Circular Motion and Centripetal Acceleration

Equipment

- Calculator, Computer, PASCO 850 Universal Interface
- Centripetal Force Apparatus
- Photogate Cable
- Pair of Banana Wires

Objective

Verify the relationship for centripetal acceleration.

Theory

We expect that the acceleration of an object that is undergoing circular motion should be:

$$a_c = \frac{v^2}{R} \tag{1}$$

where R is the radius of the circular path and v is the speed of the object. This acceleration is inward, toward the center of the circle, and is called the ***centripetal acceleration***.

The ***centripetal force*** is the ***net force*** that causes centripetal acceleration. It's impossible to measure a net force, but we can measure a single tension force. The PASCO Centripetal Force Apparatus is set up so that the tension force on a thin steel wire is equal to the net force on a revolving object (the "Free Mass"). This gives us a straightforward way to experimentally determine the centripetal acceleration of an object: Simply measure the centripetal force and use Newton's Second Law to calculate the acceleration.

Figure 1: Experimental setup, with connections. (Image adapted from PASCO EX-5506 Instructions.)

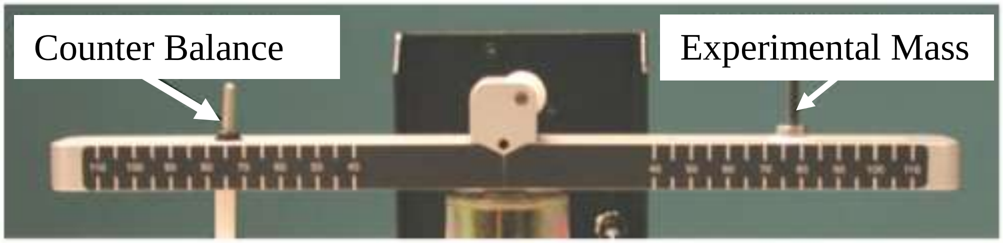

Figure 2: Rotating arm of the Centripetal Force Apparatus. The Experimental Mass is held in place when masses are secured to the top. The Counter Balance can slide freely even when masses are secured in place. (Image from PASCO ME-8088 Instructions).

Standard Operating Procedure

This section describes how to complete an experimental run. The same procedure will be used for your series of runs later. ***Caution!*** When the Signal Generator is turned On, the arm of the apparatus will rotate. Be sure it can do so without hitting anything or anybody.

1. Set the initial parameters:
   a. **Experimental Mass:** 39 g = 4 g (holder) + 35 g (extra mass).
      - The same mass is used throughout and should not be modified.

   b. **Radius:** Initially between 95 and 105 mm. It's difficult to choose an exact value. Just measure the middle of the mass after you set it.
      - This is a two-person operation: One person should support the horizontal bar and loosen the clamp. The other person should pull gently outward on the Free Mass so that the wire has some tension.
        Step 1: Raise or lower the Force Sensor until the Free Mass is at the desired radius.
        Step 2: Tighten the clamp.
        Step 3: Make sure that the wire is ***vertical*** and passes ***under the pulley***.
      - To balance the rotation and prevent wobble, move the counterbalance to the ***same radius*** as the Experimental Mass by losing the plastic rod underneath and sliding the mass.

   c. **Voltage:** This is done on the computer in Capstone.
      - Make sure the ***Signal Generator is Off***
      - Initially, set the DC Voltage to 5.5 V.
2. Zero the Force Sensor.
3. Check to make sure all wires are clear of the rotation of the Apparatus.
4. To actually run the experiment:
   a. Turn the Signal Generator On. This will start the rotation.
   b. Wait about 10 seconds for the motion to stabilize.
   c. Click Record to start recording data.
   d. The Period and Force will be measured, averaged, and displayed. When the force readings stabilize to two decimal places, click Stop.
   e. Turn the Signal Generator Off if you want to stop the rotation.
5. **Record your data**, including the run parameters (Voltage, Radius) and measurements (Period, Force). Be sure to record the radius in meters, not millimeters.

Voltage (V)	**Radius (m)**	**Period (s)**	**Force (N)**	**Angular Speed ω (rad/s)**	**Linear Speed *v* (m/s)**	**Acceleration from Kinematics (m/s^2)**	**Acceleration from Dynamics (m/s^2)**

Table 1: Template table for recording and analyzing circular motion data. Each line corresponds to one experimental run. Use a copy of this Table for each Data Series. Describe whether each column is an experimental parameters, a measurement, or a calculation. For a calculation, say what formula is used. Make sure the caption describes the data series, including and what the runs have in common and what plot will be generated from the Table. For all runs, the free mass was _____________.

Data Analysis

After each run:

- Calculate the angular speed (ω) of the Free Mass using the period (T):

$$\omega = \frac{2\pi}{T} \tag{2}$$

- Calculate the speed (v) of the Free Mass by using the period (T) and radius (R):

$$v = \frac{\text{Dist}}{\text{Time}} = \frac{2\pi R}{T} = \omega R \tag{3}$$

- Calculate the acceleration of the Experimental Mass using *kinematics formula* $a_c = \frac{v^2}{R}$.
- Calculate the acceleration of the Experimental Mass using $dynamics\ formula\ \sum F = ma$.

Part 1. Acceleration vs. Velocity (Linear speed)

1. Complete a series of runs with ***different velocities (linear speed)*** but use the ***same radius*** of 100 mm for each Run. Since the velocity can't be set directly, *adjust the motor voltage in increments of 0.5V starting from 5.5 V until 2.0 V*. For each run, measure the period and do the Data Analysis.

2. Plot each acceleration vs. velocity, so there will be two data series on the same graph: Kinematics Acceleration and Dynamics Acceleration.

- Do the two data series agree with each other?
- Based on the formulas used for calculations, what do you expect the shape of the graph should be?
- Does the curve meet the expected shape?

3. Obtain the best fit "trendline" that is appropriate for the ***both plots***. (Note: Linear trendline isn't appropriate.) Use the trendline equations and reference to the kinematics formula to determine the radius and compare the calculated value of the radius with the actual radius used in the experiment.

Part 2. Acceleration vs. Radius

1. Complete a series of runs with different radii, but use the **same voltage** of 5.0 V for each Run. This should keep the rotational period fairly consistent from Run to Run.

Use radii approximately every 10 mm. You don't have to hit each radius exactly; just get it within 5 mm. Record each actual radius in your data table.

- ~100 mm (Between 95 and 105 mm)
- ~90 mm (Between 85 and 95 mm)
- ~80 mm (Between 75 and 95 mm)
- ~70 mm (Between 65 and 75 mm)
- ~60 mm (Between 55 and 65 mm)
- ~50 mm (Between 45 and 55 mm)

2. Plot each ***acceleration vs. radius***, so there will be two data series on the same graph: Kinematics Acceleration and Dynamics Acceleration.

- Do the two data series agree with each other?
- Based on the formulas used for calculations, what do you expect the shape of the graph should be?
- Does the curve meet the expected shape?

3. Obtain the appropriate best-fit trendline for both plots. Decide which equation is more appropriate for the trendline:

$$a = \frac{v^2}{R} \qquad\qquad a = \omega^2 R$$

(Hint: is v or ω constant from Run to Run?)

4. Compare the trendline equations with the chosen kinematics formula; which value v^2 or ω^2 is present in the equations?.

Experimental Cleanup

- Keep the masses in place, and keep the Force Sensor attached to the small steel wire.
- Detach the photogate cable from both ends.
- Detach the Banana wires from both ends.
- Unplug the Force Sensor from the 850 Interface
- Hang the cables so they won't catch on anything.
- Carefully carry the apparatus back in the equipment staging area.

Requirements for Data Report 10 (also consult the rubric on Blackboard):

Save your Excel files through your Blackboard Group File Exchange

- The **abstract section** must contain the following explanations in paragraph form:
  - What is a centripetal force? How would an object released from circular motion move through space?
  - Where is the centripetal force in this experiment?
  - How the data was collected and calculated for Tables 1 and 2 (including formulas for angular speed, linear speed, and two formulas for centripetal acceleration)
  - When the period increased (decreasing voltage) while the radius remained constant, how the angular speed, linear speed, centripetal acceleration, and centripetal force were affected? Why?
  - When the period was kept constant while the radius was decreased, how the angular speed, linear speed, centripetal acceleration, and centripetal force were affected? Why?

- The **data section** must include:
  - 2 Tables (labeled and captioned)
    - Table 1: Constant Radius
    - Table 2: Constant Period
  - 2 Graphs (titled, axis labels, axis units, labeled and captioned)
    - Acceleration vs Velocity
    - Acceleration vs Radius