Chapter 1
Introduction to Physics

- Physics and the Laws of Nature
- Units of Length, Mass, and Time
- Dimensional Analysis
- Significant Figures
- Converting Units
- Order-of-Magnitude Calculations
- Scalars and Vectors
- Problem Solving in Physics

Why Study Physics?

Physics is the foundation of every science (astronomy, biology, chemistry…).

Many pieces of technology and/or medical equipment and procedures are developed with the help of physicists.

Studying physics will help you develop good thinking skills, problem solving skills, and give you the background needed to differentiate between science and pseudoscience.

Physics: the study of the fundamental laws of nature

- **these laws can be expressed as mathematical equations**
- **much complexity can arise from relatively simple laws**

Physics Speak

Be aware that physicists have their own precise definitions of some words that are different from their common English language definitions.

Examples: speed and velocity are no longer synonyms; acceleration is a change of speed ***or*** direction.

Definitions:

$$y = mx + b$$

x is multiplied by the **factor** m.

The **terms** mx and b are added together.

Example:

$$y = \frac{x}{a} + c$$

x is multiplied by the factor 1/a or x is divided by the factor a. The terms x/a and c are added together.

Percentages:

Example: You put $10,000 in a CD for one year. The APY is 3.05%. How much interest does the bank pay you at the end of the year?

$$\$10{,}000 \times 1.0305 = \$10{,}305$$

The bank pays you $305 in interest.

Example: You have $5,000 invested in stock XYZ. It loses 6.4% of its value today. How much is your investment now worth?

$$\$5{,}000 \times 0.936 = \$4{,}680$$

The general rule is to multiply by $\left(1 \pm \frac{n}{100}\right)$

where the (+) is used if the quantity is increasing and (–) is used if the quantity is decreasing.

Proportions:

$$A \propto B$$

A is proportional to B. The value of A is **directly dependent** on the value of B.

$$A \propto \frac{1}{B}$$

A is proportional to 1/B. The value of A is **inversely dependent** on the value of B.

Example: For items at the grocery store:

$$\text{cost} \propto \text{weight}$$

The more you buy, the more you pay. This is just the relationship between cost and weight.

To change from $\propto$ to = we need to know the proportionality constant.

$$\text{cost} = (\text{cost per pound}) \times (\text{weight})$$

Example: The area of a circle is $A = \pi r^2$.

The area is proportional to the radius squared. $A \propto r^2$

The proportionality constant is π.

Example: If you have one circle with a radius of 5.0 cm and a second circle with a radius of 3.0 cm, by what factor is the area of the first circle larger than the area of the second circle?

The area of a circle is proportional to r^2:

$$\frac{A_1}{A_2} = \frac{r_1^2}{r_2^2} = \frac{(5\text{ cm})^2}{(3\text{ cm})^2} = 2.8$$

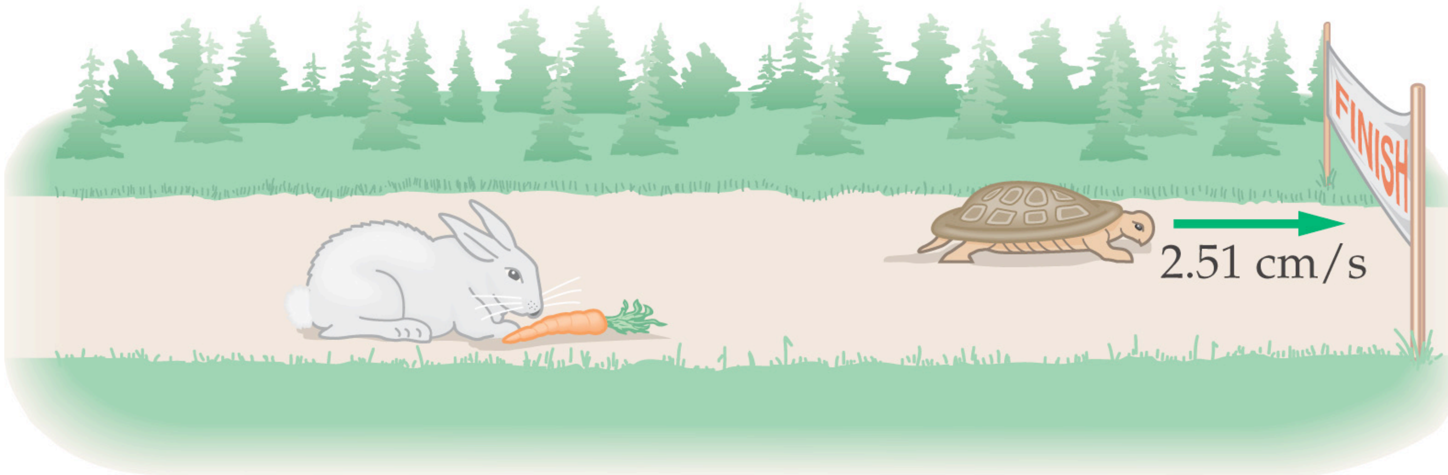
The area of the first circle is 2.8 times larger than the second circle.

§1.4 Scientific Notation & Significant Figures

This is a shorthand way of writing very large and/or very small numbers.

1-4 Significant Figures

- accuracy of measurements is limited
- significant figures: the number of digits in a quantity that are known with certainty
- number of significant figures after multiplication or division is the number of significant figures in the least-known quantity



Example:

A tortoise travels at 2.51 cm/s for 12.23 s. How far does the tortoise go?

Answer: 2.51 cm/s × 12.23 s = 30.7 cm (three significant figures)

Example: The radius of the sun is 700,000 km.

Write as 7.0×10^5 km.

When properly written this number will be between 1.0 and 10.0

Example: The radius of a hydrogen atom is 0.0000000000529 m. This is more easily written as 5.29×10^{-11} m.

Scientific Notation

- Leading or trailing zeroes can make it hard to determine number of significant figures: 2500, 0.000036
- Each of these has two significant figures
- Scientific notation writes these as a number from 1-10 multiplied by a power of 10, making the number of significant figures much clearer:

$2500 = 2.5 \times 10^3$

$0.000036 = 3.6 \times 10^{-5}$

Round-off error:

The last digit in a calculated number may vary depending on how it is calculated, due to rounding off of insignificant digits

Example:

\$2.21 + 8% tax = \$2.3868, rounds to \$2.39

\$1.35 + 8% tax = \$1.458, rounds to \$1.46

Sum: \$2.39 + \$1.46 = \$3.85

\$2.21 + \$1.35 = \$3.56

\$3.56 + 8% tax = \$3.84

Dimensions are basic types of quantities that can be measured or computed. Examples are length, time, mass, electric current, and temperature.

A **unit** is a standard amount of a dimensional quantity. There is a need for a system of units. SI units will be used throughout this class.

Units of Length, Mass, and Time

SI units of length (L), mass (M), time (T):

Length: the meter
Was: one ten-millionth of the distance from the North Pole to the equator
Now: the distance traveled by light in a vacuum in 1/299,792,458 of a second

Mass: the kilogram
One kilogram is the mass of a particular platinum-iridium cylinder kept at the International Bureau of Weights and Standards, Sèvres, France.

Time: the second
One second is the time for radiation from a cesium-133 atom to complete 9,192,631,770 oscillation cycles.

The quantities in this column are based on an agreed upon standard.

Table 1.1 SI Base Units

Quantity	Unit Name	Symbol	Definition
Length	meter	m	The distance traveled by light in vacuum during a time interval of 1/299 792 458 s.
Mass	kilogram	kg	The mass of the international prototype of the kilogram.
Time	second	s	The duration of 9 192 631 770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the cesium-133 atom.
Electric current	ampere	A	The constant current in two long, thin, straight, parallel conductors placed 1 m apart in vacuum that would produce a force on the conductors of 2×10^{-7} N per meter of length.
Temperature	kelvin	K	The fraction 1/273.16 of the thermodynamic temperature of the triple point of water.
Amount of substance	mole	mol	The amount of substance that contains as many elementary entities as there are atoms in 0.012 kg of carbon-12.
Luminous intensity	candela*	cd	The luminous intensity, in a given direction, of a source that emits radiation of frequency 540×10^{12} Hz and that has a radiant intensity in that direction of 1/683 watts per steradian.

*Not used in this book

1-2 Units of Length, Mass, and Time

TABLE 1–1 Typical Distances

Distance from Earth to the nearest large galaxy (the Andromeda galaxy, M31)	2×10^{22} m
Diameter of our galaxy (the Milky Way)	8×10^{20} m
Distance from Earth to the nearest star (other than the sun)	4×10^{16} m
One light year	9.46×10^{15} m
Average radius of Pluto's orbit	6×10^{12} m
Distance from Earth to the Sun	1.5×10^{11} m
Radius of Earth	6.37×10^{6} m
Length of a football field	10^{2} m
Height of a person	2 m
Diameter of a CD	0.12 m
Diameter of the aorta	0.018 m
Diameter of a period in a sentence	5×10^{-4} m
Diameter of a red blood cell	8×10^{-6} m
Diameter of the hydrogen atom	10^{-10} m
Diameter of a proton	2×10^{-15} m

1-2 Units of Length, Mass, and Time

TABLE 1–2 Typical Masses	
Galaxy (Milky Way)	4×10^{41} kg
Sun	2×10^{30} kg
Earth	5.97×10^{24} kg
Space shuttle	2×10^{6} kg
Elephant	5400 kg
Automobile	1200 kg
Human	70 kg
Baseball	0.15 kg
Honeybee	1.5×10^{-4} kg
Red blood cell	10^{-13} kg
Bacterium	10^{-15} kg
Hydrogen atom	1.67×10^{-27} kg
Electron	9.11×10^{-31} kg

= mass of a proton
(hydrogen atom - electron)

1-2 Units of Length, Mass, and Time

TABLE 1–3 Typical Times

Age of the universe	5×10^{17} s
Age of the Earth	1.3×10^{17} s
Existence of human species	6×10^{13} s
Human lifetime	2×10^{9} s
One year	3×10^{7} s
One day	8.6×10^{4} s
Time between heartbeats	0.8 s
Human reaction time	0.1 s
One cycle of a high-pitched sound wave	5×10^{-5} s
One cycle of an AM radio wave	10^{-6} s
One cycle of a visible light wave	2×10^{-15} s

= 63.4 years
(60x60x24x365x63.4)

1-2 Units of Length, Mass, and Time

TABLE 1–4 Common Prefixes

Power	Prefix	Abbreviation
10^{15}	peta	P
10^{12}	tera	T
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{2}	hecto	h
10^{1}	deka	da
10^{-1}	deci	d
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p
10^{-15}	femto	f

A **derived unit** is composed of combinations of base units.

Example: The SI unit of energy is the joule.

$$1 \text{ joule} = 1 \text{ kg m}^2/\text{sec}^2$$

Derived unit

Base units

1-5 Converting Units

Converting feet to meters:

1 m = 3.281 ft (this is a conversion factor)

Or: 1 = 1 m / 3.281 ft

316 ft × (1 m / 3.281 ft) = 96.3 m

Note that the units cancel properly – this is the key to using the conversion factor correctly!

Units can be freely converted from one to another.
Examples:

12 inches = 1 foot

1 inch = 2.54 cm

Example: The density of air is 1.3 kg/m^3. Change the units to slugs/ft^3.

1 slug = 14.59 kg

1 m = 3.28 feet

$$1.3\,\frac{\cancel{\text{kg}}}{\cancel{\text{m}^3}}\left(\frac{1\,\text{slug}}{14.59\,\cancel{\text{kg}}}\right)\left(\frac{1\,\cancel{\text{m}}}{3.28\,\text{feet}}\right)^3 = 2.5\times10^{-3}\ \text{slugs/ft}^3$$

Dimensional Analysis

Dimensions are basic types of quantities such as length [L]; time [T]; or mass [M].

The square brackets are referring to dimensions not units.

Dimensional Analysis

- **Any valid physical formula must be dimensionally consistent – each term must have the same dimensions**

TABLE 1–5 Dimensions of Some Common Physical Quantities

Quantity	Dimension
Distance	[L]
Area	$[L^2]$
Volume	$[L^3]$
Velocity	[L]/[T]
Acceleration	$[L]/[T^2]$
Energy	$[M][L^2]/[T^2]$

From the table:

Distance = velocity × time

Velocity = acceleration × time

Energy = mass × (velocity)^2

Example: Estimate the number of times a human heart beats during its lifetime.

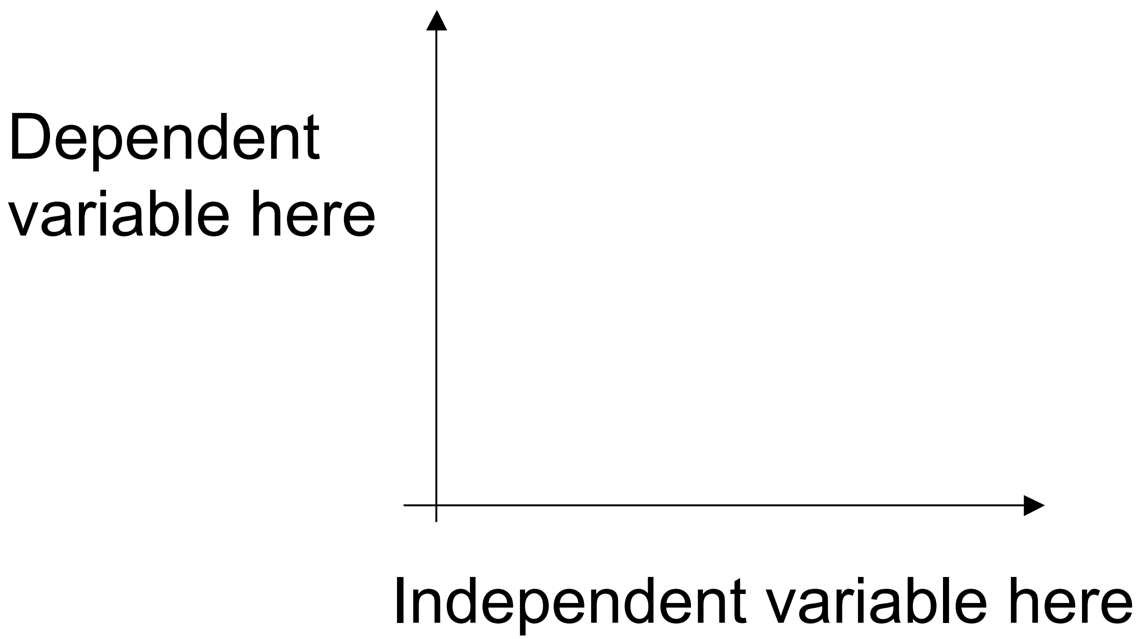
Estimate that a typical heart beats ~60 times per minute:

$$\left(\frac{60\text{ beats}}{1\cancel{\text{ minute}}}\right)\left(\frac{60\cancel{\text{ minutes}}}{1\cancel{\text{ hour}}}\right)\left(\frac{24\cancel{\text{ hours}}}{1\cancel{\text{day}}}\right)\left(\frac{365\cancel{\text{ days}}}{1\cancel{\text{ year}}}\right)\left(\frac{75\cancel{\text{ years}}}{1\text{ lifetime}}\right)$$

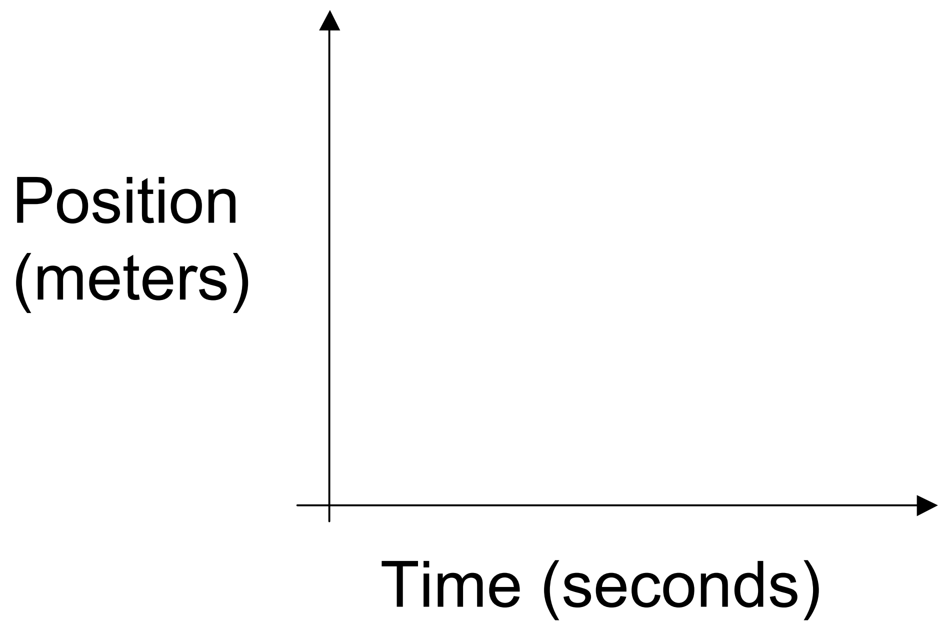
$$= 2.4\times 10^{9}\text{ beats/lifetime}$$

Graphs

Experimenters vary a quantity (the independent variable) and measure another quantity (the dependent variable).



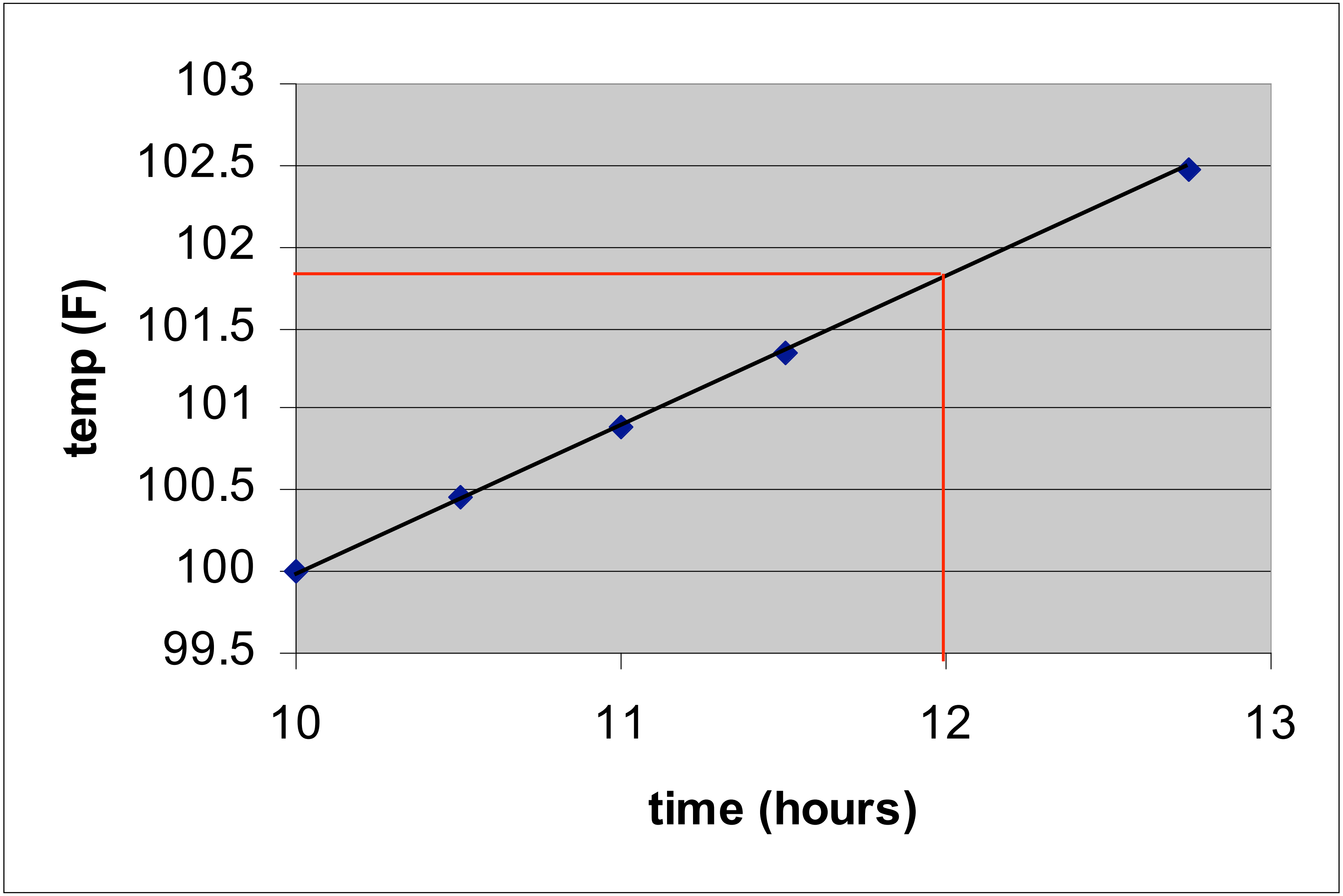
Be sure to label the axes with both the quantity and its unit.
For example:



Example: A nurse recorded the values shown in the table for a patient's temperature. Plot a graph of temperature versus time and find (a) the patient's temperature at noon, (b) the slope of the graph, and (c) if you would expect the graph to follow the same trend over the next 12 hours? Explain.

The given data:

Time	Decimal time	Temp (°F)
10:00 AM	10.0	100.00
10:30 AM	10.5	100.45
11:00 AM	11.0	100.90
11:30 AM	11.5	101.35
12:45 PM	12.75	102.48


103
102.5
102
101.5
101
100.5
100
99.5
temp (F)
10
11
12
13
time (hours)

(a) Reading from the graph: 101.8 °F.

(b) $$\text{slope} = \frac{T_2 - T_1}{t_2 - t_1} = \frac{101.8\ {}^\circ\text{F} - 100.0\ {}^\circ\text{F}}{12.0\ \text{hr} - 10.0\ \text{hr}} = 0.9\ {}^\circ\text{F/hour}$$

(c) No.

Scalars and Vectors

Scalar – a numerical value. May be positive or negative.
Examples: temperature, speed, height

Vector – a quantity with both magnitude and direction.
Examples: displacement (e.g., 10 feet north), force, magnetic field

Important for motion:

- difference between speed and velocity
- difference between distance and displacement

Problem Solving in Physics

No recipe or plug-and-chug works all the time, but here are some guidelines:

1. Read the problem carefully
2. Sketch the system
3. Visualize the physical process
4. Strategize
5. Identify appropriate equations
6. Solve the equations
7. Check your answer
8. Explore limits and special cases

Summary of Chapter 1

- Physics is based on a small number of laws and principles
- Units of length are meters; of mass, kilograms; and of time, seconds
- All terms in an equation must have the same dimensions
- The result of a calculation should have only as many significant figures as the least accurate measurement used in it

Summary of Chapter 1

•Convert one unit to another by multiplying by their ratio

• Order-of-magnitude calculations are designed to be accurate within a power of 10

• Scalars are numbers; vectors have both magnitude and direction

• Problem solving: read, sketch, visualize, strategize, identify equations, solve, check, explore limits