LAB 7
When Pigs Fly
(Centripetal Force and Acceleration)

OBJECTIVES
(1) Study the forces on an object moving in a circular path.
(2) Verify that the centripetal force is given by \( F_c = \frac{mv^2}{r} \).

EQUIPMENT
Capstone, force sensor, photogate timer, digital scale, support rods and clamps, calipers, metal cylinder (pendulum bob), and string, Flying Pig apparatus.

BACKGROUND
A pendulum bob follows a circular path. Therefore, it is acted on by a centripetal (“center-seeking”) force, which is the name given to the net force required to keep an object of mass \( m \), moving at a speed \( v \), in a circular path of radius \( r \). In the case of the pendulum, the tension in the string causes the bob to follow the circular path. At the bottom of the pendulum’s swing, the net force on the bob is the combination of the tension in the string and the force due to gravity.

From Newton’s Second Law, \( \Sigma F = T - mg = ma = F_c \) where \( T \) is the tension in the string, \( m \) is the mass of the pendulum bob, \( g \) is the acceleration due to gravity, and \( F_c \) is the centripetal force.

The centripetal force can also be found from the speed, \( v \), of the bob as it passes through the lowest point of the swing using: \( F_c = ma_c = \frac{mv^2}{r} \) where \( r \) is the radius of the circular path which, in this case, is equal to the length of the pendulum.

PROCEDURE
Part 1: Set Up and Data Taking
(1) Measure and record the mass and diameter of the metal cylinder.

(2) Mount the force sensor and photogate timer on a horizontal rod as shown in the figure. To make a pendulum, use a piece of string that
is about 60 cm long. Tie one end of the string to the hook on the force sensor and the other end to the metal cylinder.

(3) Connect the force sensor and photogate timer to the DataStudio interface and open up the document titled **P4a_lab7_centripetal_acceleration**.

(4) Arrange the photogate so the cylinder blocks the photogate’s beam when the cylinder is at rest. The center of the cylinder should be approximately at the same height as the photogate beam.

(5) Measure the length of the pendulum from the bottom of the force sensor’s hook to the middle of the pendulum bob. Record the length of the pendulum.

(6) Practice swinging the pendulum bob. Pull the cylinder to the side about 10 – 15 centimeters. Gently release the bob so it swings through the photogate as smoothly as possible. The middle of the cylinder should break the photogate beam. Adjust the position of the photogate if necessary. Do not let the cylinder hit the photogate.

(7) Lift the cylinder and zero the force sensor by pressing the tare button.

(8) Set the pendulum in motion. Let the pendulum swing back-and-forth several times to allow any oscillations to damp out.

(9) Begin recording data. Record data for about 20 seconds. End data recording.

**Part 2: Analyzing the Data**

(1) In **Capstone**, click the Force vs. Time plot to make it active. Click the ‘Smart Tool’ button.

(2) Move the Smart Tool to the first trough in the plot of Force versus Time and read the value of force. Record the absolute value of the force; this is the tension in the string at the lowest point.

(3) From the tension in the string and the weight of the cylinder, calculate the centripetal force on the cylinder at its lowest point.

(4) In DataStudio, click the Time plot to make it active. Click the ‘Smart Tool’ button.

(5) Move the Smart Cursor in the Time plot to the point that corresponds to the trough you measured in the plot of Force versus Time. Record the value of the time. This is the time that it took the cylinder to pass through the photogate at the lowest point in its motion.

(6) From the diameter of the cylinder and the time it took the cylinder to pass through the photogate, calculate the speed of the cylinder at its lowest point.
(7) From the speed, mass, and radius of the pendulum, calculate \( \frac{mv^2}{r} \) and compare it to the value of the centripetal force using a percent difference.

(8) Repeat steps (1) – (7) for four more troughs on the plot of Force versus Time. Make sure that your record all of your data.

How do your measured values of centripetal force compare to the calculated values?

What are possible reasons for the differences between the measured and calculated values of centripetal force?

Part 3: When Pigs Fly

As the flying pig travels around in a horizontal circle, there are only two forces acting on the pig: the tension in the string and the force of gravity. We can apply Newton’s second law to the pig to derive an equation that relates the speed of the pig to the length of the string and the radius of the circular path.

(1) Draw a free body diagram of the forces acting on the pig.

(2) Apply \( \sum \vec{F} = m\vec{a} \) to solve for the speed of the flying pig as a function of \( r \), \( \theta \), and \( g \).

(3) Use trigonometry to convert \( \tan \theta \) into a function of \( r \) (the radius of the circular path) and \( L \) (the length of the string).

(4) From steps 2 and 3, derive an expression for the theoretical speed \( v_{thy} \) the pig as a function of \( r \), \( L \), and \( g \).

(5) Set up the flying pig apparatus and have each of your lab partners measure the radius of the circular path \( r \), the length of the string \( L \), and the period of motion \( T \).

(6) Calculate the experimental value for the speed \( v_{exp} = \frac{(2\pi)r}{T} \) and compare with the theoretical value that you derived in step 4 using a percent difference:

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\% \text{ difference} = \frac{\text{experimental} - \text{theoretical}}{\text{theoretical}} \times 100\%
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