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Chapter 1

Describing the Physical Universe

On June 21, 2004, SpaceShipOne became the first private aircraft to leave Earth's atmosphere and enter space. What is the future of this technology? Private companies are hoping to sell tickets to adventurous people who want to take a trip beyond Earth's atmosphere. Our study of physics can help us understand how such a trip is possible.

Many people, when asked the question “What is physics?” respond with “Oh, physics is all about complicated math equations and confusing laws to memorize.” This response may describe the physics studied in some classrooms, but this is not the physics of the world around us, and this is definitely not the physics that you will study in this course! In this chapter you will be introduced to what studying physics is REALLY all about, and you will begin your physics journey by studying motion and speed.

Key Questions

- ✓ Does air have mass and take up space? What about light?
- ✓ How can an accident or mistake lead to a scientific discovery?
- ✓ What is the fastest speed in the universe?

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1.1 What Is Physics?

What is physics and why study it? Many students believe physics is a complicated set of rules, equations to memorize, and confusing laws. Although this is sometimes the way physics is taught, it is not a fair description of the science. In fact, physics is about finding the simplest and least complicated explanation for things. It is about observing how things work and finding the connections between *cause* and *effect* that explain why things happen.

Vocabulary

natural law, experiment, analysis, mass, system, variable, macroscopic, scientific method, independent variable, dependent variable, hypothesis, control variable, experimental variable, model

Objectives

- ✓ Explain what makes up the universe.
- ✓ Describe how the scientific method is used.
- ✓ Explain the effects of energy on a system.

Three aspects of physics

1. Describing the organization of the universe

The *universe* is defined as everything that exists. Everything in the universe is believed to be either matter or energy (Figure 1.1). *Matter* is all of the "stuff" in the universe that has mass. You are made of matter, and so is a rock and so is the air around you. *Energy* is a measure of the ability to make things change. Energy flows any time something gets hotter, colder, faster, slower, or changes in any other observable way.

2. Understanding natural laws

A **natural law** is a rule that tells you how (or why) something happens the particular way it does. We believe that all events in nature obey natural laws that do not change. For example, one natural law tells you a ball rolling down a ramp of a certain height will have a certain speed at the bottom. If the same ball rolls down the same ramp again, it will have the same speed again. Physics is concerned with understanding the natural laws that relate matter and energy.

3. Deducing and applying natural laws

A third important part of physics is the process of figuring out the natural laws. The natural laws are human explanations based on human experience. A ball will still roll down a ramp regardless of whether you know why or how. It is up to us to figure out how and why. This part of physics often uses experiments and analysis. An **experiment** is a situation you carefully set up to see what happens under controlled conditions. **Analysis** is the detailed thinking you do to interpret and understand what you observe. Both of these activities lead to the development and refinement of natural laws. You will learn many natural laws in this course. We don't yet know all the natural laws. There is a lot left for us to learn.

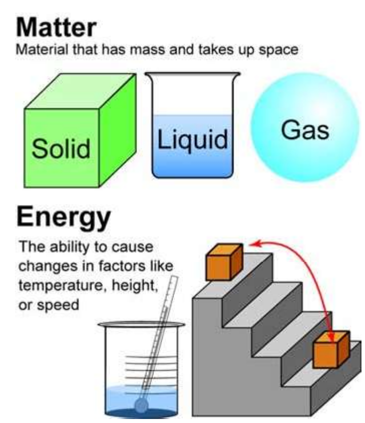

Figure 1.1: *The universe contains matter and energy.*

Matter and energy

Matter and mass *Matter* is defined as anything that has mass and takes up space. **Mass** is the measure of the amount of matter that makes up an object. A car has more mass than a bicycle. But why does the car have more mass? The answer is that the car contains more matter. Steel, plastic, and rubber are different forms of matter and the car has a lot more than the bicycle.

Is air matter? How can you tell if something takes up space? Does the air around you take up space? Think about how you could test whether or not air takes up space. An "empty" glass contains air. Imagine a cylinder you could push into the empty glass. If the cylinder formed a seal so that the air inside couldn't escape, you wouldn't be able to push the cylinder all the way to the bottom. Why? Because air is matter and takes up space (Figure 1.2). You don't always notice the mass of air because it is spread thinly, but the mass of air in an average classroom is about equal to the mass of one student.

Is light matter? Just as an empty glass is actually filled with air, it also fills with light in front of a window. Is light a kind of matter? Because light does not take up space and has no mass, it does not fit the definition of matter. Imagine pumping all of the air out of that empty glass while the cylinder is pulled back. Even if the glass were near a light source and filled with light, you could push the cylinder all the way down because light does not take up space (Figure 1.3). The glass also has the same mass in a dark room and a room full of sunlight. Later in the course we will see that light is a pure form of *energy.*

Energy Imagine dropping a stone. In your hand, the stone is described by its mass and height off the ground. Once it is falling, the stone speeds up and its height changes. If you investigate, you learn that you cannot get *any* speed by dropping the stone. You cannot make the stone go 100 miles per hour by dropping it only one meter from your hand to the floor. But why not? What limits how much speed the stone can have? The answer is energy. Energy is how we measure the amount of change that is possible. Changing the speed of the stone from zero to 100 mph takes a certain amount of energy. Lifting the stone up (changing its height) also takes energy. Change takes energy and the amount of change you can have is limited by the amount of energy available.

Figure 1.2: *Air is matter because it has mass and takes up space.*

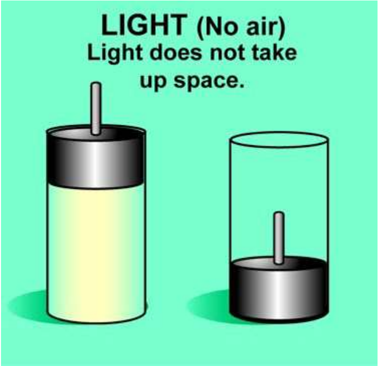

Figure 1.3: *Light is not matter because it has no mass and does not take up space.*

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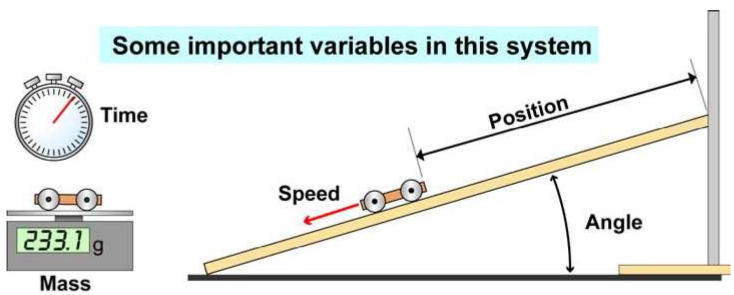
Systems and variables

Defining a system The universe is huge and complex. The only way to make sense of it is to think about only a small part at a time. If you want to understand a car rolling down a ramp, you don't need to confuse yourself with the sun, or the Milky Way galaxy or even the room next door. When you want to understand something, you focus your attention on a small group called a **system**. A system is a group of objects, effects, and variables that are related. You choose the system to include the things you wish to investigate and exclude the things you think are not relevant.

Variables A **variable** is a factor that affects the behavior of the system. When you are trying to find out how a system works, you look for relationships between the important variables of the system. For example, imagine you are doing an experiment with a car rolling down a ramp. The car and ramp are the system. The car's speed is one important variable. Time, position, and mass are other variables.



What to include The ideal choice of a system includes all the objects, effects, and variables that affect what you are trying to understand (Figure 1.4). To understand the motion of a car on a ramp you might include the car, the ramp, and the mass, angle, and speed. The fewer the variables, the easier it is to find important relationships. You can include more variables, like friction from the wheels, after you understand how the more important variables fit together (Figure 1.5).

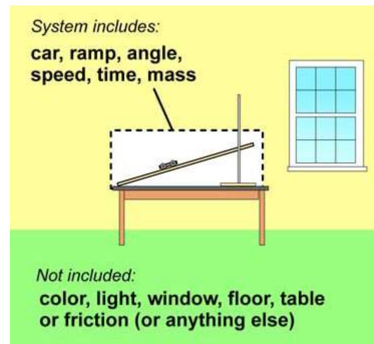


Figure 1.4: *Choose variables that are important to your investigation.*

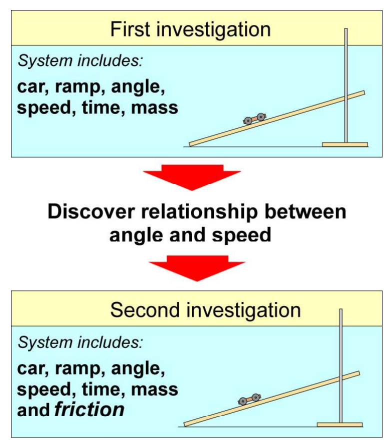


Figure 1.5: *You may change the system later to include new objects, effects, or variables. You may also remove things if they are not necessary to explain what you observe.*

The scale of a system

An example of different scales

A system almost always shows different and important behavior at different *scales*. Figure 1.6 shows a road at three different scales. To calculate driving time between cities, you use the largest scale. To design the road to be wide enough to fit a car, you use the middle scale. To understand how water drains through cracks in the road, you need to look on the smallest scale. In a similar way the universe can be understood differently on different scales. It depends on what you are trying to understand.

The macroscopic scale

Observations are on the **macroscopic** scale when they are large enough for us to see or directly measure. The mass of a car and the temperature of a pot of water are macroscopic variables. Virtually all the things you measure in experiments in this course are macroscopic. Many of the natural laws you learn will relate macroscopic variables, such as speed, temperature, and mass.

Variables that can be observed and measured directly are on the macroscopic scale.

The scale of atoms

Temperature is related to energy but it is not possible to understand *how* on the macroscopic scale. To understand temperature we must investigate the composition of matter. To understand the connection between temperature and energy we must look on the scale of atoms and molecules.

Atoms

Almost all of the matter you experience is made of atoms. Atoms are tiny particles, far too small to see directly. However, many of the macroscopic properties of matter you can observe depend on the behavior of atoms. Physics shows us that to understand certain aspects of the macroscopic world (such as temperature) we need to understand the behavior of atoms. We will use the term "*atomic*" to mean "*on the scale of atoms.*"

Variables that are on the scale of atoms and are far too small to be observed are on the atomic scale.

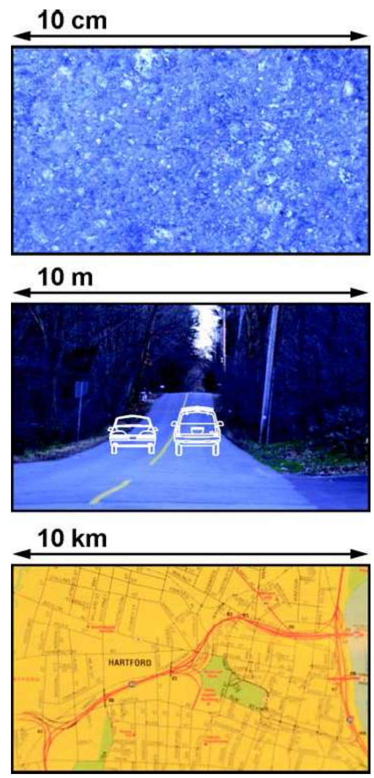


Figure 1.6: *Three different scales for looking at a road.*

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Investigating systems

Experiments An experiment is a situation set up to investigate the relationship between variables in a system. The process used to conduct an experiment is called the **scientific method** (Figure 1.7). Experiments usually have a question associated with them. An example would be: "How does the steepness of a ramp affect the speed of a ball at the bottom?"

Types of variables To answer the question you do an experiment to measure the cause-and-effect relationship between the ramp's angle and the speed of the ball. The variable that is the cause of change in the system is called the **independent variable**. This is the variable that you change in an experiment. The ramp's angle is the independent variable in this example. The variable that shows (or may show) the effect of those changes is called the **dependent variable**. The speed of the ball is the dependent variable.

Making a hypothesis A **hypothesis** is an educated guess that predicts the relationship between the independent and dependent variables in an experiment. Coming up with a good hypothesis means you must have some experience with the system you are investigating. However, don't worry if you are unsure about what will happen in an experiment. Scientists often make hypotheses that they end up proving to be incorrect. The first hypothesis is just a *starting point* for developing a correct understanding.

Designing experiments In an ideal experiment you change only one variable at a time. You keep ALL of the other variables the same. This way you can be certain any change you see in the system must be associated with the one variable you changed. A variable that is kept the same is called a **control variable**, and the variable that is changed is called the **experimental variable**. In a ball and ramp experiment, the ramp angle, the ball's mass, and the starting point are all important variables that affect the speed. In a well-designed experiment you choose only one variable at a time.

How does the angle of a ramp affect the speed of the ball?

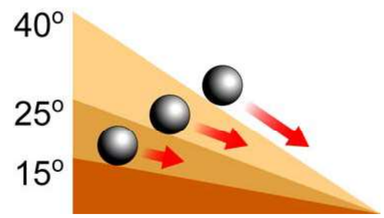


Figure 1.7: *How does the angle of the ramp affect the ball's speed?*

The scientific method

1. Ask a question.
2. Formulate a hypothesis.
3. Design a procedure to test the hypothesis.
4. Conduct the experiment and collect the data.
5. Analyze the data.
6. Use the data to make a conclusion.
7. If necessary, refine the question and go through each step again.

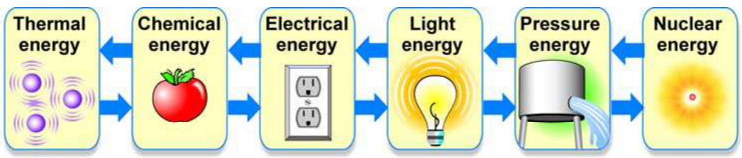
Figure 1.8: *Follow these steps when conducting an experiment.*

Energy and systems

Energy

Energy is an important concept that is difficult to define. Energy is a measure of a system's ability to change or create change in other systems. A car at the top of a ramp is able to move because it has energy due to its height on the ramp. The car's increase in speed as it moves is a change in the system that could not occur without energy.

Energy can appear in many forms, such as heat, motion, height, pressure, electricity, and chemical bonds between atoms. The key to understanding how systems change is to trace the movement of energy between objects and also between the various forms of energy.



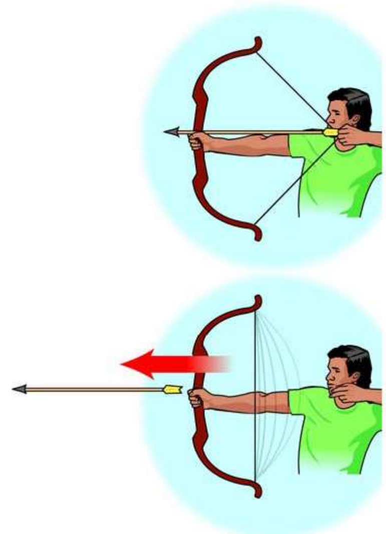


Figure 1.9: *A stretched bowstring on a bent bow has energy, so it is able to create change in itself and in the arrow.*

The stability of systems

Systems in nature tend to go from higher energy to lower energy. A system at higher energy is often unstable, while a system at lower energy is stable. The car is unstable at the top of the ramp where its energy is greatest. It will naturally move to a more stable position at the bottom of the ramp.

Creating change

The stretched bowstring on a bow is another example of a system that has energy (Figure 1.9). Released, the string springs back to its unstretched, stable position. The bow uses its energy to change its own shape. It also can create change in the arrow. While the bow and bowstring move from high to low energy, the arrow moves from low to high energy. The energy originally in the bowstring is used to change the speed of the arrow.

Macroscopic and atomic changes

Energy can create macroscopic and microscopic changes to systems. The changes in the bow and arrow are macroscopic because they can be directly observed. If you shoot many arrows one after another, the bowstring gets warm from the heat of friction. The warmth comes from energy flowing between atoms on the atomic scale.

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Models

An example system Consider the following system. A stretched rubber band is used to launch a car along a track that is straight for a distance and then turns uphill. If the rubber band is stretched more, the car has more speed. If the car has more speed it gets higher on the hill. How do we explain the relationship between the height the car reaches and the speed it has at the bottom of the hill?

What is a model? Explanations in physics typically come in the form of models. In physics, a **model** is an explanation that links the variables in a system through cause and effect relationships.

An example model Figure 1.10 shows a model of the car and ramp system. Launching the car gives it energy due to its speed. Climbing the hill takes energy. The car climbs only so high because it only has so much energy. Making the car go faster gives it more energy and that is why it goes higher. This explanation is a model that links the height and speed through the idea of energy. This model is known as the *law of conservation of energy* and is one of the natural laws of physics. The model in Figure 1.10 is *conceptual* because it is not precise enough to predict exactly how much height the car gets for a given speed. In chapter 3 you will encounter a more detailed version of the law of conservation of energy.

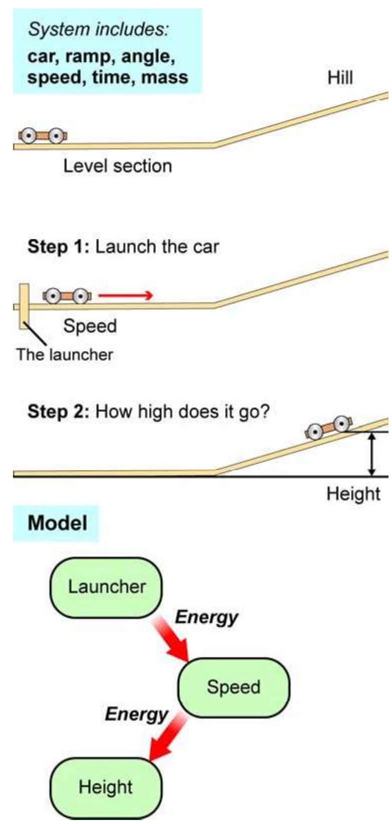

Figure 1.10: *A conceptual model of the car and ramp system.*

1.1 Section Review

1. What are the main activities involved in studying physics?
2. Which has more mass: a dollar bill or a quarter? Why?
3. Imagine that you are doing an experiment to find out if more expensive batteries will run your radio for a longer amount of time than cheaper batteries will. List a question, a hypothesis, the independent variable, the dependent variable, and the control variables for this experiment. Then write a procedure that would allow you to test your hypothesis.
4. What is needed to create change in a system?

1.2 Distance and Time

To do science you need a precise way to describe the natural world. In physics, many things are described with measurements. For example, two meters is a measurement of length that is a little more than the height of an average person. Measurements such as length, mass, speed, and temperature are important in science because they are a language which allows us to communicate information so that everyone understands exactly what we mean. In this section you will learn about measuring distance and time.

Vocabulary

distance, length, English system, metric system, time interval, second

Objectives

- ✓ Express distance measurements in both English and metric units.
- ✓ Measure time intervals in mixed units.
- ✓ Distinguish between independent and dependent variables.
- ✓ Construct graphs.
- ✓ Convert between different units of time.

Measuring distance

Measurements A *measurement* is a precise value that tells how much. How much *what*, you ask? That depends on what you are measuring. The important concept in measurement is that it communicates the amount in a way that can be understood by others. For example, two meters is a measurement because it has a *quantity,* 2, and gives a *unit,* meters.

Units All measurements must have units. Without a unit, a measurement cannot be understood. For example, if you asked someone to walk 10, she would not know how far to go: 10 feet, 10 meters, 10 miles, and 10 kilometers are all 10, but the units are different and therefore the distances are also different. Units allow people to communicate amounts. For communication to be successful, physics uses a set of units that have been agreed upon around the world.

What is distance? **Distance** is the amount of space between two points (Figure 1.11). You can also think of distance as how far apart two objects are. You probably have a good understanding of distance from everyday experiences, like the distance from one house to another, or the distance between California and Massachusetts. The concept of distance in physics is the same, but the actual distances may be much larger and much smaller than anything you normally refer to as a distance.

Distance is measured in units of length Distance is measured in units of **length**. Some of the commonly used units of length include inches, miles, centimeters, kilometers, and meters. It is important to always specify which length unit you are using for a measurement.

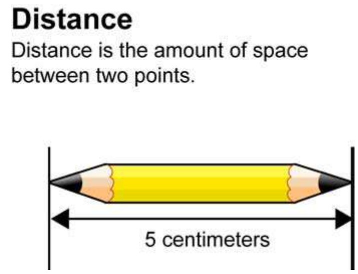

Figure 1.11: *The definition of distance.*

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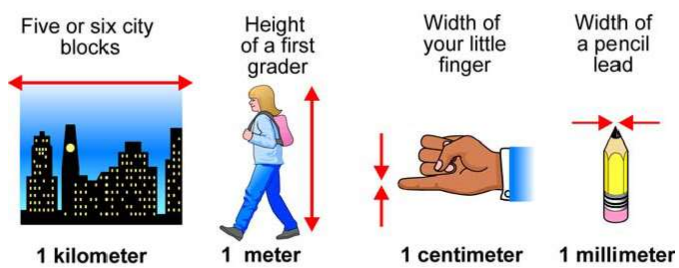
The two common systems for measuring distance

Systems of units There are two common systems of standardized (or agreed upon) units that are used for measuring distances, the **English system** and the International System of Units, commonly called the **metric system** in the United States. The English system uses inches (in.), feet (ft), yards (yd), and miles (mi). The metric system uses millimeters (mm), centimeters (cm), meters (m), and kilometers (km). The names of units in the metric system use prefixes that are based on powers of ten (Figure 1.12).

Scientists use metric units Almost all fields of science use metric units because they are 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.



You will use both systems of measurement To solve problems by applying science in the real world, you will need to know both sets of units, English and metric. For example, a doctor will measure your height and weight in English units. The same doctor will prescribe medicine in milliliters (mL) and grams (g), which are metric units. Plywood is sold in 4-by-8-foot sheets — but the thickness of many types of plywood is given in millimeters. Some of the bolts on an automobile have English dimensions, such as $^1/_2$ inch. Others have metric dimensions, such as 13 millimeters. Because both units are used, it is a good idea to know both metric and English units.

Prefix	Meaning	
giga (G)	1 billion	1,000,000,000
mega (M)	1 million	1,000,000
kilo (k)	1 thousand	1,000
centi (c)	1 one-hundredth	0.01
milli (m)	1 one-thousandth	0.001
micro (μ)	1 one-millionth	0.000001

Figure 1.12: *Metric prefixes*

Measuring time

Two ways to think about time

In physics, just as in your everyday life, there are two ways to think about time (Figure 1.13). One way is to identify a particular moment in time. The other way is to describe a quantity of time. The single word, "time," means two different things.

What time is it?

If you ask, "What time is it?" you usually want to identify a moment in time relative to the rest of the universe and everyone in it. To answer this question, you would look at a clock or your watch at one particular moment. For example, 3 P.M. Eastern Time on April 21, 2004, tells the time at a certain place on Earth.

How much time?

If you ask, "How much time?" (did something take to occur, for instance), you are looking for a quantity of time. To answer, you need to measure an interval of time that has both a beginning and an end. For example, you might measure how much time has passed between the start of a race and when the first runner crosses the finish line. A quantity of time is often called a **time interval**. Whenever you see the word *time* in physics, it usually (but not always) means a time interval. Time intervals in physics are almost always in seconds, and are represented by the lower case letter *t*.

Units for measuring time

You are probably familiar with the common units for measuring time: seconds, hours, minutes, days, and years. But you may not know how they relate to each other. Table 1.1 gives some useful relationships between units of time. In everyday life, time is often expressed in mixed units rather than with a single unit (Figure 1.14)

Table 1.1: ***Time relationships***

Time unit	. . . in seconds . . .	. . . and in 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 1.13: *There are two different ways to understand time.*

Figure 1.14: *A microwave oven can understand time in either mixed units (minutes and seconds) or in a single unit (seconds). Both 1:30 and 0:90 will result in the same cooking time.*

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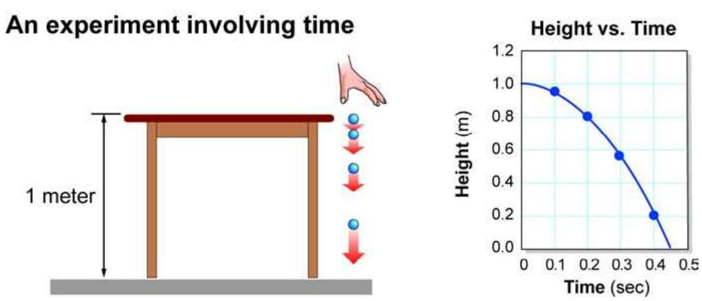
Time scales in physics

One second The **second** (sec) is the basic unit of time in both the English and metric systems. One second is about the time it takes to say "thousand." There are 60 seconds in a minute and 3,600 seconds in an hour. The second was originally defined in terms of one day: There are 86,400 seconds in an average day of 24 hours (24 hr × 3,600 $^{sec}/_{hr}$).

Time in physics Things in the universe happen over a huge range of time intervals. Figure 1.15 gives a few examples of time scales that are considered in physics and in other sciences. The average life span of a human being is 2.2 billion seconds. The time it takes a mosquito to beat its wings once is 0.0005 second. The time it takes light to get from this page to your eyes is 0.000000002 seconds.

Time in experiments In many experiments, you will observe how things change with time. For example, when you drop a ball, it falls to the ground. You can make a graph of the height of the ball versus the time since it was released. The *time* is the time interval measured from when the ball was released. This graph shows how the height of the ball changes with time. The graph shows that it takes the ball about 0.45 seconds to fall a distance of 1 meter. Many of the experiments you will do involve measuring times between 0.0001 seconds and a few seconds. When making graphs of results from experiments, the time almost always goes on the horizontal (or x) axis.



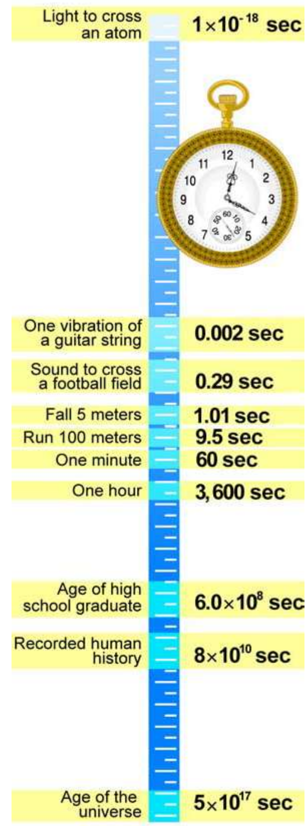


Figure 1.15: *Some time intervals in physics.*

Unit conversions

Measuring time When doing an experiment or solving a physics problem, you often need to convert from one unit to another. This happens a lot with time. If you used a stopwatch to measure the time it took a runner to finish a marathon, the stopwatch would display the time in hours, minutes, and seconds (Figure 1.16). The measurements of hours, minutes, and seconds are usually separated with colons. Accurate timers, such as those used for races, usually also have a decimal that shows fractions of a second.

Converting units Hours, minute, and seconds are *mixed units*, but people are used to hearing time this way. However, if you want to do any calculations with the race time, such as figuring out the runner's average speed, you must convert the time into a single unit. When converting to seconds the first thing you do is convert each quantity of hours and minutes to seconds. Then you add up all the seconds to get the total. Seconds are often used as the unit of time for experiments.

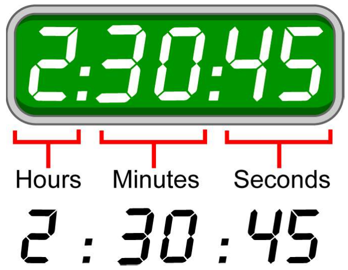


Figure 1.16: *Digital timers have displays that show time in mixed units.*

Converting time units

Convert the time 2:30:45 into seconds.

1. Looking for: You are asked for the time in seconds.

2. Given: You are given the time in mixed units.

3. Relationships: There are 60 seconds in one minute and 3,600 seconds in one hour.

4. Solution:

$2\text{ hr} \times 3600\text{ sec/hr} = 7200\text{ sec} \qquad 30\text{ min} \times 60\text{ sec/min} = 1800\text{ sec}$

Add all of the seconds: 7200 sec + 1800 sec + 45 sec = 9045 seconds

Your turn...

a. Convert 3:45:10 into seconds. **Answer:** 13,510 seconds

b. One year equals 365.25 days. How many seconds are in 5 years? **Answer:** 157,790,000 seconds

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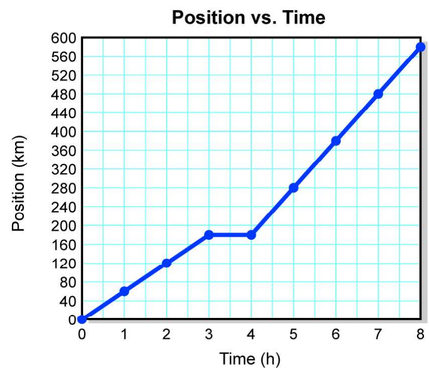
Distance and time graphs

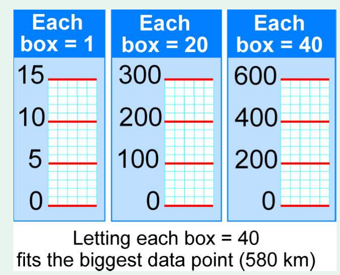


Graphs A graph is a picture that shows how two variables are related. Graphs are easier to read than tables of numbers, so they are often used to display data collected during an experiment. The graph to the right shows distance and time measurements taken during a long trip in a car.

The independent variable By convention, or common agreement, graphs are drawn with the *independent variable* on the horizontal or *x*-axis. In the graph above, time is the independent variable. We say it is independent because we are free to decide the times when we take measurements. The graph shows that measurements were taken every hour.

The dependent variable The *dependent variable* goes on the vertical or *y*-axis. Distance is the dependent variable because the distance depends on the time. If a time interval other than one hour had been chosen, the distance measurements would be different.

How to make a graph



1. Decide which variable to put on the *x*-axis and which to put on the *y*-axis.
2. Make a scale for each axis by counting boxes to fit your largest value for each axis. Count by multiples of 1, 2, 5, 10, or a larger number if needed. Write the numbers on each axis at evenly spaced intervals and label each axis with its corresponding variable and unit.
3. Plot each point by finding the *x*-value and tracing the graph upward until you get to the right *y*-value. Draw a dot for each point.
4. Draw a smooth curve that shows the pattern of the points.
5. Create a title for your graph.

1.2 Section Review

1. List two common systems of units and give examples of distance measurements for each.
2. Explain the two meanings in physics of the word “time.”
3. If you wait in a long line for 1 hour and 10 minutes, how many seconds have you waited?
4. List the steps you should follow when making a graph.

1.3 Speed

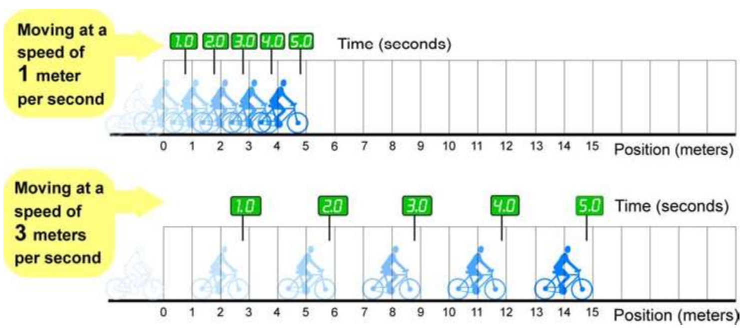
Nothing in the universe stays still. A book on a table appears to be sitting still, but Earth is moving in its orbit around the sun at a speed of 66,000 miles per hour. You and the book move with Earth. Speed is an important concept in physics and saying that something is "fast" is not descriptive enough to accurately convey its speed. A race car may be fast compared with other cars, but it is slow compared with a jet airplane. In this section, you will learn a precise definition of speed.

Speed

An example of speed

Consider a bicycle moving along the road. The diagrams below show the positions of two bicycles at different times. To understand the concept of speed, think about the following two questions.

- How many meters does the bicycle move in each second?
- Does the bicycle move the same number of meters every second?



The precise meaning of speed

The **speed** of a bicycle is the distance it travels divided by the time it takes. At 1 m/sec, a bicycle travels one meter each second. At 3 m/sec, it travels three meters each second. Both bicycles in the diagram are moving at **constant speed**. Constant speed means the same distance is traveled every second.

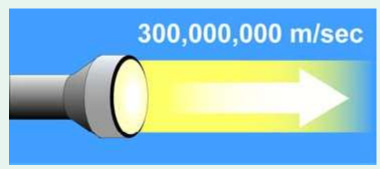
Vocabulary

speed, constant speed

Objectives

- ✓ Define speed.
- ✓ Express an object's speed using various units.
- ✓ Calculate speed, distance, or time given two of the three quantities.
- ✓ List the steps for solving physics problems.

The speed limit of the universe



The fastest speed in the universe is the speed of light. Light moves at 300 million meters per second (3×10^8 m/sec). If you could make light travel in a circle, it would go around the Earth $7\ ^1/_2$ times in one second! We believe the speed of light is the ultimate speed limit in the universe.

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Calculating speed

Speed is distance divided by time

Speed is a measure of the *distance* traveled in a given amount of *time*. Therefore, to calculate the speed of an object, you need to know two things:

- The distance traveled by the object.
- The time it took to travel the distance.

Average speed

Speed is calculated by dividing the distance traveled by the time taken. For example, if you drive 150 kilometers in 1.5 hours (Figure 1.17), then the average speed of the car is 150 kilometers divided by 1.5 hours, which is equal to 100 kilometers per hour.

What does "per" mean?

The word "per" means "for every" or "for each." The speed of 100 kilometers per hour is short for saying 100 kilometers *for each* hour. You can also think of "per" as meaning "divided by." The quantity before the word per is divided by the quantity after it. For example, 150 kilometers divided by 1.5 hours (or per every 1.5 hours) equals 100 miles per hour.

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. In the metric system, distance is measured in centimeters, meters, or kilometers. If distance is in kilometers and time in hours, then speed is expressed in kilometers per hour (km/h). Other metric units for speed are centimeters per second (cm/sec) and meters per second (m/sec). Speed is also commonly expressed in miles per hour (mph). Table 1.2 shows different units commonly used for speed.

Figure 1.17: *A driving trip with an average speed of 100 km/h.*

Table 1.2: *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

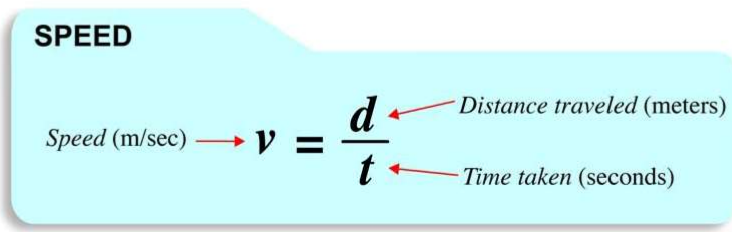
Relationships between distance, speed, and time

Mixing up distance, speed, and time

A common type of question in physics is: "How far do you go if you drive for two hours at a speed of 100 km/h?" You know how to get speed from time and distance. How do you get distance from speed and time? The answer is the reason mathematics is the language of physics. A mathematical description of speed in terms of distance and time can easily be rearranged while preserving the original connections between variables.

Calculating speed

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 a mathematically precise definition of speed.



There are three ways to arrange the variables that relate distance, time, and speed. You should be able to work out how to get any one of the three variables if you know the other two (Figure 1.18).

Using formulas

Remember that the words or letters stand for the values that the variables 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 do not know yet what the number will be. 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.

Why *v* is used to represent speed

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

It is not important for this chapter, but there is a technical difference between speed and velocity. Speed is a single measurement that tells how fast you are going, such as 80 kilometers per hour. Velocity means you know both your speed and the *direction* you are going. If you tell someone you are going 80 km/h directly south, you are telling them your velocity. If you say only that you are going 60 mph, you are telling them your speed.

Forms of the speed equation

Equation	gives you	if you know
$v = d \div t$	speed	distance and time
$d = vt$	distance	speed and time
$t = d \div v$	time	distance and speed

Figure 1.18: *Different forms of the speed equation.*

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How to solve physics problems

Physics problems

You will be asked to analyze and solve many problems in this course. In fact, learning physics will make you a better problem-solver. This skill is important in all careers. For example, financial analysts are expected to look at information about businesses and determine which companies are succeeding. Doctors collect information about patients and must figure out what is causing pain or an illness. Mechanics gather information about a car and have to figure out what is causing a malfunction and how to fix it. All these examples use problem-solving skills.

A four-step technique

The technique for solving problems has four steps. Follow these steps and you will be able to see a way to the answer most of the time and will at least make progress toward the answer almost every time. Figure 1.19 illustrates these steps, and the table below explains them.

Table 1.3: ***Steps to solving physics problems***

Step	What to do
1	Identify clearly what the problem is asking for. If you can, figure out exactly what variables or quantities need to be in the answer.
2	Identify the information you are given. Sometimes this includes numbers or values. Other times it includes descriptive information you must interpret. Look for words like *constant* or *at rest*. In a physics problem, saying something is constant means it does not change. The words "at rest" in physics mean the speed is zero. You may need conversion factors to change units.
3	Identify any relationships that involve the information you are asked to find and the information you are given. For example, suppose you are given a speed and time and asked to find a distance. The relationship $v = d \div t$ relates what you are asked for to what you are given.
4	Combine the relationships with what you know to find what you are asked for. Once you complete steps 1-3, you will be able to see how to solve most problems. If not, start working with the relationships you have and see where they lead.

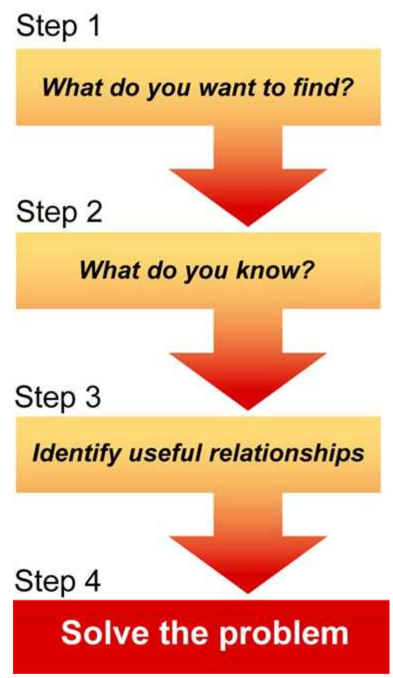


Figure 1.19: *Follow these steps and you will be able to see a way to the answer most of the time.*

Example problems

Solved example problems are provided

Throughout this book you will find example problems that have been solved for you. Following each solved example, there are two practice problems. The answers to the practice problems are provided so that you can check your work while practicing your problem-solving skills. Always remember to write out the steps when you are solving problems on your own. If you make a mistake, you will be able to look at your work and determine where you went wrong. Here is the format for example problems:

Calculating speed

An airplane flies 450 meters in 3 seconds. What is its speed in meters per second?

1. Looking for: You are asked for the speed in meters/second.

2. Given: You are given the distance in meters and the time in seconds.

3. Relationships: Use this version of the speed equation:
$v = d \div t$

4. Solution: $v = 450\text{ m} \div 3\text{ sec} = 150\text{ m/sec}$

Your turn...

a. A snake moves 20 meters in 5 seconds. What is the speed of the snake in meters per second? **Answer:** 4 m/sec
b. A train is moving at a speed of 50 kilometers per hour. How many hours will it take the train to travel 600 kilometers? **Answer:** 12 hours

1.3 Section Review

1. List three commonly used units for speed.
2. State the steps used to solve physics problems.
3. Calculate the average speed (in km/h) of a car that drives 140 kilometers in two hours.
4. How long (in seconds) will it take you to swim 100 meters if you swim at 1.25 m/sec?
5. How far (in meters) will a dog travel if he runs for 1 minute at a constant speed of 5 m/sec?

Scientific Method and Serendipity

Have you ever made a mistake that resulted in something very positive happening? Usually, we try to avoid mistakes. However, sometimes making a mistake — like taking a wrong turn — leads to a place you would not have seen if you had taken a right turn!

Serendipity is a term used to describe an event that happens by accident that results in an unexpected discovery. For example, an example of an accident might be losing your keys. An example of a serendipitous event would be that looking for your keys causes you to find the watch that you lost a week ago.

Scientists tend to follow the scientific method or some version of it to "do science." However, while searching for answers to nature's mysteries or looking for a cure to a disease, many important discoveries have come about unexpectedly. Sometimes small chance events or observations are just enough for a curious person to begin to unravel an important mystery.

A scientist made famous by serendipity

In 1928, Alexander Fleming, a British bacteriologist, was investigating the influenza virus as well as his own interests in the antibacterial properties of mucus. He was working at St. Mary's Hospital in London.

In one experiment, Fleming smeared mucus in a petri dish that had a culture of a harmful strain of bacteria called staphylococcus. Infections of staphylococcus would spread uncontrollably, and often caused the death of the infected person.

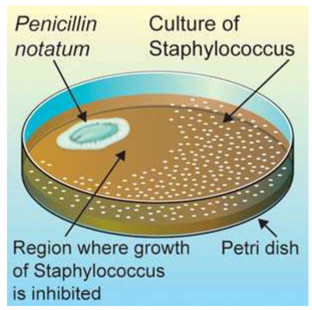

Alexander Fleming in his laboratory

Important observation brings fame and saves lives

At one point in his research, Fleming took a two-week vacation. He happened by chance to leave a petri dish containing staphylococcus on his laboratory bench. What happened next is a good example of serendipity.

When Fleming returned from his vacation he noticed that mold had grown in the plate. The growth was a simple mold that grows as green and white, fuzzy masses on food that is left out too long and exposed to the air. In Fleming's case, a mold spore had entered his lab from another lab in his building. This mold spore had traveled through the air and had landed by chance on the petri dish.

When Fleming examined the plate he saw that the staphylococcus was growing on the plate, but it was not growing near the mold. At this point, Fleming came up with a hypothesis that brought him great fame and helped save the lives of many people. His hypothesis was that a substance produced by the mold could kill harmful bacteria.



A miracle drug

After Fleming made his important hypothesis, that mold has antibiotic properties, he investigated the mold on the petri dish. He grew a pure sample of the mold and learned that it produced a substance that stopped some of the bacteria from growing. Fleming named the substance *penicillin* after the fungus (or mold) growing in the plate, *Penicillin notatum*. You may be familiar with the drug, penicillin. It is a very common and effective antibiotic.

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Although Fleming was not able to purify penicillin enough for use as an antibiotic, he published his findings so others could. In 1945, Fleming received the Nobel Prize along with two other scientists (Ernst B. Chain and Sir Howard Florey) who helped develop penicillin. Ernst B. Chain and Sir Howard Florey were very important in developing the techniques needed to make large quantities of penicillin. During World War II penicillin saved the lives of thousands of injured soldiers and civilians. Not surprisingly, penicillin became known as a "miracle drug."

More discoveries

Alexander Fleming made an important discovery by recognizing the importance of mold in a petri dish. He took advantage of a serendipitous event and opened the door for a life-saving medical breakthrough!

Penzias and Wilson used a giant antenna to record cosmic background radiation which is accepted as evidence of the Big Bang.

It is through education, and a strong sense of curiosity, tempered with a bit of creativity, (and yes, sometimes a little luck) that people can make great scientific discoveries. So, the next time you make a mistake or something does not seem to be working as you think it should, be patient and think about it. You may discover something yourself!

Here are some other serendipitous events that resulted in scientific breakthroughs. Take the time to research these important events and get inspired. Maybe one day you will make an important discovery!

- An apple falling from a tree inspires Isaac Newton to develop the idea of gravity.
- An unusual, accidental photograph revealing the bone structure of a hand leads to the discovery of X rays by Wilhelm Rontgen.
- Two photographs of the same star field, taken a few days apart by astronomy student Clyde Tombaugh, reveal that one of the "stars" moved during that time. The "star" turned out to be the previously undiscovered planet, Pluto.
- After developing safely-stored photographic film, Henri Becquerel discovers a "ghostly" image on new photographic paper. That something turned out to be coming from uranium salts stored in the same drawer. The accidental exposure of the film led to the pioneering work of Marie and Pierre Curie on "radioactivity"—a term coined by Marie Curie.
- Background radio noise coming from space led technicians Arno Penzias and Robert Wilson to the realization that they were actually listening to the *Big Bang*, an event that formed the universe billions of years ago.

Questions:

1. What serendipitous event led to the discovery of penicillin?
2. Lewis Thomas, a medical research scientist and former president of Memorial Sloan-Kettering Cancer Center, once stated "You create the lucky accidents." What do you think he meant by this statement?
3. Why is the scientific method important to follow when confirming an accidental discovery?
4. Do some research to find three additional serendipitous events (besides the ones mentioned in this reading) that led to important scientific discoveries.

Chapter 1 Review

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Understanding Vocabulary

Select the correct term to complete the sentences.

experiment	metric system	seconds
dependent	length	hypothesis
speed	natural laws	constant speed
time interval	English system	atomic
	mass	

Section 1.1

1. It is believed all events in nature obey a set of ____ that do not change.
2. _____ is the measure of the amount of matter in an object.
3. A(n) ____ can help you understand the natural laws that relate matter and energy.
4. When you formulate a(n) ____, you make an educated guess or prediction that can be tested by an experiment.
5. ____ properties are too small to be directly observed.
6. The ____ variable goes with the *y*-axis of a graph.

Section 1.2

7. Distance is measured in units of ____.
8. A quantity of time is known as a(n) ____.
9. The ____ uses length measurements of millimeters, centimeters, meters, and kilometers.
10. In physics, time is usually measured in units of ____.
11. The ____ uses length measurements of inches, feet, yards and miles.

Section 1.3

12. ____ is the distance traveled divided by the time taken.
13. A car traveling the same distance every second is moving at ____.

Reviewing Concepts

Section 1.1

1. List and define the two categories we use to classify everything in the universe.
2. How have physicists come to understand the natural laws?
3. What property does matter have that energy does not?
4. Is light matter? Why or why not?
5. Define the term *system* as it relates to experiments.
6. When designing an experiment, how do you choose the system to investigate?
7. Explain the main difference between the macroscopic scale and the atomic scale.
8. List the steps of the scientific method.
9. A hypothesis is a random guess. True or false? Explain your answer.
10. What do you call variables that are kept the same in an experiment?
11. Why is it important to only change one experimental variable at a time in an experiment?
12. You wish to do an experiment to determine how a ball's radius affects how fast it rolls down a ramp. List the independent and dependent variables in this experiment.
13. Explain the role of energy in a system that is changing.

Section 1.2

14. Why are units important when measuring quantities?
15. State whether you would measure each quantity in kilometers, meters, centimeters, or millimeters.
    a. The length of a car
    b. A single grain of rice
    c. The thickness of your textbook
    d. The distance from your house to school
16. Why is it important to understand both English and metric units?

17. Give an example of a quantity that is often measured in metric units and a quantity that is often measured in English units.
18. What are the two different meanings of the word time?
19. Summarize how to make a graph by listing the steps you would follow.
20. You wish to make a graph of the height of the moon above the horizon every 15 minutes between 9:00 p.m. and 3:00 am during one night.
    a. What is the independent variable?
    b. What is the dependent variable?
    c. On which axis should you graph each variable?

Section 1.3

21. Write the form of the speed equation that you would use in each of the following scenarios. Let v = speed, t = time, and d = distance:
    a. You know distance and speed and want to find the time.
    b. You know time and distance and want to find the speed.
    c. You know speed and time and want to find the distance.
22. What is the speed of an object that is standing still?
23. Your friend rides her bicycle across town at a constant speed. Describe how you could determine her speed.
24. Fill in the missing information in the table showing common units for speed below:

Distance	Time	Speed	Abbreviation
meters	seconds		
			km/h
		centimeters per second	

25. Summarize the four steps for solving physics problems mentioned in the text.

Solving Problems

Section 1.1

1. You want to find out whether the birds near your school prefer thistle seed or sunflower seed. You have a bag of thistle seed, a bag of sunflower seed, and two bird feeders. Describe the experiment you would do to see which type of seed birds prefer. Write down your question, your hypothesis, and the procedure you would follow when doing your experiment.
2. You are doing an experiment to determine whether a dropped ball's mass affects the rate at which it falls. Describe the system you are studying. Write down your question, your hypothesis, and the procedure you would follow when doing your experiment.

Section 1.2

3. Order the following lengths from shortest to longest.
    a. 400 millimeters
    b. 22 kilometers
    c. 170 meters
    d. 3.3 centimeters
4. Convert:
    a. 3 kilometers = ___ meters
    b. 1.5 meters = ___ centimeters
    c. 110 centimeters = ___ meters
    d. 2.5 centimeters = ___ millimeters
5. Convert:
    a. 3 minutes = ___ seconds
    b. 200 seconds = ___ minutes, ___ seconds
    c. 2 days = ___ minutes
    d. 1,000 minutes = ___ hours
6. Determine your age in each of the following units.
    a. months
    b. days
    c. hours
    d. seconds

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7. Luis rides his new bike while his brother records his position and time. They create the data table shown below.

Position (m)	0	105	270	400	540	600
Time (sec)	0	30	60	90	120	150

   a. Which is the dependent variable?
   b. Which is the independent variable?
   c. On which axis should you graph each variable?
   d. Construct a graph of Luis' bike ride.

Section 1.3

8. A bicyclist, traveling at 22 miles per hour, rides a total of 44 miles. How much time (in hours) did it take?
9. A mouse is moving in a straight line at a steady speed of 2 m/sec for 10 seconds. How far (in meters) did the mouse travel?
10. The gray wolf is a threatened animal that is native to the United States. A wildlife biologist tracks a gray wolf that moves 250 meters in 100 seconds. Calculate the wolf's speed in meters per second.
11. It takes Brooke 10 minutes to run 1 mile. What is her speed in miles per minute?
12. If it takes 500 seconds for the light from the sun to reach Earth, what is the distance to the sun in meters? (The speed of light is 300,000,000 meters/second).
13. Use the data from Luis' bike ride in question 7 to answer the following questions:
    a. What was Luis' speed (in meters per second) for the entire ride, from 0 to 150 seconds?
    b. What was Luis' speed (in meters per second) between 60 and 90 seconds?
    c. During which 30 second interval did Luis have the greatest speed? Calculate this speed in meters per second.

Applying Your Knowledge

Section 1.1

1. Read an article in a science magazine and identify how scientists have used the scientific method in their work.
2. Given a ruler, a stopwatch, a tennis ball, a 1-meter long piece of string, a rubber band, tape, and 10 pieces of paper, design an experiment. List a question, a hypothesis, the independent variable, the dependent variable, the control variables, and the procedure for your experiment.

Section 1.2

3. Research the number system and length units of an ancient civilization. What types of things did this ancient group of people need to measure? What were the smallest and largest units of length used? Write a short report on what you learn.
4. Research what the time standard is for the United States. What determines the correct time? Where is this national clock kept and how can you set your clocks at home to it? Write a short report on what you learn.
5. Find an example of a graph used to model a system in your everyday life. You might check magazines, newspapers, or the internet. Copy the graph, describe what it is modeling, and list the dependent variable, independent variable, and measurement scales used.

Section 1.3

6. Research the speeds of many kinds of animals and make a table showing slowest to fastest.
7. Determine your average walking speed. How long would it take you to walk 2,462 miles (3,962 km) from New York to Los Angeles?
8. Prepare a short report on important speeds in your favorite sport.
9. Use the Internet to find the world record times for running races of different lengths (100-meter, 200-meter, mile, marathon, etc.). Calculate and compare speeds for the different races.