

*Fun, Food,  
Fantasy...*



*and Physics?*

A SERIES OF REPRODUCIBLE LABORATORY ACTIVITIES

# Fun, Food, Fantasy...and Physics?

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*To my parents: whose dedication to and  
enthusiasm for education started me on this  
career path many years ago.*

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# Introduction

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*“Physics is becoming so unbelievably complex that it is taking longer and longer to train a physicist. It is taking so long, in fact, to train a physicist to the place where he understands the nature of physical problems that he is already too old to solve them.”*

*--Eugene Wigner  
Hungarian-American Physicist*

It is our challenge, as physics teachers and students, to change that way of thinking. The goal of this activity packet is to introduce younger students to some basic, underlying physical principles in a manner that will help them remember the concepts and their importance in the physical world. I chose to use Knoebels' Amusement Resort as the backbone for these activities because the rides at the park lend themselves to a nice variety of experiments that can be done to reinforce the concepts which I felt were important for students.

These modules are designed for students in 7<sup>th</sup> and 8<sup>th</sup> grade, and you'll note that the descriptions of the concepts are very basic and are written in terms that should make sense to those grade levels. Of course, if you would like to use these for high school physics classes, you can always add additional questions or challenge students to draw more difficult conclusions from their results. The modules are divided into three main parts: the concept descriptions, equipment instructions, and lab activity. The concept descriptions introduce students to the principles that will be explored in the laboratory exercise. While they are concise, they contain any background information that the students may need to complete the activity. The equipment instructions detail a procedure for using the devices that I found to be the most effective and yield the best results. Finally, the laboratory activity is divided into four sections. First, there are several pre-lab questions that you may want to have the students consider on their own or discuss as a class. Next, the in-class portion of the activity will familiarize students with the type of analysis they will be doing at Knoebels'. The field exercise section is where the actual data collection occurs at Knoebels' Amusement Resort. Finally, there are post-lab questions to encourage students to draw some conclusions from the data they collected.

Both the in-class and field exercise sections of each activity are designed to be independent of each other – that is, you can easily complete the in-class portion of the activity months earlier when you're dealing with that particular concept and simply save the field exercise until later in the school year when you're ready to go

the park. In the same way, you can choose not to use the concept descriptions or equipment instructions if you feel the students have a comfortable grasp of the concept without any additional reinforcement.

At the end of this packet, the appendix provides a teacher's guide to each of the five activities. This guide provides some sample responses for the pre-lab and post-lab questions as well as some additional ideas or tips to make the rest of the activity successful and valuable.

All of the activities were designed to utilize equipment that is available in the Bloomsburg University Math and Science Learning Center (MSLC). This equipment is available for all area teachers to sign out and use in their classrooms for activities such as this. If you are interested in using this packet and do not have the equipment in your classroom, feel free to contact the MSLC:

Phone: (570) 389-5254

Website: <http://orgs.bloomu.edu/msc/index.htm>

Now, I believe a few acknowledgements are in order: Dr. James Hetrick – my advisor who endured countless revisions of this laboratory packet. Dr. Emeric Schultz – Honors program director who secured the necessary funds to supplement and enhance this project. Without their help, the packet you see before you would never have been a success.

Finally, a word or two about the author. This project was my Honors Independent Study at Bloomsburg University of Pennsylvania during my junior and senior years. As you might have guessed, my major is Secondary Education with an emphasis in Physics. I decided on this project because I felt that similar activity packets that were available for HersheyPark and DorneyPark were valuable, but that this area could use a similar packet for Knoebels' Amusement Resort. You may wish to consult either of those parks for additional ideas on how to combine physics and an amusement park. I hope that you will find this compilation of activities to be a nice supplement to your physics and physical science curriculum. If you have any questions, concerns, or suggestions regarding this packet, I encourage you to get in contact with me. This entire packet is available on my website: [www.physicsworld.net](http://www.physicsworld.net). You can also email any comments you have to [stevemajor@physicsworld.net](mailto:stevemajor@physicsworld.net). Thank you for taking the time to consider using this packet in your lessons and I hope that it proves to be a worthwhile experience for you and your students!

*Stephen Major*

*Scenic  
Skyway*

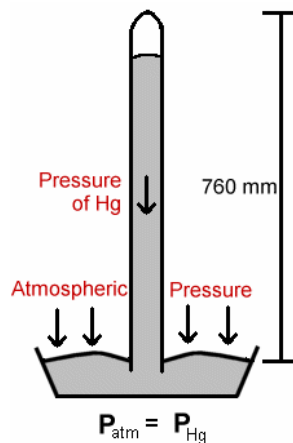
*A Laboratory Exercise*

### What is *air pressure*?

Think back to the last time you took an exam. You may recall that you felt a lot of “pressure” to do well or score high on the test. I’m sure that you can define *pressure* in terms of the feeling you get when you have to deliver a presentation to the class, but what does *pressure* mean when we talk about air? *Pressure* is defined as “any force applied to an area” and has units of pascals (Pa). In other words:

$$P = \frac{F}{A}$$

That applies to any pressure – water pressure, gauge pressure, and air pressure. However, to measure air pressure, we use a specific device called a *barometer* to measure the *atmospheric pressure*. For a barometer, air pushes down on a substance (usually Mercury). The height to which it pushes that substance in a tube (as shown below) is measured and from that, the air pressure can be calculated.



(Picture from: Texas A&M University, [www.tamu.edu](http://www.tamu.edu))

Because air pressure depends on the height of an object above the ground, air pressure is also dependent on the elevation of an object. That is:

- As elevation increases, air pressure decreases.
- As elevation decreases, air pressure increases.

At sea level, air pressure is given a specific name, called an *atmosphere* (atm):

$$1 \text{ atm} = 101.3 \text{ kPa}$$

## Barometer

How does it work?

The barometer contains a flexible membrane that flexes as the pressure changes in the environment. One side of this membrane is a vacuum so that the barometer is able to measure the absolute pressure of the atmosphere or liquid.

How to use it:

1. Connect the motion detector to the LabPro interface.
2. Use the LabPro interface with a computer or TI 83+ graphing calculator.
3. Press “Quick Setup” on the LabPro interface.
4. Adjust time in the DataMate program so that the length of time measured is appropriate for the experiment. You can also set the data collection rate – how many samples per second you want the device to measure.
5. Start data collection program.



# Scenic Skyway

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## **Introduction:**

The Scenic Skyway ride at Knoebels' Amusement Resort is a ski-lift type of attraction that takes visitors from the park to the top of a nearby mountain. The goal of this laboratory exercise is for students to measure how high they traveled on the ride. They will do this by determining the air pressure difference they experience on the ride and converting that to a height. This activity is divided into two parts: one that will be completed at or near the school, and one that will be completed at Knoebels' Amusement Resort.

## **Concept(s):**

- Air Pressure as a function of height/altitude

## **Equipment:**

- Vernier LabPro Interface
- TI 73 / 82 / 83 / 86 / 89 / 92 Calculator (with DataMate software)
- Vernier Barometer

## **Prelab Questions:**

- Will air pressure be greater at sea level or on a mountain peak? Why?
  
- What other factors, besides height, have an effect on air pressure?
  
- Is measuring height by using air pressure the best method? Why or why not?

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## **Part I: Laboratory Exercise:**

For the in-class portion of this activity, you will determine the height of a building or the difference in elevation from a place near sea-level to an elevated area using the barometer to measure the air pressure. You will then convert the air pressure measurements to a height.

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*Procedure:*

1. We first need to find a relationship between height and pressure. To do this, you will measure the pressure on one floor of the building and then measure the pressure on the floor above or the floor below. Since we will easily be able to measure the height of the floor, we can relate the pressure change to the height change.

*Pressure on Floor 1:* \_\_\_\_\_ Pa

*Pressure  
Difference:* \_\_\_\_\_ Pa

*Pressure on Floor 2:* \_\_\_\_\_ Pa

*Height Difference:* \_\_\_\_\_ ft

2. Now, the pressure difference that was calculated corresponds to the height difference:

Pressure Difference = Height Difference

\_\_\_\_\_ Pa per \_\_\_\_\_ ft

3. Have your instructor give you the locations where you will be measuring the pressure:

*Low-level area:* \_\_\_\_\_ (Basement of building, etc)

*Elevated area:* \_\_\_\_\_ (Third floor of building, etc)

4. Proceed to the low-level area. After configuring the barometer and other equipment as described by the instructor, record *at least* three readings and then calculate the average of the readings:

Reading 1: \_\_\_\_\_ Pa

Low Level  
Average: \_\_\_\_\_ Pa

Reading 2: \_\_\_\_\_ Pa

Reading 3: \_\_\_\_\_ Pa

- 
5. Proceed to the elevated area. Record *at least* three readings and then calculate the average of the readings:

Reading 1: \_\_\_\_\_ Pa

Reading 2: \_\_\_\_\_ Pa

Reading 3: \_\_\_\_\_ Pa

Elevated  
Average: \_\_\_\_\_ Pa

6. Find the difference between the two averages:

Difference = Low Level Average – Elevated Average

Difference = \_\_\_\_\_ Pa

7. Convert the difference in air pressure to height:

From the relationship we established in Step #2 above, we can relate this pressure difference to change in height. We will do this as a ratio:

$$\frac{\text{Pressure Difference from Step \#6}}{\text{Height Difference we need}} = \frac{\text{Pressure from Step \#2}}{\text{Height from Step \#2}}$$

Therefore: height = \_\_\_\_\_ m

8. We now need to determine how far off your value for height is from the known value (obtained from instructor). This is called *percent error*.

$$\% \text{ error} = \frac{\text{known} - \text{experimental}}{\text{known}} * 100$$

% error = \_\_\_\_\_ %

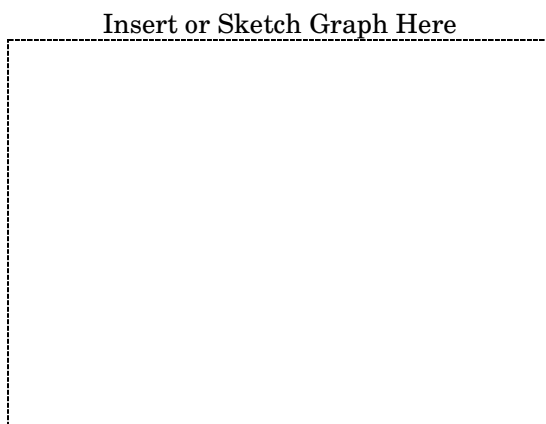
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**Part II: Field Exercise:**

The procedure for the field exercise will be very similar to what you did for the in-class portion of this lab. You will ride on the Scenic Skyway at Knoebels' and will measure the pressure at the top and at the bottom of the ride. From these measurements, you will be able to calculate how high you went on the ride.

*Procedure:*

1. You will let the barometer collect data for the entire ride on the Scenic Skyway and then complete the analysis when you return to the classroom. In order to do this, make sure that you have adjusted the barometer to sample data as directed by the instructor.
2. After returning to the classroom, graphically look at the data you collected. From the graph, determine the highest pressure reading. This is the pressure at the bottom of the ride:



Bottom of Ride Pressure: \_\_\_\_\_ Pa

Then, find the lowest pressure reading. This is the pressure at the top of the ride:

Top of Ride Pressure: \_\_\_\_\_ Pa

3. Find the difference between the two pressures:

Difference = Bottom of Ride Pressure – Top of Ride Pressure

Difference = \_\_\_\_\_ Pa

- 
4. Convert the difference in air pressure to height:

You will do this using the same procedure as you did in #7 of the in-class portion:

Total rise height:  $h = \underline{\hspace{2cm}}$  m

5. We now need to determine how far off your value for height is from the known value (obtained from instructor). This is called *percent error*.

$$\% \text{ error} = \frac{\text{known} - \text{experimental}}{\text{known}} * 100$$

$\% \text{ error} = \underline{\hspace{2cm}}\%$

---

**Post Lab / Follow-up Questions:**

- Based on your measurements, do you think measuring height by recording the changes in air pressure is an accurate method? (Is your percent error high or low?)
  
- If your measurements were not very accurate, what changes would you make to the procedure to improve the accuracy?

- 
- *(Optional)* Did you notice any unpredictable changes in pressure if you graphically looked at the data you collected on the ride? If so, what do you think caused those variations?
  
  - *(Optional)* Compare your data with that collected by another group. Whose is more accurate? Can you explain why different groups would have different measurements?

*Italian  
Trapeze*

*A Laboratory Exercise*

### What is *velocity*?

As you travel down the road in your car, you often look down at the speedometer that tells you how fast you are driving. The speedometer measures the speed of the car. Speed is simply how much distance you cover over a certain amount of time. The speed limit “55 miles per hour” means that you will cover 55 miles in one hour if you maintain that speed for the entire hour. *Velocity* is similar to speed in that it tells you how much distance you cover over a certain amount of time, but it also tells you the direction in which you are traveling.

For instance:

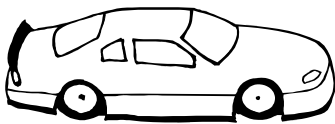
Speed: 55 miles per hour  
Velocity: 55 miles per hour **in the northwest direction**

The phrase **in the northwest direction** turns a speed into a velocity.

To calculate speed, we say that speed ( $s$ ) is the distance traveled ( $d$ ) divided by the time of travel ( $t$ ):

$$s = \frac{d}{t}$$

Let's try a sample problem. The car below travels east and covers a distance of 100 miles in two hours. Find its velocity.



→  $v = \text{velocity}$

Using the equation above:

$$s = \frac{d}{t} = \frac{100\text{miles}}{2\text{hours}} = 50\text{mph}$$

This gives us the car's speed. To convert this to velocity, we simply need to assign a direction. In this case, the problem says the car is traveling east, so:

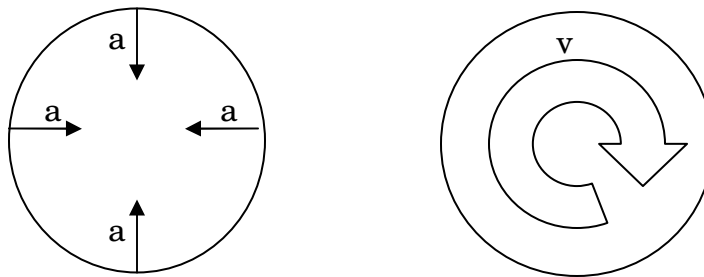
$$v = 50 \text{ mph east}$$

## What is *centripetal acceleration*?

[If you have already covered linear acceleration, skip the section in brackets].

[Imagine that you are traveling west down a road at 40 mph. Suddenly, the speed limit changes to 55 mph, and you increase your velocity accordingly. You have just *accelerated*. *Acceleration* is defined as a change in velocity over a change in time. Usually, an increase in your speed is called an *acceleration* while a decrease in speed is a *deceleration*. However, a *deceleration* can also be referred to as a negative *acceleration*. Because acceleration is proportional to velocity and velocity has both a magnitude and a direction, acceleration also has both a magnitude and a direction.]

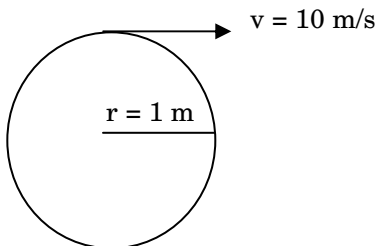
Like linear acceleration, *centripetal acceleration* has both a magnitude and a direction. For circular motion, however, the direction of acceleration is always towards the center of the circle while the speed remains constant:



The way to calculate centripetal acceleration is to relate it to the object's velocity ( $v$ ) and distance from the center of the circle ( $r$ ) as follows:

$$a = \frac{v^2}{r}$$

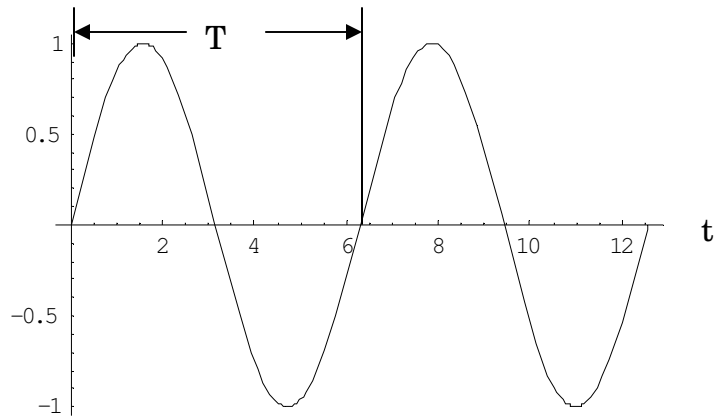
Let's try a sample problem. For the circle shown below, find the centripetal acceleration ( $a$ ):



$$a = \frac{v^2}{r} = \frac{(10\text{m/s})^2}{1\text{m}} = 100\text{m/s}^2 \text{ inward}$$

### What are *frequency* and *period*?

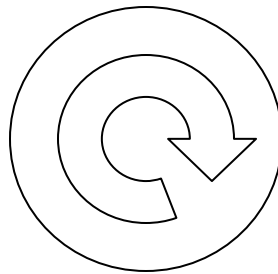
To easily explain *frequency* and *period*, we should look at a graphical analysis of these terms:



- In this snapshot of a sine curve, the graph repeats itself twice.
- The *period* ( $T$ ) is defined as the amount of time it takes for the curve to repeat itself.
- *Frequency*, is defined as “the number of times something repeats itself in a given time period.”
- Frequency is then defined as  $1/T$ :

$$f = \frac{1}{T}$$

- If we think of frequency and period in terms of circular motion:



The period ( $T$ ) is how long it takes to make one complete revolution, and the frequency ( $f$ ) is the number of revolutions per second. The term “per second” is also referred to as a Hertz (Hz).

## One Dimensional Accelerometer

How does it work?

The accelerometer uses an integrated circuit similar to those used in air-bag deployment systems that measure the acceleration of an object. The integrated circuit is designed so that any acceleration that it measures is converted to a voltage that can be understood by the system.

How to use it:

1. Connect the accelerometer to the LabPro interface.
2. Use the LabPro interface with a computer or TI 83+ graphing calculator.
3. Press “Quick Setup” on the LabPro interface.
4. Start data collection program.

Tips:

1. Try to avoid “bounces” against any objects if you are releasing the accelerometer from rest to measure gravitational acceleration.
2. The arrow on the device must be pointing in the direction you want to measure the acceleration.



# Italian Trapeze

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## **Introduction:**

The Italian Trapeze ride at Knoebels' Amusement Resort is one of the original swing rides. This exercise will be designed to accommodate students who want to ride and those who don't. Riders will be exploring the concept of linear acceleration while non-riders will investigate the concepts of frequency and period.

## **Concept(s):**

- Linear velocity
- Centripetal acceleration
- Frequency
- Period

## **Equipment:**

- Vernier LabPro Interface
- TI 73 / 82 / 83 / 86 / 89 / 92 Calculator (with DataMate software)
- Vernier 1-D Accelerometer
- Stopwatches

## **Prelab Questions:**

- How is linear velocity related to centripetal acceleration?
  
- What would be the difficulty in calculating linear velocity on this ride?
  
- A computer processor has a speed of 2 GHz. We can consider this the "frequency" of the processor. Do you think this is faster or slower than the frequency of the ride? Explain.

---

## **Part I: Laboratory Exercise:**

For the in-class portion of this activity, you will be replicating the kind of activity you will do on the ride. You will use the 1-D accelerometer to determine the acceleration as you swing it over your head. Your partner will

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be measuring the period while you do this. You will then switch places and complete the activity again.

*Procedure:*

1. Obtain a 1-D accelerometer that has been mounted on a piece of wood. This will serve as your “swing”. Make sure that you set up the accelerometer as directed by the instructor.
2. You will **carefully** swing the accelerometer over your head in this activity. Make sure that there are no other students or objects around as you do this. The goal is not to swing it as fast as you can! You should try to swing it so that the path it follows is almost level. The arrow on the device should be pointed towards you.
3. While you swing the accelerometer above your head, your partner should use the stopwatch to record how long it takes to make 20 swings. Then, divide this total time by the number of swings to get the time per swing. This is the *period*.

Time: \_\_\_\_\_s

Number of Swings: \_\_\_\_\_

Period: \_\_\_\_\_s

4. From your reading for period, calculate the frequency. Recall that:

$$f = \frac{1}{T}$$

Frequency: \_\_\_\_\_Hz

5. Switch places with your partner and repeat Steps 2 - 4 above.
6. Compare your reading for frequency with the computer frequency from the Prelab. How much greater/smaller is this frequency?

- 
7. Once you each have a set of data for acceleration from the LabPro, graph acceleration vs. time on the calculator. Find where the acceleration is roughly constant (where the graph levels off) and record that below:

Insert or Sketch Graph Here



Acceleration: \_\_\_\_\_ ft/s<sup>2</sup>

---

**Part II: Field Exercise:**

The procedure for the field exercise will be very similar to what you did for the in-class portion of this lab. If you want to ride, you will complete Steps 1-3 below. If you do not want to ride, complete Steps 4-7 below.

*Procedure:*

1. You will use the same 1-D accelerometer that you used in the in-class portion of the lab, except it will not be mounted on a piece of wood. You should ensure that, while on the ride, the detector on the accelerometer is pointed toward the center of the ride. Make sure it is set up as directed by your instructor.
2. You will allow the accelerometer to collect data for the duration of the ride and will graphically analyze the data once you return to the classroom.

Insert or Sketch Graph Here



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Record the centripetal acceleration here:

Acceleration: \_\_\_\_\_ ft/s<sup>2</sup>

3. Compare this to the acceleration you found in class. Is it faster or slower? Why do you think there is a difference?

4. Pick a spot near the ride where you have an unobstructed view of most of the ride. You will be selecting a rider to observe (could be a classmate or someone that's easy to distinguish as the riders swing through the air).
5. You need to observe *the same* rider for the duration of the ride. Once the ride reaches a steady speed, with the stopwatch record how long it takes for the rider to complete 10 full revolutions. As in the in-class exercise, you will then divide the total time necessary by the number of revolutions to get the period.

Time: \_\_\_\_\_ s

Number of Revolutions: \_\_\_\_\_

Period: \_\_\_\_\_ s

6. Now, wait until the ride starts again and record how long the ride stays at a steady velocity. Also, pick another rider and record how many times you see them go around the ride at the steady velocity:

Length of ride: \_\_\_\_\_ s

Number of revolutions: \_\_\_\_\_

7. We now want to see how accurate your measurement for period is. If we multiply the number of revolutions (from Step #6) by the average period (from Step #5), we should get the length of the ride that you recorded in Step #6.

---

$$\begin{aligned} \text{Length of ride} &= \text{Period} * \text{Number of revolutions} \\ &= \text{_____} \text{s} \end{aligned}$$

Compare this to the length of the ride you found in Step #6. How close are they?

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**Post Lab / Follow-up Questions:**

- Would there be a difference in frequency and period if you observed a rider near the edge of the ride and one near the middle? How would the velocity be different?
  
- For your ride data, convert your measurement of velocity from ft/s to miles per hour. (*Hint:* 1 mile = 5280 ft and 1 hour = 3600 seconds).
  
- (*Optional*) How would a rider be able to determine his or her period and frequency? In other words, if everyone wanted to ride but we still wanted to determine the period and frequency, what are some ways we could do this?

# *Skooters*

## *(Bumper Cars)*

*A Laboratory Exercise*

### What is *velocity*?

As you travel down the road in your car, you often look down at the speedometer that tells you how fast you are driving. The speedometer measures the speed of the car. Speed is simply how much distance you cover over a certain amount of time. The speed limit “55 miles per hour” means that you will cover 55 miles in one hour if you maintain that speed for the entire hour. *Velocity* is similar to speed in that it tells you how much distance you cover over a certain amount of time, but it also tells you the direction in which you are traveling.

For instance:

Speed: 55 miles per hour

Velocity: 55 miles per hour **in the northwest direction**

The phrase **in the northwest direction** turns a speed into a velocity.

---

To calculate speed, we say that speed ( $s$ ) is the distance traveled ( $d$ ) divided by the time of travel ( $t$ ):

$$s = \frac{d}{t}$$

Let's try a sample problem. The car below travels east and covers a distance of 100 miles in two hours. Find its velocity.



—————→  $v = \text{velocity}$

Using the equation above:

$$s = \frac{d}{t} = \frac{100\text{miles}}{2\text{hours}} = 50\text{mph}$$

This gives us the car's speed. To convert this to velocity, we simply need to assign a direction. In this case, the problem says the car is traveling east, so:

$$v = 50 \text{ mph east}$$

### What is *momentum*?

If you watch any kind of skiing sport, you may have heard the phrase “He has a lot of momentum going down the hill.” Or perhaps, if you keep track of football, you may be aware of the phrase, “That team’s got a lot of momentum going into the playoffs.” But, what exactly does that mean? It means that that skier or team will be especially hard to stop or beat. *Momentum* is an object’s mass multiplied by its velocity. Essentially, it describes how hard it would be for us, or for any force, to stop an object. We represent momentum with the letter  $p$ . In physics terms, momentum ( $p$ ) is equal to an object’s mass ( $m$ ) times its velocity ( $v$ ):

$$p = mv$$

To practice, and to show the effects of momentum, let’s do some sample problems. We will calculate the momentum of a small car and a large truck in three situations. Let’s say the mass of the car is 1,000 kg and the mass of the truck is 10,000 kg. In all three cases, you will be calculating which object has the greater momentum:

- (1) The car has a velocity of 22 m/s and the truck has a velocity of 2.2 m/s
  
- (2) The car has a velocity of 40 m/s and the truck has a velocity of 3 m/s.
  
- (3) The car has a velocity of 40 m/s and the truck has a velocity of 10 m/s.

**Answers:** (1)  $p$  of car =  $p$  of truck = 22,000 N  
(2)  $p$  of car = 40,000 N       $p$  of truck = 30,000 N  
(3)  $p$  of car = 40,000 N       $p$  of truck = 100,000 N



What does this tell you about momentum? Does the more massive object always have a greater momentum? Does the faster object always have the greater momentum?

## Motion Detector

How does it work?

The motion detector works by emitting ultrasonic sound waves from the device. It then “listens” for the return, or echo, of these sound waves and calculates how long it took for the echo to occur. From this time, the device can calculate the distance of an object using the speed of sound in air.

How to use it:

1. Connect the motion detector to the LabPro interface.
2. Use the LabPro interface with a computer or TI 83+ graphing calculator.
3. Press “Quick Setup” on the LabPro interface.
4. Adjust time in the DataMate program so that the length of time measured is appropriate for the experiment.
5. Start data collection program.

Tips:

1. Make sure that there are no objects in the “line of sight” of the motion detector.
2. If you are getting poor readings, try tilting the motion detector’s head slightly upward in order to maximize the width of the sound waves.
3. Stay within the distance range for the motion detector. For this particular device, you must be at least 0.5 meters from the detector, but no more than 6 meters from the device.



# Skooters

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## **Introduction:**

The Skooters at Knoebels' Amusement Resort have been rated the best bumper cars in the world. You will be using these world-class cars to test the principles of linear momentum and conservation of linear momentum. You will use the motion detector to determine the velocity of the impact. From that, you will be able to estimate the momentum of the car.

## **Concept(s):**

- Linear velocity
- Linear momentum
- Conservation of linear momentum

## **Equipment:**

- Vernier LabPro Interface
- TI 73 / 82 / 83 / 86 / 89 / 92 Calculator (with DataMate software)
- Wooden laboratory carts
- Vernier Motion Detector

## **Prelab Questions:**

- In your own words, explain the concept of momentum.
  
  
  
  
  
  
  
  
  
  
- Does a more massive object always have the greater momentum? Does an object with a greater velocity always have the greater momentum? Explain.
  
  
  
  
  
  
  
  
  
  
- If two objects of roughly the same mass collide, will each have the same momentum before the collision? Why or why not?

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## Part I: Laboratory Exercise:

For the in-class portion of this activity, you will be using wooden carts with the motion detectors to measure the momentum of the carts while colliding with another student.

### Procedure:

1. In groups of six, proceed to a relatively flat area with the wooden carts. Two students will sit on the carts two will push them off, and two will record the data. Then, you will switch places until each student has had a chance to perform each activity. Throughout this activity, your instructor will assign you as either a member of **Cart 1** or **Cart 2**.
2. Each student on the cart should start this experiment at rest. When everything is set up as instructed, two students will push them towards each other while the other two aim the motion detectors at the traveling students. **Be careful that your legs and arms are out of the way upon impact with the other cart.** Repeat this several times until you feel that you have a valid set of data. The setup is as follows:



3. In order to deal with momentum, we will need to know the mass of the two people riding the carts. We will assume that the carts are of roughly equal mass, so just ask your instructor for that mass. Recall that:

$$\text{mass} = \frac{\text{weight(lbs)}}{32} \leftarrow \text{the unit of mass is "slug"}$$

Determine the mass of both yourself and your partner (the two students riding the carts). Add your calculated mass to the mass of the carts provided by the instructor and record it below:

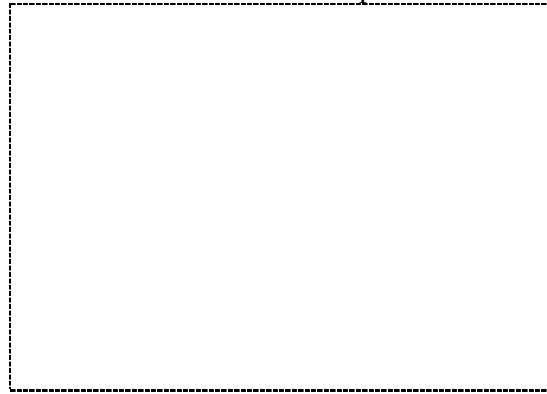
$$m_1 = \text{_____ slug} \quad m_2 = \text{_____ slug}$$

- 
4. You will now graphically analyze your data. On the calculator, graph velocity vs. time. Find a spike in the graph. Write down the velocity right before the spike and the velocity right after: **(Only fill out the first or second line, depending on whether you're Cart 1 or Cart 2)**

**Cart 1:**  $v_{1, \text{ before:}}$  \_\_\_\_\_ ft/s  $v_{1, \text{ after:}}$  \_\_\_\_\_ ft/s

**Cart 2:**  $v_{2, \text{ before:}}$  \_\_\_\_\_ ft/s  $v_{2, \text{ after:}}$  \_\_\_\_\_ ft/s

Insert or Sketch Graph Here



5. The law of conservation of momentum says that the momentum of one object plus the momentum of another object before a collision must equal the total momentum after the collision. The masses you will be using are simply the masses you found for yourself and your partner in Step #3 above. In other words:

$$m_1 * v_{1, \text{ before}} + m_2 * v_{2, \text{ before}} = m_1 * v_{1, \text{ after}} + m_2 * v_{2, \text{ after}}$$

Your momentum before the collision is simply your mass times your initial velocity (Since momentum is a vector, like velocity, it can be either positive or negative). Calculate that now and record it below:

Your momentum before = \_\_\_\_\_ lb-s

Your momentum after the collision is simply your mass times your final velocity (Since momentum is a vector, like velocity, it can be either positive or negative). Calculate that now and record it below:

Your momentum after = \_\_\_\_\_ lb-s

- 
6. Ask your partner what *he* wrote down for his final velocity and record it below:

Your partner's final velocity = \_\_\_\_\_ ft-s

7. You now know all of the information except for your partner's initial velocity. Calculate it based on your values and record it here:

Your partner's calculated initial velocity = \_\_\_\_\_ ft/s

8. Now, talk to your partner and find out what his or her value for initial velocity was and record it below:

Your partner's measured initial velocity = \_\_\_\_\_ ft/s

9. We now need to determine how far off your value for your partner's initial velocity is from the value your partner got from the graph. This is called *percent difference*.

$$\% \text{ difference} = \frac{\text{difference between \#7 and \#8 above}}{\text{average of \#7 and \#8 above}} * 100$$

% difference = \_\_\_\_\_ %

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### **Part II: Field Exercise:**

The procedure for the field exercise will be very similar to what you did for the in-class portion of this lab. You will ride the Skooters at Knoebels' and determine your momentum in several different collisions.

#### *Procedure:*

1. You will collect data for the entire length of the ride. For this to work properly, one of you will need to sit still in the bumper car and allow your partner to bump into you. Then, switch roles and do it again. You will do this several times at several different speeds. Set up the detector as instructed and then have fun on the ride!!

---

2. In order to deal with momentum, we will need to know your mass. Recall that

$$\text{mass} = \frac{\text{weight(lbs)}}{32} \leftarrow \text{the unit of mass is "slug"}$$

Determine your mass:

$$m = \text{_____ slug}$$

3. You will now graphically analyze your data. On the calculator, graph velocity vs. time. We wish to analyze several different collisions that you experienced while on the ride. If you look at the graph, you should be able to recognize a collision as a spike in the velocity. Find four such times on the graph and record the velocities below:

a. Velocity: \_\_\_\_\_ ft/s

b. Velocity: \_\_\_\_\_ ft/s

c. Velocity: \_\_\_\_\_ ft/s

d. Velocity: \_\_\_\_\_ ft/s

Insert or  
Sketch  
Graph →



4. Your momentum is simply:  $m * v$ . Calculate the momentum for each of the four velocities now and record it below:

a. Momentum = \_\_\_\_\_ lb-s

b. Momentum = \_\_\_\_\_ lb-s

c. Momentum = \_\_\_\_\_ lb-s

d. Momentum = \_\_\_\_\_ lb-s

- 
5. You should notice a change in the momentum for each of the four velocities that you recorded. Notice that, unlike the laboratory exercise, we did not use the law of conservation of momentum, simply because it would be almost impossible to isolate a certain collision with another student while on the ride and make an accurate estimate of their velocity.
- 

**Post Lab / Follow-up Questions:**

- How accurate was your prediction for the velocity of your partner for the in-class activity? If there was a high error, what factors might have made the prediction difficult?
  
- Repeat step #6 in the laboratory exercise, but this time, find the mass of your partner. In other words, use your mass, your velocity, and your partner's velocity to find your partner's mass. Compare that mass to the mass you wrote down in step #3.
  
- *(Optional)* Repeat the entire laboratory exercise with a different partner.
  
- *(Optional)* Repeat the entire laboratory exercise with different carts. Based on your results, can we safely assume that the masses of the carts are the same and don't affect the calculations?

# *Paradrop*

*A Laboratory Exercise*

## What is *velocity*?

As you travel down the road in your car, you often look down at the speedometer that tells you how fast you are driving. The speedometer measures the speed of the car. Speed is simply how much distance you cover over a certain amount of time. The speed limit “55 miles per hour” means that you will cover 55 miles in one hour if you maintain that speed for the entire hour. *Velocity* is similar to speed in that it tells you how much distance you cover over a certain amount of time, but it also tells you the direction in which you are traveling.

### For instance:

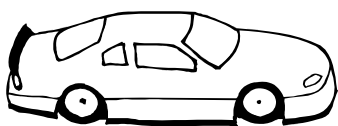
Speed: 55 miles per hour  
Velocity: 55 miles per hour **in the northwest direction**

The phrase **in the northwest direction** turns a speed into a velocity.

To calculate speed, we say that speed ( $s$ ) is the distance traveled ( $d$ ) divided by the time of travel ( $t$ ):

$$s = \frac{d}{t}$$

Let's try a sample problem. The car below travels east and covers a distance of 100 miles in two hours. Find its velocity.



→  $v = \text{velocity}$

Using the equation above:

$$s = \frac{d}{t} = \frac{100\text{miles}}{2\text{hours}} = 50\text{mph}$$

This gives us the car's speed. To convert this to velocity, we simply need to assign a direction. In this case, the problem says the car is traveling east, so:

$$v = 50 \text{ mph east}$$

### What is *linear acceleration*?

Imagine that you are traveling west down a road at 40 mph. Suddenly, the speed limit changes to 55 mph, and you increase your velocity accordingly. You have just *accelerated*. *Acceleration* is defined as a change in velocity over a change in time. Usually, an increase in your speed is called an *acceleration* while a decrease in speed is a *deceleration*. However, a *deceleration* can also be referred to as a negative *acceleration*. Because acceleration is proportional to the change in velocity and velocity has both a magnitude and a direction, acceleration also has both a magnitude and a direction (usually either forward or reverse).

To calculate acceleration, we say that acceleration ( $a$ ) is the change in velocity ( $\Delta v$ ) divided by the change in time ( $\Delta t$ ):

$$a = \frac{\Delta v}{\Delta t}$$

Let's try a sample problem. The boat below was sailing at 50 m/s due north before accelerating to 100 m/s. It took the boat 5 seconds to do this. Find its acceleration.



Using the equation above:

$$a = \frac{\Delta v}{\Delta t} = \frac{v_2 - v_1}{t} = \frac{100\text{m/s} - 50\text{m/s}}{5\text{s}} = \frac{50\text{m/s}}{5\text{s}} = 10\text{m/s}^2$$

This gives us the magnitude of the boat's acceleration. The problem says that the boat is traveling due north, so the final answer (including magnitude and direction) is:

$$a = 10 \text{ m/s}^2 \text{ north}$$

## What is a force?

One type of *force* can be commonly defined as *any push or pull on an object that either causes a change in motion or keeps an object from moving*. To properly discuss forces, we need to introduce a man by the name of Isaac Newton. He was a scientist who studied how and why objects move or stay put. He developed three laws that are now referred to as “Newton’s Three Laws of Motion.” They are as follows:

### Law of Motion #1:

*What is the law?:* An object in motion will remain in motion and an object at rest will remain at rest unless acted upon by an outside, non-zero net force.

*In English, please?:* This first law states that an object that is moving will never stop that motion, change direction, speed up, or slow down unless a net push or pull acts on it. In the same way, any object that is not moving will not move unless a non-zero net force pushes or pulls on it. A net force is defined as the total of all the forces acting on an object.

### Law of Motion #2:

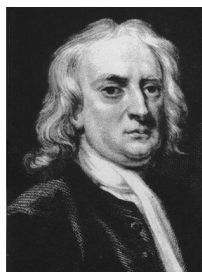
*What is the law?:* The net external force on an object (F) is equal to its mass (m) multiplied by its acceleration (a). [F= ma]

*In English, please?:* The amount that an object will be affected by a push or a pull is equal to the mass of the object multiplied by the acceleration.

### Law of Motion #3:

*What is the law?:* When one object exerts a force on another object, the second object exerts an equal and opposite force on the first object.

*In English, please?:* This law says that if you push your hand against a desk, the desk pushes back on your hand with exactly the same force. You may have also heard this law stated as “For every action, there is an equal and opposite reaction.”



Sir Isaac Newton

## One Dimensional Accelerometer

How does it work?

The accelerometer uses an integrated circuit similar to those used in air-bag deployment systems that measure the acceleration of an object. The integrated circuit is designed so that any acceleration that it measures is converted to a voltage that can be understood by the system.

How to use it:

1. Connect the accelerometer to the LabPro interface.
2. Use the LabPro interface with a computer or TI 83+ graphing calculator.
3. Press “Quick Setup” on the LabPro interface.
4. Start data collection program.

Tips:

1. Try to avoid “bounces” against any objects if you are releasing the accelerometer from rest to measure gravitational acceleration.
2. The arrow on the device must be pointing in the direction you want to measure.



# Paradrop

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## **Introduction:**

The Paradrop ride at Knoebels' Amusement Resort allows riders the opportunity to feel like they are falling through the air with a parachute. We will be exploring the concept of acceleration and seeing how that relates to force. You will be measuring the acceleration as you fall through the air and then use your mass to determine the force you experience on the ride.

## **Concept(s):**

- Linear Velocity
- Linear Acceleration
- Force (Newton's Second Law)

## **Equipment:**

- Vernier LabPro Interface
- TI 73 / 82 / 83 / 86 / 89 / 92 Calculator (with DataMate software)
- Vernier 1-D Accelerometer
- Stopwatches
- Ball

## **Prelab Questions:**

- How is acceleration related to force? (Think of Newton's Laws of Motion)
  
- Do you think your acceleration on the ride will be constant? Explain.
  
- Do you think your velocity on the ride will be constant? Explain.

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## **Part I: Laboratory Exercise:**

For the in-class portion of this activity, you will measure the time it takes for a ball to fall from a certain height. From this, you will calculate the velocity

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of the ball right before it hits the ground. This will prepare you for the procedure you will follow in the field exercise.

*Procedure:*

1. Decide on an appropriate area where you will be able to drop the ball safely. (Preferably, at the top of a building so that enough time will elapse for you to take measurements.) One person will drop the ball from rest while the other will use the stopwatch to measure the time it takes for the ball to hit the ground. Do this three times:

Time 1: \_\_\_\_\_ s

Time 2: \_\_\_\_\_ s

Time 3: \_\_\_\_\_ s

2. We can relate the time it takes for the ball to hit the ground to the velocity of the ball right before it hits the ground. By looking at the unit for acceleration ( $\text{ft/s}^2$ ) and the unit for time (s), we can see that if we multiply those quantities together, we get the unit for velocity ( $\text{ft/s}$ ). Now, the only acceleration we are concerned about is that of gravity, which is  $32 \text{ ft/s}^2$ . So, take your three measurements for time and calculate the velocity for each trial:

$$\text{Velocity} = \text{acceleration of gravity} * \text{time}$$

Velocity 1: \_\_\_\_\_  $\text{ft/s}$

Velocity 2: \_\_\_\_\_  $\text{ft/s}$

Velocity 3: \_\_\_\_\_  $\text{ft/s}$

3. Switch places with your partner and complete the above steps again.

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**Part II: Field Exercise:**

Part of the procedure for the field exercise will be very similar to what you did for the in-class portion of this lab. If you want to ride on the Paradrop, you will measure the acceleration as you fall through the air. From this measurement, you will calculate the force you felt on the ride. You will complete the first two steps below. Students who do not wish to ride will be

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calculating your velocity at the bottom of the ride and will complete Steps 3-5 below.

*Procedure:*

1. You will be collecting data with the 1-D accelerometer as you fall on the Paradrop. Make sure that the arrow on the accelerometer is pointed toward the ground and allow it to take readings for the entire duration of the ride.
2. After returning to the classroom, graphically look at the data you collected. From the graph, determine the most constant value for acceleration:

Acceleration: \_\_\_\_\_ ft/s<sup>2</sup>

Insert or Sketch Graph Here



- 
3. Find a location near the ride where you can easily observe a fellow student as they ride on the Paradrop. You will be measuring the time it takes for them to fall – measure *only* the time where they appear to be falling at a constant rate – start at the release at the top and stop when you see a visible jerk. Do this three times and find the average:

Time 1: \_\_\_\_\_ s

Time 2: \_\_\_\_\_ s

Time 3: \_\_\_\_\_ s

Average

Time: \_\_\_\_\_ s

4. As you did for the in-class portion of this experiment, you will now calculate the velocity of the rider right before you stopped the stopwatch. Do this for the average time you calculated in the previous step. Use the rider's measured value for acceleration for this calculation:

Velocity: \_\_\_\_\_ ft/s

- 
5. Compare this velocity with the one you calculated for the ball in the in-class portion. Which is greater?

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**Post Lab / Follow-up Questions:**

- Compare your measured values to the accepted values for the field exercise by filling in the chart below. Do calculations where necessary:

	<b>Measured</b>	<b>Accepted</b>
Acceleration		
Mass (same for both)		
Time (same for both)		
Force		
Final Velocity		

- 
- Give some examples of things that might have an effect on velocity.
  - What factors might have had an influence on how close the value you found for acceleration is to the acceleration of gravity?
  - *(Optional)* What is another way that we could calculate a rider's velocity?

# *Super Roundup*

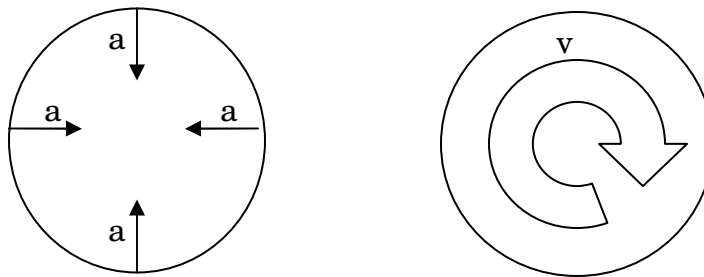
*A Laboratory Exercise*

## What is *centripetal acceleration*?

[If you have already covered linear acceleration, skip the section in brackets].

[Imagine that you are traveling west down a road at 40 mph. Suddenly, the speed limit changes to 55 mph, and you increase your velocity accordingly. You have just *accelerated*. *Acceleration* is defined as a change in velocity over a change in time. Usually, an increase in your speed is called an *acceleration* while a decrease in speed is a *deceleration*. However, a *deceleration* can also be referred to as a negative *acceleration*. Because acceleration is proportional to velocity and velocity has both a magnitude and a direction, acceleration also has both a magnitude and a direction.]

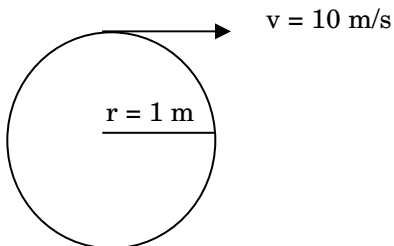
Like linear acceleration, *centripetal acceleration* has both a magnitude and a direction. For circular motion, however, the direction of acceleration is always towards the center of the circle while the speed remains constant:



The way to calculate centripetal acceleration is to relate it to the object's velocity ( $v$ ) and distance from the center of the circle ( $r$ ) as follows:

$$a = \frac{v^2}{r}$$

Let's try a sample problem. For the circle shown below, find the centripetal acceleration ( $a$ ):



$$a = \frac{v^2}{r} = \frac{(10\text{m/s})^2}{1\text{m}} = 100\text{m/s}^2 \text{ inward}$$

### What is *velocity*?

As you travel down the road in your car, you often look down at the speedometer that tells you how fast you are driving. The speedometer measures the speed of the car. Speed is simply how much distance you cover over a certain amount of time. The speed limit “55 miles per hour” means that you will cover 55 miles in one hour if you maintain that speed for the entire hour. *Velocity* is similar to speed in that it tells you how much distance you cover over a certain amount of time, but it also tells you the direction in which you are traveling.

For instance:

Speed: 55 miles per hour  
Velocity: 55 miles per hour **in the northwest direction**

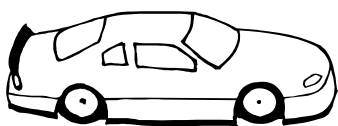
The phrase **in the northwest direction** turns a speed into a velocity.

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To calculate speed, we say that speed ( $s$ ) is the distance traveled ( $d$ ) divided by the time of travel ( $t$ ):

$$s = \frac{d}{t}$$

Let's try a sample problem. The car below travels east and covers a distance of 100 miles in two hours. Find its velocity.



→  $v = \text{velocity}$

Using the equation above:

$$s = \frac{d}{t} = \frac{100\text{miles}}{2\text{hours}} = 50\text{mph}$$

This gives us the car's speed. To convert this to velocity, we simply need to assign a direction. In this case, the problem says the car is traveling east, so:

$$v = 50 \text{ mph east}$$

## One Dimensional Accelerometer

How does it work?

The accelerometer uses an integrated circuit similar to those used in air-bag deployment systems that measure the acceleration of an object. The integrated circuit is designed so that any acceleration that it measures is converted to a voltage that can be understood by the system.

How to use it:

1. Connect the accelerometer to the LabPro interface.
2. Use the LabPro interface with a computer or TI 83+ graphing calculator.
3. Press “Quick Setup” on the LabPro interface.
4. Start data collection program.

Tips:

1. Try to avoid “bounces” against any objects if you are releasing the accelerometer from rest to measure gravitational acceleration.
2. The arrow on the device must be pointing in the direction you want to measure.



# Super Roundup

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## **Introduction:**

The Super Roundup ride at Knoebels' Amusement Resort allows riders to experience the concept of centripetal acceleration as they are pinned to a wall and swirled through the air. We will be exploring the concept of centripetal acceleration and will use that measurement to determine your velocity on the ride.

## **Concept(s):**

- Centripetal Acceleration
- Linear Velocity

## **Equipment:**

- Vernier LabPro Interface
- TI 73 / 82 / 83 / 86 / 89 / 92 Calculator (with DataMate software)
- Vernier 1-D Accelerometer
- See saw device
- Ball

## **Prelab Questions:**

- How is centripetal acceleration related to linear velocity?
  
  
  
  
  
  
  
  
  
  
- Do you think your acceleration on the ride will be constant? Explain.
  
  
  
  
  
  
  
  
  
  
- Do you think your velocity on the ride will be constant? Explain.

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## **Part I: Laboratory Exercise:**

The in-class portion of this experiment will be very conceptual and will present a qualitative representation of centripetal motion. Because it would be nearly impossible to replicate the experience on the ride for purposes of data collection in lab, we will only be considering very general relationships between the concepts.

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*Procedure:*

1. Students will be using a seesaw device attached to a set of ball bearings at the middle that will allow them to spin in a circle. They will throw the ball at the other person while spinning in hopes of having the other person catch the ball.
2. Start by having one person hold the ball while both riders move their feet so they are spinning at a comfortable speed. (If necessary, enlist the help of two other classmates to get you at a constant rate of speed.) Once at the desired speed, the student with the ball will throw the ball toward the other person. This person should try to catch the ball. Repeat this several times.
3. Explain what happens when each student tries to catch the ball. Why do you think this happens? Is it easy or very difficult to catch the ball?

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**Part II: Field Exercise:**

The field exercise for this ride will be a quantitative analysis of the concepts you explored in the in-class portion. Riders will collect data using the 1-D accelerometer and will then be calculating their velocity from that measurement.

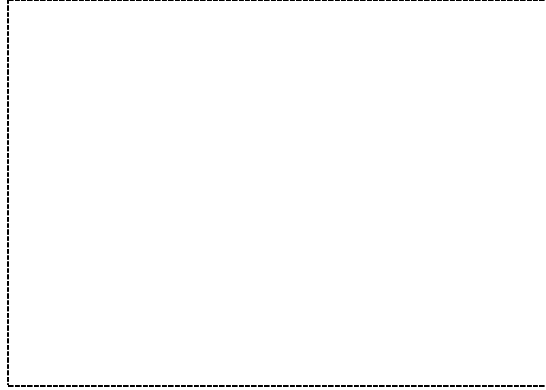
*Procedure:*

1. Set up the 1-D accelerometer as directed by your instructor and allow it to collect data throughout the entire ride. Make sure that the arrow on the device is either pointing into the center of the ride.

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2. After returning to the classroom, graphically look at the data you collected. From the graph, determine the most constant value for acceleration:

Acceleration: \_\_\_\_\_ ft/s<sup>2</sup>

Insert or Sketch Graph Here



6. We know that centripetal acceleration is related to linear velocity by the equation:

$$a = \frac{v^2}{r}$$

In order to calculate the velocity, we will need to know the radius of the ride. Obtain this value from your instructor and record it below:

Radius: \_\_\_\_\_ ft

7. Now, calculate the velocity of the ride using the above equation. Record your answer below:

Velocity: \_\_\_\_\_ ft/s

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**Post Lab / Follow-up Questions:**

- Is the velocity you calculated greater than what you expected?
- Is the acceleration you calculated greater than what you expected?
- What would happen if we doubled the radius of the ride, but needed to keep the same acceleration so no riders would fall off? What would your velocity be?
- What if we cut the radius of the ride in half? What would be the new velocity?
- *(Optional)* Design an experiment that would replicate the experience you had on the ride. (Assume both money and time are limitless).

*Teacher's  
Guides*

# Scenic Skyway

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## **Prelab Questions:**

- Will air pressure be greater at sea level or on a mountain peak? Why?

*Air pressure is a function of height – it is an inverse relationship. So, as height increases, pressure decreases and vice-versa.*

- What other factors, besides height, have an effect on air pressure?

*Other effects on air pressure include: weather (storm fronts), temperature, wind, atmospheric pressure.*

- Is measuring height by using air pressure the best method? Why or why not?

*Based on students' responses above, they should realize that there are many effects on air pressure that cannot be controlled in real life, therefore it is not the **best** method to estimate the height of an object.*

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## **Post Lab / Follow-up Questions:**

- Based on your measurements, do you think measuring height by recording the changes in air pressure is an accurate method? (Is your percent error high or low?)

*If students' percent error is low, they may conclude that measuring height using air pressure is a very good method. If this is the case, encourage them to consult their answer to the prelab question concerning the accuracy of measuring height via air pressure and have them explain why they feel they attained good results.*

- If your measurements were not very accurate, what changes would you make to the procedure to improve the accuracy?

*Changes include: completing the experiment several times to attain an average value which should account for any temporary atmospheric pressure fluctuations, developing a more accurate way to find a relationship between height and pressure (instead of using the floors in a building method), or checking the weather prior to completing the field exercise to find a calm, storm-free day.*

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- *(Optional)* Did you notice any unpredictable changes in pressure if you graphically looked at the data you collected on the ride? If so, what do you think caused those variations?

*The Scenic Skyway isn't quite a constant slope upward; it levels off slightly during the ride – this will lead to a noticeable departure from the pressure slope on a graph. Also, the sensors are sensitive enough to detect any storm fronts moving through the area; this could also cause a pressure blip.*

- *(Optional)* Compare your data with that collected by another group. Whose is more accurate? Can you explain why different groups would have different measurement

*The groups could have different measurements depending on how accurately they interpreted their graphs, how carefully the sensors were calibrated, and whether or not there was a weather front moving through at the time of the data collection.*

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# Italian Trapeze

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## **Prelab Questions:**

- How is linear velocity related to centripetal acceleration?

*Students should draw their conclusion to this answer from the laboratory introduction:*

$$a = \frac{v^2}{r}$$

- What would be the difficulty in calculating linear velocity on this ride?

*The difficulty in calculating linear velocity will be estimating or obtaining the radius of the ride to use in the above equation. While the accelerometer will give a fairly accurate value for acceleration, the radius is ultimately unknown to the students. You might want to have students estimate the radius and compare their answers (just to see how varied the estimates are!)*

- A computer processor has a speed of 2 GHz. We can consider this the “frequency” of the processor. Do you think this is faster or slower than the frequency of the ride? Explain.

*The frequency of a computer processor is incredibly faster than the speed of the riders. A frequency of 2 GHz translates to 2,000,000,000 revolutions per second – students should note that they were traveling at a tiny fraction of the speed needed to have that frequency.*

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## **Post Lab / Follow-up Questions:**

- Would there be a difference in frequency and period if you observed a rider near the edge of the ride and one near the middle? How would the velocity be different?

*There would be no difference in frequency or period if you observed a rider near the center and one near the edge of the ride – these are dependent only on angular quantities that will not change based on radius. The linear velocity of the rider does depend on their radius from the center. Therefore, since the riders have the same centripetal acceleration, but different radii, their linear velocities will differ. A*

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*rider near the center will have a slower linear velocity than one near the edge of the ride.*

- For your ride data, convert your measurement of velocity from ft/s to miles per hour. (*Hint: 1 mile = 5280 ft and 1 hour = 3600 seconds*).

*This will depend on students' calculations.*

- (*Optional*) How would a rider be able to determine his or her period and frequency? In other words, if everyone wanted to ride but we still wanted to determine the period and frequency, what are some ways we could do this?

*The easiest way for a rider to calculate his own period and frequency would be to use a stopwatch and have him record how long it takes until he makes a complete revolution – he can do this by looking at the ground for a concrete object (tree, food stand, etc). This will give him his period and allow him to calculate his frequency.*

# Skooters

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## **Prelab Questions:**

- In your own words, explain the concept of momentum.

*Students should use the relationship:  $p = mv$  to explain this concept. It is important for them to understand that momentum depends on both an object's mass and velocity; that a more massive object doesn't always have a greater momentum than a smaller object and that a faster object doesn't always have a greater momentum than a slower object.*

- Does a more massive object always have the greater momentum? Does an object with a greater velocity always have the greater momentum? Explain.

*As explained above, because an object's momentum depends on both mass and velocity, a more massive object does not always have a greater momentum nor does an object with a greater velocity always have a greater momentum.*

- If two objects of roughly the same mass collide, will each have the same momentum before the collision? Why or why not?

*Both objects do not necessarily have to have the same momentum before the collision. If both objects are traveling at the same velocity before the collision, then they will have the same momentum. However, if their speeds differ, their momenta will differ accordingly.*

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## **Post Lab / Follow-up Questions:**

- How accurate was your prediction for the velocity of your partner for the in-class activity? If there was a high error, what factors might have made the prediction difficult?

*The response to this question will be based on the students' data. However, if there was a high percent error, factors that could have influenced that are: differing masses for the carts, miscalculation of the mass of each student, or an error in the way the detector was initialized.*

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- Repeat step #6 in the laboratory exercise, but this time, find the mass of your partner. In other words, use your mass, your velocity, and your partner's velocity to find your partner's mass. Compare that mass to the mass you wrote down in step #3.

*This will be based on students' data. However, it is likely that if you have them calculate percent error for this question, it will be comparable to the above question for the same reasons listed above.*

- (Optional) Repeat the entire laboratory exercise with a different partner.

*This is simply an optional activity if you want to test the validity and reliability of the lab procedure.*

- (Optional) Repeat the entire laboratory exercise with different carts. Based on your results, can we safely assume that the masses of the carts are the same and don't affect the calculations?

*Ideally, the results will come out very similar to the first trial run. The carts should be designed to be of the same mass, allowing us to ignore their masses to simplify calculations.*

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# Paradrop

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## **Prelab Questions:**

- How is acceleration related to force? (Think of Newton's Laws of Motion)

*This is just a simple expression of Newton's 2<sup>nd</sup> Law:  $F = ma$ .*

- Do you think your acceleration on the ride will be constant? Explain.

*The students should understand that, because they are in freefall on the ride, their acceleration should be constant; ignoring air resistance, the only acceleration present is that of gravity.*

- Do you think your velocity on the ride will be constant? Explain.

*While their acceleration on the ride should be fairly constant, the students' velocity will increase as the ride progresses. This is clearly due to an application of one-dimensional kinematics that this lab does not address, but you may want to introduce to your students if time allows ( $v = v_o + at$ ).*

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## **Post Lab / Follow-up Questions:**

- Compare your measured values to the accepted values for the field exercise by filling in the chart below. Do calculations where necessary:

*The chart will be based on students' data and calculations.*

- Give some examples of some things that might have an effect on velocity.

*Factors that influence velocity include: time of freefall, acceleration, air resistance, mass of an object (due to air resistance).*

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- What factors might have had an influence on how close the value you found for acceleration is to the acceleration of gravity?

*Factors that might have influenced the data collection: any resistance in the ride that counters a freefall (there may be some safety device that doesn't allow the ride to quite get to freefall acceleration), misreading of the graph that depicts acceleration.*

- (Optional) What is another way that we could calculate a rider's velocity?

*We could have the rider use a motion sensor to determine the distance he was in freefall as well as a stopwatch to measure his time. He could then do a simple calculation to determine his velocity.*

# Super Roundup

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## Prelab Questions:

- How is centripetal acceleration related to linear velocity?

*Students should use the general relationship:*

$$a = \frac{v^2}{r}$$

- Do you think your acceleration on the ride will be constant? Explain.

*The students' centripetal acceleration will not be constant as both their linear and angular velocities will increase and decrease as the ride speeds up and slows down.*

- Do you think your velocity on the ride will be constant? Explain.

*The students' velocity will not be constant on the ride: their angular velocity will increase and decrease as will their linear velocity (due to the  $v = \omega r$  relationship).*

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## Post Lab / Follow-up Questions:

- Is the velocity you calculated greater than what you expected?

*This will be based on the data the students collected as well as their prelab predictions.*

- Is the acceleration you calculated greater than what you expected?

*This will be based on the data the students collected as well as their prelab predictions.*

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- What would happen if we doubled the radius of the ride, but needed to keep the same acceleration so no riders would fall off? What would your velocity be?

*Because of the relationship:  $a = \frac{v^2}{r}$ , the ride's velocity is proportional to  $\sqrt{r}$ . Therefore, if the radius is doubled, the velocity must increase by a factor of  $\sqrt{2}$ .*

- What if we cut the radius of the ride in half? What would be the new velocity?

*Because of the relationship:  $a = \frac{v^2}{r}$ , the ride's velocity is proportional to  $\sqrt{r}$ . Therefore, if the radius is halved, the velocity must decrease by a factor of  $\sqrt{\frac{1}{2}}$ .*

- (Optional) Design an experiment that would replicate the experience you had on the ride. (Assume both money and time are limitless).

*The reason the prelab for this experiment was so qualitative is because developing a lab experiment that would satisfactorily replicate the ride experience would be very time consuming and expensive. In essence, students would have to recreate the ride, at least in a smaller form, in order to sufficiently collect valuable data.*

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