Uniform Circular Motion

Object:

To investigate the force required to move a mass along a circular path. Verify the theoretical expression for that force in terms of the frequency of rotation, the radius of the path and the mass being held in the circular path.

Apparatus:

Centripetal force apparatus set of 5g, 10g and 20g weights, two banana plugs, triple output power supply and the Data Studio instruments: Force_Vel linear SW, Force_mass SW, and Force_rad SW.

The apparatus used for this experiment (see fig. #1) measures the centripetal force needed to hold the rotating mass (*m*) in a circular path. With *Science Workshop*, we can obtain the angular velocity (ω) of the mass at any time. The velocity (v) of the mass can be calculated from the value of angular velocity (ω) and the radius (r) of the circular path. By measuring the centripetal force and varying ω, m and r, we can verify the theory and form of the centripetal force.

Theory:

When the mass of an object remains constant, Newton's second law takes the form

$$\vec{F} = m\vec{a}.$$

Eq. (1)

The centripetal acceleration required to move an object along a circular path of radius R, is $a = v^2/R$, where v is the speed of the mass as it moves around the circular path. Substituting this into Eq. (1), gives the centripetal force required to hold the mass in its circular path:

$$F = \frac{m\,v^2}{R}.$$

Eq. (2)

In circular motion, the speed of a particle and the angular velocity in radians/sec are related by the equation $v = \omega R$. Therefore, we get:

$$F = m\omega^2 R.$$

Eq. (3)

Examples of centripetal force include the tension in a string attached to an object twirled in a circular path, the friction between the tires of a car and a curve in the road, or Earth's gravity pulling a satellite, forcing the satellite to move in a circular orbit.
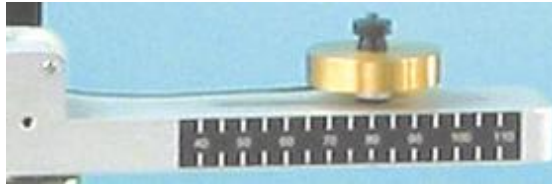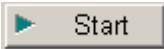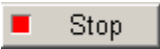
Procedure:

Experiment part 1: **FORCE VS. LINEAR VELOCITY (Radius and Mass Must be Constant)**

In this experiment, you will *vary the linear velocity* by changing the voltage to the electric motor while the centripetal force is continuously measured by the Force Sensor. The radius and mass are held constant as the angular velocity is increased. You will be using the instrument titled: Force_Vel Linear SW for this portion of the experiment. This instrument will be found in the physlab folder on your desktop.

1) Plug Force Sensor into position A on the Science workshop 750 interface

2) Plug the photogate into the position 1 on the Science workshop 750 interface

3) Use banana plugs to connect centripetal force motor to a power supply

3) To turn on the motor, turn on the power supply.

4)   Open the Physics Lab file: Force_Vel Linear SW

5)   To add mass to either of the arms, lay the components over the attachment screw in the following order: i) cable ii) mass and iii) thumbscrew.

6)   Allow the "free mass" some room to move within the slot. If the free mass cannot slide along the slot you will get a false reading.

7)   Place an equal amount of mass on both the "fixed mass" arm and the "free mass" arm.

8)   Make sure that the "free mass" and "fixed mass" have the same radius, so that the motor will be balanced when rotating.

9)   If necessary, adjust the height of the force sensor or the rotating platform, so that the masses maintain the same radius. Pull the "free" mass to tighten the cable to determine the actual radius.

10)   Turn on the power supply and adjust the voltage from 0 to 5 V. Observe the vertical section of cable. If it is not completely vertical, adjust the horizontal rod. While the instrument is running steadily, turn up the voltage on the power supply, there by speeding up the motor. When running, the instrument will be continuously plotting Force vs. angular velocity. Turn the power supply down to 0 V to stop the motor

11)   Press the "TARE" or "ZERO" button on the Force Sensor.

12)   Select [▶ Start] in DataStudio

13)   Turn on the power supply and adjust the voltage from 0 to 10 volts. Do not exceed 10 volts on the power supply. Collect data only as the velocity increases.

14)   Press [■ Stop] in DataStudio when the voltage reaches 10 volts
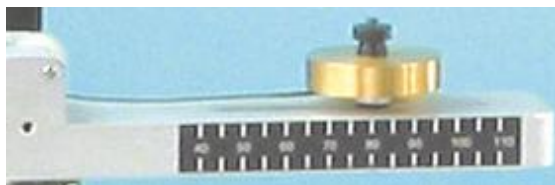15)   Turn off the motor by turning down the voltage.
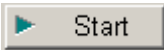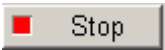
ANALYSIS: FORCE VS. LINEAR VELOCITY

1.   Observe your Force vs. Linear Velocity Graph. Select the "fit" button [Fit ▼] and choose the appropriate fit for your data.
2.   Make sure to note the mathematical form of your fit and what the various coefficients represent.
3.   Once the fit is complete print out the Force vs. Linear Velocity plot displaying the results of the fit.

Experiment part 2: **FORCE VS. MASS (Radius and Velocity Must be Constant)**

In this experiment, the radius and velocity are held constant as the *mass is varied.* By adding additional drilled masses to the rotating platform, the mass of the system is increased. Equal amounts of mass must be added to both the "fixed mass" and "free mass" side to balance the rotating platform. Centripetal force is directly measured by the Force sensor. Note, velocity is to be held constant so it is important to record force data only for the same angular velocity.

1)   Open the Science Workshop file: Force_mass SW

2)   Find the total mass of your weight. Enter that value in kilograms into the Force vs. Mass data table in DataStudio. To add mass to either of the arms, lay the components over the attachment screw in the following order: i) cable ii) mass and iii) thumbscrew.

3)   Allow the "free mass" to move (slide) within the slot. If the free mass cannot slide along the slot you will get a false reading.

4)   To avoid wobbling place an equal amount of mass on both the "fixed mass" arm and the "free mass" arm.

5)   Make sure that the "free mass" and "fixed mass" have the same radius, so that the motor will be balanced when rotating.

6)   Turn on the power supply and adjust the voltage from 0 to 5volts. Observe the vertical section of cable. If it is not completely vertical, adjust the horizontal rod. Turn the power supply down to 0 V

7)   Select **▶ Start** in DataStudio

8)   Slowly increase the voltage until the velocity maintains a constant value; for example, 2.0 m/s

9)   While the instrument is running steadily and continuously turn up the voltage to some pre-determined value on the power supply. Note the centripetal force is plotted on the computer display.

10)   Stop the instrument by clicking on **■ Stop** and lower the power supply voltage, stopping the motor.

9)   The instrument will have plotted the measured centripetal force. Use the cursor tool to find the best estimate for the centripetal force that was generated at a given/fixed velocity.

10)   The instrument for this experiment has both a data table and data display. Enter the mass and force data into the supplied table and plot the data.
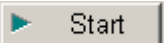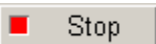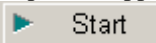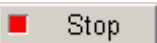
Perform several different mass runs, each time varying the mass on the free and fixed mass holders, making sure to ramp up the motor to the same angular velocity each time.

ANALYSIS: FORCE VS. MASS

1. Observe your Force vs. Mass Graph. Select the "fit" button and choose the appropriate fit for your data.
2. Make sure to note the mathematical form of your fit and what the various coefficients represent.
3. Once the fit is complete print out the Force vs. Mass plot displaying the results of the fit

EXPERIMENT 3: FORCE VS. RADIUS (Mass and Velocity Must be Constant)

In this experiment, the velocity and mass are held constant as the *radius is varied.* The radius of the "free mass" can be increased by lowering the Force Sensor, or raising the rotating platform. As the radius of the "free mass" increases, the "fixed mass" must be increased to a matching radius to balance the rotating arm. Again, centripetal force is measured by the Force Sensor.

1. Open the file: Force_rad SW
2. Make sure the power supply is off when you begin.
3. Attach 30g masses to the string and the rotating platform as in Experiment 1. The "free mass" should be able to slide freely back and forth in the slot. If it does not, adjust the nuts and washers accordingly.
4. Now, adjust the height of the force sensor so that the sliding mass maintains an approximately 0.050 m radius. Turn on the power supply and adjust the voltage from 0 to 5 V. Observe the vertical section of cable. If the vertical section of cable is not completely vertical, adjust the horizontal rod. Turn the power supply down to 0 V.
5. Pull the mass to tighten the cable to determine the actual radius. Enter the value of the radius in the Force v. Radius data table. Remember to adjust the fixed mass to match the radius of the free mass.
6. When ready press .
7. Slowly increase the voltage until the velocity acheives and maintains a constant value; for example, 2.0 m/s.
8. Press the button.
9. Without changing the voltage, turn off the power supply.
10. Press the "TARE" or "ZERO" button on the force sensor.
11. Turn on the power supply.
12. Press the button. Observe the velocity data. If it does not maintain a constant value return to step 6.
13. Allow data collection to occur for approximately 5 seconds. Press the button.
14. Enter the value of the Mean Force into the Force v. Radius data table.
15. From the Experiment Menu, select "Delete All Data Runs."
15. Return to step 4 and increase the radius by approximately 0.010 m (1.0cm).
16. Repeat data collection until at least 6 data pairs are recorded.

ANALYSIS: FORCE VS. RADIUS
1. Observe your Force vs. Radius Graph and Data Table.
2. Select the "fit" button ![Fit] and choose the appropriate fit for your data. Make sure to note the mathematical form of your fit and what the various coefficients represent.
3. Once the fit is complete print out the Force vs. Radius plot displaying the results of the fit.

<u>**Questions:**</u>

1. Using words and a mathematical expression, describe the relationship between force and mass in uniform circular motion.
2. Using words and a mathematical expression, describe the relationship between force and velocity in uniform circular motion.
3. Using words and a mathematical expression, describe the relationship between force and radius in uniform circular motion.
4. Combine the three relationships above to create one relationship for force, mass, velocity, and radius.
5. How would you convert this expression into an equation?
6. What is the constant of proportionality for this equation? Explain.
7. How could such an equation be used?
8. The figure below is an overhead view of the rotating mass. For each of the 4 points, draw the direction and relative magnitude of the force.