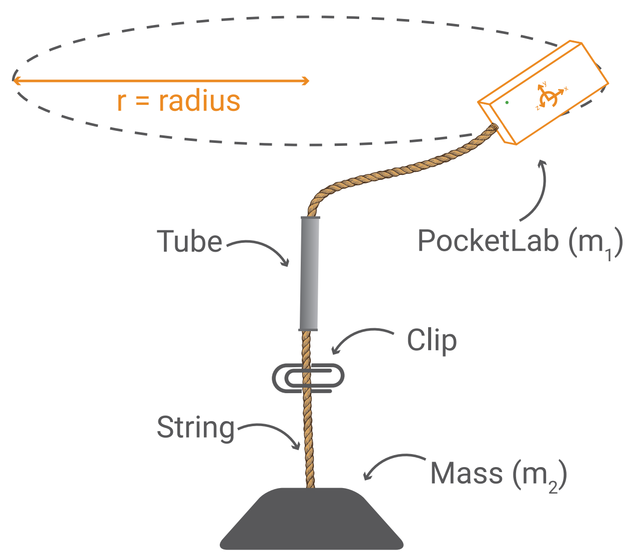
Understanding Centripetal Force

Exploration

An object experiencing a constant net force will experience a constant acceleration. Acceleration is defined as either a change in speed or a change in direction. When an object moves along a curved path it may maintain its speed, however it will be constantly changing its direction of movement. This type of acceleration along a curved path is called centripetal acceleration and is the result of a centripetal force, a force that is directed inward, toward the center of the curvature of the path. Examine the figure below.

Materials

- String or cord
- 15 cm of tubing
- Washers or masses to change m_2
- Paper clip/alligator clip/laundry clip
- PocketLab



Objective

In this experiment, students will:

1. Explore how changing m2 will affect the PocketLab's angular velocity and tangential velocity.
2. Explore how changing the radius will affect the angular velocity and tangential velocity.
3. Determine how these variables will also affect the centripetal acceleration of the PocketLab and the centripetal force acting on the PocketLab.

Equations

Use the following equations with your PocketLab measurements of angular velocity to determine tangential velocity and centripetal force and acceleration.

- The linear or tangential velocity of rotating object:

$$v_t = wr$$

where w is the angular velocity and r is the radius. (Use both the data collected from PocketLab's acceleration graph and the equation in your analysis).

- Centripetal acceleration:

$$a_c = v_t^2/r$$

Because the PocketLab is always changing direction about the radius, its centripetal acceleration can be calculated. As tangential velocity increases, so too should centripetal acceleration. The acceleration can display this relationship too.

- Equations for force and centripetal force:

$$F = ma \quad \text{therefore} \quad F_c = m_1 a_c \quad \text{or, by transitive property} \quad F_c = m_1(v_t^2/r)$$

Methods

1. Measure the mass of the PocketLab. Record as m_1.
2. Measure mass of the initial weights along with whatever is being used to hang the weights. Record as m_2.
3. Set up the apparatus as shown in the diagram. For the first part of the experiment, the radius between the tubing and the PocketLab will be kept constant. Measure the radius and record as r.
4. Place the clip 1 cm below the tubing as a reference point.
5. Begin spinning the PocketLab to a speed where the tubing is consistently 1 cm above the clip.
6. Record the angular velocity and acceleration or acceleration scalar data.
7. Change m_2 by adding weights. When changing m_2 use consistent increments of change. Repeat steps 4–6 for each change to m_2.
8. For the second part, keep m_2 constant. Change the radius, r, by moving the tubing to different points on the string. Repeat steps 4–6 for each change to r.

Predictions

- How will changing m_2 affect the angular velocity of the PocketLab? How will it then affect the PocketLab's tangential velocity, centripetal acceleration, and centripetal force? Explain your answer.
- How will changing r affect the angular velocity of the PocketLab? How will it affect the PocketLab's tangential velocity, centripetal acceleration, and centripetal force? Explain your answer.

Data Analysis and Observations

- After recording the PocketLab's angular velocity and acceleration data for each trial, use the equations to calculate the PocketLab's tangential velocity, centripetal acceleration (compare the results of the equation with the data collected for acceleration scalar), and the centripetal force acting on the PocketLab.
- As m_2 increases, what happens to the angular velocity, tangential velocity, centripetal acceleration, and centripetal force?
- As r increases, what happens to the angular velocity, tangential velocity, centripetal acceleration, and centripetal force?

Conclusions

- Explain why m_2 affected angular velocity in the way it did. Why did that in turn affect the other dependent variables?
- Explain why r affected angular velocity in the way it did. Why did that in turn affect or not affect the other dependent variables?

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TEACHER GUIDE

Ensure the apparatus is set up correctly for each group of students. Start with small weights for m_2 so the gyroscope won't max out when weight is added. The average angular velocity for each spin during the trials can also be found by timing how long it takes for the PocketLab to rotate 10 times and then calculating the degrees per second of the rotation. Students can then compare the average angular velocity that they calculated manually with the angular velocity recorded from the PocketLab throughout the trial.

Students should observe the angular velocity required will increase as m_2 increases. The centripetal force keeping the PocketLab spinning in a circle, rather than flinging off in a straight line is caused by the tension of the string and the weight of m_2. As m_2 increases, the centripetal force increases and therefore the angular velocity to keep the apparatus in equilibrium also increases.

When m_2 is constant, and the radius changes, students should observe that the angular velocity is not affected. As the radius increases, the angular velocity will remain the same. Through observation of the acceleration or acceleration scalar graph students will see the tangential velocity increase as the radius increases. The tangential velocity and therefore the centripetal acceleration increases because the PocketLab will have to travel a greater distance/arc in order to travel the same degrees per second as at a smaller radius. When students find the tangential velocity, centripetal acceleration, and centripetal force using the equations, they should observe this relationship.