UNIT 1

Forces and Motion

Chapter 1

Science and Measurement

Introduction to Chapter 1

This chapter is about measurement and how we use measurements and experiments to learn about the world. Two fundamental properties of the universe that we want to measure are time and distance. A third important measurement, speed, tells us how time and distance relate to the motion of objects.

Investigations for Chapter 1

1.1	**Time and Distance**	*How do we measure and describe the world around us?*

In the first Investigation, you will use electronic timers and other measuring tools to explore precision measurement of the fundamental quantities of time and distance.

1.2	**Investigations and Experiments**	*How do we ask questions and get answers from nature?*

Investigating a car rolling down a ramp may seem simple, but it is difficult to understand what is really happening. The key is learning to design careful experiments that test our ideas with observations. In this Investigation, you will examine the motion of a car on a ramp to explore the action of variables in experiments.

1.3	**Speed**	*What is speed and how is it measured?*

The words *fast* and *slow* are not precise enough for many questions in science. We need to know how fast is fast. You will learn to determine the speed of moving objects with great accuracy. This Investigation of speed will be the foundation for answering many questions about motion.

Learning Goals

In this chapter, you will:

- ✔ Accurately measure time using electronic timers and photogates.
- ✔ Use decimals to represent fractions of a second.
- ✔ Develop a research question or hypothesis that can be tested.
- ✔ Identify the variables that affect motion.
- ✔ Develop an experimental technique that achieves consistent results.
- ✔ Draw conclusions from experimental results.
- ✔ Accurately measure distance.
- ✔ Identify metric and English units of distance.
- ✔ Convert between units of distance.
- ✔ Calculate speed in units of inches per second, feet per second, and centimeters per second.

Vocabulary

cause and effect	experimental technique	metric system	time
control variables	experimental variable	procedure	trial
controlled experiment	hypothesis	research question	variables
distance	investigation	scientific evidence	velocity
English system	length	scientific method	
experiment	measurements	second	

1.1 Time and Distance

In this section, you will learn about two fundamental properties of the universe: time and distance. Learning about how things change with time motivates much of our study of nature. We are born and our bodies change as time passes. The steady forward movement of time creates a present, a past, and a future.

Another important quality of the universe is that it has three dimensions. To observe and learn about objects, their sizes, and their motion in the universe, we need units of length. Common measures for length are inches and meters. Other units of length are used for very small distances like atomic sizes and very large distances like those between cities.

Figure 1.1: *The flow of time is an important part of our experience of life. To understand nature we need to investigate how things change with time.*

Two ways to think about time

What time is it? There are two ways we think about **time** (Figure 1.2). One meaning for time is to identify a particular moment. If we ask "What time is it?" we usually want to know time relative to the rest of the universe and everyone in it. For example, 3:00 PM, Eastern Time, on April 21 tells the time at a certain place on Earth.

How much time? Another meaning for time is a quantity, or interval of time. The question "How much time?" is asking for an interval of time with a beginning and end. For example, we might measure how much time has passed between the start of a race and when the first runner crosses the finish line.

How is time measured? For most of physical science we measure and record time in **seconds**. Some other units of time you may see are hours, minutes, days, and years. Choose the unit most suited to the time you want to measure. Short races are best measured in seconds while the age of a person is best measured in years.

Figure 1.2: *There are two different ways to understand time.*

Time comes in mixed units

Many calculations require that time be expressed in seconds. However, seconds are very short. Hours and minutes are more convenient for everyday time measurement. As a result, time intervals are often in mixed units, such as 2 minutes and 15 seconds. If you have a time interval that is in mixed units you will have to convert it to seconds before doing calculations. Table 1.1 gives some useful relationships between units of time.

Table 1.1: ***Some units for time***

Time Unit	How Many Seconds	How Many Days
1 second	1	0.0001157
1 minute	60	0.00694
1 hour	3,600	0.0417
1 day	86,400	1
1 year	31,557,600	365.25
1 century	3,155,760,000	36,525

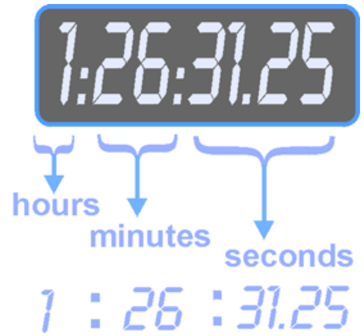


Figure 1.3: *Electronic timers have displays that show mixed units. Colons (:) separate the units.*

Why we have different units for time

How many seconds have there been since you were born? From the table you should see that for every year there are 31,557,600 seconds. To give your age in seconds would be silly. The number would be too big and change too fast. A year is a better unit for describing people's ages.

How do you read a timer?

Most timing equipment (including digital timers) displays time in three units: hours, minutes, and seconds. Colons separate the units into hours, minutes, and seconds. The seconds number may have a decimal that shows fractions of a second. To read a timer you need to recognize and separate out the different units. Figure 1.3 shows a timer display that reads 1 hour, 26 minutes, and 31.25 seconds.

How do you convert to seconds?

To convert a time to seconds you have to first separate out all the different units. For physics problems, the starting units will often be hours, minutes, and seconds. Follow the list below to convert any amount of time to seconds.

1. Separate the total time into the amount of time in each unit.
2. Convert each separate quantity of time to seconds.
3. Add all the seconds.

Example:

Convert the time in Figure 1.3 to seconds.

Solution:

Separate time into each unit.

1 hour

26 minutes

31.25 seconds

Convert each different unit into seconds.

1 hour × 3,600 seconds/hour = 3,600 seconds

26 minutes × 60 seconds/minute = 1,560 seconds

Then add all the seconds.

$$\begin{array}{r} 3{,}600.00 \\ 1{,}560.00 \\ +\quad 31.25 \\ \hline 5{,}191.25 \text{ seconds} \end{array}$$

Measuring distance

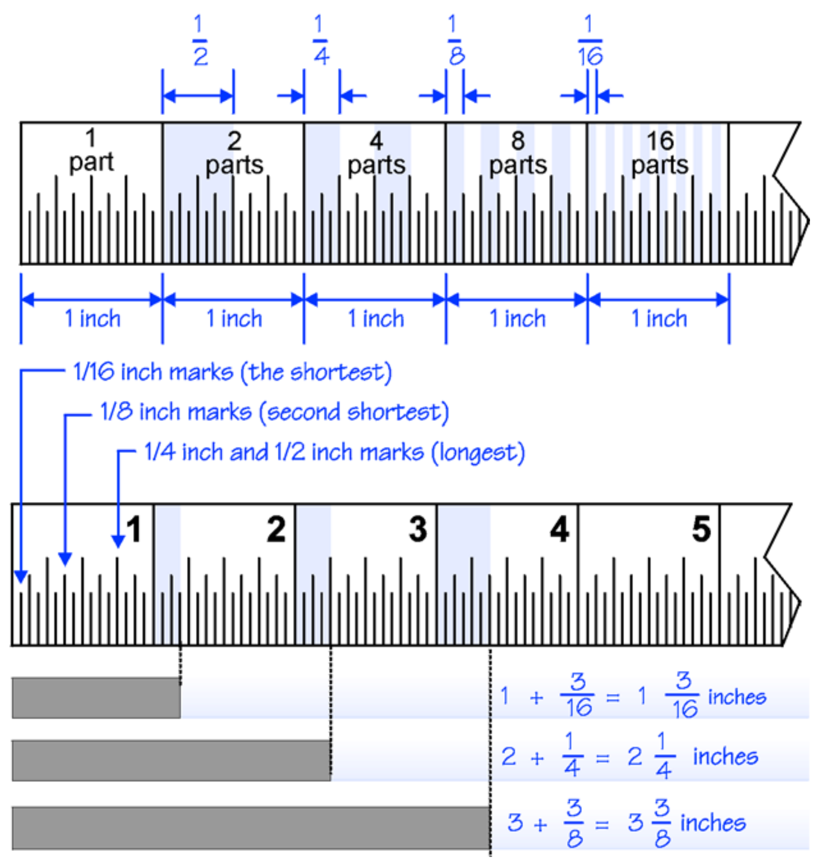
Distance is measured in units of length

Distance describes how far it is from one point to another. Distance is measured in units of length. Like other measurements, distance always has a number and a unit. It is hard to say precisely how far something has moved without units. It would be silly to ask someone to walk 25. They would ask, "Twenty-five what?" There is a big difference between 25 feet and 25 miles! Without units, distance measurements are meaningless.

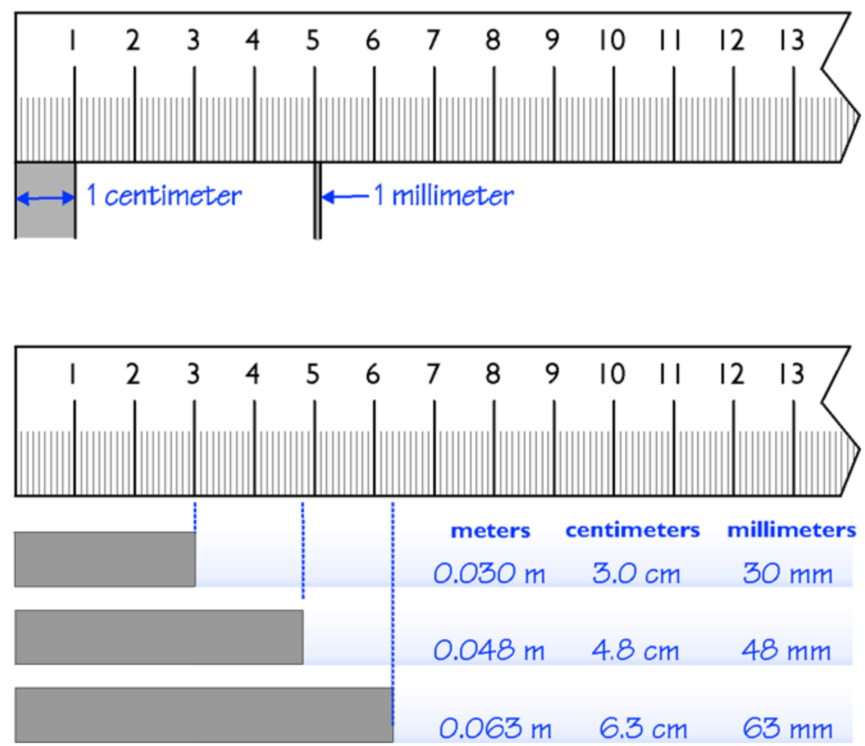
There are two common systems

There are two common systems of units that are used for measuring distance. You need to understand both systems. The English system uses inches, feet, and miles. The metric system uses millimeters, centimeters, meters, and kilometers.

Reading the English ruler



Reading the metric ruler (meter stick)



Why are there so many different ways to measure the same thing?

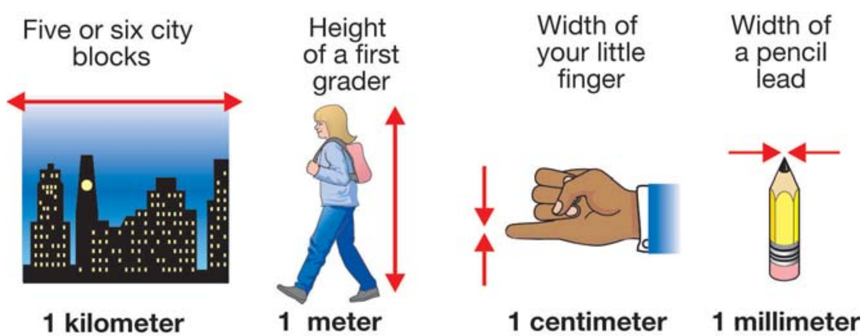
Why units were invented

Units were invented so people could communicate amounts to each other. For example, suppose you want to buy 10 feet of rope. The person selling the rope takes out a ruler that is only 10 inches long (instead of 12 inches) and counts out 10 lengths of the ruler. Do you get your money's worth of rope? Of course not! For communication to be successful, everyone's idea of one foot (or any other unit of measure) must be the same. Figure 1.4 illustrates a hot dog vendor trying to sell a foot-long hot dog that is only 10 inches long. If the girl were to buy a hot dog, would she be getting what the sign says that she is paying for?

Figure 1.4: *The hot dog vendor and the girl have different ideas about how long a foot is.*

Scientists use metric units

Almost all fields of science use metric units because they are so much easier to work with. In the English system, there are 12 inches in a foot, 3 feet in a yard, and 5,280 feet in a mile. In the metric system, there are 10 millimeters in a centimeter, 100 centimeters in a meter, and 1,000 meters in a kilometer. Factors of 10 are easier to remember than 12, 3, and 5,280. The diagram below will help you get a sense for the metric units of distance.



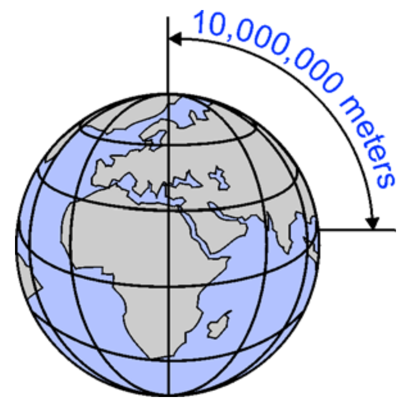


Figure 1.5: *In 1791, a meter was defined as 1/10,000,000 of the distance from a pole of Earth to its equator. Today the meter is defined more accurately using wavelengths of light.*

We use units every day

In your life, and in this book, we use both English and metric units. We measure some quantities, like power and wavelength, in metric units. We measure other quantities, like weight and speed, in both metric and English units. Science measurements are always metric, but you may use units of pounds and miles per hour in your daily experience. In many other countries, people use metric units for everyday measurements.

1.2 Investigations and Experiments

Science is about figuring out cause and effect relationships. If we do something, what happens? If we make a ramp steeper, how much faster will a car roll down? This is an easy question. However, the process we use to answer this question is the same process used to answer more difficult questions, like what keeps the moon in orbit around the Earth?

The rules of nature are often well hidden. We ask questions about nature and then design experiments to find clues. A series of one or more experiments that helps us answer a question is called an **investigation**. In this section you will learn how to design investigations using the scientific method.

Designing experiments

What is an experiment?

An **experiment** is any situation we set up to observe what happens. You do experiments every day. You might wear your hair a new way to see if people treat you differently. That is an experiment.

Measurements can be recorded

In science, we usually plan our experiments to give us **measurements,** which are observations we can record and think about. You might ask 10 friends if they like your hair the new way or the old way. That would be a way of collecting data from your experiment. From the results of the survey, you might decide to leave your hair the new way, or change it back. We usually do experiments for a reason, because we want to know something.

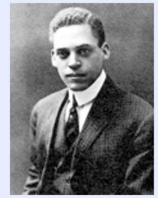
Experiments start with questions

Experiments usually have a question associated with them. The question might be "Will people like my short hair better?" Sometimes you are aware of the question and sometimes you are not. If you push a door to see if it opens, that is an experiment. You often do it without thinking about the question. But the question is still there. "What will happen if I push on this door?"

Answers from nature

Experiments are the way we ask questions of nature. You might want to know if salt water freezes at a lower temperature than fresh water. To answer the question you do an experiment. Place containers of salt water and fresh water in a freezer. Observe the water samples, and when ice forms measure and record the temperature of the sample. You can now compare the freezing points. Nature answers our questions about how things work through the results of experiments.

Ernest Just



Ernest Just was born in South Carolina in 1883. His father died when Ernest was four. His mother, a teacher, instilled in him a love of learning.

Ernest earned a scholarship to attend a boarding school in New Hampshire. The only African-American student at the school, Ernest excelled in his classes and graduated as the class valedictorian. Just went on to earn a degree in zoology from Dartmouth college and his Ph.D. in embryology from the University of Chicago.

Just taught at Howard University in Washington DC and spent summers researching marine mammal reproductive systems at the Woods Hole Oceanographic Institute on Cape Cod. He published over 50 papers detailing this work.

Just was the first American invited to join a prestigious research team at the Kaiser Wilhelm Institute in Berlin. This led to invitations to Naples, Sicily, and Paris. Just's work was greatly admired across Europe's scientific community.

The process of science

How did people learn science?

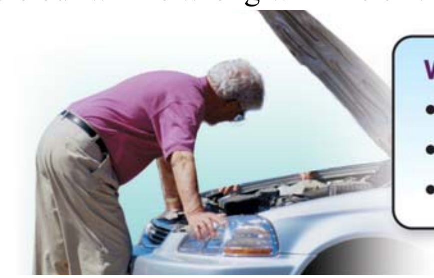
Have you ever wondered why people know so much about the world? Nobody told Sir Isaac Newton about how force and motion worked. There was no physics course he could take to learn it. Newton did his own experiments and figured it out. Once he knew, he told others, who told others, and now this course will tell *you*. But, we understand force and motion today because people did the original experiments to figure it out.

Scientists learn new information

Learning new information about the world—and the universe—is the most important thing scientists do. It is also important to *you*. Every day you have to figure out how to solve problems, like how to get your car to start in the cold. Science is a way of collecting information that can help you solve problems.

Experiments provide clues

Suppose your car will not start. You probably check obvious things first. Looking at your gas gauge is a simple experiment to test if there is any gas in your tank. Another experiment is to check the battery by trying the lights. If you are a mechanic, every experiment provides a clue. You keep doing experiments until you have enough clues to figure out what's wrong with the car.



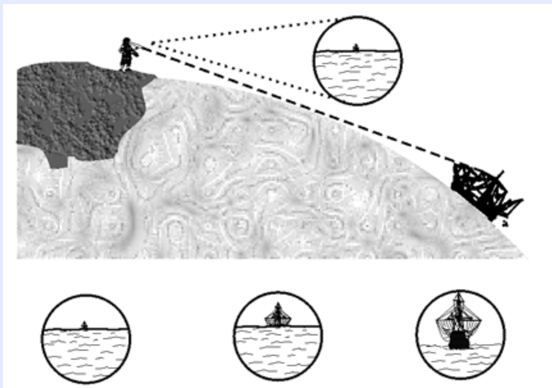
Why doesn't the car start?

- Is there any gas?
- Is the battery dead?
- Are the wires loose?

Scientific evidence

Every experiment you do provides you with evidence. If you are a good mechanic you might try each experiment a couple of times to be sure of your evidence. For example, you might test the lights two or three times to see if the battery is really dead or maybe you just did not turn the switch all the way the first time. **Scientific evidence** is any observation that can be repeated with the same result.

Earth is round?



A ship 10 miles away seen with a telescope. *A ship 5 miles away seen with a telescope.* *A ship 1 mile away seen with a telescope.*

A good example of science is how people figured out that Earth is round. If you look out your window, you don't see a round Earth. Earth looks flat. People figured out it was round by thinking scientifically about what they saw and experienced.

People saw that the tops of ships appeared first as the ships approached shore. This could be explained if Earth was round.

Over a period of time people collected all kinds of evidence that suggested Earth was round. The evidence did not make sense if Earth was flat. When there was enough evidence, people were convinced and understood that Earth really is round.

The scientific method

The scientific method

The process you use to figure out what is wrong with your car is an example of the **scientific method**. As you try to fix your car, you ask yourself questions (Is there any gas? Is the battery dead?) and formulate ideas (or hypotheses) about what is wrong. By testing your ideas, you are experimenting and collecting data. You may be able to use this data to fix the car. Even if you conclude that the car can't be fixed, you have learned information to use the next time you are faced with a similar problem. Table 1.2 shows the steps of the scientific method.

Steps in the scientific method

Table 1.2: ***Steps in the scientific method***

Step		Example
1	Ask a question.	Why doesn't the car start?
2	Formulate a hypothesis.	Maybe the battery is dead.
3	Design and conduct an experiment.	Turn the lights on to test the battery.
4	Collect and analyze data.	The lights go on.
5	Make a tentative conclusion.	Battery is OK.
6	Test conclusion, or if necessary, refine the question, and go through each step again.	Are the ignition wires loose or wet?

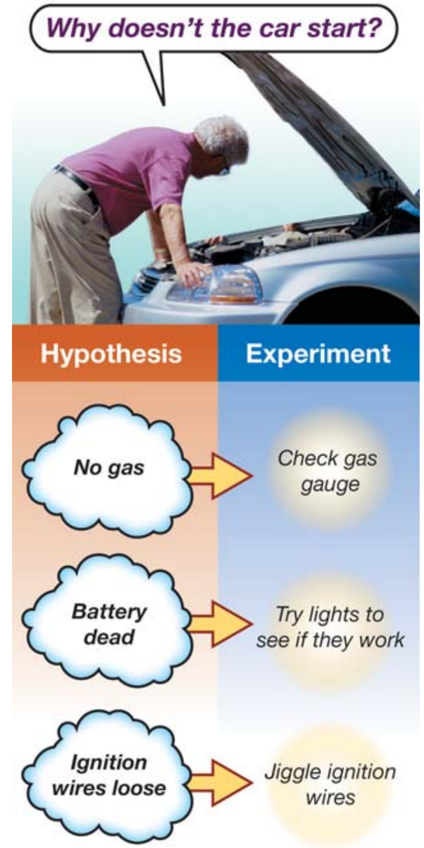


Figure 1.6: *Science is a process of collecting information through observation and experiment. The information is used to solve problems and test ideas about how things work.*

The research question and hypothesis

A research question

Suppose you are interested in how the angle of a hill affects the speed of a car rolling down. Your research question could be, "How is the speed of the car down the ramp affected by changing the steepness of the hill?"

The hypothesis

It is often useful to start with a guess (or hunch) about how something will happen. For example, you might start with a guess that making the ramp steeper will make the car roll faster. Your guesses or intuitions can take the form of a hypothesis, a prediction that can be tested by experiment. A good hypothesis might be: "Steeper hills result in cars with faster speeds." The hypothesis represents the tentative answer to the question "How is the speed of the car down the ramp affected by the angle of the hill?"

A hypothesis is an educated guess about what will happen.

Making a good hypothesis or research question

Forming a good hypothesis or research question depends on already knowing a little about how things might happen. You need to do a little experimenting before trying to form a hypothesis. For this reason, the word "hypothesis" is also defined as "an educated guess." Your experience with how objects roll down a smooth surface will help you make a hypothesis for a car and ramp experiment. However, don't worry if you cannot think of a hypothesis before you start your experiment. A good hypothesis can only be formed when you know a little about what is going to happen. The more experience you have, the better your hypothesis will be. It may be helpful to keep in mind that good hypotheses and research questions are those that you can test with an experiment.

Happy accidents

Not all discoveries in science are made using the scientific method! In fact, many important new discoveries and inventions happen by trial and error, a lucky experiment, or by accident.

The discovery of a way to waterproof fabric is a good example. Scientists tried to stretch Teflon®, a special kind of plastic into thin films. The plastic kept breaking. One day, in frustration, one scientist just ripped a piece very fast. It stretched without breaking! The resulting thin plastic film was waterproof but let water vapor through.

Stretched Teflon® film eventually became a breathable waterproof fabric called GoreTex®, used for outdoor clothing.

Designing experiments

Start with a good question

Will a car roll faster down a steeper hill?

This is a good research question because we can test it with an experiment. We could set up ramps at different angles and measure the speeds of cars as they roll down the ramp. Once you have a good question, you can design an experiment to help you find the answer.

Suppose you find that a car on a steep ramp rolls faster than a car on a ramp at a lower angle. Can you say that your experiment proves steeper ramps make cars go faster?

Identify all the factors when designing experiments

Maybe, and maybe not. Before you can design a good experiment, you must identify all the factors that affect how fast the car moves down the ramp. Maybe you pushed the car on one ramp. Maybe one car was heavier than another. Your observation of higher speed *because* the angle was steeper *could* be correct. Or, the speed could be higher for another reason, like a push at the start.

Variables

Factors that affect the results of an experiment are called variables. You can think about variables in terms of cause and effect. The weight of the car is one variable that may have an effect on the speed of the car. Some other variables are the angle of the ramp and how far down the ramp you measure the speed.

Change one thing at a time

When you can identify more than one variable that could affect the results of your experiment, it is best to change *only one variable at a time*. For example, if you change both the weight of the car and the angle of the ramp, you won't know which of the two variables caused your speed to change. If you want to test the effect of changing the angle, keep ALL the other variables the same.

Control variables and experimental variables

The variable that you change is called the experimental variable. The variables that you keep the same are called control variables. When you change one variable and control all of the others, we call it a controlled experiment. Controlled experiments are the preferred way to get reliable scientific evidence. If you observe that something happens (like the car goes faster), you know *why* it happened (because the ramp was steeper). There is no confusion over which variable caused the change.

Seven variables that affect speed

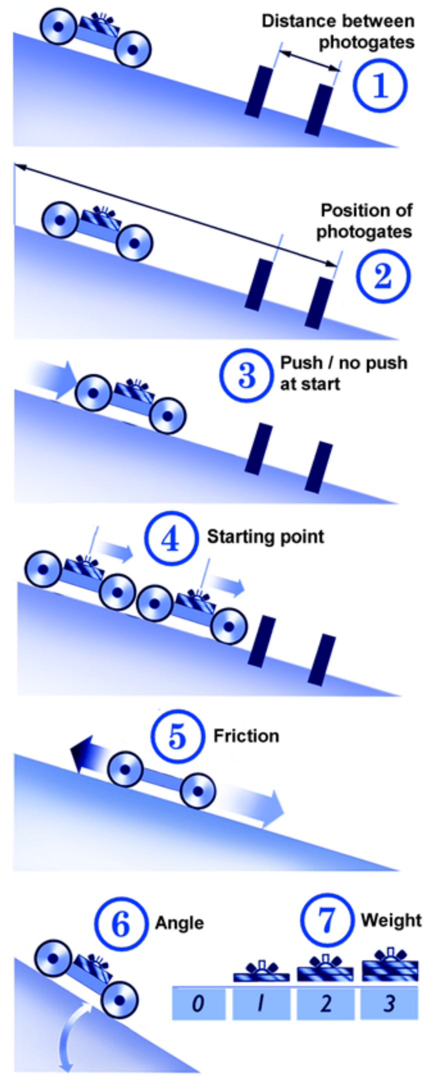


Figure 1.7: *Variables that affect a car rolling down a ramp.*

Experimental techniques

Experiments often have several trials

Many experiments are done over and over with only one variable changed. For example, you might roll a car down a ramp 10 times, each with a different angle. Each time you run the experiment is called a **trial**. To be sure of your results, each trial must be as close to identical as possible to all the others. The only exception should be the one variable you are testing.

Experimental technique

Your **experimental technique** is how you actually do the experiment. For example, you might release the car using one finger on top. If this is your technique, you want to do it the same way every time. By developing a good technique, you make sure your results accurately show the effects of changing your experimental variable. If your technique is sloppy, you may not be able to tell if any results are due to technique or changing your variable.

Procedures

The **procedure** is a collection of all the techniques you use to do an experiment. Your procedure for testing the ramp angle might have several steps (Figure 1.8). Good scientists keep careful track of their procedures so they can come back another time and repeat their experiments. Writing the procedures down in a lab notebook is a good way to keep track (Figure 1.9).

Scientific results must always be repeatable

It is important that your experiments produce measurements that are reliable and accurate. What good would a new discovery or invention be if nobody believed you? Having good techniques and procedures is the best way to be sure of your results.

Scientific discoveries and inventions must always be able to be tested by someone other than you. If other people can follow your procedure and get the same results, then most scientists would accept your results as being true. Writing good procedures is the best way to ensure that others can repeat and verify your experiments.

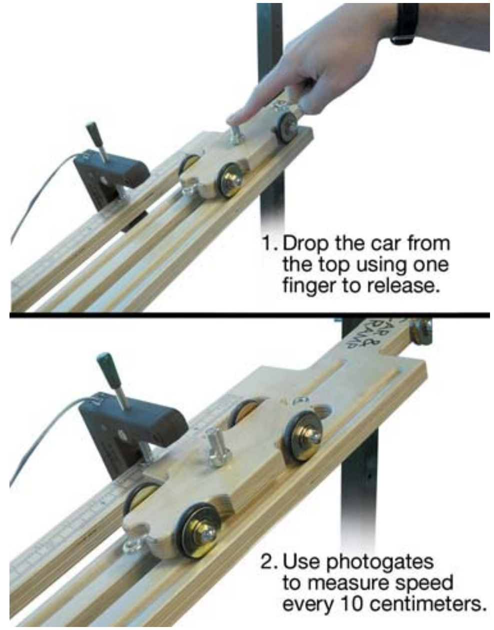


Figure 1.8: *A procedure is a collection of all the techniques that someone else would need to repeat your experiments in order to confirm your results.*

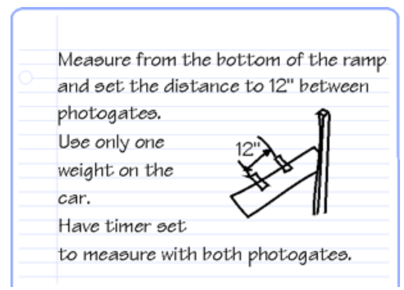


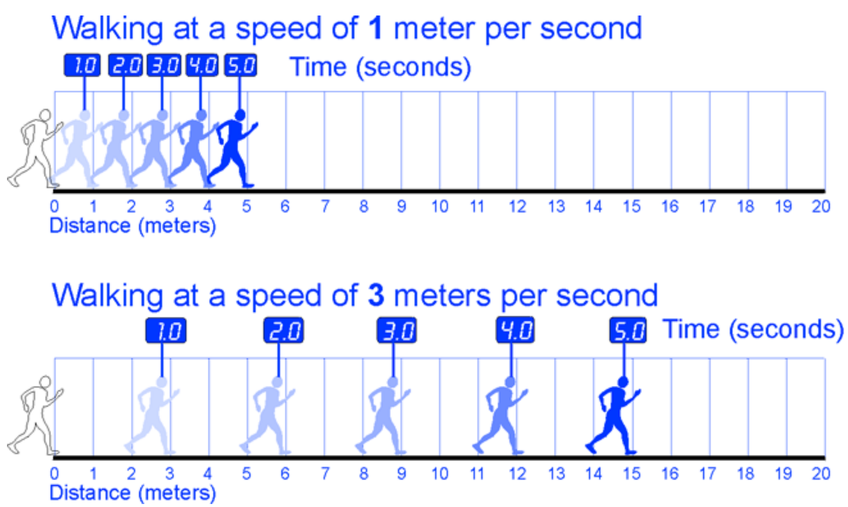
Figure 1.9: *A notebook keeps your observations and procedures from getting lost or being forgotten.*

1.3 Speed

Just saying that something is fast is often not enough description for a scientist. You can easily walk faster than a turtle, yet you would not say walking was fast compared with the speed of driving a car. In this section, you will learn how to be very precise about speed.

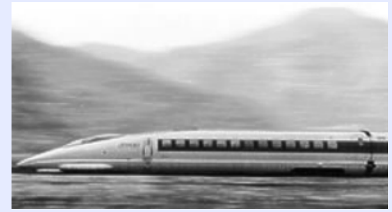
What do we mean by speed?

- Exactly how fast are you walking?
- How many meters do you walk for each second?
- Do you always walk the same number of meters every second?



What is speed? Describing movement from place to place naturally leads you to think about **speed**. The speed of an object is a measure of how quickly the object gets from one place to another. Speed is a characteristic of all objects. Even objects that are standing still have a speed of zero.

Fast trains



Fast trains are being used for transportation in several countries. In Japan, where cities are crowded, people have to travel from far away to reach their jobs. Japan's 500 Series train is the world's fastest, operating at a speed of 300 km/h (186 mph).

In France, the TGV goes almost as fast. In the United States, Amtrak runs high-speed trains from Boston to Washington, DC. Fast trains are also being considered in California and the Midwest.

Fast trains offer benefits like performance and friendliness to the environment. As airports become more crowded, the use of fast trains for long-distance travel will probably increase.

Calculating speed

Calculating speed

There are several ways to look at the concept of speed. In the simplest interpretation, speed is the distance traveled divided by the time taken. For example, if you drive 90 miles in 1.5 hours (Figure 1.10), then your speed is 90 miles divided by 1.5 hours, equal to 60 miles per hour. To determine a speed, you need to know two things:

- The **distance** traveled
- The **time** taken

Speed is calculated by taking the distance traveled divided by the time taken.

Units for speed

Since speed is a ratio of distance over time, the units for speed are a ratio of distance units over time units. If distance is in miles and time in hours, then speed is expressed in miles per hour (miles/hours). We will often measure distance in centimeters or meters, and time in seconds. The speeds we calculate would then be in units of centimeters/second or meters/second. Table 1.3 shows many different units commonly used for speed.

What does "per" mean?

The word "per" means "for every" or "for each." The speed of 60 miles per hour is really a shorthand for saying 60 miles *for each* hour. When used with units, the "per" also means "divided by." The quantity before the word per is divided by the quantity after it. For example, if you want speed in meters per second, you have to divide meters by seconds.

Table 1.3: ***Some Common Units for Speed***

Distance	Time	Speed	Abbreviation
meters	seconds	meters per second	m/sec
kilometers	hours	kilometers per hour	km/h
centimeters	seconds	centimeters per second	cm/sec
miles	hours	miles per hour	mph
inches	seconds	inches per second	in/sec, ips
feet	minutes	feet per minute	ft/min, fpm

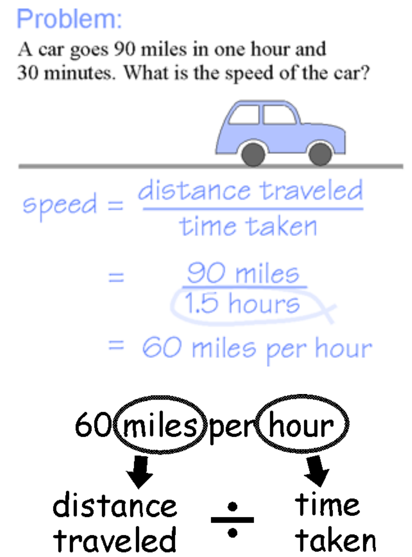


Figure 1.10: *If you drive 90 miles in 1.5 hours, your speed is 60 miles per hour. This is calculated by dividing the distance traveled (90 miles) by the time taken (1.5 hours).*

Relationships between distance, speed, and time

How far did you go if you drove for 2 hours at 60 mph?

Mixing up distance, time, and speed

This seems like a fair question. We know speed is the distance traveled divided by the time taken. Now we are given the time and the speed. We are asked to find the distance. How do you take the new information and figure out an answer?

Let the letter v stand for "speed," the letter d stand for "distance traveled," and the letter t stand for "time taken." If we remember that the letters stand for those words, we can now write our definition of speed much faster.

Speed

Speed (m/sec) →

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

Distance traveled (meters)

Time taken (seconds)

Using formulas

Also remember that the words or letters stand for the values that the variables really have. For example, the letter t will be replaced by the actual time when we plug in numbers for the letters. You can think about each letter as a box that will eventually hold a number. Maybe you don't know what the number is yet. Once we get everything arranged according to the rules we can fill the boxes with the numbers that belong in each one. The last box left will be our answer. The letters (or variables) are the labels that tell us which numbers belong in which boxes.

Three forms of the speed formula

There are three ways to arrange the three variables that relate distance, time and speed. You should be able to work out how to get any of the three variables if you know the other two.

Equation	Gives you...	If you know...
$v = d/t$	speed	time and distance
$d = vt$	distance	speed and time
$t = d/v$	time	distance and speed

Why v is used to represent speed in an equation.

When we represent speed in a formula, we use the letter *v.* If this seems confusing, remember that *v* stands for velocity.

For this chapter, it isn't important, but there is a technical difference between *speed* and *velocity*. Speed is a single measurement that tells how fast you are going, like 60 miles per hour.

Velocity really means you know both your speed, and also what direction you are going. If you told someone you were going 60 mph straight south, you told them your velocity. If you just told them you were going 60 mph, you told them your speed.

How to solve science problems

An example — An airplane is flying at a constant speed of 150 meters per second. After one hour, how far has the plane traveled?

Solution — There is a five-step process that works for almost all science problems.

Step 1 — Identify what you are asked.

The problem asks for the distance.

Step 2 — Write down what you are given.

You are given time and speed.

Step 3 — Write down any relationships you know that involve any of the information you are asked, or given.

$v = d/t$, 1 hour = 3,600 seconds.

Step 4 — Pick which relationship to start with and try to arrange it to get the variable you want on the left-hand side of an equals sign.

$d = vt$

Step 5 — Plug in the numbers and get the answer.

$$d = vt = (150 \text{ m/sec}) \times (3{,}600 \text{ sec})$$
$$= 540{,}000 \text{ meters}$$
$$= 540 \text{ kilometers}$$

For this example, you may have figured out the answer in your head. Other problems may not be obvious. It is worth going through the whole process (all five steps) with an easy problem so you know how to approach a harder problem.

Solving science problems

There is a step-by-step approach that can solve almost any science problem. It may not always be the fastest way, but it will always get you started and on the path to the correct answer.

Step 1

Read the problem carefully and figure out what it is asking for.

Step 2

Read the problem again and write down all the information you are given, such as speed and distance.

Step 3

Write down all the relationships or formulas that apply to either the answer or the information you are given.

Step 4

Choose, combine, or rearrange the relationships until you get the variable you want (the answer) by itself on one side of an equals sign.

Step 5

Plug in the numbers and calculate the answer.

Chapter 1 Review

Vocabulary review

Match the following terms with the correct definition. There is one extra definition in the list that will not match any of the terms.

Set One

1. time	a. How far it is from one point to another
2. second	b. A system of measuring that uses length units of inches, feet, and miles
3. distance	c. A type of distance measurement
4. length	d. A measurement that describes the interval between two events; the past, present, and future
5. English system	e. A system of measuring time based on the Babylonian number system
	f. A common unit used in measuring time

Set Two

1. metric system	a. A series of experiments connected to a basic question
2. investigation	b. An observation that can be recorded and thought about
3. experiment	c. An observation that can be repeated with the same result
4. measurement	d. An observation that is reported in a newspaper
5. scientific evidence	e. A situation that is set up in order to observe what happens
	f. A system of measuring that uses length units of millimeters, centimeters, meters, and kilometers

Set Three

1. scientific method	a. An educated guess about what will happen
2. research question	b. When one variable affects another
3. hypothesis	c. A process used to solve a problem or test an idea about how things work
4. variables	d. A process used to build a device
5. cause and effect	e. Factors that affect the result of an experiment
	f. A question that can be answered by an experiment or series of experiments

Set Four

1. experimental variable	a. A variable that is kept the same in an experiment
2. control variable	b. How an experiment is done
3. controlled experiment	c. The running of an experiment
4. trial	d. A variable that is not important in an experiment
5. experimental technique	e. An experiment in which one variable changes and all other variables are kept the same
	f. A variable that is changed in an experiment

Concept review

1. Units of time include seconds, minutes, hours, days, and years. Why are there so many units for time?
2. To make sense, a measurement must always have a _______ and a _______.
3. How are an investigation and an experiment related to each other?
4. Experiments usually have a question associated with them. True or false?
5. List the steps of the scientific method.
6. When doing an experiment, you must change only one________ at a time.
7. A hypothesis is a random guess. True or false?
8. Scientific discoveries and inventions must always be verified by more than one person. True or false?
9. What is the definition of speed?
10. How are speed and velocity different? Use each in a sentence.
11. Write the speed equation that you would use in each of the following scenarios:
    a. You know distance and speed.
    b. You know time and distance.
    c. You know speed and time.
12. What is the speed of an object that is standing still?
13. Describe, in your own words, how you determine the speed of an object.

Problems

1. Which one of the following times is equal to 75 seconds?
    a. 3 minutes (3:00)
    b. 1 minute, 15 seconds (1:15)
    c. 1 minute, 25 seconds (1:25)
2. How many seconds are in half an hour? Show your work.
3. Match the measurement in the first column to the corresponding equal measurement in the second column:

a) 1 centimeter	1) 12 inches
b) 1 foot	2) 1 meter
c) 5, 280 feet	3) 10 millimeters
d) 1000 millimeters	4) 1 mile

4. A student is 5 feet, 2 inches tall. What is her height in meters?
5. A model car is 30 cm in length. How many inches long is it?

6. What is the correct order of the following lengths from shortest to longest? Show your work.

   a. 16 inches
   b. 26.6 centimeters
   c. 1.1 feet
   d. 0.4 meters

7. You would like to find out whether a sports drink or plain water is better for an athlete. You have several friends on the field hockey team and the soccer team. You conduct an experiment at practice one day. You give the field hockey players the plain water and the soccer players the sports drink.

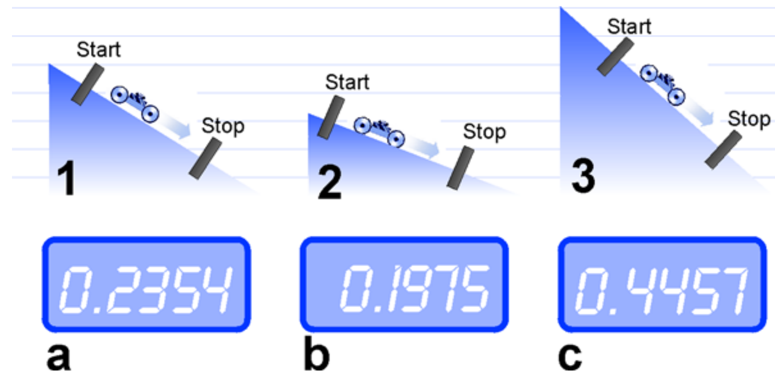
   Did you run a controlled experiment? Why or why not?

8. You have heard that plants grow better in response to music. You have permission to do an experiment to find out if this is true. You have 20 small plants and two rooms that face the same direction. Each room has a window that gets the same amount of light. Describe the experiment you would do to see if music affects plants. Write down your question, your hypothesis, and the procedure you would follow in your experiment.

9. Three groups of students are doing car and ramp experiments. Each group does three identical releases of the car and measures the following times from photogate A to photogate B.

Group 1	Group 2	Group 3
0.2315 seconds	0.2442 seconds	0.2315 seconds
0.2442 seconds	0.2437 seconds	0.2202 seconds
0.3007 seconds	0.2443 seconds	0.2255 seconds

   Which group did the best experiment and why do you think so? Be sure that you include the term *variable* in your answer.

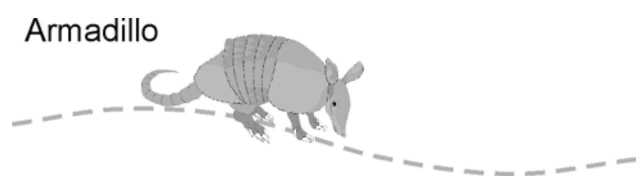


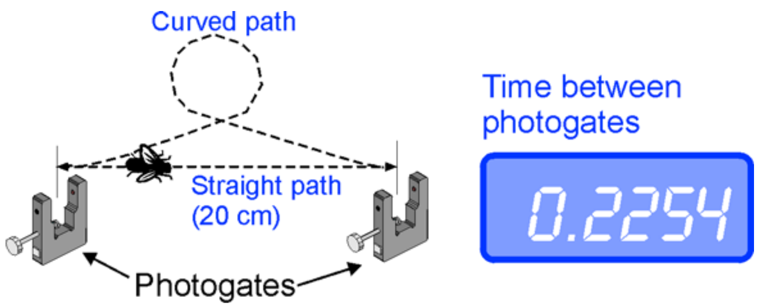
10. Match the timer with the corresponding ramp in the diagram above. You may assume that only the angle of the ramp is different, and all of the other variables are the same.

   a. Timer A corresponds to ramp # ________.
   b. Timer B corresponds to ramp # ________.
   c. Timer C corresponds to ramp # ________.

11. An armadillo is a peculiar animal that is common in the southwestern United States. You are a wildlife biologist and you observe an armadillo that moves 5 feet in 1 minute.

   a. Calculate the speed of the armadillo in feet/minute.
   b. Calculate the speed of the armadillo in inches/second.
   c. Calculate the speed of the armadillo in centimeters/second.

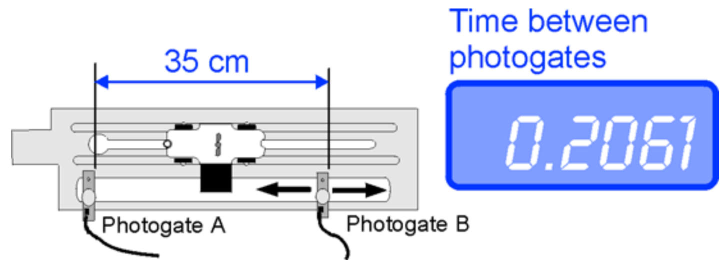




12. A bumblebee flies through two photogates that are spaced exactly 20 centimeters apart. The timer shows the measurement made for the time between gates in seconds.

    a. Calculate the speed of the bumblebee assuming it flies a straight line between the two light beams. Show your work.

    b. If the bumblebee flies a curved path in the same amount of time, will its actual speed be different? Explain your reasoning.



13. A car was timed as it passed through two photogates. The distance between the photogates is 35 centimeters. Calculate the speed of the car as it passed through the two photogates. The timer displays time in seconds.

14. A group of students is doing a speed experiment, and they measure the speed of a car rolling down a ramp five times at the exact same location on the ramp. Review their data below:

    66.7 cm/sec; 70.5 cm/sec; 64.9 cm/sec; 67.8 cm/sec; 69.1 cm/sec

    What factors could explain the variability in their data?

Applying your knowledge

1. Many old number systems were based on 12's because of the following way of counting with the hands:

    - By using the thumb on one hand, a person can easily count to twelve on the four fingers by touching the tip and then the first two joints of each finger.
    - By using the same method on the other hand, the same person could keep track of how many times he or she reached 12 on the first hand.

    Try out this method and calculate how high it is possible to count using this method.

2. Research the number system and units of an ancient civilization and write a short report on what you learned.

3. Read an article in a science magazine and try to identify how scientists have used the scientific method in their work.

4. Research the speeds of many kinds of animals and make a table showing slowest to fastest.

5. Prepare a short report on important speeds in your favorite sport.

Chapter 2
Mathematical Models

Introduction to Chapter 2

This chapter is about graphing data from your experiments with the car and ramp. You will learn that graphs are mathematical models used for making predictions and solving equations.

Investigations for Chapter 2

2.1	Using a Scientific Model to Predict Speed	*How can you predict the speed of the car at any point on the ramp?*

In this Investigation you will create a graphical model that you can use to predict the speed of the car at any point on the ramp. You will do this by determining the speed of the car at six points along the ramp and then graphing the speed of the car against the distance traveled.

2.2	Position and Time	*How do you model the motion of the car?*

In this Investigation you will make a distance vs. time graph from the data you collect with the car and ramp. You are going to model the motion of one trip of the car down the ramp. To get enough data to model motion, you will collect data at 10 or more points along the ramp. Your teacher will assign your group's ramp angle.

2.3	Acceleration	*How is the speed of the car changing?*

Since acceleration depends on the angle of the hill, a car and ramp make a good tool to discover the behavior of *uniform acceleration*, or when speed changes at a constant rate. Shallow (nearly level) angles will give very little acceleration, and the increasing speed is easy to observe. Steep (nearly vertical) angles resemble *free fall* or motion that is entirely under the influence of gravity.

Learning Goals

In this chapter, you will:

- ✔ Construct a speed vs. distance graph.
- ✔ Use a graph to make a prediction that can be quantitatively tested.
- ✔ Calculate the percent error between a measurement and a prediction.
- ✔ Create and analyze a distance vs. time graph.
- ✔ Determine the slope of a line.
- ✔ Distinguish between linear and nonlinear graphs.
- ✔ Distinguish between speed and acceleration.
- ✔ Calculate acceleration from a formula.
- ✔ Calculate acceleration from the slope of a speed vs. time graph.

Vocabulary

accelerate	deceleration	graphical model	instantaneous speed
acceleration	dependent variable	gravity	physical model
average speed	free fall	independent variable	scientific model
conceptual model			

2.1 Using a Scientific Model to Predict Speed

In this section, you will learn how to make a model that will accurately predict the speed of a car. Making models is an important part of science and engineering. For a given situation, models tell us how all the variables, like speed, distance, and time, fit together. If we have a model, we can predict what will happen because we know how changes in one variable affect the others.

Why make models?

Suppose it is your job to design a train to go from New York to Los Angeles in the shortest possible time. Your train would have to go up and down hills and across flat plains carrying 1,000 people.

How powerful a motor do you need?
How powerful do the brakes need to be?
How much fuel do you need to carry?

There are many things you have to know. You want the answers to the questions *before* you build the train. How do you get answers to a complicated problem such as how to design a high-speed train?

The way we answer complicated questions is to break them down into smaller questions. Each smaller question can be answered with simple experiments or research. One question might be how fast a train will roll down a hill of a given angle. You might do an experiment with a miniature train to get some data on downhill speeds that would help you design the brakes for the train. Other questions might be answered with research, in order to learn how other people solved similar problems.

You can often use the results of an experiment to produce a model that tells how each of the variables in the experiment are related. One model you might make is a graph showing how fuel efficiency depends on the size of the engine. If you know the engine size needed to climb the steepest hill, the model tells you how much fuel you have to carry on the train. Once you have models for each part of the train, you can evaluate different choices for your design.

Big complex question

How can I design a high-speed train that can cross the United States?

Smaller questions

How powerful does the train's motor need to be to go up hills?

How good do the train's brakes need to be to go down hills?

How much fuel should the train carry?

Experiment and research

Design experiments, collect data, do research, and create models for each question. Then figure out how all the systems of the train work together.

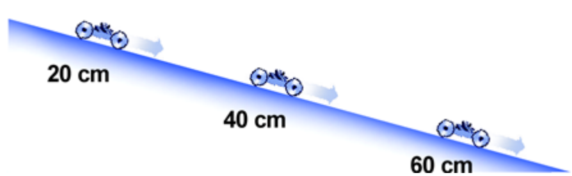
Figure 2.1: *We solve complex questions by breaking them down into smaller problems. Each small problem is solved and the results are used to solve the larger question.*

Scientific models

What do experiments tell us?

An experiment tells us about the relationship between variables. If we roll a car downhill to learn about its motion, we will need to measure its speed at several distances from the top. Speed and distance are the variables.

We will be looking for a way to connect these variables. We need to know exactly how much speed is gained by the car for every centimeter it rolls down the ramp. We collect experimental data to figure out the relationship between the variables.



Distance	Speed
20 cm	140 cm/sec
40 cm	198 cm/sec
60 cm	242 cm/sec

What is a scientific model?

We then take the results and make a **scientific model** that shows how each variable relates to another. For example, how does the distance traveled relate to the speed? The data above shows that for every 20 centimeters traveled, the speed increased by 40 cm/sec. If we graph this data, we can use it to make predictions about the speed of the car at other places along the ramp. A similar process could be used in the train design. A graphical model could answer the question "If the hill is longer by a kilometer, how much faster will the train go if the brakes fail?"

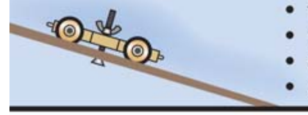
Solving the big question

Once we have models for the smaller relationships, we can put them together to solve the bigger question of how to design the train. Experiments and research have given us enough information to create and test models that tell us how each part will work. Once we know how each part of the train will work, we can design a train where all the parts work together.

Accurate measurements

Instruments like an electronic timer allow you to make *very* accurate measurements of speed. The more accurate your measurements, the better your model will be. By using very accurate data to make the graphical model, you can be sure that your predictions will be accurate also.

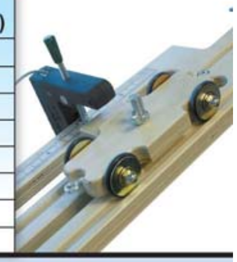
Variables



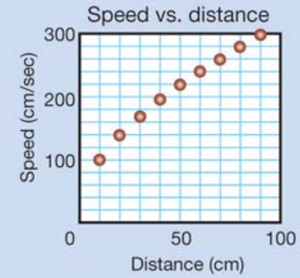
- force
- angle
- time
- weight
- speed
- distance

Experiment

Distance (cm)	Speed (cm/sec)
10	100
20	140
30	171
40	198
50	221
60	242
80	280
90	297



Model



Prediction

At 55 centimeters, the speed of the car will be 231 cm/sec.

Figure 2.2: *A model is something we make that identifies the relationships between the variables. The model can answer questions like "If I change the distance down the ramp, how much will the speed change?"*

We all make mental models

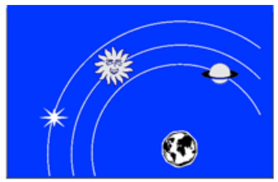
Our models of nature can take many forms. For example, suppose you want to kick a soccer ball into the goal. In your mind, you know how the ball moves on the grass of the field or through the air because of your previous experience. This mental image is a kind of model you use to make adjustments in how you kick the ball toward the goal.

Figure 2.3: *Mental models help us imagine how something will happen.*

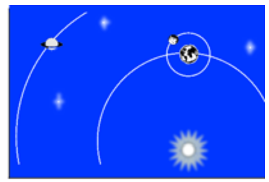
Physical models

Some models are physical. **Physical models** are models that we can look at, touch, feel, and take measurements from. Engineers often construct scale models of bridges and evaluate them for strength and design. The word *scale* means that lengths on the model are proportional to lengths on the real object. For example, a scale of 1 inch = 10 feet (120:1) means that every inch on the model represents 10 feet in real life. It is much easier to do experiments on scale models than it is to build full-size bridges! If properly constructed, models tell the engineers about the behavior of the real bridge, and help them avoid dangerous mistakes.

Early civilizations believed the Earth was covered by a dome on which the sun, stars and planets moved.



In the Middle Ages people thought the sun, stars, and planets circled the Earth which sat in the center.



Today we know the Earth and planets orbit around the sun and the stars are very far away.

Figure 2.4: *Some models are physical, like this model of a bridge. Models can tell engineers and architects a lot about how a project will be built.*

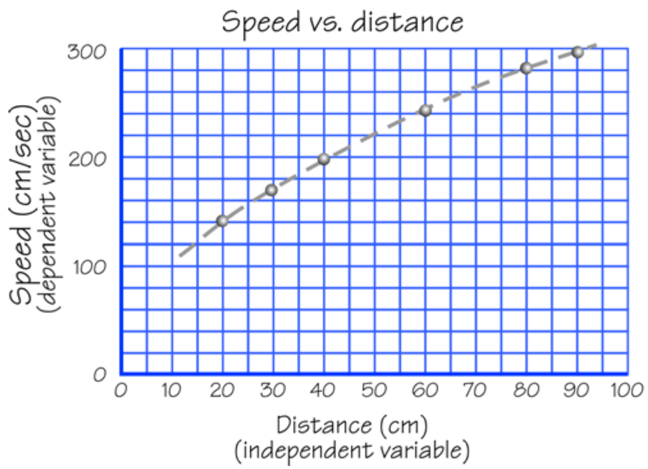
Conceptual models

Much of our scientific understanding of nature is expressed in the form of **conceptual models**. These types of models are *descriptive*, that is, we use them to describe how something works. For example, in 1543, Nicholaus Copernicus, the great astronomer, described a conceptual model of the heavens in which the Earth revolves in an orbit around the sun. Copernicus's conceptual model was a major revolution in our understanding of astronomy, since most people of his time believed in Ptolemy's model in which the sun moved around the Earth. Other astronomers added to Copernicus' model. Galileo invented the telescope in 1609, and Johannes Kepler used the telescope to work out detailed orbits for other planets. In 1687, Isaac Newton's law of universal gravitation finally provided a model that explained why planets move in orbits. Our models improve as our understanding grows.

Making a graphical model

Graphical models

While conceptual models are very useful, often they are only the first step toward making a model that can make predictions. The next step is often a graph. A graph shows how two variables are related with a picture that is easy to understand. A **graphical model** uses a graph to show a relationship between the variable on the *x*-axis and the variable on the *y*-axis. Because a graph uses numbers it is also known as a mathematical model.



Distance (cm)	Speed (cm/sec)
20	140
30	171
40	198
60	242
80	280
90	297

The dependent variable

The graph shows how the speed of a rolling car changes as it rolls downhill. We expect the speed to change. Speed is the **dependent variable** because we think the speed *depends* on how far down the ramp the car gets.

The independent variable

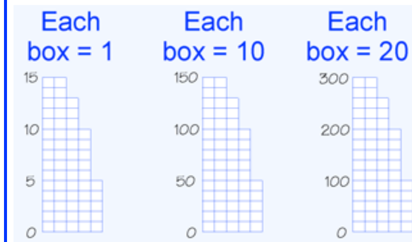
The distance is the **independent variable**. We say it is *independent* because we are free to make the distance anything we want by choosing where on the ramp to measure.

Choosing *x* and *y*

People have decided to always put the independent variable on the horizontal *(x)* axis. You should too, since this is how people will read any graph you make. The dependent variable goes on the vertical (*y*) axis.

How to Make a Graph

1. Decide what to put on *x* and *y*.



Letting each box = 20 fits the biggest data point (297 cm/sec)

2. Make a scale for each axis by counting boxes to fit your largest value. Count by multiples of 1, 2, 5, or 10 to make it easier to plot points. Make the graph big, try to use as much of the graph paper as you can.
3. Plot your points by finding the *x* value, and drawing a line up until you get to the right *y* value. Put a dot for each point.
4. Draw a smooth curve that shows the pattern of the points. Don't simply connect the dots.
5. Make a title for your graph.

Reading a graph

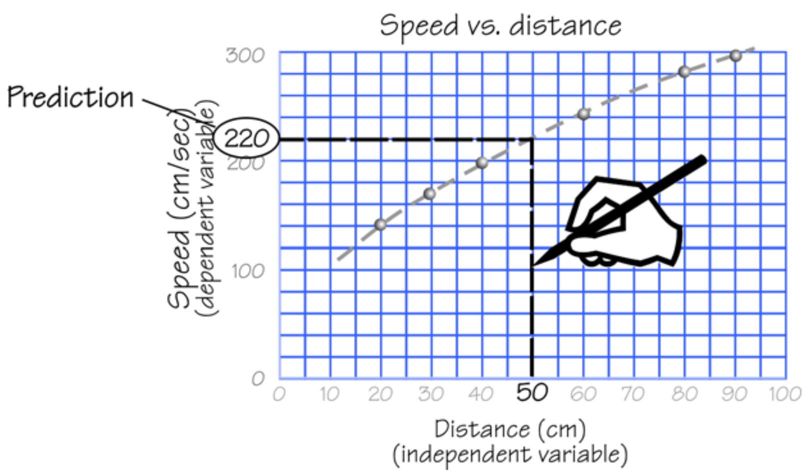
Why are graphs useful?

One purpose of making a graph is to organize your data into a model you can use to make predictions. Pictures are much easier to understand than tables of data (Figure 2.5). By making a graph, you are making a picture that shows the exact relationship between your variables.

Making predictions from a graph

Suppose you want to find out what the speed of the car would be 50 centimeters from the start. You did not measure the speed there. Yet the graph can give you an answer.

1. To predict the speed, start by finding 50 centimeters on the *x*-axis.
2. Draw a line vertically upward from 50 centimeters until it hits the curve you drew from your data.
3. Draw a line horizontally over until it reaches the *y*-axis.
4. Use the scale on the *y*-axis to read the predicted speed.
5. For this example, the model graph predicts the speed to be 220 cm/sec.



Checking the accuracy of a model

If the graph is created from accurate data, the prediction will also be accurate. You could check by doing another experiment and measuring the speed of the car at 50 centimeters. You should find it to be very close to the prediction from your graph.

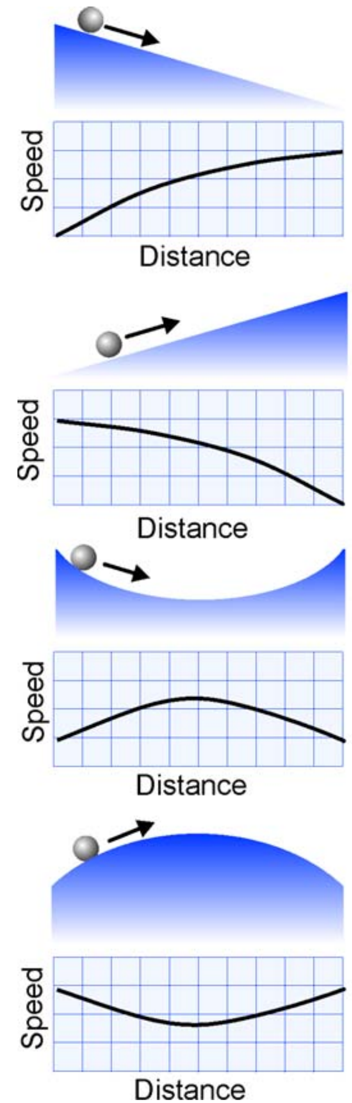


Figure 2.5: *Some different shapes for ramps and their corresponding speed vs. distance graphs.*

Cause and effect relationships

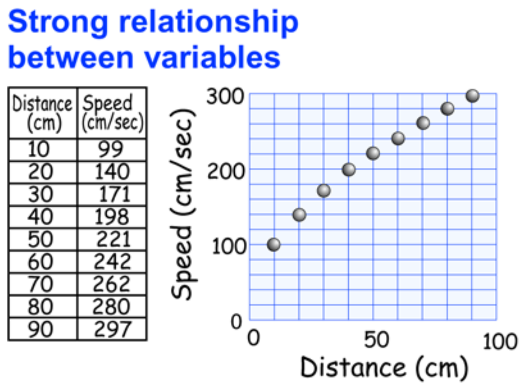
Cause and effect relationships

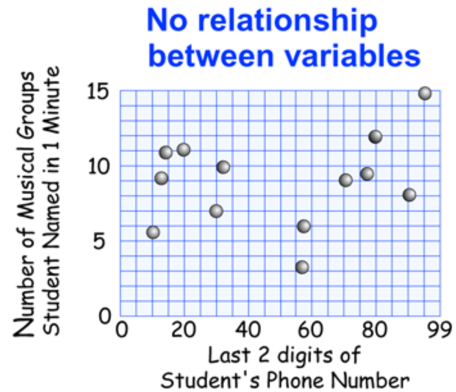
In many experiments we are looking for a cause and effect relationship. How does changing one variable effect another? Graphs are a good way to see whether there is a connection between two variables or not. You cannot always tell from looking at tables of data. With a graph, the connection is clear.

Patterns indicate relationships

When there is a relationship between the variables the graph shows a clear pattern. The speed and distance variables show a strong relationship. When there is no relationship the graph looks like a collection of dots. No pattern appears. The number of musical groups a student listed in one minute and the last two digits of his or her phone number are an example of two variables that are not related.

Distance (cm)	Speed (cm/sec)
10	99
20	140
30	171
40	198
50	221
60	242
70	262
80	280
90	297





Strong and weak relationships

You can tell how strong the relationship is from the pattern. If the relationship is strong, a small change in one variable makes a big change in another. If the relationship is weak, even a big change in one variable has little effect on the other. In weak relationships, the points may follow a pattern but there is not much change in one variable compared to big changes in the other (Figure 2.6)

Inverse relationships

Some relationships are inverse. When one variable increases, the other decreases. If you graph how much money you spend against how much you have left, you see an inverse relationship. The more you spend, the less you have. Graphs of inverse relationships always slope down to the right (Figure 2.7).

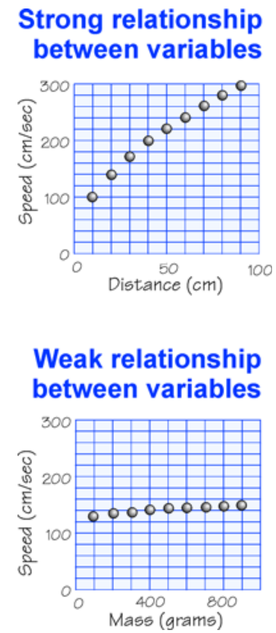


Figure 2.6: *In a strong relationship (top), a big change in distance creates a big change in speed. In a weak relationship (bottom), a big change in mass makes almost no change in speed.*

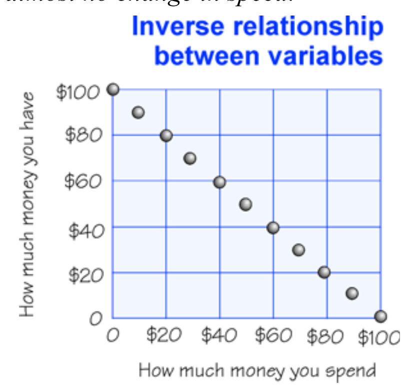
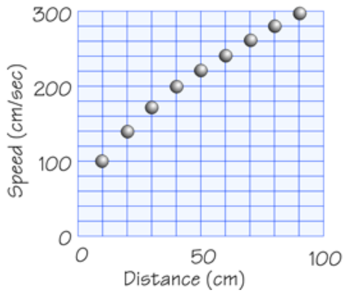


Figure 2.7: *A typical graph for an inverse relationship.*

2.2 Position and Time

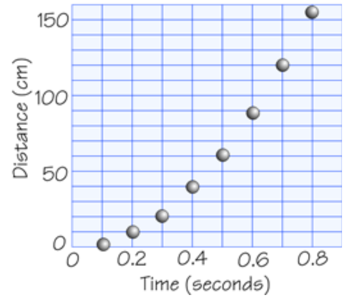
Distance (cm)	Speed (cm/sec)
10	100
20	140
30	171
40	198
50	221
60	242
80	280
90	297

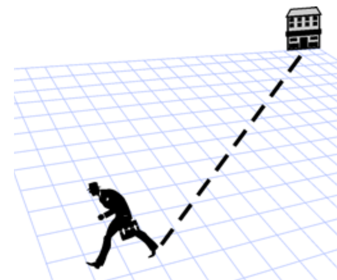
Speed versus Distance



Distance (cm)	Time (sec)
2	0.1
10	0.2
22	0.3
39	0.4
61	0.5
88	0.6
120	0.7
157	0.8

Position versus Time





Time	Position
1:00	0 (start)
2:00	3 km
3:00	6 km
4:00	7 km
5:00	5 km
6:00	3 km
7:00	1 km

Figure 2.8: *You leave at 1:00 and walk away from school in a straight line until 4:00. Then you turn around and walk back. At 7:00, you are still 1 kilometer away from school.*

Graphical models like the speed vs. distance graph are good for organizing data so you can make predictions. In this section, you will learn how to model motion with another graph: position vs. time. The position vs. time graph offers a new way to find the speed of a moving object. The position vs. time graph will also be our example as we explore different ways to use and interpret graphs. The techniques you learn in this section will help you understand acceleration, the next important idea in motion.

Position

Position In physics, the word **position** means where something is compared with where it started, including direction. As things move their position changes. If you walked in a straight line away from your school, your position would keep getting larger (Figure 2.8). If you stopped walking, your position would stop changing.

Distance Distance is an interval of length without regard to direction. You can walk a distance of 10 miles in a circle and end up exactly where you started. If you walk a curved path, the distance you walk could be much greater than the distance between where you started and where you end up (Figure 2.9).

Position and distance Position and distance are different. If you are 7 kilometers north of school, that is a statement of your position. If you walk back towards your school, your position decreases. If you get back to where you started, your position is zero even though the distance you walked is 14 kilometers (7 km away plus 7 km back)!

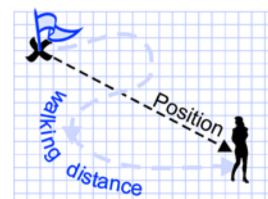


Figure 2.9: *If there are turns, the position might be different from the distance you travel.*

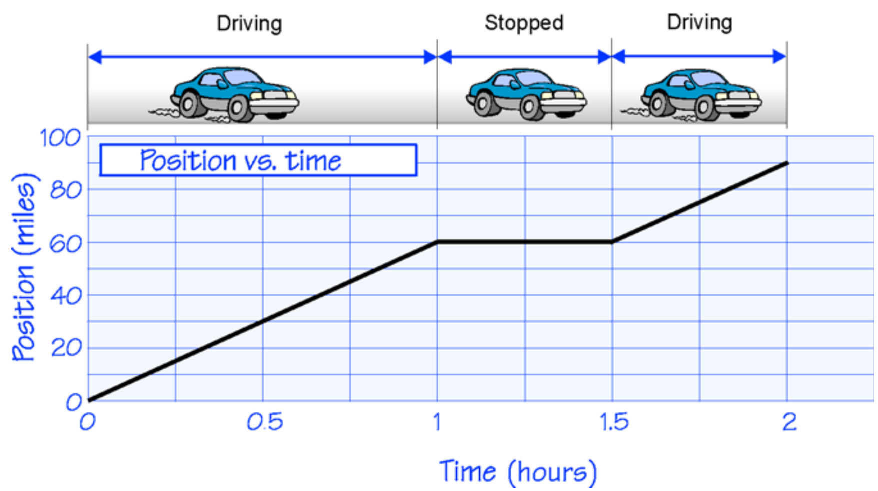
The position vs. time graph

What does the graph tell you?

The position vs. time graph shows where things are at different times. If things have moved, it is easy to see from the graph. You might think giving the speed is enough description of how things have moved. But speed does not always give you enough information.

A car trip with a rest

For example, suppose you take a car trip that includes 1.5 hours of driving and a half-hour rest stop, for a total time of 2 hours. You drive a total distance of 90 miles in a straight line. At the end you call your friends to tell them it took you 2 hours and they calculate your speed to be 45 mph (90 miles divided by 2 hours).



Actually, you drove a lot faster than 45 mph to make up for the half-hour rest stop. You really covered the 90 miles in 1.5 hours, at a speed of 60 mph. You stopped (with zero speed) for a half hour.

The graph is a better picture of the trip

The position vs. time graph shows your trip much more accurately than saying you covered 90 miles in 2 hours. For the first hour, your position gradually increases from zero (start) until you are 60 miles away. Your position stays the same between 1 hour and 1.5 hours because you stopped. Then you get going again and cover the last 30 miles in a half hour. The position vs. time graph shows a complete history of your trip including your stop.

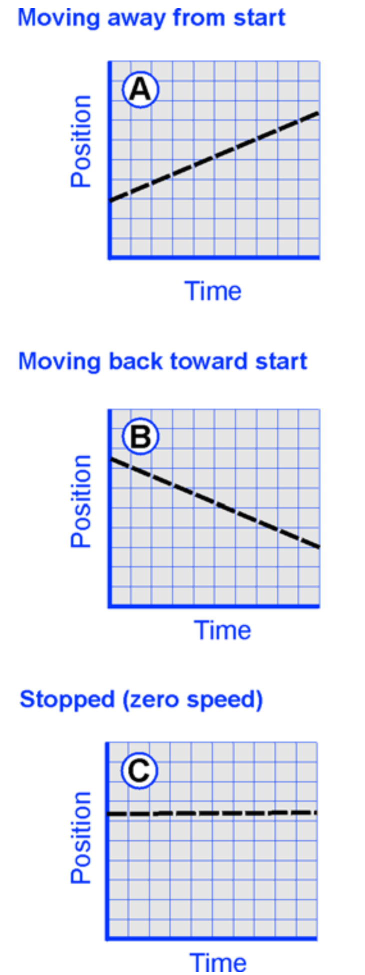


Figure 2.10: *Examples of graphs showing different speeds.*
Graph A shows movement away from start.
Graph B shows movement back toward start.
Graph C shows no motion. The object is stopped with zero speed.

Determining speed from the slope of a graph

Look at the distance vs. time

Let's take a closer look at the first hour of your driving trip (Figure 2.11). You drove at a constant speed of 60 mph. The position vs. time graph shows the position of your car on the highway as it changes with time. The line on the graph represents the motion of the car. If the graph is a complete description of the motion, you should be able to figure out the speed of the car from the graph.

The definition of slope

The definition of slope is the ratio of "rise" (vertical change) to the "run" (horizontal change) of a line. The rise is determined by finding the height of the triangle shown. The run is determined by finding the length along the base of the triangle. For this graph, the x-values represent time and the y-values represent position.

Speed is the slope of the position vs. time graph

Speed is the distance traveled divided by the time taken. The distance is really the difference in position between where you finished and where you started. This is equal to the rise (vertical distance) on the graph. The run on the graph is the time taken for the trip. The slope is rise over run, which is the distance traveled over the time taken, which is the speed.

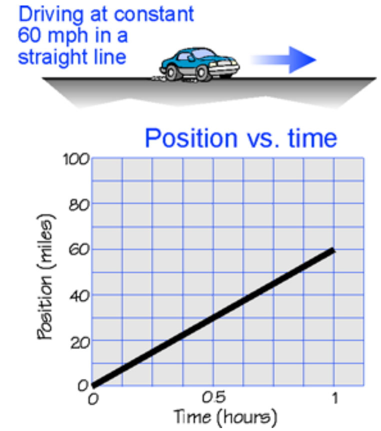
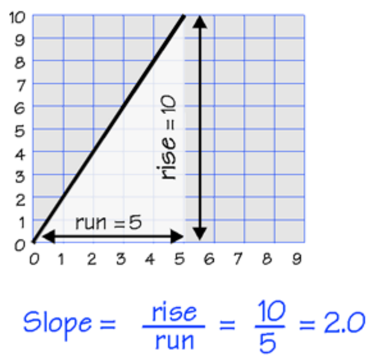


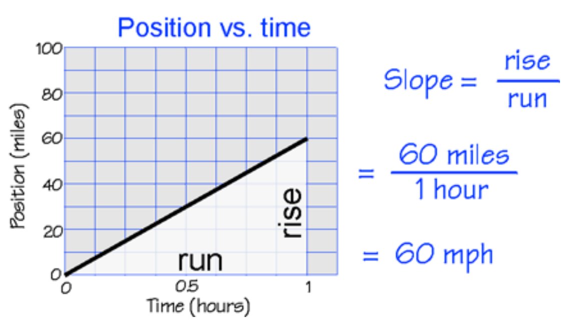
Figure 2.11: *The first hour of the driving trip. The car has a constant speed of 60 mph.*

Speed is the slope of the position vs. time graph.

The slope of a graph



Speed from the slope of the position vs. time graph



Instantaneous and average speed

Speed does not usually stay constant

Does your speed stay exactly the same during a real trip? The answer is, of course not. Your speed is almost always changing. You slow down for stop lights, and speed up to pass people. For the next example, consider taking a bicycle trip. You may remain on flat ground for a moment, but eventually you come to a hill. As you climb the hill, you slow down. As you go down the hill, you speed up.

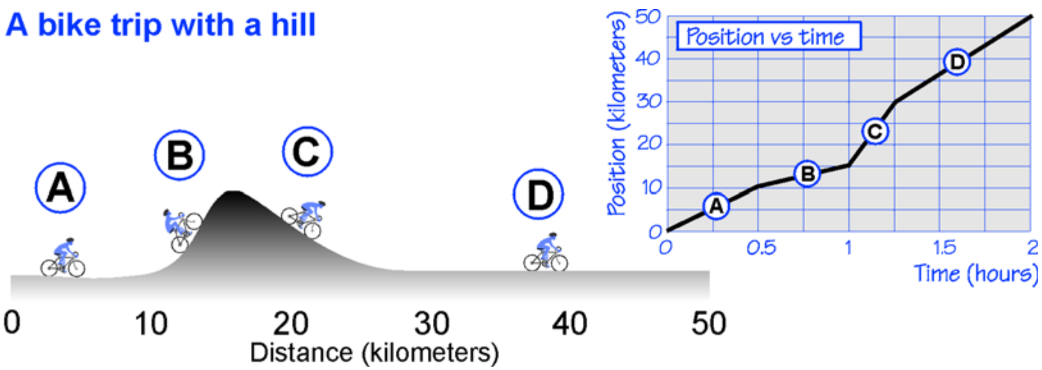
Average speed

There are two ways you should think about speed. If it takes you 2 hours to ride 50 kilometers, your **average speed** is 25 kilometers per hour (25 km/h). To calculate average speed, you simply take the total distance traveled divided by the total time taken.

Instantaneous speed

At some points along the way, you may go slower, or faster than average. The **instantaneous speed** is the speed you have at a specific point in your journey. You might go uphill at 10 km/h and downhill at 60 km/h, with an average speed of 25 km/h even though your speed may have been 25 km/h only momentarily during the trip!

A bike trip with a hill



The position vs. time graph

The real story is told by the position vs. time graph. The graph captures both the instantaneous speed and the average speed. If the slope of the graph is steep (**C**), you have lots of position changing in little time (Figure 2.12) indicating a high speed. If the slope is shallow (**B**), relatively little position changes over a long time, giving a slow speed. If the graph is level the slope is zero, so the speed is also zero, indicating you have stopped and are not moving.

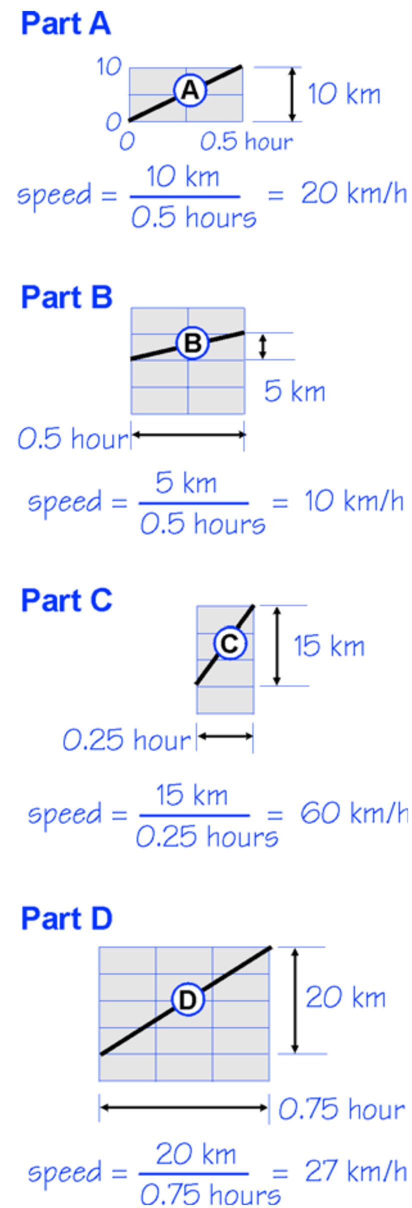


Figure 2.12: *Calculating the speed of each part of the trip.*

2.3 Acceleration

The speed of things is always changing. Your car speeds up and slows down. If you slow down gradually, it feels very different from slamming on the brakes and stopping fast. In this section we will learn how to measure and discuss changes in speed. Specifically, we will investigate objects rolling downhill. You already know that an object rolling downhill speeds up. The rate at which its speed changes is called eration.

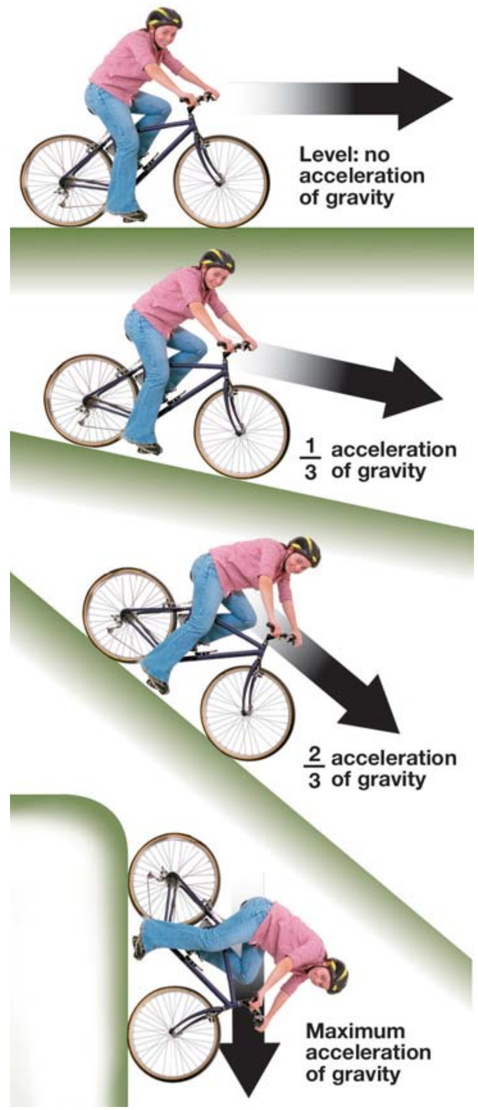


Figure 2.13: *How much of the acceleration of gravity you experience depends on the angle of the hill.*

Acceleration

You accelerate coasting downhill

What happens if you coast your bicycle down a long hill without pedaling? You accelerate, that is your speed increases steadily. If your bike has a speedometer you find that your speed increases by the same amount every second!

Time	Speed
0 (start)	0 (start)
1 second	1 mph
2 seconds	2 mph
3 seconds	3 mph
4 seconds	4 mph
5 seconds	5 mph

Time	Speed
0 (start)	0 (start)
1 second	2 mph
2 seconds	4 mph
3 seconds	6 mph
4 seconds	8 mph
5 seconds	10 mph

Steeper hills

On a steeper hill, your findings are similar. Your speed increases every second, but by a bigger amount. On the first hill your speed increased by 1 mph every second. On the steeper hill you find your speed increases by 2 mph every second.

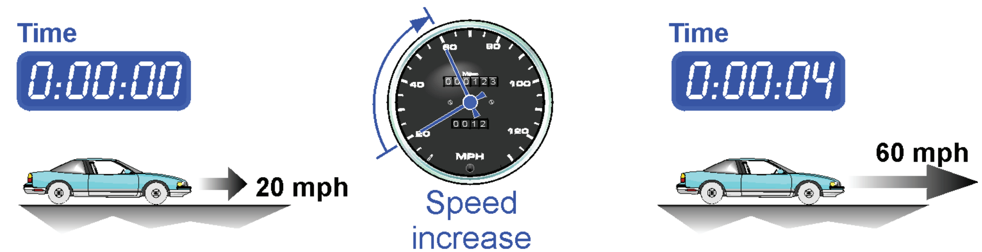
Acceleration is the amount that your speed increases, compared to how long it takes. Increasing speed by 1 mph every second means you accelerated at 1 mph per second. Every second your speed increased by 1 mile per hour. It is common to describe acceleration in units of speed (changed) per second.

Acceleration when speed is in miles per hour

Acceleration

Acceleration is the rate of change in the speed of an object. Rate of change means the ratio of the amount of change divided by how much time it took to change.

The acceleration of the car is 10 mph/sec



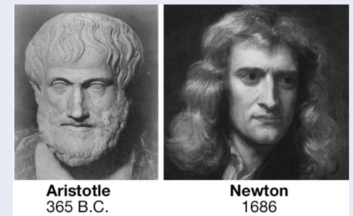
An example of acceleration

Suppose you are driving and your speed goes from 20 mph to 60 mph in four seconds. The amount of change is 60 mph minus 20 mph, or 40 miles per hour. The time it takes to change is 4 seconds. The acceleration is 40 mph divided by 4 seconds, or 10 mph/sec. Your car accelerated 10 mph per second. That means your speed increased by 10 miles per hour each second. Table 2.1 shows how your speed changed during the four seconds of acceleration.

Table 2.1: ***Your speed while accelerating***

Time	Speed
0 (start)	20 mph
1 second	30 mph
2 seconds	40 mph
3 seconds	50 mph
4 seconds	60 mph

Thinking about acceleration



People have been thinking about acceleration for a long time. In the fourth century BC two Greek scientists, Aristotle and Strato, described free fall as acceleration. In the 1580s European scientists Simon Stevinus and Galileo determined that all objects fall equally fast, if other forces do not act on them.

About 100 years later, Isaac Newton figured out the three laws of motion. Newton's attempts to fully describe acceleration inspired him and others to develop a whole new kind of math, called *calculus*. We will not be learning about calculus in this course, but we will follow some of Newton's experiments with acceleration.

Acceleration in metric units

The units of acceleration

The units of acceleration can be confusing. Almost all of the calculations of acceleration you will do will be in metric units. If we measure speed in cm/sec, then the change in speed is expressed in cm/sec as well. For example, 2 cm/sec is the difference between a speed of 3 cm/sec and a speed of 1 cm/sec.

Calculating acceleration

Acceleration is the change in speed divided by the change in time. The units for acceleration are units of speed over units of time. If speed is in cm/sec and time in seconds, then the units for acceleration are cm/sec/sec, or *centimeters per second per second*. What this means is that the acceleration is the amount that the speed changes in each second. An acceleration of 50 cm/sec/sec means that the speed increases by 50 cm/sec *every second*. If the acceleration persists for three seconds then the speed increases by a total of 150 cm/sec (3 seconds × 50 cm/sec/sec).

What do units of *seconds squared* mean?

While it may seem confusing, an acceleration in cm/sec/sec is written cm/sec^2 (centimeters per second squared). Likewise, an acceleration of m/sec/sec is written m/sec^2 (meters per second squared). If you use the rules for simplifying fractions on the units of cm/sec/sec, the denominator ends up having units of seconds times seconds, or sec^2. Saying *seconds squared* is just a math-shorthand way of talking. The units of square seconds do not have physical meaning in the same way that square inches mean surface area. It is better to think about acceleration in units of speed change per second (that is, centimeters per second *per second*).

$$\text{Acceleration} = \frac{\text{Change in speed}}{\text{Change in time}}$$

How we get units of cm/sec^2

plug in values | clear the compound fractions | final units

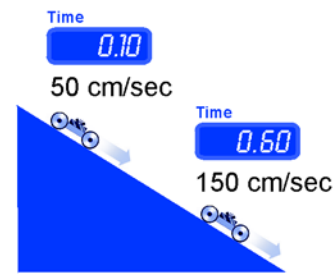
$$= \frac{50\,\frac{cm}{sec}}{sec} = \frac{50\,\frac{cm}{sec} \times sec}{sec \times sec} = \frac{50\,\frac{cm}{\cancel{sec}} \times \cancel{sec}}{sec^2} = 50\,\frac{cm}{sec^2}$$

Acceleration in m/sec^2

Many physics problems will use acceleration in m/sec^2. If you encounter an acceleration of 10 m/sec^2, this number means the speed is increasing by 10 m/sec every second.

Example

A car rolls down a ramp and you measure times and distances as shown. Calculate the acceleration in cm/sec^2.



Change in speed

$$\begin{array}{r} 150 \text{ cm/sec} \\ -\ 50 \text{ cm/sec} \\ \hline = 100 \text{ cm/sec} \end{array}$$

Change in time

$$\begin{array}{r} 0.60 \text{ sec} \\ -\ 0.10 \text{ sec} \\ \hline = 0.50 \text{ sec} \end{array}$$

$$\text{Acceleration} = \frac{\text{Change in speed}}{\text{Change in time}} = \frac{100 \text{ cm/sec}}{0.50 \text{ sec}} = 200 \text{ cm/sec}^2$$

Figure 2.14: *An example of calculating acceleration for a car on a ramp.*

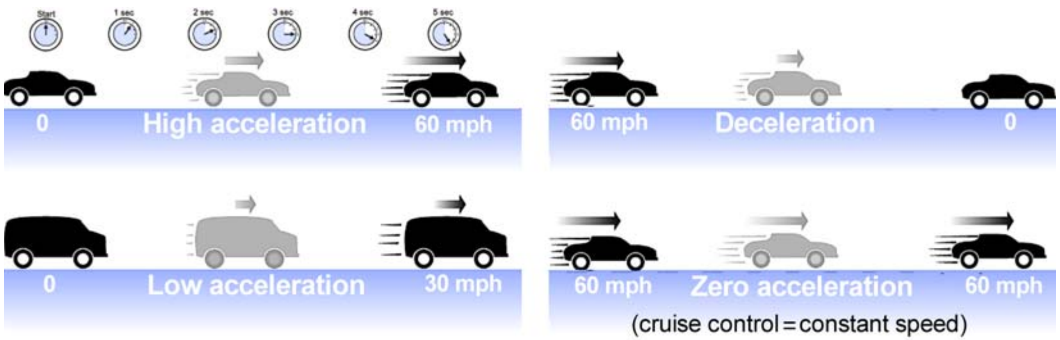
Different examples of acceleration

Any change in speed means acceleration

Acceleration means changes in speed or velocity. *Any* change in speed means there is acceleration. If you put on the brakes and slow down, your speed changes. In the example of slowing down, the acceleration is in the negative direction. We also use the term deceleration to describe this situation. *Acceleration occurs whenever the speed changes, whether the speed increases or decreases.*

Zero acceleration

An object has zero acceleration if it is traveling at constant speed in one direction. You might think of zero acceleration as "cruise control." If the speed of your car stays the same at 60 miles per hour, your acceleration is zero.



Acceleration when turning

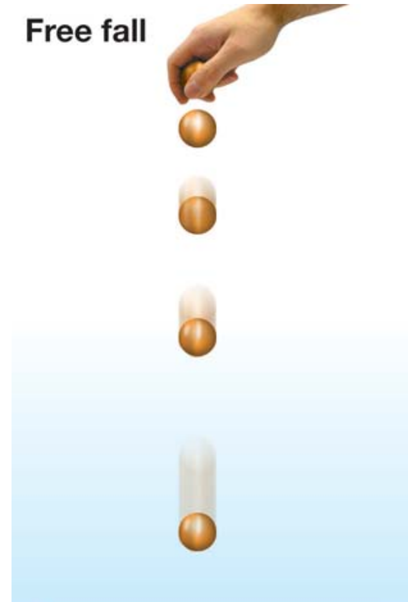
If you change direction, some acceleration happens. When you turn a sharp corner in a car you feel pulled to one side. The pull you feel comes from the acceleration due to turning. To explain this, you need to remember velocity encompasses speed *and direction*. Any time you change either speed or direction, you are accelerating.

Steep hills and acceleration

You have probably noticed that the steeper the hill, the faster you accelerate. You may already know this effect has to do with gravity. Gravity pulls everything down toward the center of Earth. The steeper the hill, the greater the amount of gravity pulling you forward, and the greater your acceleration.

Free fall

If you drop something straight down it accelerates in free fall. The speed of a free falling object in a vacuum increases by 9.8 meters per second for every second it falls (Figure 2.15). This special acceleration is called the acceleration of gravity because it is the acceleration of objects under the influence of Earth's gravity. The acceleration of gravity would be different on the moon or on other planets.



Time	Speed
0 (start)	0
1 second	9.8 m/sec
2 seconds	19.6 m/sec
3 seconds	29.4 m/sec
4 seconds	39.2 m/sec

The speed of free falling objects increases by 9.8 m/sec every second they fall.

This is how we know the acceleration of gravity is 9.8 m/sec^2 at Earth's surface.

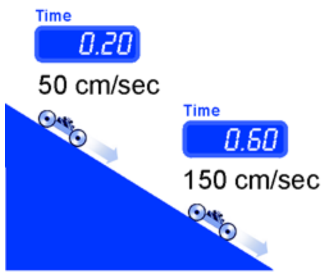
Figure 2.15: *In free fall, the speed of objects increases by 9.8 m/sec each second. Free fall is most accurately measured in a vacuum, since air friction changes the rate of fall of different objects in different ways.*

Acceleration and the speed vs. time graph

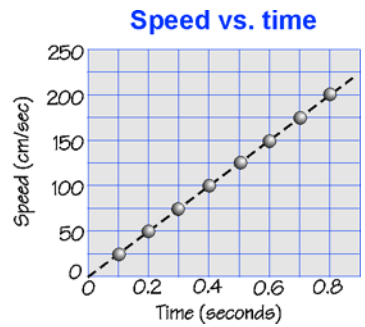
The speed vs. time graph

Another motion graph we need to understand is the graph of speed vs. time. This is the most important graph for understanding acceleration because it shows how the speed changes with time.

The graph below shows an example from an experiment with a car rolling down a ramp. The time is the time between when the car was first released and when its speed was measured after having moved farther down the ramp. You can see that the speed of the car increases the longer it rolls down.



Time (sec)	Speed (cm/sec)
0.1	25
0.2	50
0.3	75
0.4	100
0.5	125
0.6	150
0.7	175
0.8	200



The graph shows a straight line

The graph shows a straight line. This means that the speed of the car increases by the same amount every second. The graph (and data) also shows that the speed of the car increases by 25 cm/sec every one-tenth (0.1) of a second.

Acceleration

You should be thinking of acceleration. This graph shows an acceleration of 250 cm/sec/sec or 250 cm/sec^2. This is calculated by dividing the change in speed (25 cm/sec) by the change in time (0.1 seconds).

Seeing acceleration on a graph

If you see a slope on a speed vs. time graph, you are seeing acceleration. Figure 2.16 shows some examples of graphs with and without acceleration. *Any time* the graph of speed vs. time is not perfectly horizontal, it shows acceleration. If the graph slopes down, it means the speed is decreasing. If the graph slopes up, the speed is increasing.

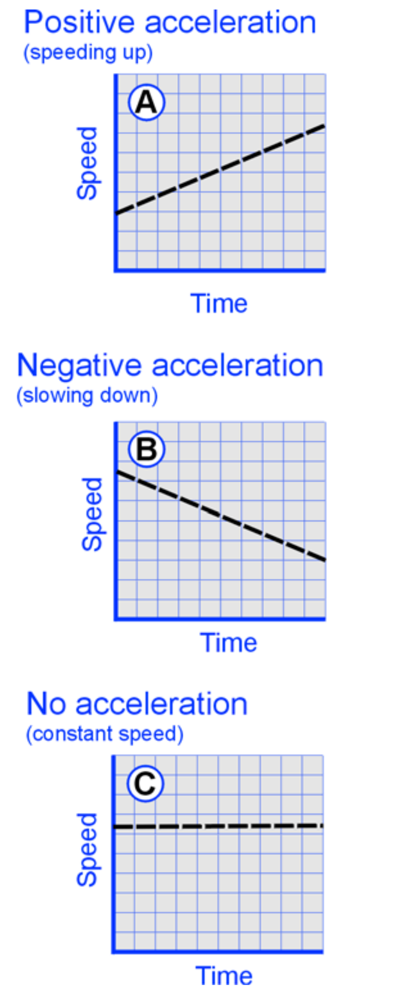


Figure 2.16: *Examples of graphs with different amounts of acceleration.*
Graph **A** *shows positive acceleration, or speeding up.*
Graph **B** *shows negative acceleration, or slowing down.*
Graph **C** *shows zero acceleration.*

Calculating acceleration from the speed vs. time graph

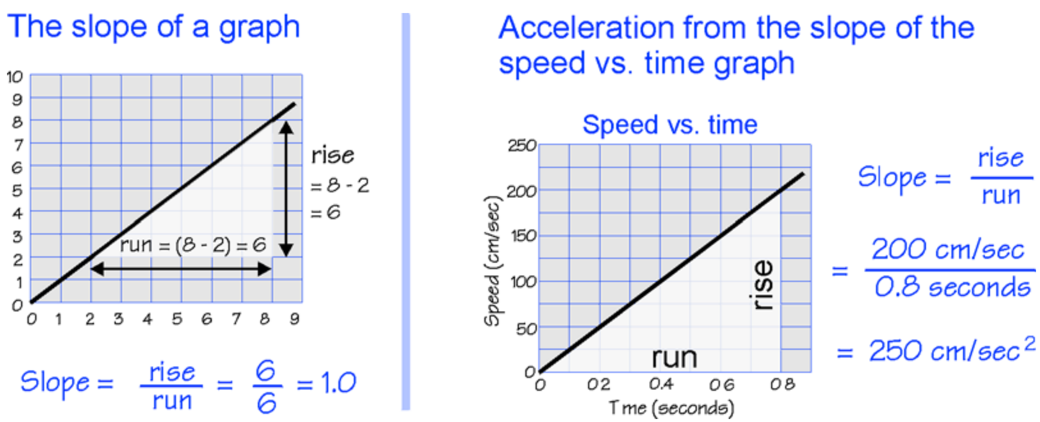
Slope

From the last section, you know that the slope of a graph is equal to the ratio of *rise* to *run*. On the speed vs. time graph, the rise and run have special meanings, as they did for the distance vs. time graph. The *rise* is the amount the speed changes. The *run* is the amount the time changes.

Acceleration and slope

Remember, acceleration is the change in speed over the change in time. This is *exactly the same* as the rise over run for the speed vs. time graph. The slope of the speed vs. time graph is the acceleration.

Acceleration is the slope of a speed vs. time graph.

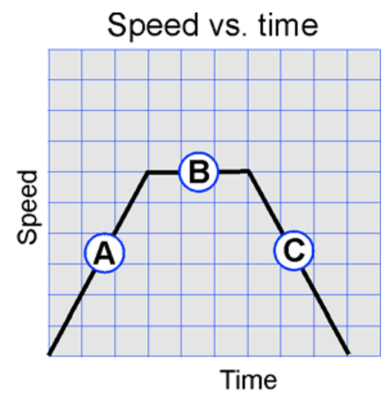


Make a triangle to get the slope

To determine the slope of the speed vs. time graph, take the rise or change in speed and divide by the run or change in time. It is helpful to draw the triangle shown above to help figure out the rise and run. The rise is the height of the triangle. The run is the length of the base of the triangle.

Complex speed vs. time graphs

Slope helps you identify acceleration in complicated speed vs. time graphs. A flat line on the graph means speed is constant and acceleration is zero (Figure 2.17).



(A) Positive acceleration

(B) Zero acceleration

(C) Negative acceleration

Figure 2.17: *How to recognize acceleration on speed vs. time graphs.*

A. Positive slope means positive acceleration (speeding up).
B. No slope (level) means zero acceleration (constant speed).
C. Negative slope means negative acceleration (slowing down).

Chapter 2 Review

Vocabulary review

Match the following terms with the correct definition. There is one extra definition in the list that will not match any of the terms.

Set One

1. scientific model	a. A way to show how something works that is descriptive in nature
2. conceptual model	b. A variable that changes in response to another variable
3. graphical model	c. A variable that doesn't change during an experiment
4. dependent variable	d. A variable that we set in an experiment
5. independent variable	e. A way to show how variables are connected
	f. A graph that shows how variables are connected

Set Three

1. deceleration	a. A measurement of a line on a graph, equal to horizontal change divided by vertical change
2. gravity	b. A force that tends to pull things toward the center of the earth
3. free fall	c. A decrease in speed over time
	d. An object that is moving freely towards the center of the Earth exhibits this type of motion

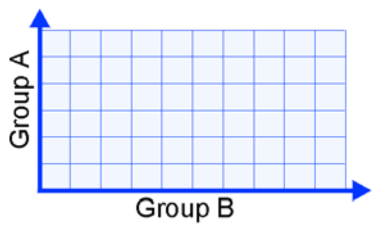
Set Two

1. position	a. Total distance traveled divided by total time elapsed
2. slope	b. The amount of time elapsed during an experiment
3. average speed	c. How speed changes over time
4. instantaneous speed	d. A measurement of a line on a graph, equal to vertical change divided by horizontal change
5. acceleration	e. Where something is compared with where it started
	f. Speed at one moment in time

Concept review

1. One of the early conceptual models of the solar system showed the other planets and the sun orbiting around the Earth. Copernicus developed a new model of the solar system that shows the Earth and other planets orbiting around the sun. Draw a picture of these two models of the solar system.

2. The following terms and phrases refer to the two axes of a graph. Divide the terms and phrases according to which group they belong in.



Words to sort
horizontal
vertical
X-axis
Y-axis
dependent variable
independent variable

Group A	Group B

3. Which of the following types of scientific models is frequently used to make numerical predictions that you can test with measurements? You may choose more than one.

   a. a graph

   b. an equation

   c. a conceptual model

   d. a physical model

4. You take a walk from your house to your friend's house around the block. If you graph your position during your walk, the longest distance on the graph is 15 meters. But you actually walked 20 meters. Explain why your position (distance from start) and the actual distance you walked were different.

5. You know the average speed of a trip, and you have a position versus time graph of the trip. Which gives you more information about the trip? Explain your answer.

6. The slope of a position vs. time graph is equal to ____________.

7. What is the difference between *average speed* and *instantaneous speed*? Use a real-life example to help you explain.

8. Is it possible for an object to simultaneously have a speed of zero but an acceleration that is not zero? Answer with an example.

9. What is the acceleration of a car that is going at a steady speed of 60 mph?

10. Does a car accelerate when it goes around a corner at a steady speed? Explain your answer.

11. Does the speedometer of a car give you the average speed or the instantaneous speed of the car? Explain your answer.

12. The slope of a speed vs. time graph is equal to ____________.

Problems

1. Engineers propose to build a bridge that is 30 meters in length. They build a model of the bridge that is 3 meters in length. What is the scale of the model? Express your answer in the form 1:x, where x is the corresponding number of meters on the bridge, when compared with 1 meter on the model.

2. You do an experiment where you measure the height of plants and calculate their growth rate. The growth rate is the amount each plant gets taller per day. You collect the following data on height and growth rate:

Week	Height of plant (cm)	Average daily growth rate (mm/day)
start	2.2	
1	7.9	8.1
2	11.8	5.6
3	15.2	4.9
4	17.7	3.6
5	19.9	3.1
6	21.2	1.9
7	22.1	1.3
8	22.3	0.3

   a. Graph the above data with height on the x-axis and growth rate on the y-axis.

   b. Does the data show (you may choose more than one):

      1) a strong relationship between variables
      2) a weak relationship between variables
      3) an inverse relationship between variables
      4) a direct relationship between variables

3. A woman goes to a store three blocks away from her home. She walks in a straight line and at a steady pace. Draw a position vs. time graph of her walk. Regard home as start.

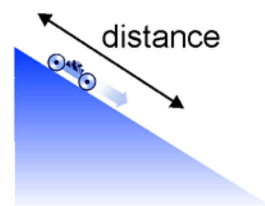
4. A woman leaves a store and goes to her home three blocks away. She walks in a straight line and at a steady pace. Draw a position vs. time graph of her walk.

5. A car rolling down a ramp starts with a speed of 50 cm/sec. The car keeps rolling and 0.5 seconds later the speed is 150 cm/sec. Calculate the acceleration of the car in cm/sec^2.

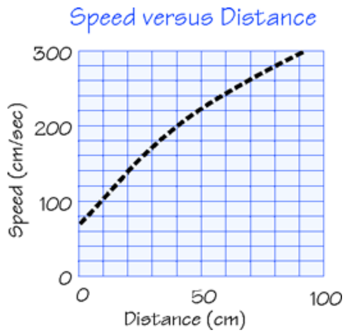
6. Think about the relationship between the amount of gas you have in your car and how far you can travel. Make a graphical model of this relationship. Which is the dependent variable (the effect)? Which is the independent variable (the cause)?

7. The data table below contains information from an experiment where a car was rolling down a ramp. You suspect some of the numbers are incorrect. Which numbers are suspect? Make a graph that demonstrates how you found the bad data.

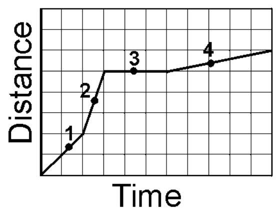
Distance (cm)	Speed (cm/sec)
10	110
20	154
30	205
40	218
50	243
60	266
80	275
90	327



8. Use the graph below to predict the speed of the car at the following distances: 20 cm, 35 cm, 60 cm, 80 cm



9. Arrange the four points on the distance vs. time graph in order from slowest to fastest.

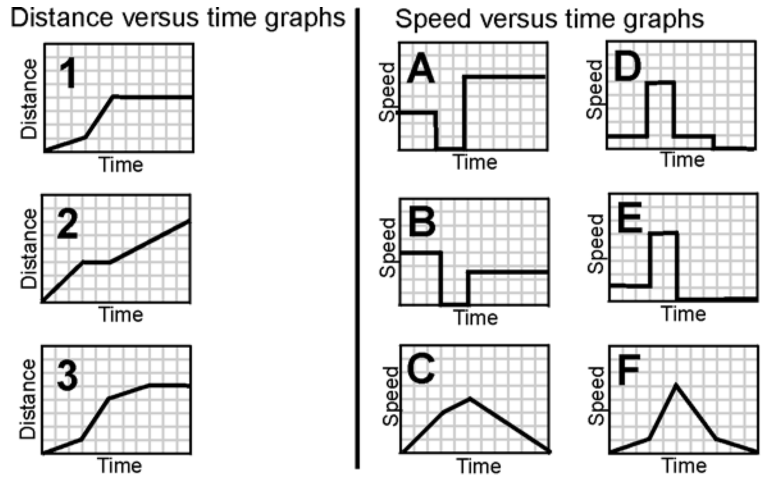


Fastest
a)
b)
c)
d)
Slowest

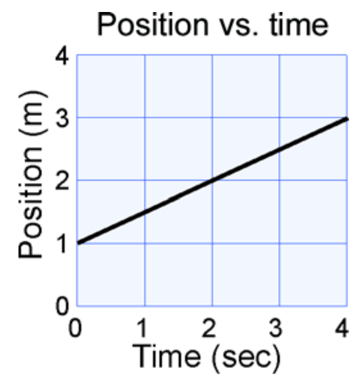
10. A bicyclist, traveling at 30 miles per hour, rides a total of 48 miles. How much time did it take?

11. A turtle is moving in a straight line at a steady speed of 15 cm/sec for 3 hours. How far did the turtle travel?

12. Match each of the three distance vs. time graphs with the corresponding speed vs. time graph. All three distance vs. time graphs contain only straight-line segments.



13. Calculate speed from the position vs. time graph on the left. Show all of your work.



Applying your knowledge

1. Research the following: What is the fastest acceleration in a human in a sprint race? What is the fastest acceleration of a race horse? Which animal is capable of the fastest acceleration?

2. How fast do your fingernails grow? Devise an experiment to determine the answer. How would you represent your measurement? What units would you use to represent the speed?

Chapter 3
Forces and Motion

Introduction to Chapter 3

Things in the universe are always moving, but what gets them going? In this chapter you will follow Sir Isaac Newton's brilliant discoveries of the link between force and motion. Newton's three laws of motion have become a foundation of scientific thought.

Investigations for Chapter 3

3.1	**Force, Mass, and Acceleration**	*What is the relationship between force, mass and acceleration?*

In this Investigation you will devise ways to measure force and acceleration. By graphing force, mass, and acceleration, you will deduce Newton's second law of motion.

3.2	**Weight, Gravity, and Friction**	*How does increasing the mass of the car affect its acceleration?*

Do heavier objects fall faster? And if so, why? In this Investigation you will measure the Earth's gravity and learn why perpetual motion machines are impossible.

3.3	**Equilibrium, Action, and Reaction**	*What is Newton's third law of motion?*

For every action there is an equal and opposite reaction. What does this famous statement really mean? In this Investigation you will explore how Newton's third law of motion explains the interaction and motion of everyday objects.

Learning Goals

In this chapter, you will:

- ✔ Explain the meaning of force.
- ✔ Show how force is required to change the motion of an object.
- ✔ Use a graph to identify relationships between variables.
- ✔ Explain and discuss Newton's second law and the relationship between force, mass, and acceleration.
- ✔ Describe how changing the mass of the car affects its acceleration.
- ✔ Draw conclusions from experimental data.
- ✔ Demonstrate qualitatively how friction can affect motion.
- ✔ Explain Newton's third law of motion.
- ✔ Identify action-reaction pairs of forces.
- ✔ Recognize how Newton's third law of motion explains the physics behind many common activities and useful objects.

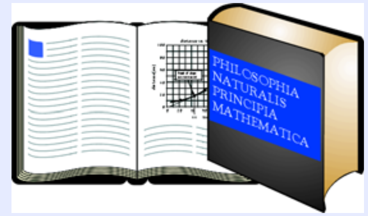
Vocabulary

air friction	inertia	newton	rolling friction
equilibrium	law of conservation of momentum	Newton's first law of motion	sliding friction
force	mass	Newton's second law of motion	viscous friction
friction	momentum	Newton's third law of motion	weight
gravity	net force	pounds	

3.1 Force, Mass, and Acceleration

Sir Isaac Newton discovered one of the most important relationships in physics: the link between the force on an object, its mass, and its acceleration. In this section, you will learn about force and mass, and then apply all that you have learned to complete an important Investigation on acceleration. Through your experiments and data analysis, you will follow the path taken by one of history's most innovative thinkers.

Newton's *Principia*



Published in England in 1687, Newton's *Principia* is possibly the most important single book in the history of science. The *Principia* contains the three laws of motion and the universal law of gravitation.

Introduction: Sir Isaac Newton's laws of motion

Sir Isaac Newton

Sir Isaac Newton (1642-1727), an English physicist and mathematician, is one of the most brilliant scientists in history. Before the age of 30, he formulated the basic laws of mechanics, discovered the universal law of gravitation, and invented calculus! His discoveries helped to explain many unanswered questions, such as how do the planets move? What causes the tides? Why doesn't the moon fall to the Earth like other objects?

Table 3.1: ***Newton's Laws of Motion***

The Three Laws	What Each One Says	In Other Words...
Newton's first law of motion	An object at rest will remain at rest unless acted on by an unbalanced force. An object in motion will continue with constant speed and direction, unless acted on by an unbalanced force.	Unless you apply force, things tend to keep on doing what they were doing in the first place.
Newton's second law of motion	The acceleration of an object is directly proportional to the force acting on it and inversely proportional to its mass.	Force causes an object to accelerate, while the object's mass resists acceleration.
Newton's third law of motion	Whenever one object exerts a force on another, the second object exerts an equal and opposite force on the first.	For every action, there is an equal and opposite reaction. If you push on the wall, you feel the wall pushing back on your hand.

Force

If your teacher asked you to move a cart containing a large, heavy box, would you: (a) push it; (b) pull it; or (c) yell at it until it moved (Figure 3.1)?

Of course, the correct answer is either (a) push it or (b) pull it!

You need force to change motion

Every object continues in a state of rest, or of motion, unless force is applied to change things. This is a fancy way of saying that things tend to keep doing what they are already doing. There is no way the cart with the heavy box is going to move unless a force is applied. Of course, the force applied has to be strong enough to actually make the cart move.

Once the cart is set into motion, it will remain in motion, unless another force is applied to stop it. You need force to start things moving and also to make any change in their motion once they are going.

What is force?

A **force** is what we call a *push or a pull*, or *any action that has the ability to change motion*. This definition does not, however, mean that forces always change motion! If you push down on a table, it probably will not move. However, if the legs were to break, the table *could* move.

Force is an action that has the ability to change motion.

Pounds and newtons

There are two units of force that are commonly used: **pounds** and **newtons** (Figure 3.2). Scientists prefer to use newtons. The newton is a smaller unit than the pound. There are 4.448 newtons in one pound. A person weighing 100 pounds would weigh 444.8 newtons.

The origin of the pound

The origin of the pound is similar to the origin of many standard units of length. Merchants needed a standard by which to trade goods without dispute. Weight is an obvious measure of quantity so the pound was standardized as a measure of weight. The oldest known standard weight was the *mina* used between 2400 and 2300 BC. One *mina* was a little more than one modern pound.

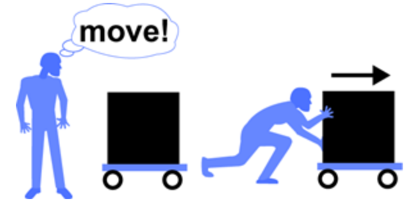


Figure 3.1: *Which action will move the cart, yelling at it or applying force to it?*

Unit	Equivalents
1 newton	0.228 pounds
1 pound	4.448 newtons

Figure 3.2: *Units of force.*

Example:

A person stands on a scale and measures a weight of 100 pounds. How much does the person weigh in newtons?

Solution:

(1) Multiply by conversion factors

$$100\text{ lbs} = 100\text{ lbs} \times \left(\frac{4.448\text{ N}}{1\text{ lb}}\right)$$

(2) Cancel units

$$= \frac{444.8\ \cancel{\text{lb}} \times \text{N}}{1\ \cancel{\text{lb}}}$$

(3) Answer $= 444.8$ lb

The difference between force and mass

The origin of the newton The metric unit of force, the newton, relates force and motion. One newton equals 1 kilogram multiplied by 1 meter per second squared. This means that a force of one newton causes a 1-kilogram mass to have an acceleration of 1 m/sec^2. In talking about force, "newton" is easier to say than "1 kilogram · m/sec^2."

Use the correct units in formulas Force and mass have different units. Force units are pounds or newtons. Mass units are grams or kilograms. To get the right answer when using formulas that include force or mass, you need to use the correct units.

Defining force and mass Force is a push or pulling action that can change motion. Mass is the amount of "stuff" or matter in an object. Mass is a basic property of objects. Mass resists the action of forces by making objects harder to accelerate.

Weight is different from mass The weight of a person can be described in pounds or newtons. On Earth, a child *weighs* 30 pounds or about 134 newtons. In other words, the force acting on the child, due to the influence of Earth's gravity, is 134 kg·m/sec^2.

Your mass is the same everywhere in the universe, but your weight is different A child that weighs 30 pounds on Earth has a *mass* of about 14 kilograms because on Earth 2.2 pounds equals 1 kilogram. Because mass is an amount of matter, mass is independent of the force of gravity. Therefore, the mass of a person is the same everywhere in the universe. However, the *weight* of a person on Earth is different from what it would be on the moon or another planet because the force of gravity is different at these other places.

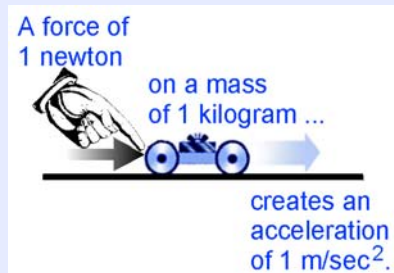
Units of force and mass can describe a quantity Mass and weight are commonly used to describe the quantity of something. For example, a kilogram of bananas weighs 2.2 pounds. You can describe the quantity of bananas as having a mass of 1 kilogram, or a weight of 2.2 pounds. Using two different kinds of measurement to describe the same quantity of bananas does *not* mean pounds and kilograms are the same thing.

Different units can describe the same quantity We often use different units to describe a quantity. For bananas, you can use a unit of mass (kilograms) or a unit of force (pounds). Likewise, buying one gallon of milk is the same as buying 8.4 pounds of milk. Pounds and gallons both describe the same quantity but one unit is a measure of volume (gallons) and one is a measure of force (pounds).

Figure 3.3: *A spring scale is a tool for measuring force. A force of 1 pound is the same as a force of 4.448 newtons.*

Newton

A newton is the metric unit of force.



A force of one newton acting on a mass of 1 kilogram produces an acceleration of 1 m/sec^2.

Mass and inertia

Newton's first law

Newton's first law is also called the *law of inertia*. Inertia is defined as the property of an object to resist changing its state of motion. An object with a lot of inertia takes a lot of force to start or stop. Big trucks have more inertia than small cars, and bicycles have even less inertia (Figure 3.4).

Inertia is a property of mass

The amount of inertia an object has depends on its mass. Mass is a measure of the inertia of an object. Mass is what we usually think of when we use words like "heavy" or "light." A heavy object has a large mass while an object described as "light as a feather" has a small mass. We can also define mass as the amount of matter an object has.

The kilogram

Mass is measured in kilograms. The kilogram is one of the primary units of the metric system, like the meter and second. For reference, 1 kilogram has a weight of about 2.2 pounds on the Earth's surface. That means gravity pulls on a mass of 1 kilogram with a force of 2.2 pounds.

You feel inertia by moving things

Which is harder to push: a ball that has a mass of 1 kilogram, or a ball that has a mass of 100 kilograms (Figure 3.5)? Once you get each ball moving, which is easier to stop? Of course, the 100 kilogram ball is harder to start and harder to stop once it gets moving. This is a direct example of the law of inertia in action.

Mass is a constant property of an object

The mass of an object does not change, no matter where the object is, what planet it is on, or how it is moving. The only exception to this rule is when things go extremely fast, close to the speed of light. For the normal world, however, mass is an unchanging property of an object. The only way to change the mass is to physically change the object, like adding weights or breaking off a piece.

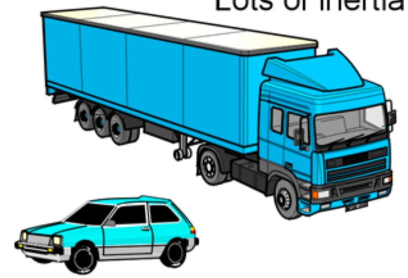


Figure 3.4: *A large truck has more inertia than a small car. As a consequence it is much harder to push a truck than to push a car.*

Discussion question:

What part of a bicycle or car is designed to overcome the law of inertia?

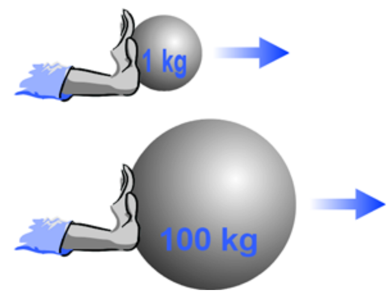
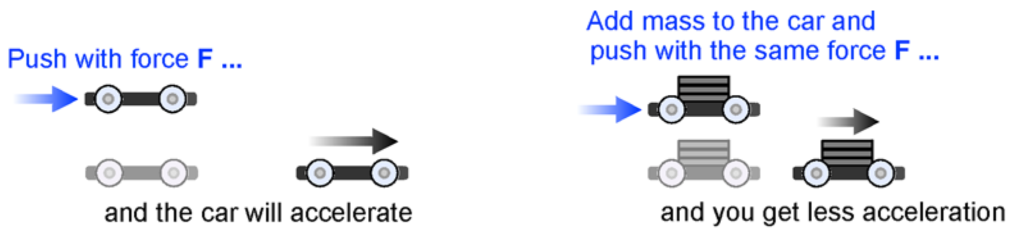


Figure 3.5: *The 100 kilogram ball has much more inertia, which makes it much harder to push.*

Newton's second law of motion

Newton's second law

Newton's second law relates the applied force on an object, the mass of the object, and acceleration.



Newton's Second Law

Acceleration (m/sec²) → $$\mathbf{a} = \frac{\mathbf{F}}{\mathbf{m}}$$ ← Force (newtons, N), ← Mass (kg)

What the second law tells us

Newton's second law is one of the most famous equations in physics. It says that:

- Force causes acceleration.
- Mass resists acceleration.
- The acceleration you get is equal to the ratio of force over mass.

The second law is common sense when you think about it. If you make something very heavy (more mass), it takes proportionally more force to cause acceleration. It does not matter whether the acceleration is a speeding up or a slowing down.

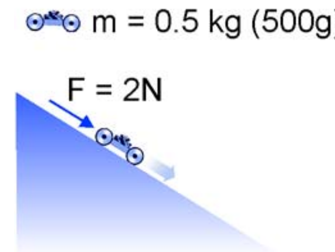
Force is related to acceleration

There are many examples that demonstrate why force should be linked to acceleration. Force isn't necessary to keep an object in motion at constant speed. An ice-skater will coast for a long time without any outside force. However, the ice-skater does need force to speed up, slow down, turn or stop. Recall that changes in speed or direction all involve acceleration. *Force* causes *acceleration*; this is how we create changes in motion.

Example:

A car rolls down a ramp and you measure a force of 2 newtons pulling the car down. The car has a mass of 500 grams (0.5 kg).

Calculate the acceleration of the car.



Solution:

(1) What are you asked for?

The acceleration

(2) What do you know?

Mass and force

(3) What relationships apply?

$a = F/m$

(4) Solve for what you need.

$a = F/m$

(5) Plug in numbers. Remember that $1\ N = 1\ kg{\cdot}m/sec^2$.

$a = (2\ N) / (0.5\ kg)$

$= (2\ kg{\cdot}m/sec^2) / (0.5\ kg)$

(6) Cancel units. In this case, kilogram cancels. The car's acceleration is:

$= 4\ m/sec^2$

Using the second law of motion

Writing the second law

The formula for the second law of motion uses *F*, *m*, and *a* to represent force, mass, and acceleration. The way you write the formula depends on what you want to know. Three ways to write the law are summarized in Table 3.1.

Table 3.1: *The three forms of Newton's second law*

Form of Newton's second law	if you want to know...	and you know....
a = F/m	the acceleration (**a**)	the mass (**m**) and the force (**F**)
F = ma	the force (**F**)	the mass (**m**) and the acceleration (**a**)
m = F/a	the mass (**m**)	the force (**F**) and the acceleration (**a**)

Units for the second law

One newton is the amount of force that causes an acceleration of 1 meter/sec^2 for a body of 1-kilogram mass. To use Newton's second law in calculations, you must be sure to have units of meters/sec^2 for acceleration, newtons for force, and kilograms for mass. In these calculations, remember that *m* stands for *mass* in the formula. In the units for acceleration, *m* stands for *meters*.

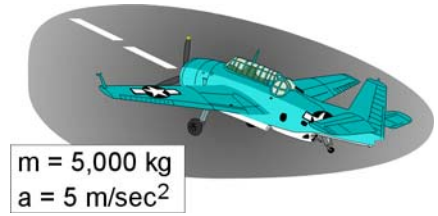
Applications of the second law

Newton's second law is frequently used by scientists and engineers to solve technical problems. For example, for an airplane to take off from a runway, it has to reach a minimum speed to be able to fly. If you know the mass of the plane, Newton's second law can be used to calculate how much force the engines must supply to accelerate the plane to take off speed.

Applying the second law to cars

Cars offer another example. If a car engine can produce so much force, the second law is used to calculate how much acceleration the car can achieve. To increase the acceleration, car designers can do two things: reduce the mass by making the car lighter, or increase the force by using a bigger engine. Both options are based directly on the Newton's second law.

Example:



An airplane with a mass of 5,000 kilograms needs to accelerate at 5 m/sec^2 to take off before it reaches the end of the runway. How much force is needed from the engine?

Solution

(1) What are you asked for?
The force

(2) What do you know?
Mass and acceleration

(3) What relationships apply?
a = F/m

(4) Solve for what you need.
F = ma

(5) Plug in numbers. Remember that 1 N = 1 kg·m/sec^2.
$F = (5{,}000\ kg) \times (5\ m/sec^2)$
$= 25{,}000\ kg{\cdot}m/sec^2$

(6) Convert the units to newtons. The force needed is:
= 25,000 N

Balanced and unbalanced forces

Net force The motion of an object depends on the *total* of all forces acting on the object. We call the total of all forces the **net force**. To figure out the net force, we usually have to make some forces positive and some negative so they can cancel out. Choose a direction to be positive, and be consistent about treating forces in the opposite direction as negative (Figure 3.6).

What is equilibrium? When forces on an object are balanced, the net force is zero, and we say that the object is in **equilibrium**. In equilibrium there is no change in motion. An object at rest stays at rest, and an object already moving keeps moving at the same speed.

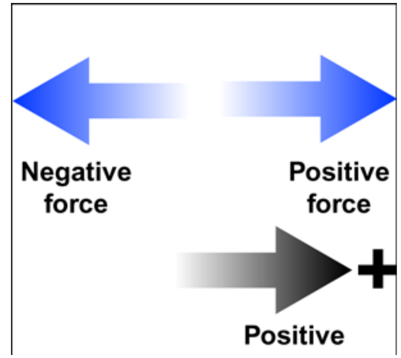
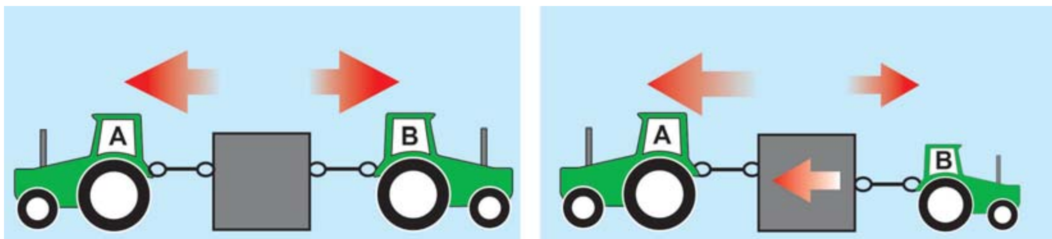


Figure 3.6: *Assigning positive and negative values to forces in opposite directions.*



An example of equilibrium and nonequilibrium The diagram above illustrates the difference between balanced and unbalanced forces. Imagine a giant box being pulled on both sides by tractors. If the tractors are equal, the forces are equal, the box is in equilibrium and does not move. If tractor A is 10 times stronger than tractor B, the forces are *not* in equilibrium. The net force points toward tractor A, so the box accelerates toward tractor A.

The second law refers to net force The force that appears in the second law is really the net force acting on an object. Acceleration is caused by a net force that is *not* zero. For motion to change, the forces acting on the object have to be unbalanced. In other words, a force acting on one side of the object has to be greater than the force acting on the other side of the object.

Solving force problems We often use equilibrium and the second law to prove the existence of forces. If we see that an object is at rest, we know its acceleration is zero. That means the net force must also be zero. If we know one force (like weight), we know there is another force in the opposite direction to make the net force zero (Figure 3.7).

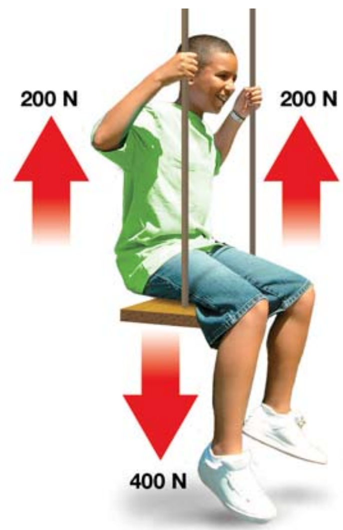


Figure 3.7: *This swing is not moving so the net force must be zero. If the weight of the person is 400 N, then each rope must pull upwards with a force of 200 N to make the net force zero.*

3.2 Weight, Gravity, and Friction

Suppose you and a friend are riding your bicycles in San Francisco. You both reach the top of a hill and stop to take in the view. You decide to coast to the bottom of the hill without pedaling. If you both push off at the same time, and with the same amount of force, will you both reach the bottom of the hill at the same time? Who will accelerate the fastest? In this section, you will learn about weight and friction. These two forces determine who gets down the hill first.

Gravity

What is gravity

What is the force that causes an object like a car to accelerate down a ramp?

You probably know gravity is involved. **Gravity** is a force that pulls every mass toward every other mass. Since Earth is the biggest mass around, gravity pulls everything toward the center of Earth. Ask someone the meaning of the word *down* and they point toward the center of Earth. Down is the direction of the force of gravity.

Gravity depends on mass

The force of gravity depends on how much mass you have. If you have more mass, gravity pulls on you with more force. That is why we can use force to measure mass. When you use a digital balance to measure the mass of a sample, you are really measuring the force of gravity acting on your sample. If you are on the surface of Earth, every kilogram of mass creates a gravitational force of 9.8 newtons. You may recognize this number—9.8 newtons is the same as 9.8 m/sec^2, the acceleration of gravity. We will talk more about the relation between newtons and the acceleration of gravity on the next page.

Mars' gravity is weaker than Earth's

If you were on Mars, your force/mass balance would have to be adjusted. The planet is much smaller than Earth and therefore Mars's gravity is weaker. Every kilogram of mass on Mars results in a gravity force of only 3.8 newtons (Figure 3.8). The larger the planet you are on, the greater the force of gravity. On Jupiter, the largest planet, gravity has a force 2.6 times stronger than on the surface of Earth. If you weighed 110 pounds on Earth, you would weigh 286 pound on Jupiter!

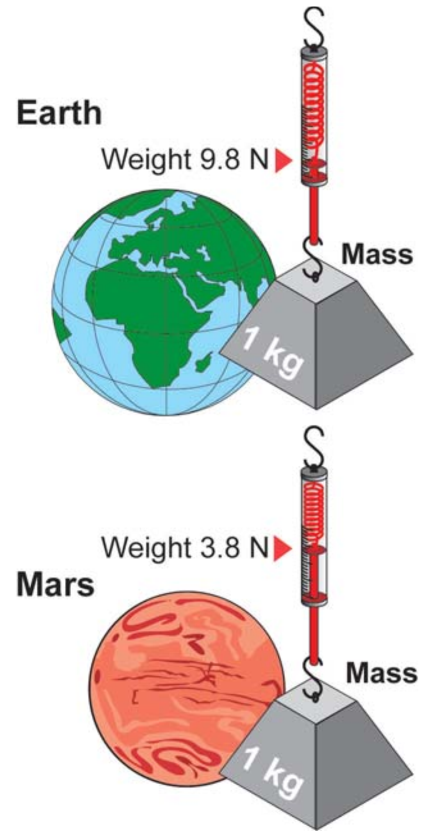


Figure 3.8: *Weight is a force that comes from gravity pulling on mass. The weight depends on how strong gravity is. Earth is bigger than Mars and has stronger gravity. A kilogram weighs 9.8 newtons on Earth but only 3.8 newtons on Mars.*

Mass and weight

What is weight? **Weight** is what we call the force created by gravity on objects. The weight of an object depends on its mass. Your mass is constant throughout the universe, but your weight changes depending on what planet you happen to be on. For example, because the gravitational force on Mars is less than that on Earth, you *weigh* less on Mars than on Earth, but your *mass* is the same at both locations!

How to calculate weight If you know the mass of an object, you can calculate its weight using Newton's second law. When you drop something on Earth, gravity causes it to accelerate at 9.8 m/sec^2. Because there is acceleration, you know there must be a force. You also know the force is exactly equal to mass times acceleration. The force we call weight is equal to an object's mass times the acceleration of gravity (9.8 m/sec^2).

Weight in formulas Since weight is a force, we use the letter *F* to represent it. To remind us that we are talking about the weight force, we add a little *w* next to the *F*. The *w* is called a **subscript**, and we would say "*F* sub *w*" if we wanted to tell someone what we were writing. The *F* and *w* always stay together since they are really one symbol for the weight force.

Weight

$$F_w = mg$$

Weight force (N) → F_w; mass (kg) → m; Acceleration of gravity (9.8 m/sec^2) → g

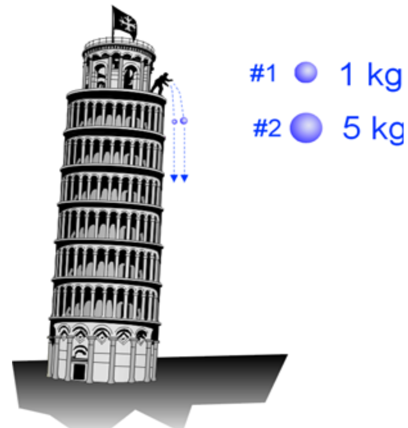
DON'T use kilograms for weight Because we live and work on the surface of Earth, we tend to use weight and mass interchangeably. Heavy objects have lots of mass and light objects have little mass. Boxes and people are "weighed" in both kilograms and pounds. This is OK for everyday use, but you must remember the difference when doing physics. Physics is about the true nature of how the universe works and mass is truly a fundamental property of an object. Force often depends on outside influences, like gravity. You cannot interchange force and mass in a formula; doing so would be like substituting a fork for a spoon when you are trying to eat soup. In physics, force and mass are different quantities with different units.

Example:

A legend has it that, around 1587, Galileo dropped two balls from the Leaning Tower of Pisa to see which would fall faster.

a) Calculate the weight of each ball.

b) Calculate the acceleration of each ball's fall.



Part a)

#1 $F_w = mg$
$= (1 \text{ kg}) \times (9.8 \text{ m/sec}^2)$
$= 9.8 \text{ N}$

#2 $F_w = (5 \text{ kg}) \times (9.8 \text{ m/sec}^2)$
$= 49 \text{ N}$

Part b)

#1 $a = F/m$
$= (9.8 \text{ N})/ 1 \text{ kg}$
$= 9.8 \text{ m/sec}^2$

#2 $a = (49 \text{ N})/ 5 \text{ kg}$
$= 9.8 \text{ m/sec}^2$

The acceleration of both balls is the same!

Newton's law of universal gravitation

Why does the moon orbit Earth?

Mars and Earth are two massive objects that orbit the sun. Similarly, Earth's moon is a massive object that orbits around Earth. The same gravity that gives you weight is what holds Earth and its moon together. If you could simply drop the moon, it would fall to Earth just like an apple falls down from a tree. That does not happen because the moon is moving quite fast in a direction perpendicular to Earth's attractive gravity. The force of gravity bends the path of the moon toward the center of Earth, resulting in a nearly circular orbit.

Gravity attracts the Moon to the Earth and the Earth to the Moon.

The velocity of the Moon is perpendicular to its distance from the Earth. Because gravity pulls toward the center of the Earth, the Moon's path is bent into a (nearly) circular orbit.

What is the law of universal gravitation?

Gravity is a force of attraction that exists between any two objects that have mass. This idea is known as the law of universal gravitation. The force of attraction increases when the mass of the objects increases. The force of gravity also increases when the objects get closer together. Given this information, does this mean that we feel forces of attraction between ourselves and other objects?

The force of attraction between two objects is directly related to the masses of the objects and inversely related to the square of the distance between them.

It takes a lot of mass to create gravity you can feel

You may feel attracted to a chocolate cake, but gravity has nothing to do with it! The force of gravity between ordinary masses is so weak that you can't really feel it (Figure 3.9). We notice the effects of gravity because the mass of one particular object (Earth) is huge, and relatively close to us. For gravity to create noticeable forces between two objects, the mass of at least one of them must be very large, like a planet or a star (Figure 3.10).

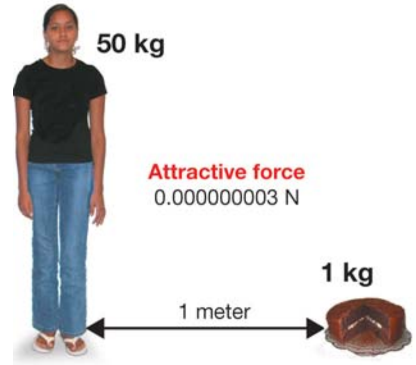


Figure 3.9: *The attractive force from gravity between objects of ordinary mass is incredibly small.*

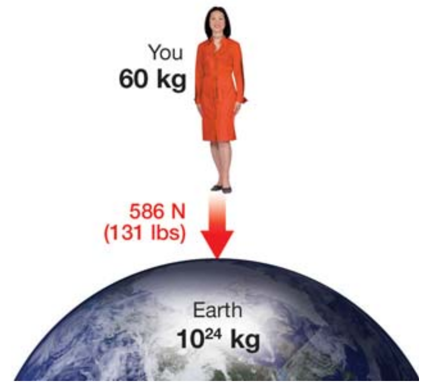


Figure 3.10: *You feel weight because the mass of Earth is large enough to create significant gravity forces.*

Calculating the gravitational force between objects

Calculating the force of gravity

You can calculate the gravity force between two objects using the equation for universal gravitation. The attractive force between two objects is equal to 'G' times the product of their masses divided by the square of the distance between them. 'G' is the gravitational constant, and is the same everywhere in the universe. This one equation describes gravity for small things, like people and chocolate cakes. It also works for huge things like galaxies, stars, and planets.

Equation of Universal Gravitation:

Mass 1 (kg) Mass 2 (kg)

Force (N)

$$F = G\frac{m_1 m_2}{R^2}$$

Gravitational constant (6.67×10^{-11} N•m²/kg²)

Distance between mass 1 and mass 2 (m)

Example:

The mass of Jupiter's third largest moon, Io, is 8.9×10^{22} kg. The radius of Io is 1,815 kilometers. Use the equation of universal gravitation to calculate your weight if you were on the surface of Io and had a mass of 50 kilograms.

1) Use the formula for the universal law of gravitation.

$$F = G \times \frac{m_1 \times m_2}{d^2}$$

2) Plug in values.

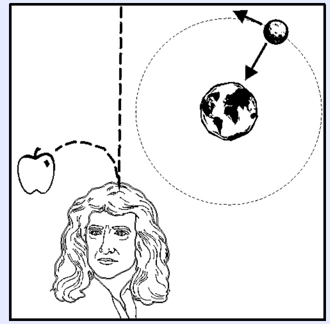
$F = 6.7 \times 10^{-11}$ N·m²/sec²; $m_1 = 50$ kg; $m_2 = 8.9 \times 10^{22}$ kg; R = 1,815,000 m

$= [(6.7 \times 10^{-11}$ N·m²/sec²$) \times (50$ kg$) \times (8.9 \times 10^{22}$ kg$)] \div (1{,}815{,}000$ m$)^2$

= 91 N or 20 lbs (4.448 N = 1 lb)

Your weight on Io is about 20 pounds! On Earth your weight would be 110 pounds. With such a small weight, you could jump 13 meters (43 feet) high on Io.

Newton and gravity



Many people associate the discovery of the law of gravitation with a falling apple. As the story goes, Newton observed an apple fall from a tree and was inspired to wonder if the moon experienced a similar force that affected its motion around Earth. Newton deduced that the force responsible for accelerating a falling apple is the same force involved in keeping the moon in orbit. As Newton developed his theories about motion, he concluded that gravity is a force that behaves the same throughout the universe—it's universal!

Friction

How is space travel different from Earth travel?

When Newton was developing the law of universal gravitation, he realized that with enough speed, an object would orbit forever as long as nothing slowed it down. For an object like a space shuttle, orbiting around Earth can be nearly effortless because there is no air resistance in space. Air resistance "resists" forward movement of cars and other objects on Earth. Air resistance is a kind of force kind called friction.

What is friction?

Friction is a term that is used to describe forces that result from relative motion between objects (like the wheel and axle of a car). *Frictional forces always work against the motion that produces them.* For example, when a model car rolls down a ramp frictional forces resist the motion. Friction is a force that holds the car back. Axles and ball bearings are inventions that help reduce friction.

What causes friction?

Friction comes from two surfaces moving against each other. Surfaces of objects that appear smooth and shiny actually have microscopic hills and valleys. As the surfaces slide across each other the hills and valleys interfere causing friction.

Friction and wear

Objects that continuously rub against each other cause wear. Wear refers to how moving parts can erode each other. In old cars, the parts are often so worn down due to friction that they are too loose and no longer fit correctly.

Kinds of friction

We use the word *friction* to describe any force that is caused by motion and that acts to slow motion down. Some examples of friction include:

- Air Friction: The air moving around moving objects creates an opposing force. This is why many cars have rounded, *aerodynamic* shapes. A rounded design reduces air friction, allowing cars to go faster and get better gas mileage.
- Sliding Friction: When two surfaces rub against each other, we get sliding friction. Sliding friction is caused by irregularities in the surfaces.
- Viscous Friction: Objects that move in water or other fluids create this type of friction. Oil changes sliding friction to viscous friction and helps reduce wear.
- Rolling Friction: This type of friction is caused by one object rolling over another, like a wheel rolling over the road. Ball bearings in wheels are designed to reduce the effect of rolling friction.

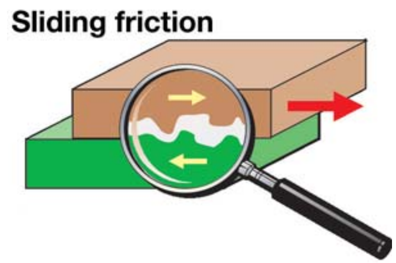
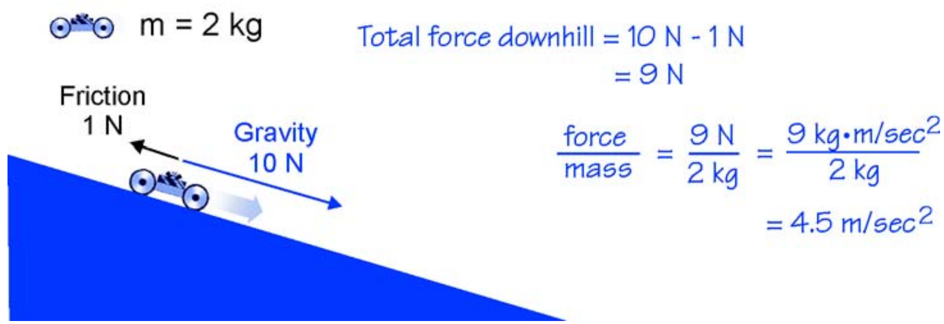


Figure 3.11: *Sliding friction is caused by microscopic hills and valleys on the surface of materials.*

Figure 3.12: *The wheels of the car have ball bearings to reduce sliding friction. Even ball bearings have rolling friction and may also have viscous friction from oil.*

Friction and motion

How does friction affect acceleration? Friction is a force that always opposes motion. That means the force of friction is opposite whatever force is causing motion. For a car rolling downhill, gravity supplies a force pulling down the hill. Friction opposes motion, so it pushes the car up the hill while gravity is pulling the car down the hill.



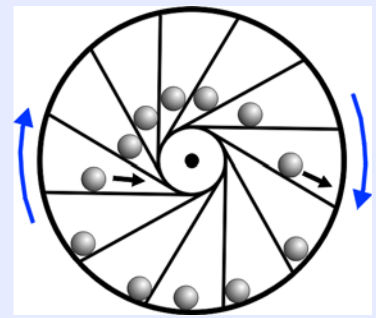
The net force The F that appears in Newton's second law stands for the total force acting on the car. This includes gravity and friction. To find out the total force we need to subtract the friction force from gravity. What is left is often called the **net force**. When talking about forces, the word *net* means total.

Friction reduces acceleration The acceleration we observe will always be less than it would have been if there were no friction. This is because the friction force partly cancels some of the gravity force pulling the car down.

All machines have friction All true machines have friction. That means there are always forces that tend to oppose motion. Unless you continually supply force, eventually, friction slows everything to a stop. Bicycles have very low friction, but even the best bicycle slows down if you coast on a level road.

Perpetual Motion

Throughout history, many people have claimed to have invented a machine that will run forever with no outside force. We call them perpetual motion machines and none have ever worked.



Perpetual motion machines never work because there is always some friction. Friction always opposes motion so sooner or later everything slows down.

If someone shows you a device that seems to go without stopping, be suspicious. There is no escape from friction. Somewhere, you will always find a hidden plug or battery supplying force.

3.3 Equilibrium, Action, and Reaction

In this section, you will come to understand the truth behind the phrase "For every action there is an equal and opposite reaction." This statement is known as Newton's third law of motion and it explains the interaction and motion of objects. You will learn that forces are always at work when the motion of an object changes. However, this is not to say that objects at rest experience no forces. What keeps your book perfectly still on a table as you are trying to read it (Figure 3.13)? Why would your book fall to the ground if you lifted the table at one end? "Force" is a good answer to both of these questions.

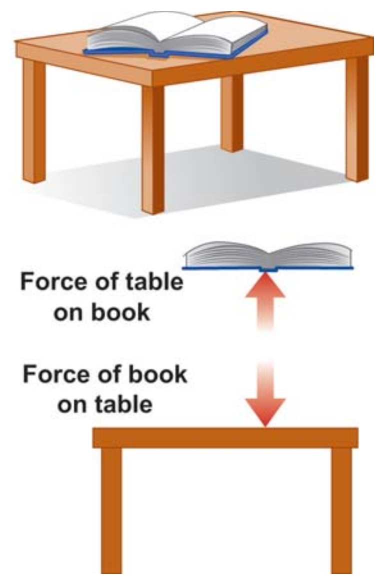
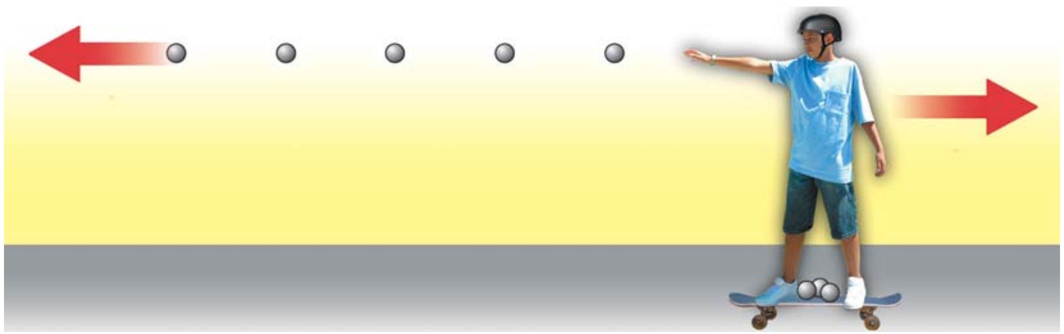


Figure 3.13: *Even when things are not moving there are forces acting. Gravity pulls the book down with a force. The table pushes back up with an equal and opposite force. The book stays still because the two forces are balanced*

Newton on a skateboard

An imaginary skateboard contest

Imagine a skateboard contest in which each person has to move his or her skateboard without their bodies touching the ground. Neither their feet nor their hands may touch the ground. How would you win this contest? How would you move your skateboard? Here are some possible strategies.



- Wave your arms back and forth.
- Walk from one end of the skateboard to the other.
- Start the contest at the top of an inclined plane.
- Stuff tennis balls in your pockets and throw them away from you.

Which strategies would work? Can you think of any others? Newton's third law of motion explains why you use your feet in the first place to get a skateboard moving. This law also explains why you can move a skateboard even if you don't use your hands or feet.

Newton's third law of motion

Review the first and second laws

The first and second laws apply to single objects. For example, the first law states that an object will remain at rest or in motion at constant velocity unless acted upon by an external force. The second law states that the acceleration of an object is directly proportional to force and inversely proportional to the mass.

The third law operates with pairs of objects

In contrast to the first two laws, the third law of motion deals with pairs of objects. This is because *all forces come in pairs*. **Newton's third law states that for every action force there has to be a reaction force that is equal in magnitude (in size) and opposite in direction to the action force.**

The third law applied to a skateboard

The action/reaction forces act on separate objects, *not* the same object. For example, the action-reaction pair required to move your skateboard includes your foot and the ground. Your foot pushing against the ground is the action force. The ground pushing back on you is the reaction force. The reaction force makes you move because it acts on *you* (Figure 3.14). If you were on slippery ice, you could push just as hard, but without a reaction force you would not move.

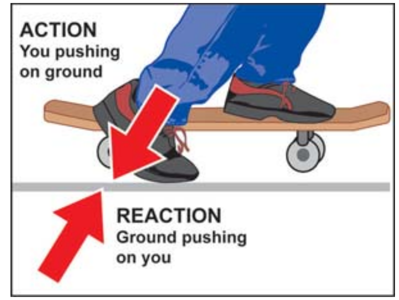
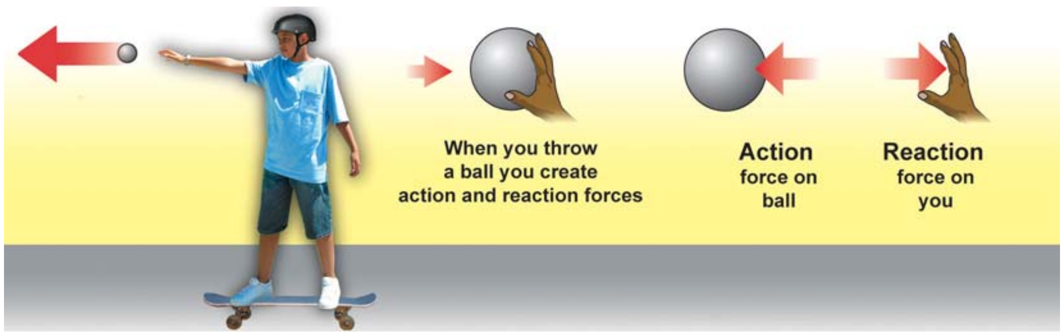


Figure 3.14: *All forces come in pairs. When you push on the ground (action), the reaction of the ground pushing back on your foot is what makes you move.*



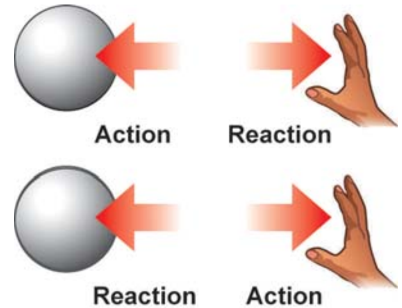


Figure 3.15: *It doesn't matter which force you call the action and which the reaction. The action and reaction forces are interchangeable.*

Stopping action and reaction confusion

It is easy to get confused thinking about action and reaction forces. Why don't they always cancel each other out? The reason is that the action and reaction forces act on different objects. When you throw a ball you apply the action force to the ball, creating acceleration of the ball. The reaction is the ball pushing back against your hand. The forces don't cancel because they act on different objects.

Momentum

The motion of objects

When two objects exchange forces in an action-reaction pair, their motions are also affected as a pair. If you throw a ball from your skateboard you must apply a force to the ball. The third law says the ball exerts an equal and opposite force on you. Your force makes the ball accelerate in one direction and the reaction makes you accelerate in the opposite direction.

What happens if you throw faster or heavier balls?

Because of the third law, the speed at which you and the ball move away from each other are related in a special way. If you throw the ball away very fast, your backward acceleration is higher than when you throw the ball away slowly. If you throw a heavier ball away fast, your backward acceleration is greater than if you throw a lighter ball (Figure 3.16). The backward acceleration from the reaction force is called **recoil**.

Momentum is mass times velocity

Momentum is the mass of an object multiplied by its speed or velocity. If you increase the mass or the speed of an object, you increase its momentum. The units for momentum are kilograms-meters per second or kg-m/sec.

Momentum

Mass (kg)

Momentum (kg•m/sec) → $$P = mv$$ ← Velocity (m/sec)

The law of conservation of momentum

Because of the third law, the momentum of you and the ball are connected. If the ball takes away momentum to the left, you must take away an equal amount of momentum to the right. This rule is an example of the **law of conservation of momentum**. The law of conservation of momentum says that as long as interacting objects are not influenced by outside forces (like friction), the total amount of momentum cannot change.

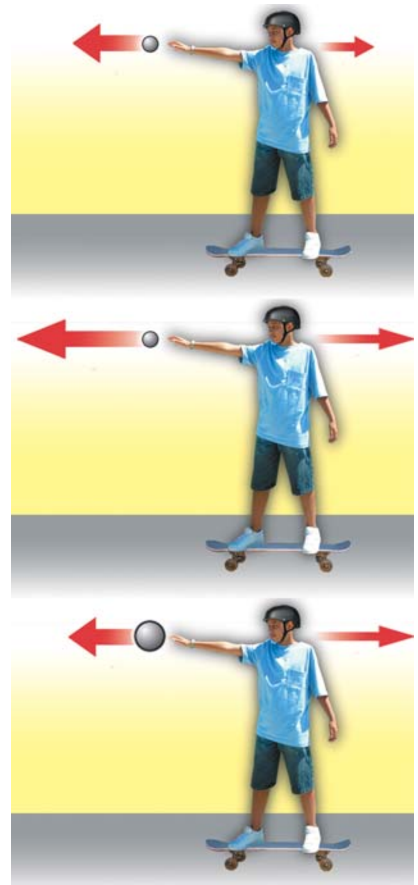


Figure 3.16: *The speed and mass of the ball you throw affect your backward acceleration (recoil).*

Using positive and negative

When talking about momentum we usually need to use positive and negative to tell the direction of motion (Figure 3.17). That means momentum can also be positive (moving to the right) or negative (moving to the left).

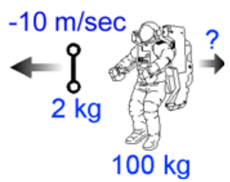
Before you throw the ball, your speed (and the ball's) is zero. Since momentum is mass times speed, the total momentum is also zero. The law of conservation of momentum says that *after* you throw the ball, the total momentum *still* has to be zero.

An example of the conservation of momentum

If the ball has a mass of 1 kilogram and you throw it at a speed of -20 m/sec to the left, the ball takes away -20 kg·m/sec of momentum. To make the total momentum zero, *you* must take away +20 kg·m/sec of momentum. If your mass is 40 kg and you ignore friction, then your speed is +0.5 m/sec to the right (Figure 3.18).

Rockets and jet planes

Rockets and jet planes use the law of conservation of momentum to move. A jet engine pushes exhaust air at very high speed out of the back of the engine. The momentum lost by the air going backward must be compensated by the momentum gained by the jet moving forward. A rocket can accelerate in space without touching anything because it throws mass at high speed out the end of the engine. The forward momentum of a rocket is exactly equal to the momentum of the escaping mass ejected from the end of the engine.



Example: An astronaut in space throws a 2-kilogram wrench away from him at a speed of -10 m/sec. If the astronaut's mass is 100 kilograms, at what speed does the astronaut move backward after throwing the wrench?

Solution: (1) You are asked for the speed. Since the astronaut is in space, we can ignore friction.

(2) You are given the mass and speed of the wrench and the mass of the astronaut.

(3) This is enough to apply the law of conservation of momentum.

$m_1 v_1 + m_2 v_2 = 0$

(4) Plug in numbers.

$[2\text{ kg} \times (-10\text{ m/sec})] + [(100\text{ kg}) \times v_2] = 0$

$v_2 = +20 / 100 = +0.2\text{ m/sec}$

The astronaut moves backward at a speed of +0.2 m/sec.

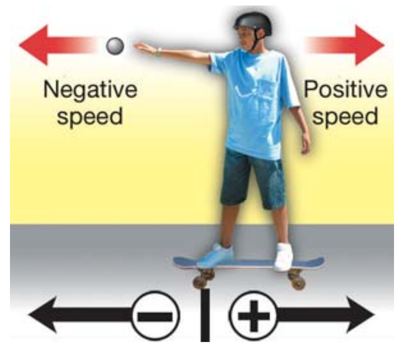


Figure 3.17: *The direction is important when using the law of conservation of momentum. We use positive and negative numbers to represent opposite directions.*

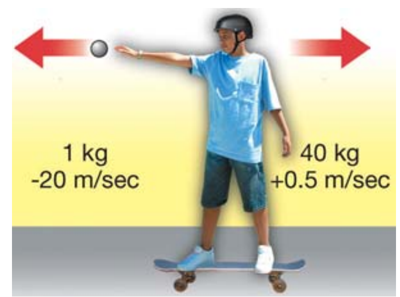


Figure 3.18: *The result of the skateboarder throwing a 1-kg ball at a speed of -20 m/sec is that he and the skateboard with a total mass of 40 kg move backward at a speed of +0.5 m/sec if you ignore friction. If you account for friction, would the calculation for speed of the skateboarder on the skateboard end up being less or more than 0.5 m/sec?*

Chapter 3 Review

Vocabulary review

Match the following terms with the correct definition. There is one extra definition in the list that will not match any of the terms.

Set One

1. force	a. The metric unit of force
2. pound	b. Objects at rest stay at rest, and objects in motion stay in motion, unless acted on by a force
3. newton	c. The English unit of force
4. Newton's first law of motion	d. An object that is in a state of motion
5. inertia	e. An action that has the ability to change motion
	f. The property of a body to resist changing its state of motion

Set Two

1. mass	a. When an object has a net force of zero acting on it
2. kilogram	b. A measurement of the amount of matter
3. Newton's second law of motion	c. The total forces acting on an object
4. net force	d. Force causes an object to accelerate, while the object's mass resists acceleration
5. equilibrium	e. When an object has a net force acting on it
	f. The metric unit of mass

Set Three

1. gravity	a. Forces that result from chemical reactions
2. weight	b. Pulls every mass toward every other mass
3. friction	c. For every action, there is an equal and opposite reaction
4. wear	d. Force that results from the relative motion between objects
5. Newton's third law of motion	e. The grinding away of moving parts that are in contact with each other
	f. The force created by gravity

Set Four

1. viscous friction	a. Friction caused by the movement of two surfaces against each other
2. sliding friction	b. Friction caused by one object rolling over another
3. rolling friction	c. Friction caused by the movement of air around moving objects
4. air friction	d. Friction caused by the movement of an object through a liquid
5. momentum	e. The mass of an object multiplied by its acceleration
	f. The mass of an object multiplied by its velocity

Concept review

1. Define the term *force*, and give some examples of forces.
2. Give an example of Newton's first law in everyday life.
3. Which has more inertia, a 1-kilogram ball or a 10-kilogram ball?
4. An object with more inertia is both harder to __________ and to __________.
5. Give an example of Newton's second law in everyday life.
6. Explain how the unit of 1 newton is defined.
7. Any object with mass exerts a force on any other object with mass. This force is called __________.
8. On the surface of the Earth, the force of gravity acting on one kilogram is:
    a. 9.8 pounds
    b. 3.8 newtons
    c. 9.8 newtons
    d. varies according to your mass
9. What is the difference between the *mass* of an object and the *weight* of an object?
10. According to the law of universal gravitation, what two factors are important in determining the force of gravity between two objects?
11. Name a unit for measuring:
    a. force
    b. mass
    c. weight
12. The net force acting on a car rolling down a ramp is the addition of three forces. One of the forces is the ramp pushing up to support the car. Name the other two forces acting on the car.
    a. Name the two forces on the car.
    b. Which of these two forces helps the motion of the car?
    c. Which of these two forces opposes the motion of the car?
13. Give an example of Newton's third law acting in everyday life.
14. Fill in the blanks in the following statements:
    a. Forces always occur in __________.
    b. Each force in an action-reaction pair of forces is equal in __________.
    c. Each force in an action-reaction pair of forces is opposite in __________.
15. The momentum of an object depends on what two factors?
16. Give an example of the law of conservation of momentum from everyday life.

Problems

1. A company uses a ramp to slide boxes of parts to a shipping area. Each box has a mass of 10 kilograms. When sliding down the ramp, the boxes accelerate at a rate of 0.1 m/sec^2. What is the force acting on each box? For this problem, ignore the effects of friction acting on each box.
2. You have an object that has a mass of 4 kilograms.
   a. What is its weight in newtons?
   b. What is its weight in pounds?
3. You drop an object from a second-floor window.
   a. Describe the speed of the object after 1 second.
   b. Describe the speed of the object after 2 seconds.
4. A heavy block of lead is placed on a table. The block of lead has a weight, or a force, of 500 newtons. Explain why it doesn't fall through the table.
5. From the text you learned that a 110-pound person would weigh 20 pounds (89 N) on Jupiter's moon Io. The mass of Jupiter is 1.9 x 10^{27} kg and its diameter is 142, 984 km. Would this same person weigh more on Io or on Jupiter? Explain your answer. What would this person weigh on Jupiter?
6. In the supermarket you return a cart to the cart area. You stand still and push the cart towards the other carts. You've just learned that the cart pushes back on you too, according to Newton's third law.
   a. Explain why the cart moves and you do not.
   Hint: Consider the cart and yourself separately. Also consider all the forces acting on you and on the cart.
   b. Is the cart in equilibrium once you let go of the handle? Explain.
7. What is the momentum of a 0.5-kilogram object traveling at

Applying your knowledge

1. You learned in this chapter that an object in motion will stay in motion unless acted on by a force. However, in everyday life, friction always slows things down. Research ways that people reduce friction in machines, such as by using ball bearings.
2. Joints like knees and elbows are designed to move freely. Find out how friction is reduced in a joint.
3. Research the effects of weightlessness on people and what astronauts do to counter those effects.
4. When an ice skater is on ice, a small amount of melting occurs under the blades of the skates. How does this help the skater glide? Your answer should discuss two different types of friction.
5. A situation involving conservation of momentum: A fish swims forward and pushes a mass of water backward with its tail.
   a. Identify m_1 and v_1, and m_2 and v_2 for this situation.
   b. How might the fish's tail and body size affect how fast it swims?