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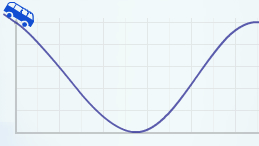
**Student Exploration:** **Energy of a Pendulum**

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

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

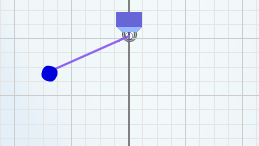
1. A toy car is about to roll down a track, as shown below. At what point do you think the car will reach its greatest speed?

Mark this point on the image.



1. 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.

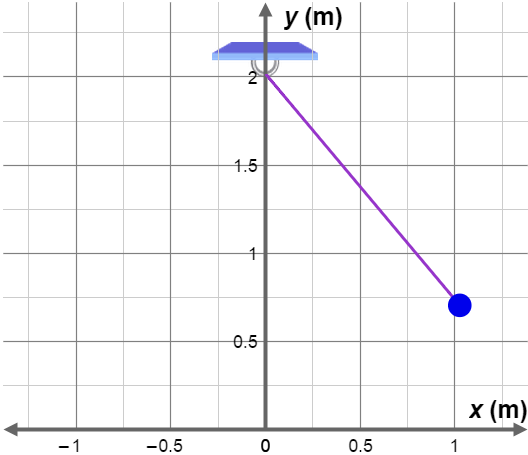


1. What do these two situations have in common? \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

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**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** (1). How does the **velocity** (speed and direction) of the pendulum change as it swings from right to left?

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1. 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.

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| **Activity A:**  **Potential and kinetic energy** | Get the Gizmo ready:   * Click **Reset** (3). * Check that ***m*** is 0.5 kg, ***L*** is 2.0 m, ***g*** is 9.8 m/s2, and ***θ*** is 40 degrees. | 390SE2 |

**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***)?

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1. Measure: Click **Reset**. Turn on **Show numerical values**.
2. What is the gravitational potential energy? \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_
3. What is the kinetic energy? \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_
4. What is the total energy? \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_
5. Measure: Click **Play**, and then try to click **Pause** (2) when the pendulum is in the middle of its swing. (This might require several tries.)
6. What is the gravitational potential energy now? \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_
7. What is the kinetic energy now? \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_
8. What is the total energy? \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_
9. Analyze: At any given time, what can you say about the total energy of the pendulum?

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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.

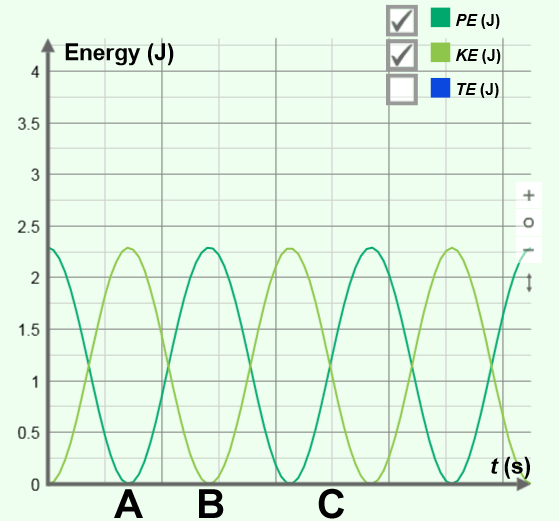
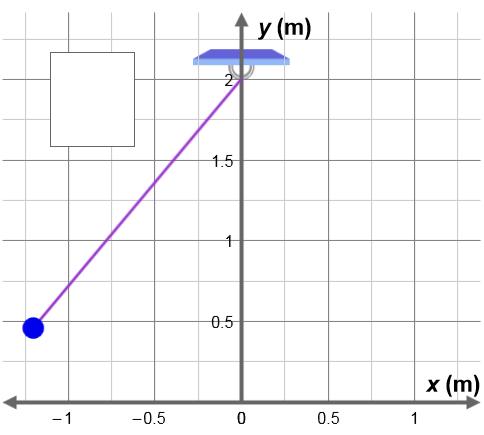
**(Activity A continued on next page)Activity A (continued from previous page)**

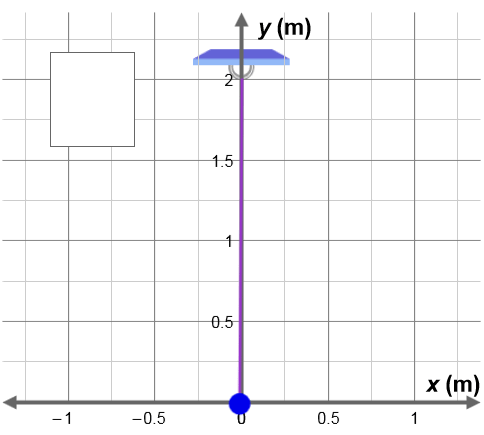
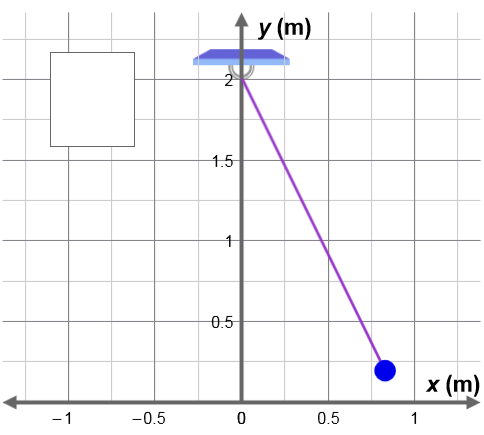
1. Interpret: Click **Reset**. Select the GRAPH tab and turn on the ***PE*** and ***KE*** checkboxes. Click **Play**, wait about 4 seconds, and then click **Pause**.

What is the relationship between potential and kinetic energy? \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

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1. 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*).

1. 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.

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| **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/s2. (Note: You can set the slider values directly by entering values into the text boxes.) * Set ***θ*** to 0 degrees. | 390SE7 |

**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? \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

1. 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.)

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| ***m* (kg)** | ***L* (m)** | ***h* (m)** | ***g* (m/s2)** | ***PE* (J)** |
| 0.5 kg | 1.0 m |  | 6.0 m/s2 |  |
| 1.0 kg | 1.2 m |  | 2.0 m/s2 |  |
| 0.3 kg | 1.1 m |  | 1.0 m/s2 |  |
| 0.2 kg | 1.5 m |  | 3.0 m/s2 |  |

1. 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*)?

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

*PE* =

1. 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/s2?

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

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| **Activity C:**  **Kinetic energy and velocity** | Get the Gizmo ready:   * Select the DESCRIPTION tab. * Set ***m*** to 1.0 kg, ***L*** to 1.3 m, ***g*** to 1.0 m/s2, and ***θ*** to –40 degrees. | 390SE8 |

**Question: How is potential energy converted to kinetic energy?**

1. Observe: Select the BAR CHART tab, and check that **Show numerical values** is on.
2. What is the height of the pendulum? \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_
3. What is the potential energy of the pendulum? \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_
4. What is the kinetic energy of the pendulum? \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_
5. Observe: Click **Play**, and then click **Pause** when the pendulum is at the bottom of its swing.
6. What is the approximate height of the pendulum now? \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_
7. What is the potential energy of the pendulum? \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_
8. What is the kinetic energy of the pendulum? \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_
9. Calculate: The formula for kinetic energy is as follows:



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

Velocity = \_\_\_\_\_\_\_\_\_\_\_\_\_\_

1. Apply: Click **Reset**. Set ***m*** to 1.0 kg, ***L*** to 2.0 m, ***g*** to 9.8 m/s2, 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 = \_\_\_\_\_\_\_\_\_\_\_\_\_\_