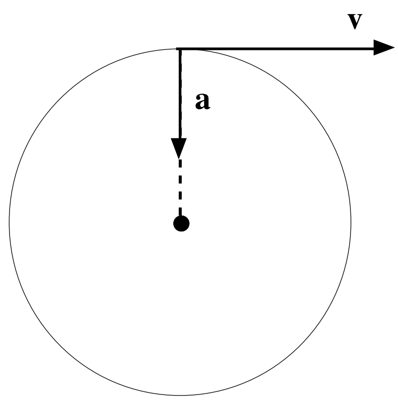
Experiment 5: Centripetal Force

Introduction

The word **centripetal** means "center-seeking". It is used in physics to describe any force that causes an object to move in a curved path. In our experiment today, we shall study the centripetal force on an object moving in a circular path.



We will be concerned with **uniform circular motion**, which occurs when an object moves in a circular path with constant speed. The object's *speed* (v) is constant because the object covers the circumference of the circle in equal intervals of time. Notice, however, that the *velocity* ($\mathbf{v}$) of the object is not constant because the object continuously changes its direction. As we have seen in class, this means that the object is being *accelerated* towards the center of the circle. A force (or net force) must provide this acceleration and this force is called the **centripetal force**. It points in the same direction as the acceleration, namely towards the center of the circle.

Please note the following important points about the centripetal force. First, the centripetal force is not a new kind of physical force; the word "centripetal" is simply an adjective which describes the direction of some already-existing force or forces. Second, the centripetal force which causes an object to move in a curved path is always the *net force* on the object in question; there may not actually be any single distinct physical force pointing towards the center of the curved path.

If the object has a mass m, a speed v, and moves in a circle of radius r, then the magnitude of the centripetal force acting on the object must be

$$F_{cent} = \frac{mv^2}{r} \tag{1}$$

From this equation, we see that the centripetal force required to keep a given object on a circular path depends on the speed with which the object travels the path and also on the radius of the path. We are familiar with this effect if a ball, attached to a string, is whirled over our head. As we increase the speed of the whirling, we feel the tension in the string increase. Also, if we change the radius of the path, we can feel the change in the centripetal force needed to keep the object on the new circular path. This force must increase if we decrease the radius of the path. We will investigate Equation 1 quanitatively in this lab experiment.

Apparatus

The apparatus for this experiment looks rather like a fishing pole. A spring scale (the "reel") is mounted on the pole so that you can slide it back and forth along the pole. A string runs from the scale, along the pole to its tip, and then extends beyond the pole. At the end of the string a mass is attached (a rubber stopper).

In normal operation, you hold the pole vertically, and whirl the mass around in a horizontal circular path over your head. The spring scale measures the tension in the string, which provides the centripetal force.With a bit of practice you can whirl the mass around at a constant speed so that the centripetal force (as measured by the spring scale) remains constant.

By sliding the spring scale back and forth along the pole, you change the amount of string that extends past the tip of the pole, and thereby the radius of the circular path of revolution.

Part I: Constant Force, Varying Radius

1. Measure the mass of the stopper. You can do this while leaving the stopper fastened to the string.

2. Lay the apparatus on the table and slide the spring scale along the rod until the length of the string from the tip of the rod to the center of the stopper is exactly 30 cm, when the string is pulled so that the spring scale reads 2.0 Newtons.

3. Whirl the stopper at constant speed, such that the spring scale reads 2.0 N, and measure the time that it takes for 20 revolutions. Record this time and repeat *two* more times. Find the average time of these three trials. Record the spring scale reading as your "measured" centripetal force.

4. Repeat Steps 2—3 four more times for string lengths of 40 cm, 50 cm, 60 cm, and 70 cm. Each time, move the scale so that the string is the specified length (from the tip of the pole to the stopper) when the spring scale reads 2.0 N.

5. For each of the five trials, compute the speed of the stopper, using the average time and the distance the stopper traveled during that time.

6. Predict the "theoretical" centripetal force for each trial using Equation 1. Calculate the percent differences between the "theoretical" and "experimental" values for the centripetal force.

Part II: Constant Radius, Varying Force

7. Lay the apparatus on the table and slide the spring scale along the rod until the length of the string from the tip of the rod to the center of the stopper is exactly 75 cm, when the string is pulled so that the spring scale reads 2 Newtons.

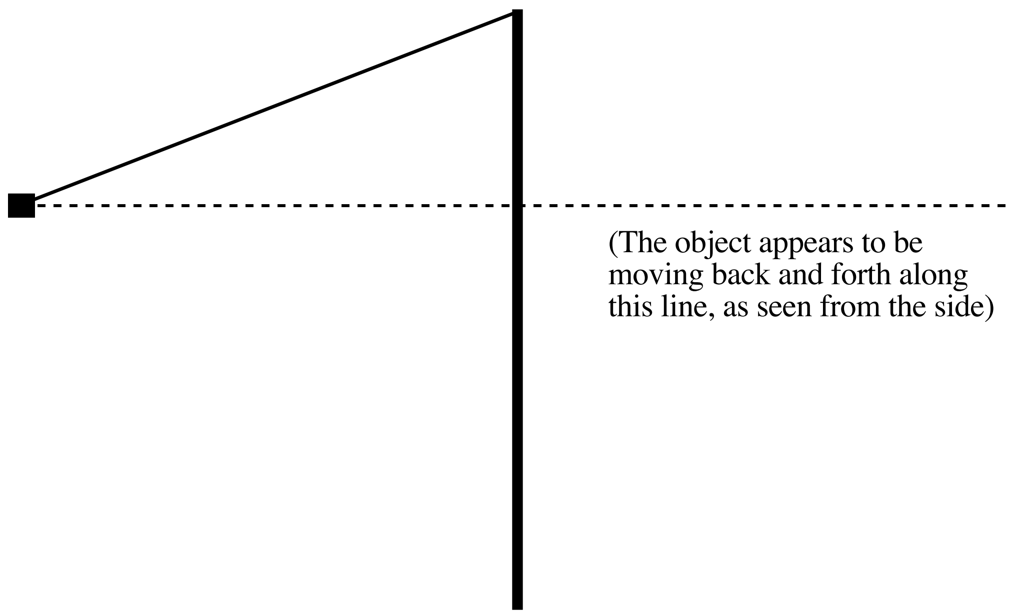
8. Take data as in Part I (Step 3).

9. Repeat Step 7—8 for a radius of 75 cm, but with spring scale readings of 2.5, 3.0, 3.5, and 4.0 Newtons. Notice that you must slightly adjust the position of the spring scale along the rod when you change the force, in order to keep the radius the same.

10. Analyze your measurements similarly to Part I, steps 5—6.

Questions

1. In our discussion of the experiment, we assumed that the string extends horizontally from the tip of the rod, when the stopper is "orbiting," as shown in Figure 1. Actually the string hangs at an angle, as shown in Figure 2 (which is a *side view* of the apparatus). This should be plainly visible as you watch the stopper orbiting. (Nevertheless, for the purpose of deriving the equation in Advance Question #4, you may safely assume that the string is horizontal, amazingly enough!)



On the diagram above, sketch vector arrows which represent all the separate physical forces which act on the orbiting object (ignoring air friction). Also, sketch the *resultant* of these forces.

2. On Figure 2 above, mark the center of the stopper's circular path. Which of the forces (whose vector arrows you just drew) is also the centripetal force that keeps the stopper in its circular path?

3. Describe carefully the motion of the stopper if the string breaks. What does this look like from a top view and from a side view? (draw sketches)

4. In a similar experiment, but using a different stopper, it is found that when the force on the spring scale is 1.80 N and the length of the string is 30.0 cm, the stopper completes 50 revolutions in 17.2 s. What is the mass of the stopper?

Advance Questions

1. In uniform circular motion, which of the following is constant: the object's speed, velocity, both, or neither?

2. If you double the speed of an object which is moving in uniform circular motion, while keeping the radius of the circle constant, by what factor does the centripetal force change?

3. If you double the radius of the circle,while keeping the speed the same, by what factor does the centripetal force change?

4. Find a single formula which you can use to calculate the speed of the stopper in step 5 of the Procedure, given the radius of the circular path and the time required for 20 revolutions.