Name: ______________________________________ Date: ________________________

Student Exploration: Roller Coaster Physics

Vocabulary: friction, gravitational potential energy, kinetic energy, momentum

Prior Knowledge Questions (Do these BEFORE using the Gizmo.)
Sally gets onto the roller coaster car, a bit nervous already. Her heart beats faster as the car slowly goes up the first long, steep hill.

1. What happens at the beginning of every roller coaster ride?

____

2. Does the roller coaster ever get higher than the first hill? _______

Explain. ____

____

Gizmo Warm-up
The *Roller Coaster Physics* Gizmo models a roller coaster with a toy car on a track that leads to an egg. You can change the track or the car. For the first experiment, use the default settings (**Hill 1** = 70 cm, **Hill 2** = 0 cm, **Hill 3** = 0 cm, 35-g car).

1. Press **Play** (▶) to roll the 35-gram toy car down the track. Does the car break the egg? _________

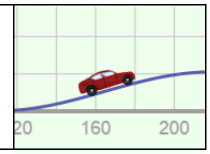
2. Click **Reset** (↺). Set **Hill 1** to 80 cm, and click **Play**. Does the car break the egg? ________

3. Click **Reset**. Lower **Hill 1** back to 70 cm and select the 50-gram toy car. Click **Play**. Does the 50-gram car break the egg? _________

4. What factors seem to determine whether the car will break the egg? ___________________

____

____

Activity A: **Roller coaster speed**	Get the Gizmo ready: • Click **Reset**. • Select the 35-g toy car.	

Question: What factors determine the speed of a roller coaster?

1. Observe: Set **Hill 1** to 100 cm, **Hill 2** to 0 cm, and **Hill 3** to 0 cm. Be sure the **Coefficient of friction** is set to 0.00. (This means that there is no **friction**, or resistance to motion.)

   A. Click **Play**. What is the final speed of the toy car? _________________

   B. Try the other cars. Does the mass of the car affect its final speed? _______________

2. Collect data: Find the final speed of a toy car in each situation. Leave the last column blank.

Hill 1	Hill 2	Hill 3	Final speed	
40 cm	0 cm	0 cm		
40 cm	30 cm	0 cm		
60 cm	50 cm	20 cm		
60 cm	0 cm	0 cm		
60 cm	45 cm	0 cm		
90 cm	75 cm	30 cm		

3. Analyze: Look at the data carefully. Notice that it is organized into two sets of three trials.

   A. What did each set of trials have in common? _________________________________

   B. Did hill 2 have any effect on the final speed? _______________

   C. Label the last column of the table **Total height lost**. Fill in this column by subtracting the height of hill 3 from the height of hill 1.

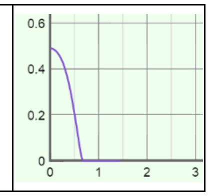
   D. What do you notice about the **Total height lost** in each set of trials? _____________

   ____

4. Draw conclusions: When there is no friction, what is the *only* factor that affects the final speed of a roller coaster? ____

   What factors do *not* affect the final speed of a roller coaster? __________________________

   ____

Activity B: **Energy on a roller coaster**	Get the Gizmo ready: • Click **Reset**. Select the 50-g car. • Check that the **Coefficient of friction** is 0.00. • Set **Hill 1** to 100 cm, and **Hill 2** and **3** to 0 cm.	

Question: How does energy change on a moving roller coaster?

1. Observe: Turn on **Show graph** and select ***E* vs *t*** to see a graph of energy (*E*) versus time. Click **Play** and observe the graph as the car goes down the track.

   Does the total energy of the car change as it goes down the hill? _______________________

2. Experiment: The **gravitational potential energy** (*U*) of a car describes its energy of position. Click **Reset**. Set **Hill 3** to 99 cm. Select the ***U* vs *t*** graph, and click **Play**.

   A. What happens to potential energy as the car goes down the hill? ________________

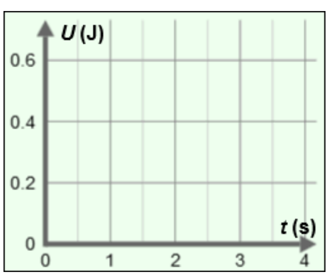
   B. What happens to potential energy as the car goes up the hill? ___________________

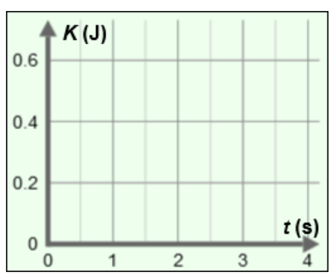
3. Experiment: The **kinetic energy** (*K*) of a car describes its energy of motion. Click **Reset**. Select the ***K* vs *t*** (kinetic energy vs. time) graph, and click **Play**.

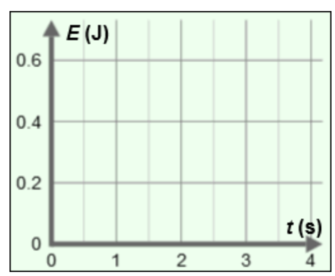
   A. What happens to kinetic energy as the car goes down the hill? __________________

   B. What happens to kinetic energy as the car goes up the hill? _____________________

4. Compare: Click **Reset**. Set **Hill 1** to 80 cm, **Hill 2** to 60 cm, and **Hill 3** to 79 cm. Be sure the 50-g toy car is selected, and press **Play**. Sketch the ***U* vs *t***, ***K* vs *t***, and ***E* vs *t*** graphs below.







5. Draw conclusions: How are potential energy, kinetic energy, and total energy related?

   ____

   ____

(Activity B continued on next page)

Activity B (continued from previous page)

6. Calculate: Gravitational potential energy (U) depends on three things: the object's mass (m), its height (h), and gravitational acceleration (g), which is 9.81 m/s^2 on Earth's surface:

$$U = mgh$$

Energy is measured in joules (J). One joule is equal to one 1 $kg \cdot m^2/s^2$. When calculating the energy of an object, it is helpful to convert the mass and height to kilograms and meters. (Recall there are 1,000 grams in a kilogram and 100 centimeters in a meter.)

   A. What is the mass of the 50-gram car, in kilograms? _______________

   B. Set **Hill 1** to 75 cm and the other hills to 0 cm. What is the height in meters? _______

   C. What is the potential energy of the car, in joules? ___________

7. Calculate: Kinetic energy (K) depends on the mass and speed (v) of the object. The equation for kinetic energy is:

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

With **Hill 1** set to 75 cm, click **Play** and allow the car to reach the bottom.

   A. What is the final speed of the car, in meters per second? ________________

   B. What is the kinetic energy of the car, in joules? (Use the mass in kg.) _____________

   C. How does the car's kinetic energy at the bottom of the hill compare to its potential

   energy at the top? ____

8. Challenge: With no friction, you can use the relationship between potential and kinetic energy to predict the speed of the car at the bottom of this hill from its starting height. To do this, start by setting the kinetic and potential energy equations equal to one another:

$$K = U$$

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

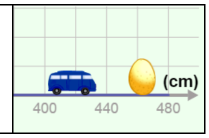
   A. Use algebra to solve for the speed. $v =$

   B. With no friction, does the final speed depend on the mass of the car? _______

   C. With no friction, does the final speed depend on the steepness of the hill? _________

   D. What is the final speed of the car if the height of the hill is 55 cm (0.55 m)? ________

   Use the Gizmo to check your answer.

Activity C: Breaking the egg	Get the Gizmo ready: • Click **Reset**. • Check that the **Coefficient of friction** is 0.00.	

Introduction: As the car rolls down a hill, it speeds up, gaining kinetic energy. The car also gains **momentum**. The magnitude of an object's momentum (p) can be found by multiplying the mass and speed ($p = mv$).

Question: What determines whether the car will break the egg?

1. Form hypothesis: Which factor(s) do you think determine whether the car breaks the egg?

   ☐ The mass of the car only ☐ The momentum of the car

   ☐ The speed of the car only ☐ The kinetic energy of the car

2. Collect data: Use the Gizmo to find the *minimum* hill height at which each car breaks the egg. In the table below, fill in the hill height (in centimeters and meters), and the speed of the car (in cm/s and m/s). Leave the last two columns blank for now.

Car mass (kg)	Height (cm)	Height (m)	Speed (cm/s)	Speed (m/s)	Momentum (kg•m/s)	Kinetic energy (J)
0.035 kg						
0.050 kg						
0.100 kg						

3. Analyze: Using the equations $p = mv$ and $K = \frac{1}{2}mv^2$, calculate the momentum and kinetic energy of each car. Remember to use the kg and m/s values for each calculation. Fill in the last two columns of the table.

   A. Does the car's mass alone determine whether the egg breaks? ____________________

   B. Does the car's speed alone determine whether the egg breaks? ____________________

   C. Does the car's momentum determine whether the egg breaks? ____________________

   D. Does the car's kinetic energy determine whether the egg breaks? ________________

   Explain your answers: ____

   ____

   ____

4. Draw conclusions: What is the minimum energy required to break the egg? ________________

Name: ______________________________________ Date: ________________________

Student Exploration: Inclined Plane – Sliding Objects

Vocabulary: acceleration, coefficient of friction, conservation of energy, friction, gravitational potential energy, inclined plane, kinetic energy, potential energy, velocity

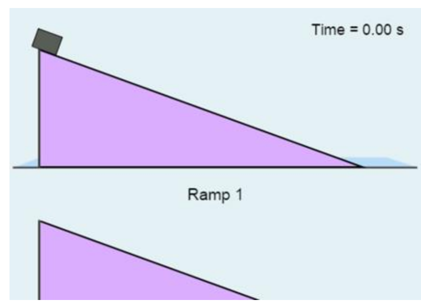
Prior Knowledge Questions (Do these BEFORE using the Gizmo.)
Two skiers are at the top of a mountain. Amanda decides to go down a steep trail that leads directly to the bottom. Brandon decides to take a longer, more gradual trail.

1. Assuming neither skier tries to slow down, who will reach the bottom first? ______________

2. Who will be going faster at the bottom? Explain. ___________________________________

   ____

Gizmo Warm-up
The two ski trails are examples of **inclined planes**. As objects move from the top of an inclined plane to the bottom, their **potential energy**, or energy of position, is converted into **kinetic energy**, or energy of motion. This process is explored in the *Inclined Plane – Sliding Objects* Gizmo.



To begin, check that **Ramp 1** has a **Steel block** on a **Frictionless ramp** with an **Angle** of 20°.

1. Click **Play** ( ). How does the block's speed change as it slides? ____________________

2. Select the TABLE tab and scroll to the bottom of the table.

   A. What is the final **velocity** (*v*) of the block? ____________________

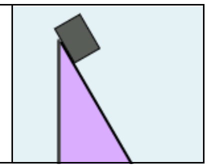
   B. What is the **acceleration** (*a*) of the block? ____________________

   The acceleration of the block is equal to how much its velocity increases each second.

3. Click **Reset** ( ). On the CONTROLS tab, change the **Angle** of **Ramp 1** to 60°. Select the TABLE tab and click **Play**. What is the final velocity and acceleration of the block this time?

   Final velocity: ____________________ Acceleration: ____________________

   Did the steepness of the plane affect the final velocity of the block? __________________

Activity A: **Potential and kinetic energy**	Get the Gizmo ready: • Click **Reset**. • Check that **Ramp 1** is a **Frictionless ramp**. • Check that the **Angle** of **Ramp 1** is 60°.	

Introduction: Potential energy is energy of position or shape. In this Gizmo, the block at the top of the ramp has **gravitational potential energy**, which is equal to the product of the block's weight and height: *GPE* = *wh*. The weight of an object is equal to the product of its mass and gravitational acceleration, which is 9.8 m/s^2 on Earth's surface. So, *GPE* = 9.8 $m/s^2 \cdot m \cdot h$.

Question: How is potential energy converted into kinetic energy?

1. Predict: As the block slides down the ramp, how do you expect the gravitational potential energy and kinetic energy of the block to change?

   ____

   ____

2. Observe: Select the ENERGY tab, and turn on **Show values**. Click **Play**.

   A. What happens to the potential energy (*PE*) over time? _________________________

   B. What happens to the kinetic energy (*KE*) over time? __________________________

   C. Click **Reset**. Click **Play**, and then click **Pause** ( ) when the block is about halfway down the plane. What is the sum of the potential and kinetic energy percentages?

   PE %: __________ *KE* %: __________ *PE* % + *KE* %: __________

3. Observe: Click **Reset**. Select the GRAPH tab, and check that the graph shows **Energy vs. Time**. Click **Play**. What do you notice? ____

   ____

4. Confirm: Repeat the experiment with ramps of varying steepness. Does the same pattern hold true? Explain.

   ____

   ____

   This demonstrates the law of **conservation of energy**, which states that in a closed system, energy is neither created nor destroyed.

(Activity A continued on next page)

Activity A (continued from previous page)

5. Manipulate: The kinetic energy (*KE*) of an object is equal to half of its mass (*m*) multiplied by the square of its velocity (*v*):

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

Rearrange the terms in this equation to solve for velocity:

$v =$

6. Demonstrate: If you know an object's mass and height, you can determine its gravitational potential energy. You can then use conservation of energy to determine the object's kinetic energy when it slides to the bottom of a frictionless ramp. Finally, you can determine the object's final velocity because you know its kinetic energy and mass.

   Click **Reset**. In the Gizmo, the object has a mass of 1 kg and an initial height of 1 m.

   A. What is the initial gravitational potential energy of the block? ___________________

   B. Based on conservation of energy, what will be the kinetic energy of the block when it gets to the bottom? ___________________

   C. What will be the final velocity of the block? __________

   Show your work:

   D. Click **Play** and select the TABLE tab. What is the block's final velocity? __________

   E. How does this experiment demonstrate conservation of energy? ________________

   ____

   ____

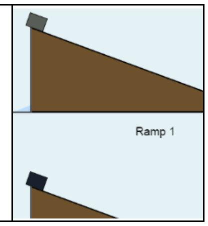
7. Think and discuss: Why doesn't the steepness of a frictionless ramp affect the velocity of the block at the bottom of the ramp? (Hint: Discuss conservation of energy in your answer.)

   ____

   ____

   ____

   ____

Activity B: **Friction**	Get the Gizmo ready: • Click **Reset**. On the CONTROLS pane, select a **Steel block** on a **Wood ramp** for **Ramp 1**. Select a **Rubber block** on a **Wood ramp** for **Ramp 2**. • Set the **Angle** of both ramps to 45°.	

Introduction: Friction is a force that opposes motion. The **coefficient of friction** (μ) is a value that represents how much friction exists between an object and a surface.

Question: How does friction affect a block sliding down an inclined plane?

1. Predict: Which block do you think will slide down the ramp most quickly? _______________

2. Observe: Select the ENERGY tab. Click **Play**.

   A. Which block reached the bottom first? _______________

   B. For the steel block, what percentage of its potential energy was converted into kinetic energy? __________ What percentage was lost due to friction? __________

   C. For the rubber block, what percentage of its potential energy was converted into kinetic energy? __________ What percentage was lost due to friction? __________

   D. Which block was more affected by friction? Explain. __________________________

   ____

3. Observe: Click **Reset**. Change the **Angle** of both ramps to 20°. Click **Play**. What happens?

   ____

   In some cases, the friction is so great that the object doesn't move at all!

4. Gather data: On the CONTROLS pane, turn on **Show coefficient of friction** for each ramp. Use the Gizmo to find the smallest ramp angle that still allows each block to slide. Use a calculator to find the sine (sin), cosine (cos), and tangent (tan) of that angle.

Block	Ramp	Angle	Sine	Cosine	Tangent	μ
Steel	Wood					
Rubber	Wood					

(Activity B continued on next page)

Activity B (continued from previous page)

5. Analyze: What pattern do you notice? ____

____

You can use this relationship to calculate an unknown coefficient of friction.

6. Apply: Click **Reset**. Turn off **Show coefficient of friction** for each ramp. For each combination of materials, use the Gizmo to find the smallest ramp angle that still allows each block to slide. Use a calculator to find each coefficient of friction. Then, turn on **Show coefficient of friction** and record the actual values.

Block	Ramp	Angle	μ (calculated)	μ (actual)
Ice	Rubber			
Rubber	Steel			
Wood	Ice			
Steel	Steel			
Wood	Wood			
Rubber	Rubber			

7. Interpret: Which combination resulted in the greatest friction? ________________________

Which combination had the least friction? _______________________________________

8. Analyze: Based on your results, which factors do you think are most important in determining the amount of friction between two surfaces?

____

____

____

9. Think and discuss: When an object slides down a ramp with friction, the kinetic energy at the bottom of the ramp is not equal to the potential energy at the top. Why doesn't this situation violate the law of conservation of energy?

____

____

____

Name: ______________________________________ Date: ________________________

Student Exploration: Energy of a Pendulum

Vocabulary: conservation of energy, gravitational potential energy, kinetic energy, pendulum, potential energy, velocity

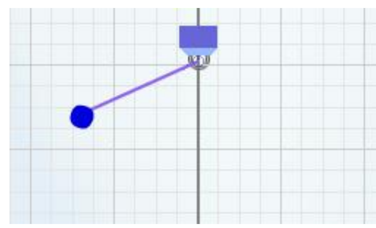
Prior Knowledge Questions (Do these BEFORE using the Gizmo.)

1. A toy car is about to roll down a track, as shown below. At what point do you think the car will reach its greatest speed?

   Mark this point on the image.

2. A **pendulum** consists of a weight that is suspended from a pivot. At what point will the pendulum below move fastest?

   Mark this point on the image.



3. What do these two situations have in common? ___________________________________

   ____

Gizmo Warm-up

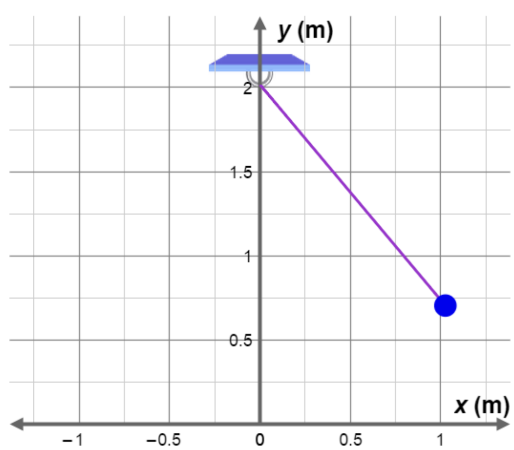
Objects have several types of energy. **Potential energy** depends on an object's position or shape. **Kinetic energy** is the energy of movement. The *Energy of a Pendulum* Gizmo allows you to explore how the amounts of these types of energy change for a pendulum in motion.

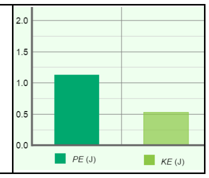
1. On the DESCRIPTION pane, change the initial angle (***θ***) to 40 degrees. Click **Play** (▶). How does the **velocity** (speed and direction) of the pendulum change as it swings from right to left?

   ____

   ____

2. On the image at right, mark the point where the pendulum swings fastest with an *X*. Then, circle the two points where the velocity is zero.



Activity A: **Potential and kinetic energy**	Get the Gizmo ready: • Click **Reset** ( ). • Check that ***m*** is 0.5 kg, ***L*** is 2.0 m, ***g*** is 9.8 m/s^2, and ***θ*** is 40 degrees.	

Introduction: An object that is a certain height (*h*) above the ground has the potential to do work, and therefore has potential energy. This type of potential energy is called **gravitational potential energy** (*GPE*, or *PE* for short). The unit of energy is the joule (J).

Question: How are potential and kinetic energy related?

1. Observe: Select the BAR CHART tab. Click **Play** and observe. What do you notice about the gravitational potential energy (***PE***), kinetic energy (***KE***), and total energy (***TE***)?

____

____

____

2. Measure: Click **Reset**. Turn on **Show numerical values**.

   A. What is the gravitational potential energy? ____________________

   B. What is the kinetic energy? ____________________

   C. What is the total energy? ____________________

3. Measure: Click **Play**, and then try to click **Pause** ( ) when the pendulum is in the middle of its swing. (This might require several tries.)

   A. What is the gravitational potential energy now? ____________________

   B. What is the kinetic energy now? ____________________

   C. What is the total energy? ____________________

4. Analyze: At any given time, what can you say about the total energy of the pendulum?

____

____

This illustrates the principle of **conservation of energy**. In a closed system, energy can be converted from one form to another, but the total amount of energy remains the same.

(Activity A continued on next page)

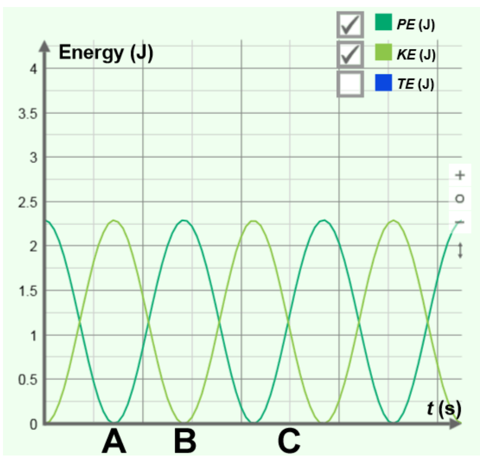
Activity A (continued from previous page)

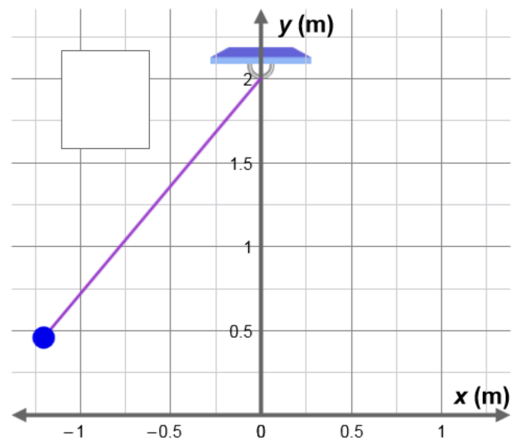
5. Interpret: Click **Reset**. Select the GRAPH tab and turn on the ***PE*** and ***KE*** checkboxes. Click **Play**, wait about 4 seconds, and then click **Pause**.

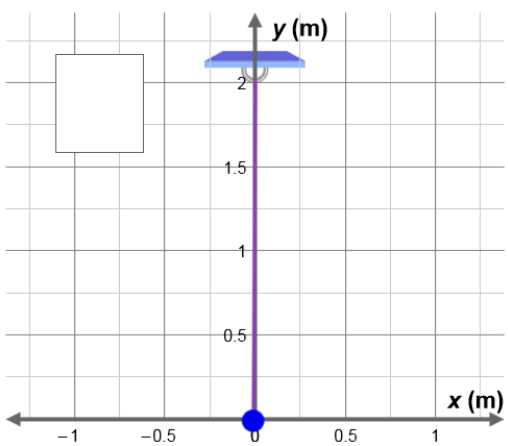
   What is the relationship between potential and kinetic energy? ______________________

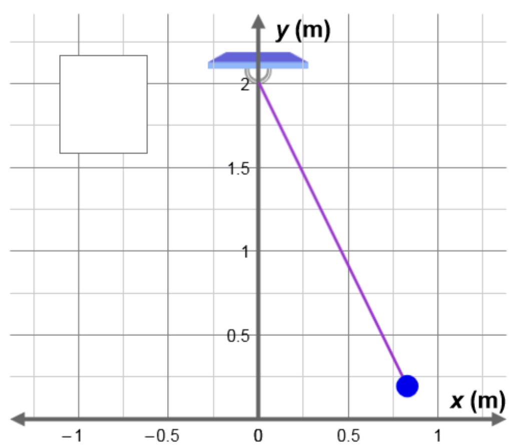
   ____

6. Match: The graph below shows the potential and kinetic energy curves for a pendulum. Label each pendulum image with the corresponding letter on the graph (*A, B,* or *C*).







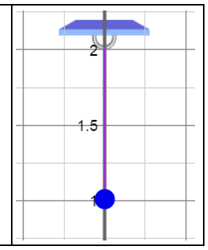


7. Apply: Suppose a pendulum starts with a potential energy of 100 J. Assuming the pendulum has a height of 0 m at the bottom of its swing, what is its maximum kinetic energy? Explain.

   ____

   ____

   ____

Activity B: **Calculating potential energy**	Get the Gizmo ready: • Click **Reset**. • Set ***m*** to 1.0 kg, ***L*** to 1.0 m, and ***g*** to 1.0 m/s^2. (Note: You can set the slider values directly by entering values into the text boxes.) • Set ***θ*** to 0 degrees.	

Question: How is gravitational potential energy calculated?

1. Observe: Select the BAR CHART tab, and check that **Show numerical values** is on.

   What is the potential energy of the pendulum? ___________________________________

2. Gather data: Record the potential energy of the pendulum for each of the following sets of values for ***m***, ***L***, and ***g***. Record the height (*h*) of the pendulum as well. (Because the pendulum's pivot is 2 m above the ground, the height is equal to 2 meters – *L* meters.)

m **(kg)**	***L*** **(m)**	***h*** **(m)**	***g*** **(m/s^2)**	***PE*** **(J)**
0.5 kg	1.0 m		6.0 m/s^2	
1.0 kg	1.2 m		2.0 m/s^2	
0.3 kg	1.1 m		1.0 m/s^2	
0.2 kg	1.5 m		3.0 m/s^2	

3. Find a pattern: What is the relationship between the potential energy of a pendulum and the values for mass (*m*), height (*h*), and gravitational acceleration (*g*)?

   ____

   ____

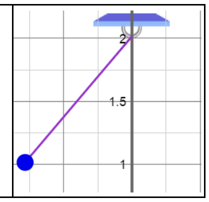
4. Make a rule: Write an expression for potential energy based on *m*, *h*, and *g*. Test your expression using the Gizmo.

   PE =

5. Apply: What is the potential energy of a pendulum with a mass of 0.7 kg, a height of 0.3 m, and a value of *g* equal to 9.8 m/s^2?

   ____

   Check your answer using the Gizmo. (Hint: Set the length of the pendulum to 1.7 m.)

Activity C: **Kinetic energy and velocity**	<u>Get the Gizmo ready</u>: • Select the DESCRIPTION tab. • Set ***m*** to 1.0 kg, ***L*** to 1.3 m, ***g*** to 1.0 m/s^2, and ***θ*** to $^-$40 degrees.	

Question: How is potential energy converted to kinetic energy?

1. <u>Observe</u>: Select the BAR CHART tab, and check that **Show numerical values** is on.

   A. What is the height of the pendulum? ____________________

   B. What is the potential energy of the pendulum? ____________________

   C. What is the kinetic energy of the pendulum? ____________________

2. <u>Observe</u>: Click **Play**, and then click **Pause** when the pendulum is at the bottom of its swing.

   A. What is the approximate height of the pendulum now? ____________________

   B. What is the potential energy of the pendulum? ____________________

   C. What is the kinetic energy of the pendulum? ____________________

3. <u>Calculate</u>: The formula for kinetic energy is as follows:

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

   Based on this formula, what is the velocity (*v*) of the pendulum at the bottom of its swing? Show your work.

   Velocity = ______________

4. <u>Apply</u>: Click **Reset**. Set ***m*** to 1.0 kg, ***L*** to 2.0 m, ***g*** to 9.8 m/s^2, and ***θ*** to –40 degrees. What is the maximum velocity of this pendulum? Show your work. (Hint: The exact height of the pendulum is now 0.468 m.)

   Velocity = ______________