Lab 10 – Circular Motion and Centripetal Acceleration

Equipment

- Calculator, Computer, PASCO 850 Universal Interface
- Partially-assembled 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.

Experimental Setup:

1. Place the apparatus on the lab bench near the PASCO Interface, but away from the computer. Make sure the person using the keyboard and mouse is safe.
2. Use the Photogate Cable to connect the Photogate to Digital Input 1.
3. Use the Banana cables to the connect the power sockets on the Apparatus to the Outputs of the 850 Interface. It doesn't matter which plug is in which socket.
4. Connect the Force Sensor to PASPort 1 on the 850 Interface.
5. Manually rotate the arm (Figure 1) of the apparatus to make sure nothing is in the way. Don't get in the path of the beam when power might be applied!

When the setup is complete, it should look something like Figure 2.

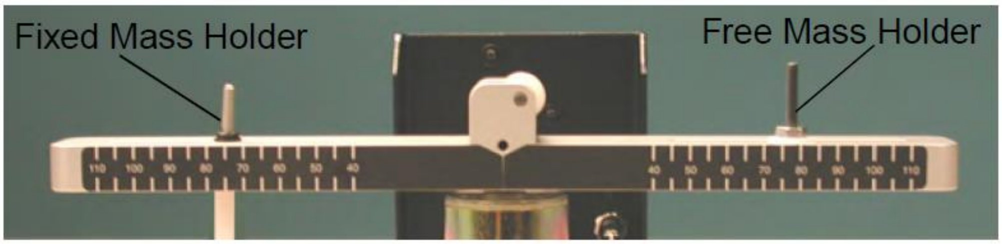

Figure 1: Rotating arm of the Centripetal Force Apparatus. The Fixed Mass Holder is held in place when masses are secured to the top. The Free Mass Holder can slide freely even when masses are secured in place. (Image from PASCO ME-8088 Instructions.)

Figure 2: Experimental setup, with connections. (Image adapted from PASCO EX-5506 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. **Decide** on the parameters of the Run. Use these parameters for the first run:
    a. **Free Mass:** 39 g = 4 g (holder) + 35 g (extra mass). (Never changes.)
    b. **Radius:** between 95 and 105 mm. It's difficult to set an exact value.
    c. **Voltage:** 5.0 V.
2. Set the mass. Don't do anything for this step. Both masses should already be 39 grams. If you were going to change the amount of mass, this is when you would do it.
3. **Set the radius.** This is a two-person operation.
    a. 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.
    b. Raise or lower the Force Sensor until the Free Mass is at the desired radius. It's tough to get an exact value, so just get it within the selected range of values.
    c. Tighten the clamp.
    d. **Make sure:**
        i. the wire is **vertical** and passes **under the pulley**.
        ii. the Free Mass is in the selected Radius range.
    e. Move the other mass to the **same radius** as the Free Mass Holder. This is to balance the rotation and prevent wobble. Loosen the plastic rod underneath to allow the mass to slide.
4. **Set the voltage.** This is done on the computer in Capstone.
    a. The Signal Generator tool panel should already be open.
    b. Make sure the Signal Generator is Off.
    c. Set the Waveform to DC.
    d. Set the DC Voltage to the desired voltage.
5. Zero the Force Sensor.
6. Check to make sure all wires are clear of the rotation of the Apparatus.
7. 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.
8. **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)	Theoretical Acceleration (m/s^2)	Experimental Acceleration (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 theoretical acceleration of the Free Mass using Eq. 1 above.
- Calculate the experimental acceleration using $F = ma$.

Data Series 1. Acceleration vs. Velocity

Complete a series of runs with **different velocities**, but use the **same radius** of 100 mm for each Run.

We can't set the velocity directly. The best we can do is set the motor voltage and measure the period. Use voltages of 2.0 V, 2.5 V, 3.0 V, 3.5 V, 4.0 V, 4.5 V, 5.0 V, and 5.5 V. (Note: you already have data for 5.0 V.) Do the Data Analysis for each run.

Graph each acceleration vs. velocity. There should be two data series on the graph: Theoretical Acceleration and Experimental Acceleration. What do you expect the shape of the graph should be? Does it meet that shape? Do the two data series agree with each other?

PHYS-2425: Obtain the best fit "trendline" that is appropriate for the **experimental acceleration**. (Note: a Linear trendline isn't appropriate.) Use the trendline to experimentally determine the radius, and compare it with the actual radius you used.

Data Series 2. Acceleration vs. Radius

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)

Graph each acceleration vs. radius. There should be two data series on the graph: Theoretical Acceleration and Experimental Acceleration. What do you expect the shape of the graph should be? Does it meet that shape? Why not? Do the two data series agree with each other?

PHYS-2425: Obtain the appropriate best-fit trendline for your **experimental acceleration**. 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?) Compare the results from your trendline to your experimental v^2 or ω^2.

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.