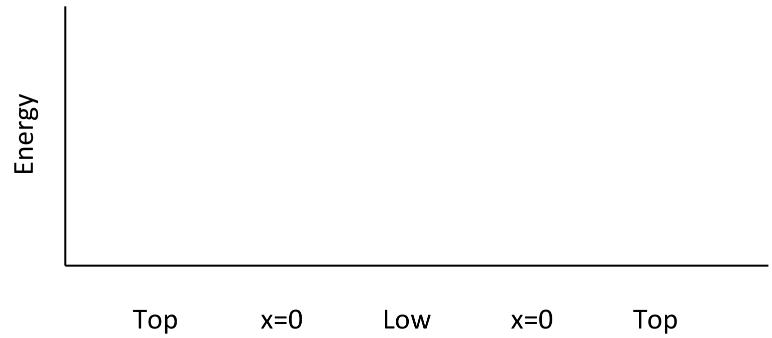
3.) Example 2: A “massless” spring of k = 1.00E2 N/m is stretched 5.00E-2 m from its equilibrium position due to a 20.0g mass hanging from it. Consider ONLY the mass-spring as the system. What is the elastic potential energy of the spring? What’s the internal energy of the system?

4.) Example 3: The same “mass-spring”[1] in example 2 hangs from a hook so that the center of mass of the mass is 2.00m above the ground. What is the system? What is the internal energy of the system from this perspective?

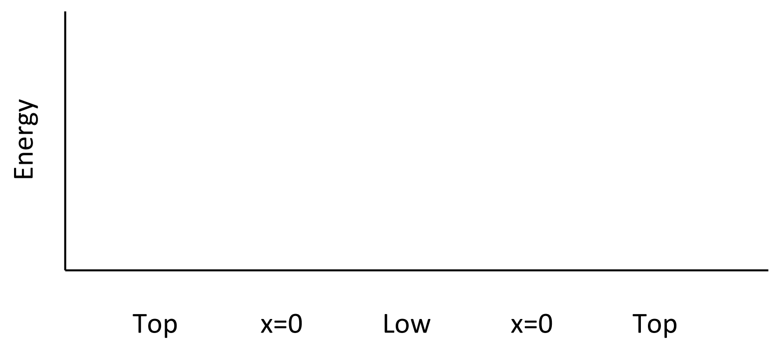
[1] “Mass-spring” means that a mass hangs from a spring.

4. ________________________________: The energy of a ________________ object
   a. Symbol:
   b. Formula:
   c. <u>Example 4</u>: The dog in example 1 rolls off of the couch. (a) As she collides with the fluffy carpet below, what is her kinetic energy? (b) What is her gravitational potential energy? (c) What is the internal energy of the dog-Earth system? (d) What do you think happens to the internal energy when she stops moving? (Answer this last question both from a perspective of the carpet-dog interaction having friction and a perspective of the interaction being friction-free.)
   d. **Note: Can an object have gravitational potential energy by itself? NO.** Classically, considering only gravitational potential energy and kinetic energy, an object can only have kinetic energy, since potential energy requires an interaction between two or more objects. Relate this narratively to our example of the dog:

a. <u>Example 5</u>: The mass-spring-Earth system from examples 2 and 3 bobs up and down. Create an energy-time graph for the mass-spring-Earth system. Plot four lines to represent gravitational potential energy, elastic potential energy, kinetic energy, and internal energy as the mass oscillates. This can be semi-quantitative, meaning that the relationships between the lines should represent the relative amounts of energy, but accurate numbers aren't needed.



NOW WHAT HAPPENS if we consider only the mass-spring system isolated from the Earth? Redraw the graph.



Explanation:

Important detail: The sum of potential and kinetic energies in a system is called the <u>mechanical energy</u> of the system.

II. ________________

A. Work has two related meanings:

1. It is a ________________: ________________ can be ________________________ by an ________________________ exerted on an object or system that ____ through a ________________. This ____ is called ________________________on a system.

2. It is ________ the ________________________________.

B. Calculating Work:

1. Only the ________________________ of the ________ that is ________________to the ________________of the object actually transfers energy.

2. Symbol:

3. Formula:

Where…

a. ΔE is the amount of energy transferred.

b. F is the magnitude of the net force.

c. $F_{\parallel}$ is the component of the force parallel to the motion.

d. θ is the angle between the force and the displacement (motion.)

e. d is the displacement of the center of the mass of the object

4. SI Units:

5. A ________________ value

6. Example 6: A father pushes on the shoulders of his kiddo at an angle of 60 degrees above horizontal to accelerate a 25 kg child on a sled from 0m/s to 2m/s in 2.5 seconds. (a) How much energy transfers? (b) What's the work done? (c) How far does the child move while the father pushes? (d) How much force did the father apply to the child?

7. Example 7: A 2000 kg car moving at 40 m/s undergoes a braking force of 40,000 N as it stops. Describe the work done by the brakes both qualitatively and quantitatively. Be sure to quantify how much energy transfers and how far the car travels before stopping.

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C. Positive/Negative/Zero work done by a force:

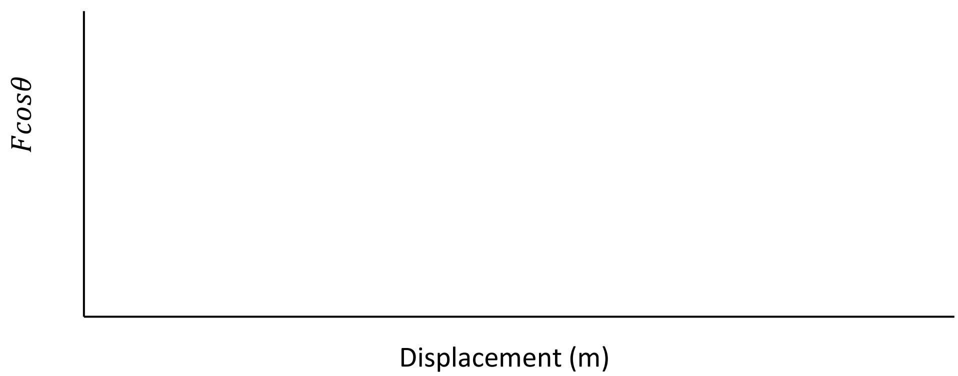
1. _________________ work ________ mechanical energy to the object; occurs when a component of the force is _________________ to the displacement; examples…

2. _________________ work ________ mechanical energy from the object; occurs when a component of the force is a_________________________ to the displacement; examples…

3. _________________ work _________________________the mechanical energy of the object; occurs when __________________________________is _________________ to the displacement ________ when there is _________________________; the force can change the object’s direction but not its energy; examples…

D. ________________v. ________________________ graphs:

1. ________ can be found from the ________________________ of the magnitude of the ________________component ________________to the displacement versus ________________________.



2. This is particularly helpful when the force is not consistent. Generate an example of a variable force. Qualitatively describe a scenario involving this force, narrate it below, and plot a semi-quantitative graph on the axes above.

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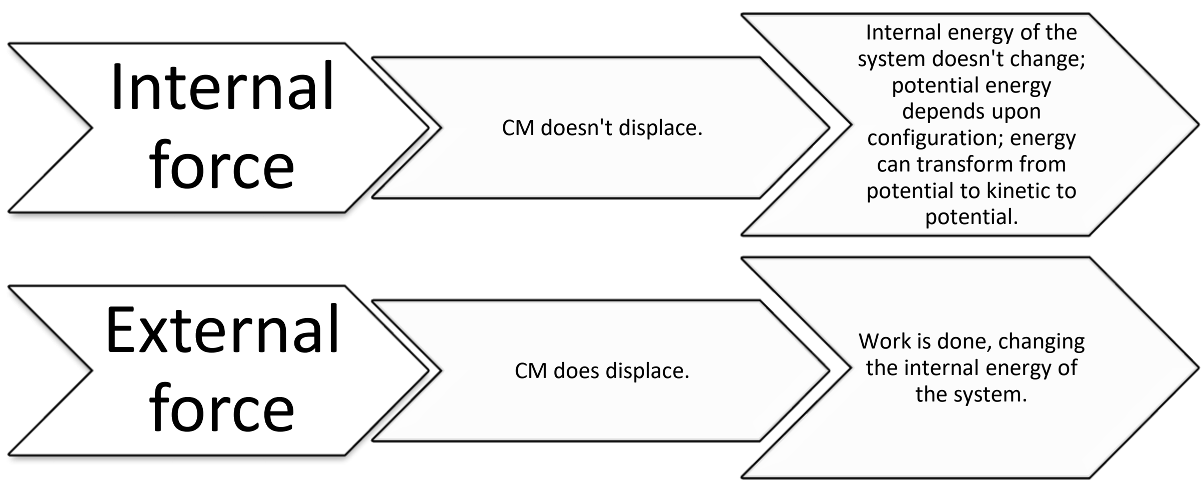
Important detail:

When a force is internal to a system so that the center of mass of the system doesn't displace, the concept of potential energy is appropriate. For example, a dog on a couch interacts via forces with the Earth. As a dog-Earth system, these forces are internal, the cm of the system doesn't displace, and the energy is potential. (Remember Newton's third law…)

When the force is external to a system and causes the center of mass of the system to displace, the concept of work is appropriate. For example, if the dog's owner picks the dog up for a snuggle, the cm of the dog-Earth system shifts upward. The owner did work, and energy transferred to the dog-Earth system.



GUIDED NOTES

III. ________________________________

A. ________________________an object's mechanical energy. Therefore an object may change its ________________________________during the time that work is being done such that

This is not on the formula sheet.

B. Examples:

1. <u>Example 8</u>: Use net force and velocity vectors to show how work can increase the kinetic energy of an object.

2. <u>Example 9</u>: Use net force and velocity vectors to show how work can decrease the kinetic energy of an object.

3. <u>Example 10</u>: Use net force and velocity vectors to show how work can have no effect on the kinetic energy of an object.

4. Example 11: On a roller coaster, a 1500.0 kg rider/cart system is dropped 40.0 m along a track that makes an angle of 70.0° to the ground. The cart experiences 500.0 N of friction and 100N of air resistance. (a) How much work is done by each force? (b) What is the work done on the rider/cart system as it falls? (c)What is the total change in kinetic energy? (d) Use velocity and force vectors and to describe the situation both quantitatively and qualitatively.

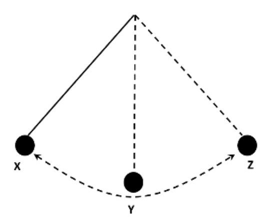
5. Example 12: Assuming the rollercoaster cart in the previous problem began at rest, what is its velocity at the end of the 40.0 m?

6. Example 13: If the track flattens out immediately at the end of the 40.0 m long hill, and if the ride needs to stop in 30.0 m along that flat track, how much braking force is required?

IV. Conservative and Nonconservative Forces: Terms you may come across

A. ________________________________: A force whose ________________done depends on the displacement but ____the object moves. Examples are ________________ and ________________. This concept *is* in the curriculum.

- Example: For a swinging pendulum, the force of gravity (or the force to lift the pendulum) does not depend on the path. Therefore ΔU_g and ΔK only depend on vertical displacement, not actual distance.



B. ________________________________: A force whose work done ____the object moves. Examples are ________________and ________________________. This concept is *not* expressly used in the curriculum, but it could come up.

<u>Big Idea 5</u>: Changes that occur as a result of interactions are constrained by conservation laws.

V. ____

A. The energy of a ________________is conserved. ________________________________act, mechanical ________________________________between objects _____________________, but the ____, and __________________ of the system ________________________.

1. Generate a formula for this.

…Note: This is not on the formula sheet.

2. Generate an example of this qualitatively and semi-quantitatively.

3. <u>Example 14</u>: Consider a closed system in which a machine part that is located above the floor is moving downward on an incline with a rough surface within the machine when, during its normal function, it collides with a spring attached to a rigid metal plate welded within the machine that is on the floor. The machine was mounted to the floor when the collision occurred and does not move during the collision. The spring, initially at equilibrium, compressed during the collision before returning to equilibrium immediately after the collision. (a) Decide how to conceptualize the objects in the system. (b) Sketch a bar graph showing gravitational potential energy, elastic potential energy, kinetic energy, and internal energy before the part began to roll. (c) Sketch a corresponding second set of bars on the graph to represent when the part hit the spring but did not compress it yet. (d) Sketch a corresponding set of bars on the graph showing the same values for the moment the part comes to a stop with the spring at its maximum compression. (e) Sketch a corresponding set of bars on the graph showing the same values for the moment the leaves the spring, and the spring is no longer compressed.

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B. In an ________________________, an interaction in which ________________________is exerted ________________________the system ________________________into or out of the system.

1. How do you know if the system is open or closed? “The boundary between a system and its environment is a decision made by the person considering the situation in order to simplify or otherwise assist in analysis.”
2. When an outside force does work on the system, the mechanical energy of the system changes, and its cm displaces. Generate an example of this.

3. Oftentimes when nonconservative work is done, such as by friction, the system is considered to be open. The formula then becomes...

…Note: This is not on the formula sheet.

4. <u>Example 15</u>: A 1000kg car at rest at the top of a 40m high hill coasts down the hill and up a second hill where it reaches a vertical height of only 25m. The total distance it travels is 400m. Estimate the average kinetic fiction force.

5. Example 16: A person playing pool uses a cue stick to apply a force parallel to a pool table to a cue ball that remains alone on the pool table with one other ball, the eight ball, whose mass is slightly lower than the cue ball's mass. While in contact with the cue, the cue ball displaces a certain distance. Consider the system to contain only the cue ball and the eight ball. (a) Describe qualitatively how the internal energy of the system of the two balls changed when the cue stick struck the cue ball and thereafter. (b) If the cue ball bounces backward upon striking the eight ball, describe semi-quantitatively the gain in kinetic energy of the eight ball. Assume there are no significant nonconservative forces. (c) Describe qualitatively the effect of this collision on the velocity of the cm of the system. (d) Zoom out. Redefine the system to include the cue stick. Revisit questions a-c from this perspective.

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VI. ________________

A. Energy transfer in mechanical or electrical systems may occur at different rates. Power is defined as the ________________________________into, out of, or within a system.

1. Symbol:
2. Formula:

3. Unit:

B. Examples:

1. <u>Example 17</u>: A 70kg jogger jogs up a long flight of stairs in 4.0s with a constant velocity. The vertical height of the stairs is 4.5m. (a) Estimate the jogger's power output (a.k.a. power dissipation.) (b) How much energy did this require?

2. Example 18: Engine A is more powerful than Engine B. Both engines haul identical objects vertically from ground level to the second floor of a factory. Compare the work done by each and the time it takes for each engine to lift its load.

FINAL NOTE: There is a formula on the formula sheet that is not expressly mentioned in the curriculum. (At least your teacher can't find it!) The formula is

$$U_G = -\frac{Gm_1m_2}{r}$$

(All variables are the same as with the gravitational force equation.)

Here's what it means.

Consider a planet. Usually we use the surface of the planet as the reference point for measuring a gravitational potential energy of zero. This new formula looks at it from another perspective: At an infinite distance from the planet's surface, there is no gravitational potential energy. Therefore anything close to the planet can be considered to have *negative* gravitational potential energy, meaning that it's not at infinity distance away. This idea is sometimes called an "energy well."

This relates to the escape velocity of a planet. To escape the planet's gravitational pull, an object must move itself to where $U_G = 0$. The object launches, and as it rises, it slows down (at a rate of g) while its kinetic energy transforms into gravitational potential energy. In the "energy well" concept, the gravitational potential energy is *approaching zero* (towards infinity) because it started with negative gravitational potential energy *relative to infinity*. We then get…

initial system energy = final system energy

$$\frac{1}{2}mv^2 - \frac{Gm_1m_2}{r} = 0$$

From this, derive a formula for the escape velocity from a planet of radius r.

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