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# Investigation 3.1.1: Analyzing Uniform Circular Motion

INQUIRY SKILLS

- ○ Questioning
- ● Hypothesizing
- ● Predicting
- ○ Planning
- ● Conducting
- ● Recording
- ● Analyzing
- ● Evaluating
- ● Communicating

We have noted that the velocity of an object in circular motion at a constant speed is constantly changing in direction. Consequently, the object is undergoing acceleration directed toward the centre of the circle. The apparatus shown in **Figure 1** is designed for you to gather data as a rubber stopper travels with uniform circular motion. The apparatus consists of a hollow tube that can be held vertically in your hand and twirled around, causing the rubber stopper at the end of the string to revolve horizontally. The string to which the stopper is attached hangs through the tube and supports various masses. The force of gravity acting on these masses provides the tension force needed to keep the stopper moving along a circle.

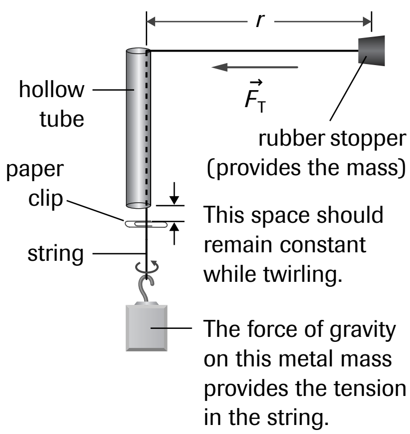


**Figure 1**
A rubber stopper twirled in the horizontal plane at a constant speed with a constant radius experiences uniform circular motion.

## Question

What is the relationship between the frequency of revolution of an object in uniform circular motion and

- the magnitude of the force causing the circular motion?
- the radius of the circular path?
- the mass of the object?

## Hypothesis/Prediction

(a) State what you think is the relationship between the frequency of revolution and each variable named in the Question. Give a reason in each case.

(b) Sketch three graphs to illustrate your answers to (a).

**LEARNING TIP**

**Data Analysis**
Investigation 3.1.1 is a controlled experiment in which three independent sets of data are analyzed to determine three different proportionality statements. An overall relationship can then be determined by combining the statements. Any one of the following methods can be used for the analysis:

- proportioning
- plotting of graphs to obtain straight lines
- log-log graphing
- using a graphing calculator

Appendix A discusses these methods.

*(continued)*

## Materials

*For each group of three or four students:*
a reinforced glass tube with smooth ends
1.5 m of fishing line or strong, smooth string
three one-holed rubber stoppers of equal size
metal masses (50 g, 100 g, and 200 g)
small paper clip or masking tape
electronic or triple-beam balance
metre stick

*For each student, depending on the method of data analysis chosen:*
linear graph paper (optional)
log-log graph paper (optional)
graphing calculator (optional)

## Procedure

1. Prepare a data table. You will need to have three sets of values when varying the tension force, three sets when varying the radius, and three sets when varying the mass.

*(continued)*

 

**Appoint a spotter, responsible for keeping the working area clear of other students.**
**Wear impact-resistant safety goggles.**

2. Measure and record the mass, in kilograms, of each rubber stopper.
3. With one rubber stopper attached securely to one end of the string, hang a 200-g mass on the other end of the string and begin twirling the stopper around your head. Practise twirling the stopper in such a way that its path remains horizontal and at a constant radius. Do not proceed to the next step until you have gained proficiency in twirling the stopper at a constant speed.
4. Use the following method to control a constant radius of 75 cm: attach a paper clip or a small piece of masking tape 1 cm below the bottom of the tube when $r = 75$ cm. With this radius, a constant mass of one rubber stopper, and a tension force of 1.96 N (caused by the 200-g mass), twirl the stopper at a constant speed and measure the time for 20 complete cycles. Repeat this measurement until you think you have a good average value. Calculate the frequency of revolution. Enter your data in your data table.

5. Repeat step 4 using a tension force of 1.47 N, then 0.98 N, placing the appropriate mass on the end of the string both times.

*(continued)*

6. With the mass constant at one rubber stopper and the tension force constant at 0.98 N, measure the time for 20 complete cycles when $r = 60$ cm and $r = 45$ cm. Repeat any measurements for accuracy. Calculate the frequencies and tabulate the data.

7. With a constant radius of 75 cm and a constant tension force of 1.96 N, add a second rubber stopper and measure the time for 20 complete cycles. Add a third rubber stopper and repeat the procedure. Calculate the frequencies and tabulate the data.

## Analysis

(c) Use graphing techniques to determine the relationship (proportionality statement) between the frequency of revolution and each of the following:
- the magnitude of the tension force (varied in steps 4 and 5)
- the radius of the circle (varied in step 6)
- the mass of the object in motion (varied in step 7)

*(continued)*

 

(d) Combine the three results from (c) to obtain an equation for the frequency in terms of the tension, the radius, and the mass. Check your equation using your data points.

(e) The following relationship gives the magnitude of the net force causing the acceleration of an object in uniform circular motion:

$$\sum F = 4\pi^2 m r f^2$$

Rearrange this equation to isolate the frequency. Compare this result with the equation you derived in (d). Indicate the likely causes for any discrepancies.

(f) Draw an FBD of the mass in circular motion in this investigation. Be realistic here: Is the tension force on the stopper truly horizontal?

*(continued)*

## Evaluation

(g) For the greatest accuracy in this investigation, the tension force acting on the stopper should be horizontal. In this context, what happens to the accuracy as the frequency of revolution of the stopper increases (with other variables held constant)?

(h) Describe the sources of random, systematic, and human error in this investigation, as well as ways you tried to minimize them.

## Synthesis

(i) Explain how this investigation illustrates all three of Newton's laws of motion.

 