15. Acceleration

Objectives

This activity introduces students to the concept of representing acceleration as a change of velocity in a graphical form. This activity allows students to:

- Understand that average acceleration over a given time is the change in velocity divided by the change in time
- Describe acceleration properly as the change in velocity with respect to time
- Interpret a velocity versus time graph

Procedural Overview

Students will gain experience conducting the following procedures:

- Measuring the velocity of an object using a motion sensor
- Tracking the change of velocity of an object using a graphical representation
- Interpreting a graphical representation of velocity versus time

Time Requirement

♦ Preparation time	5 minutes
♦ Pre-lab discussion and activity	10 minutes
♦ Lab activity	30 minutes

Materials and Equipment

For each student or group:

- Data collection system
- Dynamics track
- Dynamics cart
- Rod stand
- Motion sensor
- Dynamics track pivot clamp
- Dynamics track end stop

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- ♦ Velocity consists of speed and direction
- ♦ Interpreting a position versus time graph for different situations

Related Labs in This Guide

Labs conceptually related to this one include:

- ♦ Position: Match Graph
- ♦ Speed and Velocity
- ♦ Newton’s First Law
- ♦ Newton’s Second Law

Using Your Data Collection System

Students use the following technical procedures in this activity. The instructions for them (identified by the number following the symbol: "�") are on the storage device that accompanies this manual. Choose the file that corresponds to your PASCO data collection system. Please make copies of these instructions available for your students.

- ♦ Starting a new experiment on the data collection system �(1.2)
- ♦ Connecting a sensor to the data collection system �(2.1)
- ♦ Connecting multiple sensors to the data collection system �(2.2)
- ♦ Changing the sample rate �(5.1)
- ♦ Starting and stopping data recording �(6.2)
- ♦ Displaying data in a graph �(7.1.1)
- ♦ Displaying multiple variables on the *y*-axis �(7.1.10)
- ♦ Finding the slope and intercept of a best-fit line �(9.6)
- ♦ Saving your experiment �(11.1)

Background

The definitions of velocity and acceleration are often presented similarly and therefore are easily confused. It is critical that students remember that velocity tells us how much an object's position has changed and acceleration tells us how much the object's velocity has changed. A graph of position versus time for an object can be used to determine the object's velocity: the slope of a graph of position versus time is equal to the velocity.

A graph of velocity versus time for an object can be used to determine the object's acceleration: the slope of a graph of velocity versus time is equal to the acceleration. It is especially important for the students to note the direction of the acceleration as an object increases or decreases its velocity. Students will have heard of the concept of "deceleration," and you should help them realize that this is *not* a different concept than acceleration. It is just acceleration in a different direction.

Acceleration is the rate at which the velocity of an object changes.

$$\text{acceleration} = \frac{\text{velocity}_{\text{final}} - \text{velocity}_{\text{initial}}}{\Delta\text{time}}$$

Because velocity is the speed and direction of an object's motion, acceleration can mean speeding up, slowing down, or changing direction.

A car can have a positive acceleration when it is speeding up and a negative acceleration when it is slowing down, depending on its direction of travel.

When a car is speeding up, its acceleration is in the same direction as its velocity: both acceleration and velocity are positive or negative. When a car is slowing down, its acceleration is in the opposite direction of its velocity: velocity and acceleration have opposite signs.

Constant, non-zero acceleration means that an object's velocity is changing at a uniform rate. For example, when you throw a ball into the air, it experiences a velocity change of 9.8 m/s every 1 second. Since the acceleration's direction is pointing toward the earth, the ball will decelerate (slow down) when moving up and accelerate (speed up) when falling down.

Note: In this activity, the direction away from the motion sensor is the positive direction, so down the track will be the positive direction. This is a good time to review frame of reference with you students.

Pre-Lab Discussion and Activity

We commonly use the term acceleration when an object is speeding up. Most of us probably experienced this when someone steps on the gas pedal in the car (even called the accelerator). But if we want to be able to compare objects that are accelerating under different conditions, then we need to have a very precise definition of the term acceleration. We will define acceleration using the data we collect as the slope of the Velocity versus Time graph. This will allow us to see how much the velocity of the object changes in one second.

For a demonstration station:

- ♦ Data collection system
- ♦ Dynamics track (2)
- ♦ Constant velocity cart
- ♦ Motion sensor (2)
- ♦ Fan cart
- ♦ Projection system

1. Set the tracks on a flat table side by side.

2. Connect a motion sensor to each track pointing in the same direction.

3. Place the fan cart and the constant velocity cart each on one track just over 15 cm from the motion sensors with the carts set to move away from the sensor.

4. Connect the motion sensors to the data collection system. �(2.2)

5. Create a Velocity versus Time graph with both sensors on the same graph. �(7.1.10)

6. Ask a student to catch the carts at the opposite end of the track.

7. Start collecting data, and send the carts down the track. �(6.2)

8. Stop collecting data just before the student catches the carts. �(6.2)

Challenge your students to describe the motion of each cart, and identify the one that is accelerating. You may want to show a Position versus Time graph at the same time to tie back to earlier position and velocity discussions.

Lab Preparation

These are the materials and equipment to set up prior to the lab:

1. Remind students that they need sufficient distance between the motion sensor and the cart both when the cart is moving toward the motion sensor and when they start the cart moving away from the motion sensor (greater than 15 cm). The motion sensor will respond to the strongest signal it receives.

2. Be sure that students do not have too steep a slope for the data collection using the dynamics track. This will allow for a more gradual motion and collecting more data points.

Safety

Follow all standard laboratory procedures.

Sequencing Challenge

The steps below are part of the Procedure for this lab activity. They are not in the right order. Determine the proper order and write numbers in the circles that put the steps in the correct sequence.

3	4	2	1
Repeat the data collection procedure this time pushing the cart up the incline away from the motion sensor.	Determine the acceleration of each trial from the slope of the graphed data.	Release the cart from the elevated end of the track to produce a Velocity versus Time graph.	Assemble the inclined track with the end stop at one end and the motion sensor at the opposite end.

Procedure with Inquiry

After you complete a step (or answer a question), place a check mark in the box (☐) next to that step.

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Set Up

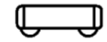
1. ☐ Start a new experiment on the data collection system. �(1.2)

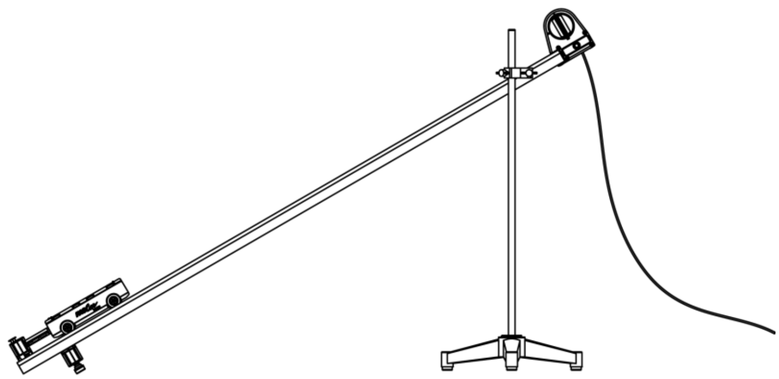
2. ☐ Connect a motion sensor to the data collection system. �(2.1)

3. ☐ Display Velocity on the y-axis of a graph with Time on the x-axis. �(7.1.1)

4. ☐ When a car's acceleration is negative but its velocity is positive, what is the car doing?

Slowing down, or decelerating.

5. ☐ Ensure that your sampling rate is set to at least 20 samples per second. If your motion sensor has a selector switch, ensure that it is in the cart or near setting. �(5.1) 



6. ☐ Attach the end stop to the lower end of the dynamics track.

7. ☐ Mount the track to your rod stand using the pivot clamp, slightly inclining the track at one end.

8. ☐ Attach the motion sensor to the elevated end of the track with the face of the sensor pointed down the length of the track.

Collect Data

9. ☐ Set the cart at the top of the inclined end of the track, holding it just over 15 cm from the motion sensor.

10. ☐ Start data collection, and release the cart allowing it to roll down the track. �(6.2)

11. ☐ Catch the cart at the bottom of the inclined track just before it hits the end stop, and stop data collection. �(6.2)

12. ☐ Set the cart at the bottom of the inclined end of the track.

13. ☐ Start data collection, and give the cart a quick push with your hand up the track. �(6.2)

14. ☐ Allow the cart to roll back down the track, and catch the cart at the bottom of the inclined track just before it hits the end stop, and stop data collection. �(6.2)

Analyze Data

15. ☐ Sketch both runs of data in Velocity versus Time Graph in the Data Analysis section.

16. ☐ Use your data collection system to apply a linear fit to each run (applied only to the data while the cart was in motion), and record the slope in Table 1 in the Data Analysis section. �(9.6)

17. ☐ Save your data as instructed by your teacher. �(11.1)

Data Analysis

Velocity versus Time

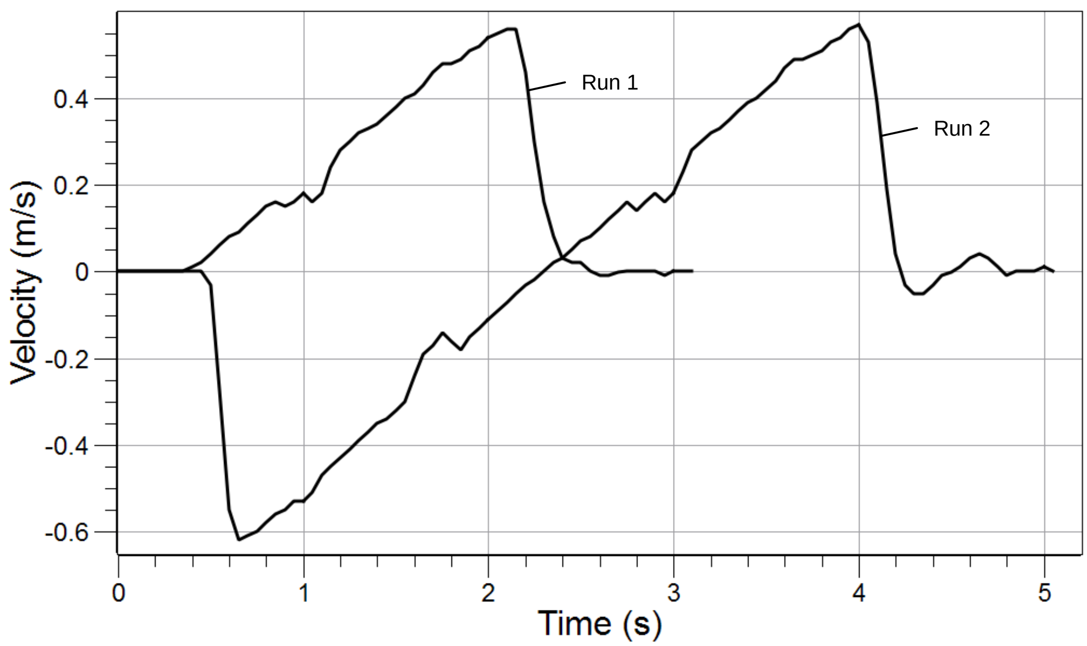


Table 1: Slope of Velocity versus Time

Run	Slope
Run 1	0.778 m/s^2
Run 2	0.738 m/s^2

Analysis Questions

1. During the period when the cart was in motion, are the Velocity versus Time graphs straight lines? Refer to the previous page if necessary. How is the acceleration of the cart changing if your Velocity versus Time graphs are straight lines?

The Velocity versus Time data plots are straight lines. The acceleration is constant if the Velocity versus Time data plot is a straight line.

2. Although the paths of the cart in both trials were different, the slopes of the Velocity versus Time graphs for each trial are the same (during the period in which the cart was in motion). Why is this the case? Justify your answer.

The slopes are the same because the cart is subject to the same acceleration in both trails.

3. Looking at the Velocity versus Time graph, what would a negative slope tell you about the cart's acceleration? What would a positive slope tell you?

A negative slope tells us that the acceleration is negative. A positive slope tells us that the acceleration is positive. Because moving away from the motion sensor, down the track, is the positive direction, the acceleration is positive.

4. What was causing the cart to accelerate after releasing it from rest at the top of the track? Was that acceleration constant?

Gravity. The acceleration was constant because the slope of velocity versus time stayed the same.

5. Describe the motion of an object that has a velocity versus time graph that is a horizontal straight line (a slope of zero).

The velocity of the object is constant, or the object moves at a constant speed in a constant direction. No change in velocity means no acceleration.

Synthesis Questions

Use available resources to help you answer the following questions.

1. The term "acceleration" is used in our everyday lives and language, but is often used in a non-physical context. Now that you have developed a physical definition of "acceleration," give an example of where the physical definition matches the "everyday" definition. Give an example where they are different.

An example where the definitions are similar is how a car accelerates. The car experiences a change in velocity due to acceleration

An example where the definitions are different is when a doctor describes the accelerated heart rate of a patient. Although the rate at which the heart is beating has increased, the actual position of the heart has not changed, thus there is no real velocity and no acceleration.

2. Modern aircraft carriers use a steam powered catapult system to launch jets from a very short range. These catapults can provide a constant acceleration to bring jets up to speed in only 2 seconds. If each jet requires a minimum take-off speed of 82.3 m/s, how much acceleration must the catapult supply so the jet can take off?

$$a = \frac{v_f - v_i}{\Delta t}$$

$$a = \frac{82.3 \text{ m/s} - 0.00 \text{ m/s}}{2 \text{ s}}$$

$$a = 41.2 \text{ m/s}^2$$

3. How many different devices in a car help to accelerate the vehicle? What are they?

Three. The throttle, the brakes, and the steering wheel all cause a change in velocity.

Multiple Choice Questions

Select the best answer or completion to each of the questions or incomplete statements below.

1. If the acceleration due to gravity is –9.8 m/s^2, which of the following choices would best describe the acceleration of a 0.5 kg frictionless block sliding down the track used in our experiment?

- **A. 3.5 m/s^2 down the ramp**
- **B.** 3.5 m/s^2 up the ramp
- **C.** 0 m/s^2
- **D.** Indefinable

2. A cart with an initial velocity of zero and a final velocity of 12 m/s after 2 s will have an acceleration of?

- **A.** 4 m/s^2
- **B. 6 m/s^2**
- **C.** 8 m/s^2
- **D.** 12 m/s^2

3. A race car starting from rest accelerates uniformly at a rate of 5 m/s^2. What is the car's speed after it has traveled for 5 s?

- **A.** 5 m/s
- **B.** 10 m/s
- **C.** 20 m/s
- **D. 25 m/s**

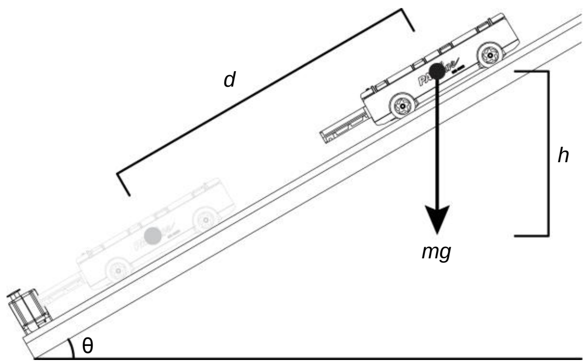
Key Term Challenge

Fill in the blanks from the list of randomly ordered words in the Key Term Challenge Answers section.

1. Acceleration is defined as the change in velocity over time. If an object is sitting still or moving at a constant **velocity**, it has an acceleration of zero. If an object has a constant, non-**zero**, acceleration, the velocity of the object is **continuously** changing at the same rate. In common usage, an object with a positive velocity and a negative acceleration is said to be **decelerating**, and an object with a positive velocity and a positive acceleration is said to be accelerating.

Extended Inquiry Suggestions

Ask your students to measure the angle of their track and use trigonometry to determine the acceleration due to gravity based on the component they measured.



Review the answer to Synthesis Question 3. Elaborate on the use of a steering wheel as a means of changing velocity. This can be a tough concept for students to grasp and is a natural lead-in to discussing circular motion.