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).

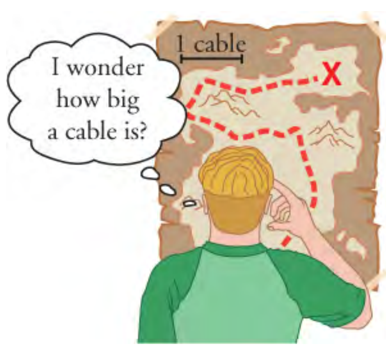


Figure 1.13 Distances given in unknown units are maddeningly useless.

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).

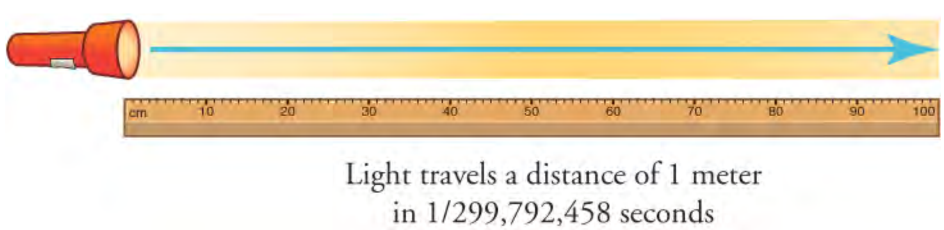


Figure 1.14 The meter is defined to be the distance light travels in 1/299,792,458 of a second through a vacuum. Distance traveled is speed multiplied by time.

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).

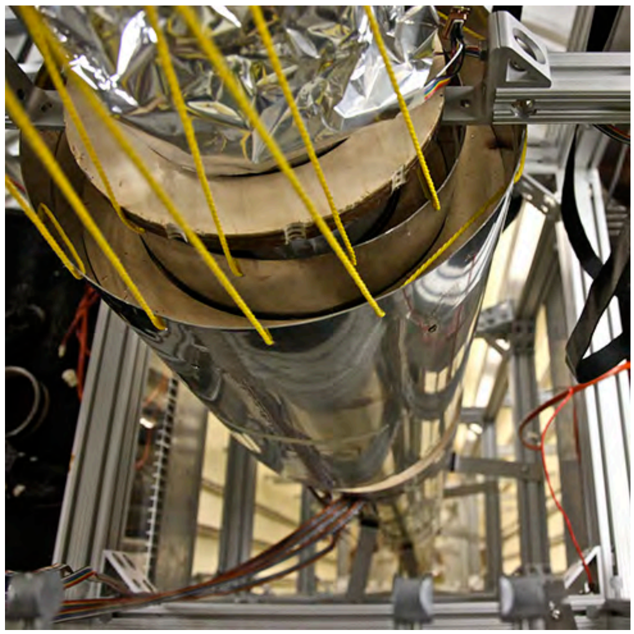


Figure 1.15 An atomic clock such as this one uses the vibrations of cesium atoms to keep time to a precision of one microsecond per year. The fundamental unit of time, the second, is based on such clocks. This image is looking down from the top of an atomic clock. (Steve Jurvetson/Flickr)

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.

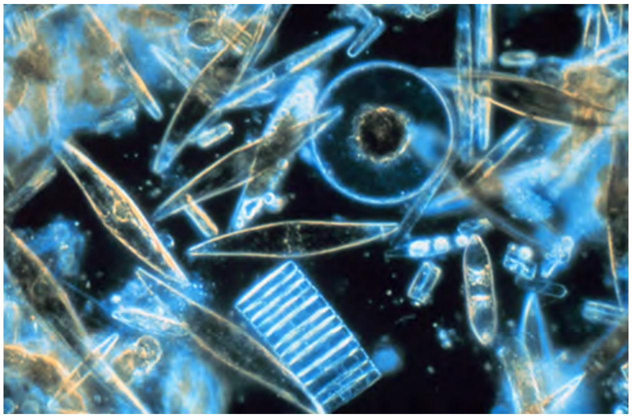


Figure 1.16 Tiny phytoplankton float among crystals of ice in the Antarctic Sea. They range from a few micrometers to as much as 2 millimeters in length. (Prof. Gordon T. Taylor, Stony Brook University; NOAA Corps Collections)

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.

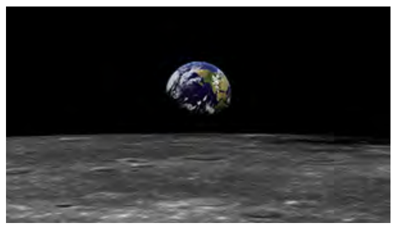


Figure 1.18 The distance from Earth to the moon may seem immense, but it is just a tiny fraction of the distance from Earth to our closest neighboring star. (NASA)

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:

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

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

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

$$\text{Averagespeed} = 8.33\frac{\text{m}}{\text{s}}$$

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

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

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

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

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.

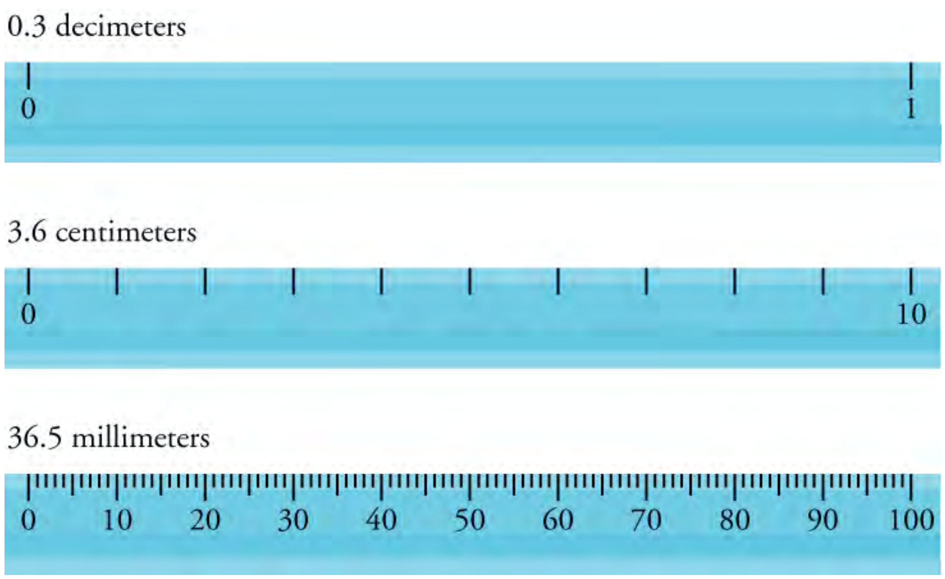


Figure 1.24 Three metric rulers are shown. The first ruler is in decimeters and can measure point three decimeters. The second ruler is in centimeters long and can measure three point six centimeters. The last ruler is in millimeters and can measure thirty-six point five millimeters.

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,

$$6527.23 + 2 = 6528.23 = 6528 \text{ .}$$

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).

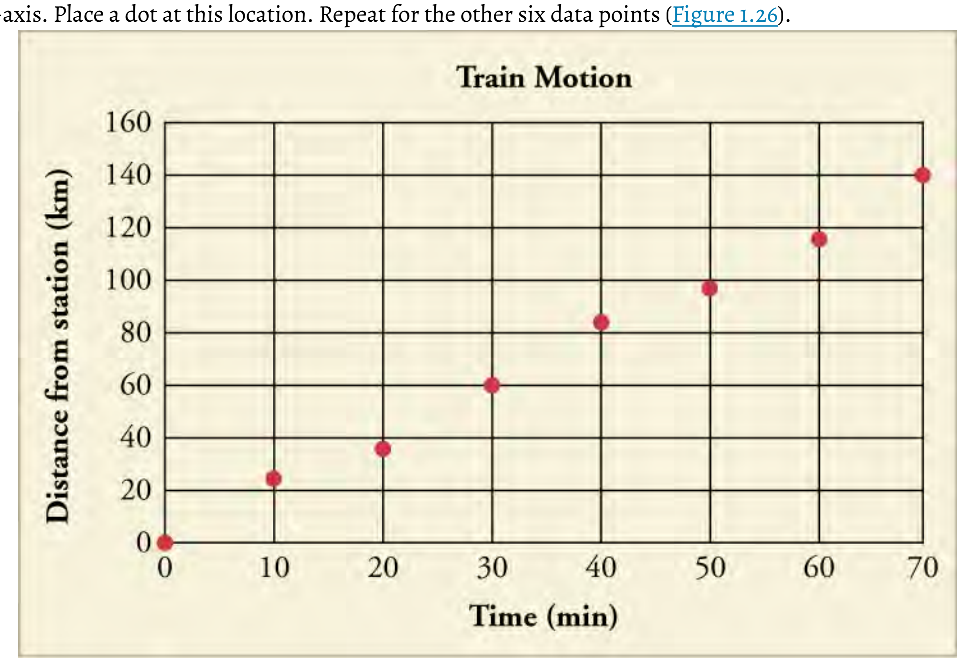


Figure 1.26 The graph of the train's distance from the station versus time from the exercise above.

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.

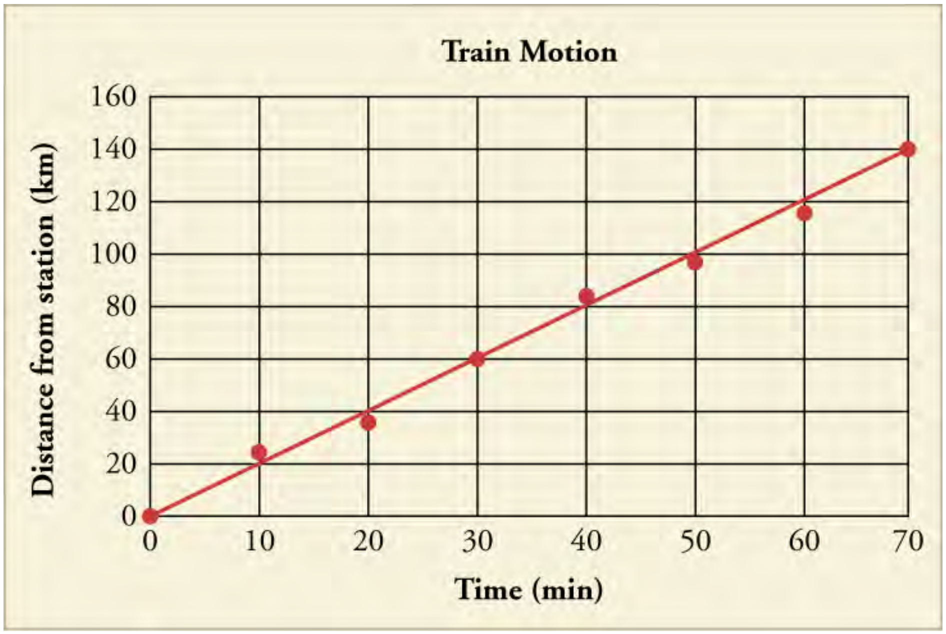


Figure 1.27 The completed graph with the trend line included.

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).

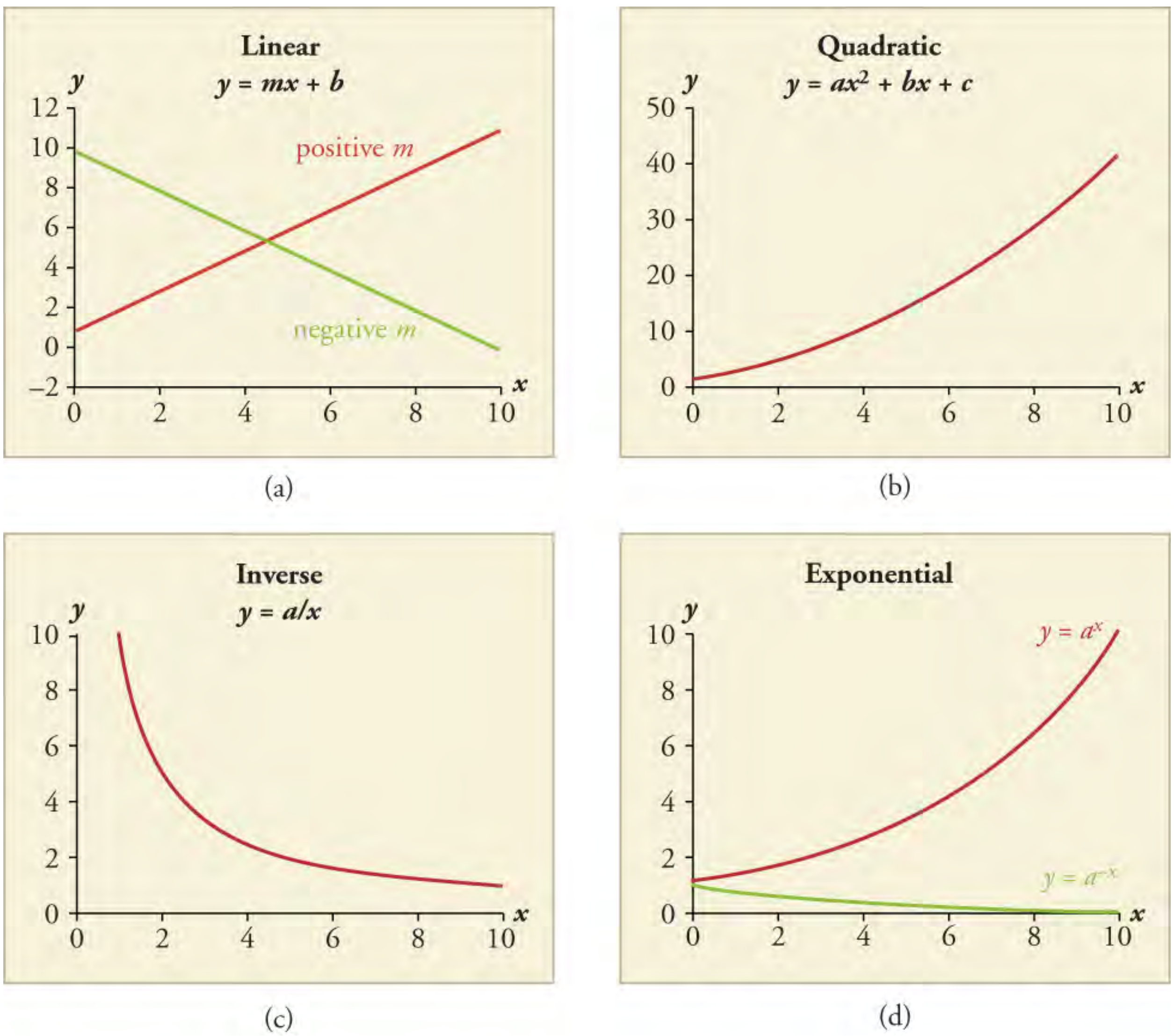


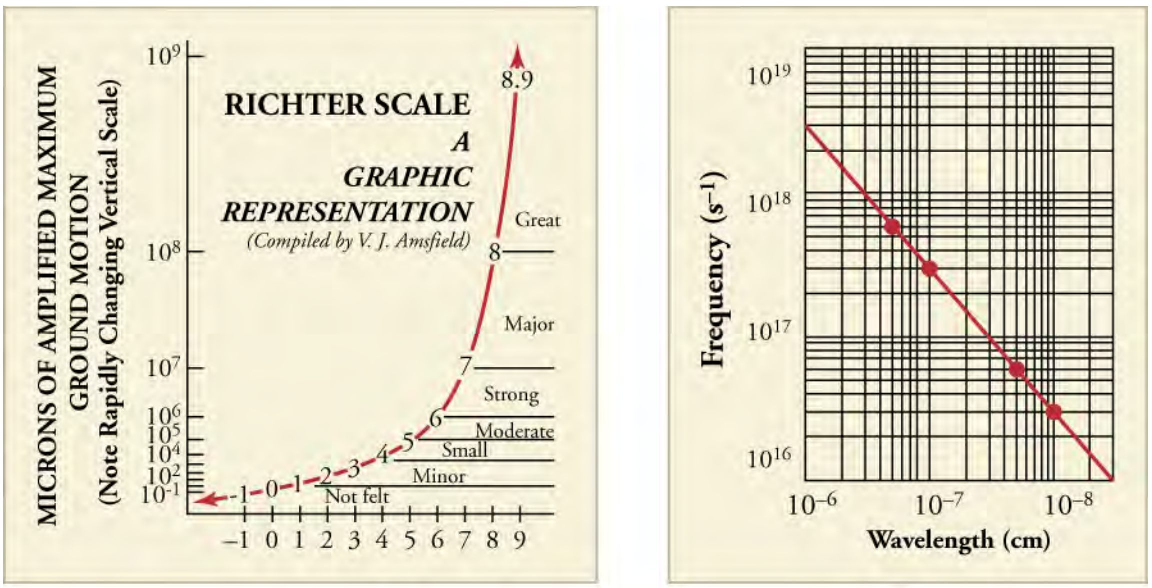
Figure 1.28 Examples of (a) linear, (b) quadratic, (c) inverse, and (d) exponential relationship graphs.

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.



(a) (b)

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 yd, excluding the end zones. How long is the field in meters? Round to the nearest 0.1 m.

a. 10.2 m
b. 91.4 m
c. 109.4 m
d. 328.1 m

14. The speed limit on some interstate highways is roughly 100 km/h. How many miles per hour is this if 1.0 mile is about 1.609 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 km course in 2 h, 30 min, and 12 s. There is an uncertainty of 25 m in the distance traveled and an uncertainty of 1 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 cm and 2.05 cm long and 3.1 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 $80\ \text{km/h}$. 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 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 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%

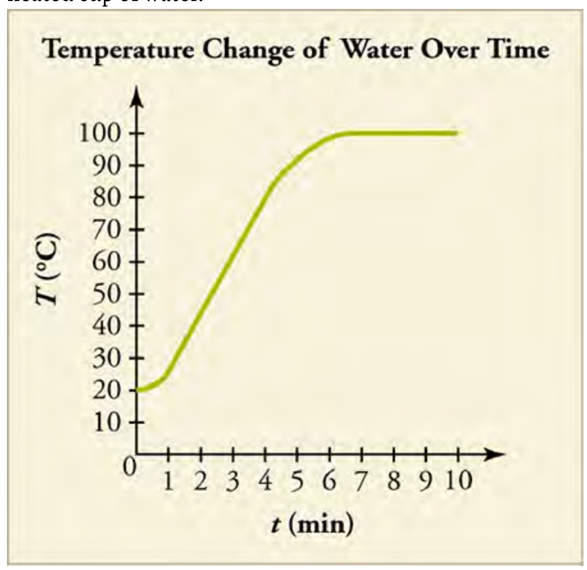
68. Explain how the uncertainty of a measurement relates to the accuracy and precision of the measuring device. Include the definitions of accuracy and precision in your answer.

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 cm/year. What distance does it move in 1.0 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. $y = \frac{x}{2} + 9$