Moving in a Vertical Circle

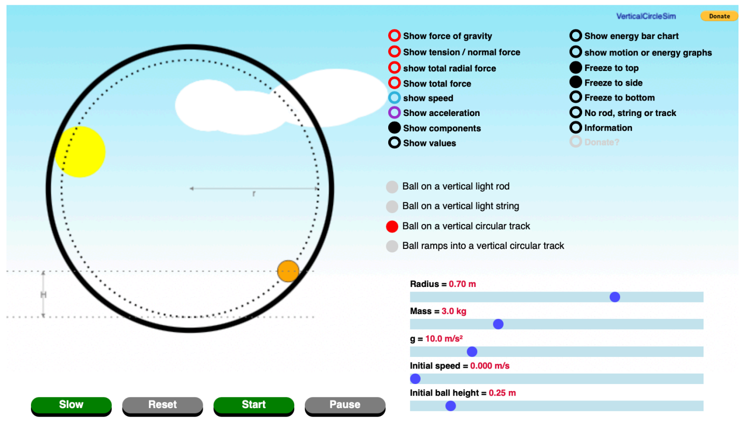
Purpose: To analyze the motion of objects moving in a vertical circle.

Getting Ready: Navigate to the **Vertical Circle Simulation** found in the **Physics Interactives** section at **The Physics Classroom**.

https://www.physicsclassroom.com/Physics-Interactives/Circular-and-Satellite-Motion/Vertical-Circle-Simulation

Navigation:
www.physicsclassroom.com => Physics Interactives => Circular Motion and Gravitation => Vertical Circle 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, Vertical Circle Simulation opens showing a ball hanging from the end of a light string and swinging in a vertical circle. By tapping on the **radio buttons**, you can select three other options: a ball attached to a rigid rod and moving in a vertical circle, a ball moving along a vertical, circular track, and a ball rolling down an incline into a circular track. Experiment with each. The focus of this activity will be **a ball on a vertical, circular track**. Select that option.



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.

Ball on a Vertical, Circular Track
Part 1: Force Analysis

1. Reset the animation. Make sure you have selected **Ball on a vertical circular track**. Enable the **Show force of gravity** and the **Show tension / normal …** options. Disable all other options. The forces acting on the ball will change direction and size as the ball rolls 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 0.50 m. Set the other values to whatever you wish.

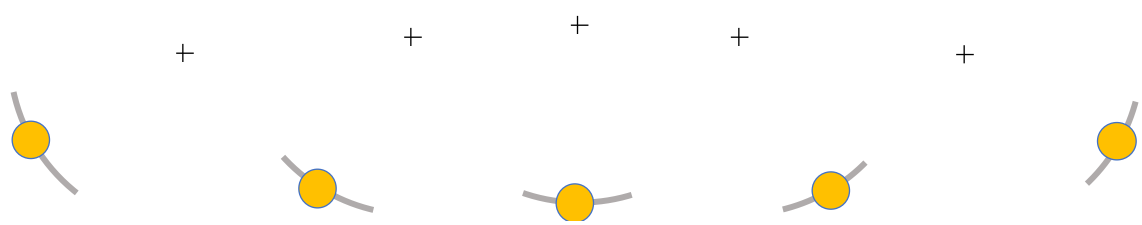
2. Tap **Start** and observe the forces acting upon the ball. Does the magnitude and/or the direction of the force of gravity change during the motion? (If necessary, tap on the **Slow** option.)

3. Does the magnitude and/or the direction of the normal 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(s) (A, B, C, D, and/or E) is the normal 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 normal force?

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

8. Tap on the **Show Speed** radio button. A vector arrow is drawn on the ball as it rolls back and forth. The length of the arrow indicates the magnitude of the ball's velocity (a.k.a., speed). The direction of the arrow represents the direction of the velocity vector. Circle the adjective that best describes the direction of the velocity vector:

   Inward   Outward   Tangent   A combination of these

9. At what position(s) is the ball when the velocity is a maximum value? _________

10. At what position(s) is the ball when the velocity is a 0 m/s value? ____________

11. Complete these sentences:

    As the ball rolls from an extreme position (A or E) towards the central position (C), the speed _____________________ (increases, decreases). As the ball rolls from the central position (C) to and extreme position (A or E), the speed _____________________ (increases, decreases).

12. Any object that is **moving** along a circular path must experience a **centripetal force** (a net inward force) that is dependent upon the speed. At which labeled position(s) is this net inward force the greatest? ______________ Propose a reason for why this is so:

13. For an object moving in a circle at a constant speed, the net force is 100% centripetal. But the ball is changing its speed. Thus, there will be a component of force tangent to the circle to speed it up and to slow it down. At which labeled position(s) is this tangential component of force the greatest? ______________

14. At which labeled position(s) is this tangential component of force the greatest? ______________ Propose a reason for why this is so:

Part 2: Energy Analysis

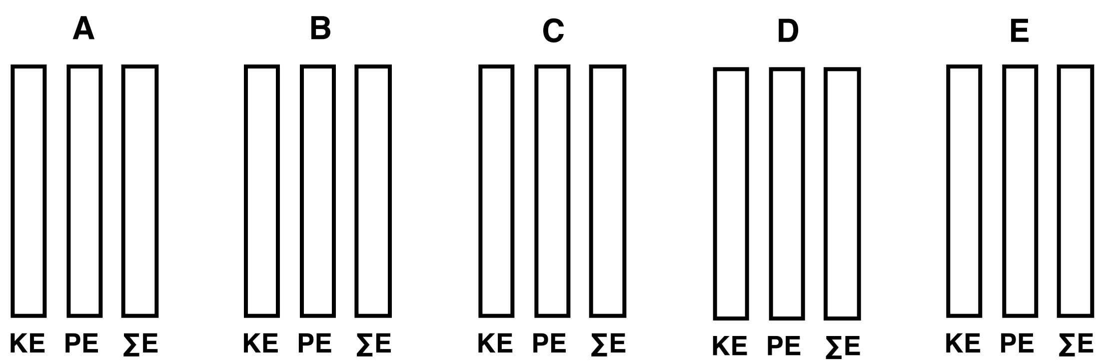
15. Reset the simulation. Keep the **Radius** at 0.70 m. Increase the **Initial ball height** to 0.50 m. Tap on the **Show energy bar chart** option. Make observations of the bar heights for **KE** (kinetic energy), **PE** (potential energy), and **∑E** (total mechanical energy). Use the **Slow** and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

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

17. At what labeled position(s) is the kinetic energy the greatest? _____________

18. At what labeled position(s) is the potential energy the greatest? _____________

19. Complete the bar charts below for positions A through E:



20. 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 _______.

Part 3: Loop the Loop

Now tap on the option **Ball ramps into a vertical, circular track**. Observe how the ball is positioned at the end of an inclined plane that leads into the track. Set the **Initial Speed** to 0 m/s and the **Radius** to 40.0 m.

21. Your goal is to determine the minimum required height in order for the ball to travel through the circular loop without losing contact with the track. You'll know contact is lost if you observe a sudden energy loss. You can change the height by first tapping on **Reset** and then either dragging the ball to a new height or dragging the **Initial ball height** slider. You will likely have to repeat several trials until you find that *perfect height* that is required for the ball to make the loop. Record findings in the table.

Radius (m)	Min. Height (m)	H_{min} / R ratio
40.0 m		
50.0 m		
(Your choice)		
(Your choice)		

22. Make a **Claim** in which you identify a general rule that determines what minimum height the ball must be released from in order to make it through a loop of known radius (**R**) without losing contact with the track. Justify your claim with **Evidence** and **Reasoning**.

Part 4: Theoretically Speaking …

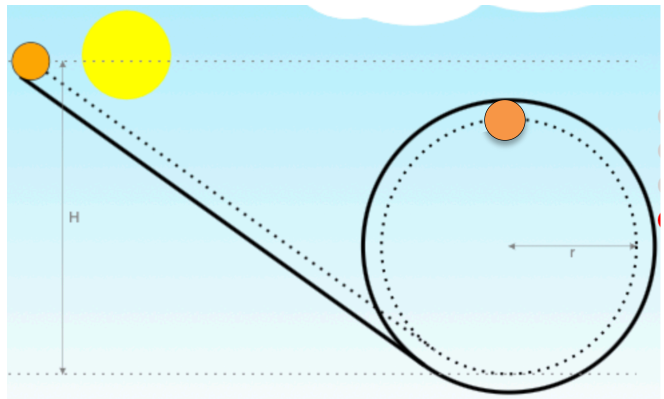
As the saying goes, “There is a reason for things, and that reason is usually Physics.” While the saying may not be universally true, it is certainly true when it comes to explaining the reason for your Part 3 discovery. Now you will use the Physics of energy conservation and circular motion principles to explain the last column of the Part 3 Data Table. You will derive an equation that shows the $\mathbf{H_{minimum}}$ **– Radius** relationship.

Here's what you know:

A. Total energy is conserved.

B. The acceleration (a) for an object moving in a circle is **$a = v^2/R$** where v = speed.

C. The minimum acceleration for traversing the loop while still maintaining contact is 9.8 m/s/s (g). If the acceleration becomes ≤ g, contact is lost.



Use equations for kinetic energy, potential energy, energy conservation, and centripetal acceleration to derive the $\mathbf{H_{minimum}}$ **– Radius** relationship. Introduce each step of the derivation with a short sentence describing the step.