Name: ____________________

PHYSICS 20 – TOPIC 1

ENERGY & WORK

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Title	Due Date
Science 10 Physics Review (A-C)	
Mechanical Forms of Energy	
Energy Conservation	
Science 10 Physics Review (D-E)	
Lab: Energy Transformations on a Ramp	
Non-Isolated Systems	
Energy Transformations (Work)	
Work-Energy Theorem	
Power & Efficiency	

SCIENCE 10 PHYSICS REVIEW

Part A — Energy

1. A student holds a 0.400-kilogram ball 2.00 metres above the ground.

   a) What *kind* of "energy" does the ball have?

   b) What is the SI *unit* (symbol and name) used to measure energy?

   c) How much energy does the ball have? [*Show the formula you are using and the values you are substituting. Your answer must have units and be rounded correctly to the appropriate number of significant digits.*]

   d) What happens to the ball's energy when the student releases the ball? Assume the student just allows the ball to begin falling but does not throw the ball.

   e) What will the ball's speed be *just before* it contacts the ground? [*Show your work as in question (c). Also show the steps of your algebra.*]

   f) What happens to the ball's energy after it contacts the ground?

Part B – Scientific Notation

2. a) An electron has a speed of 219 000 m/s. Express this speed in *scientific notation*.

   b) In an atom, this electron orbits with a radius of 5.29×10^{-11} m. Express this radius in *decimal notation* (i.e. as a regular number not in scientific notation.)

   c) There is an equation (that we will earn about later in Physics 20) that allows us to calculate the acceleration of an object when it is orbiting in a circle:

$$a = \frac{v^2}{r}$$

   Use this equation – without a calculator – to **estimate** the electron's acceleration. [*Show how you obtained your estimate*.]

   d) Use a calculator to **evaluate** the electron's acceleration accurately. How close is the result to your estimate?

Part C – SI Units

3. In Physics, we always express mass using kilograms when we want to perform calculations such as kinetic energy. If you measured the mass of a tennis ball to be 56.8 grams, what would this be in kilograms? [*Show your work*.]

4. A red laser pointer has a wavelength of 633 nanometres. The "standard" unit for measuring distance or length in Physics is metres. Convert the light's wavelength from nm to m. [*Show your work*.]

5. A car is traveling the road at 60.0 km/h. In Physics, we need to express speeds in the "standard" unit which is m/s. Convert the car's speed to m/s. [*Show your work*.]

Mechanical Forms of Energy

Definition of Energy

Energy is the ability to produces *changes* in motion, temperature, or other physical or chemical properties.

- Energy comes in many different forms.
- Energy is a *scalar* quantity; it has no direction.
- Energy is a *conserved* quantity.
- The SI unit of energy is called the *joule*. A joule can be expressed in terms of more fundamental units:

$$\mathrm{J} = \mathrm{N} \cdot \mathrm{m} = \mathrm{kg} \cdot \frac{\mathrm{m}^2}{\mathrm{s}^2}$$

Mechanical Energy

Forms of energy that are related to motion are called **mechanical** forms of energy. When you are asked how much "mechanical energy" a system has, you must calculate the *total* of all the mechanical forms of energy present at a particular time. Mechanical energy includes…

Kinetic Energy

Motion is itself a form of energy, which we call the **kinetic** energy:

$$E_k = \frac{1}{2}mv^2$$

- In this equation, m is the *mass* of the object in kilograms.
- The symbol v is the *speed* of the object in metres per second (m/s).

Rotational Energy

An object that is spinning in place has energy. We call this **rotational** energy.

- We can use rotational energy to pull or lift an object (a winch) or to create electricity (a generator).
- The equation for rotational energy depends on the shape of the object and whether it is solid or hollow.
- A ball rolling on a playing field has *both* kinetic and rotational energy.

Gravitational Potential Energy

When an object is elevated above the ground, it has energy because gravity will cause the object to move when it is released.

- This type of energy is called **gravitational potential** energy:

$$E_g = mgh$$

- In this equation, g is the *gravitational field strength*. Close to Earth's surface, g = 9.81 m/s^2.
- The symbol h is the *height* of the object relative to the origin (usually the ground).
- As with kinetic energy, m is the mass in kilograms.
- This formula is only valid when the gravitational field is constant and uniform. When a spacecraft is launched into space for example, gravity gets weaker as it gets farther from Earth, so g is not constant.

Elastic Potential Energy

Elasticity is a property of objects that return to their original shape when they are stretched or compressed. Elastic objects include springs, rubber bands, bungees, and archery bows.

The energy stored in a stretched or compressed elastic is called **elastic potential** energy:

$$E_{elas} = \frac{1}{2}k(\Delta L)^2$$

- The variable k is called the *elastic constant*. It measures the strength of the elastic object in newtons per metre (N/m); if a spring has k = 20.0 N/m, this means it would take 20.0 newtons of force to stretch the spring by 1.00 metre from its unstretched length.
- The variable ΔL is the distance the elastic is stretched or compressed (the *change* in length) from its equilibrium shape.

Non-Mechanical Forms of Energy

There are many different forms of energy that are related to properties other than motion (e.g. temperature or chemical composition). Some non-mechanical forms of energy include:

- Thermal energy
- Sound energy
- Electrical energy
- Chemical energy
- Nuclear energy
- Light and other electromagnetic energy

Energy Bar Chart

An energy bar chart is a bar graph that illustrates how much of each form of energy is present in a system at any instant. It is often useful to draw two or more energy bar charts to compare the energy in a system at two different times.

Practice

Answer these questions on a separate sheet of paper. Be sure to write your name and the lesson title on your work and keep the completed assignment in your Physics 20 binder. Keep your binder organized (i.e. assignments in the correct order) so that it will be easy to find assignments when required.

Write the equations you are using exactly as they appear on the Physics 20 Data Sheet. Perform any algebra on the equations before substituting any numerical values and show all steps of your algebra. Also show the values you are substituting when you evaluate the expression and record your final answer with proper units and significant digits.

Draw a labelled energy bar chart for each question (except #3).

1. A baseball player hits a home run. The 250-gram baseball has a height of 9.25 metres and a speed of 24.0 m/s when it goes over the centre field wall.

   a) Calculate the baseball's *kinetic energy*.

   b) Calculate the baseball's *gravitational potential energy*.

   c) Calculate the baseball's *mechanical energy*.

2. a) An archer has a bow with an elastic constant k = 200 N/m. She draws the bowstring back 65.0 cm. How much *elastic potential energy* is stored in the stretched bow?

   b) If the arrow has a mass of 55.0 grams and is being held 1.60 m above the ground, how much *gravitational potential energy* does it have?

   c) Calculate the *mechanical energy* of the bow and arrow system.

3. A toy car has a mass of 35.0 grams. The car is launched using a spring with k = 20.0 N/m that is compressed by 4.00 cm. Calculate the *mechanical energy* stored in the spring.

4. A 50.0-kilogram cyclist has a speed of 8.00 m/s at the top of a 4.50-metre high hill.

   a) Calculate his kinetic energy, gravitational potential energy, and mechanical energy.

   b) Assuming that his mechanical energy remains constant (he neither gains nor loses mechanical energy) what will his *speed* be when he reaches the *bottom* of the hill? [Before trying to answer this, draw two separate energy bar charts for the system at the (i) top and (ii) bottom of the hill.]

5. A solid metal ball with a mass of 200 grams rolls down a ramp starting from rest. When the ball is *halfway* down the ramp, its speed is measured to be 2.00 m/s. For a solid sphere that rolls without slipping, the rotational energy equation is:

$$E_r = \frac{1}{5}mv^2$$

   a) Calculate the ball's *kinetic* and *rotational* energies.

   b) 🗲 Calculate the ball's gravitational potential energy and its mechanical energy. Remember that the ball is **halfway** down the ramp at this point. Assume there is no change in the mechanical energy as the ball rolls. [Before trying to answer this, draw two separate energy bar charts for the system at the (i) top and (ii) halfway point of the hill.]

Energy Conservation

Law of Energy Conservation

One of the most important properties of energy is the fact that it is **conserved**. This means that *the total amount of energy always remains constant.*

It is possible to **transform** energy from one form to another and to **transfer** energy from one object or place to another.

- When a ball rises into the air, its kinetic energy is *transformed* into gravitational potential energy.
- When a bowling ball strikes a pin, some of the ball's kinetic energy *transfers* to the pin.

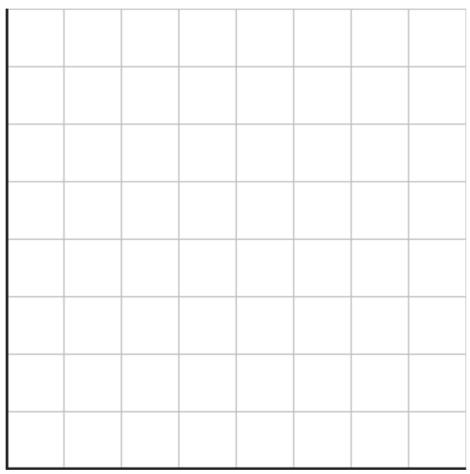
Energy conservation tells of the energy losses are always exactly balanced by energy gains elsewhere.

Example

1. A student shoots a 170-gram hockey puck up an icy (frictionless) hill with an initial speed of 3.00 m/s at the bottom of the hill. The puck eventually comes to rest a certain height up the hill before beginning to slide back down.

   a) Use energy conservation to determine the maximum height that the puck reaches. Draw energy bar charts at the bottom and the top of the hill.

   Bottom

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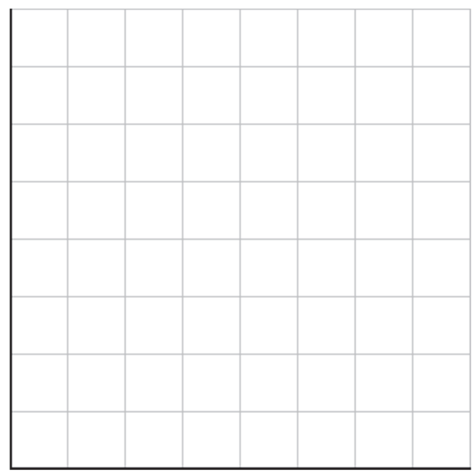
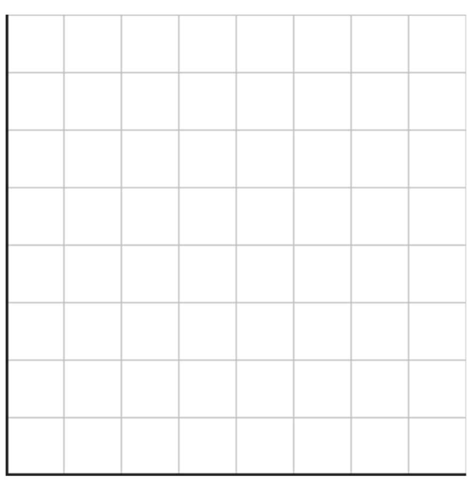
   

   b) As the puck slides back down the hill it picks up speed again. Use energy conservation and energy bar charts to determine the speed of the puck when its height is 30.0 cm above the bottom of the hill.

   Bottom

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   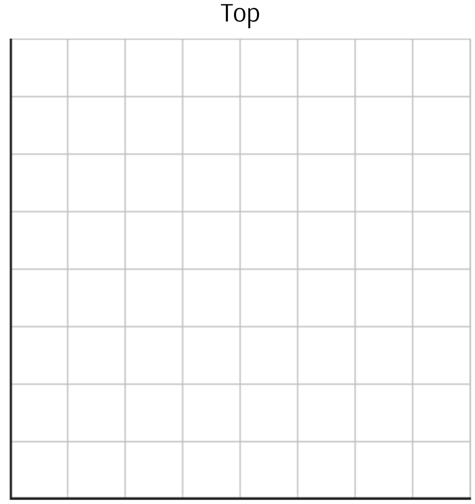

Practice

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Write the equations you are using exactly as they appear on the Physics 20 Data Sheet. Perform any algebra on the equations before substituting any numerical values and show all steps of your algebra. Also show the values you are substituting when you evaluate the expression and record your final answer with proper units and significant digits.

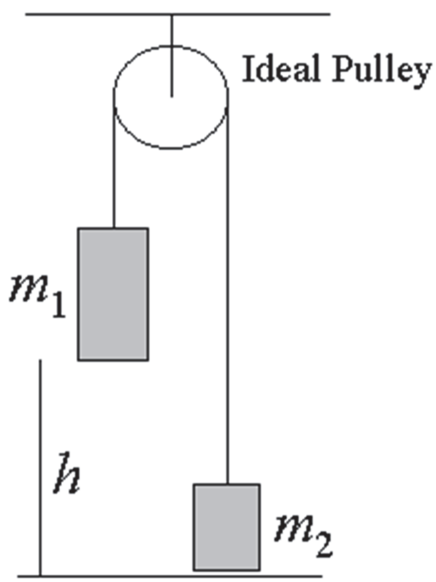
Draw a labelled energy bar charts for each question.

2. A 50.0-gram Hot Wheels® car is at rest at ground level. The toy car is set in motion using a spring launcher with an elastic constant k = 90.0 N/m that has been compressed 10.0 cm. The car follows a track to the finish line 30.0 cm above ground level.

   Create energy bar charts for the car/launcher system for the "initial" and "final" (finish line) states. Show all relevant calculations and use the bar charts to calculate the car's speed as it crosses the finish line. Assume there is no change in the system's mechanical energy.

3. Robin Hood's bow has an elastic constant k = 500 N/m. He pulls the bowstring back 70.0 cm to shoot a 100-gram arrow from an initial height of 1.25 metres. Assuming no change in mechanical energy, what will the speed of the arrow be (a) immediately after Robin Hood releases it, and (b) when it reaches a target 20.0 metres above the ground? You will need to draw three energy bar charts: one for the initial state of the system before the arrow is released, and one each for (a) and (b).

4. In the illustrated pulley system, m_1 = 15.0 kg, m_2 = 8.50 kg, and h = 3.00 m. The masses are released from rest. A pulley system is "ideal" when there is no friction or air resistance and its rotational energy is negligible. The mechanical energy of the masses is assumed to be constant.



   Use energy bar charts to calculate the final speed of the masses just before m_1 contacts the ground. Sketch the bar charts on a separate sheet of paper. Your bar charts should have <u>four</u> bars: E_{k1}, E_{k2}, E_{g1}, and E_{g2}.

SCIENCE 10 PHYSICS REVIEW

Part D – Experiment Design

Science 10 students tried to measure the specific heat capacity of water by heating a beaker of water using a 150-watt hot plate. The beaker contained 200 grams of water. The students measured the temperature of the water at 30-second intervals and obtained the data below.

Heating Water

Time t / s	Temperature T / °C
0	15.7
30	21.7
60	27.4
90	33.2
120	40.2
150	41.9
180	50.3
210	53.4
240	54.7

1. a) Which variable is the **manipulated variable** for this experiment? __________
   b) Which variable is the **responding** variable for this experiment? __________
   c) Identify two **controlled** variables for this experiment. __________
2. Write the **hypothesis** that the students are testing.

   ____
3. Define the following terms:
   a) Variable __________
   b) Manipulated __________
   c) Responding __________
   d) Controlled __________
   e) Hypothesis __________

Part E – Scatter Plots & Best-Fit Lines

4. Draw a **scatter plot** of the students' data. Use the grid provided on the next page.
5. a) Add a **best-fit line** to the graph.
   b) Calculate the **slope** of your best fit line. Show all work.
   c) Determine the ***y*-intercept** of your best fit line. Show all work.
   d) Write the **equation** of your best fit line.
   e) Use your "model equation" to **interpolate** the data to estimate the temperature of the water after 100 s.
   f) How long will it take the water to reach the boiling point? Use your model equation to **extrapolate** from the data to find the time at which the temperature will reach 100 °C.

- Graphs must be drawn on graph paper and should be *large*; use all available space.
- Graphs must have a descriptive title. The subtitle should identify the variables being plotted in the form "responding vs. manipulated."
- Each axis must be labelled with the variable name, symbol, and units.
- The *manipulated* variable must be graphed on the horizontal (x) axis and the responding variable on the vertical (y) axis.
- Label the axes so that all data points fit on the graph, using as much space as possible.
- The "tick marks" on each axis must be evenly spaced. Tick marks must be numbered using a common interval and must start either at zero or a multiple of the interval used.
- For example, if you are counting by 5's on your y-axis, your first labelled tick mark must be 0 or a multiple of 5.
- Data points must be drawn *accurately* and must *not* be connected.
- If the data shows a linear trend, you can add a best-fit line.
- A good best-fit line illustrates the trend of the data with equal numbers of data points above and below the line.
- The average distance between the data points and the best-fit line should be minimized.

NON-ISOLATED SYSTEMS

Types of Systems

When solving problems in Physics, we often distinguish between our system and its environment. The **system** comprises the objects and energy forms that we are interested in, and the **environment** means the system's surroundings.

- An **isolated** system is one that does not interact with its environment in any way. There is no exchange of matter or energy between the system and its surroundings.
- A **closed** system is one in which energy may transfer between the system and its environment, but matter may not.
- An **open** system allows both energy and matter to enter or leave the system.

Energy Conservation

When we use the Law of Energy Conservation for systems that are not isolated, we must account for energy added to or removed from the system.

$$E_f = E_i + E_{added} - E_{removed}$$

An alternative way of writing this is:

$$E_f + E_{removed} = E_i + E_{added}$$

When drawing our energy bar charts, energy to be *added* to the system must be included with the *initial* energy, and energy *removed* from the system must be included with the *final* energy.

Common Causes of Energy Changes

Non-isolated systems often lose energy due to the presence of friction or air resistance forces. These forces cause mechanical energy to be transformed into thermal and sound energy, which becomes part of the environment.

When there is an applied force acting on the system, this often causes a gain in mechanical energy. This is offset by a loss of chemical (e.g. gasoline, diesel, propane, food energy) or electrical energy depending on how the applied force is generated.

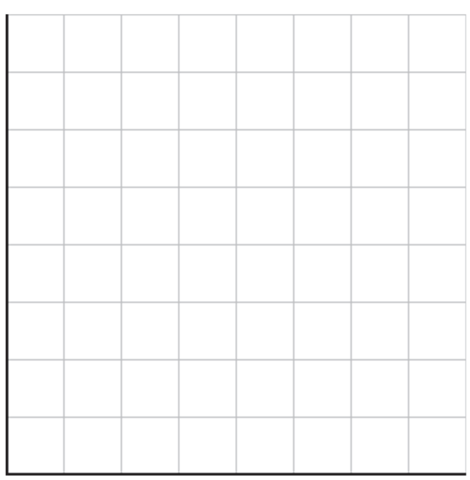
Example

1. A 500-gram ball is dropped from a height of 2.00 metres.

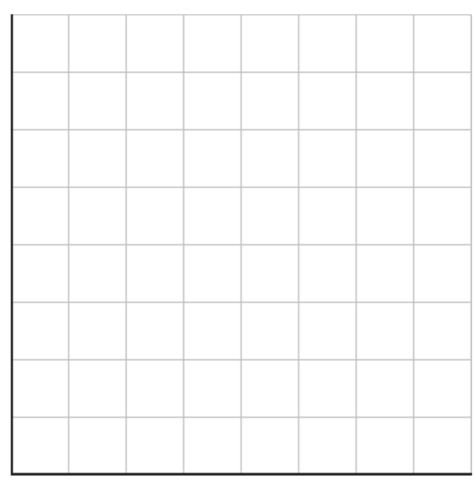
   a) Calculate what the final speed of the ball *should be* just before it contacts the ground, if the mechanical energy remains constant.

   b) The *actual* final speed of the ball just before it contacts the ground is measured as 5.00 m/s. Calculate the *change* in mechanical energy. Use energy bar charts.

Initial



Final



c) Does the change in mechanical energy represent energy gained by the system from the environment, or energy lost by the system to the environment?

d) Classify the system as isolated, closed, or open. Explain.

Practice

2. a) A 32.0 kg child is skating with an initial speed of 1.25 m/s. The child's father pushes her, causing her speed to increase to 2.30 m/s. Draw energy bar charts to illustrate the energy transformations. Calculate the energy added to the system by the child's father.

   b) In order for the system to have gained energy, the surroundings must have lost energy. Explain what form of energy the surroundings lost.

3. A 2.50 kg mass is slid up an incline (ramp) with an *initial* speed of 2.50 m/s (i.e. at the bottom of the ramp).

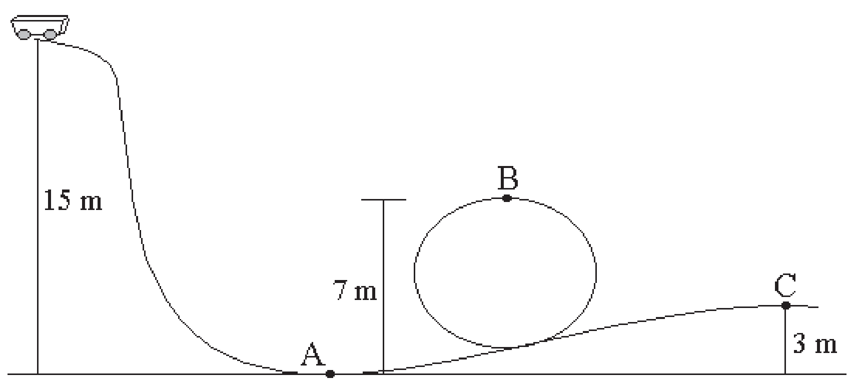
   a) Imagine that there is *no friction*. Use energy conservation to determine the height that the mass reaches before coming to stop and then starting to slide back down the ramp. Include energy bar charts as part of your solution.

   b) If *there is friction*, would the maximum height of the mass be higher, lower, or the same as you calculated in (a)? Explain.

   c) The maximum height that the mass reaches up the ramp is *measured* to be 25.0 cm. Draw a new "final" energy bar graph to determine the amount of "waste" energy produced by the friction force.

4. A 60.0-gram arrow is loaded into an archery bow and held 1.25 metres above the ground. The bow has an elastic constant of 100 N/m. The arrow is shot by pulling the bowstring back 40.0 cm, aiming, and releasing. As the arrow flies toward the target, air resistance transforms 3.00 joules of energy into sound and thermal energy. Find the speed of the arrow just before it strikes the target 80.0 cm above the ground.

5. A 625 kg roller coaster car starts from rest along a track as illustrated.



   a) Determine the speed of the car at point C, *neglecting friction and air resistance*.

   b) Write a *general* relationship (equation) between the car's height and speed and use it to calculate the speed at points A and B. Do this by equating the *formulas* for the initial and final energy rather than the calculated numerical values.

   c) When *friction and air resistance* are accounted for, they are responsible for transforming 21.7 kilojoules of mechanical energy into sound and/or thermal energy, between the start of the ride and point C. Recalculate the speed at point C.

Energy Transformations (Work)

Force

A **force** is an interaction in which two objects push or pull on each other.

- Force is measured in newtons:

$$\mathrm{N} = \mathrm{kg} \cdot \frac{\mathrm{m}}{\mathrm{s}^2}$$

- A newton is the amount of force needed to make a 1-kilogram object accelerate at 1 $\mathrm{m/s^2}$.
- Force is a *vector*; it acts in a specific direction.

Conservative Forces

Forces that transform kinetic energy to or from potential energy are sometimes called conservative forces, because they “conserve” the mechanical energy; the gain or loss of kinetic energy is balanced by an opposite change in potential energy. These energy transformations are reversible. Conservative forces include:

- *Gravity*: an attractive force between masses. It is responsible for converting gravitational potential energy into kinetic energy when the object is moving “down” and for the reverse when the object is moving “up”.
- *Elastic*: a force exerted by a stretched or compressed object trying to return to its original shape (bow, spring, bungee). It converts elastic potential energy into kinetic energy when the object is being restored to its original shape, and it does the reverse when the object is becoming more stretch or compressed.

Non-Conservative Forces

Forces that cause objects or gain or lose kinetic energy by transforming a non-mechanical energy form are non-conservative. These energy transformations cannot be reversed (at least not by the same force).

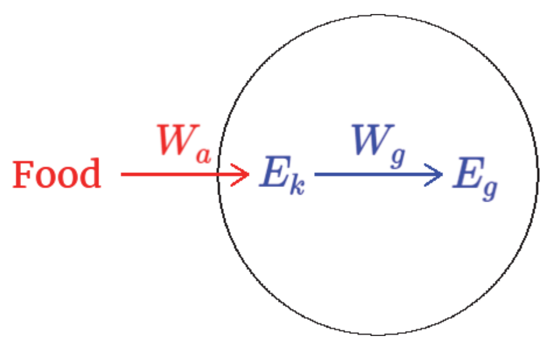
- *Friction*: a force exerted by a surface on an object, directed parallel to surface and opposite to the motion. Friction transforms kinetic energy into thermal and possibly sound energy.
- *Air Resistance* (*Drag*): a force exerted by air (or other fluids) on objects moving through. Like friction it converts kinetic energy into thermal and possibly sound energy.
- *Applied*: a force exerted by a person, animal, or machine. People and animals are powered by chemical energy (food) while machines could be powered chemically (gasoline, diesel, propane) or by electric or nuclear energy.
- *Tension*: a force exerted by an object that does not stretch (rope, rod).
- *Normal*: a force exerted by a surface (ground, floor, table) on an object in contact; acts perpendicular to the surface.
- Others: *Buoyancy*, *Electric*, *Magnetic*, *Nuclear*

Work

The amount of *kinetic energy gained* due to a force acting on an object is called the **work** done by the force. A *negative* amount of work indicates that kinetic energy has been *lost*.

Energy Flow Diagram

An **energy flow diagram** (sometimes called a Sankey diagram) is an illustration showing the energy transformations happening because of the forces or process taking place. Remember that forces always involve *kinetic* energy. When you lift an object from the ground, you are transforming chemical energy (food) into gravitational potential energy in a two-step process: the applied force transforms the chemical energy into kinetic energy, and gravity transforms that kinetic energy into gravitational potential energy.



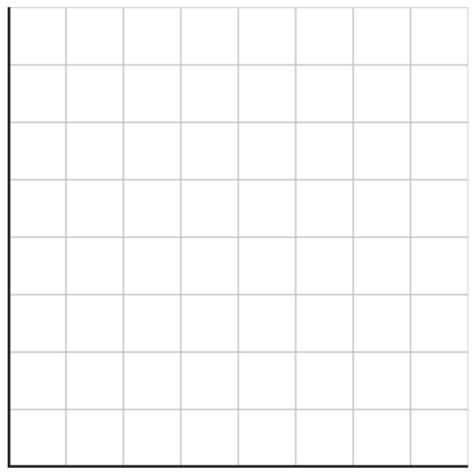
- The circle in the diagram, represents the boundary between the system and its environment.
- The symbols W_a and W_g represent the work done (energy transformed) by the applied and gravity forces.
- W_a is positive because it is increasing E_k, while W_g is negative because it is decreasing E_k.

Example

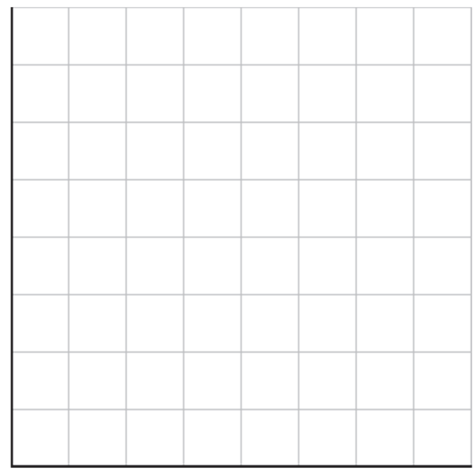
1. A 30.0-kilogram students slides down an icy hill on a sled. The student's speed is 3.00 m/s at the top of the 5.00-metre high hill. When the student reaches the bottom of the hill, her speed has increased to 8.00 m/s.

   a) Draw energy bar graphs for the student's initial (top of hill) and final (bottom of hill) state. Show all calculations.

   Initial

   Final

   b) Draw an energy flow diagram for this scenario. Label the amount of work done by each force.

Practice

2. A 200-gram package is dropped from the top of a 27.6 m tall building. The package strikes the ground with a speed of 18.4 m/s. Use a "LOL Diagram" (i.e. energy bar charts for the initial and final state, plus an energy flow diagram) to determine how much "waste" (sound and thermal energy) was produced due to the air resistance force.
3. A 1200 kg car is moving at 40.0 km/h initially. When the driver steps on the accelerator, the car experiences an applied force due to the engine that does 50.0 kJ of work while moving 100 metres. While the car is accelerating, friction and air resistance do –15.0 kJ of work. Use a LOL Diagram to determine the final speed of the car.
4. In question #4 of the *Energy Conservation* assignment, you used the Law of Energy Conservation to find the final speed of the masses in a pulley system. Draw a labelled energy flow diagram for this problem.
5. A student slowly lifts a weight at constant speed. How is it possible that the student is doing work, but the object is not gaining kinetic energy?

Work-Energy Theorem

Work & Force

We saw in the previous lesson that mechanical *energy transformations* are caused by *forces*. The amount of kinetic energy gained (or lost) as a result of a force is called the *work* done. How much work is done is determined by how strong the force is and by how far the object moves while the force is acting. This can be summarized in an equation:

$$W = \vec{\mathbf{F}} \cdot \Delta\vec{\mathbf{d}}$$

The change in an object's kinetic energy is equal to the *total* work done by all forces:

$$\Delta E_k = \Sigma W$$

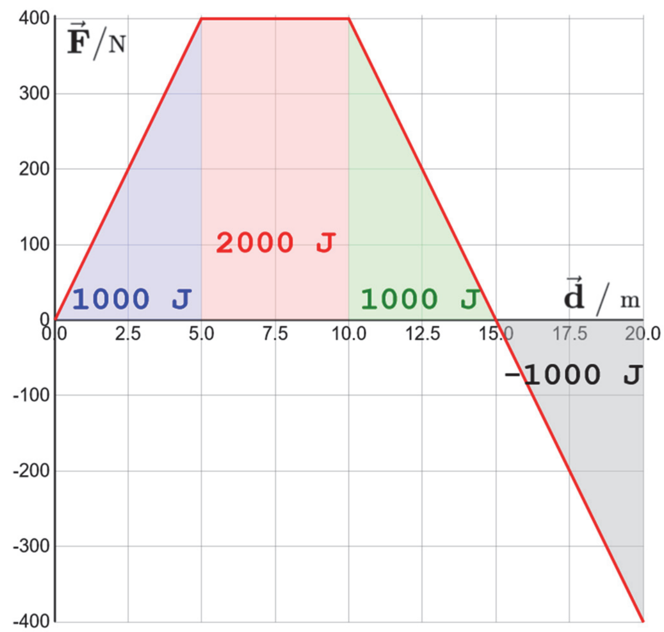
This is known as the **work-energy theorem**.

- When the force acts in the same direction as the object's motion (displacement) the work will be positive, meaning the object gains kinetic energy.
- When the force acts in the opposite direction as the object's displacement the work will be negative, meaning the object loses kinetic energy.

Non-Constant Force

If the force acting on an object does not remain constant while the object is moving, we must calculate the work using the *average* force. This can be done by graphing the force against the object's position and calculating the *area* under the graph.

In the graph below for example, the force increases from 0 to 400 newtons over the first 5.00 metres. The average force is 200 newtons, which gives 1000 joules (200 N × 5.00 m) for the work. This is the area of the triangle! If we repeat this for each section of the graph, we can calculate that the total work done over the entire 20.0 metres is 3000 joules.



Work in 2D & 3D

When the motion of the object involves more than one dimension, the force may act an angle to the motion rather than directly forward or backwards. The equation for work becomes:

$$W = \left|\vec{\mathbf{F}}\right| \cdot \left|\Delta\vec{\mathbf{d}}\right| \cos\Delta\theta$$

- $\Delta\theta$ is the difference between the direction of the force and the direction of the displacement as an angle.
- The work will be positive whenever $\Delta\theta < 90°$ and negative when $\Delta\theta > 90°$.
- If the angle is 90° exactly, the work will always be zero! Perpendicular forces change the direction of motion but do not change the object's speed.
- Note the absolute value symbols! Do not use negative values for the force or displacement.

Example

1. A student pushes a 15.0-kilogram crate from rest with a force of 50.0 newtons for 1.25 seconds. The crate moves 1.50 metres while the student is pushing.

   a) How much work did the student (applied force) do?

   b) If there was no friction or air resistance acting on the crate, how much kinetic energy would the crate have? Explain.

   c) Calculate the final velocity of the crate when there is no friction.

   d) Suppose there is a friction force of 20.0 N *opposing* the motion. Calculate the work done by the friction force and the final speed.

   e) Draw a "LOL Diagram" for this scenario.

Practice

Draw LOL Diagrams for each problem. Remember that "work" can be calculated as force times displacement ***or*** *as the amount of energy transformed.*

2. A 75.0 kg cyclist is initially moving at 5.00 m/s. She then accelerates to a final speed of 12.0 m/s while moving 20.0 metres. Neglect the effects of air resistance and friction.

   a) How much work did the student do in accelerating herself?

   b) How much average force did the cyclist experience?

3. A shopper pushes a 35.0-kilogram shopping cart 10.0 metres, using an applied force of 12.0 newtons. The cart was initially at rest.

   a) How much work did the shopper do? What would the final speed of the cart be if there is no friction or air resistance force?

   b) When friction/air resistance is present, the actual final speed of the cart is only 1.20 m/s. How much "waste" energy was generated by these forces? Calculate the force.

4. A student uses 10.0 newtons of force to push a 5.00-kilogram mass 2.00 metres up an 8.00° incline. The mass starts and ends at rest. Calculate (a) the amount of "waste" (sound and thermal energy) produced and (b) the average force of friction acting on the mass.

Power & Efficiency

Power

Power is the *rate* at which energy is transformed:

$$P = \frac{\Delta E}{\Delta t}$$

- A more powerful engine can transform energy more quickly than a less powerful one. A car with a lot of power can reach highway speed faster than a car of the same mass with a less powerful engine. However, the second car will reach highway speed eventually.
- The unit of power is watts (W). A watt is equal to one joule per second.
- Horsepower (hp) is a non-SI unit of power. The conversion factor is: 1 hp = 748 W.
- Do not confuse the symbol for watts (W, not italicized) with the symbol for work (*W*, italics).

Efficiency

Most energy transformations produce unwanted "waste" forms of energy.

- An incandescent light bulb is intended to transform electrical energy into light energy, but a significant fraction of the energy used will be wasted as thermal energy.
- LED and fluorescent lights are more "efficient" because they produce less heat and therefore use less electricity to produce the same amount of light.

Efficiency describes the fraction or percentage of the energy *input* that is transformed into its intended or *useful* output:

$$\epsilon = \left|\frac{\Delta E_{useful}}{\Delta E_{input}}\right|$$

- To say that a light bulb is 20% efficient means that 20% of the electrical energy consumed becomes light energy, and the remaining 80% of the energy consumed becomes waste (thermal energy).

Example

1. a) How long does it take a 1200 kg car with a 150 hp engine to accelerate from rest to 80.0 km/h?

   b) The car's efficiency is 0.230. How much chemical energy (gasoline) does the car use in accelerating to 80.0 km/h?

   c) Draw an energy flow diagram for this transformation.

Practice

2. How long will it take for a car engine that develops 75.0 kW of power to do 247 kJ of work in accelerating the car to highway speed?

Draw an energy flow diagram for each of the remaining problems.

3. A student running on a treadmill burns 120 kJ of food energy and produces 97.2 kJ of heat. What is the *efficiency* of the energy transformation?

4. A 60.0-kilogram sprinter metabolizes 7.00 kilojoules of food energy while accelerating from rest to 8.00 m/s over 2.00 seconds. Calculate the (a) efficiency of the energy transformation, (b) power developed by the student, and (c) the amount of thermal and sound ("waste") energy produced by the student.
5. The diesel engine of a locomotive has an efficiency of 12.5% in transforming the chemical energy of the fuel into useful work as the locomotive hauls the train up a hill.

a) If the engine does 4.25×10^7 J of *useful work* in hauling the train up the hill, how much chemical energy (fuel) did the engine consume?

b) How much waste (thermal and sound energy) did the engine produce?

6. A 1250 kg car moving at 65.0 km/h accelerates to 90.0 km/h in 5.20 s to pass a slower car. The car has a hybrid engine which is 42.9% efficient.

a) Calculate the input, useful output, and waste energies.

b) Calculate the average power produced by the engine. The power of a vehicle engine is often described using horsepower; convert your answer to hp.

c) If the car's engine is advertised as being able to produce 140 hp, how long would it take the car to accelerate from 65.0 to 90.0 km/h at maximum power?

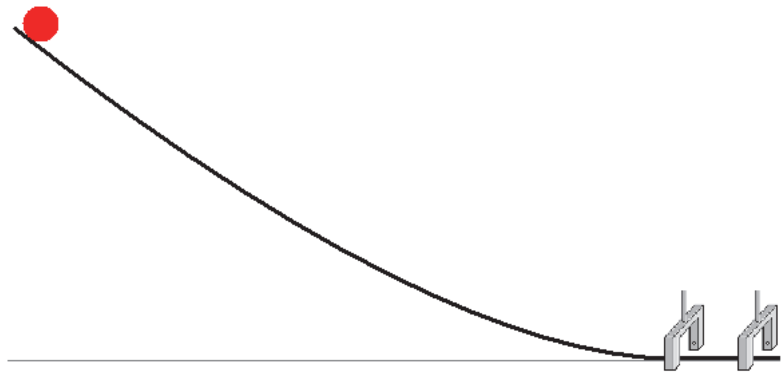
d) Will a more powerful engine always be able to do more work than a less powerful one? Explain.

Name: ______________________________

ENERGY TRANSFORMATION ON A RAMP

Pre-Lab

In this activity, we will allow a ball bearing to roll down a ramp, starting from rest. At the bottom of the ramp, we will set up a pair a "photogates" that will allow us to measure the speed of the ball bearing at the bottom of the ramp.



1. a) What type(s) of mechanical energy is(are) present when the ball bearing is at the top of the ramp?

   b) State the equation(s) needed to calculate the ball bearing's initial mechanical energy.

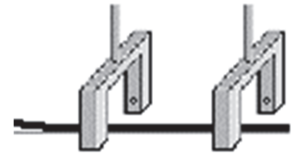
   c) What measurements do we need to make to be able to calculate the initial mechanical energy?

2. a) What type(s) of mechanical energy is(are) present when the ball bearing reaches the bottom of the ramp?

   b) State the equation(s) needed to calculate the ball bearing's final mechanical energy.

   c) What measurements do we need to make to be able to calculate the final mechanical energy?

3. Each photogate creates a beam of infrared light that passes across the path of the ball bearing. When the ball blocks (or unblocks) the light, the photogate sends a signal to the computer, which records the time.

   a) Suppose the computer records that the second photogate becomes blocked 75.0 ms after the first gate was blocked, and the distance between the photogates is 17.5 cm. Calculate the speed of the ball bearing.

b) Does the speed you calculated in (a) represent the ball bearing's *initial* speed, *final* speed, or *average* speed? Explain.

4. In this experiment, we will release the ball from different starting heights along the ramp. The initial height is the manipulated variable. We will then measure the ball bearing's speed when it reaches the bottom of the ramp. The final speed is the responding variable. Write a hypothesis: a prediction as to how changing the initial height will affect the final speed. Use the concept of *mechanical energy* to justify your hypothesis.

Data Collection

5. Variables that are kept *constant* during data collection process are called controlled variables. Measure and record the relevant controlled variables:

   a) The mass of the ball bearing:

   b) The distance between the photogates:

6. a) Position the ball bearing near the top of the ramp. Measure its height *relative to the bottom of the track*. (The track may rest a small distance above the floor!) Record the initial height in the table on the back page.

   b) Prepare the photogate software to collect data. Release the ball bearing. After it passes through the photogates, record the time as measured by the photogate software. Repeat this step from the same initial height until you have three trials.

7. Repeat step 6 from a different height. Continue repeating this step, changing the initial height each time until the first two columns of the data table are filled.

Data Analysis

8. For each row in your data table above, calculate and record the average of the three time trials. Calculate each final speed by dividing the distance between photogates by the average photogate time, $v = \Delta d/\Delta t$.

9. a) For each row in your data table above, use the initial height to calculate the initial gravitational potential energy. Record the results in the next column of the table.

   b) For each row in your data table above, use the final speed to calculate the final kinetic and rotational energies. Record the results in the second and third columns of the table below.

   c) If you compare the final mechanical energy ($E_{kf} + E_{rf}$) to the initial mechanical energy, you should find that some of the mechanical energy has gone missing! Calculate and record the "missing" energy in the final column of the data table.

   d) Suggest what has happened to this "missing" energy.

10. a) Use the graph paper on the back of this booklet to make a scatter plot of the final *kinetic* energy (y-axis) versus the initial energy (x-axis). Add a best-fit line and calculate its slope. The best-fit line should pass through the origin since the final energy must be zero when the initial energy is zero. Show your slope calculation here:

b) On the *same graph*, plot the final *rotational* energy versus the initial energy. Use a different colour or marker shape and add a legend to distinguish the "Rotational" data from the "Kinetic" data. Add a best-fit line for the rotational energy and calculate its slope. Show your slope calculation here:

c) On the same graph, plot the "missing" energy versus the initial energy using another colour or marker shape. Add this data set to your legend. Add a best-fit line for the missing energy and calculate its slope. Show your slope calculation here:

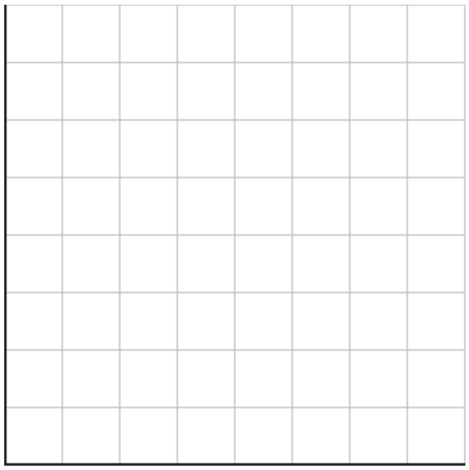
Conclusion

11. Describe the mechanical energy transformations that occurred as the ball bearing rolled down the ramp. Specifically, what do your three calculated slopes tell you about the amount of energy transformed? [Hint: What is the *sum* of the three slope values?]

Initial Height	Photogate Time, Δt / s		Final Speed	Initial Energy	Final Energy		
h_i / m	Trials	Average	v_f / (m/s)	E_{gi} / J	E_{kf} / J	E_{rf} / J	E_{wf} / J

Name: ____________________________

Question 1



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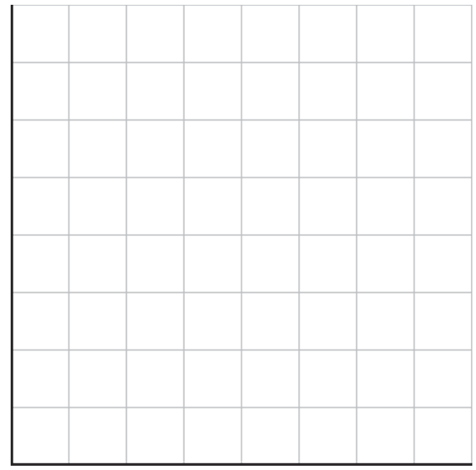
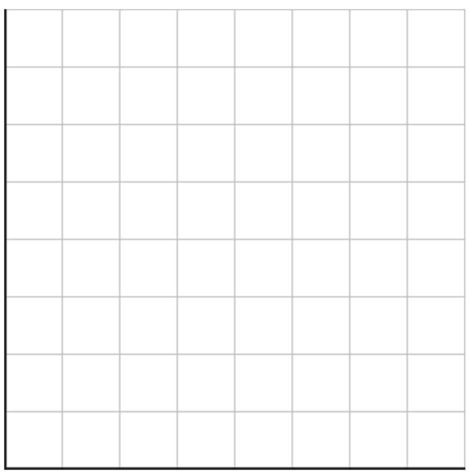
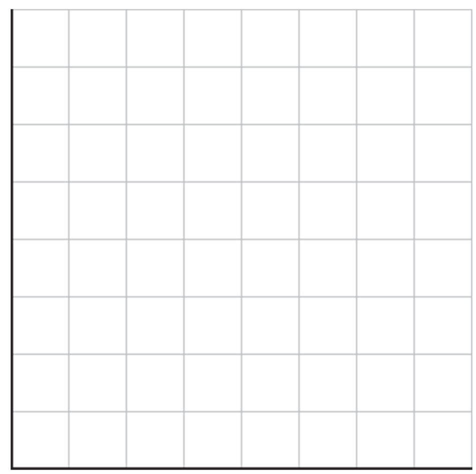


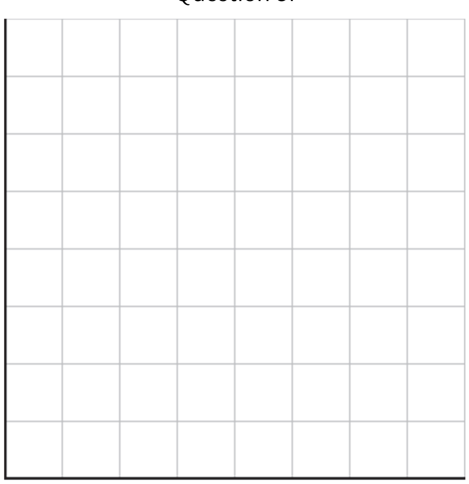
Question 4i



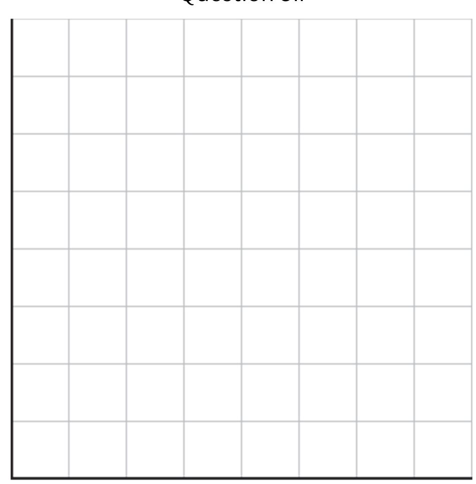
Question 4ii



Question 5i



Question 5ii



Energy Conservation Name: ______________________

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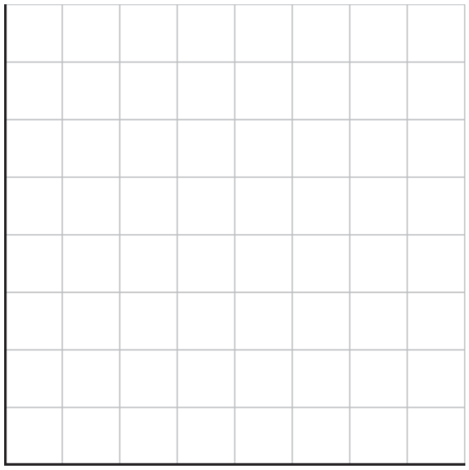

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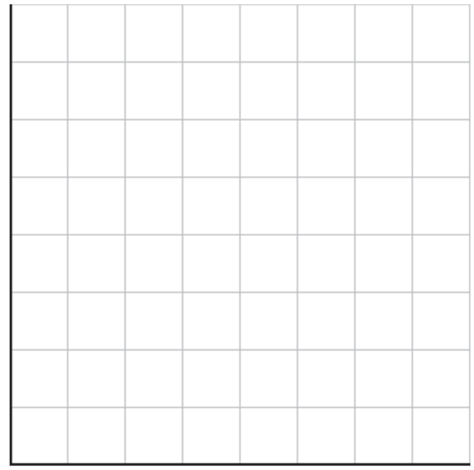

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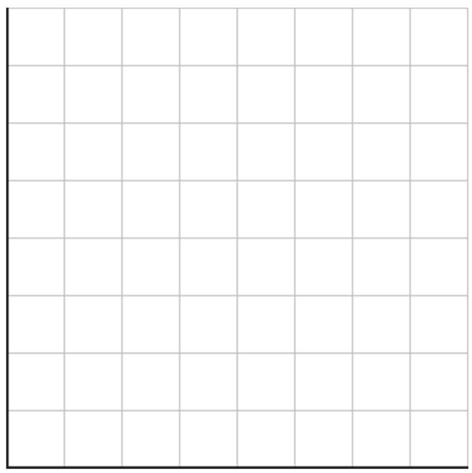
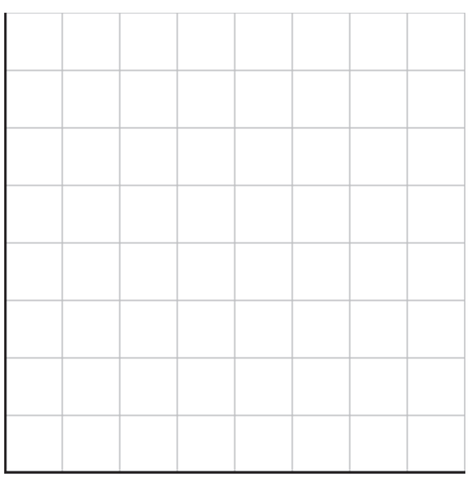
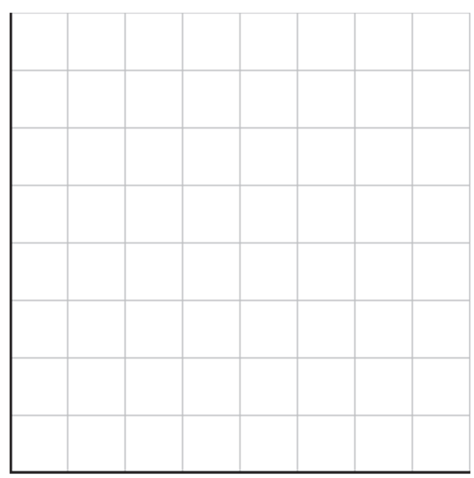


Question 3a



Question 3b



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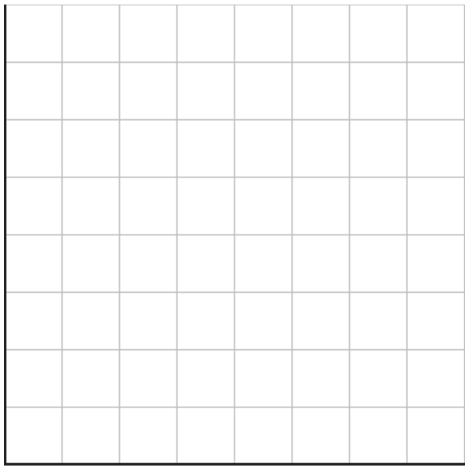

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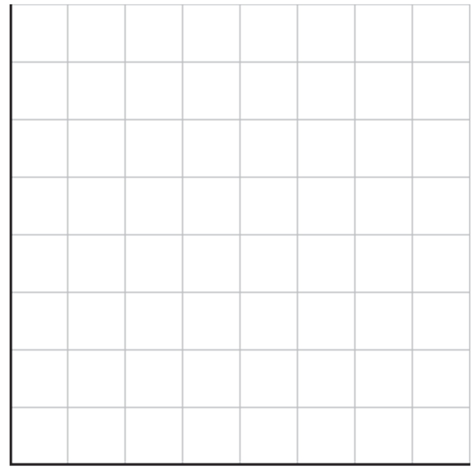

Name: ______________________________

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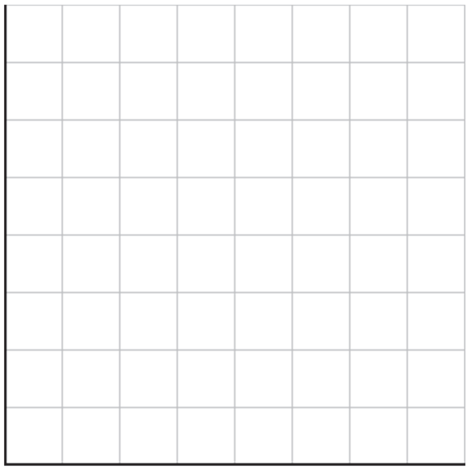

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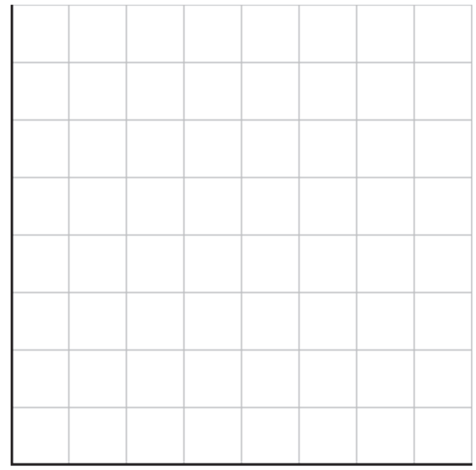

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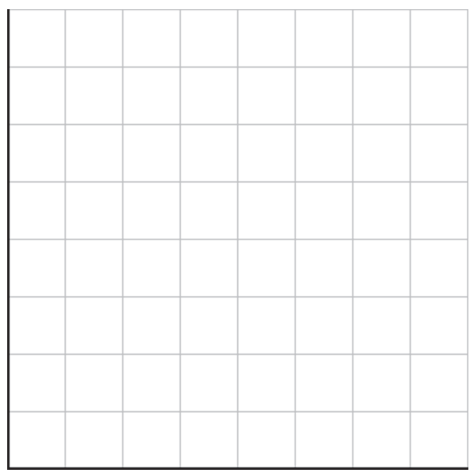

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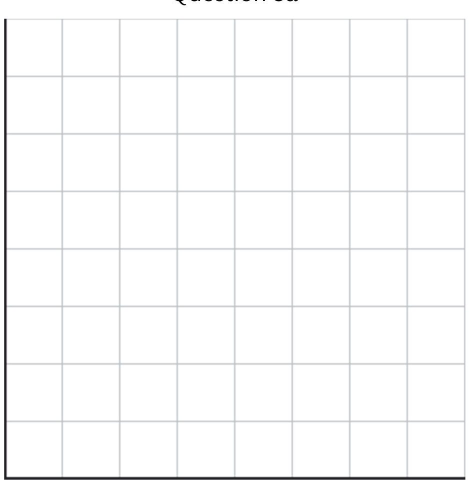
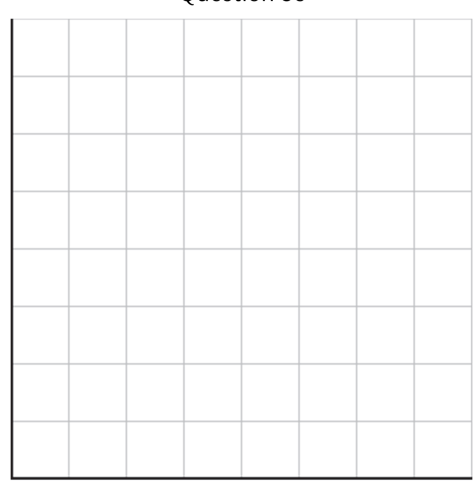


Question 3c



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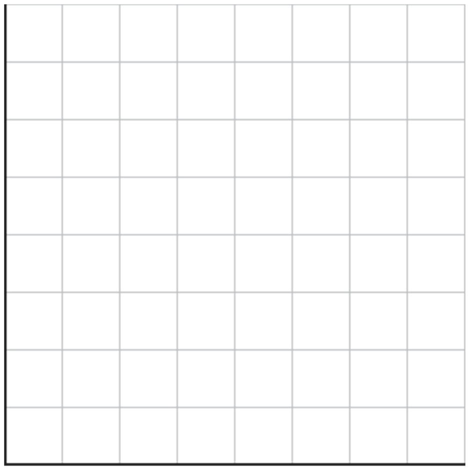

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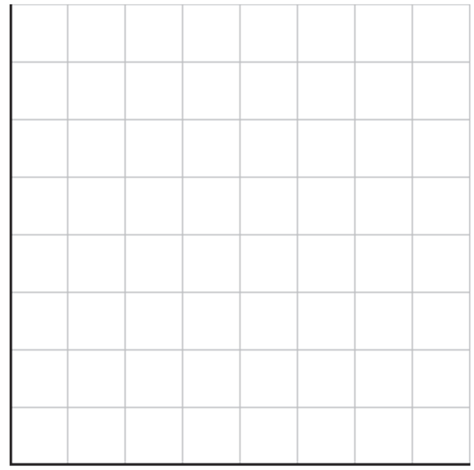

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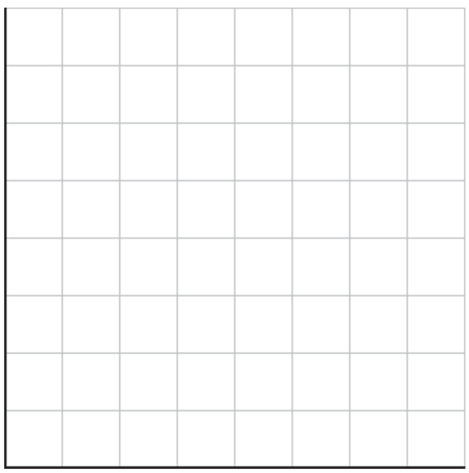
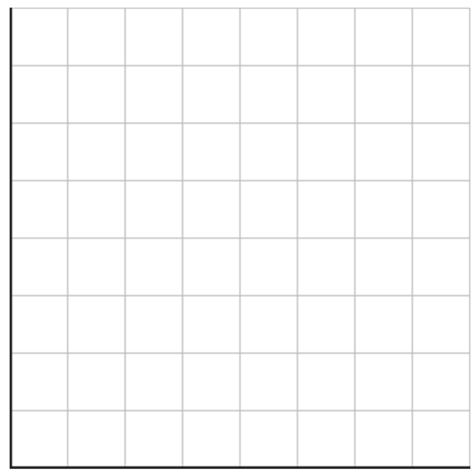
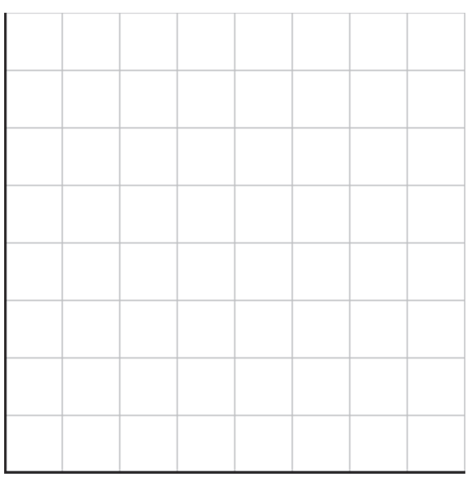


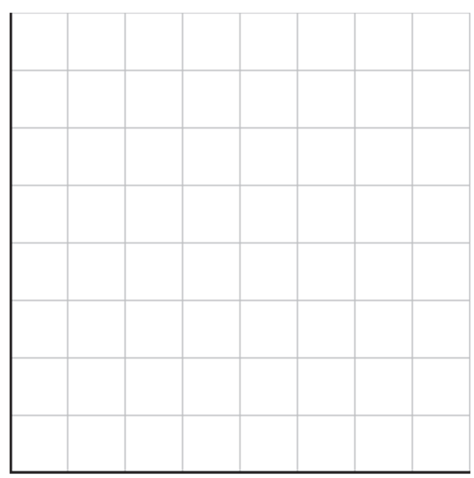
Question 5 (Point C – No Friction)



Question 5 (Point B)



Question 5 (Point C - Friction)



Energy Transformations (Work) Name: ______________________________

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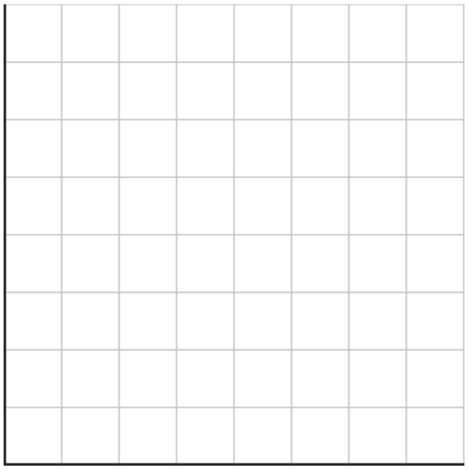

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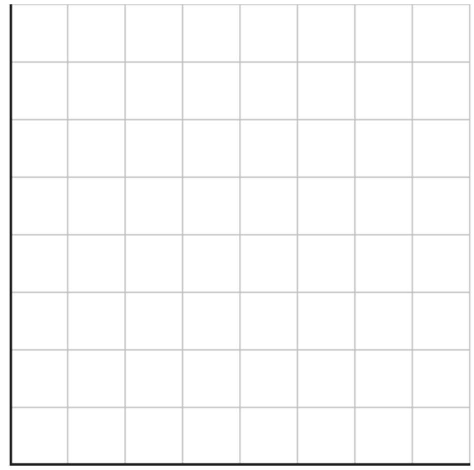

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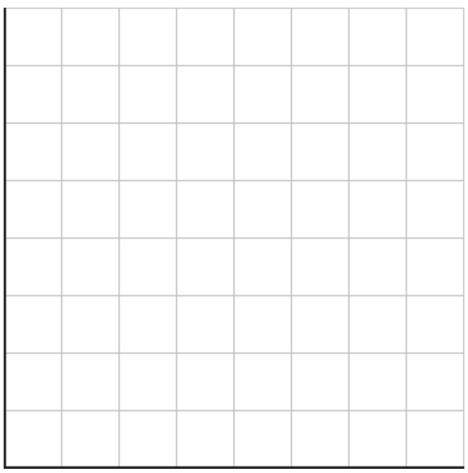

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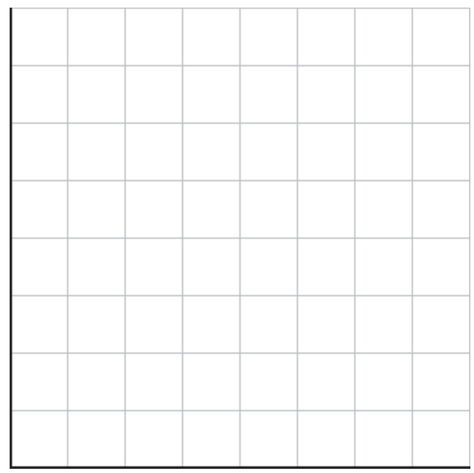

Name: ____________________________

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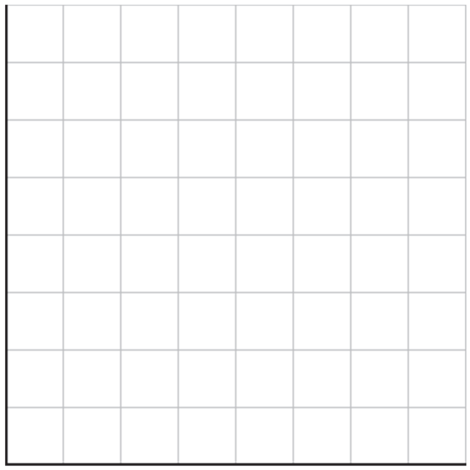

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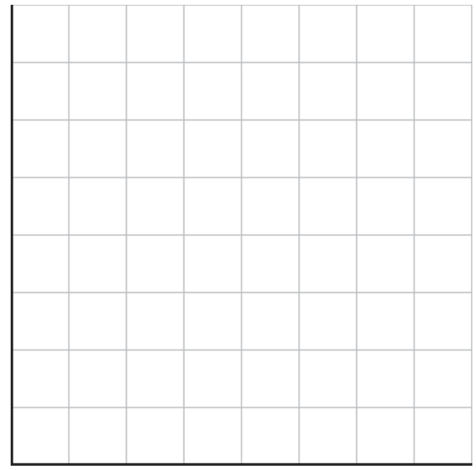

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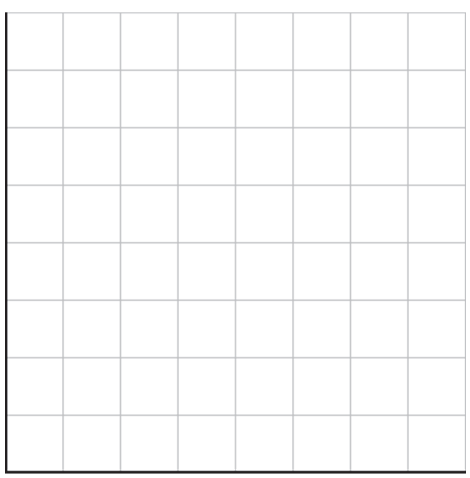

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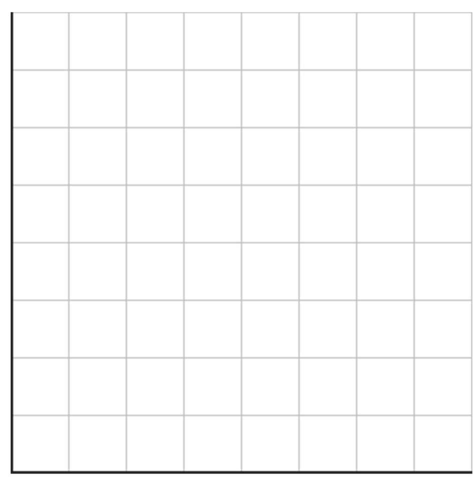

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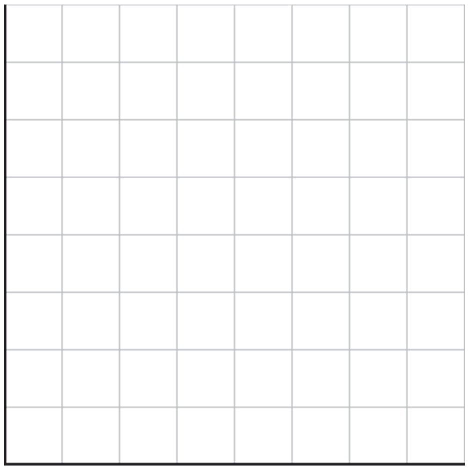

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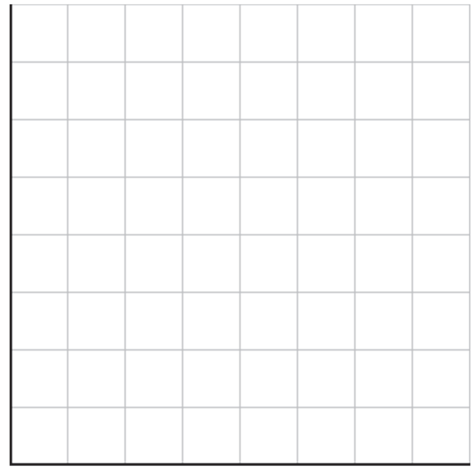

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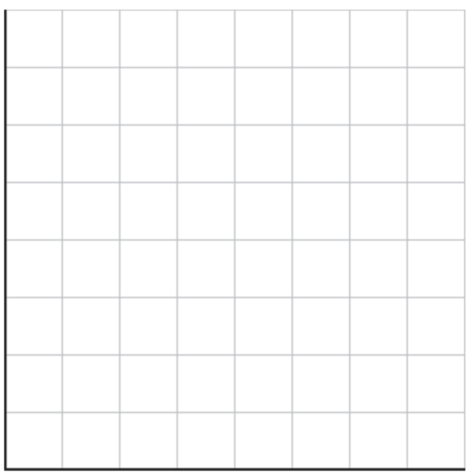

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