Lab Handout

Lab 11. Circular Motion: How Does Changing the Angular Velocity of the Swinging Mass at the Top of a Whirligig and the Amount of Mass at the Bottom of a Whirligig Affect the Distance From the Top of the Tube to the Swinging Mass?

Introduction

Many things move in a circular path. For example, protons in the Large Hadron Collider, a car making a turn, and people on swing rides at amusement parks (see Figure L11.1) all move in a circular path. The orbital motion of many moons and planets is nearly circular as well. Even the stars in the spiral arms of the Milky Way galaxy, as they make their way around what may be a supermassive black hole at the galactic center, undergo circular motion.

Newton's first law of motion indicates that, without an unbalanced force acting on an object, an object moves in a straight line at constant speed. When we see an object traveling in a circular path, we must therefore assume that there is an unbalanced force acting on it. The unbalanced force is called a *centripetal* force. A force pulling toward the center of an object's circular path is what keeps it from moving in a straight line (*centripetal* comes from Latin, meaning "toward the center"). A centripetal force is whatever is causing the motion to be circular. For a planet, the centripetal force is gravity. For a turning car, friction between the tires and the road is the centripetal force. The string tension in the swing ride shown in Figure L11.1 is the force that keeps the people moving in a circle.

FIGURE L11.1

The people on an a swing ride at an amusement park move in a circular path over time

We use the term *uniform circular motion* to describe the motion of an object when it follows the path of a circle with a constant speed. As it moves, it travels around the perimeter of the circle. The distance of one complete cycle around the perimeter of a circle is equal to the circumference of the circle. The average speed of an object in uniform circular motion can therefore be calculated using the following equation:

$$\text{Average speed} = \frac{2\pi \mathbf{r}}{T}$$

Velocity, unlike speed, has both a magnitude and a direction. The magnitude of the velocity vector is the instantaneous speed of the object. The velocity vector of an object in uniform circular motion is constant in magnitude but changing in direction. Since the object is constantly changing direction as it travels around the perimeter of a circle, it is also constantly accelerating. It is constantly accelerating because the direction of the velocity vector is constantly changing. This description of an object in uniform circular motion is also consistent with Newton's first and second laws. Because there is an unbalanced force acting on an object undergoing uniform circular motion, the object must also be accelerating.

In this investigation you will have an opportunity to learn more about the nature of uniform circular motion by attempting to explain how a whirligig works. A whirligig is a toy that has two masses attached to each other by a string. One mass, which is called the swinging mass, can be made to move in a stable circular path. Your goal is to develop a conceptual model of the whirligig that will allow you to explain what keeps the swinging mass moving in a stable circular path and predict the radius of the circle that it follows.

Your Task

Use what you know about uniform circular motion, centripetal force, vector and scalar quantities, and stability and change in systems to develop a conceptual model that will allow you to (a) explain what keeps the swinging mass at the end of a whirligig moving in a stable circular path and (b) predict the radius of the circle that the swinging mass follows when it is stable. To develop this conceptual model, you will also need to design and carry out an investigation to determine (a) the relationship between the radius of the circle that the swinging mass follows and its angular velocity and (b) the relationship between the radius of the circle that the swinging mass follows and the centripetal force caused by the mass at the bottom of the whirligig. You will then need to test it to determine if it is valid and acceptable.

The guiding question of this investigation is, ***How does changing the angular velocity of the swinging mass at the top of a whirligig and the amount of mass at the bottom of a whirligig affect the distance from the top of the tube to the swinging mass?***

Materials

You may use any of the following materials during your investigation:

- Safety glasses or goggles (required)
- Electronic or triple beam balance
- Hooked masses
- String or cord
- Rubber stopper
- PVC or metal tube
- Stopwatch

If you have access to the following equipment, you may also consider using a video camera and a computer or tablet with video analysis software.

Safety Precautions

Follow all normal lab safety rules. In addition, take the following safety precautions:

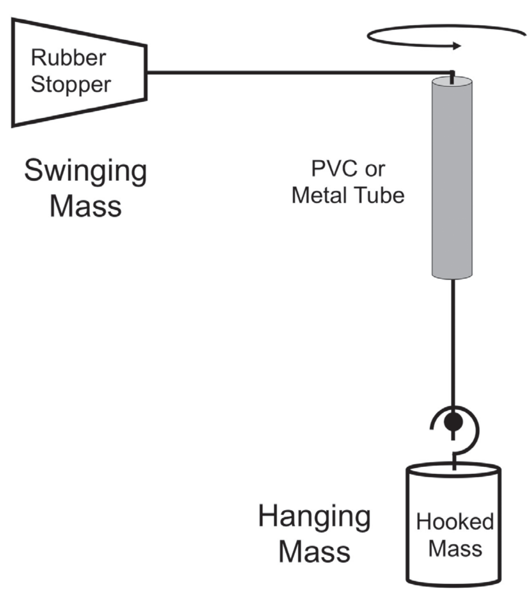
1. Wear sanitized safety glasses or goggles during lab setup, hands-on activity, and takedown.
2. Keep fingers and toes out of the way of moving objects.
3. Be aware of others around you when swinging the whirligig.
4. Wash hands with soap and water after completing the lab.

Investigation Proposal Required? ☐ Yes ☐ No

Getting Started

The first step in developing your conceptual model is to build a whirligig. You can make a whirligig using a rubber stopper, some string, a PVC or metal tube, and a hooked mass. Figure L11.2 shows how to assemble a whirligig with these materials. Once assembled, you can make the swinging mass (the rubber stopper in Figure L11.2) at the end of the whirligig move in a stable circle by changing the amount of mass you hang from the bottom of the whirligig or changing the angular velocity of the swinging mass.

FIGURE L11.2
A whirligig



You will then design and carry out two experiments using your whirligig. In the first experiment you will need to determine how changing the angular velocity of swinging mass affects the radius of the circle that the swinging mass follows when it is stable. You will then need to conduct a second experiment to determine how changing the centripetal force caused by the mass at the bottom of the whirligig affects the radius of the circle that the swinging mass follows when it is stable. Before you can design these two experiments, however, you must determine what type of data you need to collect, how you will collect it, and how you will analyze it.

To determine *what type of data you need to collect,* think about the following questions:

- What are the boundaries and the components of the system under study?
- How can you describe the components of the system quantitatively?
- When is this phenomenon stable, and under which conditions does it change?
- Which factor(s) might control the rate of change in this system?
- How could you keep track of changes in this system quantitatively?
- How will you determine the radius of the stopper's orbit?
- How will you determine the stopper's velocity?
- What will be the independent variable and the dependent variable for each experiment?

To determine *how you will collect the data,* think about the following questions:

- Which variables are scalar quantities, and which variables are vector quantities?
- What other factors will you need to account for or control during each experiment?
- What measurement scale or scales should you use to collect data?
- What equipment will you need to collect the data?
- How will you make sure that your data are of high quality (i.e., how will you reduce error)?
- How will you keep track of and organize the data you collect?

To determine *how you will analyze the data,* think about the following questions:

- What types of patterns might you look for as you analyze your data?
- Are there any proportional relationships that you can identify?
- How could you use mathematics to describe a relationship between variables?
- What type of calculations will you need to make?
- What type of table or graph could you create to help make sense of your data?

Once you have determined (a) the relationship between the radius of the circle that the swinging mass follows and its angular velocity and (b) the relationship between the radius of the circle that the swinging mass follows and the centripetal force caused by the mass at the bottom of the whirligig, your group will need to develop your conceptual model. The model must be able to explain what keeps the swinging mass moving in a stable circular path and allow you to predict the radius of the circle that it follows. To be considered complete, your model must include information about the forces acting on the swinging mass. You should therefore consider including free-body diagrams in your model.

The last step in this investigation is to test your model. To accomplish this goal, you can add different hanging masses to the end of the whirligig (amounts that you did not test) to determine if your model of the motion of the swinging mass enables you to accurately predict the radius of the circle that the swinging mass follows when it is stable. If you are able to use your model to make accurate predictions about the radius of the circle that the swinging mass follows when it is stable, then you will be able to generate the evidence you need to convince others that your model is valid or acceptable.

Connections to the Nature of Scientific Knowledge and Scientific Inquiry

As you work through your investigation, you may want to consider

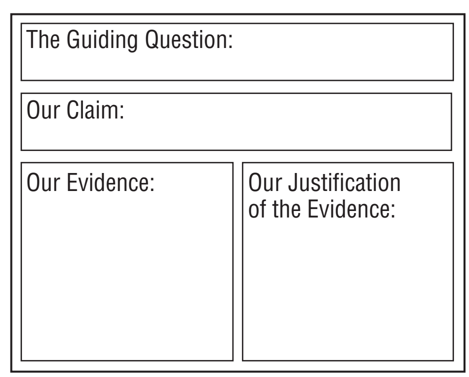
- the difference between laws and theories in science, and
- the difference between data and evidence.

Initial Argument

Once your group has finished collecting and analyzing your data, your group will need to develop an initial argument. Your argument must include a claim, evidence to support your claim, and a justification of the evidence. The *claim* is your group's answer to the guiding question. The *evidence* is an analysis and interpretation of your data. Finally, the *justification* of the evidence is why your group thinks the evidence matters. The justification of the evidence is important because scientists can use different kinds of evidence to support their claims. Your group will create your initial argument on a whiteboard. Your whiteboard should include all the information shown in Figure L11.3.

FIGURE L11.3

Argument presentation on a whiteboard



Argumentation Session

The argumentation session allows all of the groups to share their arguments. One or two members of each group will stay at the lab station to share that group's argument, while the other members of the group go to the other lab stations to listen to and critique the other arguments. This is similar to what scientists do when they propose, support, evaluate, and refine new ideas during a poster session at a conference. If you are presenting your group's argument, your goal is to share your ideas and answer questions. You should also keep a record of the critiques and suggestions made by your classmates so you can use this feedback to make your initial argument stronger. You can keep track of specific critiques and suggestions for improvement that your classmates mention in the space below.

Critiques about our initial argument and suggestions for improvement:

If you are critiquing your classmates' arguments, your goal is to look for mistakes in their arguments and offer suggestions for improvement so these mistakes can be fixed. You should look for ways to make your initial argument stronger by looking for things that the other groups did well. You can keep track of interesting ideas that you see and hear during the argumentation in the space below. You can also use this space to keep track of any questions that you will need to discuss with your team.

Interesting ideas from other groups or questions to take back to my group:

Once the argumentation session is complete, you will have a chance to meet with your group and revise your initial argument. Your group might need to gather more data or design a way to test one or more alternative claims as part of this process. Remember, your goal at this stage of the investigation is to develop the best argument possible.

Report

Once you have completed your research, you will need to prepare an investigation report that consists of three sections. Each section should provide an answer to the following questions:

1. What question were you trying to answer and why?
2. What did you do to answer your question and why?
3. What is your argument?

Your report should answer these questions in two pages or less. This report must be typed, and any diagrams, figures, or tables should be embedded into the document. Be sure to write in a persuasive style; you are trying to convince others that your claim is acceptable or valid!