Pendulum Motion

Purpose: To analyze the back-and-forth motion of a pendulum.

Getting Ready: Navigate to the **Pendulum Motion Simulation** found in the **Waves and Sound** unit of the **Physics Interactives** section at **The Physics Classroom**. (**NOTE**: this simulation can also be found in the **Circular and Satellite Motion** unit.)

https://www.physicsclassroom.com/Physics-Interactives/Waves-and-Sound/Pendulum-Motion-Simulation/

Navigation:

www.physicsclassroom.com => Physics Interactives => Waves and Sound => Pendulum Motion Simulation

Getting Acquainted/Play:
This interactive consists of a simulation on the left side of the screen and a series of controls on the right side of the screen. The controls include **radio buttons** and **sliders**. By default, the simulation opens showing a ball hanging from the end of a light string and swinging along a circular arc. The radio button labeled **Ball on a vertical light string** is selected. There are three other options to explore. In this lab we will focus on the default option – the back-and-forth motion of the ball on a string, a.k.a., a pendulum. The buttons below the simulation allow you to play, pause, reset, and view in slow motion.
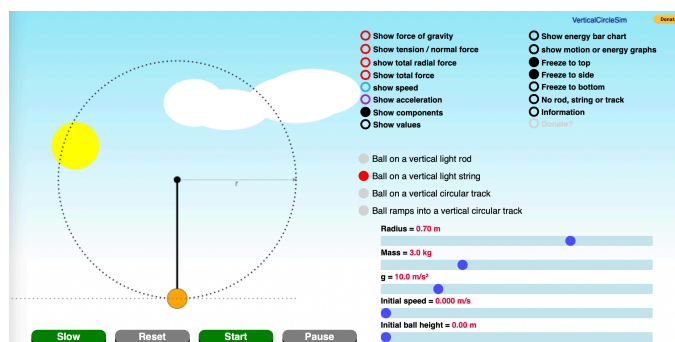
Observe the **radio buttons** that control the various displays (top). Experiment with the various display options, turning each on and off by tapping on the buttons and observing what they do.

Finally, the **sliders** at the bottom right side of the screen are motion parameters that can be changed. Experiment with each parameter by dragging their sliders left and right and observing their effect upon the simulated motion. We will be studying these cause-and-effect relationships later in this activity.

Part 1: Force Analysis

1. Reset the animation. Make sure you have selected **Ball on a vertical light string**. Enable the **Show force of gravity** and the **Show tension …** options. Disable all other options. The forces acting on the pendulum are shown on the ball and will change direction and size as the ball swings back and forth. We will analyze these forces and look for patterns. Using the sliders, set the **Radius** to 0.70 m; set the **Mass** to 3.0 kg; set the **Initial ball height** to 0.25 m. Set the other values to whatever you wish.
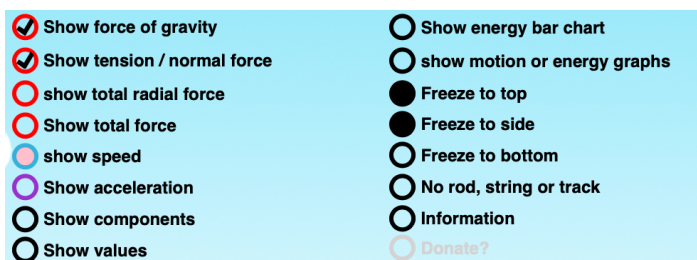
2. Tap **Start** and observe the forces acting upon the pendulum bob (ball). Does the magnitude and/or the direction of the force of gravity change during the motion?

3. Does the magnitude and/or the direction of the tension force change during the motion?

4. Use a short sentence to describe the direction of these two forces.

5. Consider the following five positions along the trajectory. Draw a free-body diagram for each of the positions. Label the forces according to type. Size your arrows to indicate the relative strength of the forces at each position.
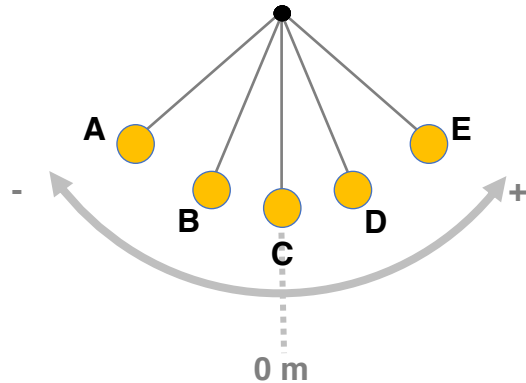
| **Position A** | **Position B** | **Position C** | **Position D** | **Position E** |
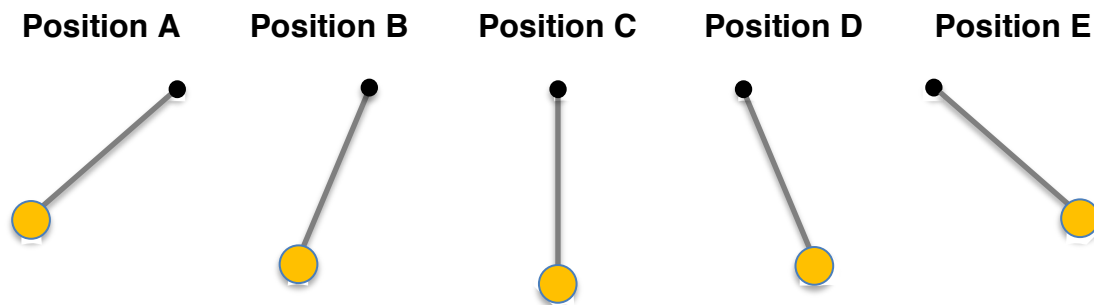
6. At what labeled position is the tension force …

   a. … the greatest? _____   b. … the smallest? _____

7. Now enable the **Show components** by tapping on the corresponding radio button. Note that the gravity force is resolved into two components – one tangent to the circular path and one that is directed towards center of the circle (radially).

   At positions A and E (the extreme positions), how does the size of the radial component of gravity compare to the size of the tension force?

   At position C, how does the size of the radial component of gravity compare to the size of the tension force?

8. Note that the tangential component of gravity is always directed tangent to the arc back towards position C. This is referred to as a **restoring force**. All objects undergoing periodic motion must experience a restoring force. At which labeled position(s) is the restoring force the greatest? _____

9. Any object moving along a circular path must experience a **centripetal force** (a net inward force). At which labeled position(s) is this net inward force the greatest? _____
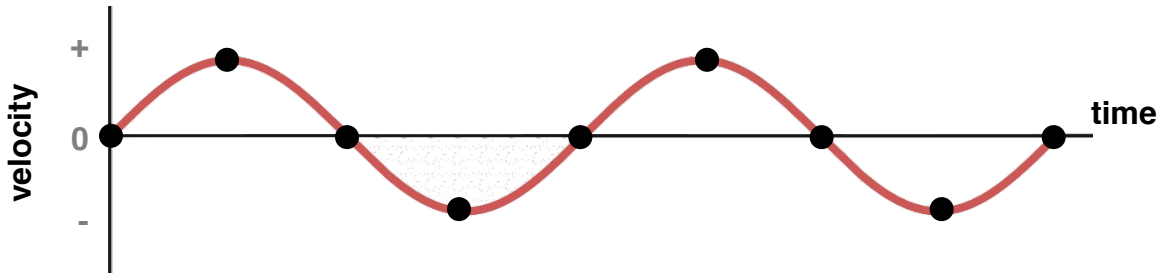
Part 2: Position-Velocity-Acceleration

10. Reset the simulation. Keep the **Radius** at 0.70 m. Increase the **Initial ball height** to 0.50 m. Tap on the **Show motion or energy graphs** option. Tap the graph to toggle to the display of position, speed (velocity), and acceleration. The displays assume a **reference frame** where the bottom-most position (**C**) is 0 m. A movement to the right of this position is in the + direction. A movement to the left of this position is in the – direction.

11. **Start** the simulation and observe the graphs as the pendulum moves back-and-forth. Tap on the **Slow** motion button if necessary. At what labeled position(s) is the pendulum bob (ball) when the velocity (speed graph) is 0 m/s? _____

12. At what labeled position(s) is the pendulum bob (ball) when the velocity is a maximum + value? _____

13. At what labeled position(s) is the pendulum bob (ball) when the velocity is a maximum - value? _____

14. Complete these sentences:

    As the bob moves from an extreme position (A or E) towards the central position (C), the speed _____ (increases, decreases). As the bob moves from C to A, the velocity becomes _____ (more +, more -, less +, less -). As the bob moves from C to E, the velocity becomes _____ (more +, more -, less +, less -).

15. Observe the Acceleration plot. Use the **Slow** and **Pause** buttons as necessary to answer:

    - The acceleration is a maximum + (rightward) value at position _____.
    - The acceleration is a maximum - (leftward) value at position _____.
    - The acceleration is a 0 m/s/s value at position _____.
    - Referring back to Part 1 of this lab, the acceleration is a maximum when the tangential component of gravity is _____ (greatest, 0 N). And the acceleration is 0 m/s/s when the tangential component of gravity is _____ (greatest, 0 N).

16. Consider the velocity-time graph below for two complete back-and-forth cycles. Label each dot on the graph with an A, C, or E based on its position at that point in time.

Part 3: Energy Analysis

17. Reset the simulation. Keep the **Radius** at 0.70 m. Increase the **Initial ball height** to 0.50 m. Close the **Graphs** option by tapping the Close button (bottom right). Tap on the **Show energy bar chart** option. Make observations of the bar heights for **KE** (kinetic energy), **PE** (potential energy), and **∑E** (total mechanical energy). Use the **Slow** and **Pause** buttons as necessary.

18. As the pendulum bob swings to and fro, how would you describe the amount of total mechanical energy?

19. At what labeled position(s) is the kinetic energy the greatest? _____

20. At what labeled position(s) is the potential energy the greatest? _____

21. Complete the bar charts below for positions A through E:
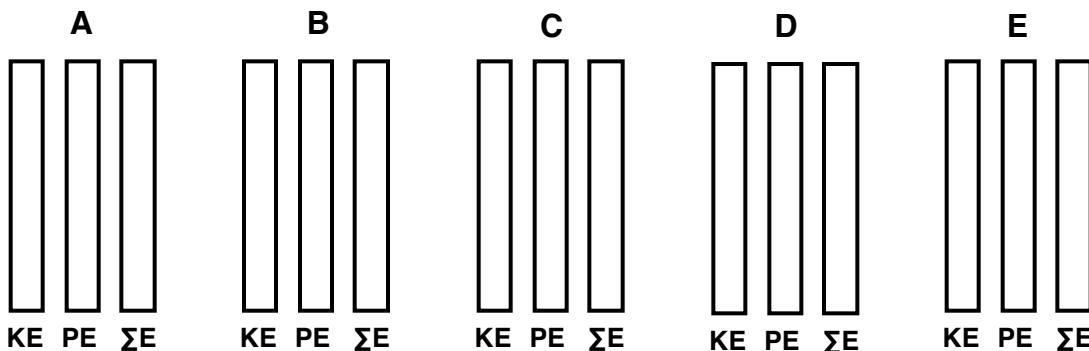
21. Complete the sentences using ↑, ↓, and = for increase, decrease, and remains the same.

As the pendulum bob moves from and extreme position (A or E) to the central position (C), the KE _____, the PE _____, and the ∑E _____.

And as the pendulum bob moves from the central position (C) to an extreme position (A or E), the KE _____, the PE _____, and the ∑E _____.