CHAPTER 1
What is Physics?

Figure 1.1 Galaxies, such as the Andromeda galaxy pictured here, are immense in size. The small blue spots in this photo are also galaxies. The same physical laws apply to objects as large as galaxies or objects as small as atoms. The laws of physics are, therefore, surprisingly few in number. (NASA, JPL-Caltech, P. Barmby, Harvard-Smithsonian Center for Astrophysics).

Chapter Outline

INTRODUCTION Take a look at the image above of the Andromeda Galaxy (Figure 1.1), which contains billions of stars. This galaxy is the nearest one to our own galaxy (the Milky Way) but is still a staggering 2.5 million light years from Earth. (A light year is a measurement of the distance light travels in a year.) Yet, the primary force that affects the movement of stars within Andromeda is the same force that we contend with here on Earth—namely, gravity.

You may soon realize that physics plays a much larger role in your life than you thought. This section introduces you to the realm of physics, and discusses applications of physics in other disciplines of study. It also describes the methods by which science is done, and how scientists communicate their results to each other.

1.1 Physics: Definitions and Applications

Section Learning Objectives

By the end of this section, you will be able to do the following:

- Describe the definition, aims, and branches of physics
- Describe and distinguish classical physics from modern physics and describe the importance of relativity, quantum mechanics, and relativistic quantum mechanics in modern physics
- Describe how aspects of physics are used in other sciences (e.g., biology, chemistry, geology, etc.) as well as in everyday technology

Section Key Terms

atom	classical physics	modern physics
physics	quantum mechanics	theory of relativity

What Physics Is

Think about all of the technological devices that you use on a regular basis. Computers, wireless internet, smart phones, tablets, global positioning system (GPS), MP3 players, and satellite radio might come to mind. Next, think about the most exciting modern technologies that you have heard about in the news, such as trains that levitate above their tracks, *invisibility cloaks* that bend light around them, and microscopic robots that fight diseased cells in our bodies. All of these groundbreaking advancements rely on the principles of **physics**.

Physics is a branch of science. The word *science* comes from a Latin word that means *having knowledge*, and refers the knowledge of how the physical world operates, based on objective evidence determined through observation and experimentation. A key requirement of any scientific explanation of a natural phenomenon is that it must be testable; one must be able to devise and conduct an experimental investigation that either supports or refutes the explanation. It is important to note that some questions fall outside the realm of science precisely because they deal with phenomena that are not scientifically testable. This need for objective evidence helps define the investigative process scientists follow, which will be described later in this chapter.

Physics is the science aimed at describing the fundamental aspects of our universe. This includes what things are in it, what properties of those things are noticeable, and what processes those things or their properties undergo. In simpler terms, physics attempts to describe the basic mechanisms that make our universe behave the way it does. For example, consider a smart phone (Figure 1.2). Physics describes how electric current interacts with the various circuits inside the device. This knowledge helps engineers select the appropriate materials and circuit layout when building the smart phone. Next, consider a GPS. Physics describes the relationship between the speed of an object, the distance over which it travels, and the time it takes to travel that distance. When you use a GPS device in a vehicle, it utilizes these physics relationships to determine the travel time from one location to another.

Figure 1.2 Physics describes the way that electric charge flows through the circuits of this device. Engineers use their knowledge of physics to construct a smartphone with features that consumers will enjoy, such as a GPS function. GPS uses physics equations to determine the driving time between two locations on a map. (@gletham GIS, Social, Mobile Tech Images)

As our technology evolved over the centuries, physics expanded into many branches. Ancient peoples could only study things that they could see with the naked eye or otherwise experience without the aid of scientific equipment. This included the study of kinematics, which is the study of moving objects. For example, ancient people often studied the apparent motion of objects in the sky, such as the sun, moon, and stars. This is evident in the construction of prehistoric astronomical observatories, such as Stonehenge in England (shown in Figure 1.3).

Figure 1.3 Stonehenge is a monument located in England that was built between 3000 and 1000 B.C. It functions as an ancient astronomical observatory, with certain rocks in the monument aligning with the position of the sun during the summer and winter solstices. Other rocks align with the rising and setting of the moon during certain days of the year. (Citypeek, Wikimedia Commons)

Ancient people also studied statics and dynamics, which focus on how objects start moving, stop moving, and change speed and direction in response to forces that push or pull on the objects. This early interest in kinematics and dynamics allowed humans to invent simple machines, such as the lever, the pulley, the ramp, and the wheel. These simple machines were gradually combined and integrated to produce more complicated machines, such as wagons and cranes. Machines allowed humans to gradually do more work more effectively in less time, allowing them to create larger and more complicated buildings and structures, many of which still exist today from ancient times.

As technology advanced, the branches of physics diversified even more. These include branches such as acoustics, the study of sound, and optics, the study of the light. In 1608, the invention of the telescope by a Germany spectacle maker, Hans Lippershey, led to huge breakthroughs in astronomy—the study of objects or phenomena in space. One year later, in 1609, Galileo Galilei began the first studies of the solar system and the universe using a telescope. During the Renaissance era, Isaac Newton used observations made by Galileo to construct his three laws of motion. These laws were the standard for studying kinematics and dynamics even today.

Another major branch of physics is thermodynamics, which includes the study of thermal energy and the transfer of heat. James Prescott Joule, an English physicist, studied the nature of heat and its relationship to work. Joule's work helped lay the foundation for the first of three laws of thermodynamics that describe how energy in our universe is transferred from one object to another or transformed from one form to another. Studies in thermodynamics were motivated by the need to make engines more efficient, keep people safe from the elements, and preserve food.

The 18th and 19th centuries also saw great strides in the study of electricity and magnetism. Electricity involves the study of electric charges and their movements. Magnetism had long ago been noticed as an attractive force between a magnetized object and a metal like iron, or between the opposite poles (North and South) of two magnetized objects. In 1820, Danish physicist Hans Christian Oersted showed that electric currents create magnetic fields. In 1831, English inventor Michael Faraday showed that moving a wire through a magnetic field could induce an electric current. These studies led to the inventions of the electric motor and electric generator, which revolutionized human life by bringing electricity and magnetism into our machines.

The end of the 19th century saw the discovery of radioactive substances by the French scientists Marie and Pierre Curie. Nuclear physics involves studying the nuclei of **atoms**, the source of nuclear radiation. In the 20th century, the study of nuclear physics eventually led to the ability to split the nucleus of an atom, a process called nuclear fission. This process is the basis for nuclear power plants and nuclear weapons. Also, the field of **quantum mechanics**, which involves the mechanics of atoms and molecules, saw great strides during the 20th century as our understanding of atoms and subatomic particles increased (see below).

Early in the 20th century, Albert Einstein revolutionized several branches of physics, especially relativity. Relativity revolutionized our understanding of motion and the universe in general as described further in this chapter. Now, in the 21st century, physicists continue to study these and many other branches of physics.

By studying the most important topics in physics, you will gain analytical abilities that will enable you to apply physics far beyond the scope of what can be included in a single book. These analytical skills will help you to excel academically, and they will also help you to think critically in any career you choose to pursue.

Physics: Past and Present

The word physics is thought to come from the Greek word *phusis*, meaning nature. The study of nature later came to be called *natural philosophy*. From ancient times through the Renaissance, natural philosophy encompassed many fields, including astronomy, biology, chemistry, mathematics, and medicine. Over the last few centuries, the growth of scientific knowledge has resulted in ever-increasing specialization and branching of natural philosophy into separate fields, with physics retaining the most basic facets. Physics, as it developed from the Renaissance to the end of the 19th century, is called **classical physics**. Revolutionary discoveries starting at the beginning of the 20th century transformed physics from classical physics to **modern physics**.

Classical physics is not an exact description of the universe, but it is an excellent approximation under the following conditions: (1) matter must be moving at speeds less than about 1 percent of the speed of light, (2) the objects dealt with must be large enough to be seen with the naked eye, and (3) only weak gravity, such as that generated by Earth, can be involved. Very small objects, such as atoms and molecules, cannot be adequately explained by classical physics. These three conditions apply to almost all of everyday experience. As a result, most aspects of classical physics should make sense on an intuitive level.

Many laws of classical physics have been modified during the 20th century, resulting in revolutionary changes in technology, society, and our view of the universe. As a result, many aspects of modern physics, which occur outside of the range of our everyday experience, may seem bizarre or unbelievable. So why is most of this textbook devoted to classical physics? There are two main reasons. The first is that knowledge of classical physics is necessary to understand modern physics. The second reason is that classical physics still gives an accurate description of the universe under a wide range of everyday circumstances.

Modern physics includes two revolutionary theories: relativity and quantum mechanics. These theories deal with the very fast and the very small, respectively. The **theory of relativity** was developed by Albert Einstein in 1905. By examining how two observers moving relative to each other would see the same phenomena, Einstein devised radical new ideas about time and space. He came to the startling conclusion that the measured length of an object travelling at high speeds (greater than about one percent of the speed of light) is shorter than the same object measured at rest. Perhaps even more bizarre is the idea the time for the same process to occur is different depending on the motion of the observer. Time passes more slowly for an object travelling at high speeds. A trip to the nearest star system, Alpha Centauri, might take an astronaut 4.5 Earth years if the ship travels near the speed of light. However, because time is slowed at higher speeds, the astronaut would age only 0.5 years during the trip. Einstein's ideas of relativity were accepted after they were confirmed by numerous experiments.

Gravity, the force that holds us to Earth, can also affect time and space. For example, time passes more slowly on Earth's surface than for objects farther from the surface, such as a satellite in orbit. The very accurate clocks on global positioning satellites have to correct for this. They slowly keep getting ahead of clocks at Earth's surface. This is called time dilation, and it occurs because gravity, in essence, slows down time.

Large objects, like Earth, have strong enough gravity to distort space. To visualize this idea, think about a bowling ball placed on a trampoline. The bowling ball depresses or curves the surface of the trampoline. If you rolled a marble across the trampoline, it would follow the surface of the trampoline, roll into the depression caused by the bowling ball, and hit the ball. Similarly, the Earth curves space around it in the shape of a funnel. These curves in space due to the Earth cause objects to be attracted to Earth (i.e., gravity).

Because of the way gravity affects space and time, Einstein stated that gravity affects the space-time continuum, as illustrated in Figure 1.4. This is why time proceeds more slowly at Earth's surface than in orbit. In black holes, whose gravity is hundreds of times that of Earth, time passes so slowly that it would appear to a far-away observer to have stopped!

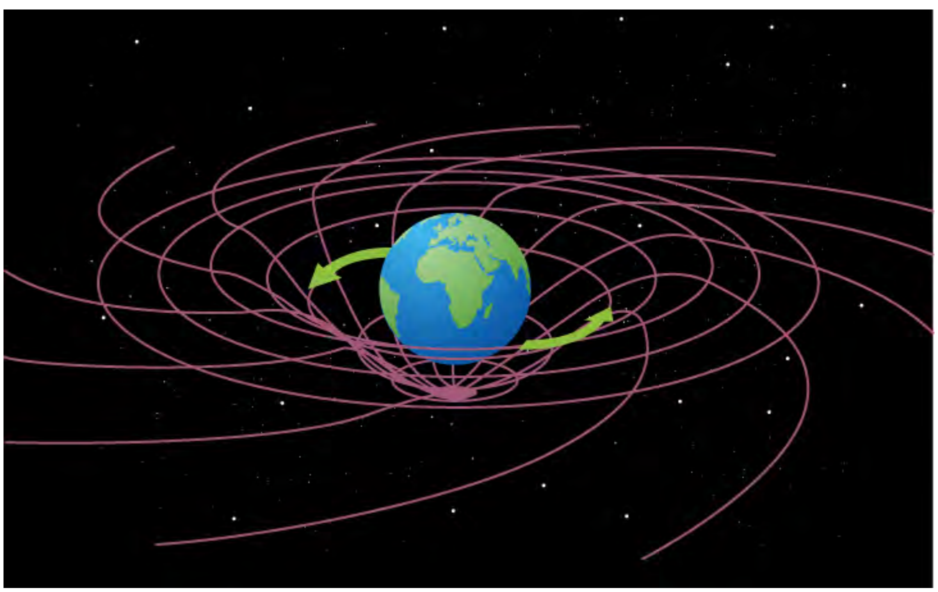


Figure 1.4 Einstein's theory of relativity describes space and time as an interweaved mesh. Large objects, such as a planet, distort space, causing objects to fall in toward the planet due to the action of gravity. Large objects also distort time, causing time to proceed at a slower rate near the surface of Earth compared with the area outside of the distorted region of space-time.

In summary, relativity says that in describing the universe, it is important to realize that time, space and speed are not absolute. Instead, they can appear different to different observers. Einstein's ability to reason out relativity is even more amazing because we cannot see the effects of relativity in our everyday lives.

Quantum mechanics is the second major theory of modern physics. Quantum mechanics deals with the very small, namely, the subatomic particles that make up atoms. Atoms (Figure 1.5) are the smallest units of elements. However, atoms themselves are constructed of even smaller subatomic particles, such as protons, neutrons and electrons. Quantum mechanics strives to describe the properties and behavior of these and other subatomic particles. Often, these particles do not behave in the ways expected by classical physics. One reason for this is that they are small enough to travel at great speeds, near the speed of light.

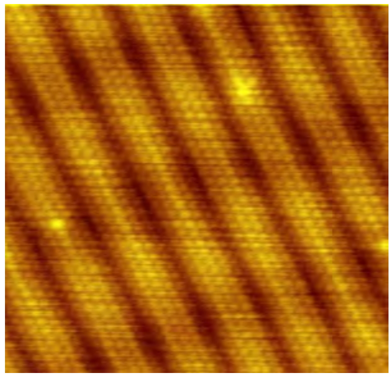


Figure 1.5 Using a scanning tunneling microscope (STM), scientists can see the individual atoms that compose this sheet of gold. (Erwinrossen)

At particle colliders (Figure 1.6), such as the Large Hadron Collider on the France-Swiss border, particle physicists can make subatomic particles travel at very high speeds within a 27 kilometers (17 miles) long superconducting tunnel. They can then study the properties of the particles at high speeds, as well as collide them with each other to see how they exchange energy. This has led to many intriguing discoveries such as the Higgs-Boson particle, which gives matter the property of mass, and antimatter, which causes a huge energy release when it comes in contact with matter.

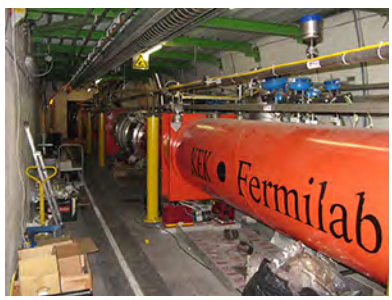


Figure 1.6 Particle colliders such as the Large Hadron Collider in Switzerland or Fermilab in the United States (pictured here), have long tunnels that allows subatomic particles to be accelerated to near light speed. (Andrius.v)

Physicists are currently trying to unify the two theories of modern physics, relativity and quantum mechanics, into a single, comprehensive theory called relativistic quantum mechanics. Relating the behavior of subatomic particles to gravity, time, and space will allow us to explain how the universe works in a much more comprehensive way.

Application of Physics

You need not be a scientist to use physics. On the contrary, knowledge of physics is useful in everyday situations as well as in nonscientific professions. For example, physics can help you understand why you shouldn't put metal in the microwave (Figure 1.7), why a black car radiator helps remove heat in a car engine, and why a white roof helps keep the inside of a house cool. The operation of a car's ignition system, as well as the transmission of electrical signals through our nervous system, are much easier to understand when you think about them in terms of the basic physics of electricity.

Figure 1.7 Why can't you put metal in the microwave? Microwaves are high-energy radiation that increases the movement of electrons in

metal. These moving electrons can create an electrical current, causing sparking that can lead to a fire. (= MoneyBlogNewz)

Physics is the foundation of many important scientific disciplines. For example, chemistry deals with the interactions of atoms and molecules. Not surprisingly, chemistry is rooted in atomic and molecular physics. Most branches of engineering are also applied physics. In architecture, physics is at the heart of determining structural stability, acoustics, heating, lighting, and cooling for buildings. Parts of geology, the study of nonliving parts of Earth, rely heavily on physics; including radioactive dating, earthquake analysis, and heat transfer across Earth's surface. Indeed, some disciplines, such as biophysics and geophysics, are hybrids of physics and other disciplines.

Physics also describes the chemical processes that power the human body. Physics is involved in medical diagnostics, such as x-rays, magnetic resonance imaging (MRI), and ultrasonic blood flow measurements (Figure 1.8). Medical therapy Physics also has many applications in biology, the study of life. For example, physics describes how cells can protect themselves using their cell walls and cell membranes (Figure 1.9). Medical therapy sometimes directly involves physics, such as in using X-rays to diagnose health conditions. Physics can also explain what we perceive with our senses, such as how the ears detect sound or the eye detects color.

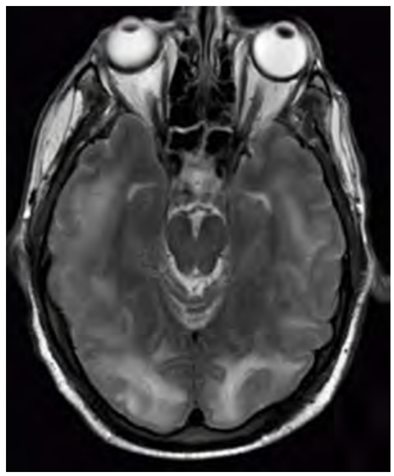


Figure 1.8 Magnetic resonance imaging (MRI) uses electromagnetic waves to yield an image of the brain, which doctors can use to find diseased regions. (Rashmi Chawla, Daniel Smith, and Paul E. Marik)

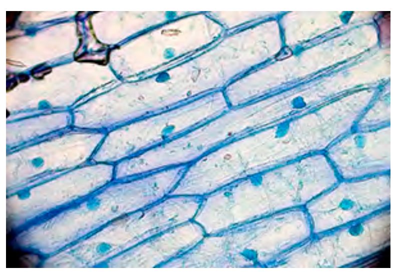


Figure 1.9 Physics, chemistry, and biology help describe the properties of cell walls in plant cells, such as the onion cells seen here. (Umberto Salvagnin)

BOUNDLESS PHYSICS

The Physics of Landing on a Comet

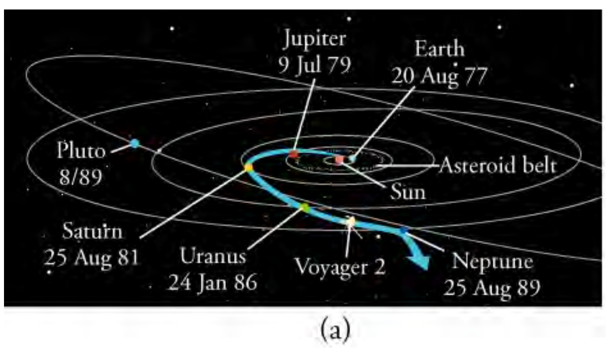
On November 12, 2014, the European Space Agency's Rosetta spacecraft (shown in Figure 1.10) became the first ever to reach and orbit a comet. Shortly after, Rosetta's rover, Philae, landed on the comet, representing the first time humans have ever landed a space probe on a comet.

Figure 1.10 The Rosetta spacecraft, with its large and revolutionary solar panels, carried the Philae lander to a comet. The lander then detached and landed on the comet's surface. (European Space Agency)

After traveling 6.4 billion kilometers starting from its launch on Earth, Rosetta landed on the comet 67P/Churyumov-Gerasimenko, which is only 4 kilometers wide. Physics was needed to successfully plot the course to reach such a small, distant, and rapidly moving target. Rosetta's path to the comet was not straight forward. The probe first had to travel to Mars so that Mars's gravity could accelerate it and divert it in the exact direction of the comet.

This was not the first time humans used gravity to power our spaceships. Voyager 2, a space probe launched in 1977, used the gravity of Saturn to *slingshot* over to Uranus and Neptune (illustrated in Figure 1.11), providing the first pictures ever taken of these planets. Now, almost 40 years after its launch, Voyager 2 is at the very edge of our solar system and is about to enter interstellar space. Its sister ship, Voyager 1 (illustrated in Figure 1.11), which was also launched in 1977, is already there.

To listen to the sounds of interstellar space or see images that have been transmitted back from the Voyager I or to learn more about the Voyager mission, visit the Voyager's Mission website (https://openstax.org/l/28voyager) .



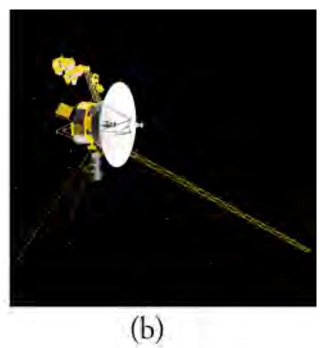


Figure 1.11 a) Voyager 2, launched in 1977, used the gravity of Saturn to slingshot over to Uranus and Neptune. NASA b) A rendering of Voyager 1, the first space probe to ever leave our solar system and enter interstellar space. NASA

Both Voyagers have electrical power generators based on the decay of radioisotopes. These generators have served them for almost 40 years. Rosetta, on the other hand, is solar-powered. In fact, Rosetta became the first space probe to travel beyond the asteroid belt by relying only on solar cells for power generation.

At 800 million kilometers from the sun, Rosetta receives sunlight that is only 4 percent as strong as on Earth. In addition, it is very cold in space. Therefore, a lot of physics went into developing Rosetta's low-intensity low-temperature solar cells.

In this sense, the Rosetta project nicely shows the huge range of topics encompassed by physics: from modeling the movement of gigantic planets over huge distances within our solar systems, to learning how to generate electric power from low-intensity light. Physics is, by far, the broadest field of science.

GRASP CHECK

What characteristics of the solar system would have to be known or calculated in order to send a probe to a distant planet, such as Jupiter?

a. the effects due to the light from the distant stars
b. the effects due to the air in the solar system
c. the effects due to the gravity from the other planets
d. the effects due to the cosmic microwave background radiation

In summary, physics studies many of the most basic aspects of science. A knowledge of physics is, therefore, necessary to understand all other sciences. This is because physics explains the most basic ways in which our universe works. However, it is not necessary to formally study all applications of physics. A knowledge of the basic laws of physics will be most useful to you, so that you can use them to solve some everyday problems. In this way, the study of physics can improve your problem-solving skills.

Check Your Understanding

1. Which of the following is *not* an essential feature of scientific explanations?
a. They must be subject to testing.
b. They strictly pertain to the physical world.
c. Their validity is judged based on objective observations.
d. Once supported by observation, they can be viewed as a fact.

2. Which of the following does *not* represent a question that can be answered by science?
a. How much energy is released in a given nuclear chain reaction?
b. Can a nuclear chain reaction be controlled?
c. Should uncontrolled nuclear reactions be used for military applications?
d. What is the half-life of a waste product of a nuclear reaction?

3. What are the three conditions under which classical physics provides an excellent description of our universe?
a. 1. Matter is moving at speeds less than about 1 percent of the speed of light
   2. Objects dealt with must be large enough to be seen with the naked eye.
   3. Strong electromagnetic fields are involved.

b. 1. Matter is moving at speeds less than about 1 percent of the speed of light.
   2. Objects dealt with must be large enough to be seen with the naked eye.
   3. Only weak gravitational fields are involved.

c. 1. Matter is moving at great speeds, comparable to the speed of light.
   2. Objects dealt with are large enough to be seen with the naked eye.
   3. Strong gravitational fields are involved.

d. 1. Matter is moving at great speeds, comparable to the speed of light.
   2. Objects are just large enough to be visible through the most powerful telescope.
   3. Only weak gravitational fields are involved.

4. Why is the Greek word for nature appropriate in describing the field of physics?
a. Physics is a natural science that studies life and living organism on habitable planets like Earth.
b. Physics is a natural science that studies the laws and principles of our universe.
c. Physics is a physical science that studies the composition, structure, and changes of matter in our universe.
d. Physics is a social science that studies the social behavior of living beings on habitable planets like Earth.

5. Which aspect of the universe is studied by quantum mechanics?
a. objects at the galactic level
b. objects at the classical level
c. objects at the subatomic level
d. objects at all levels, from subatomic to galactic

1.2 The Scientific Methods

Section Learning Objectives

By the end of this section, you will be able to do the following:

- Explain how the methods of science are used to make scientific discoveries
- Define a scientific model and describe examples of physical and mathematical models used in physics
- Compare and contrast hypothesis, theory, and law

Section Key Terms

experiment	hypothesis	model	observation	principle
scientific law	scientific methods	theory	universal	

Scientific Methods

Scientists often plan and carry out investigations to answer questions about the universe around us. Such laws are intrinsic to the universe, meaning that humans did not create them and cannot change them. We can only discover and understand them. Their discovery is a very human endeavor, with all the elements of mystery, imagination, struggle, triumph, and disappointment inherent in any creative effort. The cornerstone of discovering natural laws is observation. Science must describe the universe as it is, not as we imagine or wish it to be.

We all are curious to some extent. We look around, make generalizations, and try to understand what we see. For example, we look up and wonder whether one type of cloud signals an oncoming storm. As we become serious about exploring nature, we become more organized and formal in collecting and analyzing data. We attempt greater precision, perform controlled experiments (if we can), and write down ideas about how data may be organized. We then formulate models, theories, and laws based on the data we have collected, and communicate those results with others. This, in a nutshell, describes the **scientific method** that scientists employ to decide scientific issues on the basis of evidence from observation and experiment.

An investigation often begins with a scientist making an **observation**. The scientist observes a pattern or trend within the natural world. Observation may generate questions that the scientist wishes to answer. Next, the scientist may perform some research about the topic and devise a **hypothesis**. A hypothesis is a testable statement that describes how something in the natural world works. In essence, a hypothesis is an educated guess that explains something about an observation.

Scientists may test the hypothesis by performing an **experiment**. During an experiment, the scientist collects data that will help them learn about the phenomenon they are studying. Then the scientists analyze the results of the experiment (that is, the data), often using statistical, mathematical, and/or graphical methods. From the data analysis, they draw conclusions. They may conclude that their experiment either supports or rejects their hypothesis. If the hypothesis is supported, the scientist usually goes on to test another hypothesis related to the first. If their hypothesis is rejected, they will often then test a new and different hypothesis in their effort to learn more about whatever they are studying.

Scientific processes can be applied to many situations. Let's say that you try to turn on your car, but it will not start. You have just made an observation! You ask yourself, "Why won't my car start?" You can now use scientific processes to answer this question. First, you generate a hypothesis such as, "The car won't start because it has no gasoline in the gas tank." To test this hypothesis, you put gasoline in the car and try to start it again. If the car starts, then your hypothesis is supported by the experiment. If the car does not start, then your hypothesis is rejected. You will then need to think up a new hypothesis to test such as, "My car won't start because the fuel pump is broken." Hopefully, your investigations lead you to discover why the car won't start and enable you to fix it.

Modeling

A **model** is a representation of something that is often too difficult (or impossible) to study directly. Models can take the form of physical models, equations, computer programs, or simulations—computer graphics/animations. Models are tools that are especially useful in modern physics because they let us visualize phenomena that we normally cannot observe with our senses, such as very small objects or objects that move at high speeds. For example, we can understand the structure of an atom using models, despite the fact that no one has ever seen an atom with their own eyes. Models are always approximate, so they are simpler to consider than the real situation; the more complete a model is, the more complicated it must be. Models put the intangible or the extremely complex into human terms that we can visualize, discuss, and hypothesize about.

Scientific models are constructed based on the results of previous experiments. Even still, models often only describe a phenomenon partially or in a few limited situations. Some phenomena are so complex that they may be impossible to model them in their entirety, even using computers. An example is the electron cloud model of the atom in which electrons are moving around the atom's center in distinct clouds (Figure 1.12), that represent the likelihood of finding an electron in different places. This model helps us to visualize the structure of an atom. However, it does not show us exactly where an electron will be within its cloud at any one particular time.

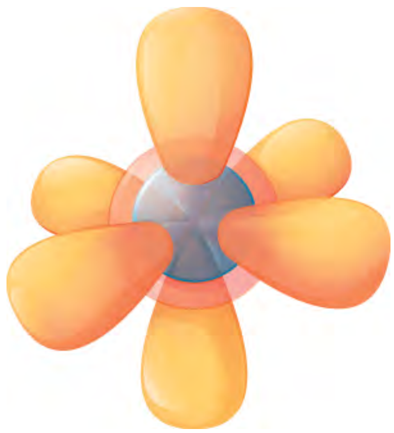


Figure 1.12 The electron cloud model of the atom predicts the geometry and shape of areas where different electrons may be found in an atom. However, it cannot indicate exactly where an electron will be at any one time.

As mentioned previously, physicists use a variety of models including equations, physical models, computer simulations, etc. For example, three-dimensional models are often commonly used in chemistry and physics to model molecules. Properties other than appearance or location are usually modelled using mathematics, where functions are used to show how these properties relate to one another. Processes such as the formation of a star or the planets, can also be modelled using computer simulations. Once a simulation is correctly programmed based on actual experimental data, the simulation can allow us to view processes that happened in the past or happen too quickly or slowly for us to observe directly. In addition, scientists can also run virtual experiments using computer-based models. In a model of planet formation, for example, the scientist could alter the amount or type of rocks present in space and see how it affects planet formation.

Scientists use models and experimental results to construct explanations of observations or design solutions to problems. For example, one way to make a car more fuel efficient is to reduce the friction or drag caused by air flowing around the moving car. This can be done by designing the body shape of the car to be more aerodynamic, such as by using rounded corners instead of sharp ones. Engineers can then construct physical models of the car body, place them in a wind tunnel, and examine the flow of air around the model. This can also be done mathematically in a computer simulation. The air flow pattern can be analyzed for regions smooth air flow and for eddies that indicate drag. The model of the car body may have to be altered slightly to produce the smoothest pattern of air flow (i.e., the least drag). The pattern with the least drag may be the solution to increasing fuel efficiency of the car. This solution might then be incorporated into the car design.

Snap Lab

Using Models and the Scientific Processes

Be sure to secure loose items before opening the window or door.

In this activity, you will learn about scientific models by making a model of how air flows through your classroom or a room in your house.

- One room with at least one window or door that can be opened
- Piece of single-ply tissue paper
    1. Work with a group of four, as directed by your teacher. Close all of the windows and doors in the room you are working in. Your teacher may assign you a specific window or door to study.

2. Before opening any windows or doors, draw a to-scale diagram of your room. First, measure the length and width of your room using the tape measure. Then, transform the measurement using a scale that could fit on your paper, such as 5 centimeters = 1 meter.
3. Your teacher will assign you a specific window or door to study air flow. On your diagram, add arrows showing your hypothesis (before opening any windows or doors) of how air will flow through the room when your assigned window or door is opened. Use pencil so that you can easily make changes to your diagram.
4. On your diagram, mark four locations where you would like to test air flow in your room. To test for airflow, hold a strip of single ply tissue paper between the thumb and index finger. Note the direction that the paper moves when exposed to the airflow. Then, for each location, predict which way the paper will move if your air flow diagram is correct.
5. Now, each member of your group will stand in one of the four selected areas. Each member will test the airflow Agree upon an approximate height at which everyone will hold their papers.
6. When you teacher tells you to, open your assigned window and/or door. Each person should note the direction that their paper points immediately after the window or door was opened. Record your results on your diagram.
7. Did the airflow test data support or refute the hypothetical model of air flow shown in your diagram? Why or why not? Correct your model based on your experimental evidence.
8. With your group, discuss how accurate your model is. What limitations did it have? Write down the limitations that your group agreed upon.

GRASP CHECK

Your diagram is a model, based on experimental evidence, of how air flows through the room. Could you use your model to predict how air would flow through a new window or door placed in a different location in the classroom? Make a new diagram that predicts the room's airflow with the addition of a new window or door. Add a short explanation that describes how.

a. Yes, you could use your model to predict air flow through a new window. The earlier experiment of air flow would help you model the system more accurately.
b. Yes, you could use your model to predict air flow through a new window. The earlier experiment of air flow is not useful for modeling the new system.
c. No, you cannot model a system to predict the air flow through a new window. The earlier experiment of air flow would help you model the system more accurately.
d. No, you cannot model a system to predict the air flow through a new window. The earlier experiment of air flow is not useful for modeling the new system.

Scientific Laws and Theories

A **scientific law** is a description of a pattern in nature that is true in all circumstances that have been studied. That is, physical laws are meant to be **universal**, meaning that they apply throughout the known universe. Laws are often also concise, whereas theories are more complicated. A law can be expressed in the form of a single sentence or mathematical equation. For example, Newton's second law of motion, which relates the motion of an object to the force applied (F), the mass of the object (m), and the object's acceleration (a), is simply stated using the equation

$$F = ma.$$

Scientific ideas and explanations that are true in many, but not all situations in the universe are usually called **principles**. An example is Pascal's principle, which explains properties of liquids, but not solids or gases. However, the distinction between laws and principles is sometimes not carefully made in science.

A **theory** is an explanation for patterns in nature that is supported by much scientific evidence and verified multiple times by multiple researchers. While many people confuse theories with educated guesses or hypotheses, theories have withstood more rigorous testing and verification than hypotheses.

As a closing idea about scientific processes, we want to point out that scientific laws and theories, even those that have been supported by experiments for centuries, can still be changed by new discoveries. This is especially true when new technologies emerge that allow us to observe things that were formerly unobservable. Imagine how viewing previously invisible objects with a microscope or viewing Earth for the first time from space may have instantly changed our scientific theories and laws! What discoveries still await us in the future? The constant retesting and perfecting of our scientific laws and theories allows our knowledge of nature to progress. For this reason, many scientists are reluctant to say that their studies *prove* anything. By saying *support* instead of *prove*, it keeps the door open for future discoveries, even if they won't occur for centuries or even millennia.

Check Your Understanding

6. Explain why scientists sometimes use a model rather than trying to analyze the behavior of the real system.
   a. Models are simpler to analyze.
   b. Models give more accurate results.
   c. Models provide more reliable predictions.
   d. Models do not require any computer calculations.

7. Describe the difference between a question, generated through observation, and a hypothesis.
   a. They are the same.
   b. A hypothesis has been thoroughly tested and found to be true.
   c. A hypothesis is a tentative assumption based on what is already known.
   d. A hypothesis is a broad explanation firmly supported by evidence.

8. What is a scientific model and how is it useful?
   a. A scientific model is a representation of something that can be easily studied directly. It is useful for studying things that can be easily analyzed by humans.
   b. A scientific model is a representation of something that is often too difficult to study directly. It is useful for studying a complex system or systems that humans cannot observe directly.
   c. A scientific model is a representation of scientific equipment. It is useful for studying working principles of scientific equipment.
   d. A scientific model is a representation of a laboratory where experiments are performed. It is useful for studying requirements needed inside the laboratory.

9. Which of the following statements is correct about the hypothesis?
   a. The hypothesis must be validated by scientific experiments.
   b. The hypothesis must not include any physical quantity.
   c. The hypothesis must be a short and concise statement.
   d. The hypothesis must apply to all the situations in the universe.

10. What is a scientific theory?
   a. A scientific theory is an explanation of natural phenomena that is supported by evidence.
   b. A scientific theory is an explanation of natural phenomena without the support of evidence.
   c. A scientific theory is an educated guess about the natural phenomena occurring in nature.
   d. A scientific theory is an uneducated guess about natural phenomena occurring in nature.

11. Compare and contrast a hypothesis and a scientific theory.
   a. A hypothesis is an explanation of the natural world with experimental support, while a scientific theory is an educated guess about a natural phenomenon.
   b. A hypothesis is an educated guess about natural phenomenon, while a scientific theory is an explanation of natural world with experimental support.
   c. A hypothesis is experimental evidence of a natural phenomenon, while a scientific theory is an explanation of the natural world with experimental support.
   d. A hypothesis is an explanation of the natural world with experimental support, while a scientific theory is experimental evidence of a natural phenomenon.

1.3 The Language of Physics: Physical Quantities and Units

Section Learning Objectives

By the end of this section, you will be able to do the following:

- Associate physical quantities with their International System of Units (SI)and perform conversions among SI units using scientific notation
- Relate measurement uncertainty to significant figures and apply the rules for using significant figures in calculations
- Correctly create, label, and identify relationships in graphs using mathematical relationships (e.g., slope, *y*-intercept, inverse, quadratic and logarithmic)

Section Key Terms

accuracy	ampere	constant	conversion factor	dependent variable
derived units	English units	exponential relationship	fundamental physical units	independent variable
inverse relationship	inversely proportional	kilogram	linear relationship	logarithmic (log) scale
log-log plot	meter	method of adding percents	order of magnitude	precision
quadratic relationship	scientific notation	second	semi-log plot	SI units
significant figures	slope	uncertainty	variable	*y*-intercept

The Role of Units

Physicists, like other scientists, make observations and ask basic questions. For example, how big is an object? How much mass does it have? How far did it travel? To answer these questions, they make measurements with various instruments (e.g., meter stick, balance, stopwatch, etc.).

The measurements of physical quantities are expressed in terms of units, which are standardized values. For example, the length of a race, which is a physical quantity, can be expressed in meters (for sprinters) or kilometers (for long distance runners). Without standardized units, it would be extremely difficult for scientists to express and compare measured values in a meaningful way (Figure 1.13).

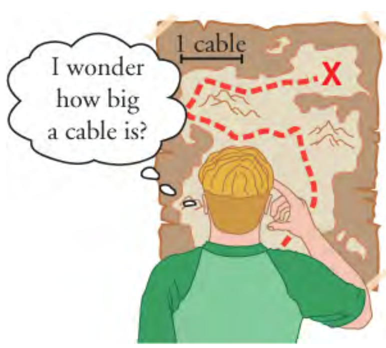


Figure 1.13 Distances given in unknown units are maddeningly useless.

All physical quantities in the International System of Units (SI) are expressed in terms of combinations of seven **fundamental**

physical units, which are units for: length, mass, time, electric current, temperature, amount of a substance, and luminous intensity.

SI Units: Fundamental and Derived Units

There are two major systems of units used in the world: **SI units** (acronym for the French Le Système International d'Unités, also known as the metric system), and **English units** (also known as the imperial system). English units were historically used in nations once ruled by the British Empire. Today, the United States is the only country that still uses English units extensively. Virtually every other country in the world now uses the metric system, which is the standard system agreed upon by scientists and mathematicians.

Some physical quantities are more fundamental than others. In physics, there are seven fundamental physical quantities that are measured in base or physical fundamental units: length, mass, time, electric current temperature, amount of substance, and luminous intensity. Units for other physical quantities (such as force, speed, and electric charge) described by mathematically combining these seven base units. In this course, we will mainly use five of these: length, mass, time, electric current and temperature. The units in which they are measured are the meter, kilogram, second, ampere, kelvin, mole, and candela (Table 1.1). All other units are made by mathematically combining the fundamental units. These are called **derived units**.

Quantity	Name	Symbol
Length	Meter	m
Mass	Kilogram	kg
Time	Second	s
Electric current	Ampere	a
Temperature	Kelvin	k
Amount of substance	Mole	mol
Luminous intensity	Candela	cd

Table 1.1 SI Base Units

The Meter

The SI unit for length is the **meter** (m). The definition of the meter has changed over time to become more accurate and precise. The meter was first defined in 1791 as 1/10,000,000 of the distance from the equator to the North Pole. This measurement was improved in 1889 by redefining the meter to be the distance between two engraved lines on a platinum-iridium bar. (The bar is now housed at the International Bureau of Weights and Meaures, near Paris). By 1960, some distances could be measured more precisely by comparing them to wavelengths of light. The meter was redefined as 1,650,763.73 wavelengths of orange light emitted by krypton atoms. In 1983, the meter was given its present definition as the distance light travels in a vacuum in 1/299,792,458 of a second (Figure 1.14).

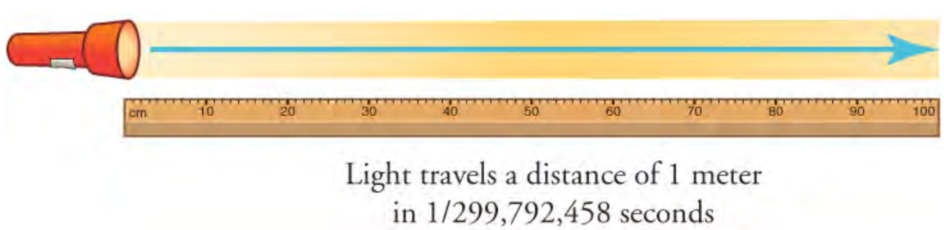


Figure 1.14 The meter is defined to be the distance light travels in 1/299,792,458 of a second through a vacuum. Distance traveled is speed multiplied by time.

The Kilogram

The SI unit for mass is the **kilogram** (kg). It is defined to be the mass of a platinum-iridium cylinder, housed at the International Bureau of Weights and Measures near Paris. Exact replicas of the standard kilogram cylinder are kept in numerous locations throughout the world, such as the National Institute of Standards and Technology in Gaithersburg, Maryland. The determination of all other masses can be done by comparing them with one of these standard kilograms.

The Second

The SI unit for time, the **second** (s) also has a long history. For many years it was defined as 1/86,400 of an average solar day. However, the average solar day is actually very gradually getting longer due to gradual slowing of Earth's rotation. Accuracy in the fundamental units is essential, since all other measurements are derived from them. Therefore, a new standard was adopted to define the second in terms of a non-varying, or constant, physical phenomenon. One constant phenomenon is the very steady vibration of Cesium atoms, which can be observed and counted. This vibration forms the basis of the cesium atomic clock. In 1967, the second was redefined as the time required for 9,192,631,770 Cesium atom vibrations (Figure 1.15).

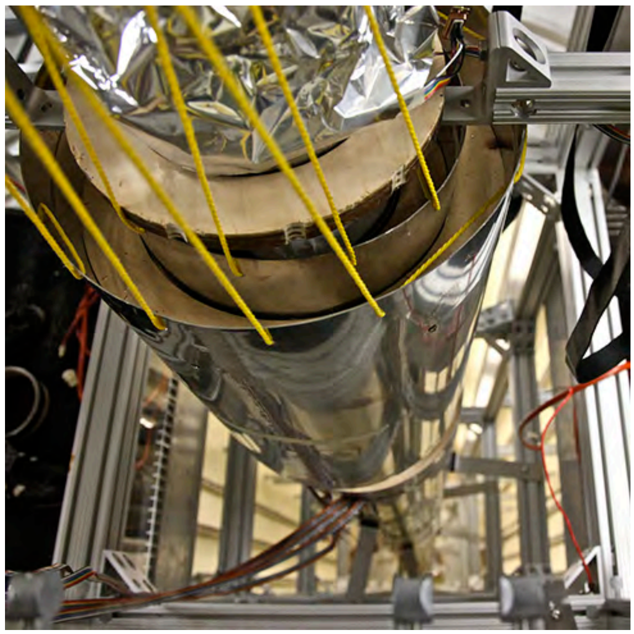


Figure 1.15 An atomic clock such as this one uses the vibrations of cesium atoms to keep time to a precision of one microsecond per year. The fundamental unit of time, the second, is based on such clocks. This image is looking down from the top of an atomic clock. (Steve Jurvetson/Flickr)

The Ampere

Electric current is measured in the **ampere** (A), named after Andre Ampere. You have probably heard of amperes, or *amps*, when people discuss electrical currents or electrical devices. Understanding an ampere requires a basic understanding of electricity and magnetism, something that will be explored in depth in later chapters of this book. Basically, two parallel wires with an electric current running through them will produce an attractive force on each other. One ampere is defined as the amount of electric current that will produce an attractive force of 2.7×10^{-7} newton per meter of separation between the two wires (the newton is the derived unit of force).

Kelvins

The SI unit of temperature is the **kelvin** (or kelvins, but not degrees kelvin). This scale is named after physicist William Thomson, Lord Kelvin, who was the first to call for an absolute temperature scale. The Kelvin scale is based on absolute zero. This is the point at which all thermal energy has been removed from all atoms or molecules in a system. This temperature, 0 K, is equal to –273.15 °C and –459.67 °F. Conveniently, the Kelvin scale actually changes in the same way as the Celsius scale. For example, the freezing point (0 °C) and boiling points of water (100 °C) are 100 degrees apart on the Celsius scale. These two temperatures are also 100 kelvins apart (freezing point = 273.15 K; boiling point = 373.15 K).

Metric Prefixes

Physical objects or phenomena may vary widely. For example, the size of objects varies from something very small (like an atom) to something very large (like a star). Yet the standard metric unit of length is the meter. So, the metric system includes many prefixes that can be attached to a unit. Each prefix is based on factors of 10 (10, 100, 1,000, etc., as well as 0.1, 0.01, 0.001, etc.). Table 1.2 gives the metric prefixes and symbols used to denote the different various factors of 10 in the metric system.

Prefix	Symbol	Value[1]	Example Name	Example Symbol	Example Value	Example Description
exa	E	10^{18}	Exameter	Em	10^{18} m	Distance light travels in a century
peta	P	10^{15}	Petasecond	Ps	10^{15} s	30 million years
tera	T	10^{12}	Terawatt	TW	10^{12} W	Powerful laser output
giga	G	10^{9}	Gigahertz	GHz	10^{9} Hz	A microwave frequency
mega	M	10^{6}	Megacurie	MCi	10^{6} Ci	High radioactivity
kilo	k	10^{3}	Kilometer	km	10^{3} m	About 6/10 mile
hector	h	10^{2}	Hectoliter	hL	10^{2} L	26 gallons
deka	da	10^{1}	Dekagram	dag	10^{1} g	Teaspoon of butter
____	____	10^{0} (=1)				
deci	d	10^{-1}	Deciliter	dL	10^{-1} L	Less than half a soda
centi	c	10^{-2}	Centimeter	Cm	10^{-2} m	Fingertip thickness
milli	m	10^{-3}	Millimeter	Mm	10^{-3} m	Flea at its shoulder
micro	µ	10^{-6}	Micrometer	µm	10^{-6} m	Detail in microscope
nano	n	10^{-9}	Nanogram	Ng	10^{-9} g	Small speck of dust
pico	p	10^{-12}	Picofarad	pF	10^{-12} F	Small capacitor in radio
femto	f	10^{-15}	Femtometer	Fm	10^{-15} m	Size of a proton
atto	a	10^{-18}	Attosecond	as	10^{-18} s	Time light takes to cross an atom

Table 1.2 Metric Prefixes for Powers of 10 and Their Symbols [1]See Appendix A for a discussion of powers of 10. Note—Some examples are approximate.

The metric system is convenient because conversions between metric units can be done simply by moving the decimal place of a number. This is because the metric prefixes are sequential powers of 10. There are 100 centimeters in a meter, 1000 meters in a kilometer, and so on. In nonmetric systems, such as U.S. customary units, the relationships are less simple—there are 12 inches in a foot, 5,280 feet in a mile, 4 quarts in a gallon, and so on. Another advantage of the metric system is that the same unit can be used over extremely large ranges of values simply by switching to the most-appropriate metric prefix. For example, distances in meters are suitable for building construction, but kilometers are used to describe road construction. Therefore, with the metric system, there is no need to invent new units when measuring very small or very large objects—you just have to move the decimal point (and use the appropriate prefix).

Known Ranges of Length, Mass, and Time

Table 1.3 lists known lengths, masses, and time measurements. You can see that scientists use a range of measurement units. This wide range demonstrates the vastness and complexity of the universe, as well as the breadth of phenomena physicists study. As you examine this table, note how the metric system allows us to discuss and compare an enormous range of phenomena, using one system of measurement (Figure 1.16 and Figure 1.17).

Length (m)	Phenomenon Measured	Mass (Kg)	Phenomenon Measured[1]	Time (s)	Phenomenon Measured[1]
10^{-18}	Present experimental limit to smallest observable detail	10^{-30}	Mass of an electron (9.11×10^{-31} kg)	10^{-23}	Time for light to cross a proton
10^{-15}	Diameter of a proton	10^{-27}	Mass of a hydrogen atom (1.67×10^{-27} kg)	10^{-22}	Mean life of an extremely unstable nucleus
10^{14}	Diameter of a uranium nucleus	10^{-15}	Mass of a bacterium	10^{-15}	Time for one oscillation of a visible light
10^{-10}	Diameter of a hydrogen atom	10^{-5}	Mass of a mosquito	10^{-13}	Time for one vibration of an atom in a solid
10^{-8}	Thickness of membranes in cell of living organism	10^{-2}	Mass of a hummingbird	10^{-8}	Time for one oscillation of an FM radio wave
10^{-6}	Wavelength of visible light	1	Mass of a liter of water (about a quart)	10^{-3}	Duration of a nerve impulse
10^{-3}	Size of a grain of sand	10^{2}	Mass of a person	1	Time for one heartbeat
1	Height of a 4-year-old child	10^{3}	Mass of a car	10^{5}	One day (8.64×10^{4} s)
10^{2}	Length of a football field	10^{8}	Mass of a large ship	10^{7}	One year (3.16×10^{7} s)
10^{4}	Greatest ocean depth	10^{12}	Mass of a large iceberg	10^{9}	About half the life expectancy of a human
10^{7}	Diameter of Earth	10^{15}	Mass of the nucleus of a comet	10^{11}	Recorded history
10^{11}	Distance from Earth to the sun	10^{23}	Mass of the moon (7.35×10^{22} kg)	10^{17}	Age of Earth
10^{16}	Distance traveled by light in 1 year (a light year)	10^{25}	Mass of Earth (5.97×10^{24} kg)	10^{18}	Age of the universe
10^{21}	Diameter of the Milky Way Galaxy	10^{30}	Mass of the Sun (1.99×10^{24} kg)		

Table 1.3 Approximate Values of Length, Mass, and Time [1] More precise values are in parentheses.

Length (m)	Phenomenon Measured	Mass (Kg)	Phenomenon Measured[1]	Time (s)	Phenomenon Measured[1]
10^{22}	Distance from Earth to the nearest large galaxy (Andromeda)	10^{42}	Mass of the Milky Way galaxy (current upper limit)		
10^{26}	Distance from Earth to the edges of the known universe	10^{53}	Mass of the known universe (current upper limit)		

Table 1.3 Approximate Values of Length, Mass, and Time [1] More precise values are in parentheses.

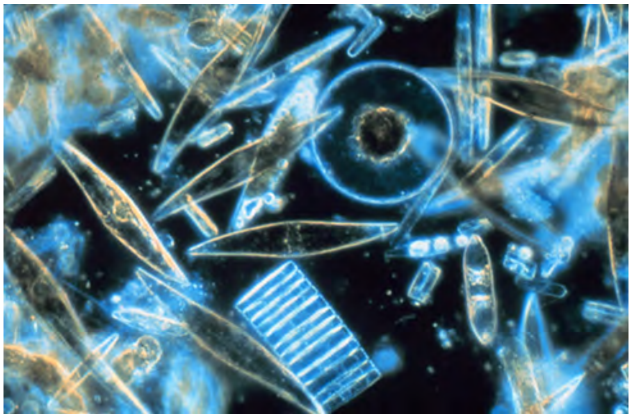


Figure 1.16 Tiny phytoplankton float among crystals of ice in the Antarctic Sea. They range from a few micrometers to as much as 2 millimeters in length. (Prof. Gordon T. Taylor, Stony Brook University; NOAA Corps Collections)

Figure 1.17 Galaxies collide 2.4 billion light years away from Earth. The tremendous range of observable phenomena in nature challenges the imagination. (NASA/CXC/UVic./A. Mahdavi et al. Optical/lensing: CFHT/UVic./H. Hoekstra et al.)

Using Scientific Notation with Physical Measurements

Scientific notation is a way of writing numbers that are too large or small to be conveniently written as a decimal. For example, consider the number 840,000,000,000,000. It's a rather large number to write out. The scientific notation for this number is 8.40×10^{14}. Scientific notation follows this general format

$$x \times 10^y.$$

In this format x is the value of the measurement with all placeholder zeros removed. In the example above, x is 8.4. The x is multiplied by a factor, 10^y, which indicates the number of placeholder zeros in the measurement. Placeholder zeros are those at the end of a number that is 10 or greater, and at the beginning of a decimal number that is less than 1. In the example above, the factor is 10^{14}. This tells you that you should move the decimal point 14 positions to the right, filling in placeholder zeros as you go. In this case, moving the decimal point 14 places creates only 13 placeholder zeros, indicating that the actual measurement value is 840,000,000,000,000.

Numbers that are fractions can be indicated by scientific notation as well. Consider the number 0.0000045. Its scientific notation is 4.5×10^{-6}. Its scientific notation has the same format

$$x \times 10^{y}.$$

Here, x is 4.5. However, the value of y in the 10^{y} factor is negative, which indicates that the measurement is a fraction of 1. Therefore, we move the decimal place to the left, for a negative y. In our example of 4.5×10^{-6}, the decimal point would be moved to the left six times to yield the original number, which would be 0.0000045.

The term **order of magnitude** refers to the power of 10 when numbers are expressed in scientific notation. Quantities that have the same power of 10 when expressed in scientific notation, or come close to it, are said to be of the same order of magnitude. For example, the number 800 can be written as 8×10^{2}, and the number 450 can be written as 4.5×10^{2}. Both numbers have the same value for y. Therefore, 800 and 450 are of the same order of magnitude. Similarly, 101 and 99 would be regarded as the same order of magnitude, 10^{2}. Order of magnitude can be thought of as a ballpark estimate for the scale of a value. The diameter of an atom is on the order of 10^{-9} m, while the diameter of the sun is on the order of 10^{9} m. These two values are 18 orders of magnitude apart.

Scientists make frequent use of scientific notation because of the vast range of physical measurements possible in the universe, such as the distance from Earth to the moon (Figure 1.18), or to the nearest star.

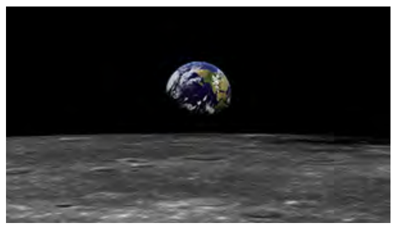


Figure 1.18 The distance from Earth to the moon may seem immense, but it is just a tiny fraction of the distance from Earth to our closest neighboring star. (NASA)

Unit Conversion and Dimensional Analysis

It is often necessary to convert from one type of unit to another. For example, if you are reading a European cookbook in the United States, some quantities may be expressed in liters and you need to convert them to cups. A Canadian tourist driving through the United States might want to convert miles to kilometers, to have a sense of how far away his next destination is. A doctor in the United States might convert a patient's weight in pounds to kilograms.

Let's consider a simple example of how to convert units within the metric system. How can we want to convert 1 hour to seconds?

Next, we need to determine a **conversion factor** relating meters to kilometers. A **conversion factor** is a ratio expressing how many of one unit are equal to another unit. A conversion factor is simply a fraction which equals 1. You can multiply any number by 1 and get the same value. When you multiply a number by a conversion factor, you are simply multiplying it by one. For example, the following are conversion factors: (1 foot)/(12 inches) = 1 to convert inches to feet, (1 meter)/(100 centimeters) = 1 to convert centimeters to meters, (1 minute)/(60 seconds) = 1 to convert seconds to minutes. In this case, we know that there are 1,000 meters in 1 kilometer.

Now we can set up our unit conversion. We will write the units that we have and then multiply them by the conversion factor (1 km/1,000m) = 1, so we are simply multiplying 80m by 1:

$$1\ \cancel{h} \times \frac{60\ \cancel{\text{min}}}{1\ \cancel{h}} \times \frac{60\ \text{s}}{1\ \cancel{\text{min}}} = 3600\ \text{s} = 3.6 \times 10^{2}\ \text{s} \qquad 1.1$$

When there is a unit in the original number, and a unit in the denominator (bottom) of the conversion factor, the units cancel. In this case, hours and minutes cancel and the value in seconds remains.

You can use this method to convert between any types of unit, including between the U.S. customary system and metric system. Notice also that, although you can multiply and divide units algebraically, you cannot add or subtract different units. An expression like *10 km + 5 kg* makes no sense. Even adding two lengths in different units, such as *10 km + 20 m* does not make sense. You express both lengths in the same unit. See Appendix C for a more complete list of conversion factors.

WORKED EXAMPLE

Unit Conversions: A Short Drive Home

Suppose that you drive the 10.0 km from your university to home in 20.0 min. Calculate your average speed (a) in kilometers per hour (km/h) and (b) in meters per second (m/s). (Note—Average speed is distance traveled divided by time of travel.)

Strategy

First we calculate the average speed using the given units. Then we can get the average speed into the desired units by picking the correct conversion factor and multiplying by it. The correct conversion factor is the one that cancels the unwanted unit and leaves the desired unit in its place.

Solution for (a)

1. Calculate average speed. Average speed is distance traveled divided by time of travel. (Take this definition as a given for now—average speed and other motion concepts will be covered in a later module.) In equation form,

$$\text{average speed} = \frac{\text{distance}}{\text{time}}.$$

2. Substitute the given values for distance and time.

$$\text{average speed} = \frac{10.0\ \text{km}}{20.0\ \text{min}} = 0.500\ \frac{\text{km}}{\text{min}}$$

3. Convert km/min to km/h: multiply by the conversion factor that will cancel minutes and leave hours. That conversion factor is $60\ \text{min}/1\text{h}$. Thus,

$$\text{average speed} = 0.500\ \frac{\text{km}}{\text{min}} \times \frac{60\ \text{min}}{1\ \text{h}} = 30.0\ \frac{\text{km}}{\text{h}}.$$

Discussion for (a)

To check your answer, consider the following:

1. Be sure that you have properly cancelled the units in the unit conversion. If you have written the unit conversion factor upside down, the units will not cancel properly in the equation. If you accidentally get the ratio upside down, then the units will not cancel; rather, they will give you the wrong units as follows

$$\frac{\text{km}}{\text{min}} \times \frac{1\ \text{hr}}{60\ \text{min}} = \frac{1}{60}\frac{\text{km}\cdot\text{h}}{\text{min}^2},$$

which are obviously not the desired units of km/h.

2. Check that the units of the final answer are the desired units. The problem asked us to solve for average speed in units of km/h and we have indeed obtained these units.
3. Check the significant figures. Because each of the values given in the problem has three significant figures, the answer should also have three significant figures. The answer 30.0 km/h does indeed have three significant figures, so this is appropriate. Note that the significant figures in the conversion factor are not relevant because an hour is *defined* to be 60 min, so the precision of the conversion factor is perfect.
4. Next, check whether the answer is reasonable. Let us consider some information from the problem—if you travel 10 km in a third of an hour (20 min), you would travel three times that far in an hour. The answer does seem reasonable.

Solution (b)

There are several ways to convert the average speed into meters per second.

1. Start with the answer to (a) and convert km/h to m/s. Two conversion factors are needed—one to convert hours to seconds, and another to convert kilometers to meters.
2. Multiplying by these yields

$$\text{Averagespeed} = 30.0\frac{\text{km}}{\text{h}} \times \frac{1\ \text{h}}{3{,}600\ \text{s}} \times \frac{1{,}000\ \text{m}}{1\ \text{km}}$$

$$\text{Average speed} = 8.33\frac{\text{m}}{\text{s}}$$

Discussion for (b)

If we had started with 0.500 km/min, we would have needed different conversion factors, but the answer would have been the same: 8.33 m/s.

You may have noted that the answers in the worked example just covered were given to three digits. Why? When do you need to be concerned about the number of digits in something you calculate? Why not write down all the digits your calculator produces?

WORKED EXAMPLE

Using Physics to Evaluate Promotional Materials

A commemorative coin that is 2" in diameter is advertised to be plated with 15 mg of gold. If the density of gold is 19.3 g/cc, and the amount of gold around the edge of the coin can be ignored, what is the thickness of the gold on the top and bottom faces of the coin?

Strategy

To solve this problem, the volume of the gold needs to be determined using the gold's mass and density. Half of that volume is distributed on each face of the coin, and, for each face, the gold can be represented as a cylinder that is 2" in diameter with a height equal to the thickness. Use the volume formula for a cylinder to determine the thickness.

Solution

The mass of the gold is given by the formula $m = \rho V = 15 \times 10^{-3}\ \text{ g}$, where $\rho = 19.3\ \text{ g/cc}$ and V is the volume. Solving for the volume gives $V = \frac{m}{\rho} = \frac{15 \times 10^{-3}\ \text{ g}}{19.3\ \text{ g/cc}} \cong 7.8 \times 10^{-4}\ \text{ cc}.$

If t is the thickness, the volume corresponding to half the gold is $\frac{1}{2}\left(7.8 \times 10^{-4}\right) = \pi r^2 t = \pi (2.54)^2 \text{t}$, where the 1" radius has been converted to cm. Solving for the thickness gives $t = \frac{\left(3.9 \times 10^{-4}\right)}{\pi (2.54)^2} \cong 1.9 \times 10^{-5}\ \text{ cm} = 0.00019\text{ mm}.$

Discussion

The amount of gold used is stated to be 15 mg, which is equivalent to a thickness of about 0.00019 mm. The mass figure may make the amount of gold sound larger, both because the number is much bigger (15 versus 0.00019), and because people may have a more intuitive feel for how much a millimeter is than for how much a milligram is. A simple analysis of this sort can clarify the significance of claims made by advertisers.

Accuracy, Precision and Significant Figures

Science is based on experimentation that requires good measurements. The validity of a measurement can be described in terms of its accuracy and its precision (see Figure 1.19 and Figure 1.20). **Accuracy** is how close a measurement is to the correct value for that measurement. For example, let us say that you are measuring the length of standard piece of printer paper. The packaging in which you purchased the paper states that it is 11 inches long, and suppose this stated value is correct. You measure the length of the paper three times and obtain the following measurements: 11.1 inches, 11.2 inches, and 10.9 inches. These measurements are quite accurate because they are very close to the correct value of 11.0 inches. In contrast, if you had obtained a measurement of 12 inches, your measurement would not be very accurate. This is why measuring instruments are calibrated based on a known measurement. If the instrument consistently returns the correct value of the known measurement, it is safe for use in finding unknown values.

Figure 1.19 A double-pan mechanical balance is used to compare different masses. Usually an object with unknown mass is placed in one pan and objects of known mass are placed in the other pan. When the bar that connects the two pans is horizontal, then the masses in both pans are equal. The known masses are typically metal cylinders of standard mass such as 1 gram, 10 grams, and 100 grams. (Serge Melki)

Figure 1.20 Whereas a mechanical balance may only read the mass of an object to the nearest tenth of a gram, some digital scales can measure the mass of an object up to the nearest thousandth of a gram. As in other measuring devices, the precision of a scale is limited to the last measured figures. This is the hundredths place in the scale pictured here. (Splarka, Wikimedia Commons)

Precision states how well repeated measurements of something generate the same or similar results. Therefore, the precision of measurements refers to how close together the measurements are when you measure the same thing several times. One way to analyze the precision of measurements would be to determine the range, or difference between the lowest and the highest measured values. In the case of the printer paper measurements, the lowest value was 10.9 inches and the highest value was 11.2 inches. Thus, the measured values deviated from each other by, at most, 0.3 inches. These measurements were reasonably precise because they varied by only a fraction of an inch. However, if the measured values had been 10.9 inches, 11.1 inches, and 11.9 inches, then the measurements would not be very precise because there is a lot of variation from one measurement to another.

The measurements in the paper example are both accurate and precise, but in some cases, measurements are accurate but not precise, or they are precise but not accurate. Let us consider a GPS system that is attempting to locate the position of a restaurant in a city. Think of the restaurant location as existing at the center of a bull's-eye target. Then think of each GPS attempt to locate the restaurant as a black dot on the bull's eye.

In Figure 1.21, you can see that the GPS measurements are spread far apart from each other, but they are all relatively close to the actual location of the restaurant at the center of the target. This indicates a low precision, high accuracy measuring system. However, in Figure 1.22, the GPS measurements are concentrated quite closely to one another, but they are far away from the target location. This indicates a high precision, low accuracy measuring system. Finally, in Figure 1.23, the GPS is both precise and accurate, allowing the restaurant to be located.

Figure 1.21 A GPS system attempts to locate a restaurant at the center of the bull’s-eye. The black dots represent each attempt to pinpoint the location of the restaurant. The dots are spread out quite far apart from one another, indicating low precision, but they are each rather close to the actual location of the restaurant, indicating high accuracy. (Dark Evil)

Figure 1.22 In this figure, the dots are concentrated close to one another, indicating high precision, but they are rather far away from the actual location of the restaurant, indicating low accuracy. (Dark Evil)

Figure 1.23 In this figure, the dots are concentrated close to one another, indicating high precision, but they are rather far away from the actual location of the restaurant, indicating low accuracy. (Dark Evil)

Uncertainty

The accuracy and precision of a measuring system determine the **uncertainty** of its measurements. Uncertainty is a way to describe how much your measured value deviates from the actual value that the object has. If your measurements are not very accurate or precise, then the uncertainty of your values will be very high. In more general terms, uncertainty can be thought of as a disclaimer for your measured values. For example, if someone asked you to provide the mileage on your car, you might say that it is 45,000 miles, plus or minus 500 miles. The plus or minus amount is the uncertainty in your value. That is, you are indicating that the actual mileage of your car might be as low as 44,500 miles or as high as 45,500 miles, or anywhere in between. All measurements contain some amount of uncertainty. In our example of measuring the length of the paper, we might say that the length of the paper is 11 inches plus or minus 0.2 inches or 11.0 ± 0.2 inches. The uncertainty in a measurement, A, is often denoted as δA ("delta A"),

The factors contributing to uncertainty in a measurement include the following:

1. Limitations of the measuring device
2. The skill of the person making the measurement
3. Irregularities in the object being measured
4. Any other factors that affect the outcome (highly dependent on the situation)

In the printer paper example uncertainty could be caused by: the fact that the smallest division on the ruler is 0.1 inches, the person using the ruler has bad eyesight, or uncertainty caused by the paper cutting machine (e.g., one side of the paper is slightly longer than the other.) It is good practice to carefully consider all possible sources of uncertainty in a measurement and reduce or eliminate them,

Percent Uncertainty

One method of expressing uncertainty is as a percent of the measured value. If a measurement, A, is expressed with uncertainty, δA, the percent uncertainty is

$$\% \text{ uncertainty} = \frac{\delta \mathrm{A}}{\mathrm{A}} \times 100\%. \tag{1.2}$$

WORKED EXAMPLE

Calculating Percent Uncertainty: A Bag of Apples

A grocery store sells 5-lb bags of apples. You purchase four bags over the course of a month and weigh the apples each time. You obtain the following measurements:

- Week 1 weight: $4.\ 8\text{lb}$
- Week 2 weight: $5.3\ \text{lb}$
- Week 3 weight: $4.\ 9\text{lb}$
- Week 4 weight: $5.4\ \text{lb}$

You determine that the weight of the 5 lb bag has an uncertainty of ±0.4 lb. What is the percent uncertainty of the bag's weight?

Strategy

First, observe that the expected value of the bag's weight, A, is 5 lb. The uncertainty in this value, δA, is 0.4 lb. We can use the following equation to determine the percent uncertainty of the weight

$$\% \text{ uncertainty} \ = \frac{\delta \mathrm{A}}{\mathrm{A}} \times 100\%.$$

Solution

Plug the known values into the equation

$$\% \text{ uncertainty} = \frac{0.4\ \ \text{lb}}{5\ \ \text{lb}} \times 100\% = 8\%.$$

Discussion

We can conclude that the weight of the apple bag is 5 lb ± 8 percent. Consider how this percent uncertainty would change if the bag of apples were half as heavy, but the uncertainty in the weight remained the same. Hint for future calculations: when calculating percent uncertainty, always remember that you must multiply the fraction by 100 percent. If you do not do this, you will have a decimal quantity, not a percent value.

Uncertainty in Calculations

There is an uncertainty in anything calculated from measured quantities. For example, the area of a floor calculated from measurements of its length and width has an uncertainty because the both the length and width have uncertainties. How big is the uncertainty in something you calculate by multiplication or division? If the measurements in the calculation have small uncertainties (a few percent or less), then the **method of adding percents** can be used. This method says that the percent uncertainty in a quantity calculated by multiplication or division is the sum of the percent uncertainties in the items used to make the calculation. For example, if a floor has a length of 4.00 m and a width of 3.00 m, with uncertainties of 2 percent and 1 percent, respectively, then the area of the floor is 12.0 m^2 and has an uncertainty of 3 percent (expressed as an area this is 0.36 m^2, which we round to 0.4 m^2 since the area of the floor is given to a tenth of a square meter).

For a quick demonstration of the accuracy, precision, and uncertainty of measurements based upon the units of measurement, try this simulation (http://openstax.org/l/28precision) . You will have the opportunity to measure the length and weight of a desk, using milli- versus centi- units. Which do you think will provide greater accuracy, precision and uncertainty when measuring the desk and the notepad in the simulation? Consider how the nature of the hypothesis or research question might influence how precise of a measuring tool you need to collect data.

Precision of Measuring Tools and Significant Figures

An important factor in the accuracy and precision of measurements is the precision of the measuring tool. In general, a precise measuring tool is one that can measure values in very small increments. For example, consider measuring the thickness of a coin. A standard ruler can measure thickness to the nearest millimeter, while a micrometer can measure the thickness to the nearest 0.005 millimeter. The micrometer is a more precise measuring tool because it can measure extremely small differences in thickness. The more precise the measuring tool, the more precise and accurate the measurements can be.

When we express measured values, we can only list as many digits as we initially measured with our measuring tool (such as the rulers shown in Figure 1.24). For example, if you use a standard ruler to measure the length of a stick, you may measure it with a decimeter ruler as 3.6 cm. You could not express this value as 3.65 cm because your measuring tool was not precise enough to measure a hundredth of a centimeter. It should be noted that the last digit in a measured value has been estimated in some way by the person performing the measurement. For example, the person measuring the length of a stick with a ruler notices that the stick length seems to be somewhere in between 36 mm and 37 mm. He or she must estimate the value of the last digit. The rule is that the last digit written down in a measurement is the first digit with some uncertainty. For example, the last measured value 36.5 mm has three digits, or three significant figures. The number of **significant figures** in a measurement indicates the precision of the measuring tool. The more precise a measuring tool is, the greater the number of significant figures it can report.

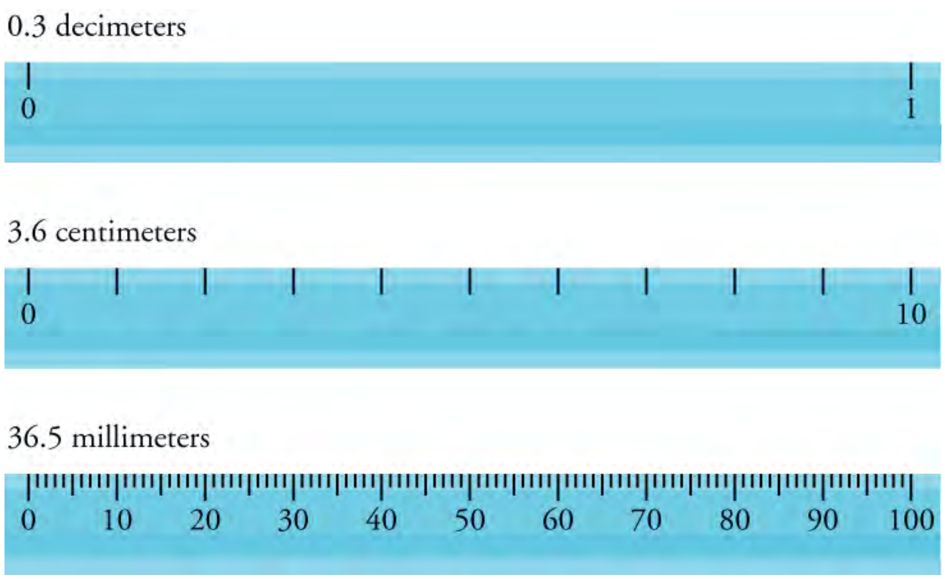


Figure 1.24 Three metric rulers are shown. The first ruler is in decimeters and can measure point three decimeters. The second ruler is in centimeters long and can measure three point six centimeters. The last ruler is in millimeters and can measure thirty-six point five millimeters.

Zeros

Special consideration is given to zeros when counting significant figures. For example, the zeros in 0.053 are not significant because they are only placeholders that locate the decimal point. There are two significant figures in 0.053—the 5 and the 3. However, if the zero occurs between other significant figures, the zeros are significant. For example, both zeros in 10.053 are significant, as these zeros were actually measured. Therefore, the 10.053 placeholder has five significant figures. The zeros in 1300 may or may not be significant, depending on the style of writing numbers. They could mean the number is known to the last zero, or the zeros could be placeholders. So 1300 could have two, three, or four significant figures. To avoid this ambiguity, write 1300 in scientific notation as 1.3×10^3. Only significant figures are given in the x factor for a number in scientific notation (in the form $x \times 10^y$). Therefore, we know that 1 and 3 are the only significant digits in this number. In summary, zeros are significant except when they serve only as placeholders. Table 1.4 provides examples of the number of significant figures in various numbers.

Number	Significant Figures	Rationale
1.657	4	There are no zeros and all non-zero numbers are always significant.
0.4578	4	The first zero is only a placeholder for the decimal point.
0.000458	3	The first four zeros are placeholders needed to report the data to the ten-thoudsandths place.
2000.56	6	The three zeros are significant here because they occur between other significant figures.
45,600	3	With no underlines or scientific notation, we assume that the last two zeros are placeholders and are not significant.
$15895\underline{00}0$	7	The two underlined zeros are significant, while the last zero is not, as it is not underlined.
5.457×10^{13}	4	In scientific notation, all numbers reported in front of the multiplication sign are significant
6.520×10^{-23}	4	In scientific notation, all numbers reported in front of the multiplication sign are significant, including zeros.

Table 1.4

Significant Figures in Calculations

When combining measurements with different degrees of accuracy and precision, the number of significant digits in the final answer can be no greater than the number of significant digits in the least precise measured value. There are two different rules, one for multiplication and division and another rule for addition and subtraction, as discussed below.

1. **For multiplication and division:** The answer should have the same number of significant figures as the starting value with the fewest significant figures. For example, the area of a circle can be calculated from its radius using $A = \pi r^2$. Let us see how many significant figures the area will have if the radius has only two significant figures, for example, $r = 2.0$ m. Then, using a calculator that keeps eight significant figures, you would get

$$A = \pi r^2 = (3.1415927...) \times (2.0 \ \text{m})^2 = 4.5238934 \ \text{m}^2.$$

But because the radius has only two significant figures, the area calculated is meaningful only to two significant figures or

$$A = 4.5 \ \text{m}^2$$

even though the value of π is meaningful to at least eight digits.

2. **For addition and subtraction**: The answer should have the same number places (e.g. tens place, ones place, tenths place, etc.) as the least-precise starting value. Suppose that you buy 7.56 kg of potatoes in a grocery store as measured with a scale having a precision of 0.01 kg. Then you drop off 6.052 kg of potatoes at your laboratory as measured by a scale with a precision of 0.001 kg. Finally, you go home and add 13.7 kg of potatoes as measured by a bathroom scale with a precision of 0.1 kg. How many kilograms of potatoes do you now have, and how many significant figures are appropriate in the answer? The mass is found by simple addition and subtraction:

$$\begin{array}{rl} 7.56 & \text{kg} \\ -6.052 & \text{kg} \\ +13.7 & \text{kg} \\ \hline 15.208 & \text{kg} \end{array}$$

The least precise measurement is 13.7 kg. This measurement is expressed to the 0.1 decimal place, so our final answer must also be expressed to the 0.1 decimal place. Thus, the answer should be rounded to the tenths place, giving 15.2 kg. The same is true for non-decimal numbers. For example,

$$6527.23 + 2 = 6528.23 = 6528 \; .$$

We cannot report the decimal places in the answer because *2* has no decimal places that would be significant. Therefore, we can only report to the ones place.

It is a good idea to keep extra significant figures while calculating, and to round off to the correct number of significant figures only in the final answers. The reason is that small errors from rounding while calculating can sometimes produce significant errors in the final answer. As an example, try calculating $5{,}098 - (5.000) \times (1{,}010)$ to obtain a final answer to only two significant figures. Keeping all significant during the calculation gives 48. Rounding to two significant figures in the middle of the calculation changes it to $5{,}100 - (5.000) \times (1{,}000) = 100$, which is way off. You would similarly avoid rounding in the middle of the calculation in counting and in doing accounting, where many small numbers need to be added and subtracted accurately to give possibly much larger final numbers.

Significant Figures in this Text

In this textbook, most numbers are assumed to have three significant figures. Furthermore, consistent numbers of significant figures are used in all worked examples. You will note that an answer given to three digits is based on input good to at least three digits. If the input has fewer significant figures, the answer will also have fewer significant figures. Care is also taken that the number of significant figures is reasonable for the situation posed. In some topics, such as optics, more than three significant figures will be used. Finally, if a number is exact, such as the *2* in the formula, $c = 2\pi r$, it does not affect the number of significant figures in a calculation.

WORKED EXAMPLE

Approximating Vast Numbers: a Trillion Dollars

The U.S. federal deficit in the 2008 fiscal year was a little greater than $10 trillion. Most of us do not have any concept of how much even one trillion actually is. Suppose that you were given a trillion dollars in $100 bills. If you made 100-bill stacks, like that shown in Figure 1.25, and used them to evenly cover a football field (between the end zones), make an approximation of how high the money pile would become. (We will use feet/inches rather than meters here because football fields are measured in yards.) One of your friends says 3 in., while another says 10 ft. What do you think?

Figure 1.25 A bank stack contains one hundred $100 bills, and is worth $10,000. How many bank stacks make up a trillion dollars? (Andrew Magill)

Strategy

When you imagine the situation, you probably envision thousands of small stacks of 100 wrapped $100 bills, such as you might see in movies or at a bank. Since this is an easy-to-approximate quantity, let us start there. We can find the volume of a stack of 100 bills, find out how many stacks make up one trillion dollars, and then set this volume equal to the area of the football field multiplied by the unknown height.

Solution

1. Calculate the volume of a stack of 100 bills. The dimensions of a single bill are approximately 3 in. by 6 in. A stack of 100 of these is about 0.5 in. thick. So the total volume of a stack of 100 bills is

$$\begin{aligned}\text{volume of stack} &= \text{length} \times \text{width} \times \text{height},\\ \text{volume of stack} &= 6\text{ in.} \times 3\text{ in.} \times 0.5\text{ in.},\\ \text{volume of stack} &= 9\text{ in.}^3.\end{aligned}$$

2. Calculate the number of stacks. Note that a trillion dollars is equal to $\$1 \times 10^{12}$, and a stack of one-hundred $\$100$ bills is equal to $\$10,000$, or $\$1 \times 10^4$. The number of stacks you will have is

$$\$1 \times 10^{12}\text{ (a trillion dollars) / }\$1 \times 10^4\text{ per stack} = 1 \times 10^8\text{ stacks.} \tag{1.3}$$

3. Calculate the area of a football field in square inches. The area of a football field is $100\ \text{yd} \times 50\text{yd}$, which gives $5,000\ \text{yd}^2$. Because we are working in inches, we need to convert square yards to square inches

$$\begin{aligned}\text{Area} &= 5{,}000\text{ yd}^2 \times \frac{3\text{ ft}}{1\text{yd}} \times \frac{3\text{ ft}}{1\text{yd}} \times \frac{12\text{ in.}}{1\text{ foot}} \times \frac{12\text{ in.}}{1\text{ foot}} = 6{,}480{,}000\text{ in.}^2,\\ \text{Area} &\approx 6 \times 10^6\text{ in.}^2.\end{aligned}$$

This conversion gives us $6 \times 10^6\ \text{in.}^2$ for the area of the field. (Note that we are using only one significant figure in these calculations.)

4. Calculate the total volume of the bills. The volume of all the $100-bill stacks is
$9\text{ in.}^3\text{ / stack} \times 10^8\text{ stacks} = 9 \times 10^8\text{ in.}^3$
5. Calculate the height. To determine the height of the bills, use the following equation

$$\begin{aligned}\text{volume of bills} &= \text{area of field} \times \text{height of money}\\ \text{Height of money} &= \frac{\text{volume of bills}}{\text{area of field}}\\ \text{Height of money} &= \frac{9 \times 10^8 \text{ in.}^3}{6 \times 10^6 \text{ in.}^2} = 1.33 \times 10^2 \text{ in.}\\ \text{Height of money} &= 1 \times 10^2 \text{ in.} = 100 \text{ in.}\end{aligned}$$

The height of the money will be about 100 in. high. Converting this value to feet gives

$$100 \text{ in.} \times \frac{1\text{ft}}{12 \text{ in.}} = 8.33 \text{ ft} \approx 8 \text{ ft.}$$

Discussion

The final approximate value is much higher than the early estimate of 3 in., but the other early estimate of 10 ft (120 in.) was roughly correct. How did the approximation measure up to your first guess? What can this exercise tell you in terms of rough *guesstimates* versus carefully calculated approximations?

In the example above, the final approximate value is much higher than the first friend's early estimate of 3 in. However, the other friend's early estimate of 10 ft. (120 in.) was roughly correct. How did the approximation measure up to your first guess? What can this exercise suggest about the value of rough *guesstimates* versus carefully calculated approximations?

Graphing in Physics

Most results in science are presented in scientific journal articles using graphs. Graphs present data in a way that is easy to visualize for humans in general, especially someone unfamiliar with what is being studied. They are also useful for presenting large amounts of data or data with complicated trends in an easily-readable way.

One commonly-used graph in physics and other sciences is the line graph, probably because it is the best graph for showing how one quantity changes in response to the other. Let's build a line graph based on the data in Table 1.5, which shows the measured distance that a train travels from its station versus time. Our two **variables**, or things that change along the graph, are time in minutes, and distance from the station, in kilometers. Remember that measured data may not have perfect accuracy.

Time (min)	Distance from Station (km)
0	0
10	24
20	36
30	60
40	84
50	97
60	116
70	140

Table 1.5

1. Draw the two axes. The horizontal axis, or x-axis, shows the **independent variable**, which is the variable that is controlled or manipulated. The vertical axis, or y-axis, shows the **dependent variable**, the non-manipulated variable that changes with (or is dependent on) the value of the independent variable. In the data above, time is the independent variable and should be plotted on the x-axis. Distance from the station is the dependent variable and should be plotted on the y-axis.

2. Label each axes on the graph with the name of each variable, followed by the symbol for its units in parentheses. Be sure to leave room so that you can number each axis. In this example, use *Time (min)* as the label for the x-axis.
3. Next, you must determine the best scale to use for numbering each axis. Because the time values on the x-axis are taken every 10 minutes, we could easily number the x-axis from 0 to 70 minutes with a tick mark every 10 minutes. Likewise, the y-axis scale should start low enough and continue high enough to include all of the *distance from station* values. A scale from 0 km to 160 km should suffice, perhaps with a tick mark every 10 km.

   In general, you want to pick a scale for both axes that 1) shows all of your data, and 2) makes it easy to identify trends in your data. If you make your scale too large, it will be harder to see how your data change. Likewise, the smaller and more fine you make your scale, the more space you will need to make the graph. The number of significant figures in the axis values should be coarser than the number of significant figures in the measurements.

4. Now that your axes are ready, you can begin plotting your data. For the first data point, count along the x-axis until you find the 10 min tick mark. Then, count up from that point to the 10 km tick mark on the y-axis, and approximate where 22 km is along the y-axis. Place a dot at this location. Repeat for the other six data points (Figure 1.26).

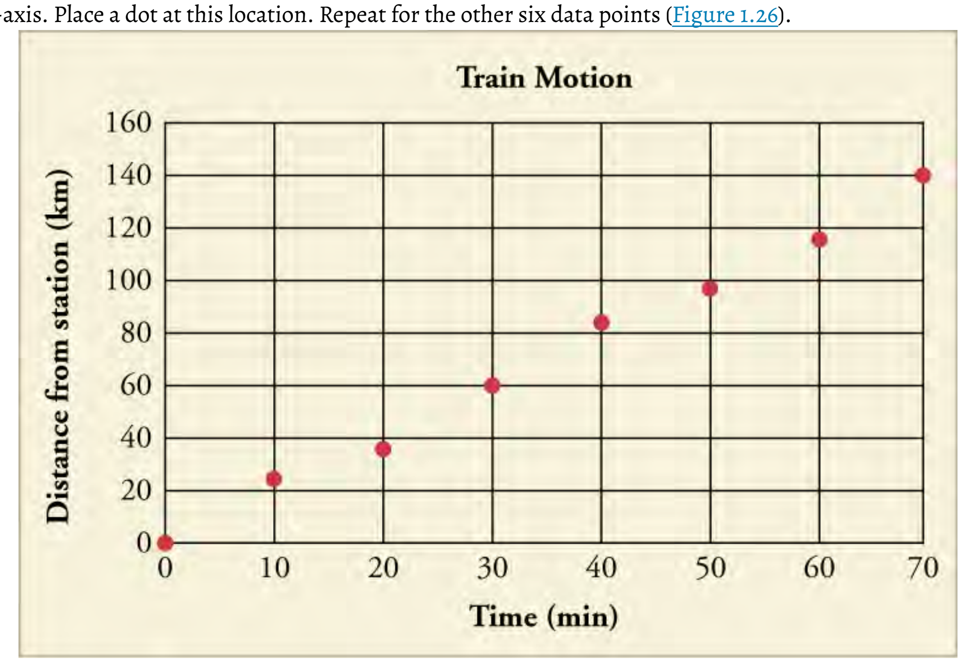


Figure 1.26 The graph of the train's distance from the station versus time from the exercise above.

5. Add a title to the top of the graph to state what the graph is describing, such as the y-axis parameter vs. the x-axis parameter. In the graph shown here, the title is *train motion*. It could also be titled distance of the train from the station vs. time.
6. Finally, with data points now on the graph, you should draw a trend line (Figure 1.27). The trend line represents the dependence you think the graph represents, so that the person who looks at your graph can see how close it is to the real data. In the present case, since the data points look like they ought to fall on a straight line, you would draw a straight line as the trend line. Draw it to come closest to all the points. Real data may have some inaccuracies, and the plotted points may not all fall on the trend line. In some cases, none of the data points fall exactly on the trend line.

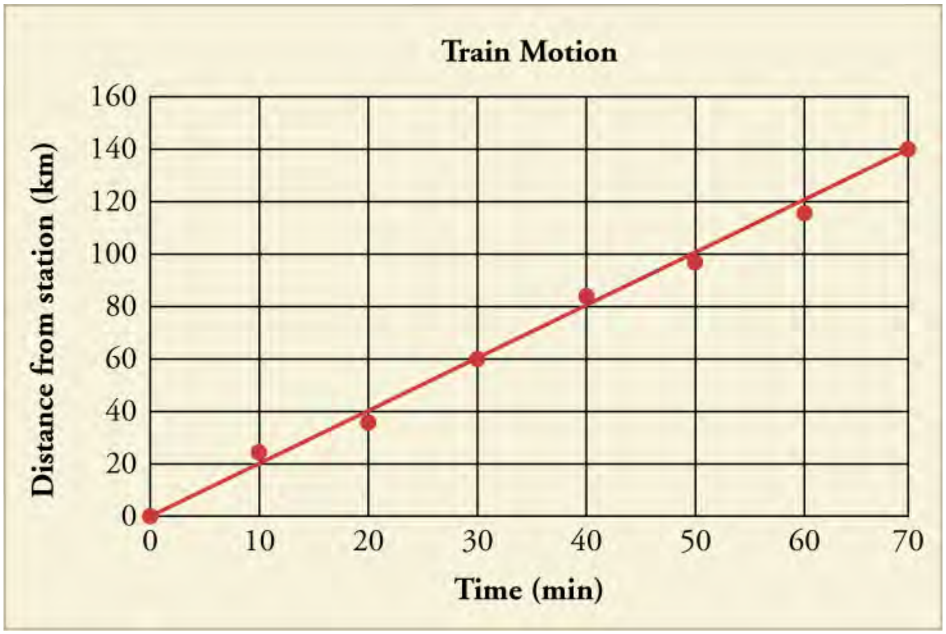


Figure 1.27 The completed graph with the trend line included.

Analyzing a Graph Using Its Equation

One way to get a quick snapshot of a dataset is to look at the equation of its trend line. If the graph produces a straight line, the equation of the trend line takes the form

$$y = mx + b.$$

The b in the equation is the y-intercept while the m in the equation is the **slope**. The y-intercept tells you at what y value the line intersects the y-axis. In the case of the graph above, the y-intercept occurs at 0, at the very beginning of the graph. The y-intercept, therefore, lets you know immediately where on the y-axis the plot line begins.

The m in the equation is the slope. This value describes how much the line on the graph moves up or down on the y-axis along the line's length. The slope is found using the following equation

$$m = \frac{Y_2 - Y_1}{X_2 - X_1}.$$

In order to solve this equation, you need to pick two points on the line (preferably far apart on the line so the slope you calculate describes the line accurately). The quantities Y_2 and Y_1 represent the y-values from the two points on the line (not data points) that you picked, while X_2 and X_1 represent the two x-values of the those points.

What can the slope value tell you about the graph? The slope of a perfectly horizontal line will equal zero, while the slope of a perfectly vertical line will be undefined because you cannot divide by zero. A positive slope indicates that the line moves up the y-axis as the x-value increases while a negative slope means that the line moves down the y-axis. The more negative or positive the slope is, the steeper the line moves up or down, respectively. The slope of our graph in Figure 1.26 is calculated below based on the two endpoints of the line

$$\begin{aligned} m &= \frac{Y_2 - Y_1}{X_2 - X_1} \\ m &= \frac{(80\text{ km}) - (20\text{ km})}{(40\text{ min}) - (10\text{ min})} \\ m &= \frac{60\text{ km}}{30\text{ min}} \\ m &= 2.0\text{ km/min}. \end{aligned}$$

Equation of line: $y = (2.0\ \text{km/min})\,x + 0$

Because the x axis is time in minutes, we would actually be more likely to use the time t as the independent (x-axis) variable and write the equation as

$$y = (2.0 \text{ km/min})\, t + 0. \tag{1.4}$$

The formula $y = mx + b$ only applies to **linear relationships**, or ones that produce a straight line. Another common type of line in physics is the **quadratic relationship**, which occurs when one of the variables is squared. One quadratic relationship in physics is the relation between the speed of an object its centripetal acceleration, which is used to determine the force needed to keep an object moving in a circle. Another common relationship in physics is the **inverse relationship**, in which one variable decreases whenever the other variable increases. An example in physics is Coulomb's law. As the distance between two charged objects increases, the electrical force between the two charged objects decreases. **Inverse proportionality**, such the relation between x and y in the equation

$$y = k/x,$$

for some number k, is one particular kind of inverse relationship. A third commonly-seen relationship is the **exponential relationship**, in which a change in the independent variable produces a proportional change in the dependent variable. As the value of the dependent variable gets larger, its rate of growth also increases. For example, bacteria often reproduce at an exponential rate when grown under ideal conditions. As each generation passes, there are more and more bacteria to reproduce. As a result, the growth rate of the bacterial population increases every generation (Figure 1.28).

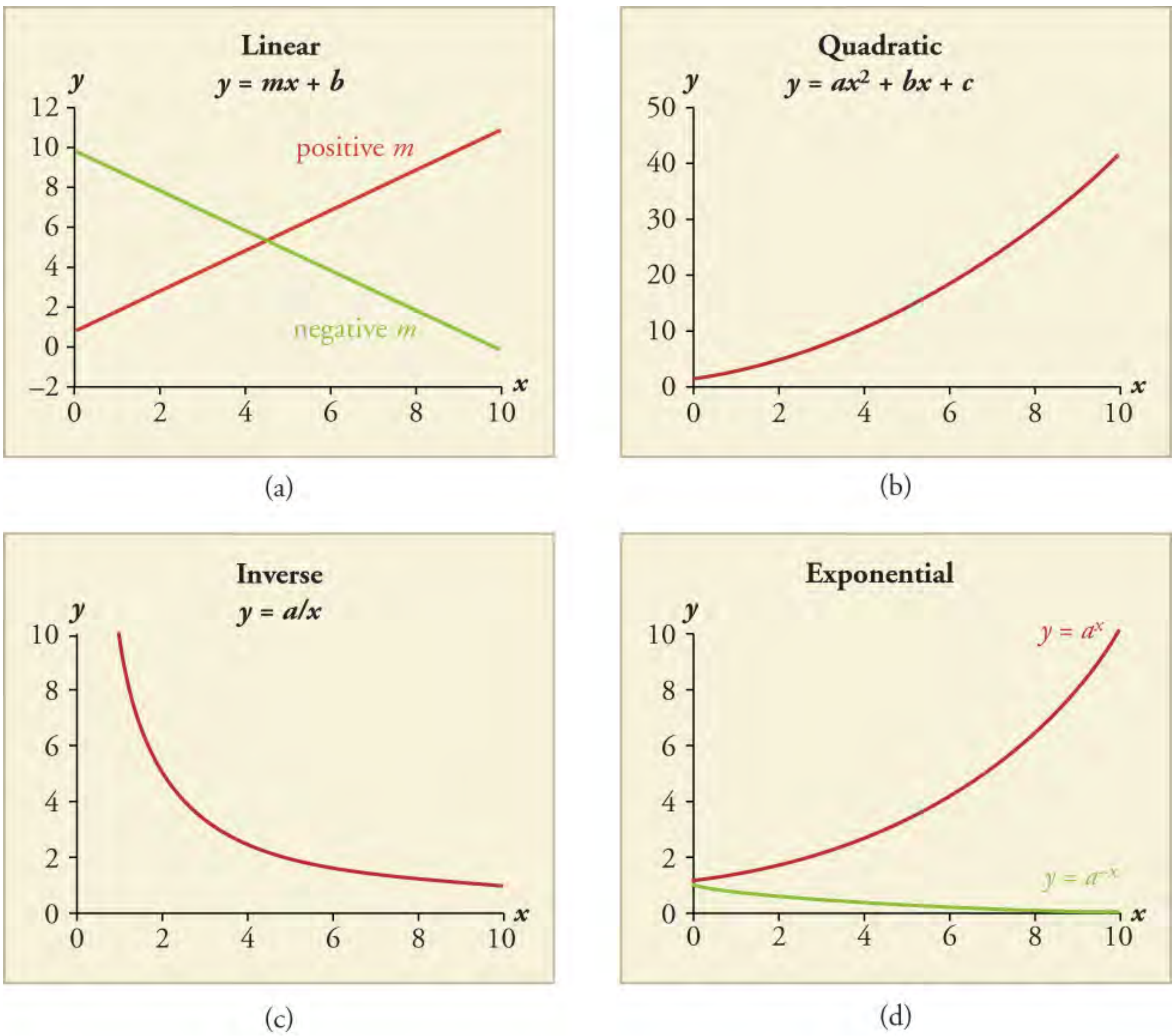


Figure 1.28 Examples of (a) linear, (b) quadratic, (c) inverse, and (d) exponential relationship graphs.

Using Logarithmic Scales in Graphing

Sometimes a variable can have a very large range of values. This presents a problem when you're trying to figure out the best scale to use for your graph's axes. One option is to use a **logarithmic (log) scale**. In a logarithmic scale, the value each mark labels is the previous mark's value multiplied by some constant. For a log base 10 scale, each mark labels a value that is 10 times the value of the mark before it. Therefore, a base 10 logarithmic scale would be numbered: 0, 10, 100, 1,000, etc. You can see how the logarithmic scale covers a much larger range of values than the corresponding linear scale, in which the marks would label the values 0, 10, 20, 30, and so on.

If you use a logarithmic scale on one axis of the graph and a linear scale on the other axis, you are using a **semi-log plot**. The Richter scale, which measures the strength of earthquakes, uses a semi-log plot. The degree of ground movement is plotted on a logarithmic scale against the assigned intensity level of the earthquake, which ranges linearly from 1-10 (Figure 1.29 **(a)**).

If a graph has both axes in a logarithmic scale, then it is referred to as a **log-log plot**. The relationship between the wavelength and frequency of electromagnetic radiation such as light is usually shown as a log-log plot (Figure 1.29 **(b)**). Log-log plots are also commonly used to describe exponential functions, such as radioactive decay.

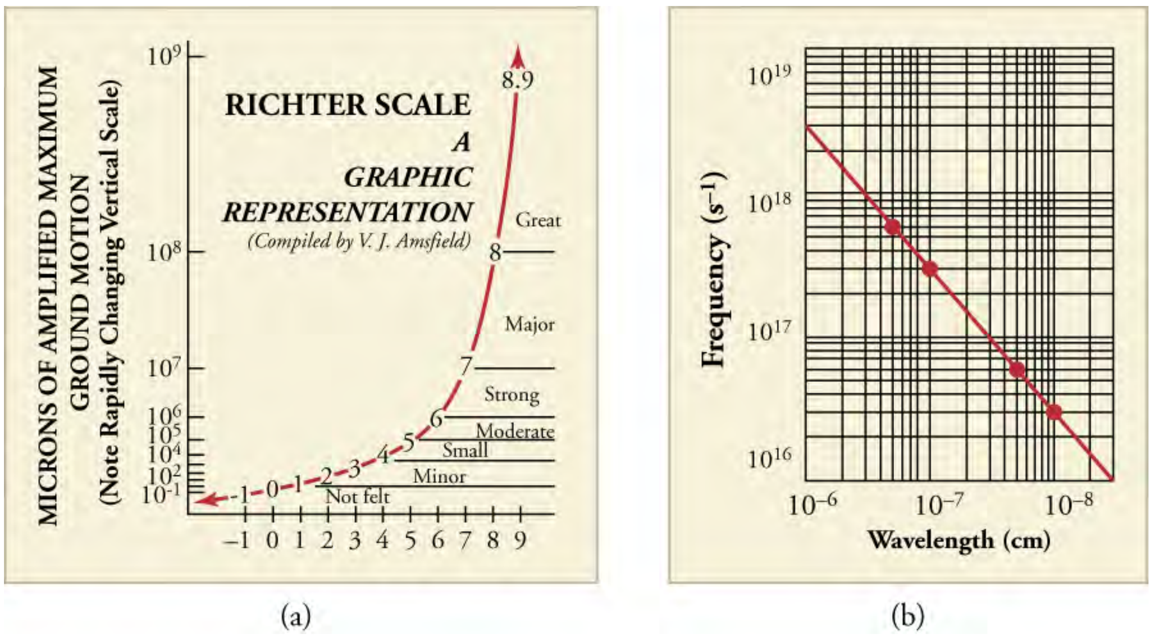


Figure 1.29 (a) The Richter scale uses a log base 10 scale on its *y-axis* (microns of amplified maximum ground motion). (b) The relationship between the frequency and wavelength of electromagnetic radiation can be plotted as a straight line if a log-log plot is used.

Virtual Physics

Graphing Lines

In this simulation you will examine how changing the slope and *y*-intercept of an equation changes the appearance of a plotted line. Select slope-intercept form and drag the blue circles along the line to change the line's characteristics. Then, play the line game and see if you can determine the slope or *y*-intercept of a given line.

Click to view content (https://phet.colorado.edu/sims/html/graphing-lines/latest/graphing-lines_en.html)

GRASP CHECK

How would the following changes affect a line that is neither horizontal nor vertical and has a positive slope?

1. increase the slope but keeping the *y*-intercept constant
2. increase the *y*-intercept but keeping the slope constant
   a. Increasing the slope will cause the line to rotate clockwise around the *y*-intercept. Increasing the *y*-intercept will cause the line to move vertically up on the graph without changing the line's slope.
   b. Increasing the slope will cause the line to rotate counter-clockwise around the *y*-intercept. Increasing the *y*-intercept will cause the line to move vertically up on the graph without changing the line's slope.
   c. Increasing the slope will cause the line to rotate clockwise around the *y*-intercept. Increasing the *y*-intercept will cause the line to move horizontally right on the graph without changing the line's slope.

d. Increasing the slope will cause the line to rotate counter-clockwise around the *y*-intercept. Increasing the *y*-intercept will cause the line to move horizontally right on the graph without changing the line's slope.

Check Your Understanding

12. Identify some advantages of metric units.

a. Conversion between units is easier in metric units.
b. Comparison of physical quantities is easy in metric units.
c. Metric units are more modern than English units.
d. Metric units are based on powers of 2.

13. The length of an American football field is $100\ \mathrm{yd}$, excluding the end zones. How long is the field in meters? Round to the nearest $0.1\ \mathrm{m}$.

a. $10.2\ \mathrm{m}$
b. $91.4\ \mathrm{m}$
c. $109.4\ \mathrm{m}$
d. $328.1\ \mathrm{m}$

14. The speed limit on some interstate highways is roughly $100\ \mathrm{km/h}$. How many miles per hour is this if $1.0\ \mathrm{mile}$ is about $1.609\ \mathrm{km}$?

a. 0.1 mi/h
b. 27.8 mi/h
c. 62 mi/h
d. 160 mi/h

15. Briefly describe the target patterns for accuracy and precision and explain the differences between the two.

a. Precision states how much repeated measurements generate the same or closely similar results, while accuracy states how close a measurement is to the true value of the measurement.
b. Precision states how close a measurement is to the true value of the measurement, while accuracy states how much repeated measurements generate the same or closely similar result.
c. Precision and accuracy are the same thing. They state how much repeated measurements generate the same or closely similar results.
d. Precision and accuracy are the same thing. They state how close a measurement is to the true value of the measurement.

KEY TERMS

accuracy how close a measurement is to the correct value for that measurement

ampere the SI unit for electrical current

atom smallest and most basic units of matter

classical physics physics, as it developed from the Renaissance to the end of the nineteenth century

constant a quantity that does not change

conversion factor a ratio expressing how many of one unit are equal to another unit

dependent variable the vertical, or y-axis, variable, which changes with (or is dependent on) the value of the independent variable

derived units units that are derived by combining the fundamental physical units

English units (also known as the customary or imperial system) system of measurement used in the United States; includes units of measurement such as feet, gallons, degrees Fahrenheit, and pounds

experiment process involved with testing a hypothesis

exponential relationship relation between variables in which a constant change in the independent variable is accompanied by change in the dependent variable that is proportional to the value it already had

fundamental physical units the seven fundamental physical units in the SI system of units are length, mass, time, electric current, temperature, amount of a substance, and luminous intensity

hypothesis testable statement that describes how something in the natural world works

independent variable the horizontal, or x-axis, variable, which is not influence by the second variable on the graph, the dependent variable

inverse proportionality a relation between two variables expressible by an equation of the form $y = k/x$ where k stays constant when x and y change; the special form of inverse relationship that satisfies this equation

inverse relationship any relation between variables where one variable decreases as the other variable increases

kilogram the SI unit for mass, abbreviated (kg)

linear relationships relation between variables that produce a straight line when graphed

log-log plot a plot that uses a logarithmic scale in both axes

logarithmic scale a graphing scale in which each tick on an axis is the previous tick multiplied by some value

meter the SI unit for length, abbreviated (m)

method of adding percents calculating the percent uncertainty of a quantity in multiplication or division by adding the percent uncertainties in the quantities being added or divided

model system that is analogous to the real system of interest in essential ways but more easily analyzed

modern physics physics as developed from the twentieth century to the present, involving the theories of relativity and quantum mechanics

observation step where a scientist observes a pattern or trend within the natural world

order of magnitude the size of a quantity in terms of its power of 10 when expressed in scientific notation

physics science aimed at describing the fundamental aspects of our universe—energy, matter, space, motion, and time

precision how well repeated measurements generate the same or closely similar results

principle description of nature that is true in many, but not all situations

quadratic relationship relation between variables that can be expressed in the form $y = ax^2 + bx + c$, which produces a curved line when graphed

quantum mechanics major theory of modern physics which describes the properties and nature of atoms and their subatomic particles

science the study or knowledge of how the physical world operates, based on objective evidence determined through observation and experimentation

scientific law pattern in nature that is true in all circumstances studied thus far

scientific methods techniques and processes used in the constructing and testing of scientific hypotheses, laws, and theories, and in deciding issues on the basis of experiment and observation

scientific notation way of writing numbers that are too large or small to be conveniently written in simple decimal form; the measurement is multiplied by a power of 10, which indicates the number of placeholder zeros in the measurement

second the SI unit for time, abbreviated (s)

semi-log plot A plot that uses a logarithmic scale on one axis of the graph and a linear scale on the other axis.

SI units International System of Units (SI); the international system of units that scientists in most countries have agreed to use; includes units such as meters, liters, and grams; also known as the metric system

significant figures when writing a number, the digits, or number of digits, that express the precision of a measuring tool used to measure the number

slope the ratio of the change of a graph on the y axis to the change along the x-axis, the value of m in the equation of a line, $y = mx + b$

theory explanation of patterns in nature that is supported by much scientific evidence and verified multiple times by various groups of researchers

theory of relativity theory constructed by Albert Einstein which describes how space, time and energy are different for different observers in relative motion

uncertainty a quantitative measure of how much measured values deviate from a standard or expected value

universal applies throughout the known universe

***y*-intercept** the point where a plot line intersects the y-axis

SECTION SUMMARY

1.1 Physics: Definitions and Applications

- Physics is the most fundamental of the sciences, concerning itself with energy, matter, space and time, and their interactions.
- Modern physics involves the theory of relativity, which describes how time, space and gravity are not constant in our universe can be different for different observers, and quantum mechanics, which describes the behavior of subatomic particles.
- Physics is the basis for all other sciences, such as chemistry, biology and geology, because physics describes the fundamental way in which the universe functions.

1.2 The Scientific Methods

- Science seeks to discover and describe the underlying order and simplicity in nature.
- The processes of science include observation, hypothesis, experiment, and conclusion.
- Theories are scientific explanations that are supported by a large body experimental results.
- Scientific laws are concise descriptions of the universe that are universally true.

1.3 The Language of Physics: Physical Quantities and Units

- Physical quantities are a characteristic or property of an object that can be measured or calculated from other measurements.
- The four fundamental units we will use in this textbook are the meter (for length), the kilogram (for mass), the second (for time), and the ampere (for electric current). These units are part of the metric system, which uses powers of 10 to relate quantities over the vast ranges encountered in nature.
- Unit conversions involve changing a value expressed in one type of unit to another type of unit. This is done by using conversion factors, which are ratios relating equal quantities of different units.
- Accuracy of a measured value refers to how close a measurement is to the correct value. The uncertainty in a measurement is an estimate of the amount by which the measurement result may differ from this value.
- Precision of measured values refers to how close the agreement is between repeated measurements.
- Significant figures express the precision of a measuring tool.
- When multiplying or dividing measured values, the final answer can contain only as many significant figures as the least precise value.
- When adding or subtracting measured values, the final answer cannot contain more decimal places than the least precise value.

KEY EQUATIONS

1.3 The Language of Physics: Physical Quantities and Units

slope intercept form	$y = mx + b$
quadratic formula	$y = ax^2 + bx + c$
positive exponential formula	$y = a^x$
negative exponential formula	$y = a^{-x}$

CHAPTER REVIEW

Concept Items

1.1 Physics: Definitions and Applications

1. Which statement best compares and contrasts the aims and topics of natural philosophy had versus physics?
   a. Natural philosophy included all aspects of nature including physics.
   b. Natural philosophy included all aspects of nature excluding physics.
   c. Natural philosophy and physics are different.
   d. Natural philosophy and physics are essentially the

same thing.

2. Which of the following is not an underlying assumption essential to scientific understanding?
   a. Characteristics of the physical universe can be perceived and objectively measured by human beings.
   b. Explanations of natural phenomena can be established with absolute certainty.
   c. Fundamental physical processes dictate how characteristics of the physical universe evolve.
   d. The fundamental processes of nature operate the same way everywhere and at all times.

3. Which of the following questions regarding a strain of genetically modified rice is not one that can be answered by science?
   a. How does the yield of the genetically modified rice compare with that of existing rice?
   b. Is the genetically modified rice more resistant to infestation than existing rice?
   c. How does the nutritional value of the genetically modified rice compare to that of existing rice?
   d. Should the genetically modified rice be grown commercially and sold in the marketplace?

4. What conditions imply that we can use classical physics without considering special relativity or quantum mechanics?
   a. 1. matter is moving at speeds of less than roughly 1 percent the speed of light,
      2. objects are large enough to be seen with the naked eye, and
      3. there is the involvement of a strong gravitational field.
   b. 1. matter is moving at speeds greater than roughly 1 percent the speed of light,
      2. objects are large enough to be seen with the naked eye, and
      3. there is the involvement of a strong gravitational field.
   c. 1. matter is moving at speeds of less than roughly 1 percent the speed of light,
      2. objects are too small to be seen with the naked eye, and
      3. there is the involvement of only a weak gravitational field.
   d. 1. matter is moving at speeds of less than roughly 1 percent the speed of light,
      2. objects are large enough to be seen with the naked eye, and
      3. there is the involvement of a weak gravitational field.

5. How could physics be useful in weather prediction?
   a. Physics helps in predicting how burning fossil fuel releases pollutants.
   b. Physics helps in predicting dynamics and movement of weather phenomena.
   c. Physics helps in predicting the motion of tectonic plates.
   d. Physics helps in predicting how the flowing water affects Earth's surface.

6. How do physical therapists use physics while on the job? Explain.
   a. Physical therapists do not require knowledge of physics because their job is mainly therapy and not physics.
   b. Physical therapists do not require knowledge of physics because their job is more social in nature and unscientific.
   c. Physical therapists require knowledge of physics know about muscle contraction and release of energy.
   d. Physical therapists require knowledge of physics to know about chemical reactions inside the body and make decisions accordingly.

7. What is meant when a physical law is said to be universal?
   a. The law can explain everything in the universe.
   b. The law is applicable to all physical phenomena.
   c. The law applies everywhere in the universe.
   d. The law is the most basic one and all laws are derived from it.

8. What subfield of physics could describe small objects traveling at high speeds or experiencing a strong gravitational field?
   a. general theory of relativity
   b. classical physics
   c. quantum relativity
   d. special theory of relativity

9. Why is Einstein's theory of relativity considered part of modern physics, as opposed to classical physics?
   a. Because it was considered less outstanding than the classics of physics, such as classical mechanics.
   b. Because it was popular physics enjoyed by average people today, instead of physics studied by the elite.
   c. Because the theory deals with very slow-moving objects and weak gravitational fields.
   d. Because it was among the new 19th-century discoveries that changed physics.

1.2 The Scientific Methods

10. Describe the difference between an observation and a hypothesis.

a. An observation is seeing what happens; a hypothesis is a testable, educated guess.
b. An observation is a hypothesis that has been confirmed.
c. Hypotheses and observations are independent of each other.
d. Hypotheses are conclusions based on some observations.

11. Describe how modeling is useful in studying the structure of the atom.
a. Modeling replaces the real system by something similar but easier to examine.
b. Modeling replaces the real system by something more interesting to examine.
c. Modeling replaces the real system by something with more realistic properties.
d. Modeling includes more details than are present in the real system.

12. How strongly is a hypothesis supported by evidence compared to a theory?
a. A theory is supported by little evidence, if any, at first, while a hypothesis is supported by a large amount of available evidence.
b. A hypothesis is supported by little evidence, if any, at first. A theory is supported by a large amount of available evidence.
c. A hypothesis is supported by little evidence, if any, at first. A theory does not need any experiments in support.
d. A theory is supported by little evidence, if any, at first. A hypothesis does not need any experiments in support.

1.3 The Language of Physics: Physical Quantities and Units

13. Which of the following does not contribute to the uncertainty?
a. the limitations of the measuring device
b. the skill of the person making the measurement
c. the regularities in the object being measured
d. other factors that affect the outcome (depending on the situation)

14. How does the independent variable in a graph differ from the dependent variable?
a. The dependent variable varies linearly with the independent variable.
b. The dependent variable depends on the scale of the axis chosen while independent variable does not.
c. The independent variable is directly manipulated or controlled by the person doing the experiment, while dependent variable is the one that changes as a result.
d. The dependent and independent variables are fixed by a convention and hence they are the same.

15. What could you conclude about these two lines?

1. Line A has a slope of -4.7
2. Line B has a slope of 12.0

a. Line A is a decreasing line while line B is an increasing line, with line A being much steeper than line B.
b. Line A is a decreasing line while line B is an increasing line, with line B being much steeper than line A.
c. Line B is a decreasing line while line A is an increasing line, with line A being much steeper than line B.
d. Line B is a decreasing line while line A is an increasing line, with line B being much steeper than line A.

16. Velocity, or speed, is measured using the following formula: $v = \frac{d}{t}$, where v is velocity, d is the distance travelled, and t is the time the object took to travel the distance. If the velocity-time data are plotted on a graph, which variable will be on which axis? Why?
a. Time would be on the x-axis and velocity on the y-axis, because time is an independent variable and velocity is a dependent variable.
b. Velocity would be on the x-axis and time on the y-axis, because time is the independent variable and velocity is the dependent variable.
c. Time would be on the x-axis and velocity on the y-axis, because time is a dependent variable and velocity is a independent variable.
d. Velocity would be on x-axis and time on the y-axis, because time is a dependent variable and velocity is a independent variable.

17. The uncertainty of a triple-beam balance is 0.05 g. What is the percent uncertainty in a measurement of 0.445 kg?
a. 0.011%
b. 0.11%
c. 1.1%
d. 11%

18. What is the definition of uncertainty?
a. Uncertainty is the number of assumptions made prior to the measurement of a physical quantity.
b. Uncertainty is a measure of error in a measurement due to the use of a non-calibrated instrument.
c. Uncertainty is a measure of deviation of the measured value from the standard value.
d. Uncertainty is a measure of error in measurement

due to external factors like air friction and temperature.

Critical Thinking Items

1.1 Physics: Definitions and Applications

19. In what sense does Einstein's theory of relativity illustrate that physics describes fundamental aspects of our universe?
   a. It describes how speed affects different observers' measurements of time and space.
   b. It describes how different parts of the universe are far apart and do not affect each other.
   c. It describes how people think of other people's views from their own frame of reference.
   d. It describes how a frame of reference is necessary to describe position or motion.

20. Can classical physics be used to accurately describe a satellite moving at a speed of 7500 m/s? Explain why or why not.
   a. No, because the satellite is moving at a speed much smaller than the speed of the light and is not in a strong gravitational field.
   b. No, because the satellite is moving at a speed much smaller than the speed of the light and is in a strong gravitational field.
   c. Yes, because the satellite is moving at a speed much smaller than the speed of the light and it is not in a strong gravitational field.
   d. Yes, because the satellite is moving at a speed much smaller than the speed of the light and is in a strong gravitational field.

21. What would be some ways in which physics was involved in building the features of the room you are in right now?
   a. Physics is involved in structural strength, dimensions, etc., of the room.
   b. Physics is involved in the air composition inside the room.
   c. Physics is involved in the desk arrangement inside the room.
   d. Physics is involved in the behavior of living beings inside the room.

22. What theory of modern physics describes the interrelationships between space, time, speed, and gravity?
   a. atomic theory
   b. nuclear physics
   c. quantum mechanics
   d. general relativity

23. According to Einstein's theory of relativity, how could you effectively travel many years into Earth's future, but not age very much yourself?
   a. by traveling at a speed equal to the speed of light
   b. by traveling at a speed faster than the speed of light
   c. by traveling at a speed much slower than the speed of light
   d. by traveling at a speed slightly slower than the speed of light

1.2 The Scientific Methods

24. You notice that the water level flowing in a stream near your house increases when it rains and the water turns brown. Which of these are the best hypothesis to explain why the water turns brown. Assume you have all of the means to test the contents of the stream water.
   a. The water in the stream turns brown because molecular forces between water molecules are stronger than mud molecules
   b. The water in the stream turns brown because of the breakage of a weak chemical bond with the hydrogen atom in the water molecule.
   c. The water in the stream turns brown because it picks up dirt from the bank as the water level increases when it rains.
   d. The water in the stream turns brown because the density of the water increases with increase in water level.

25. Light travels as waves at an approximate speed of 300,000,000 m/s (186,000 mi/s). Designers of devices that use mirrors and lenses model the traveling light by straight lines, or light rays. Describe why it would be useful to model the light as rays of light instead of describing them accurately as electromagnetic waves.
   a. A model can be constructed in such a way that the speed of light decreases.
   b. Studying a model makes it easier to analyze the path that the light follows.
   c. Studying a model will help us to visualize why light travels at such great speed.
   d. Modeling cannot be used to study traveling light as our eyes cannot track the motion of light.

26. A friend says that he doesn't trust scientific explanations because they are just theories, which are basically educated guesses. What could you say to convince him that scientific theories are different from the everyday use of the word theory?
   a. A theory is a scientific explanation that has been repeatedly tested and supported by many experiments.
   b. A theory is a hypothesis that has been tested and

supported by some experiments.
c. A theory is a set of educated guesses, but at least one of the guesses remain true in each experiment.
d. A theory is a set of scientific explanations that has at least one experiment in support of it.

27. Give an example of a hypothesis that cannot be tested experimentally.
a. The structure of any part of the broccoli is similar to the whole structure of the broccoli.
b. Ghosts are the souls of people who have died.
c. The average speed of air molecules increases with temperature.
d. A vegetarian is less likely to be affected by night blindness.

28. Would it be possible to scientifically prove that a supreme being exists or not? Briefly explain your answer.
a. It can be proved scientifically because it is a testable hypothesis.
b. It cannot be proved scientifically because it is not a testable hypothesis.
c. It can be proved scientifically because it is not a testable hypothesis.
d. It cannot be proved scientifically because it is a testable hypothesis.

1.3 The Language of Physics: Physical Quantities and Units

29. A marathon runner completes a $42.188\ \text{km}$ course in $2\ \text{h}$, $30\ \text{min}$, and $12\ \text{s}$. There is an uncertainty of $25\ \text{m}$ in the distance traveled and an uncertainty of $1\ \text{s}$ in the elapsed time.

1. Calculate the percent uncertainty in the distance.
2. Calculate the uncertainty in the elapsed time.
3. What is the average speed in meters per second?
4. What is the uncertainty in the average speed?

a. $0.059\ \%, 0.01\ \%, 0.468\text{m/s}, 0.0003\text{m/s}$
b. $0.059\ \%, 0.01\ \%, 0.468\ \text{m/s}, 0.07\ \text{m/s}$
c. $0.59\ \%, 8.33\ \%, 4.681\ \text{m/s}, 0.003\ \text{m/s}$
d. $0.059\ \%, 0.01\ \%, 4.681\ \text{m/s}, 0.003\ \text{m/s}$

30. A car engine moves a piston with a circular cross section of $7.500 \pm 0.002\ \text{cm}$ diameter a distance of $3.250 \pm 0.001\ \text{cm}$ to compress the gas in the cylinder. By what amount did the gas decrease in volume in cubic centimeters? Find the uncertainty in this volume.
a. $143.6 \pm 0.002\ \text{cm}^3$
b. $143.6 \pm 0.003\ \text{cm}^3$
c. $143.6 \pm 0.005\ \text{cm}^3$
d. $143.6 \pm 0.1\ \text{cm}^3$

31. What would be the slope for a line passing through the two points below?

Point 1: (1, 0.1) Point 2: (7, 26.8)

a. 2.4
b. 4.5
c. 6.2
d. 6.8

32. The sides of a small rectangular box are measured $1.80\ \text{cm}$ and $2.05\ \text{cm}$ long and $3.1\ \text{cm}$ high. Calculate its volume and uncertainty in cubic centimeters. Assume the measuring device is accurate to $\pm 0.05\ \text{cm}$.
a. $11.4 \pm 0.1\ \text{cm}^3$
b. $11.4 \pm 0.6\,\text{cm}^3$
c. $11.4 \pm 0.8\,\text{cm}^3$
d. $11.4 \pm 0.10\,\text{cm}^3$

33. Calculate the approximate number of atoms in a bacterium. Assume that the average mass of an atom in the bacterium is ten times the mass of a hydrogen atom. (Hint—The mass of a hydrogen atom is on the order of 10^{-27} kg and the mass of a bacterium is on the order of 10^{-15} kg .)
a. 10^{10} atoms
b. 10^{11} atoms
c. 10^{12} atoms
d. 10^{13} atoms

Problems

1.3 The Language of Physics: Physical Quantities and Units

34. A commemorative coin that sells for $40 is advertised to be plated with 15 mg of gold. Suppose gold is worth about $1,300 per ounce. Which of the following best represents the value of the gold in the coin?
a. $0.33
b. $0.69
c. $3.30
d. $6.90

35. If a marathon runner runs 9.5 miles in one direction, 8.89 miles in another direction and 2.333 miles in a third direction, how much distance did the runner run? Be sure to report your answer using the proper number of significant figures.
a. 20
b. 20.7
c. 20.72

d. 20.732

36. The speed limit on some interstate highways is roughly 80 km/h. What is this in meters per second? How many miles per hour is this?

a. 62 m/s, 27.8 mi/h
b. 22.2 m/s, 49.7 mi/h
c. 62 m/s, 2.78 mi/h
d. 2.78 m/s, 62 mi/h

37. The length and width of a rectangular room are measured to be $3.955 \pm 0.005 \text{ m}$ by $3.050 \pm 0.005 \text{ m}$. Calculate the area of the room and its uncertainty in square meters.

a. $12.06 \pm 0.29 \text{ m}^2$
b. $12.06 \pm 0.01 \text{ m}^2$
c. $12.06 \pm 0.25 \text{ m}^2$
d. $12.06 \pm 0.04 \text{ m}^2$

Performance Task

1.3 The Language of Physics: Physical Quantities and Units

38. a. Create a new system of units to describe something that interests you. Your unit should be described using at least two subunits. For example, you can decide to measure the quality of songs using a new unit called *song awesomeness*. Song awesomeness is measured by: the number of songs downloaded and the number of times the song was used in movies.

b. Create an equation that shows how to calculate your unit. Then, using your equation, create a sample dataset that you could graph. Are your two subunits related linearly, quadratically, or inversely?

TEST PREP

Multiple Choice

1.1 Physics: Definitions and Applications

39. Modern physics could best be described as the combination of which theories?

a. quantum mechanics and Einstein's theory of relativity
b. quantum mechanics and classical physics
c. Newton's laws of motion and classical physics
d. Newton's laws of motion and Einstein's theory of relativity

40. Which of the following could be studied accurately using classical physics?

a. the strength of gravity within a black hole
b. the motion of a plane through the sky
c. the collisions of subatomic particles
d. the effect of gravity on the passage of time

41. Which of the following best describes why knowledge of physics is necessary to understand all other sciences?

a. Physics explains how energy passes from one object to another.
b. Physics explains how gravity works.
c. Physics explains the motion of objects that can be seen with the naked eye.
d. Physics explains the fundamental aspects of the universe.

42. What does radiation therapy, used to treat cancer patients, have to do with physics?

a. Understanding how cells reproduce is mainly about physics.
b. Predictions of the side effects from the radiation therapy are based on physics.
c. The devices used for generating some kinds of radiation are based on principles of physics.
d. Predictions of the life expectancy of patients receiving radiation therapy are based on physics.

1.2 The Scientific Methods

43. The free-electron model of metals explains some of the important behaviors of metals by assuming the metal's electrons move freely through the metal without repelling one another. In what sense is the free-electron theory based on a model?

a. Its use requires constructing replicas of the metal wire in the lab.
b. It involves analyzing an imaginary system simpler than the real wire it resembles.
c. It examines a model, or ideal, behavior that other metals should imitate.
d. It attempts to examine the metal in a very realistic, or model, way.

44. A scientist wishes to study the motion of about 1,000 molecules of gas in a container by modeling them as tiny billiard balls bouncing randomly off one another. Which of the following is needed to calculate and store data on their detailed motion?

a. a group of hypotheses that cannot be practically tested in real life

b. a computer that can store and perform calculations on large data sets
c. a large amount of experimental results on the molecules and their motion
d. a collection of hypotheses that have not yet been tested regarding the molecules

45. When a large body of experimental evidence supports a hypothesis, what may the hypothesis eventually be considered?
a. observation
b. insight
c. conclusion
d. law

46. While watching some ants outside of your house, you notice that the worker ants gather in a specific area on your lawn. Which of the following is a testable hypothesis that attempts to explain why the ants gather in that specific area on the lawn.
a. The worker thought it was a nice location.
b. because ants may have to find a spot for the queen to lay eggs
c. because there may be some food particles lying there
d. because the worker ants are supposed to group together at a place.

1.3 The Language of Physics: Physical Quantities and Units

47. Which of the following would describe a length that is 2.0×10^{-3} of a meter?
a. 2.0 kilometers
b. 2.0 megameters
c. 2.0 millimeters
d. 2.0 micrometers

48. Suppose that a bathroom scale reads a person's mass as 65 kg with a 3 percent uncertainty. What is the uncertainty in their mass in kilograms?
a. a. 2 kg
b. b. 98 kg
c. c. 5 kg
d. d. 0

49. Which of the following best describes a variable?
a. a trend that shows an exponential relationship
b. something whose value can change over multiple measurements
c. a measure of how much a plot line changes along the y-axis
d. something that remains constant over multiple measurements

50. A high school track coach has just purchased a new stopwatch that has an uncertainty of ±0.05 s . Runners on the team regularly clock 100-m sprints in 12.49 s to 15.01 s . At the school's last track meet, the first-place sprinter came in at 12.04 s and the second-place sprinter came in at 12.07 s . Will the coach's new stopwatch be helpful in timing the sprint team? Why or why not?
a. No, the uncertainty in the stopwatch is too large to effectively differentiate between the sprint times.
b. No, the uncertainty in the stopwatch is too small to effectively differentiate between the sprint times.
c. Yes, the uncertainty in the stopwatch is too large to effectively differentiate between the sprint times.
d. Yes, the uncertainty in the stopwatch is too small to effectively differentiate between the sprint times.

Short Answer

1.1 Physics: Definitions and Applications

51. Describe the aims of physics.
a. Physics aims to explain the fundamental aspects of our universe and how these aspects interact with one another.
b. Physics aims to explain the biological aspects of our universe and how these aspects interact with one another.
c. Physics aims to explain the composition, structure and changes in matter occurring in the universe.
d. Physics aims to explain the social behavior of living beings in the universe.

52. Define the fields of magnetism and electricity and state how are they are related.
a. Magnetism describes the attractive force between a magnetized object and a metal like iron. Electricity involves the study of electric charges and their movements. Magnetism is not related to the electricity.
b. Magnetism describes the attractive force between a magnetized object and a metal like iron. Electricity involves the study of electric charges and their movements. Magnetism is produced by a flow electrical charges.
c. Magnetism involves the study of electric charges and their movements. Electricity describes the attractive force between a magnetized object and a metal. Magnetism is not related to the electricity.
d. Magnetism involves the study of electric charges and their movements. Electricity describes the attractive force between a magnetized object and a metal. Magnetism is produced by the flow electrical charges.

53. Describe what two topics physicists are trying to unify with relativistic quantum mechanics. How will this unification create a greater understanding of our universe?
   a. Relativistic quantum mechanics unifies quantum mechanics with Einstein's theory of relativity. The unified theory creates a greater understanding of our universe because it can explain objects of all sizes and masses.
   b. Relativistic quantum mechanics unifies classical mechanics with Einstein's theory of relativity. The unified theory creates a greater understanding of our universe because it can explain objects of all sizes and masses.
   c. Relativistic quantum mechanics unifies quantum mechanics with Einstein's theory of relativity. The unified theory creates a greater understanding of our universe because it is unable to explain objects of all sizes and masses.
   d. Relativistic quantum mechanics unifies classical mechanics with the Einstein's theory of relativity. The unified theory creates a greater understanding of our universe because it is unable to explain objects of all sizes and masses.

54. The findings of studies in quantum mechanics have been described as strange or weird compared to those of classical physics. Explain why this would be so.
   a. It is because the phenomena it explains are outside the normal range of human experience which deals with much larger objects.
   b. It is because the phenomena it explains can be perceived easily, namely, ordinary-sized objects.
   c. It is because the phenomena it explains are outside the normal range of human experience, namely, the very large and the very fast objects.
   d. It is because the phenomena it explains can be perceived easily, namely, the very large and the very fast objects.

55. How could knowledge of physics help you find a faster way to drive from your house to your school?
   a. Physics can explain the traffic on a particular street and help us know about the traffic in advance.
   b. Physics can explain about the ongoing construction of roads on a particular street and help us know about delays in the traffic in advance.
   c. Physics can explain distances, speed limits on a particular street and help us categorize faster routes.
   d. Physics can explain the closing of a particular street and help us categorize faster routes.

56. How could knowledge of physics help you build a sound and energy-efficient house?
   a. An understanding of force, pressure, heat, electricity, etc., which all involve physics, will help me design a sound and energy-efficient house.
   b. An understanding of the air composition, chemical composition of matter, etc., which all involves physics, will help me design a sound and energy-efficient house.
   c. An understanding of material cost and economic factors involving physics will help me design a sound and energy-efficient house.
   d. An understanding of geographical location and social environment which involves physics will help me design a sound and energy-efficient house.

57. What aspects of physics would a chemist likely study in trying to discover a new chemical reaction?
   a. Physics is involved in understanding whether the reactants and products dissolve in water.
   b. Physics is involved in understanding the amount of energy released or required in a chemical reaction.
   c. Physics is involved in what the products of the reaction will be.
   d. Physics is involved in understanding the types of ions produced in a chemical reaction.

1.2 The Scientific Methods

58. You notice that it takes more force to get a large box to start sliding across the floor than it takes to get the box sliding faster once it is already moving. Create a testable hypothesis that attempts to explain this observation.
   a. The floor has greater distortions of space-time for moving the sliding box faster than for the box at rest.
   b. The floor has greater distortions of space-time for the box at rest than for the sliding box.
   c. The resistance between the floor and the box is less when the box is sliding then when the box is at rest.
   d. The floor dislikes having objects move across it and therefore holds the box rigidly in place until it cannot resist the force.

59. Design an experiment that will test the following hypothesis: driving on a gravel road causes greater damage to a car than driving on a dirt road.
   a. To test the hypothesis, compare the damage to the car by driving it on a smooth road and a gravel road.
   b. To test the hypothesis, compare the damage to the car by driving it on a smooth road and a dirt road.
   c. To test the hypothesis, compare the damage to the car by driving it on a gravel road and the dirt road.
   d. This is not a testable hypothesis.

60. How is a physical model, such as a spherical mass held in place by springs, used to represent an atom vibrating in a solid, similar to a computer-based model, such as that predicting how gravity affects the orbits of the planets?

a. Both a physical model and a computer-based model should be built around a hypothesis and could be able to test the hypothesis.
b. Both a physical model and a computer-based model should be built around a hypothesis but they cannot be used to test the hypothesis.
c. Both a physical model and a computer-based model should be built around the results of scientific studies and could be used to make predictions about the system under study.
d. Both a physical model and a computer-based model should be built around the results of scientific studies but cannot be used to make predictions about the system under study.

61. Explain the advantages and disadvantages of using a model to predict a life-or-death situation, such as whether or not an asteroid will strike Earth.

a. The advantage of using a model is that it provides predictions quickly, but the disadvantage of using a model is that it could make erroneous predictions.
b. The advantage of using a model is that it provides accurate predictions, but the disadvantage of using a model is that it takes a long time to make predictions.
c. The advantage of using a model is that it provides predictions quickly without any error. There are no disadvantages of using a scientific model.
d. The disadvantage of using models is that it takes longer time to make predictions and the predictions are inaccurate. There are no advantages to using a scientific model.

62. A friend tells you that a scientific law cannot be changed. State whether or not your friend is correct and then briefly explain your answer.

a. Correct, because laws are theories that have been proved true.
b. Correct, because theories are laws that have been proved true.
c. Incorrect, because a law is changed if new evidence contradicts it.
d. Incorrect, because a law is changed when a theory contradicts it.

63. How does a scientific law compare to a local law, such as that governing parking at your school, in terms of whether or not laws can be changed, and how universal a law is?

a. A local law applies only in a specific area, but a scientific law is applicable throughout the universe. Both the local law and the scientific law can change.
b. A local law applies only in a specific area, but a scientific law is applicable throughout the universe. A local law can change, but a scientific law cannot be changed.
c. A local law applies throughout the universe but a scientific law is applicable only in a specific area. Both the local and the scientific law can change.
d. A local law applies throughout the universe, but a scientific law is applicable only in a specific area. A local law can change, but a scientific law cannot be changed.

64. Can the validity of a model be limited, or must it be universally valid? How does this compare to the required validity of a theory or a law?

a. Models, theories and laws must be universally valid.
b. Models, theories, and laws have only limited validity.
c. Models have limited validity while theories and laws are universally valid.
d. Models and theories have limited validity while laws are universally valid.

1.3 The Language of Physics: Physical Quantities and Units

65. The speed of sound is measured at $342\ \text{m/s}$ on a certain day. What is this in km/h? Report your answer in scientific notation.

a. 1.23×10^4 km/h
b. 1.23×10^3 km/h
c. 9.5×10^1 km/h
d. 2.05×10^{-1} km/h

66. Describe the main difference between the metric system and the U.S. Customary System.

a. In the metric system, unit changes are based on powers of 10, while in the U.S. customary system, each unit conversion has unrelated conversion factors.
b. In the metric system, each unit conversion has unrelated conversion factors, while in the U.S. customary system, unit changes are based on powers of 10.
c. In the metric system, unit changes are based on powers of 2, while in the U.S. customary system, each unit conversion has unrelated conversion factors.
d. In the metric system, each unit conversion has unrelated conversion factors, while in the U.S. customary system, unit changes are based on

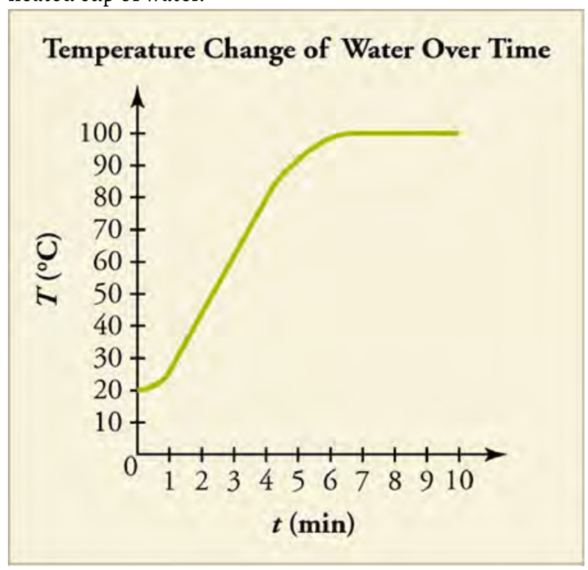
powers of 2.

67. An infant's pulse rate is measured to be 130 ± 5 beats/min. What is the percent uncertainty in this measurement?
   a. 2%
   b. 3%
   c. 4%
   d. 5%

68. Explain how the uncertainty of a measurement relates to the accuracy and precision of the measuring device. Include the definitions of accuracy and precision in your answer.
   a. A decrease in the precision of a measurement increases the uncertainty of the measurement, while a decrease in accuracy does not.
   b. A decrease in either the precision or accuracy of a measurement increases the uncertainty of the measurement.
   c. An increase in either the precision or accuracy of a measurement will increase the uncertainty of that measurement.
   d. An increase in the accuracy of a measurement will increase the uncertainty of that measurement, while an increase in precision will not.

69. Describe all of the characteristics that can be determined about a straight line with a slope of -3 and a y-intercept of 50 on a graph.
   a. Based on the information, the line has a negative slope. Because its y-intercept is 50 and its slope is negative, this line gradually rises on the graph as the x-value increases.
   b. Based on the information, the line has a negative slope. Because its y-intercept is 50 and its slope is negative, this line gradually moves downward on the graph as the x-value increases.
   c. Based on the information, the line has a positive slope. Because its y-intercept is 50 and its slope is positive, this line gradually rises on the graph as the x-value increases.
   d. Based on the information, the line has a positive slope. Because its y-intercept is 50 and its slope is positive, this line gradually moves downward on the graph as the x-value increases.

70. The graph shows the temperature change over time of a heated cup of water.



What is the slope of the graph between the time period 2 min and 5 min?
   a. −15 °C/min
   b. −0.07 °C/min
   c. 0.07 °C/min
   d. 15 °C/min

Extended Response

1.2 The Scientific Methods

71. You wish to perform an experiment on the stopping distance of your new car. Create a specific experiment to measure the distance. Be sure to specifically state how you will set up and take data during your experiment.
   a. Drive the car at exactly 50 mph and then press harder on the accelerator pedal until the velocity reaches the speed 60 mph and record the distance this takes.
   b. Drive the car at exactly 50 mph and then apply the brakes until it stops and record the distance this takes.
   c. Drive the car at exactly 50 mph and then apply the brakes until it stops and record the time it takes.
   d. Drive the car at exactly 50 mph and then apply the accelerator until it reaches the speed of 60 mph and record the time it takes.

72. You wish to make a model showing how traffic flows around your city or local area. Describe the steps you would take to construct your model as well as some hypotheses that your model could test and the model's limitations in terms of what could not be tested.
   a. 1. Testable hypotheses like the gravitational pull on each vehicle while in motion and the average speed of vehicles is 40 mph
      2. Non-testable hypotheses like the average number of vehicles passing is 935 per day and carbon emission from each of the moving vehicle

b. 1. Testable hypotheses like the average number of vehicles passing is 935 per day and the average speed of vehicles is 40 mph
   2. Non-testable hypotheses like the gravitational pull on each vehicle while in motion and the carbon emission from each of the moving vehicle

c. 1. Testable hypotheses like the average number of vehicles passing is 935 per day and the carbon emission from each of the moving vehicle
   2. Non-testable hypotheses like the gravitational pull on each vehicle while in motion and the average speed of the vehicles is 40 mph

d. 1. Testable hypotheses like the average number of vehicles passing is 935 per day and the gravitational pull on each vehicle while in motion
   2. Non-testable hypotheses like the average speed of vehicles is 40 mph and the carbon emission from each of the moving vehicle

73. What would play the most important role in leading to an experiment in the scientific world becoming a scientific law?
   a. Further testing would need to show it is a universally followed rule.
   b. The observation would have to be described in a published scientific article.
   c. The experiment would have to be repeated once or twice.
   d. The observer would need to be a well-known scientist whose authority was accepted.

1.3 The Language of Physics: Physical Quantities and Units

74. Tectonic plates are large segments of the Earth's crust that move slowly. Suppose that one such plate has an average speed of $4.0\ \text{cm/year}$. What distance does it move in $1.0\ \text{s}$ at this speed? What is its speed in kilometers per million years? Report all of your answers using scientific notation.
   a. $1.3 \times 10^{-9}\ \text{m};\ 4.0 \times 10^{1}\ \text{km/million years}$
   b. $1.3 \times 10^{-6}\ \text{m};\ 4.0 \times 10^{1}\ \text{km/million years}$
   c. $1.3 \times 10^{-9}\ \text{m};\ 4.0 \times 10^{-11}\ \text{km/million years}$
   d. $1.3 \times 10^{-6}\ \text{m};\ 4.0 \times 10^{-11}\ \text{km/million years}$

75. At $x = 3$, a function f(x) has a positive value, with a positive slope that is decreasing in magnitude with increasing x. Which option could correspond to f(x)?
   a. $y = 13x$
   b. $y = x^2$
   c. $y = 2x + 9$
   d. $y = \frac{x}{2} + 9$

CHAPTER 2
Motion in One Dimension

Figure 2.1 Shanghai Maglev. At this rate, a train traveling from Boston to Washington, DC, a distance of 439 miles, could make the trip in under an hour and a half. Presently, the fastest train on this route takes over six hours to cover this distance. (Alex Needham, Public Domain)

Chapter Outline

INTRODUCTION Unless you have flown in an airplane, you have probably never traveled faster than 150 mph. Can you imagine traveling in a train like the one shown in Figure 2.1 that goes over 300 mph? Despite the high speed, the people riding in this train may not notice that they are moving at all unless they look out the window! This is because motion, even motion at 300 mph, is relative to the observer.

In this chapter, you will learn why it is important to identify a reference frame in order to clearly describe motion. For now, the motion you describe will be one-dimensional. Within this context, you will learn the difference between distance and displacement as well as the difference between speed and velocity. Then you will look at some graphing and problem-solving techniques.

2.1 Relative Motion, Distance, and Displacement

Section Learning Objectives

By the end of this section, you will be able to do the following:

- Describe motion in different reference frames
- Define distance and displacement, and distinguish between the two
- Solve problems involving distance and displacement

Section Key Terms

displacement	distance	kinematics	magnitude
position	reference frame	scalar	vector

Defining Motion

Our study of physics opens with **kinematics**—the study of motion without considering its causes. Objects are in motion everywhere you look. Everything from a tennis game to a space-probe flyby of the planet Neptune involves motion. When you are resting, your heart moves blood through your veins. Even in inanimate objects, atoms are always moving.

How do you know something is moving? The location of an object at any particular time is its **position**. More precisely, you need to specify its position relative to a convenient **reference frame**. Earth is often used as a reference frame, and we often describe the position of an object as it relates to stationary objects in that reference frame. For example, a rocket launch would be described in terms of the position of the rocket with respect to Earth as a whole, while a professor's position could be described in terms of where she is in relation to the nearby white board. In other cases, we use reference frames that are not stationary but are in motion relative to Earth. To describe the position of a person in an airplane, for example, we use the airplane, not Earth, as the reference frame. (See Figure 2.2.) Thus, you can only know how fast and in what direction an object's position is changing against a background of something else that is either not moving or moving with a known speed and direction. The reference frame is the coordinate system from which the positions of objects are described.

Figure 2.2 Are clouds a useful reference frame for airplane passengers? Why or why not? (Paul Brennan, Public Domain)

Your classroom can be used as a reference frame. In the classroom, the walls are not moving. Your motion as you walk to the door, can be measured against the stationary background of the classroom walls. You can also tell if other things in the classroom are moving, such as your classmates entering the classroom or a book falling off a desk. You can also tell in what direction something is moving in the classroom. You might say, "The teacher is moving toward the door." Your reference frame allows you to determine not only that something is moving but also the direction of motion.

You could also serve as a reference frame for others' movement. If you remained seated as your classmates left the room, you would measure their movement away from your stationary location. If you and your classmates left the room together, then your perspective of their motion would be change. You, as the reference frame, would be moving in the same direction as your other moving classmates. As you will learn in the **Snap Lab**, your description of motion can be quite different when viewed from different reference frames.

Snap Lab

Looking at Motion from Two Reference Frames

In this activity you will look at motion from two reference frames. Which reference frame is correct?

- Choose an open location with lots of space to spread out so there is less chance of tripping or falling due to a collision and/or loose basketballs.
- 1 basketball

Procedure

1. Work with a partner. Stand a couple of meters away from your partner. Have your partner turn to the side so that you are looking at your partner's profile. Have your partner begin bouncing the basketball while standing in place. Describe the motion of the ball.
2. Next, have your partner again bounce the ball, but this time your partner should walk forward with the bouncing ball. You will remain stationary. Describe the ball's motion.
3. Again have your partner walk forward with the bouncing ball. This time, you should move alongside your partner while continuing to view your partner's profile. Describe the ball's motion.
4. Switch places with your partner, and repeat Steps 1–3.

GRASP CHECK

How do the different reference frames affect how you describe the motion of the ball?

a. The motion of the ball is independent of the reference frame and is same for different reference frames.
b. The motion of the ball is independent of the reference frame and is different for different reference frames.
c. The motion of the ball is dependent on the reference frame and is same for different reference frames.
d. The motion of the ball is dependent on the reference frames and is different for different reference frames.

LINKS TO PHYSICS

History: Galileo's Ship

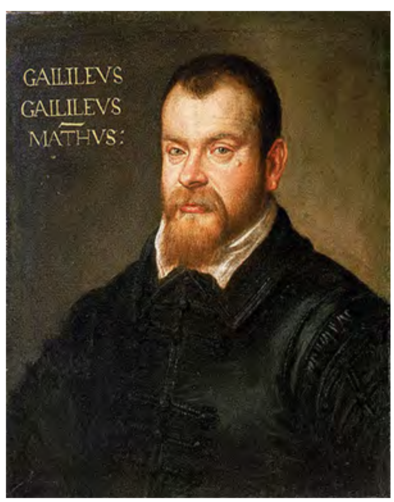


Figure 2.3 Galileo Galilei (1564–1642) studied motion and developed the concept of a reference frame. (Domenico Tintoretto)

The idea that a description of motion depends on the reference frame of the observer has been known for hundreds of years. The 17th-century astronomer Galileo Galilei (Figure 2.3) was one of the first scientists to explore this idea. Galileo suggested the following thought experiment: Imagine a windowless ship moving at a constant speed and direction along a perfectly calm sea. Is there a way that a person inside the ship can determine whether the ship is moving? You can extend this thought experiment by also imagining a person standing on the shore. How can a person on the shore determine whether the ship is moving?

Galileo came to an amazing conclusion. Only by looking at each other can a person in the ship or a person on shore describe the motion of one relative to the other. In addition, their descriptions of motion would be identical. A person inside the ship would describe the person on the land as moving past the ship. The person on shore would describe the ship and the person inside it as moving past. Galileo realized that observers moving at a constant speed and direction relative to each other describe motion in the same way. Galileo had discovered that a description of motion is only meaningful if you specify a reference frame.

GRASP CHECK

Imagine standing on a platform watching a train pass by. According to Galileo's conclusions, how would your description of motion and the description of motion by a person riding on the train compare?

a. I would see the train as moving past me, and a person on the train would see me as stationary.
b. I would see the train as moving past me, and a person on the train would see me as moving past the train.
c. I would see the train as stationary, and a person on the train would see me as moving past the train.
d. I would see the train as stationary, and a person on the train would also see me as stationary.

Distance vs. Displacement

As we study the motion of objects, we must first be able to describe the object's position. Before your parent drives you to school, the car is sitting in your driveway. Your driveway is the starting position for the car. When you reach your high school, the car has changed position. Its new position is your school.

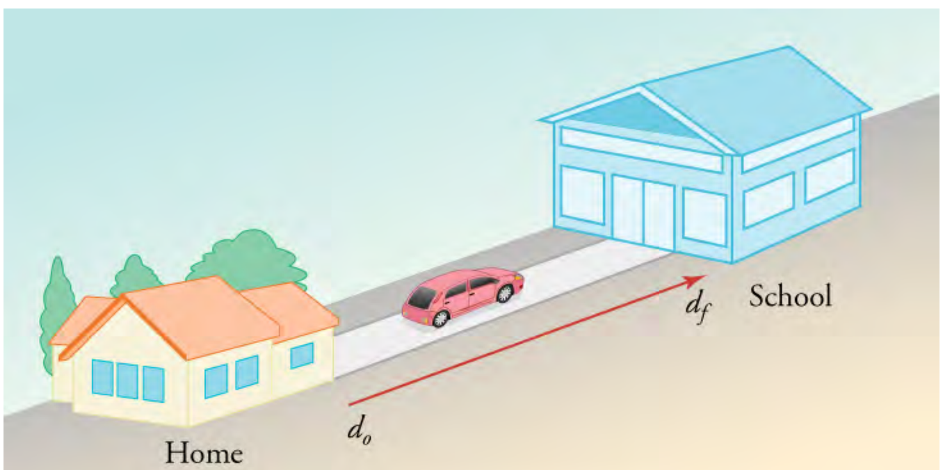


Figure 2.4 Your total change in position is measured from your house to your school.

Physicists use variables to represent terms. We will use **d** to represent car's position. We will use a subscript to differentiate between the initial position, $\mathbf{d}_0$, and the final position, $\mathbf{d}_f$. In addition, vectors, which we will discuss later, will be in bold or will have an arrow above the variable. Scalars will be italicized.

TIPS FOR SUCCESS

In some books, **x** or **s** is used instead of **d** to describe position. In $\mathbf{d}_0$, said *d naught*, the subscript 0 stands for *initial*. When we begin to talk about two-dimensional motion, sometimes other subscripts will be used to describe horizontal position, $\mathbf{d}_x$, or vertical position, $\mathbf{d}_y$. So, you might see references to $\mathbf{d}_{0x}$ and $\mathbf{d}_{fy}$.

Now imagine driving from your house to a friend's house located several kilometers away. How far would you drive? The **distance** an object moves is the length of the path between its initial position and its final position. The distance you drive to your friend's house depends on your path. As shown in Figure 2.5, distance is different from the length of a straight line between two points. The distance you drive to your friend's house is probably longer than the straight line between the two houses.

Figure 2.5 A short line separates the starting and ending points of this motion, but the distance along the path of motion is considerably longer.

We often want to be more precise when we talk about position. The description of an object's motion often includes more than just the distance it moves. For instance, if it is a five kilometer drive to school, the distance traveled is 5 kilometers. After dropping you off at school and driving back home, your parent will have traveled a total distance of 10 kilometers. The car and your parent will end up in the same starting position in space. The net change in position of an object is its **displacement**, or $\Delta \mathbf{d}$. The Greek letter delta, Δ, means *change in*.

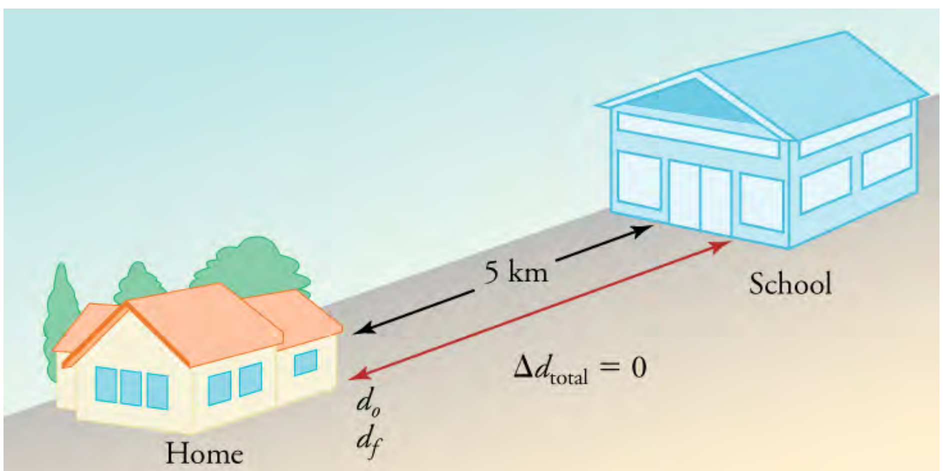


Figure 2.6 The total distance that your car travels is 10 km, but the total displacement is 0.

Snap Lab

Distance vs. Displacement

In this activity you will compare distance and displacement. Which term is more useful when making measurements?

- 1 recorded song available on a portable device
- 1 tape measure
- 3 pieces of masking tape
- A room (like a gym) with a wall that is large and clear enough for all pairs of students to walk back and forth without running into each other.

Procedure

1. One student from each pair should stand with their back to the longest wall in the classroom. Students should stand at least 0.5 meters away from each other. Mark this starting point with a piece of masking tape.
2. The second student from each pair should stand facing their partner, about two to three meters away. Mark this point

with a second piece of masking tape.
3. Student pairs line up at the starting point along the wall.
4. The teacher turns on the music. Each pair walks back and forth from the wall to the second marked point until the music stops playing. Keep count of the number of times you walk across the floor.
5. When the music stops, mark your ending position with the third piece of masking tape.
6. Measure from your starting, initial position to your ending, final position.
7. Measure the length of your path from the starting position to the second marked position. Multiply this measurement by the total number of times you walked across the floor. Then add this number to your measurement from step 6.
8. Compare the two measurements from steps 6 and 7.

GRASP CHECK

1. Which measurement is your total distance traveled?
2. Which measurement is your displacement?
3. When might you want to use one over the other?

a. Measurement of the total length of your path from the starting position to the final position gives the distance traveled, and the measurement from your initial position to your final position is the displacement. Use distance to describe the total path between starting and ending points,and use displacement to describe the shortest path between starting and ending points.
b. Measurement of the total length of your path from the starting position to the final position is distance traveled, and the measurement from your initial position to your final position is displacement. Use distance to describe the shortest path between starting and ending points, and use displacement to describe the total path between starting and ending points.
c. Measurement from your initial position to your final position is distance traveled, and the measurement of the total length of your path from the starting position to the final position is displacement. Use distance to describe the total path between starting and ending points, and use displacement to describe the shortest path between starting and ending points.
d. Measurement from your initial position to your final position is distance traveled, and the measurement of the total length of your path from the starting position to the final position is displacement. Use distance to describe the shortest path between starting and ending points, and use displacement to describe the total path between starting and ending points.

If you are describing only your drive to school, then the distance traveled and the displacement are the same—5 kilometers. When you are describing the entire round trip, distance and displacement are different. When you describe distance, you only include the **magnitude**, the size or amount, of the distance traveled. However, when you describe the displacement, you take into account both the magnitude of the change in position and the direction of movement.

In our previous example, the car travels a total of 10 kilometers, but it drives five of those kilometers forward toward school and five of those kilometers back in the opposite direction. If we ascribe the forward direction a positive (+) and the opposite direction a negative (–), then the two quantities will cancel each other out when added together.

A quantity, such as distance, that has magnitude (i.e., how big or how much) but does not take into account direction is called a **scalar**. A quantity, such as displacement, that has both magnitude and direction is called a **vector**.

WATCH PHYSICS

Vectors & Scalars

This video (http://openstax.org/l/28vectorscalar) introduces and differentiates between vectors and scalars. It also introduces quantities that we will be working with during the study of kinematics.

Click to view content (https://www.khanacademy.org/embed_video?v=ihNZlp7iUHE)

GRASP CHECK

How does this video (https://www.khanacademy.org/science/ap-physics-1/ap-one-dimensional-motion/ap-physics-foundations/v/introduction-to-vectors-and-scalars) help you understand the difference between distance and displacement? Describe the differences between vectors and scalars using physical quantities as examples.

a. It explains that distance is a vector and direction is important, whereas displacement is a scalar and it has no direction attached to it.
b. It explains that distance is a scalar and direction is important, whereas displacement is a vector and it has no direction attached to it.
c. It explains that distance is a scalar and it has no direction attached to it, whereas displacement is a vector and direction is important.
d. It explains that both distance and displacement are scalar and no directions are attached to them.

Displacement Problems

Hopefully you now understand the conceptual difference between distance and displacement. Understanding concepts is half the battle in physics. The other half is math. A stumbling block to new physics students is trying to wade through the math of physics while also trying to understand the associated concepts. This struggle may lead to misconceptions and answers that make no sense. Once the concept is mastered, the math is far less confusing.

So let's review and see if we can make sense of displacement in terms of numbers and equations. You can calculate an object's displacement by subtracting its original position, $\mathbf{d}_o$, from its final position $\mathbf{d}_f$. In math terms that means

$$\Delta \mathbf{d} = \mathbf{d}_\mathrm{f} - \mathbf{d}_0 .$$

If the final position is the same as the initial position, then $\Delta \mathbf{d} = 0$.

To assign numbers and/or direction to these quantities, we need to define an axis with a positive and a negative direction. We also need to define an origin, or *O*. In Figure 2.6, the axis is in a straight line with home at zero and school in the positive direction. If we left home and drove the opposite way from school, motion would have been in the negative direction. We would have assigned it a negative value. In the round-trip drive, $\mathbf{d}_\mathrm{f}$ and $\mathbf{d}_\mathrm{o}$ were both at zero kilometers. In the one way trip to school, $\mathbf{d}_\mathrm{f}$ was at 5 kilometers and $\mathbf{d}_\mathrm{o}$ was at zero km. So, $\Delta \mathbf{d}$ was 5 kilometers.

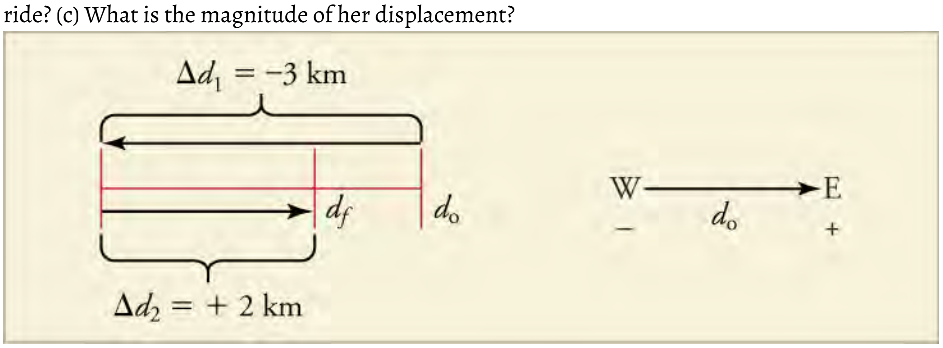
TIPS FOR SUCCESS

You may place your origin wherever you would like. You have to make sure that you calculate all distances consistently from your zero and you define one direction as positive and the other as negative. Therefore, it makes sense to choose the easiest axis, direction, and zero. In the example above, we took home to be zero because it allowed us to avoid having to interpret a solution with a negative sign.

WORKED EXAMPLE

Calculating Distance and Displacement

A cyclist rides 3 km west and then turns around and rides 2 km east. (a) What is her displacement? (b) What distance does she ride? (c) What is the magnitude of her displacement?



Strategy

To solve this problem, we need to find the difference between the final position and the initial position while taking care to note the direction on the axis. The final position is the sum of the two displacements, $\Delta\mathbf{d}_1$ and $\Delta\mathbf{d}_2$.

Solution

a. Displacement: The rider's displacement is $\Delta\mathbf{d} = \mathbf{d}_\mathrm{f} - \mathbf{d}_0 = -1\ \ \mathrm{km}$.
b. Distance: The distance traveled is 3 km + 2 km = 5 km.
c. The magnitude of the displacement is 1 km.

Discussion

The displacement is negative because we chose east to be positive and west to be negative. We could also have described the displacement as 1 km west. When calculating displacement, the direction mattered, but when calculating distance, the direction did not matter. The problem would work the same way if the problem were in the north–south or *y*-direction.

TIPS FOR SUCCESS

Physicists like to use standard units so it is easier to compare notes. The standard units for calculations are called *SI* units (International System of Units). SI units are based on the metric system. The SI unit for displacement is the meter (m), but sometimes you will see a problem with kilometers, miles, feet, or other units of length. If one unit in a problem is an SI unit and another is not, you will need to convert all of your quantities to the same system before you can carry out the calculation.

Practice Problems

1. On an axis in which moving from right to left is positive, what is the displacement and distance of a student who walks 32 m to the right and then 17 m to the left?
   a. Displacement is -15 m and distance is -49 *m*.
   b. Displacement is -15 m and distance is 49 m.
   c. Displacement is 15 m and distance is -49 m.
   d. Displacement is 15 m and distance is 49 m.

2. Tiana jogs 1.5 km along a straight path and then turns and jogs 2.4 km in the opposite direction. She then turns back and jogs 0.7 km in the original direction. Let Tiana's original direction be the positive direction. What are the displacement and distance she jogged?
   a. Displacement is 4.6 km,and distance is -0.2 km.
   b. Displacement is -0.2 km, and distance is 4.6 km.
   c. Displacement is 4.6 km, and distance is +0.2 km.
   d. Displacement is +0.2 km, and distance is 4.6 km.

WORK IN PHYSICS

Mars Probe Explosion

Figure 2.7 The Mars Climate Orbiter disaster illustrates the importance of using the correct calculations in physics. (NASA)

Physicists make calculations all the time, but they do not always get the right answers. In 1998, NASA, the National Aeronautics and Space Administration, launched the Mars Climate Orbiter, shown in Figure 2.7, a $125-million-dollar satellite designed to monitor the Martian atmosphere. It was supposed to orbit the planet and take readings from a safe distance. The American scientists made calculations in English units (feet, inches, pounds, etc.) and forgot to convert their answers to the standard metric SI units. This was a very costly mistake. Instead of orbiting the planet as planned, the Mars Climate Orbiter ended up flying into the Martian atmosphere. The probe disintegrated. It was one of the biggest embarrassments in NASA's history.

GRASP CHECK

In 1999 the Mars Climate Orbiter crashed because calculation were performed in English units instead of SI units. At one point the orbiter was just 187,000 feet above the surface, which was too close to stay in orbit. What was the height of the orbiter at this time in kilometers? (Assume 1 meter equals 3.281 feet.)

a. 16 km
b. 18 km
c. 57 km
d. 614 km

Check Your Understanding

3. What does it mean when motion is described as relative?
   a. It means that motion of any object is described relative to the motion of Earth.
   b. It means that motion of any object is described relative to the motion of any other object.
   c. It means that motion is independent of the frame of reference.
   d. It means that motion depends on the frame of reference selected.

4. If you and a friend are standing side-by-side watching a soccer game, would you both view the motion from the same reference frame?
   a. Yes, we would both view the motion from the same reference point because both of us are at rest in Earth's frame of reference.
   b. Yes, we would both view the motion from the same reference point because both of us are observing the motion from two points on the same straight line.
   c. No, we would both view the motion from different reference points because motion is viewed from two different points; the reference frames are similar but not the same.
   d. No, we would both view the motion from different reference points because response times may be different; so, the motion observed by both of us would be different.

5. What is the difference between distance and displacement?
   a. Distance has both magnitude and direction, while displacement has magnitude but no direction.
   b. Distance has magnitude but no direction, while displacement has both magnitude and direction.
   c. Distance has magnitude but no direction, while displacement has only direction.
   d. There is no difference. Both distance and displacement have magnitude and direction.

6. Which situation correctly identifies a race car's distance traveled and the magnitude of displacement during a one-lap car race?
   a. The perimeter of the race track is the distance, and the shortest distance between the start line and the finish line is the magnitude of displacement.
   b. The perimeter of the race track is the magnitude of displacement, and the shortest distance between the start and finish line is the distance.
   c. The perimeter of the race track is both the distance and magnitude of displacement.
   d. The shortest distance between the start line and the finish line is both the distance and magnitude of displacement.

7. Why is it important to specify a reference frame when describing motion?
   a. Because Earth is continuously in motion; an object at rest on Earth will be in motion when viewed from outer space.
   b. Because the position of a moving object can be defined only when there is a fixed reference frame.

c. Because motion is a relative term; it appears differently when viewed from different reference frames.
d. Because motion is always described in Earth's frame of reference; if another frame is used, it has to be specified with each situation.

2.2 Speed and Velocity

Section Learning Objectives

By the end of this section, you will be able to do the following:

- Calculate the average speed of an object
- Relate displacement and average velocity

Section Key Terms

average speed	average velocity	instantaneous speed
instantaneous velocity	speed	velocity

Speed

There is more to motion than distance and displacement. Questions such as, "How long does a foot race take?" and "What was the runner's speed?" cannot be answered without an understanding of other concepts. In this section we will look at time, speed, and velocity to expand our understanding of motion.

A description of how fast or slow an object moves is its speed. **Speed** is the rate at which an object changes its location. Like distance, speed is a scalar because it has a magnitude but not a direction. Because speed is a rate, it depends on the time interval of motion. You can calculate the elapsed time or the change in time, Δt, of motion as the difference between the ending time and the beginning time

$$\Delta t = t_f - t_0.$$

The SI unit of time is the second (s), and the SI unit of speed is meters per second (m/s), but sometimes kilometers per hour (km/h), miles per hour (mph) or other units of speed are used.

When you describe an object's speed, you often describe the average over a time period. **Average speed**, v_{avg}, is the distance traveled divided by the time during which the motion occurs.

$$v_{avg} = \frac{\text{distance}}{\text{time}}$$

You can, of course, rearrange the equation to solve for either distance or time

$$\text{time} = \frac{\text{distance}}{v_{avg}}.$$

$$\text{distance} = v_{avg} \times \text{time}$$

Suppose, for example, a car travels 150 kilometers in 3.2 hours. Its average speed for the trip is

$$\begin{aligned} v_{avg} &= \frac{\text{distance}}{\text{time}} \\ &= \frac{150 \text{ km}}{3.2 \text{ h}} \\ &= 47 \text{ km/h}. \end{aligned}$$

A car's speed would likely increase and decrease many times over a 3.2 hour trip. Its speed at a specific instant in time, however, is its **instantaneous speed**. A car's speedometer describes its instantaneous speed.

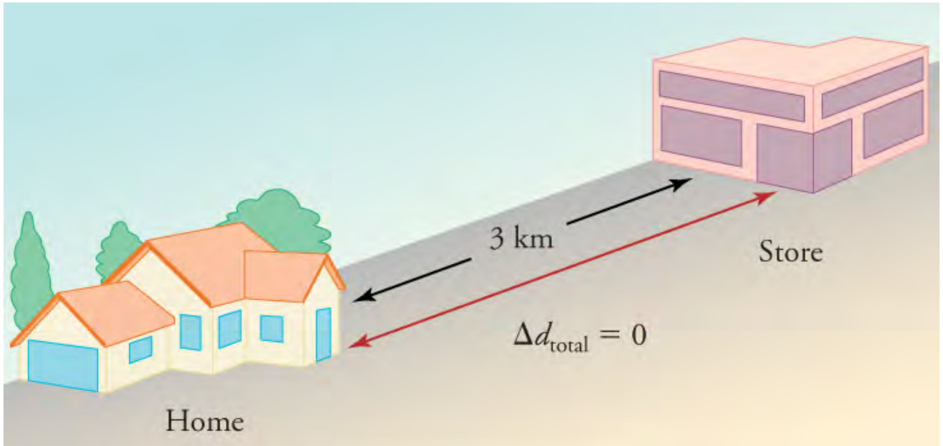


Figure 2.8 During a 30-minute round trip to the store, the total distance traveled is 6 km. The average speed is 12 km/h. The displacement for the round trip is zero, because there was no net change in position.

WORKED EXAMPLE

Calculating Average Speed

A marble rolls 5.2 m in 1.8 s. What was the marble's average speed?

Strategy

We know the distance the marble travels, 5.2 m, and the time interval, 1.8 s. We can use these values in the average speed equation.

Solution

$$v_{avg} = \frac{\text{distance}}{\text{time}} = \frac{5.2 \text{ m}}{1.8 \text{ s}} = 2.9 \text{ m/s}$$

Discussion

Average speed is a scalar, so we do not include direction in the answer. We can check the reasonableness of the answer by estimating: 5 meters divided by 2 seconds is 2.5 m/s. Since 2.5 m/s is close to 2.9 m/s, the answer is reasonable. This is about the speed of a brisk walk, so it also makes sense.

Practice Problems

8. A pitcher throws a baseball from the pitcher's mound to home plate in 0.46 s. The distance is 18.4 m. What was the average speed of the baseball?
   a. 40 m/s
   b. - 40 m/s
   c. 0.03 m/s
   d. 8.5 m/s

9. Cassie walked to her friend's house with an average speed of 1.40 m/s. The distance between the houses is 205 m. How long did the trip take her?
   a. 146 s
   b. 0.01 s
   c. 2.50 min
   d. 287 s

Velocity

The vector version of speed is velocity. **Velocity** describes the speed and direction of an object. As with speed, it is useful to describe either the average velocity over a time period or the velocity at a specific moment. **Average velocity** is displacement divided by the time over which the displacement occurs.

$$v_{avg} = \frac{\text{distance}}{\text{time}} = \frac{\Delta \mathbf{d}}{\Delta t} = \frac{\mathbf{d}_f - \mathbf{d}_0}{t_f - t_0}$$

Velocity, like speed, has SI units of meters per second (m/s), but because it is a vector, you must also include a direction. Furthermore, the variable **v** for velocity is bold because it is a vector, which is in contrast to the variable *v* for speed which is italicized because it is a scalar quantity.

TIPS FOR SUCCESS

It is important to keep in mind that the average speed is not the same thing as the average velocity without its direction. Like we saw with displacement and distance in the last section, changes in direction over a time interval have a bigger effect on speed and velocity.

Suppose a passenger moved toward the back of a plane with an average velocity of –4 m/s. We cannot tell from the average velocity whether the passenger stopped momentarily or backed up before he got to the back of the plane. To get more details, we must consider smaller segments of the trip over smaller time intervals such as those shown in Figure 2.9. If you consider infinitesimally small intervals, you can define **instantaneous velocity**, which is the velocity at a specific instant in time. Instantaneous velocity and average velocity are the same if the velocity is constant.

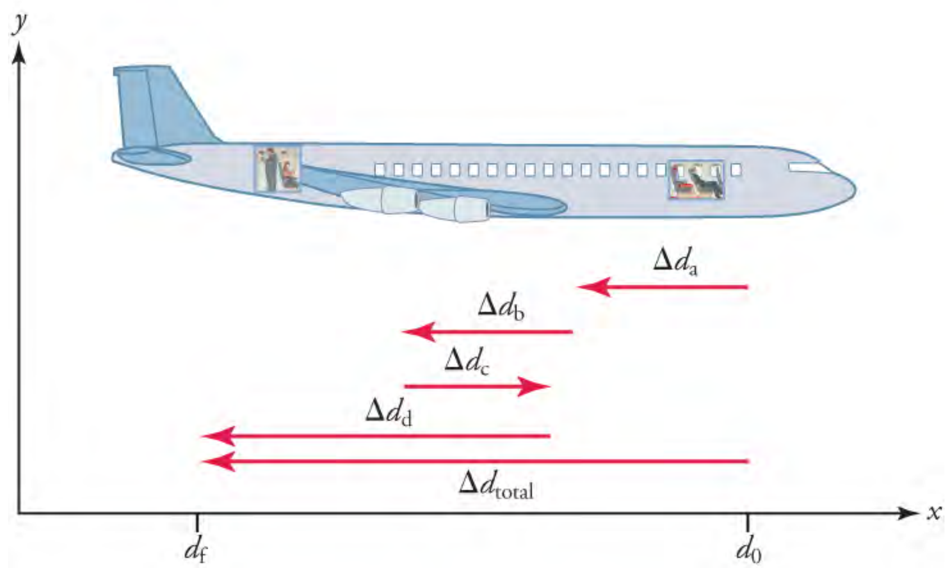


Figure 2.9 The diagram shows a more detailed record of an airplane passenger heading toward the back of the plane, showing smaller segments of his trip.

Earlier, you have read that distance traveled can be different than the magnitude of displacement. In the same way, speed can be different than the magnitude of velocity. For example, you drive to a store and return home in half an hour. If your car's odometer shows the total distance traveled was 6 km, then your average speed was 12 km/h. Your average velocity, however, was zero because your displacement for the round trip is zero.

WATCH PHYSICS

Calculating Average Velocity or Speed

This video (http://openstax.org/l/28avgvelocity) reviews vectors and scalars and describes how to calculate average velocity and average speed when you know displacement and change in time. The video also reviews how to convert km/h to m/s.

Click to view content (https://www.khanacademy.org/embed_video?v=MAS6mBRZZXA)

GRASP CHECK

Which of the following fully describes a vector and a scalar quantity and correctly provides an example of each?

a. A scalar quantity is fully described by its magnitude, while a vector needs both magnitude and direction to fully describe it. Displacement is an example of a scalar quantity and time is an example of a vector quantity.
b. A scalar quantity is fully described by its magnitude, while a vector needs both magnitude and direction to fully describe it. Time is an example of a scalar quantity and displacement is an example of a vector quantity.
c. A scalar quantity is fully described by its magnitude and direction, while a vector needs only magnitude to fully describe it. Displacement is an example of a scalar quantity and time is an example of a vector quantity.
d. A scalar quantity is fully described by its magnitude and direction, while a vector needs only magnitude to fully describe it. Time is an example of a scalar quantity and displacement is an example of a vector quantity.

WORKED EXAMPLE

Calculating Average Velocity

A student has a displacement of 304 m north in 180 s. What was the student's average velocity?

Strategy

We know that the displacement is 304 m north and the time is 180 s. We can use the formula for average velocity to solve the problem.

Solution

$$\mathbf{v}_{\text{avg}} = \frac{\Delta \mathbf{d}}{\Delta t} = \frac{304\ \text{m}}{180\ \text{s}} = 1.7\ \text{m/s north} \tag{2.1}$$

Discussion

Since average velocity is a vector quantity, you must include direction as well as magnitude in the answer. Notice, however, that the direction can be omitted until the end to avoid cluttering the problem. Pay attention to the significant figures in the problem. The distance 304 m has three significant figures, but the time interval 180 s has only two, so the quotient should have only two significant figures.

TIPS FOR SUCCESS

Note the way scalars and vectors are represented. In this book d represents distance and displacement. Similarly, v represents speed, and v represents velocity. A variable that is not bold indicates a scalar quantity, and a bold variable indicates a vector quantity. Vectors are sometimes represented by small arrows above the variable.

WORKED EXAMPLE

Solving for Displacement when Average Velocity and Time are Known

Layla jogs with an average velocity of 2.4 m/s east. What is her displacement after 46 seconds?

Strategy

We know that Layla's average velocity is 2.4 m/s east, and the time interval is 46 seconds. We can rearrange the average velocity formula to solve for the displacement.

Solution

$$\begin{aligned} \mathbf{v}_{\text{avg}} &= \frac{\Delta \mathbf{d}}{\Delta t} \\ \Delta \mathbf{d} &= \mathbf{v}_{avg} \Delta t \\ &= (2.4\ \text{m/s})(46\ \text{s}) \\ &= 1.1 \times 10^2\ \text{m east} \end{aligned} \tag{2.2}$$

Discussion

The answer is about 110 m east, which is a reasonable displacement for slightly less than a minute of jogging. A calculator shows the answer as 110.4 m. We chose to write the answer using scientific notation because we wanted to make it clear that we only used two significant figures.

TIPS FOR SUCCESS

Dimensional analysis is a good way to determine whether you solved a problem correctly. Write the calculation using only units to be sure they match on opposite sides of the equal mark. In the worked example, you have m = (m/s)(s). Since seconds is in the denominator for the average velocity and in the numerator for the time, the unit cancels out leaving only m and, of course, m = m.

WORKED EXAMPLE

Solving for Time when Displacement and Average Velocity are Known

Phillip walks along a straight path from his house to his school. How long will it take him to get to school if he walks 428 m west with an average velocity of 1.7 m/s west?

Strategy

We know that Phillip's displacement is 428 m west, and his average velocity is 1.7 m/s west. We can calculate the time required for the trip by rearranging the average velocity equation.

Solution

$$\begin{aligned} \mathbf{v}_{\text{avg}} &= \frac{\Delta \mathbf{d}}{\Delta t} \\ \Delta t &= \frac{\Delta \mathbf{d}}{\mathbf{v}_{\text{avg}}} \\ &= \frac{428 \text{ m}}{1.7 \text{ m/s}} \\ &= 2.5 \times 10^2 \text{ s} \end{aligned} \tag{2.3}$$

Discussion

Here again we had to use scientific notation because the answer could only have two significant figures. Since time is a scalar, the answer includes only a magnitude and not a direction.

Practice Problems

10. A trucker drives along a straight highway for 0.25 h with a displacement of 16 km south. What is the trucker's average velocity?
    a. 4 km/h north
    b. 4 km/h south
    c. 64 km/h north
    d. 64 km/h south

11. A bird flies with an average velocity of 7.5 m/s east from one branch to another in 2.4 s. It then pauses before flying with an average velocity of 6.8 m/s east for 3.5 s to another branch. What is the bird's total displacement from its starting point?
    a. 42 m west
    b. 6 m west
    c. 6 m east
    d. 42 m east

Virtual Physics

The Walking Man

In this simulation you will put your cursor on the man and move him first in one direction and then in the opposite direction. Keep the *Introduction* tab active. You can use the *Charts* tab after you learn about graphing motion later in this chapter. Carefully watch the sign of the numbers in the position and velocity boxes. Ignore the acceleration box for now. See if you can make the man's position positive while the velocity is negative. Then see if you can do the opposite.

[Click to view content (https://archive.cnx.org/specials/e2ca52af-8c6b-450e-ac2f-9300b38e8739/moving-man/)](https://archive.cnx.org/specials/e2ca52af-8c6b-450e-ac2f-9300b38e8739/moving-man/)

GRASP CHECK

Which situation correctly describes when the moving man's position was negative but his velocity was positive?

a. Man moving toward 0 from left of 0
b. Man moving toward 0 from right of 0
c. Man moving away from 0 from left of 0
d. Man moving away from 0 from right of 0

Check Your Understanding

12. Two runners travel along the same straight path. They start at the same time, and they end at the same time, but at the halfway mark, they have different instantaneous velocities. Is it possible for them to have the same average velocity for the trip?

a. Yes, because average velocity depends on the net or total displacement.
b. Yes, because average velocity depends on the total distance traveled.
c. No, because the velocities of both runners must remain the exactly same throughout the journey.
d. No, because the instantaneous velocities of the runners must remain same midway but can be different elsewhere.

13. If you divide the total distance traveled on a car trip (as determined by the odometer) by the time for the trip, are you calculating the average speed or the magnitude of the average velocity, and under what circumstances are these two quantities the same?

a. Average speed. Both are the same when the car is traveling at a constant speed and changing direction.
b. Average speed. Both are the same when the speed is constant and the car does not change its direction.
c. Magnitude of average velocity. Both are same when the car is traveling at a constant speed.
d. Magnitude of average velocity. Both are same when the car does not change its direction.

14. Is it possible for average velocity to be negative?

a. Yes, in cases when the net displacement is negative.
b. Yes, if the body keeps changing its direction during motion.
c. No, average velocity describes only magnitude and not the direction of motion.
d. No, average velocity describes only the magnitude in the positive direction of motion.

2.3 Position vs. Time Graphs

Section Learning Objectives

By the end of this section, you will be able to do the following:

- Explain the meaning of slope in position vs. time graphs
- Solve problems using position vs. time graphs

Section Key Terms

dependent variable	independent variable	tangent

Graphing Position as a Function of Time

A graph, like a picture, is worth a thousand words. Graphs not only contain numerical information, they also reveal relationships between physical quantities. In this section, we will investigate kinematics by analyzing graphs of position over time.

Graphs in this text have perpendicular axes, one horizontal and the other vertical. When two physical quantities are plotted against each other, the horizontal axis is usually considered the **independent variable**, and the vertical axis is the **dependent variable**. In algebra, you would have referred to the horizontal axis as the x-axis and the vertical axis as the y-axis. As in Figure 2.10, a straight-line graph has the general form $y = mx + b$.

Here m is the slope, defined as the rise divided by the run (as seen in the figure) of the straight line. The letter b is the y-intercept which is the point at which the line crosses the vertical, y-axis. In terms of a physical situation in the real world, these quantities will take on a specific significance, as we will see below. (Figure 2.10.)

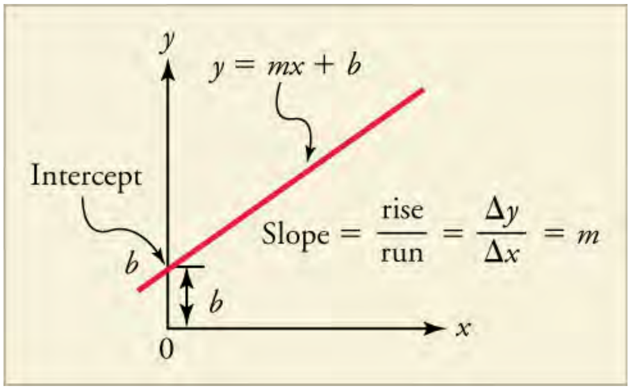


Figure 2.10 The diagram shows a straight-line graph. The equation for the straight line is y equals $mx + b$.

In physics, time is usually the independent variable. Other quantities, such as displacement, are said to depend upon it. A graph of position versus time, therefore, would have position on the vertical axis (dependent variable) and time on the horizontal axis (independent variable). In this case, to what would the slope and y-intercept refer? Let's look back at our original example when studying distance and displacement.

The drive to school was 5 km from home. Let's assume it took 10 minutes to make the drive and that your parent was driving at a constant velocity the whole time. The position versus time graph for this section of the trip would look like that shown in Figure 2.11.

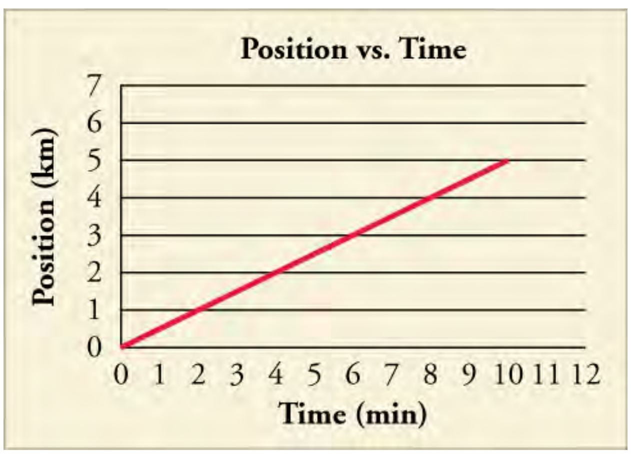


Figure 2.11 A graph of position versus time for the drive to school is shown. What would the graph look like if we added the return trip?

As we said before, $\mathbf{d}_0 = 0$ because we call home our O and start calculating from there. In Figure 2.11, the line starts at $\mathbf{d} = 0$, as well. This is the b in our equation for a straight line. Our initial position in a position versus time graph is always the place where the graph crosses the x-axis at $t = 0$. What is the slope? The *rise* is the change in position, (i.e., displacement) and the *run* is the change in time. This relationship can also be written

$$\frac{\Delta \mathbf{d}}{\Delta t}. \tag{2.4}$$

This relationship was how we defined average velocity. Therefore, the slope in a $\mathbf{d}$ versus t graph, is the average velocity.

TIPS FOR SUCCESS

Sometimes, as is the case where we graph both the trip to school and the return trip, the behavior of the graph looks different during different time intervals. If the graph looks like a series of straight lines, then you can calculate the average velocity for each time interval by looking at the slope. If you then want to calculate the average velocity for the entire trip, you can do a weighted average.

Let's look at another example. Figure 2.12 shows a graph of position versus time for a jet-powered car on a very flat dry lake bed in Nevada.

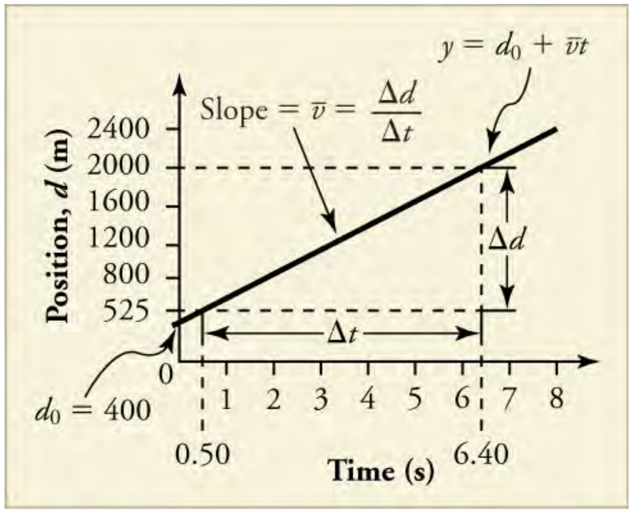


Figure 2.12 The diagram shows a graph of position versus time for a jet-powered car on the Bonneville Salt Flats.

Using the relationship between dependent and independent variables, we see that the slope in the graph in Figure 2.12 is average velocity, $\mathbf{v}_{avg}$ and the intercept is displacement at time zero—that is, $\mathbf{d}_0$. Substituting these symbols into $y = mx + b$ gives

$$\mathbf{d} = \mathbf{v}t + \mathbf{d}_0 \tag{2.5}$$

or

$$\mathbf{d} = \mathbf{d}_0 + \mathbf{v}t. \tag{2.6}$$

Thus a graph of position versus time gives a general relationship among displacement, velocity, and time, as well as giving detailed numerical information about a specific situation. From the figure we can see that the car has a position of 400 m at $t = 0$ s, 650 m at $t = 1.0$ s, and so on. And we can learn about the object's velocity, as well.

Snap Lab

Graphing Motion

In this activity, you will release a ball down a ramp and graph the ball's displacement vs. time.

- Choose an open location with lots of space to spread out so there is less chance for tripping or falling due to rolling balls.

- 1 ball
- 1 board
- 2 or 3 books
- 1 stopwatch
- 1 tape measure
- 6 pieces of masking tape
- 1 piece of graph paper
- 1 pencil

Procedure

1. Build a ramp by placing one end of the board on top of the stack of books. Adjust location, as necessary, until there is no obstacle along the straight line path from the bottom of the ramp until at least the next 3 m.
2. Mark distances of 0.5 m, 1.0 m, 1.5 m, 2.0 m, 2.5 m, and 3.0 m from the bottom of the ramp. Write the distances on the tape.

3. Have one person take the role of the experimenter. This person will release the ball from the top of the ramp. If the ball does not reach the 3.0 m mark, then increase the incline of the ramp by adding another book. Repeat this Step as necessary.
4. Have the experimenter release the ball. Have a second person, the timer, begin timing the trial once the ball reaches the bottom of the ramp and stop the timing once the ball reaches 0.5 m. Have a third person, the recorder, record the time in a data table.
5. Repeat Step 4, stopping the times at the distances of 1.0 m, 1.5 m, 2.0 m, 2.5 m, and 3.0 m from the bottom of the ramp.
6. Use your measurements of time and the displacement to make a position vs. time graph of the ball's motion.
7. Repeat Steps 4 through 6, with different people taking on the roles of experimenter, timer, and recorder. Do you get the same measurement values regardless of who releases the ball, measures the time, or records the result? Discuss possible causes of discrepancies, if any.

GRASP CHECK

True or False: The average speed of the ball will be less than the average velocity of the ball.

a. True
b. False

Solving Problems Using Position vs. Time Graphs

So how do we use graphs to solve for things we want to know like velocity?

WORKED EXAMPLE

Using Position–Time Graph to Calculate Average Velocity: Jet Car

Find the average velocity of the car whose position is graphed in Figure 1.13.

Strategy

The slope of a graph of d vs. t is average velocity, since slope equals rise over run.

$$\text{slope} = \frac{\Delta \mathbf{d}}{\Delta t} = \mathbf{v} \tag{2.7}$$

Since the slope is constant here, any two points on the graph can be used to find the slope.

Solution

1. Choose two points on the line. In this case, we choose the points labeled on the graph: (6.4 s, 2000 m) and (0.50 s, 525 m). (Note, however, that you could choose any two points.)
2. Substitute the **d** and t values of the chosen points into the equation. Remember in calculating change (Δ) we always use final value minus initial value.

$$\begin{aligned} \mathbf{v} &= \frac{\Delta \mathbf{d}}{\Delta t} \\ &= \frac{2000\ \text{m} - 525\ \text{m}}{6.4\ \text{s} - 0.50\ \text{s}}, \\ &= 250\ \text{m/s} \end{aligned} \tag{2.8}$$

Discussion

This is an impressively high land speed (900 km/h, or about 560 mi/h): much greater than the typical highway speed limit of 27 m/s or 96 km/h, but considerably shy of the record of 343 m/s or 1,234 km/h, set in 1997.

But what if the graph of the position is more complicated than a straight line? What if the object speeds up or turns around and goes backward? Can we figure out anything about its velocity from a graph of that kind of motion? Let's take another look at the jet-powered car. The graph in Figure 2.13 shows its motion as it is getting up to speed after starting at rest. Time starts at zero for this motion (as if measured with a stopwatch), and the displacement and velocity are initially 200 m and 15 m/s, respectively.

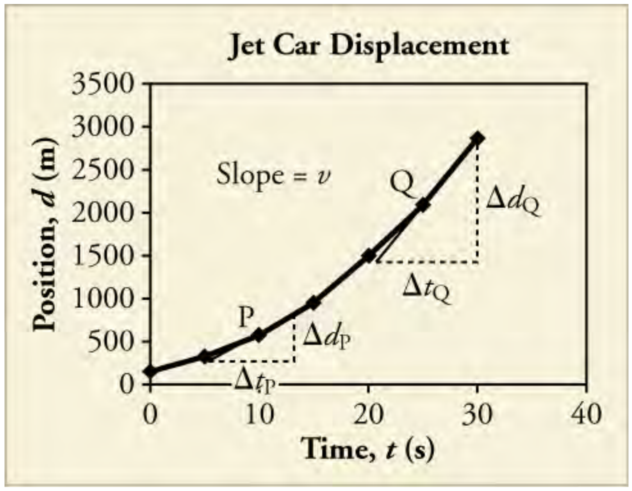


Figure 2.13 The diagram shows a graph of the position of a jet-powered car during the time span when it is speeding up. The slope of a distance versus time graph is velocity. This is shown at two points. Instantaneous velocity at any point is the slope of the tangent at that point.

Figure 2.14 A U.S. Air Force jet car speeds down a track. (Matt Trostle, Flickr)

The graph of position versus time in Figure 2.13 is a curve rather than a straight line. The slope of the curve becomes steeper as time progresses, showing that the velocity is increasing over time. The slope at any point on a position-versus-time graph is the instantaneous velocity at that point. It is found by drawing a straight line **tangent** to the curve at the point of interest and taking the slope of this straight line. Tangent lines are shown for two points in Figure 2.13. The average velocity is the net displacement divided by the time traveled.

WORKED EXAMPLE

Using Position–Time Graph to Calculate Average Velocity: Jet Car, Take Two

Calculate the instantaneous velocity of the jet car at a time of 25 s by finding the slope of the tangent line at point Q in Figure 2.13.

Strategy

The slope of a curve at a point is equal to the slope of a straight line tangent to the curve at that point.

Solution

1. Find the tangent line to the curve at $t = 25\ \text{s}$.
2. Determine the endpoints of the tangent. These correspond to a position of 1,300 m at time 19 s and a position of 3120 m at time 32 s.

3. Plug these endpoints into the equation to solve for the slope, **v**.

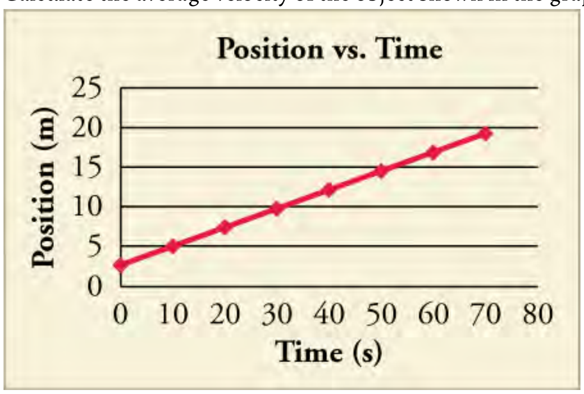
$$\begin{aligned}\text{slope} &= v_Q = \frac{\Delta d_Q}{\Delta t_Q} \\ &= \frac{(3120-1300)\ \text{m}}{(32-19)\ \text{s}} \\ &= \frac{1820\ \ \text{m}}{13\ \ \text{s}} \\ &= 140\ \ \text{m/s}\end{aligned} \tag{2.9}$$

Discussion

The entire graph of **v** versus *t* can be obtained in this fashion.

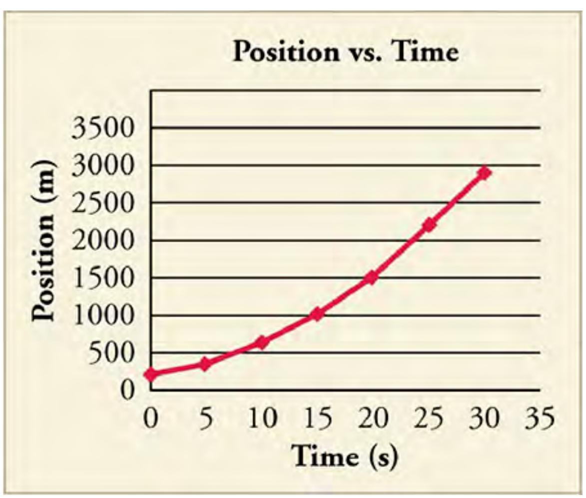
Practice Problems

15. Calculate the average velocity of the object shown in the graph below over the whole time interval.



a. 0.25 m/s
b. 0.31 m/s
c. 3.2 m/s
d. 4.00 m/s

16. True or False: By taking the slope of the curve in the graph you can verify that the velocity of the jet car is 115 m/s at $t = 20$ s.



a. True
b. False

Check Your Understanding

17. Which of the following information about motion can be determined by looking at a position vs. time graph that is a straight line?

a. frame of reference
b. average acceleration
c. velocity
d. direction of force applied

18. True or False: The position vs time graph of an object that is speeding up is a straight line.
a. True
b. False

2.4 Velocity vs. Time Graphs

Section Learning Objectives

By the end of this section, you will be able to do the following:

- Explain the meaning of slope and area in velocity vs. time graphs
- Solve problems using velocity vs. time graphs

Section Key Terms

acceleration

Graphing Velocity as a Function of Time

Earlier, we examined graphs of position versus time. Now, we are going to build on that information as we look at graphs of velocity vs. time. Velocity is the rate of change of displacement. **Acceleration** is the rate of change of velocity; we will discuss acceleration more in another chapter. These concepts are all very interrelated.

Virtual Physics

Maze Game

In this simulation you will use a vector diagram to manipulate a ball into a certain location without hitting a wall. You can manipulate the ball directly with position or by changing its velocity. Explore how these factors change the motion. If you would like, you can put it on the *a* setting, as well. This is acceleration, which measures the rate of change of velocity. We will explore acceleration in more detail later, but it might be interesting to take a look at it here.

Click to view content (https://archive.cnx.org/specials/30e37034-2fbd-11e5-83a2-03be60006ece/maze-game/)

GRASP CHECK

Click to view content (https://archive.cnx.org/specials/30e37034-2fbd-11e5-83a2-03be60006ece/maze-game/#sim-maze-game)

a. The ball can be easily manipulated with displacement because the arena is a position space.
b. The ball can be easily manipulated with velocity because the arena is a position space.
c. The ball can be easily manipulated with displacement because the arena is a velocity space.
d. The ball can be easily manipulated with velocity because the arena is a velocity space.

What can we learn about motion by looking at velocity vs. time graphs? Let's return to our drive to school, and look at a graph of position versus time as shown in Figure 2.15.

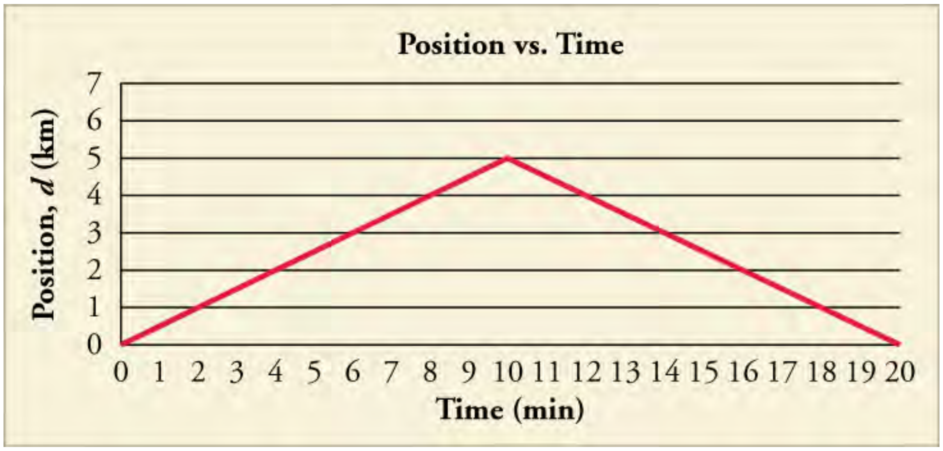


Figure 2.15 A graph of position versus time for the drive to and from school is shown.

We assumed for our original calculation that your parent drove with a constant velocity to and from school. We now know that the car could not have gone from rest to a constant velocity without speeding up. So the actual graph would be curved on either end, but let's make the same approximation as we did then, anyway.

TIPS FOR SUCCESS

It is common in physics, especially at the early learning stages, for certain things to be *neglected*, as we see here. This is because it makes the concept clearer or the calculation easier. Practicing physicists use these kinds of short-cuts, as well. It works out because usually the thing being *neglected* is small enough that it does not significantly affect the answer. In the earlier example, the amount of time it takes the car to speed up and reach its cruising velocity is very small compared to the total time traveled.

Looking at this graph, and given what we learned, we can see that there are two distinct periods to the car's motion—the way to school and the way back. The average velocity for the drive to school is 0.5 km/minute. We can see that the average velocity for the drive back is –0.5 km/minute. If we plot the data showing velocity versus time, we get another graph (Figure 2.16):

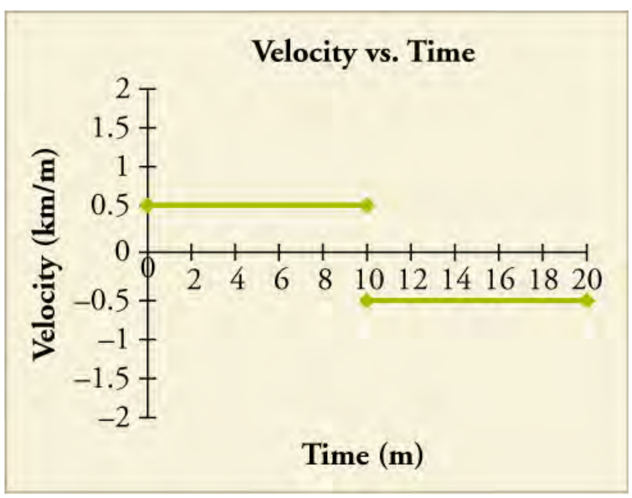


Figure 2.16 Graph of velocity versus time for the drive to and from school.

We can learn a few things. First, we can derive a **v** versus *t* graph from a **d** versus *t* graph. Second, if we have a straight-line position–time graph that is positively or negatively sloped, it will yield a horizontal velocity graph. There are a few other interesting things to note. Just as we could use a position vs. time graph to determine velocity, we can use a velocity vs. time graph to determine position. We know that $\mathbf{v} = \mathbf{d}/t$. If we use a little algebra to re-arrange the equation, we see that $\mathbf{d} = \mathbf{v} \times t$. In Figure 2.16, we have velocity on the *y*-axis and time along the *x*-axis. Let's take just the first half of the motion. We get 0.5 km/minute × 10 minutes. The units for *minutes* cancel each other, and we get 5 km, which is the displacement for the trip to school. If we calculate the same for the return trip, we get –5 km. If we add them together, we see that the net displacement for the whole trip is 0 km, which it should be because we started and ended at the same place.

TIPS FOR SUCCESS

You can treat units just like you treat numbers, so a km/km=1 (or, we say, it cancels out). This is good because it can tell us whether or not we have calculated everything with the correct units. For instance, if we end up with m × s for velocity instead of m/s, we know that something has gone wrong, and we need to check our math. This process is called dimensional analysis, and it is one of the best ways to check if your math makes sense in physics.

The area under a velocity curve represents the displacement. The velocity curve also tells us whether the car is speeding up. In our earlier example, we stated that the velocity was constant. So, the car is not speeding up. Graphically, you can see that the slope of these two lines is 0. This slope tells us that the car is not speeding up, or accelerating. We will do more with this information in a later chapter. For now, just remember that the area under the graph and the slope are the two important parts of the graph. Just like we could define a linear equation for the motion in a position vs. time graph, we can also define one for a velocity vs. time graph. As we said, the slope equals the acceleration, **a**. And in this graph, the *y*-intercept is $\mathbf{v}_0$. Thus, $\mathbf{v} = \mathbf{v}_0 + \mathbf{a}t$.

But what if the velocity is not constant? Let's look back at our jet-car example. At the beginning of the motion, as the car is speeding up, we saw that its position is a curve, as shown in Figure 2.17.

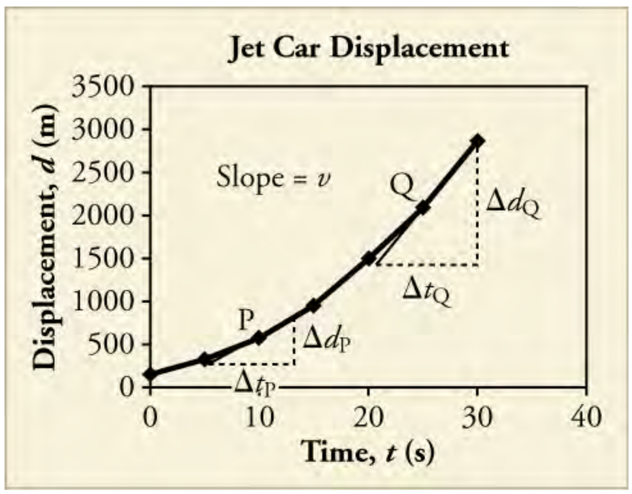


Figure 2.17 A graph is shown of the position of a jet-powered car during the time span when it is speeding up. The slope of a d vs. t graph is velocity. This is shown at two points. Instantaneous velocity at any point is the slope of the tangent at that point.

You do not have to do this, but you could, theoretically, take the instantaneous velocity at each point on this graph. If you did, you would get Figure 2.18, which is just a straight line with a positive slope.

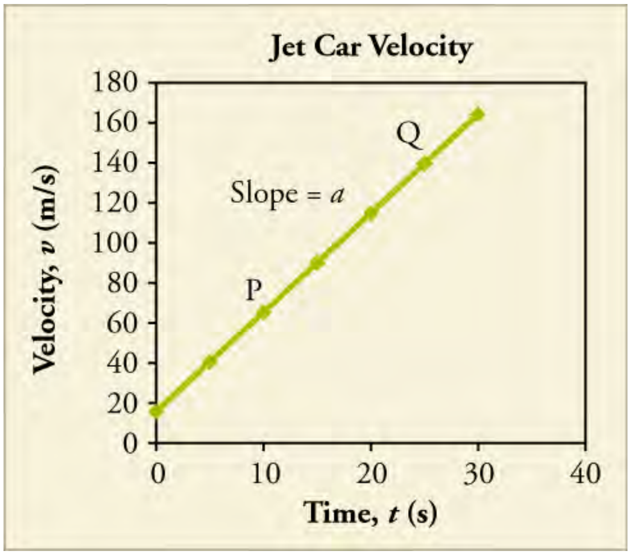


Figure 2.18 The graph shows the velocity of a jet-powered car during the time span when it is speeding up.

Again, if we take the slope of the velocity vs. time graph, we get the acceleration, the rate of change of the velocity. And, if we take the area under the slope, we get back to the displacement.

Solving Problems using Velocity–Time Graphs

Most velocity vs. time graphs will be straight lines. When this is the case, our calculations are fairly simple.

WORKED EXAMPLE

Using Velocity Graph to Calculate Some Stuff: Jet Car

Use this figure to (a) find the displacement of the jet car over the time shown (b) calculate the rate of change (acceleration) of the velocity. (c) give the instantaneous velocity at 5 s, and (d) calculate the average velocity over the interval shown.

Strategy

a. The displacement is given by finding the area under the line in the velocity vs. time graph.
b. The acceleration is given by finding the slope of the velocity graph.
c. The instantaneous velocity can just be read off of the graph.
d. To find the average velocity, recall that $\mathbf{v}_{\text{avg}} = \frac{\Delta \mathbf{d}}{\Delta t} = \frac{\mathbf{d}_\text{f} - \mathbf{d}_0}{t_\text{f} - t_0}$

Solution

a. 1. Analyze the shape of the area to be calculated. In this case, the area is made up of a rectangle between 0 and 20 m/s stretching to 30 s. The area of a rectangle is length × width. Therefore, the area of this piece is 600 m.
   2. Above that is a triangle whose base is 30 s and height is 140 m/s. The area of a triangle is 0.5 × length × width. The area of this piece, therefore, is 2,100 m.
   3. Add them together to get a net displacement of 2,700 m.

b. 1. Take two points on the velocity line. Say, $t = 5$ s and $t = 25$ s. At $t = 5$ s, the value of $\mathbf{v} = 40$ m/s. At $t = 25$ s, $\mathbf{v} = 140$ m/s.
   2. Find the slope.
$$\begin{aligned}\mathbf{a} &= \frac{\Delta \mathbf{v}}{\Delta t} \\ &= \frac{100\ \text{m/s}}{20\ \text{s}} \\ &= 5\ \text{m/s}^2\end{aligned}$$

c. The instantaneous velocity at $t = 5$ s, as we found in part (b) is just 40 m/s.

d. 1. Find the net displacement, which we found in part (a) was 2,700 m.
   2. Find the total time which for this case is 30 s.
   3. Divide 2,700 m/30 s = 90 m/s.

Discussion

The average velocity we calculated here makes sense if we look at the graph. 100m/s falls about halfway across the graph and since it is a straight line, we would expect about half the velocity to be above and half below.

TIPS FOR SUCCESS

You can have negative position, velocity, and acceleration on a graph that describes the way the object is moving. You should never see a graph with negative time on an axis. Why?

Most of the velocity vs. time graphs we will look at will be simple to interpret. Occasionally, we will look at curved graphs of velocity vs. time. More often, these curved graphs occur when something is speeding up, often from rest. Let's look back at a more realistic velocity vs. time graph of the jet car's motion that takes this *speeding up* stage into account.

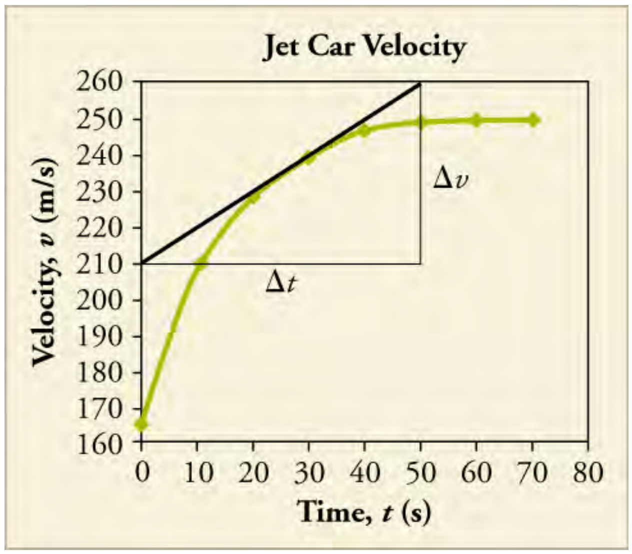


Figure 2.19 The graph shows a more accurate graph of the velocity of a jet-powered car during the time span when it is speeding up.

WORKED EXAMPLE

Using Curvy Velocity Graph to Calculate Some Stuff: jet car, Take Two

Use Figure 2.19 to (a) find the approximate displacement of the jet car over the time shown, (b) calculate the instantaneous acceleration at $t = 30$ s, (c) find the instantaneous velocity at 30 s, and (d) calculate the approximate average velocity over the interval shown.

Strategy

a. Because this graph is an undefined curve, we have to estimate shapes over smaller intervals in order to find the areas.
b. Like when we were working with a curved displacement graph, we will need to take a tangent line at the instant we are interested and use that to calculate the instantaneous acceleration.
c. The instantaneous velocity can still be read off of the graph.
d. We will find the average velocity the same way we did in the previous example.

Solution

a.
1. This problem is more complicated than the last example. To get a good estimate, we should probably break the curve into four sections. 0 → 10 s, 10 → 20 s, 20 → 40 s, and 40 → 70 s.
2. Calculate the bottom rectangle (common to all pieces). 165 m/s × 70 s = 11,550 m.
3. Estimate a triangle at the top, and calculate the area for each section. Section 1 = 225 m; section 2 = 100 m + 450 m = 550 m; section 3 = 150 m + 1,300 m = 1,450 m; section 4 = 2,550 m.
4. Add them together to get a net displacement of 16,325 m.

b. Using the tangent line given, we find that the slope is 1 m/s^2.

c. The instantaneous velocity at $t = 30$ s, is 240 m/s.
d. 1. Find the net displacement, which we found in part (a), was 16,325 m.
   2. Find the total time, which for this case is 70 s.
   3. Divide $\frac{16{,}325 \ \text{m}}{70 \ \text{s}} \sim 233 \ \text{m/s}$

Discussion

This is a much more complicated process than the first problem. If we were to use these estimates to come up with the average velocity over just the first 30 s we would get about 191 m/s. By approximating that curve with a line, we get an average velocity of 202.5 m/s. Depending on our purposes and how precise an answer we need, sometimes calling a curve a straight line is a worthwhile approximation.

Practice Problems

19.

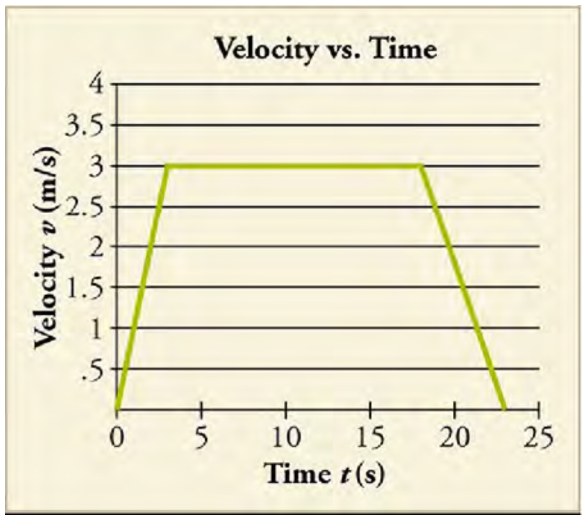


Figure 2.20

Consider the velocity vs. time graph shown below of a person in an elevator. Suppose the elevator is initially at rest. It then speeds up for 3 seconds, maintains that velocity for 15 seconds, then slows down for 5 seconds until it stops. Find the instantaneous velocity at $t = 10$ s and $t = 23$ s.

a. Instantaneous velocity at $t = 10$ s and $t = 23$ s are 0 m/s and 0 m/s.
b. Instantaneous velocity at $t = 10$ s and $t = 23$ s are 0 m/s and 3 m/s.
c. Instantaneous velocity at $t = 10$ s and $t = 23$ s are 3 m/s and 0 m/s.
d. Instantaneous velocity at $t = 10$ s and $t = 23$ s are 3 m/s and 1.5 m/s.

20.

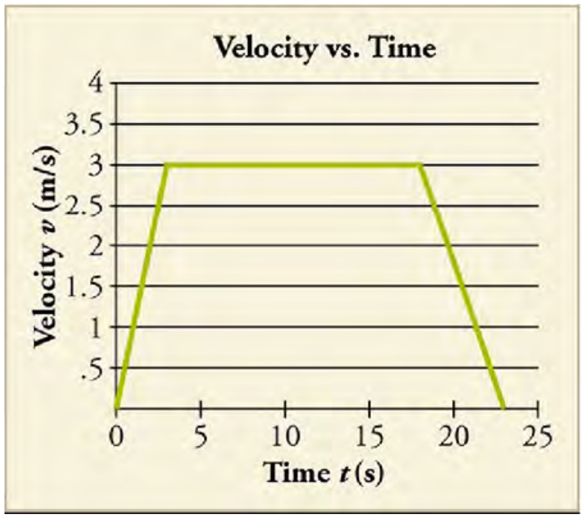


Figure 2.21

Calculate the net displacement and the average velocity of the elevator over the time interval shown.

a. Net displacement is 45 m and average velocity is 2.10 m/s.
b. Net displacement is 45 m and average velocity is 2.28 m/s.
c. Net displacement is 57 m and average velocity is 2.66 m/s.
d. Net displacement is 57 m and average velocity is 2.48 m/s.

Snap Lab

Graphing Motion, Take Two

In this activity, you will graph a moving ball's velocity vs. time.

- your graph from the earlier Graphing Motion Snap Lab!
- 1 piece of graph paper
- 1 pencil

Procedure

1. Take your graph from the earlier Graphing Motion Snap Lab! and use it to create a graph of velocity vs. time.
2. Use your graph to calculate the displacement.

GRASP CHECK

Describe the graph and explain what it means in terms of velocity and acceleration.

a. The graph shows a horizontal line indicating that the ball moved with a constant velocity, that is, it was not accelerating.
b. The graph shows a horizontal line indicating that the ball moved with a constant velocity, that is, it was accelerating.
c. The graph shows a horizontal line indicating that the ball moved with a variable velocity, that is, it was not accelerating.
d. The graph shows a horizontal line indicating that the ball moved with a variable velocity, that is, it was accelerating.

Check Your Understanding

21. What information could you obtain by looking at a velocity vs. time graph?

a. acceleration
b. direction of motion
c. reference frame of the motion

d. shortest path

22. How would you use a position vs. time graph to construct a velocity vs. time graph and vice versa?

a. Slope of position vs. time curve is used to construct velocity vs. time curve, and slope of velocity vs. time curve is used to construct position vs. time curve.
b. Slope of position vs. time curve is used to construct velocity vs. time curve, and area of velocity vs. time curve is used to construct position vs. time curve.
c. Area of position vs. time curve is used to construct velocity vs. time curve, and slope of velocity vs. time curve is used to construct position vs. time curve.
d. Area of position/time curve is used to construct velocity vs. time curve, and area of velocity vs. time curve is used to construct position vs. time curve.

KEY TERMS

acceleration the rate at which velocity changes
average speed distance traveled divided by time during which motion occurs
average velocity displacement divided by time over which displacement occurs
dependent variable the variable that changes as the independent variable changes
displacement the change in position of an object against a fixed axis
distance the length of the path actually traveled between an initial and a final position
independent variable the variable, usually along the horizontal axis of a graph, that does not change based on human or experimental action; in physics this is usually time
instantaneous speed speed at a specific instant in time
instantaneous velocity velocity at a specific instant in time
kinematics the study of motion without considering its causes
magnitude size or amount
position the location of an object at any particular time
reference frame a coordinate system from which the positions of objects are described
scalar a quantity that has magnitude but no direction
speed rate at which an object changes its location
tangent a line that touches another at exactly one point
vector a quantity that has both magnitude and direction
velocity the speed and direction of an object

SECTION SUMMARY

2.1 Relative Motion, Distance, and Displacement

- A description of motion depends on the reference frame from which it is described.
- The distance an object moves is the length of the path along which it moves.
- Displacement is the difference in the initial and final positions of an object.

2.2 Speed and Velocity

- Average speed is a scalar quantity that describes distance traveled divided by the time during which the motion occurs.
- Velocity is a vector quantity that describes the speed and direction of an object.
- Average velocity is displacement over the time period during which the displacement occurs. If the velocity is constant, then average velocity and instantaneous velocity are the same.

2.3 Position vs. Time Graphs

- Graphs can be used to analyze motion.
- The slope of a position vs. time graph is the velocity.
- For a straight line graph of position, the slope is the average velocity.
- To obtain the instantaneous velocity at a given moment for a curved graph, find the tangent line at that point and take its slope.

2.4 Velocity vs. Time Graphs

- The slope of a velocity vs. time graph is the acceleration.
- The area under a velocity vs. time curve is the displacement.
- Average velocity can be found in a velocity vs. time graph by taking the weighted average of all the velocities.

KEY EQUATIONS

2.1 Relative Motion, Distance, and Displacement

Displacement $\Delta \mathbf{d} = \mathbf{d_f} - \mathbf{d_0}$

2.2 Speed and Velocity

Average speed $v_{\text{avg}} = \frac{\textbf{distance}}{\textbf{time}}$

Average velocity $\mathbf{v}_{\text{avg}} = \frac{\Delta \mathbf{d}}{\Delta t} = \frac{\mathbf{d}_\text{f} - \mathbf{d}_0}{t_\text{f} - t_0}$

2.3 Position vs. Time Graphs

Displacement $\mathbf{d} = \mathbf{d}_0 + \mathbf{v}t$.

2.4 Velocity vs. Time Graphs

Velocity $\mathbf{v} = \mathbf{v}_0 + at$

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

CHAPTER REVIEW

Concept Items

2.1 Relative Motion, Distance, and Displacement

1. Can one-dimensional motion have zero distance but a nonzero displacement? What about zero displacement but a nonzero distance?
   a. One-dimensional motion can have zero distance with a nonzero displacement. Displacement has both magnitude and direction, and it can also have zero displacement with nonzero distance because distance has only magnitude.
   b. One-dimensional motion can have zero distance with a nonzero displacement. Displacement has both magnitude and direction, but it cannot have zero displacement with nonzero distance because distance has only magnitude.
   c. One-dimensional motion cannot have zero distance with a nonzero displacement. Displacement has both magnitude and direction, but it can have zero displacement with nonzero distance because distance has only magnitude and any motion will be the distance it moves.
   d. One-dimensional motion cannot have zero distance with a nonzero displacement. Displacement has both magnitude and direction, and it cannot have zero displacement with nonzero distance because distance has only magnitude.

2. In which example would you be correct in describing an object in motion while your friend would also be correct in describing that same object as being at rest?
   a. You are driving a car toward the east and your friend drives past you in the opposite direction with the same speed. In your frame of reference, you will be in motion. In your friend's frame of reference, you will be at rest.
   b. You are driving a car toward the east and your friend is standing at the bus stop. In your frame of reference, you will be in motion. In your friend's frame of reference, you will be at rest.
   c. You are driving a car toward the east and your friend is standing at the bus stop. In your frame of reference, your friend will be moving toward the west. In your friend's frame of reference, he will be at rest.
   d. You are driving a car toward the east and your friend is standing at the bus stop. In your frame of reference, your friend will be moving toward the east. In your friend's frame of reference, he will be at rest.

3. What does your car's odometer record?
   a. displacement
   b. distance
   c. both distance and displacement
   d. the sum of distance and displacement

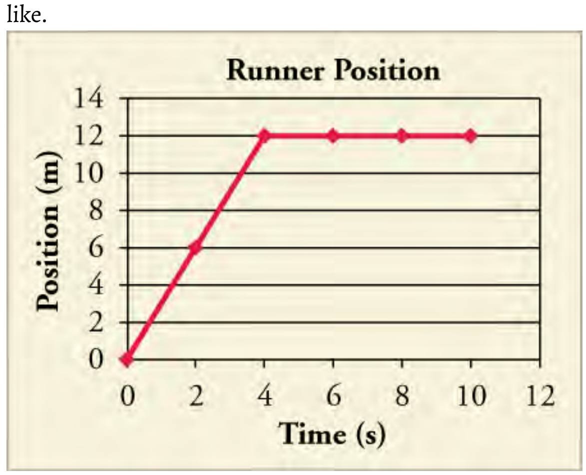
2.2 Speed and Velocity

4. In the definition of velocity, what physical quantity is changing over time?
   a. speed
   b. distance
   c. magnitude of displacement
   d. position vector

5. Which of the following best describes the relationship between instantaneous velocity and instantaneous speed?
   a. Both instantaneous speed and instantaneous velocity are the same, even when there is a change in direction.
   b. Instantaneous speed and instantaneous velocity cannot be the same even if there is no change in direction of motion.
   c. Magnitude of instantaneous velocity is equal to instantaneous speed.
   d. Magnitude of instantaneous velocity is always greater than instantaneous speed.

2.3 Position vs. Time Graphs

6. Use the graph to describe what the runner's motion looks like.



How are average velocity for only the first four seconds and instantaneous velocity related? What is the runner's net displacement over the time shown?
   a. The net displacement is 12 m and the average velocity is equal to the instantaneous velocity.
   b. The net displacement is 12 m and the average velocity

is two times the instantaneous velocity.

c. The net displacement is 10 + 12 = 22 m and the average velocity is equal to the instantaneous velocity.

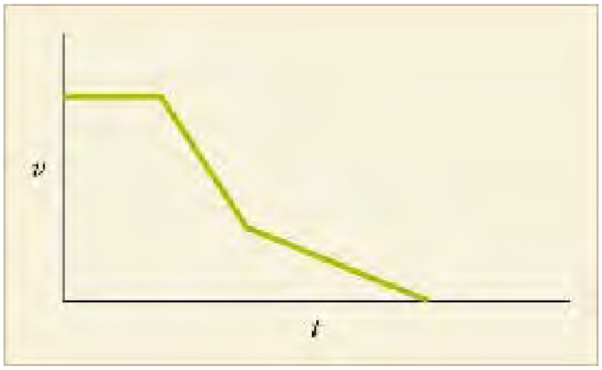
d. The net displacement is 10 + 12 = 22 m and the average velocity is two times the instantaneous velocity.

7. A position vs. time graph of a frog swimming across a pond has two distinct straight-line sections. The slope of the first section is $1\ \text{m/s}$. The slope of the second section is $0\ \text{m/s}$. If each section lasts 1 second, then what is the frog's total average velocity?

a. $0\ \text{m/s}$
b. $2\ \text{m/s}$
c. $0.5\ \text{m/s}$
d. $1\ \text{m/s}$

2.4 Velocity vs. Time Graphs

8. A graph of velocity vs. time of a ship coming into a harbor is shown.



Describe the acceleration of the ship based on the graph.

a. The ship is moving in the forward direction at a steady rate. Then it accelerates in the forward direction and then decelerates.

b. The ship is moving in the forward direction at a steady rate. Then it turns around and starts decelerating, while traveling in the reverse direction. It then accelerates, but slowly.

c. The ship is moving in the forward direction at a steady rate. Then it decelerates in the forward direction, and then continues to slow down in the forward direction, but with more deceleration.

d. The ship is moving in the forward direction at a steady rate. Then it decelerates in the forward direction, and then continues to slow down in the forward direction, but with less deceleration.

Critical Thinking Items

2.1 Relative Motion, Distance, and Displacement

9. Boat A and Boat B are traveling at a constant speed in opposite directions when they pass each other. If a person in each boat describes motion based on the boat's own reference frame, will the description by a person in Boat A of Boat B's motion be the same as the description by a person in Boat B of Boat A's motion?

a. Yes, both persons will describe the same motion because motion is independent of the frame of reference.

b. Yes, both persons will describe the same motion because they will perceive the other as moving in the backward direction.

c. No, the motion described by each of them will be different because motion is a relative term.

d. No, the motion described by each of them will be different because the motion perceived by each will be opposite to each other.

10. Passenger A sits inside a moving train and throws a ball vertically upward. How would the motion of the ball be described by a fellow train passenger B and an observer C who is standing on the platform outside the train?

a. Passenger B sees that the ball has vertical, but no horizontal, motion. Observer C sees the ball has vertical as well as horizontal motion.

b. Passenger B sees the ball has vertical as well as horizontal motion. Observer C sees the ball has the vertical, but no horizontal, motion.

c. Passenger B sees the ball has horizontal but no vertical motion. Observer C sees the ball has vertical as well as horizontal motion.

d. Passenger B sees the ball has vertical as well as horizontal motion. Observer C sees the ball has horizontalbut no vertical motion.

2.2 Speed and Velocity

11. Is it possible to determine a car's instantaneous velocity from just the speedometer reading?

a. No, it reflects speed but not the direction.

b. No, it reflects the average speed of the car.

c. Yes, it sometimes reflects instantaneous velocity of the car.

d. Yes, it always reflects the instantaneous velocity of the car.

12. Terri, Aaron, and Jamal all walked along straight paths.

Terri walked 3.95 km north in 48 min. Aaron walked 2.65 km west in 31 min. Jamal walked 6.50 km south in 81 min. Which of the following correctly ranks the three boys in order from lowest to highest average speed?

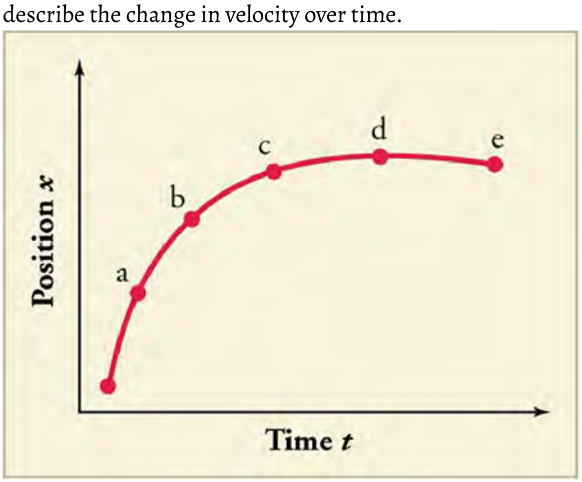
a. Jamal, Terri, Aaron
b. Jamal, Aaron, Terri
c. Terri, Jamal, Aaron
d. Aaron, Terri, Jamal

13. Rhianna and Logan start at the same point and walk due north. Rhianna walks with an average velocity $v_{\text{avg,R}}$. Logan walks three times the distance in twice the time as Rhianna. Which of the following expresses Logan's average velocity in terms of $v_{\text{avg,R}}$?

a. Logan's average velocity = $1.5v_{avg,R}$.
b. Logan's average velocity = $\frac{2}{3}v_{avg,R}$.
c. Logan's average velocity = $3v_{avg,R}$.
d. Logan's average velocity = $\frac{1}{2}v_{avg,R}$.

2.3 Position vs. Time Graphs

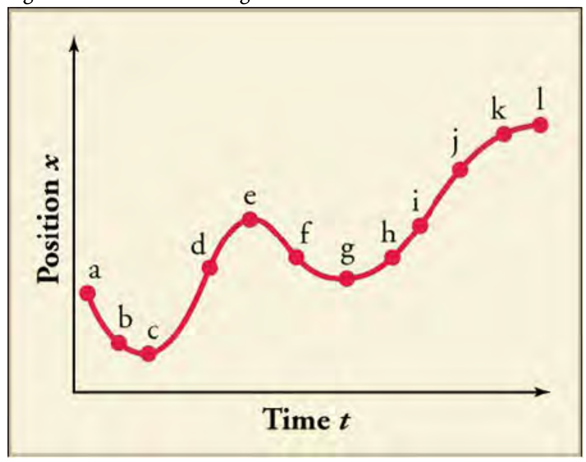
14. Explain how you can use the graph of position vs. time to describe the change in velocity over time.



Identify the time (t_a, t_b, t_c, t_d, or t_e) at which at which the instantaneous velocity is greatest, the time at which it is zero, and the time at which it is negative.

2.4 Velocity vs. Time Graphs

15. Identify the time, or times, at which the instantaneous velocity is greatest, and the time, or times, at which it is negative. A sketch of velocity vs. time derived from the figure will aid in arriving at the correct answers.



a. The instantaneous velocity is greatest at *f*, and it is negative at *d*, *h*, *I*, *j*, and *k*.
b. The instantaneous velocity is greatest at *e*, and it is negative at *a*, *b*, and *f*.
c. The instantaneous velocity is greatest at *f*, and it is negative at *d*, *h*, *I*, *j*, and *k*
d. The instantaneous velocity is greatest at *d*, and it is negative at *a*, *b*, and *f*.

Problems

2.1 Relative Motion, Distance, and Displacement

16. In a coordinate system in which the direction to the right is positive, what are the distance and displacement of a person who walks 35 meters to the left, 18 meters to the right, and then 26 meters to the left?

a. Distance is 79 m and displacement is −43 m.
b. Distance is −79 m and displacement is 43 m.
c. Distance is 43 m and displacement is −79 m.
d. Distance is −43 m and displacement is 79 m.

17. Billy drops a ball from a height of 1 m. The ball bounces back to a height of 0.8 m, then bounces again to a height of 0.5 m, and bounces once more to a height of 0.2 m. Up is the positive direction. What are the total displacement of the ball and the total distance traveled by the ball?

a. The displacement is equal to -4 m and the distance is equal to 4 m.
b. The displacement is equal to 4 m and the distance is equal to 1 m.
c. The displacement is equal to 4 m and the distance is equal to 1 m.
d. The displacement is equal to -1 m and the distance is equal to 4 m.

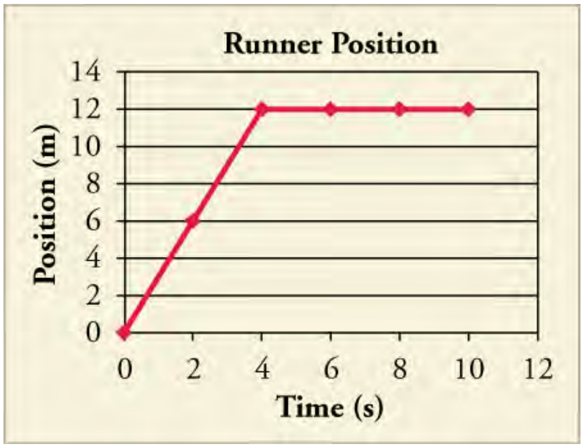
2.2 Speed and Velocity

18. You sit in a car that is moving at an average speed of 86.4 km/h. During the 3.3 s that you glance out the window, how far has the car traveled?

a. 7.27 m
b. 79 m
c. 285 km
d. 1026 m

2.3 Position vs. Time Graphs

19. Using the graph, what is the average velocity for the whole 10 seconds?



a. The total average velocity is 0 m/s.
b. The total average velocity is 1.2 m/s.
c. The total average velocity is 1.5 m/s.
d. The total average velocity is 3.0 m/s.

20. A train starts from rest and speeds up for 15 minutes until it reaches a constant velocity of 100 miles/hour. It stays at this speed for half an hour. Then it slows down for another 15 minutes until it is still. Which of the following correctly describes the position vs time graph of the train's journey?

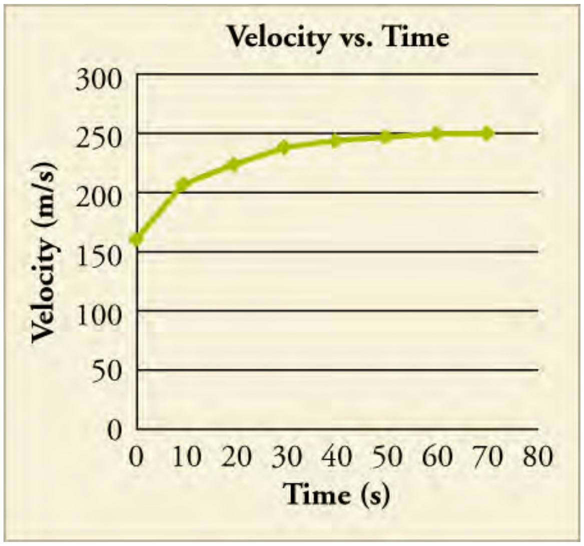
a. The first 15 minutes is a curve that is concave upward, the middle portion is a straight line with slope 100 miles/hour, and the last portion is a concave downward curve.
b. The first 15 minutes is a curve that is concave downward, the middle portion is a straight line with slope 100 miles/hour, and the last portion is a concave upward curve.
c. The first 15 minutes is a curve that is concave upward, the middle portion is a straight line with slope zero, and the last portion is a concave downward curve.
d. The first 15 minutes is a curve that is concave downward, the middle portion is a straight line with slope zero, and the last portion is a concave upward curve.

2.4 Velocity vs. Time Graphs

21. You are characterizing the motion of an object by measuring the location of the object at discrete moments in time. What is the minimum number of data points you would need to estimate the average acceleration of the object?

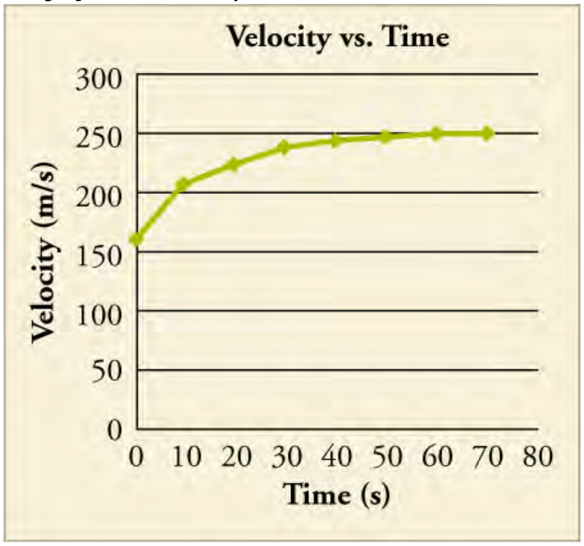
a. 1
b. 2
c. 3
d. 4

22. Which option best describes the average acceleration from 40 to 70 s?



a. It is negative and smaller in magnitude than the initial acceleration.
b. It is negative and larger in magnitude than the initial acceleration.
c. It is positive and smaller in magnitude than the initial acceleration.
d. It is positive and larger in magnitude than the initial acceleration.

23. The graph shows velocity vs. time.



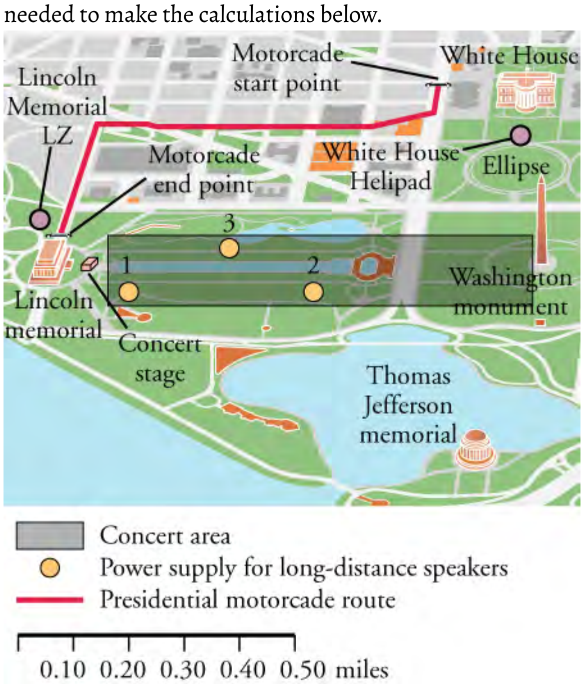
Calculate the net displacement using seven different divisions. Calculate it again using two divisions: 0 → 40 s and 40 → 70 s . Compare. Using both, calculate the average velocity.

a. Displacement and average velocity using seven divisions are 14,312.5 m and 204.5 m/s while with two divisions are 15,500 m and 221.4 m/s respectively.
b. Displacement and average velocity using seven divisions are 15,500 m and 221.4 m/s while with two divisions are 14,312.5 m and 204.5 m/s respectively.
c. Displacement and average velocity using seven divisions are 15,500 m and 204.5 m/s while with two divisions are 14,312.5 m and 221.4 m/s respectively.
d. Displacement and average velocity using seven divisions are 14,312.5 m and 221.4 m/s while with two divisions are 15,500 m and 204.5 m/s respectively.

Performance Task

2.4 Velocity vs. Time Graphs

24. The National Mall in Washington, DC, is a national park containing most of the highly treasured memorials and museums of the United States. However, the National Mall also hosts many events and concerts. The map in shows the area for a benefit concert during which the president will speak. The concert stage is near the Lincoln Memorial. The seats and standing room for the crowd will stretch from the stage east to near the Washington Monument, as shown on the map. You are planning the logistics for the concert. Use the map scale to measure any distances needed to make the calculations below.



The park has three new long-distance speakers. They would like to use these speakers to broadcast the concert audio to other parts of the National Mall. The speakers can project sound up to 0.35 miles away but they must be connected to one of the power supplies within the concert area. What is the minimum amount of wire needed for each speaker, in miles, in order to project the audio to the following areas? Assume that wire cannot be placed over buildings or any memorials.

Part A. The center of the Jefferson Memorial using power supply 1 (This will involve an elevated wire that can travel over water.)

Part B. The center of the Ellipse using power supply 3 (This wire cannot travel over water.)

Part C. The president's motorcade will be traveling to the concert from the White House. To avoid concert traffic, the motorcade travels from the White House west down E Street and then turns south on 23rd Street to reach the Lincoln memorial. What minimum speed, in miles per hour to the nearest tenth, would the motorcade have to travel to make the trip in 5 minutes?

Part D. The president could also simply fly from the White House to the Lincoln Memorial using the presidential helicopter, Marine 1. How long would it take Marine 1, traveling slowly at 30 mph, to travel from directly above the White House landing zone (LZ) to directly above the Lincoln Memorial LZ? Disregard liftoff and landing times and report the travel time in minutes to the nearest minute.

TEST PREP

Multiple Choice

2.1 Relative Motion, Distance, and Displacement

25. Why should you specify a reference frame when describing motion?

a. a description of motion depends on the reference frame
b. motion appears the same in all reference frames
c. reference frames affect the motion of an object
d. you can see motion better from certain reference frames

26. Which of the following is true for the displacement of an object?

a. It is always equal to the distance the object moved

between its initial and final positions.
   b. It is both the straight line distance the object moved as well as the direction of its motion.
   c. It is the direction the object moved between its initial and final positions.
   d. It is the straight line distance the object moved between its initial and final positions.

27. If a biker rides west for 50 miles from his starting position, then turns and bikes back east 80 miles. What is his net displacement?
   a. 130 miles
   b. 30 miles east
   c. 30 miles west
   d. Cannot be determined from the information given

28. Suppose a train is moving along a track. Is there a single, correct reference frame from which to describe the train’s motion?
   a. Yes, there is a single, correct frame of reference because motion is a relative term.
   b. Yes, there is a single, correct frame of reference which is in terms of Earth’s position.
   c. No, there is not a single, correct frame of reference because motion is a relative term.
   d. No, there is not a single, correct frame of reference because motion is independent of frame of reference.

29. If a space shuttle orbits Earth once, what is the shuttle’s distance traveled and displacement?
   a. Distance and displacement both are zero.
   b. Distance is circumference of the circular orbit while displacement is zero.
   c. Distance is zero while the displacement is circumference of the circular orbit.
   d. Distance and displacement both are equal to circumference of the circular orbit.

2.2 Speed and Velocity

30. Four bicyclists travel different distances and times along a straight path. Which cyclist traveled with the greatest average speed?
   a. Cyclist 1 travels 95 m in 27 s.
   b. Cyclist 2 travels 87 m in 22 s.
   c. Cyclist 3 travels 106 m in 26 s.
   d. Cyclist 4 travels 108 m in 24 s.

31. A car travels with an average velocity of 23 m/s for 82 s. Which of the following could NOT have been the car's displacement?
   a. 1,700 m east
   b. 1,900 m west
   c. 1,600 m north
   d. 1,500 m south

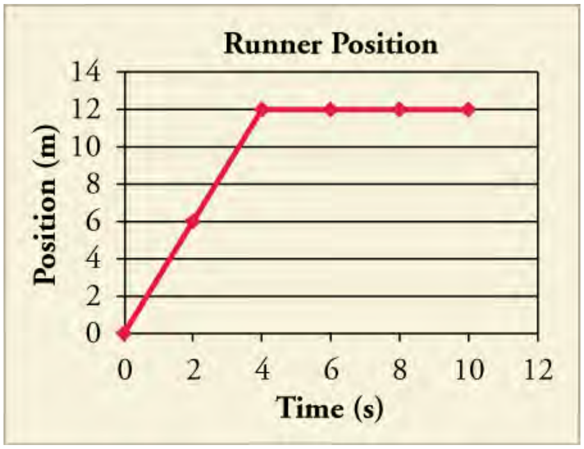
32. A bicyclist covers the first leg of a journey that is d_1 meters long in t_1 seconds, at a speed of v_1 m/s, and the second leg of d_2 meters in t_2 seconds, at a speed of v_2 m/s. If his average speed is equal to the average of v_1 and v_2, then which of the following is true?
   a. $t_1 = t_2$
   b. $t_1 \neq t_2$
   c. $d_1 = d_2$
   d. $d_1 \neq d_2$

33. A car is moving on a straight road at a constant speed in a single direction. Which of the following statements is true?
   a. Average velocity is zero.
   b. The magnitude of average velocity is equal to the average speed.
   c. The magnitude of average velocity is greater than the average speed.
   d. The magnitude of average velocity is less than the average speed.

2.3 Position vs. Time Graphs

34. What is the slope of a straight line graph of position vs. time?
   a. Velocity
   b. Displacement
   c. Distance
   d. Acceleration

35. Using the graph, what is the runner’s velocity from 4 to 10 s?



   a. −3 m/s
   b. 0 m/s
   c. 1.2 m/s
   d. 3 m/s

2.4 Velocity vs. Time Graphs

36. What does the area under a velocity vs. time graph line represent?
   a. acceleration
   b. displacement
   c. distance
   d. instantaneous velocity

37. An object is moving along a straight path with constant acceleration. A velocity vs. time graph starts at 0 and ends at $10\ \mathrm{m/s}$, stretching over a time-span of $15\ \mathrm{s}$. What is the object's net displacement?
   a. $75\ \mathrm{m}$
   b. $130\ \mathrm{m}$
   c. $150\ \mathrm{m}$
   d. cannot be determined from the information given

Short Answer

2.1 Relative Motion, Distance, and Displacement

38. While standing on a sidewalk facing the road, you see a bicyclist passing by toward your right. In the reference frame of the bicyclist, in which direction are you moving?
   a. in the same direction of motion as the bicyclist
   b. in the direction opposite the motion of the bicyclist
   c. stationary with respect to the bicyclist
   d. in the direction of velocity of the bicyclist

39. Maud sends her bowling ball straight down the center of the lane, getting a strike. The ball is brought back to the holder mechanically. What are the ball's net displacement and distance traveled?
   a. Displacement of the ball is twice the length of the lane, while the distance is zero.
   b. Displacement of the ball is zero, while the distance is twice the length of the lane.
   c. Both the displacement and distance for the ball are equal to zero.
   d. Both the displacement and distance for the ball are twice the length of the lane.

40. A fly buzzes four and a half times around Kit Yan's head. The fly ends up on the opposite side from where it started. If the diameter of his head is $14\ \mathrm{cm}$, what is the total distance the fly travels and its total displacement?
   a. The distance is $63\pi\ \mathrm{cm}$ with a displacement of zero.
   b. The distance is $7\ \mathrm{cm}$ with a displacement of zero.
   c. The distance is $63\pi\ \mathrm{cm}$ with a displacement of $14\ \mathrm{cm}$.
   d. The distance is $7\ \mathrm{cm}$ with a displacement of $63\pi\ \mathrm{cm}$.

2.2 Speed and Velocity

41. Rob drove to the nearest hospital with an average speed of v m/s in t seconds. In terms of t, if he drives home on the same path, but with an average speed of 3v m/s, how long is the return trip home?
   a. t/6
   b. t/3
   c. 3t
   d. 6t

42. What can you infer from the statement, *Velocity of an object is zero*?
   a. Object is in linear motion with constant velocity.
   b. Object is moving at a constant speed.
   c. Object is either at rest or it returns to the initial point.
   d. Object is moving in a straight line without changing its direction.

43. An object has an average speed of 7.4 km/h. Which of the following describes two ways you could increase the average speed of the object to 14.8 km/h?
   a. Reduce the distance that the object travels by half, keeping the time constant, or keep the distance constant and double the time.
   b. Double the distance that the object travels, keeping the time constant, or keep the distance constant and reduce the time by half.
   c. Reduce the distance that the object travels to one-fourth, keeping the time constant, or keep the distance constant and increase the time by fourfold.
   d. Increase the distance by fourfold, keeping the time constant, or keep the distance constant and reduce the time by one-fourth.

44. Swimming one lap in a pool is defined as going across a pool and back again. If a swimmer swims 3 laps in 9 minutes, how can his average velocity be zero?
   a. His average velocity is zero because his total distance is zero.
   b. His average velocity is zero because his total displacement is zero.
   c. His average velocity is zero because the number of laps completed is an odd number.
   d. His average velocity is zero because the velocity of each successive lap is equal and opposite.

2.3 Position vs. Time Graphs

45. A hockey puck is shot down the arena in a straight line. Assume it does not slow until it is stopped by an opposing player who sends it back in the direction it came. The players are 20 m apart and it takes 1 s for the puck to go there and back. Which of the following describes the graph of the displacement over time? Consider the initial direction of the puck to be positive.

a. The graph is an upward opening V.
b. The graph is a downward opening V.
c. The graph is an upward opening U.
d. The graph is downward opening U.

46. A defensive player kicks a soccer ball 20 m back to her own goalie. It stops just as it reaches her. She sends it back to the player. Without knowing the time it takes, draw a rough sketch of the displacement over time. Does this graph look similar to the graph of the hockey puck from the previous question?

a. Yes, the graph is similar to the graph of the hockey puck.
b. No, the graph is not similar to the graph of the hockey puck.
c. The graphs cannot be compared without knowing the time the soccer ball was rolling.

47. What are the net displacement, total distance traveled, and total average velocity in the previous two problems?

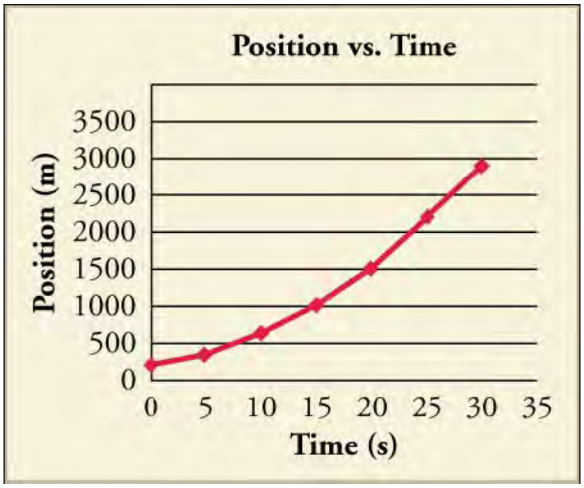
a. net displacement = 0 m, total distance = 20 m, total average velocity = 20 m/s
b. net displacement = 0 m, total distance = 40 m, total average velocity = 20 m/s
c. net displacement = 0 m, total distance = 20 m, total average velocity = 0 m/s
d. net displacement = 0 m, total distance = 40 m, total average velocity = 0 m/s

48. A bee flies straight at someone and then back to its hive along the same path. Assuming it takes no time for the bee to speed up or slow down, except at the moment it changes direction, how would the graph of position vs time look? Consider the initial direction to be positive.

a. The graph will look like a downward opening V shape.
b. The graph will look like an upward opening V shape.
c. The graph will look like a downward opening parabola.
d. The graph will look like an upward opening parabola.

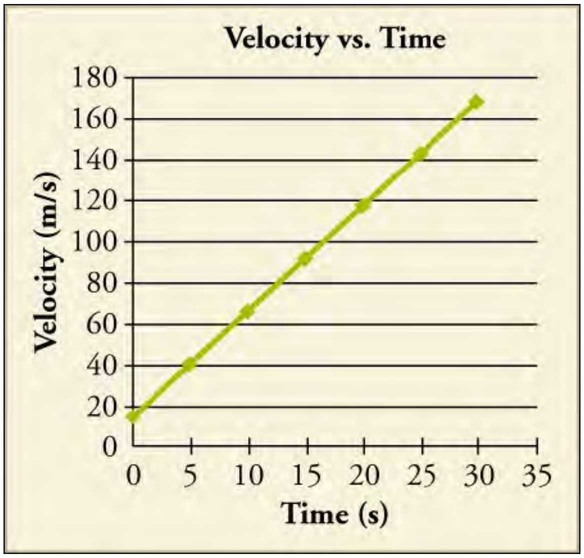
2.4 Velocity vs. Time Graphs

49. What would the velocity vs. time graph of the object whose position is shown in the graph look like?



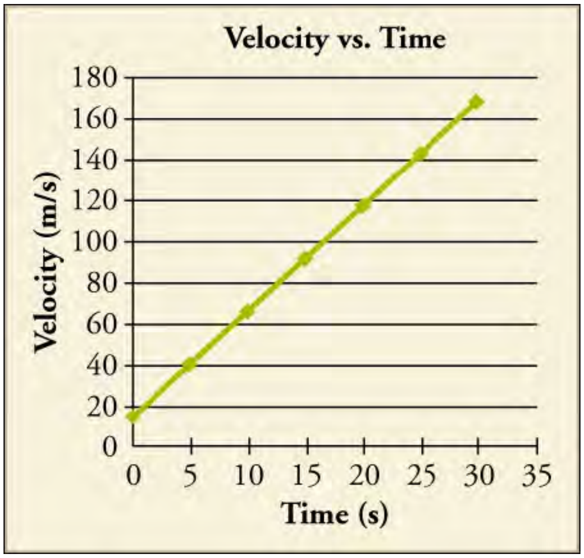
a. It is a straight line with negative slope.
b. It is a straight line with positive slope.
c. It is a horizontal line at some negative value.
d. It is a horizontal line at some positive value.

50. Which statement correctly describes the object's speed, as well as what a graph of acceleration vs. time would look like?

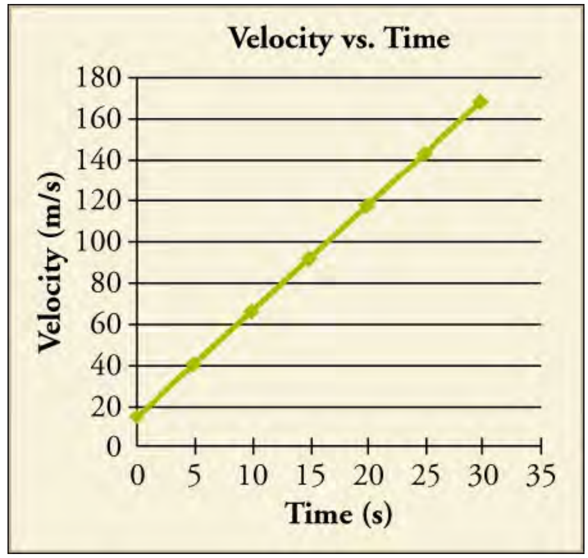


a. The object is not speeding up, and the acceleration vs. time graph is a horizontal line at some negative value.
b. The object is not speeding up, and the acceleration vs. time graph is a horizontal line at some positive value.
c. The object is speeding up, and the acceleration vs. time graph is a horizontal line at some negative value.
d. The object is speeding up, and the acceleration vs. time graph is a horizontal line at some positive value.

51. Calculate that object's net displacement over the time shown.



a. 540 m
b. 2,520 m
c. 2,790 m
d. 5,040 m



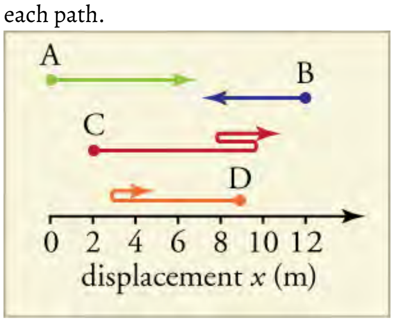
a. 18 m/s
b. 84 m/s
c. 93 m/s
d. 168 m/s

52. What is the object's average velocity?

Extended Response

2.1 Relative Motion, Distance, and Displacement

53. Find the distance traveled from the starting point for each path.



Which path has the maximum distance?

a. The distance for Path A is 6 m, Path B is 4 m, Path C is 12 m and for Path D is 7 m. The net displacement for Path A is 7 m, Path B is −4m, Path C is 8 m and for Path D is −5m. Path C has maximum distance and it is equal to 12 meters.
b. The distance for Path A is 6 m, Path B is 4 m, Path C is 8 m and for Path D is 7 m. The net displacement for Path A is 6 m, Path B is −4m, Path C is 12 m and for Path D is −5 m. Path A has maximum distance and it is equal to 6 meters.
c. The distance for Path A is 6 m, Path B is 4 m, Path C is 12 m and for Path D is 7 m. The net displacement for Path A is 6 m, Path B is −4 m, Path C is 8 m and for Path D is −5 m. Path C has maximum distance and it is equal to 12 meters.
d. The distance for Path A is 6 m, Path B is −4 m, Path C is 12 m and for Path D is −5 m. The net displacement for Path A is 7 m, Path B is 4 m, Path C is 8 m and for Path D is 7 m. Path A has maximum distance and it is equal to 6 m.

54. Alan starts from his home and walks 1.3 km east to the library. He walks an additional 0.68 km east to a music store. From there, he walks 1.1 km north to a friend's house and an additional 0.42 km north to a grocery store before he finally returns home along the same path. What is his final displacement and total distance traveled?

a. Displacement is 0 km and distance is 7 km.
b. Displacement is 0 km and distance is 3.5 km.
c. Displacement is 7 km towards west and distance is 7 km.
d. Displacement is 3.5 km towards east and distance is 3.5 km.

2.2 Speed and Velocity

55. Two runners start at the same point and jog at a constant speed along a straight path. Runner A starts at time t = 0 s, and Runner B starts at time t = 2.5 s. The runners both reach a distance 64 m from the starting point at time t = 25 s. If the runners continue at the same speeds, how far from the starting point will each be at time t = 45 s?

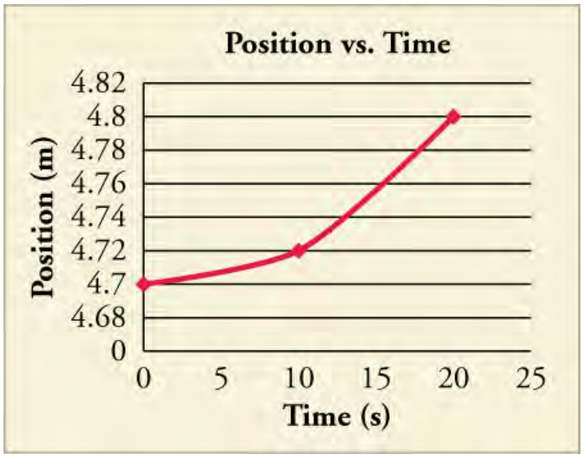
a. Runner A will be 72×10^3 m away and Runner B

will be 59.5×10^3 m away from the starting point.
  b. Runner A will be 1.2×10^2 m away and runner B will be 1.1×10^2 m away from the starting point.
  c. Runner A will be 1.2×10^2 m away and Runner B will be 1.3×10^2 m away from the starting point.
  d. Runner A will be 7.2×10^2 m away and Runner B will be 1.3×10^2 m away from the starting point.

56. A father and his daughter go to the bus stop that is located 75 m from their front door. The father walks in a straight line while his daughter runs along a varied path. Despite the different paths, they both end up at the bus stop at the same time. The father's average speed is 2.2 m/s, and his daughter's average speed is 3.5 m/s. (a) How long does it take the father and daughter to reach the bus stop? (b) What was the daughter's total distance traveled? (c) If the daughter maintained her same average speed and traveled in a straight line like her father, how far beyond the bus stop would she have traveled?
  a. (a) 21.43 s (b) 75 m (c) 0 m
  b. (a) 21.43 s (b) 119 m (c) 44 m
  c. (a) 34 s (b) 75 m (c) 0 m
  d. (a) 34 s (b) 119 m (c) 44 m

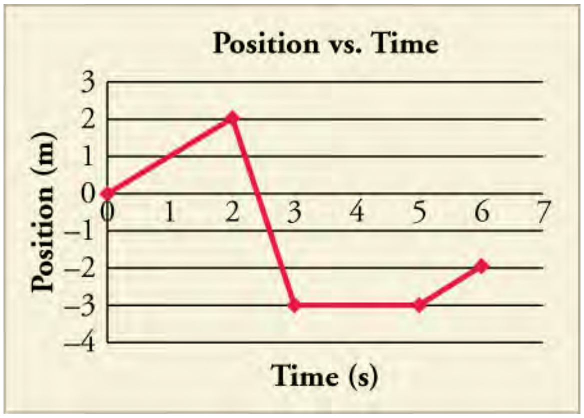
2.3 Position vs. Time Graphs

57. What kind of motion would create a position graph like the one shown?



  a. uniform motion
  b. any motion that accelerates
  c. motion that stops and then starts
  d. motion that has constant velocity

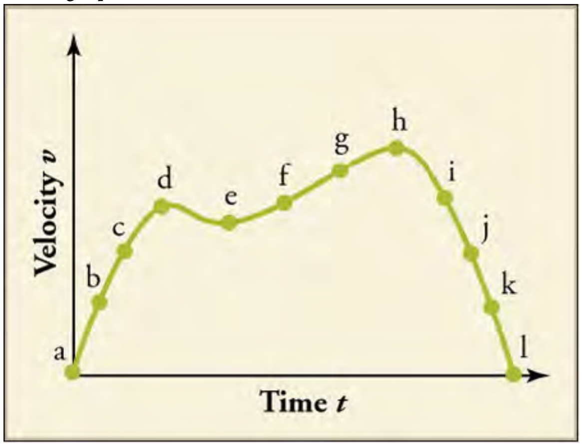
58. What is the average velocity for the whole time period shown in the graph?



  a. $-\frac{1}{3}$m/s
  b. $-\frac{3}{4}$m/s
  c. $\frac{1}{3}$m/s
  d. $\frac{3}{4}$m/s

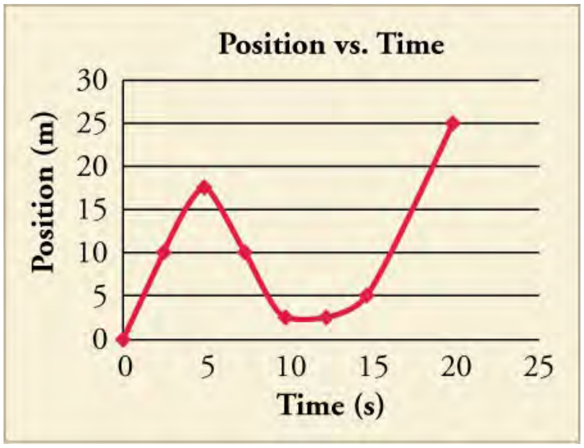
2.4 Velocity vs. Time Graphs

59. Consider the motion of the object whose velocity is charted in the graph.



During which points is the object slowing down and speeding up?
  a. It is slowing down between *d* and *e*. It is speeding up between *a* and *d* and *e* and *h*
  b. It is slowing down between *a* and *d* and *e* and *h*. It is speeding up between *d* and *e* and then after *i*.
  c. It is slowing down between *d* and *e* and then after *h*. It is speeding up between *a* and *d* and *e* and *h*.
  d. It is slowing down between *a* and *d* and *e* and *h*. It is speeding up between *d* and *e* and then after *i*.

60. Divide the graph into approximate sections, and use those sections to graph the velocity vs. time of the object.



Then calculate the acceleration during each section, and calculate the approximate average velocity.

a. Acceleration is zero and average velocity is 1.25 m/s.
b. Acceleration is constant with some positive value and average velocity is 1.25 m/s.
c. Acceleration is zero and average velocity is 0.25 m/s.
d. Acceleration is constant with some positive value and average velocity is 0.25 m/s.

CHAPTER 3
Acceleration

Figure 3.1 A plane slows down as it comes in for landing in St. Maarten. Its acceleration is in the opposite direction of its velocity. (Steve Conry, Flickr)

Chapter Outline

INTRODUCTION You may have heard the term *accelerator*, referring to the gas pedal in a car. When the gas pedal is pushed down, the flow of gasoline to the engine increases, which increases the car's velocity. Pushing on the gas pedal results in acceleration because the velocity of the car increases, and acceleration is defined as a change in velocity. You need two quantities to define velocity: a speed and a direction. Changing either of these quantities, or both together, changes the velocity. You may be surprised to learn that pushing on the brake pedal or turning the steering wheel also causes acceleration. The first reduces the *speed* and so changes the velocity, and the second changes the *direction* and also changes the velocity.

In fact, any change in velocity—whether positive, negative, directional, or any combination of these—is called an acceleration in physics. The plane in the picture is said to be accelerating because its velocity is decreasing as it prepares to land. To begin our study of acceleration, we need to have a clear understanding of what acceleration means.

3.1 Acceleration

Section Learning Objectives

By the end of this section, you will be able to do the following:

- Explain acceleration and determine the direction and magnitude of acceleration in one dimension
- Analyze motion in one dimension using kinematic equations and graphic representations

Section Key Terms

average acceleration | instantaneous acceleration | negative acceleration

Defining Acceleration

Throughout this chapter we will use the following terms: *time*, *displacement*, *velocity*, and *acceleration*. Recall that each of these terms has a designated variable and SI unit of measurement as follows:

- Time: t, measured in seconds (s)
- Displacement: Δd, measured in meters (m)
- Velocity: v, measured in meters per second (m/s)
- Acceleration: a, measured in meters per second per second (m/s^2, also called meters per second squared)
- Also note the following:
  - Δ means *change in*
  - The subscript 0 refers to an initial value; sometimes subscript i is instead used to refer to initial value.
  - The subscript f refers to final value
  - A bar over a symbol, such as $\overline{a}$, means *average*

Acceleration is the change in velocity divided by a period of time during which the change occurs. The SI units of velocity are m/s and the SI units for time are s, so the SI units for acceleration are m/s^2. **Average acceleration** is given by

$$\overline{a} = \frac{\Delta v}{\Delta t} = \frac{v_f - v_0}{t_f - t_0}.$$

Average acceleration is distinguished from **instantaneous acceleration**, which is acceleration at a specific instant in time. The magnitude of acceleration is often not constant over time. For example, runners in a race accelerate at a greater rate in the first second of a race than during the following seconds. You do not need to know all the instantaneous accelerations at all times to calculate average acceleration. All you need to know is the change in velocity (i.e., the final velocity minus the initial velocity) and the change in time (i.e., the final time minus the initial time), as shown in the formula. Note that the average acceleration can be positive, negative, or zero. A **negative acceleration** is simply an acceleration in the negative direction.

Keep in mind that although acceleration points in the same direction as the *change* in velocity, it is not always in the direction of the velocity itself. When an object slows down, its acceleration is opposite to the direction of its velocity. In everyday language, this is called deceleration; but in physics, it is acceleration—whose direction happens to be opposite that of the velocity. For now, let us assume that motion to the right along the x-axis is *positive* and motion to the left is *negative*.

Figure 3.2 shows a car with positive acceleration in (a) and negative acceleration in (b). The arrows represent vectors showing both direction and magnitude of velocity and acceleration.

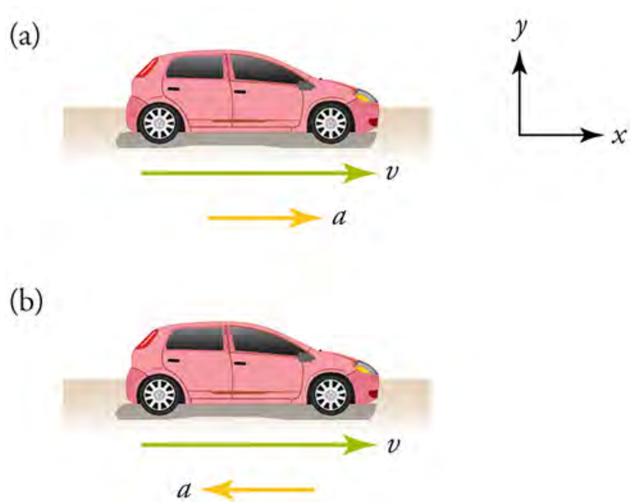


Figure 3.2 The car is speeding up in (a) and slowing down in (b).

Velocity and acceleration are both vector quantities. Recall that vectors have both magnitude and direction. An object traveling at a constant velocity—therefore having no acceleration—does accelerate if it changes direction. So, turning the steering wheel of a moving car makes the car accelerate because the velocity changes direction.

Virtual Physics

The Moving Man

With this animation in , you can produce both variations of acceleration and velocity shown in Figure 3.2, plus a few more variations. Vary the velocity and acceleration by sliding the red and green markers along the scales. Keeping the velocity marker near zero will make the effect of acceleration more obvious. Try changing acceleration from positive to negative while the man is moving. We will come back to this animation and look at the *Charts* view when we study graphical representation of motion.

Click to view content (https://archive.cnx.org/specials/e2ca52af-8c6b-450e-ac2f-9300b38e8739/moving-man/)

GRASP CHECK

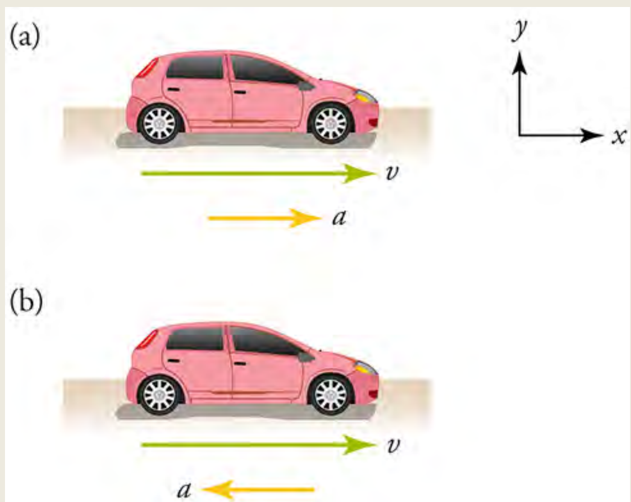


Figure 3.3

Which part, (a) or (b), is represented when the velocity vector is on the positive side of the scale and the acceleration vector is set on the negative side of the scale? What does the car's motion look like for the given scenario?

a. Part (a). The car is slowing down because the acceleration and the velocity vectors are acting in the opposite direction.
b. Part (a). The car is speeding up because the acceleration and the velocity vectors are acting in the same direction.
c. Part (b). The car is slowing down because the acceleration and velocity vectors are acting in the opposite directions.
d. Part (b). The car is speeding up because the acceleration and the velocity vectors are acting in the same direction.

Calculating Average Acceleration

Look back at the equation for average acceleration. You can see that the calculation of average acceleration involves three values: change in time, (Δt); change in velocity, (Δv); and acceleration (a).

Change in time is often stated as a time interval, and change in velocity can often be calculated by subtracting the initial velocity from the final velocity. Average acceleration is then simply change in velocity divided by change in time. Before you begin calculating, be sure that all distances and times have been converted to meters and seconds. Look at these examples of acceleration of a subway train.

WORKED EXAMPLE

An Accelerating Subway Train

A subway train accelerates from rest to 30.0 km/h in 20.0 s. What is the average acceleration during that time interval?

Strategy

Start by making a simple sketch.

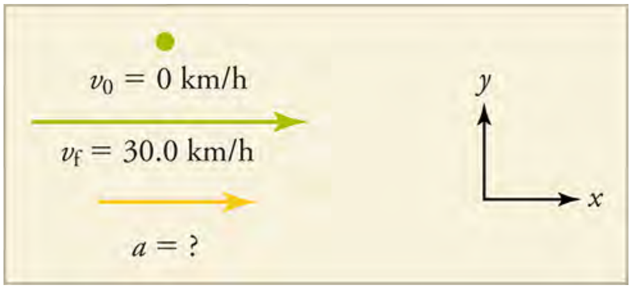


Figure 3.4

This problem involves four steps:

1. Convert to units of meters and seconds.
2. Determine the change in velocity.
3. Determine the change in time.
4. Use these values to calculate the average acceleration.

Solution

1. Identify the knowns. Be sure to read the problem for given information, which may not *look* like numbers. When the problem states that the train starts from rest, you can write down that the initial velocity is 0 m/s. Therefore, $v_0 = 0$; $v_f = 30.0\text{ km/h}$; and $\Delta t = 20.0\text{ s}$.
2. Convert the units.

$$\frac{30.0\text{ km}}{\text{h}} \times \frac{10^3\text{m}}{1\text{ km}} \times \frac{1\text{ h}}{3600\text{ s}} = 8.333\ \frac{\text{m}}{\text{s}} \tag{3.1}$$

3. Calculate change in velocity, $\Delta v = v_f - v_0 = 8.333\text{ m/s} - 0 = +\ 8.333\text{ m/s}$, where the plus sign means the change in velocity is to the right.
4. We know Δt, so all we have to do is insert the known values into the formula for average acceleration.

$$\bar{a} = \frac{\Delta v}{\Delta t} = \frac{8.333\text{ m/s}}{20.00\text{ s}} = +0.417\frac{\text{m}}{\text{s}^2} \tag{3.2}$$

Discussion

The plus sign in the answer means that acceleration is to the right. This is a reasonable conclusion because the train starts from rest and ends up with a velocity directed to the right (i.e., positive). So, acceleration is in the same direction as the *change* in velocity, as it should be.

WORKED EXAMPLE

An Accelerating Subway Train

Now, suppose that at the end of its trip, the train slows to a stop in 8.00 s from a speed of 30.0 km/h. What is its average acceleration during this time?

Strategy

Again, make a simple sketch.

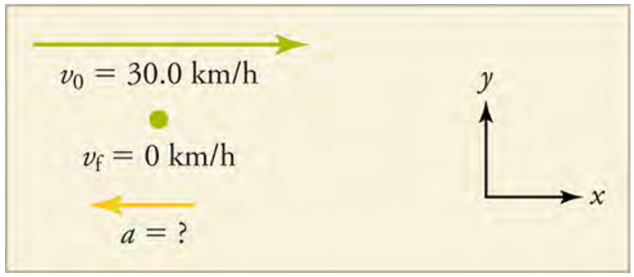


Figure 3.5

In this case, the train is decelerating and its acceleration is negative because it is pointing to the left. As in the previous example, we must find the change in velocity and change in time, then solve for acceleration.

Solution

1. Identify the knowns: $v_0 = 30.0$ km/h; $v_f = 0$; and $\Delta t = 8.00$ s.
2. Convert the units. From the first problem, we know that 30.0 km/h = 8.333 m/s.
3. Calculate change in velocity, $\Delta v = v_f - v_0 = 0 - 8.333 \text{ m/s} = -8.333 \text{ m/s}$, where the minus sign means that the change in velocity points to the left.
4. We know $\Delta t = 8.00$ s, so all we have to do is insert the known values into the equation for average acceleration.

$$\bar{a} = \frac{\Delta v}{\Delta t} = \frac{-8.333 \text{ m/s}}{8.00 \text{ s}} = -1.04 \frac{\text{m}}{\text{s}^2} \tag{3.3}$$

Discussion

The minus sign indicates that acceleration is to the left. This is reasonable because the train initially has a positive velocity in this problem, and a negative acceleration would reduce the velocity. Again, acceleration is in the same direction as the *change* in velocity, which is negative in this case. This acceleration can be called a deceleration because it has a direction opposite to the velocity.

TIPS FOR SUCCESS

- It is easier to get plus and minus signs correct if you always assume that motion is away from zero and toward positive values on the *x*-axis. This way *v* always starts off being positive and points to the right. If speed is increasing, then acceleration is positive and also points to the right. If speed is decreasing, then acceleration is negative and points to the left.
- It is a good idea to carry two extra significant figures from step-to-step when making calculations. Do not round off with each step. When you arrive at the final answer, apply the rules of significant figures for the operations you carried out and round to the correct number of digits. Sometimes this will make your answer slightly more accurate.

Practice Problems

1. A cheetah can accelerate from rest to a speed of 30.0 m/s in 7.00 s. What is its acceleration?

a. -0.23 m/s^2
b. -4.29 m/s^2
c. 0.23 m/s^2
d. 4.29 m/s^2

2. A women backs her car out of her garage with an acceleration of 1.40 m/s^2. How long does it take her to reach a speed of 2.00 m/s?

a. 0.70 s
b. 1.43 s
c. 2.80 s
d. 3.40 s

WATCH PHYSICS

Acceleration

This video shows the basic calculation of acceleration and some useful unit conversions.

[Click to view content (https://www.khanacademy.org/embed_video?v=FOkQszg1-j8)](https://www.khanacademy.org/embed_video?v=FOkQszg1-j8)

GRASP CHECK

Why is acceleration a vector quantity?

a. It is a vector quantity because it has magnitude as well as direction.
b. It is a vector quantity because it has magnitude but no direction.
c. It is a vector quantity because it is calculated from distance and time.
d. It is a vector quantity because it is calculated from speed and time.

GRASP CHECK

What will be the change in velocity each second if acceleration is 10 m/s/s?

a. An acceleration of 10 m/s/s means that every second, the velocity increases by 10 m/s.
b. An acceleration of 10 m/s/s means that every second, the velocity decreases by 10 m/s.
c. An acceleration of 10 m/s/s means that every 10 seconds, the velocity increases by 10 m/s.
d. An acceleration of 10 m/s/s means that every 10 seconds, the velocity decreases by 10 m/s.

Snap Lab

Measure the Acceleration of a Bicycle on a Slope

In this lab you will take measurements to determine if the acceleration of a moving bicycle is constant. If the acceleration is constant, then the following relationships hold: $\overline{v} = \frac{\Delta d}{\Delta t} = \frac{v_0 + v_\text{f}}{2}$ If $v_0 = 0$, then $v_\text{f} = 2\overline{v}$ and $\overline{a} = \frac{v_\text{f}}{\Delta t}$

You will work in pairs to measure and record data for a bicycle coasting down an incline on a smooth, gentle slope. The data will consist of distances traveled and elapsed times.

- Find an open area to minimize the risk of injury during this lab.

- stopwatch
- measuring tape
- bicycle

1. Find a gentle, paved slope, such as an incline on a bike path. The more gentle the slope, the more accurate your data will likely be.
2. Mark uniform distances along the slope, such as 5 m, 10 m, etc.
3. Determine the following roles: the bike rider, the timer, and the recorder. The recorder should create a data table to collect the distance and time data.
4. Have the rider at the starting point at rest on the bike. When the timer calls *Start*, the timer starts the stopwatch and the rider begins coasting down the slope on the bike without pedaling.
5. Have the timer call out the elapsed times as the bike passes each marked point. The recorder should record the times in the data table. It may be necessary to repeat the process to practice roles and make necessary adjustments.
6. Once acceptable data has been recorded, switch roles. Repeat Steps 3–5 to collect a second set of data.
7. Switch roles again to collect a third set of data.
8. Calculate average acceleration for each set of distance-time data. If your result for $\overline{a}$ is not the same for different pairs of Δv and Δt, then acceleration is not constant.
9. Interpret your results.

GRASP CHECK

If you graph the average velocity (y-axis) vs. the elapsed time (x-axis), what would the graph look like if acceleration is uniform?

a. a horizontal line on the graph
b. a diagonal line on the graph
c. an upward-facing parabola on the graph
d. a downward-facing parabola on the graph

Check Your Understanding

3. What are three ways an object can accelerate?

a. By speeding up, maintaining constant velocity, or changing direction
b. By speeding up, slowing down, or changing direction
c. By maintaining constant velocity, slowing down, or changing direction
d. By speeding up, slowing down, or maintaining constant velocity

4. What is the difference between average acceleration and instantaneous acceleration?

a. Average acceleration is the change in displacement divided by the elapsed time; instantaneous acceleration is the acceleration at a given point in time.
b. Average acceleration is acceleration at a given point in time; instantaneous acceleration is the change in displacement divided by the elapsed time.
c. Average acceleration is the change in velocity divided by the elapsed time; instantaneous acceleration is acceleration at a given point in time.
d. Average acceleration is acceleration at a given point in time; instantaneous acceleration is the change in velocity divided by the elapsed time.

5. What is the rate of change of velocity called?

a. Time
b. Displacement
c. Velocity
d. Acceleration

3.2 Representing Acceleration with Equations and Graphs

Section Learning Objectives

By the end of this section, you will be able to do the following:

- Explain the kinematic equations related to acceleration and illustrate them with graphs
- Apply the kinematic equations and related graphs to problems involving acceleration

Section Key Terms

acceleration due to gravity	kinematic equations	uniform acceleration

How the Kinematic Equations are Related to Acceleration

We are studying concepts related to motion: time, displacement, velocity, and especially acceleration. We are only concerned with motion in one dimension. The **kinematic equations** apply to conditions of constant acceleration and show how these concepts are related. **Constant acceleration** is acceleration that does not change over time. The first kinematic equation relates displacement d, average velocity $\bar{v}$, and time t.

$$d = d_0 + \bar{v}t \tag{3.4}$$

The initial displacement d_0 is often 0, in which case the equation can be written as $\bar{v} = \frac{d}{t}$

This equation says that average velocity is displacement per unit time. We will express velocity in meters per second. If we graph displacement versus time, as in Figure 3.6, the slope will be the velocity. Whenever a rate, such as velocity, is represented graphically, time is usually taken to be the independent variable and is plotted along the *x* axis.

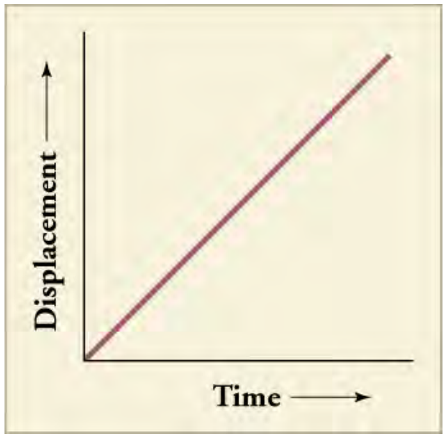


Figure 3.6 The slope of displacement versus time is velocity.

The second kinematic equation, another expression for average velocity $\overline{v}$, is simply the initial velocity plus the final velocity divided by two.

$$\overline{v} = \frac{v_0 + v_f}{2} \tag{3.5}$$

Now we come to our main focus of this chapter; namely, the kinematic equations that describe motion with constant acceleration. In the third kinematic equation, acceleration is the rate at which velocity increases, so velocity at any point equals initial velocity plus acceleration multiplied by time

$$v = v_0 + at \text{ Also, if we start from rest } (v_0 = 0 \text{), we can write } a = \frac{v}{t} \tag{3.6}$$

Note that this third kinematic equation does not have displacement in it. Therefore, if you do not know the displacement and are not trying to solve for a displacement, this equation might be a good one to use.

The third kinematic equation is also represented by the graph in Figure 3.7.

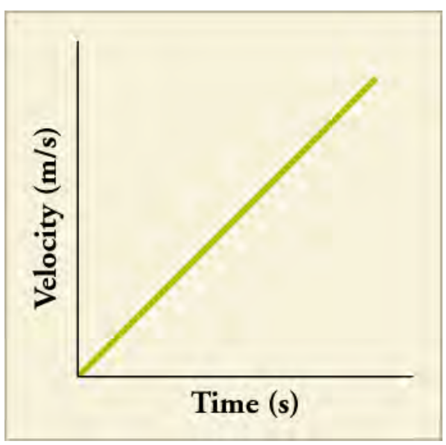


Figure 3.7 The slope of velocity versus time is acceleration.

The fourth kinematic equation shows how displacement is related to acceleration

$$d = d_0 + v_0 t + \frac{1}{2}at^2. \tag{3.7}$$

When starting at the origin, $d_0 = 0$ and, when starting from rest, $v_0 = 0$, in which case the equation can be written as

$$a = \frac{2d}{t^2}.$$

This equation tells us that, for constant acceleration, the slope of a plot of $2d$ versus t^2 is acceleration, as shown in Figure 3.8.

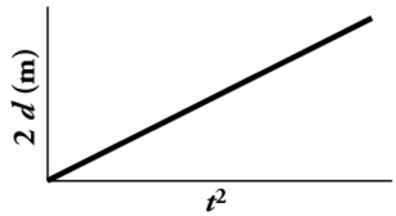


Figure 3.8 When acceleration is constant, the slope of $2d$ versus t^2 gives the acceleration.

The fifth kinematic equation relates velocity, acceleration, and displacement

$$v^2 = v_0^2 + 2a\left(d - d_0\right). \quad (3.8)$$

This equation is useful for when we do not know, or do not need to know, the time.

When starting from rest, the fifth equation simplifies to

$$a = \frac{v^2}{2d}.$$

According to this equation, a graph of velocity squared versus twice the displacement will have a slope equal to acceleration.

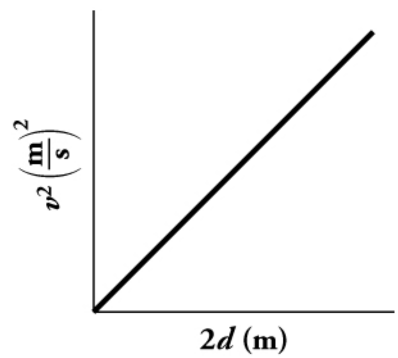


Figure 3.9

Note that, in reality, knowns and unknowns will vary. Sometimes you will want to rearrange a kinematic equation so that the knowns are the values on the axes and the unknown is the slope. Sometimes the intercept will not be at the origin (0,0). This will happen when v_0 or d_0 is not zero. This will be the case when the object of interest is already in motion, or the motion begins at some point other than at the origin of the coordinate system.

Virtual Physics

The Moving Man (Part 2)

Look at the Moving Man simulation again and this time use the *Charts* view. Again, vary the velocity and acceleration by sliding the red and green markers along the scales. Keeping the velocity marker near zero will make the effect of acceleration more obvious. Observe how the graphs of position, velocity, and acceleration vary with time. Note which are linear plots and which are not.

Click to view content (https://archive.cnx.org/specials/e2ca52af-8c6b-450e-ac2f-9300b38e8739/moving-man/)

GRASP CHECK

On a velocity versus time plot, what does the slope represent?

a. Acceleration

b. Displacement
c. Distance covered
d. Instantaneous velocity

GRASP CHECK

On a position versus time plot, what does the slope represent?

a. Acceleration
b. Displacement
c. Distance covered
d. Instantaneous velocity

The kinematic equations are applicable when you have constant acceleration.

1. $d = d_0 + \bar{v}t$, or $\bar{v} = \frac{d}{t}$ when $d_0 = 0$
2. $\bar{v} = \frac{v_0 + v_f}{2}$
3. $v = v_0 + at$, or $a = \frac{v}{t}$ when $v_0 = 0$
4. $d = d_0 + v_0 t + \frac{1}{2}at^2$, or $a = \frac{2d}{t^2}$ when $d_0 = 0$ and $v_0 = 0$
5. $v^2 = v_0^2 + 2a\,(d - d_0)$, or $a = \frac{2d}{t^2}$ when $d_0 = 0$ and $v_0 = 0$

Applying Kinematic Equations to Situations of Constant Acceleration

Problem-solving skills are essential to success in a science and life in general. The ability to apply broad physical principles, which are often represented by equations, to specific situations is a very powerful form of knowledge. It is much more powerful than memorizing a list of facts. Analytical skills and problem-solving abilities can be applied to new situations, whereas a list of facts cannot be made long enough to contain every possible circumstance. Essential analytical skills will be developed by solving problems in this text and will be useful for understanding physics and science in general throughout your life.

Problem-Solving Steps

While no single step-by-step method works for every problem, the following general procedures facilitate problem solving and make the answers more meaningful. A certain amount of creativity and insight are required as well.

1. *Examine the situation to determine which physical principles are involved. It is vital to draw a simple sketch at the outset.* Decide which direction is positive and note that on your sketch.
2. *Identify the knowns: Make a list of what information is given or can be inferred from the problem statement.* Remember, not all given information will be in the form of a number with units in the problem. If something starts *from rest*, we know the initial velocity is zero. If something *stops*, we know the final velocity is zero.
3. *Identify the unknowns: Decide exactly what needs to be determined in the problem.*
4. *Find an equation or set of equations that can help you solve the problem.* Your list of knowns and unknowns can help here. For example, if time is not needed or not given, then the fifth kinematic equation, which does not include time, could be useful.
5. *Insert the knowns along with their units into the appropriate equation and obtain numerical solutions complete with units.* This step produces the numerical answer; it also provides a check on units that can help you find errors. If the units of the answer are incorrect, then an error has been made.
6. *Check the answer to see if it is reasonable: Does it make sense?* This final step is extremely important because the goal of physics is to accurately describe nature. To see if the answer is reasonable, check its magnitude, its sign, and its units. Are the significant figures correct?

Summary of Problem Solving

- Determine the knowns and unknowns.
- Find an equation that expresses the unknown in terms of the knowns. More than one unknown means more than one equation is needed.
- Solve the equation or equations.

- Be sure units and significant figures are correct.
- Check whether the answer is reasonable.

FUN IN PHYSICS

Drag Racing

Figure 3.10 Smoke rises from the tires of a dragster at the beginning of a drag race. (Lt. Col. William Thurmond. Photo courtesy of U.S. Army.)

The object of the sport of drag racing is acceleration. Period! The races take place from a standing start on a straight one-quarter-mile (402 m) track. Usually two cars race side by side, and the winner is the driver who gets the car past the quarter-mile point first. At the finish line, the cars may be going more than 300 miles per hour (134 m/s). The driver then deploys a parachute to bring the car to a stop because it is unsafe to brake at such high speeds. The cars, called dragsters, are capable of accelerating at 26 m/s^2. By comparison, a typical sports car that is available to the general public can accelerate at about 5 m/s^2.

Several measurements are taken during each drag race:

- Reaction time is the time between the starting signal and when the front of the car crosses the starting line.
- Elapsed time is the time from when the vehicle crosses the starting line to when it crosses the finish line. The record is a little over 3 s.
- Speed is the average speed during the last 20 m before the finish line. The record is a little under 400 mph.

The video shows a race between two dragsters powered by jet engines. The actual race lasts about four seconds and is near the end of the video (https://openstax.org/l/28dragsters) .

GRASP CHECK

A dragster crosses the finish line with a velocity of 140 m/s. Assuming the vehicle maintained a constant acceleration from start to finish, what was its average velocity for the race?

a. 0 m/s
b. 35 m/s
c. 70 m/s
d. 140 m/s

WORKED EXAMPLE

Acceleration of a Dragster

The time it takes for a dragster to cross the finish line is unknown. The dragster accelerates from rest at 26 m/s^2 for a quarter mile (0.250 mi). What is the final velocity of the dragster?

Strategy

The equation $v^2 = v_0^2 + 2a(d - d_0)$ is ideally suited to this task because it gives the velocity from acceleration and displacement, without involving the time.

Solution

1. Convert miles to meters.

$$(0.250\ \ \text{mi}) \times \frac{1609\ \ \text{m}}{1\ \ \text{mi}} = 402\ \ \text{m} \tag{3.9}$$

2. Identify the known values. We know that $v_0 = 0$ since the dragster starts from rest, and we know that the distance traveled, $d - d_0$ is 402 m. Finally, the acceleration is constant at $a = 26.0\ \text{m/s}^2$.
3. Insert the knowns into the equation $v^2 = v_0^2 + 2a\left(d - d_0\right)$ and solve for v.

$$v^2 = 0 + 2\left(26.0\frac{\text{m}}{\text{s}^2}\right)(402\ \ \text{m}) = 2.09 \times 10^4\frac{\text{m}^2}{\text{s}^2} \tag{3.10}$$

Taking the square root gives us $v = \sqrt{2.09 \times 10^4\,\frac{\text{m}^2}{\text{s}^2}} = 145\frac{\text{m}}{\text{s}}$.

Discussion

145 m/s is about 522 km/hour or about 324 mi/h, but even this breakneck speed is short of the record for the quarter mile. Also, note that a square root has two values. We took the positive value because we know that the velocity must be in the same direction as the acceleration for the answer to make physical sense.

An examination of the equation $v^2 = v_0^2 + 2a\left(d - d_0\right)$ can produce further insights into the general relationships among physical quantities:

- The final velocity depends on the magnitude of the acceleration and the distance over which it applies.
- For a given acceleration, a car that is going twice as fast does not stop in twice the distance—it goes much further before it stops. This is why, for example, we have reduced speed zones near schools.

Practice Problems

6. Dragsters can reach a top speed of 145 m/s in only 4.45 s. Calculate the average acceleration for such a dragster.

a. $-32.6\ \text{m/s}^2$
b. $0\ \text{m/s}^2$
c. $32.6\ \text{m/s}^2$
d. $145\ \text{m/s}^2$

7. An Olympic-class sprinter starts a race with an acceleration of $4.50\ \text{m/s}^2$. Assuming she can maintain that acceleration, what is her speed 2.40 s later?

a. 4.50 m/s
b. 10.8 m/s
c. 19.6 m/s
d. 44.1 m/s

Constant Acceleration

In many cases, acceleration is not uniform because the force acting on the accelerating object is not constant over time. A situation that gives constant acceleration is the acceleration of falling objects. When air resistance is not a factor, all objects near Earth's surface fall with an acceleration of about $9.80\ \text{m/s}^2$. Although this value decreases slightly with increasing altitude, it may be assumed to be essentially constant. The value of $9.80\ \text{m/s}^2$ is labeled g and is referred to as **acceleration due to gravity**. Gravity is the force that causes nonsupported objects to accelerate downward—or, more precisely, toward the center of Earth. The magnitude of this force is called the weight of the object and is given by mg where m is the mass of the object (in kg). In places other than on Earth, such as the Moon or on other planets, g is not $9.80\ \text{m/s}^2$, but takes on other values. When using g for the acceleration a in a kinematic equation, it is usually given a negative sign because the acceleration due to gravity is downward.

WORK IN PHYSICS

Effects of Rapid Acceleration

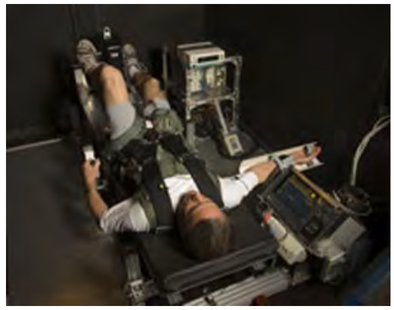


Figure 3.11 Astronauts train using G Force Simulators. (NASA)

When in a vehicle that accelerates rapidly, you experience a force on your entire body that accelerates your body. You feel this force in automobiles and slightly more on amusement park rides. For example, when you ride in a car that turns, the car applies a force on your body to make you accelerate in the direction in which the car is turning. If enough force is applied, you will accelerate at 9.80 m/s^2. This is the same as the acceleration due to gravity, so this force is called one G.

One G is the force required to accelerate an object at the acceleration due to gravity at Earth's surface. Thus, one G for a paper cup is much less than one G for an elephant, because the elephant is much more massive and requires a greater force to make it accelerate at 9.80 m/s^2. For a person, a G of about 4 is so strong that his or her face will distort as the bones accelerate forward through the loose flesh. Other symptoms at extremely high Gs include changes in vision, loss of consciousness, and even death. The space shuttle produces about 3 Gs during takeoff and reentry. Some roller coasters and dragsters produce forces of around 4 Gs for their occupants. A fighter jet can produce up to 12 Gs during a sharp turn.

Astronauts and fighter pilots must undergo G-force training in simulators. The video (https://www.youtube.com/watch?v=n-8QHOUWECU) shows the experience of several people undergoing this training.

People, such as astronauts, who work with G forces must also be trained to experience zero G—also called free fall or weightlessness—which can cause queasiness. NASA has an aircraft that allows it occupants to experience about 25 s of free fall. The aircraft is nicknamed the *Vomit Comet*.

GRASP CHECK

A common way to describe acceleration is to express it in multiples of g, Earth's gravitational acceleration. If a dragster accelerates at a rate of 39.2 m/s^2, how many g's does the driver experience?

a. 1.5 g
b. 4.0 g
c. 10.5 g
d. 24.5 g

WORKED EXAMPLE

Falling Objects

A person standing on the edge of a high cliff throws a rock straight up with an initial velocity v_0 of 13 m/s.
(a) Calculate the position and velocity of the rock at 1.00, 2.00, and 3.00 seconds after it is thrown. Ignore the effect of air resistance.

Strategy

Sketch the initial velocity and acceleration vectors and the axes.

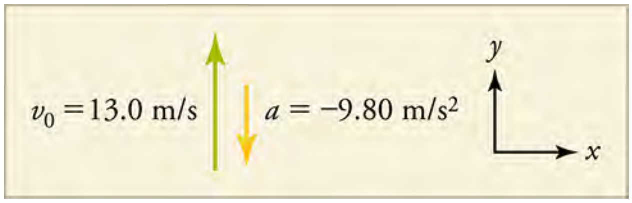


Figure 3.12 Initial conditions for rock thrown straight up.

List the knowns: time $t = 1.00$ s, 2.00 s, and 3.00 s; initial velocity $v_0 = 13$ m/s; acceleration $a = g = -9.80$ m/s^2; and position $y_0 = 0$ m

List the unknowns: y_1, y_2, and y_3; v_1, v_2, and v_3—where 1, 2, 3 refer to times 1.00 s, 2.00 s, and 3.00 s

Choose the equations.

$$d = d_0 + v_0 t + \frac{1}{2}at^2 \text{ becomes } y = y_0 + v_0 t - \frac{1}{2}gt^2 \tag{3.11}$$

$$v = v_0 + at \text{ becomes } v = v_0 + -gt \tag{3.12}$$

These equations describe the unknowns in terms of knowns only.

Solution

$$y_1 = 0 + (13.0 \text{ m/s})(1.00 \text{ s}) + \frac{(-9.80 \text{m/s}^2)(1.00 \text{ s})^2}{2} = 8.10 \text{ m}$$
$$y_2 = 0 + (13.0 \text{ m/s})(2.00 \text{ s}) + \frac{(-9.80 \text{m/s}^2)(2.00 \text{ s})^2}{2} = 6.40 \text{ m}$$
$$y_3 = 0 + (13.0 \text{ m/s})(3.00 \text{ s}) + \frac{(-9.80 \text{m/s}^2)(3.00 \text{ s})^2}{2} = -5.10 \text{ m}$$
$$v_1 = 13.0 \text{ m/s} + \left(-9.80 \text{m/s}^2\right)(1.00 \text{ s}) = 3.20 \text{ m/s}$$
$$v_2 = 13.0 \text{ m/s} + \left(-9.80 \text{m/s}^2\right)(2.00 \text{ s}) = -6.60 \text{ m/s}$$
$$v_3 = 13.0 \text{ m/s} + \left(-9.80 \text{m/s}^2\right)(3.00 \text{ s}) = -16.4 \text{ m/s}$$

Discussion

The first two positive values for y show that the rock is still above the edge of the cliff, and the third negative y value shows that it has passed the starting point and is below the cliff. Remember that we set *up* to be positive. Any position with a positive value is above the cliff, and any velocity with a positive value is an upward velocity. The first value for v is positive, so the rock is still on the way up. The second and third values for v are negative, so the rock is on its way down.

(b) Make graphs of position versus time, velocity versus time, and acceleration versus time. Use increments of 0.5 s in your graphs.

Strategy

Time is customarily plotted on the *x*-axis because it is the independent variable. Position versus time will not be linear, so calculate points for 0.50 s, 1.50 s, and 2.50 s. This will give a curve closer to the true, smooth shape.

Solution

The three graphs are shown in Figure 3.13.

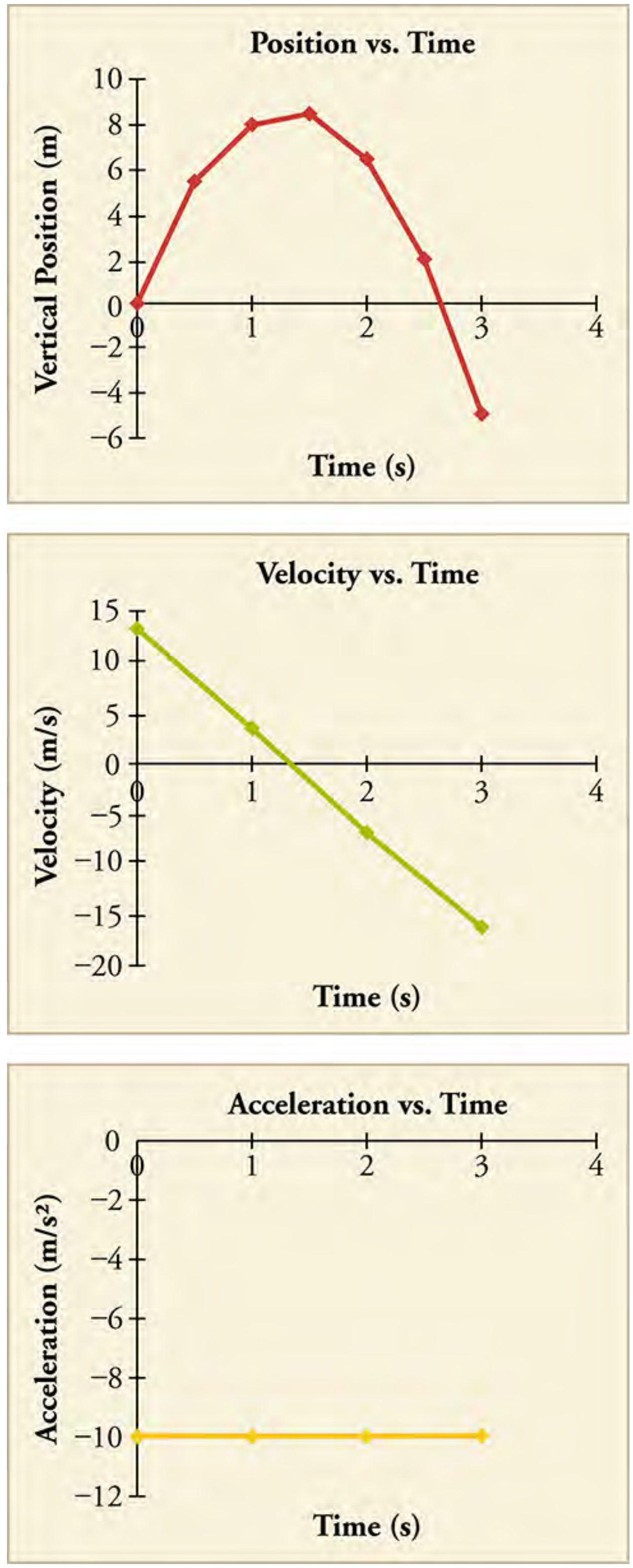


Figure 3.13

Discussion

- *y* vs. *t* does *not* represent the two-dimensional parabolic path of a trajectory. The path of the rock is straight up and straight down. The slope of a line tangent to the curve at any point on the curve equals the velocity at that point—i.e., the instantaneous velocity.

- Note that the v vs. t line crosses the vertical axis at the initial velocity and crosses the horizontal axis at the time when the rock changes direction and begins to fall back to Earth. This plot is linear because acceleration is constant.
- The a vs. t plot also shows that acceleration is constant; that is, it does not change with time.

Practice Problems

8. A cliff diver pushes off horizontally from a cliff and lands in the ocean 2.00 s later. How fast was he going when he entered the water?
   a. 0 m/s
   b. 19.0 m/s
   c. 19.6 m/s
   d. 20.0 m/s

9. A girl drops a pebble from a high cliff into a lake far below. She sees the splash of the pebble hitting the water 2.00 s later. How fast was the pebble going when it hit the water?
   a. 9.80 m/s
   b. 10.0 m/s
   c. 19.6 m/s
   d. 20.0 m/s

Check Your Understanding

10. Identify the four variables found in the kinematic equations.
   a. Displacement, Force, Mass, and Time
   b. Acceleration, Displacement, Time, and Velocity
   c. Final Velocity, Force, Initial Velocity, and Mass
   d. Acceleration, Final Velocity, Force, and Initial Velocity

11. Which of the following steps is always required to solve a kinematics problem?
   a. Find the force acting on the body.
   b. Find the acceleration of a body.
   c. Find the initial velocity of a body.
   d. Find a suitable kinematic equation and then solve for the unknown quantity.

12. Which of the following provides a correct answer for a problem that can be solved using the kinematic equations?
   a. A body starts from rest and accelerates at $4\ \mathrm{m/s^2}$ for 2 s. The body's final velocity is 8 m/s.
   b. A body starts from rest and accelerates at $4\ \mathrm{m/s^2}$ for 2 s. The body's final velocity is 16 m/s.
   c. A body with a mass of 2 kg is acted upon by a force of 4 N. The acceleration of the body is $2\ \mathrm{m/s^2}$.
   d. A body with a mass of 2 kg is acted upon by a force of 4 N. The acceleration of the body is $0.5\ \mathrm{m/s^2}$.

KEY TERMS

acceleration due to gravity acceleration of an object that is subject only to the force of gravity; near Earth's surface this acceleration is 9.80 m/s^2

average acceleration change in velocity divided by the time interval over which it changed

constant acceleration acceleration that does not change with respect to time

instantaneous acceleration rate of change of velocity at a specific instant in time

kinematic equations the five equations that describe motion in terms of time, displacement, velocity, and acceleration

negative acceleration acceleration in the negative direction

SECTION SUMMARY

3.1 Acceleration

- Acceleration is the rate of change of velocity and may be negative or positive.
- Average acceleration is expressed in m/s^2 and, in one dimension, can be calculated using $\overline{a} = \frac{\Delta v}{\Delta t} = \frac{v_f - v_0}{t_f - t_o}$.

3.2 Representing Acceleration with Equations and Graphs

- The kinematic equations show how time, displacement, velocity, and acceleration are related for objects in motion.
- In general, kinematic problems can be solved by identifying the kinematic equation that expresses the unknown in terms of the knowns.
- Displacement, velocity, and acceleration may be displayed graphically versus time.

KEY EQUATIONS

3.1 Acceleration

Average acceleration	$\overline{a} = \frac{\Delta v}{\Delta t} = \frac{v_f - v_0}{t_f - t_o}$

3.2 Representing Acceleration with Equations and Graphs

Average velocity	$d = d_0 + \overline{v}t$, or $\overline{v} = \frac{d}{t}$ when $d_0 = 0$
Average velocity	$\overline{v} = \frac{v_0 + v_f}{2}$
Velocity	$v = v_0 + at$, or when $v_0 = 0$
Displacement	$d = d_0 + v_0 t + \frac{1}{2}at^2$, or $a = \frac{2d}{t^2}$ when $d_0 = 0$ and $v_0 = 0$
Acceleration	$v^2 = v_0^2 + 2a(d - d_0)$, or $a = \frac{v^2}{2d}$ when $d_0 = 0$ and $v_0 = 0$

CHAPTER REVIEW

Concept Items

3.1 Acceleration

1. How can you use the definition of acceleration to explain the units in which acceleration is measured?
   a. Acceleration is the rate of change of velocity. Therefore, its unit is m/s^2.
   b. Acceleration is the rate of change of displacement. Therefore, its unit is m/s.
   c. Acceleration is the rate of change of velocity. Therefore, its unit is m^2/s.
   d. Acceleration is the rate of change of displacement. Therefore, its unit is m^2/s.

2. What are the SI units of acceleration?
   a. m^2/s
   b. cm^2/s
   c. m/s^2
   d. cm/s^2

3. Which of the following statements explains why a racecar going around a curve is accelerating, even if the speed is constant?
   a. The car is accelerating because the magnitude as well as the direction of velocity is changing.
   b. The car is accelerating because the magnitude of velocity is changing.
   c. The car is accelerating because the direction of velocity is changing.

d. The car is accelerating because neither the magnitude nor the direction of velocity is changing.

3.2 Representing Acceleration with Equations and Graphs

4. A student calculated the final velocity of a train that decelerated from 30.5 m/s and got an answer of −43.34 m/s. Which of the following might indicate that he made a mistake in his calculation?

a. The sign of the final velocity is wrong.
b. The magnitude of the answer is too small.
c. There are too few significant digits in the answer.
d. The units in the initial velocity are incorrect.

5. Create your own kinematics problem. Then, create a flow chart showing the steps someone would need to take to solve the problem.

a. Acceleration
b. Distance
c. Displacement
d. Force

6. Which kinematic equation would you use to find the velocity of a skydiver 2.0 s after she jumps from a plane and before she opens her parachute? Assume the positive direction is downward.

a. $v = v_0 + at$
b. $v = v_0 - at$
c. $v^2 = {v_0}^2 + at$
d. $v^2 = {v_0}^2 - at$

Critical Thinking Items

3.1 Acceleration

7. Imagine that a car is traveling from your left to your right at a constant velocity. Which two actions could the driver take that may be represented as (a) a velocity vector and an acceleration vector both pointing to the right and then (b) changing so the velocity vector points to the right and the acceleration vector points to the left?

a. (a) Push down on the accelerator and then (b) push down again on the accelerator a second time.
b. (a) Push down on the accelerator and then (b) push down on the brakes.
c. (a) Push down on the brakes and then (b) push down on the brakes a second time.
d. (a) Push down on the brakes and then (b) push down on the accelerator.

8. A motorcycle moving at a constant velocity suddenly accelerates at a rate of $4.0\ \text{m/s}^2$ to a speed of 35 m/s in 5.0 s. What was the initial speed of the motorcycle?

a. -34 m/s
b. -15 m/s
c. 15 m/s
d. 34 m/s

3.2 Representing Acceleration with Equations and Graphs

9. A student is asked to solve a problem:
An object falls from a height for 2.0 s, at which point it is still 60 m above the ground. What will be the velocity of the object when it hits the ground?
Which of the following provides the correct order of kinematic equations that can be used to solve the problem?

a. First use $v^2 = {v_0}^2 + 2a(d - d_0)$, then use $v = v_0 + at$.
b. First use $v = v_0 + at$, then use $v^2 = {v_0}^2 + 2a(d - d_0)$.
c. First use $d = d_0 + v_0 t + \frac{1}{2}at^2$, then use $v = v_0 + at$.
d. First use $v = v_0 + at$, then use $d - d_0 = v_0 t + \frac{1}{2}at^2$.

10. Skydivers are affected by acceleration due to gravity and by air resistance. Eventually, they reach a speed where the force of gravity is almost equal to the force of air resistance. As they approach that point, their acceleration decreases in magnitude to near zero.
Part A. Describe the shape of the graph of the magnitude of the acceleration versus time for a falling skydiver.
Part B. Describe the shape of the graph of the magnitude of the velocity versus time for a falling skydiver.
Part C. Describe the shape of the graph of the magnitude of the displacement versus time for a falling skydiver.

a. Part A. Begins with a nonzero y-intercept with a downward slope that levels off at zero; Part B. Begins at zero with an upward slope that decreases in magnitude until the curve levels off; Part C. Begins at zero with an upward slope that increases in magnitude until it becomes a positive constant
b. Part A. Begins with a nonzero y-intercept with an upward slope that levels off at zero; Part B. Begins at zero with an upward slope that decreases in magnitude until the curve levels off; Part C. Begins at zero with an upward slope that increases in magnitude until it becomes a positive constant
c. Part A. Begins with a nonzero y-intercept with a downward slope that levels off at zero; Part B. Begins at zero with a downward slope that

decreases in magnitude until the curve levels off; Part C. Begins at zero with an upward slope that increases in magnitude until it becomes a positive constant

d. Part A. Begins with a nonzero y-intercept with an upward slope that levels off at zero; Part B. Begins at zero with a downward slope that decreases in magnitude until the curve levels off; Part C. Begins at zero with an upward slope that increases in magnitude until it becomes a positive constant

11. Which graph in the previous problem has a positive slope?

a. Displacement versus time only
b. Acceleration versus time and velocity versus time
c. Velocity versus time and displacement versus time
d. Acceleration versus time and displacement versus time

Problems

3.1 Acceleration

12. The driver of a sports car traveling at 10.0 m/s steps down hard on the accelerator for 5.0 s and the velocity increases to 30.0 m/s. What was the average acceleration of the car during the 5.0 s time interval?

a. $-1.0 \times 102\ m/s^2$
b. $-4.0\ m/s^2$
c. $4.0\ m/s^2$
d. $1.0 \times 102\ m/s^2$

13. A girl rolls a basketball across a basketball court. The ball slowly decelerates at a rate of $-0.20\ m/s^2$. If the initial velocity was 2.0 m/s and the ball rolled to a stop at 5.0 sec after 12:00 p.m., at what time did she start the ball rolling?

a. 0.1 seconds before noon
b. 0.1 seconds after noon
c. 5 seconds before noon
d. 5 seconds after noon

3.2 Representing Acceleration with Equations and Graphs

14. A swan on a lake gets airborne by flapping its wings and running on top of the water. If the swan must reach a velocity of 6.00 m/s to take off and it accelerates from rest at an average rate of $0.350\ m/s^2$, how far will it travel before becoming airborne?

a. −8.60 m
b. 8.60 m
c. −51.4 m
d. 51.4 m

15. A swimmer bounces straight up from a diving board and falls feet first into a pool. She starts with a velocity of 4.00 m/s and her takeoff point is 8 m above the pool. How long are her feet in the air?

a. 0.408 s
b. 0.816 s
c. 1.34 s
d. 1.75 s
e. 1.28 s

Performance Task

3.2 Representing Acceleration with Equations and Graphs

16. Design an experiment to measure displacement and elapsed time. Use the data to calculate final velocity, average velocity, acceleration, and acceleration.

Materials

- a small marble or ball bearing
- a garden hose
- a measuring tape
- a stopwatch or stopwatch software download
- a sloping driveway or lawn as long as the garden hose with a level area beyond

(a) How would you use the garden hose, stopwatch, marble, measuring tape, and slope to measure displacement and elapsed time? Hint—The marble is the accelerating object, and the length of the hose is total displacement.
(b) How would you use the displacement and time data to calculate velocity, average velocity, and acceleration? Which kinematic equations would you use?
(c) How would you use the materials, the measured and calculated data, and the flat area below the slope to determine the negative acceleration? What would you measure, and which kinematic equation would you use?

TEST PREP

Multiple Choice

3.1 Acceleration

17. Which variable represents displacement?

a. *a*
b. *d*
c. *t*
d. *v*

18. If a velocity increases from 0 to 20 m/s in 10 s, what is the average acceleration?

a. 0.5 m/s^2
b. 2 m/s^2
c. 10 m/s^2
d. 30 m/s^2

3.2 Representing Acceleration with Equations and Graphs

19. For the motion of a falling object, which graphs are straight lines?

a. Acceleration versus time only
b. Displacement versus time only
c. Displacement versus time and acceleration versus time
d. Velocity versus time and acceleration versus time

20. A bullet in a gun is accelerated from the firing chamber to the end of the barrel at an average rate of 6.30×10^5 m/s^2 for 8.10×10^{-4} s. What is the bullet's final velocity when it leaves the barrel, commonly known as the muzzle velocity?

a. 7.79 m/s
b. 51.0 m/s
c. 510 m/s
d. 1020 m/s

Short Answer

3.1 Acceleration

21. True or False—The vector for a negative acceleration points in the opposite direction when compared to the vector for a positive acceleration.

a. True
b. False

22. If a car decelerates from 20 m/s to 15 m/s in 5 s, what is Δv?

a. -5 m/s
b. -1 m/s
c. 1 m/s
d. 5 m/s

23. How is the vector arrow representing an acceleration of magnitude 3 m/s^2 different from the vector arrow representing a negative acceleration of magnitude 3 m/s^2?

a. They point in the same direction.
b. They are perpendicular, forming a 90° angle between each other.
c. They point in opposite directions.
d. They are perpendicular, forming a 270° angle between each other.

24. How long does it take to accelerate from 8.0 m/s to 20.0 m/s at a rate of acceleration of 3.0 m/s^2?

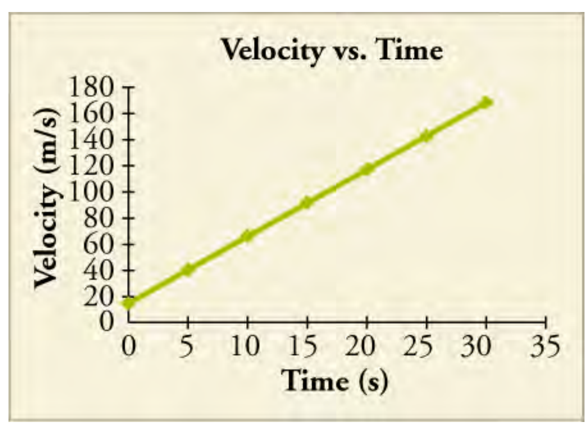
a. 0.25 s
b. 4.0 s
c. 9.33 s
d. 36 s

3.2 Representing Acceleration with Equations and Graphs

25. If a plot of displacement versus time is linear, what can be said about the acceleration?

a. Acceleration is 0.
b. Acceleration is a non-zero constant.
c. Acceleration is positive.
d. Acceleration is negative.

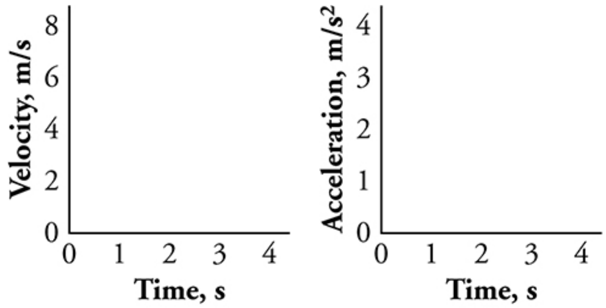
26.



True or False: —The image shows a velocity vs. time graph for a jet car. If you take the slope at any point on the graph, the jet car's acceleration will be 5.0 m/s^2.

a. True
b. False

27. When plotted on the blank plots, which answer choice would show the motion of an object that has uniformly accelerated from 2 m/s to 8 m/s in 3 s?



a. The plot on the left shows a line from (0,2) to (3,8) while the plot on the right shows a line from (0,2) to (3,2).
b. The plot on the left shows a line from (0,2) to (3,8) while the plot on the right shows a line from (0,3) to (3,3).
c. The plot on the left shows a line from (0,8) to (3,2) while the plot on the right shows a line from (0,2) to (3,2).
d. The plot on the left shows a line from (0,8) to (3,2) while the plot on the right shows a line from (0,3) to (3,3).

28. When is a plot of velocity versus time a straight line and when is it a curved line?

a. It is a straight line when acceleration is changing and is a curved line when acceleration is constant.
b. It is a straight line when acceleration is constant and is a curved line when acceleration is changing.
c. It is a straight line when velocity is constant and is a curved line when velocity is changing.
d. It is a straight line when velocity is changing and is a curved line when velocity is constant.

Extended Response

3.1 Acceleration

29. A test car carrying a crash test dummy accelerates from 0 to 30 m/s and then crashes into a brick wall. Describe the direction of the initial acceleration vector and compare the initial acceleration vector's magnitude with respect to the acceleration magnitude at the moment of the crash.

a. The direction of the initial acceleration vector will point towards the wall, and its magnitude will be less than the acceleration vector of the crash.
b. The direction of the initial acceleration vector will point away from the wall, and its magnitude will be less than the vector of the crash.
c. The direction of the initial acceleration vector will point towards the wall, and its magnitude will be more than the acceleration vector of the crash.
d. The direction of the initial acceleration vector will point away from the wall, and its magnitude will be more than the acceleration vector of the crash.

30. A car accelerates from rest at a stop sign at a rate of 3.0 m/s^2 to a speed of 21.0 m/s, and then immediately begins to decelerate to a stop at the next stop sign at a rate of 4.0 m/s^2. How long did it take the car to travel from the first stop sign to the second stop sign? Show your work.

a. 1.7 seconds
b. 5.3 seconds
c. 7.0 seconds
d. 12 seconds

3.2 Representing Acceleration with Equations and Graphs

31. True or False: Consider an object moving with constant acceleration. The plot of displacement versus time for such motion is a curved line while the plot of displacement versus time squared is a straight line.

a. True
b. False

32. You throw a ball straight up with an initial velocity of 15.0 m/s. It passes a tree branch on the way up at a height of 7.00 m. How much additional time will pass before the ball passes the tree branch on the way back down?

a. 0.574 s
b. 0.956 s
c. 1.53 s
d. 1.91 s