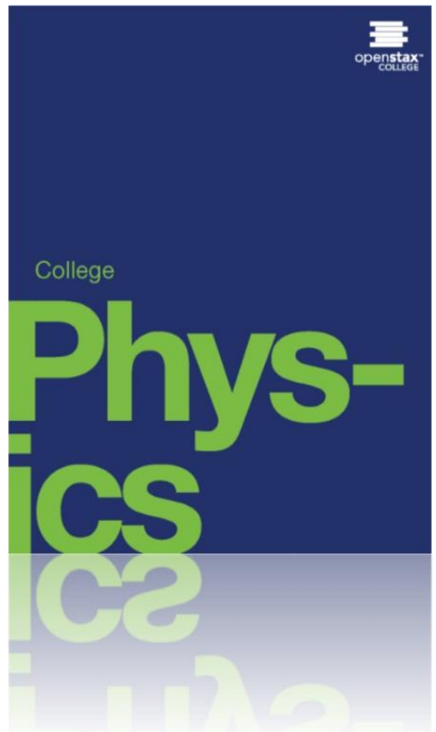
COLLEGE PHYSICS

Chapter 1 INTRODUCTION: THE NATURE OF SCIENCE AND PHYSICS



- Physics and Its Relation to Other Fields
- Models, Theories, and Laws
- Accuracy, Precision and Significant Numbers
- Units, Standards, and the SI System
- Converting Units

Physics and Its Relation to Other Fields

Physics is needed in both architecture and engineering.

Other fields that use physics, and make contributions to it: chemistry, biology, physiology, zoology, life sciences, …

FIGURE 1.1-1.4,1.6,1.7

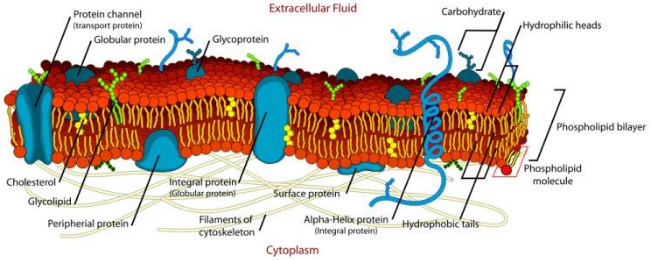
Galaxies are as immense as atoms are small. Yet the same laws of physics describe both, and all the rest of nature.

The Apple “iPhone” is a common smart phone with a GPS function. Physics describes the way that electricity flows through the circuits of this device. GPS uses physics equations to determine the driving time between two locations on a map.

The flight formations of migratory birds such as Canada geese are governed by the laws of physics.

The laws of physics help us understand how common appliances work. The laws of physics can help explain how microwave ovens heat up food.

Physics, chemistry, and biology help describe the properties of cell walls in plant cells, such as the onion cells seen here.



An artist’s rendition of the structure of a cell membrane. Many of the most fundamental properties of life, such as the firing of nerve cells, are related to membranes. The disciplines of biology, chemistry, and physics all help us understand the membranes of animal cells.

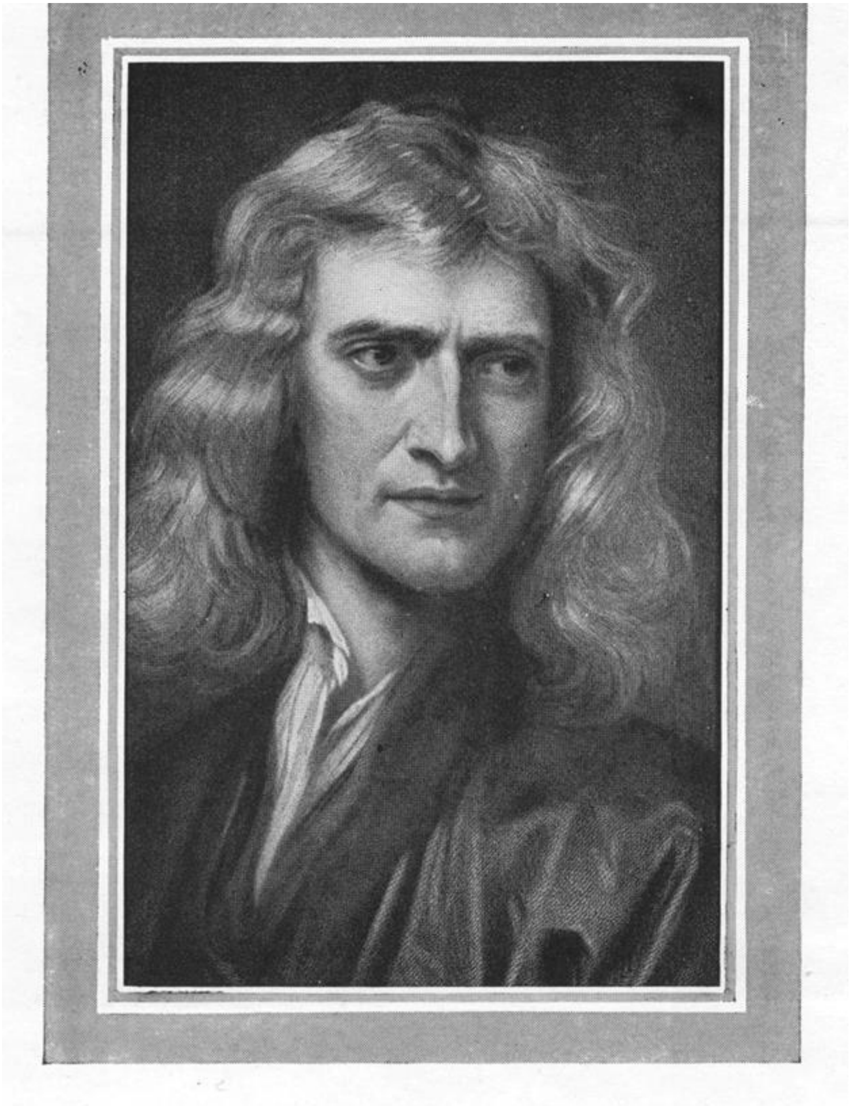
The Nature of Science

Observation: important first step toward scientific theory; it requires imagination to tell what is important.

Theories are created to explain observations; they will make predictions.

Observations will tell if the prediction is accurate, and the cycle goes on.

FIGURE 1.8



Isaac Newton (1642–1727) was very reluctant to publish his revolutionary work and had to be convinced to do so. In his later years, he stepped down from his academic post and became exchequer of the Royal Mint. He took this post seriously, inventing reeding (or creating ridges) on the edge of coins to prevent unscrupulous people from trimming the silver off of them before using them as currency.

FIGURE 1.9

Marie Curie (1867–1934) sacrificed monetary assets to help finance her early research and damaged her physical well-being with radiation exposure. She is the only person to win Nobel prizes in both physics and chemistry. One of her daughters also won a Nobel Prize.

Models, Theories, and Laws

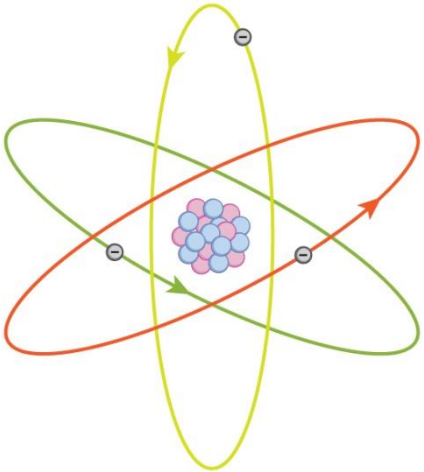
Models are very useful during the process of understanding phenomena. A model creates mental pictures; care must be taken to understand the limits of the model and not take it too seriously.

A theory is detailed and can give testable predictions.

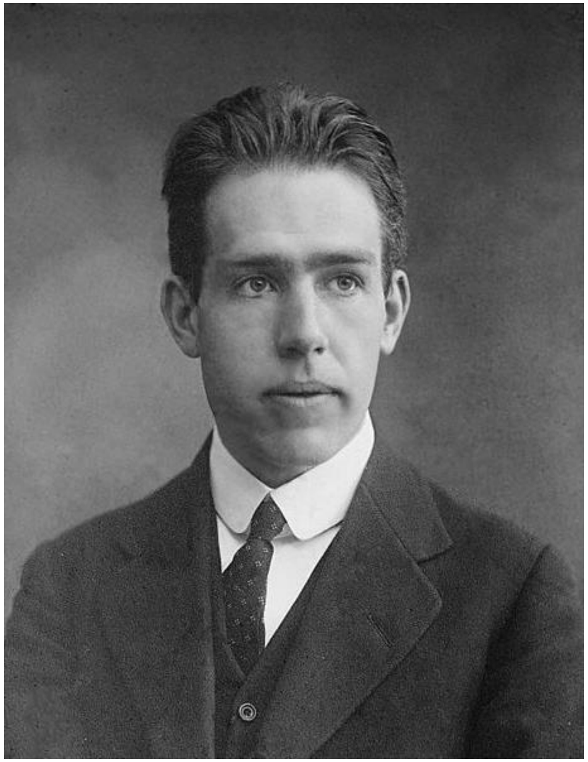
A law is a brief description of how nature behaves in a broad set of circumstances.

A principle is similar to a law, but applies to a narrower range of phenomena.

FIGURE 1.10, 1.13



What is a model? This planetary model of the atom shows electrons orbiting the nucleus. It is a drawing that we use to form a mental image of the atom that we cannot see directly with our eyes because it is too small.



Niels Bohr (1885–1962) made fundamental contributions to the development of quantum mechanics, one part of modern physics.

Measurement and Uncertainty
Significant Figures

No measurement is exact; there is always some uncertainty due to limited instrument accuracy and difficulty reading results.

The photograph to the left illustrates this – it would be difficult to measure the width of this 2x4 to better than a millimeter.

Measurement and Uncertainty
Significant Figures

Estimated uncertainty is written with a ± sign; for example: $8.8 \pm 0.1\ \mathrm{cm}$

Percent uncertainty is the ratio of the uncertainty to the measured value, multiplied by 100:

$$\frac{0.1}{8.8} \times 100\% \approx 1\%$$

Measurement and Uncertainty
Significant Figures

The number of significant figures is the number of reliably known digits in a number. It is usually possible to tell the number of significant figures by the way the number is written:

23.21 cm has 4 significant figures

0.062 cm has 2 significant figures (the initial zeroes don’t count)

80 km is ambiguous – it could have 1 or 2 significant figures. If it has 3, it should be written 80.0 km.

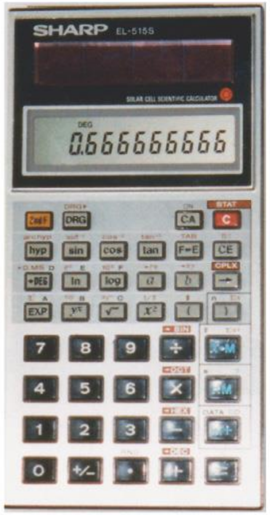
Measurement and Uncertainty
Significant Figures

When multiplying or dividing numbers, the result has as many significant figures as the number used in the calculation with the fewest significant figures.

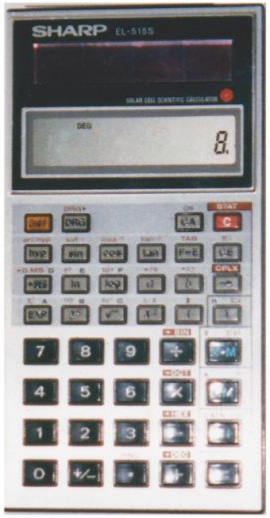
Example: 11.3 cm x 6.8 cm = 77 cm^2

When adding or subtracting, the answer is no more accurate than the least accurate number used.

Measurement and Uncertainty; Significant Figures



(a)



(b)

Calculators will not give you the right number of significant figures; they usually give too many but sometimes give too few (especially if there are trailing zeroes after a decimal point).

The top calculator shows the result of 2.0 / 3.0.

The bottom calculator shows the result of 2.5 x 3.2.

Units, Standards, and the SI System

Quantity	Unit	Standard
Length	Meter	Length of the path traveled by light in 1/299,792,458 second.
Time	Second	Time required for 9,192,631,770 periods of radiation emitted by cesium atoms
Mass	Kilogram	Platinum-iridium cylinder in International Bureau of Weights and Measures, Paris

Units, Standards, and the SI System

Metric (SI) Prefixes

Prefix	Abbreviation	Value
yotta	Y	10^{24}
zetta	Z	10^{21}
exa	E	10^{18}
peta	P	10^{15}
tera	T	10^{12}
giga	G	10^{9}
mega	M	10^{6}
kilo	k	10^{3}
hecto	h	10^{2}
deka	da	10^{1}
deci	d	10^{-1}
centi	c	10^{-2}
milli	m	10^{-3}
micro†	μ	10^{-6}
nano	n	10^{-9}
pico	p	10^{-12}
femto	f	10^{-15}
atto	a	10^{-18}
zepto	z	10^{-21}
yocto	y	10^{-24}

† μ is the Greek letter "mu."

These are the standard SI prefixes for indicating powers of 10. Many are familiar; Y, Z, E, h, da, a, z, and y are rarely used.

Units, Standards, and the SI System

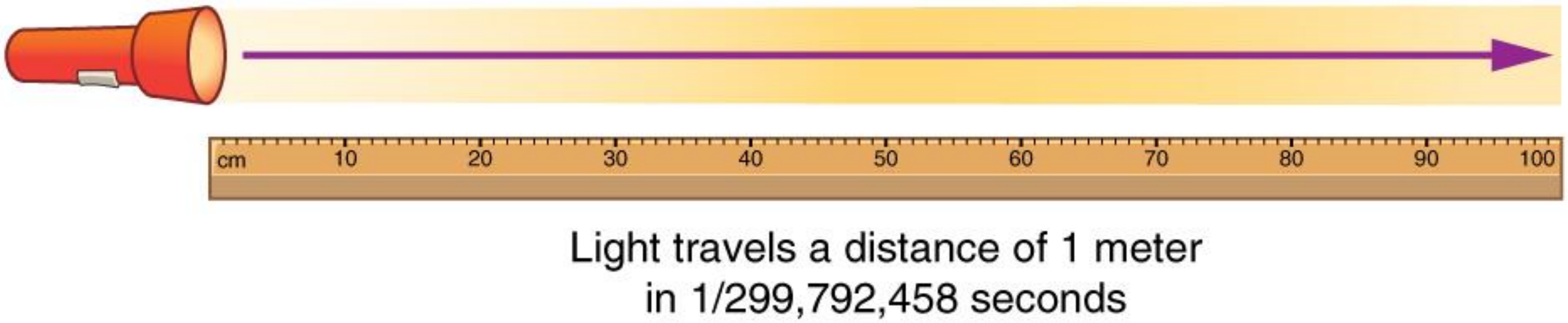
We will be working in the SI system, where the basic units are kilograms, meters, and seconds.

Quantity	Unit	Unit Abbre-viation
Length	meter	m
Time	second	s
Mass	kilogram	kg
Electric current	ampere	A
Temperature	kelvin	K
Amount of substance	mole	mol
Luminous intensity	candela	cd

Other systems: cgs; units are grams, centimeters, and seconds.

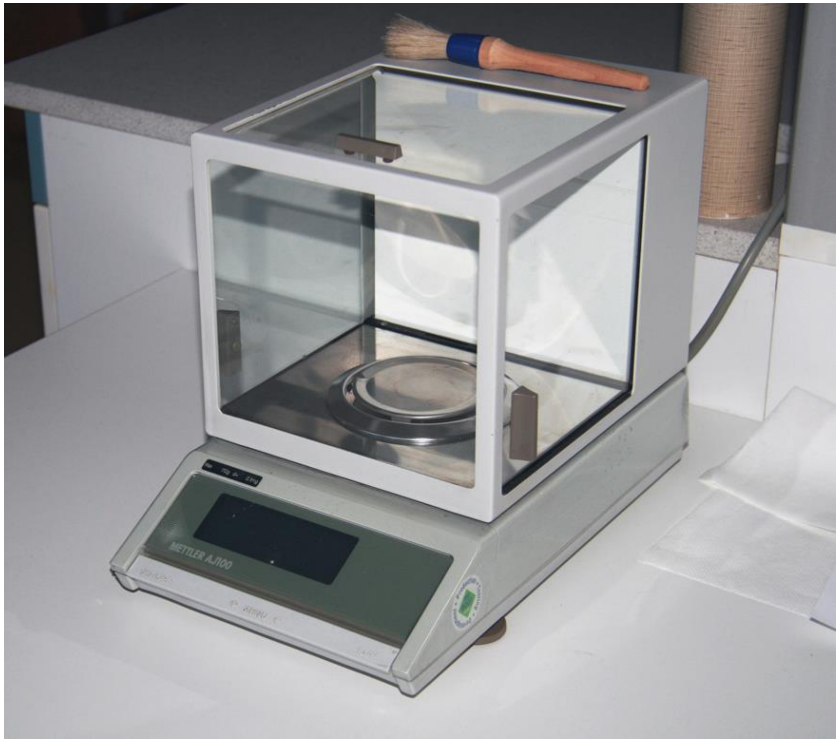
British engineering system has force instead of mass as one of its basic quantities, which are feet, pounds, and seconds.

FIGURE 1.19



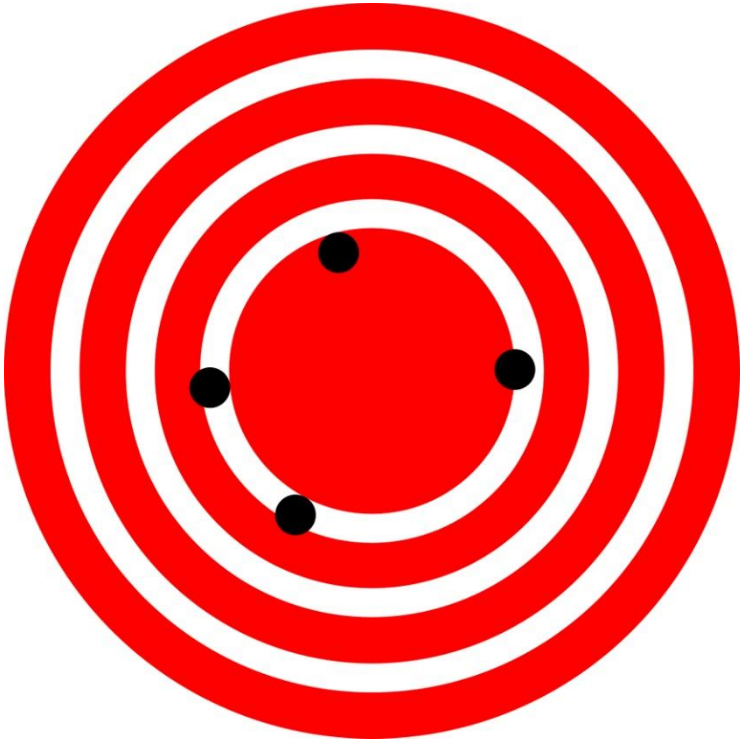
The meter is defined to be the distance light travels in 1/299,792,458 of a second in a vacuum. Distance traveled is speed multiplied by time.

FIGURE 1.23



Many mechanical balances, such as double-pan balances, have been replaced by digital scales, which can typically measure the mass of an object more precisely. Whereas a mechanical balance may only read the mass of an object to the nearest tenth of a gram, many digital scales can measure the mass of an object up to the nearest thousandth of a gram.

FIGURE 1.24



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.

FIGURE 1.25

In this figure, the dots are concentrated rather closely to one another, indicating high precision, but they are rather far away from the actual location of the restaurant, indicating low accuracy.

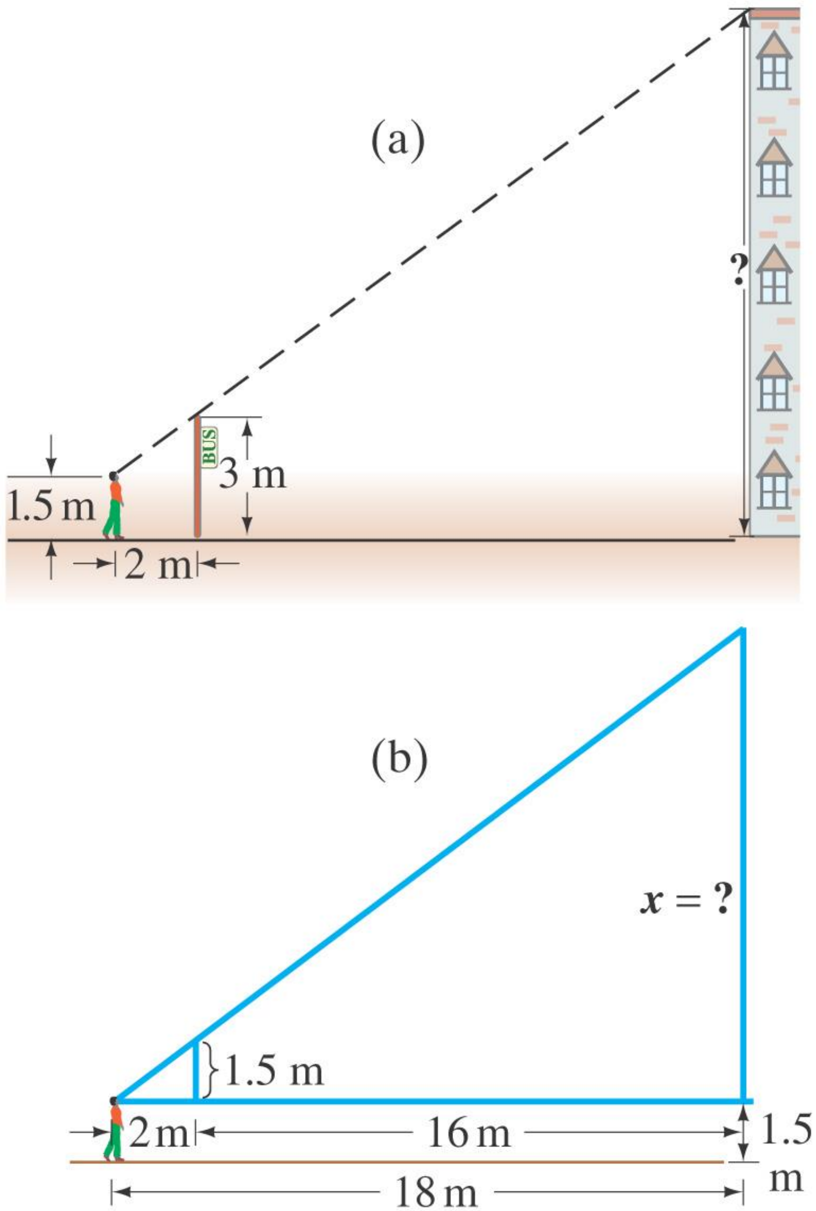
Converting Units

Converting between metric units, for example from kg to g, is easy, as all it involves is powers of 10.

Converting to and from British units is considerably more work.

For example, given that 1 m = 3.28084 ft, this 8611 m mountain is 28251 feet high.

Order of Magnitude: Rapid Estimating



A quick way to estimate a calculated quantity is to round off all numbers to one significant figure and then calculate. Your result should at least be the right order of magnitude; this can be expressed by rounding it off to the nearest power of 10.

Diagrams are also very useful in making estimations.

Dimensions and Dimensional Analysis

Dimensions of a quantity are the base units that make it up; they are generally written using square brackets.

Example: Speed = distance / time

Dimensions of speed: [L/T]

Quantities that are being added or subtracted must have the same dimensions. In addition, a quantity calculated as the solution to a problem should have the correct dimensions.

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.)

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,

$$\text{average speed} = \frac{\text{distance}}{\text{time}}. \tag{1.2}$$

$$\text{average speed} = \frac{10.0\text{ km}}{20.0\text{ min}} = 0.500\frac{\text{km}}{\text{min}}. \tag{1.3}$$

(3) Convert km/min to km/h: multiply by the conversion factor that will cancel minutes and leave hours. That conversion factor is 60 min/hr. Thus,

$$\text{average speed} = 0.500\frac{\text{km}}{\text{min}} \times \frac{60\text{ min}}{1\text{ h}} = 30.0\frac{\text{km}}{\text{h}}. \tag{1.4}$$

Solution for (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

$$\text{Average speed} = 30.0\frac{\text{km}}{\text{h}} \times \frac{1\text{ h}}{3{,}600\text{ s}} \times \frac{1{,}000\text{ m}}{1\text{ km}}, \tag{1.6}$$

$$\text{Average speed} = 8.33\frac{\text{m}}{\text{s}}. \tag{1.7}$$

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** (%unc) is defined to be

$$\% \text{ unc} = \delta A / A \times 100\%.$$

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 lb
- Week 2 weight: 5.3 lb
- Week 3 weight: 4.9 lb
- Week 4 weight: 5.4 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:

$\% \text{ unc} = \delta A / A \times 100\%$.

Solution

Plug the known values into the equation:

$\% \text{ unc} = 0.4 \text{ lb} / 5 \text{ lb} \times 100\% = 8\%$.

Discussion

We can conclude that the weight of the apple bag is 5 lb ± 8% .

Uncertainties in Calculations

The method of adding percents can be used for multiplication or division. This method says that

***<u>the percent uncertainty</u> 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% and 1% , respectively, then the area of the floor is 12.0 m^2 and has an uncertainty of 3% .

The method of **significant figures**

The rule is that *the last digit written down in a measurement is the first digit with some uncertainty*.

For example, the measured value 36.7 cm has three digits, or significant figures.
Significant figures indicate the precision of a measuring tool that was used to measure a value.

Zeros

The zeros in 0.053 are not significant, because they are only place keepers. There are two significant figures in 0.053.
The zeros in 10.053 are not place keepers but are significant—this number 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 digit, or they could be place keepers. So 1300 could have two, three, or four significant figures. (To avoid this ambiguity, write 1300 in scientific notation)

Zeros are significant except when they serve only as place keepers.

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 the other for addition and subtraction.

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*.

1. For multiplication and division: *The result should have the same number of significant figures as the quantity having the least significant figures entering into the calculation*. 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 has if the radius has only two—say, $r = 1.2$ m . Then,

$A = \pi r^2 = (3.1415927...)\times(1.2\ \text{m})^2 = 4.5238934\ \text{m}^2$

is what you would get using a calculator that has an eight-digit output. But because the radius has only two significant figures, it limits the calculated quantity to two significant figures or $A = 4.5\ \text{m}^2$, even though π is good to at least eight digits.

2. For addition and subtraction: *The answer can contain no more decimal places than the least precise measurement.*

Suppose that you buy 7.56-kg of potatoes in a grocery store as measured with a scale with precision 0.01 kg. Then you drop off 6.052-kg of potatoes at your laboratory as measured by a scale with precision 0.001 kg. Finally, you go home and add 13.7 kg of potatoes as measured by a bathroom scale with precision 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:

7.56 kg

- 6.052 kg

+13.7 kg

15.208 kg = 15.2 kg.

Next, we identify the least precise measurement: 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 is rounded to the tenths place, giving us 15.2 kg.

Summary

- Theories are created to explain observations, and then tested based on their predictions.
- A model is like an analogy; it is not intended to be a true picture, but just to provide a familiar way of envisioning a quantity.
- A theory is much more well-developed, and can make testable predictions; a law is a theory that can be explained simply, and which is widely applicable.
- Dimensional analysis is useful for checking calculations.

Summary

- Measurements can never be exact; there is always some uncertainty. It is important to write them, as well as other quantities, with the correct number of significant figures.
- The most common system of units in the world is the SI system.
- When converting units, check dimensions to see that the conversion has been done properly.
- Order-of-magnitude estimates can be very helpful.