Chapter 1: Measurement

Homework: All questions on the “Multiple-Choice” and the odd-numbered questions on “Exercises” sections at the end of the chapter.
What is Physical Science?

- Subset of the Natural Sciences along with Biological Sciences
- **Physical Sciences** = Physics, Chemistry, Geology, Meteorology, and Astronomy
This Course

- Physics & Chemistry
- Attempts to describe the physical world in which we live
- Measurements – movement, temperature, weather conditions, time, etc.
- Constant use of measurements – many examples in book.
- Can everything be measured with certainty??
- As smaller and smaller objects were measured it became apparent that the act of measuring distorted the object.
Experiment & Explanation

• Experimentation and explanation are at the heart of scientific research.

• **Experiment** – observation of natural phenomena that can be –
  – Carried out in a controlled manner
  – Results can be duplicated
  – Can be done by other researchers
Scientific Law

• **Scientific Law** – after a series of experiments a concise statement (words/math) about a relationship/regularity of nature

• **Example** – **Law of Conservation of Mass** *(no gain or loss during chemical reaction)*

• The law simply states the finding, but *does not* explain the behavior.
Hypotheses

• **Hypothesis** – tentative explanation(s) of the relationship/regularity in nature

• *Example: Matter consists of small particles (atoms) that simply rearrange themselves*

• A good Hypothesis

• It must suggest new experiments that serve to test its validity.

• The Hypothesis is supported if it correctly predicts the experimental results
Theory

- **Theory** – tested explanation for a broad segment of basic natural phenomena

- **Example:** Atomic Theory – *This theory has withstood testing for 200+ years and continues to correctly predict atomic behavior.*
Scientific Method

- **Scientific Method** - the process of experimentation and explanation
- No concept or model of nature is valid unless the predictions are in agreement with experimental results.
- Hypotheses/Theories must withstand testing and may be modified or even rejected.
The Senses

- Sight, Hearing, Smell, Taste, Touch
- Sight and Hearing provide the most information to our brains about our environment.
- Sensory Limitations – can be reduced by using measuring devices
- Instruments extend our ability to measure and learn about our environment.
- Our senses can also be deceived ->
Some Optical Illusions

Is the diagonal line $b$ longer than the diagonal line $a$?

Lines “a” and “b” are equal in length!
Optical Illusions

Are the horizontal lines parallel or do they slope? *The lines are all horizontal!*
Some Optical Illusions

Going down?
Some Optical Illusions

Is something dimensionally wrong here?
Standard Units and Systems of Units

- Expressed in magnitude and units
- Fundamental quantities – length, mass, & time
- The study of Force and Motion requires only these three quantities.
- Standard Unit – fixed and reproducible value to take accurate measurements
Standard Units and Systems of Units continued...

- Two major systems of units
- **British (English) system** – only used widely in the United States (miles, inches, pounds, seconds, etc.)
- **Metric system** – used throughout most of the world (kilometers, meters, grams, etc.)
- The U.S. “officially” adopted the metric system in 1893, but continues to use the British system.
# A Brief, Chronological History of the Metric System

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>1670</td>
<td>Gabriel Moulton, a French mathematician, proposes a measurement system based on a physical quantity of nature and not on human anatomy.</td>
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<tr>
<td>1790</td>
<td>The French Academy of Science recommends the adoption of a system with a unit of length equal to one ten-millionth of the distance on a meridian between the Earth’s North Pole and equator.</td>
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<td>1870</td>
<td>A French conference is set up to work out standards for a unified metric system.</td>
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<tr>
<td>1875</td>
<td>The Treaty of the Meter is signed by 17 nations, including the United States. This establishes a permanent body with the authority to set standards.</td>
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<tr>
<td>1893</td>
<td>The United States officially adopts the metric system standards as bases for weights and measures (but continues to use British units).</td>
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<tr>
<td>1975</td>
<td>The Metric Conversion Act is enacted by Congress. It states, “The policy of the United States shall be to coordinate and plan the increasing use of the metric system in the United States and to establish a United States Metric Board to coordinate the voluntary conversion to the metric system.” (No mandatory requirements are made.)</td>
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Length

- *The measurement of space in any direction*
- Space has three dimensions – length, width, and height.
- **Metric Standard Unit = Meter** (m), originally defined as 1/10,000,000 of distance from equator to north pole
- **British Standard Unit = Foot**, originally referenced to the human foot.
The Meter

Originally defined as a physical quantity of nature.

1/10,000,000 of the distance from the equator to the pole.

1 meter

1 yard

3.37 in.
The meter is now defined by the distance light travels in a vacuum in \( \frac{1}{299,792,458} \) s.

The meter is now defined by the distance light travels in a vacuum/time.
Mass (metric)

- *The amount of matter an object contains*
- An object’s mass is always constant
- Mass is a fundamental unit that will remain constant throughout the universe.
- **Metric Standard Unit** = **Kilogram** (kg) – originally defined as the amount of water in a 0.1m cube. Now referenced to a cylinder in Paris
Kilogram Standard

U.S. Prototype #20 Kilogram, at NIST in Washington, D.C. Actually – 0.999 999 961 kg of “the” standard in Paris
Mass (British)

- **British Standard Unit** = Slug (rarely used)
- We use the **Pound** (lb.)
- The pound is actually not a unit of mass, but rather of weight, related to gravitational attraction (depends on where the object is!)
- Object: Earth = 1lb. ➔ Moon = 1/6lb.
- In fact, the weight of an object will vary slightly depending on where it is on earth (higher altitude ➔ less weight)
Mass is a Fundamental Quantity and Remains Constant - Weight Varies
Time

• **Time** - the continuous, forward flowing of events
• Time has only one direction → forward
• **Second** (s) – the standard unit in both the metric and British systems
• Originally 1/86,400 of a solar day
• Now based on the vibration of the Cs\textsuperscript{133} atom (Atomic Clock)
A Second of Time

Originally defined as a fraction of the average solar day.

1 s = 1/86,400 of an average solar day
A Second of Time

Defined by the radiation frequency of the $\text{Cs}^{133}$ atom

1 s = 9,192,631,770 oscillations
Metric System

• Uses acronym “mks system” from standard units of length, mass, and time – meter, kilogram, second
• It is a decimal (base-10) system – this is much better than the British system
• Administered by -- Bureau International des Poids et Mesures (BIPM) in Paris
• International System of Units (SI)
• Contains seven base units
Modern Metric System (SI)

- The fundamental units are a choice of seven well-defined units which by convention are regarded as dimensionally independent:
  - meter, m (length)
  - kilogram, kg (mass)
  - second, s (time)
  - ampere, A (electrical current)
  - kelvin, K (temperature)
  - mole, mol (amount of a substance)
  - candela, cd (luminous intensity)
Base-10 → Convenient

• Easy expression and conversion
• Metric examples vs. British examples
  – 1 kilometer = 1000 meters
  – 1 mile = 5280 feet
  – 1 meter = 100 centimeters
  – 1 yard = 3 feet or 36 inches
  – 1 liter = 1000 milliliters
  – 1 quart = 32 ounces or 2 pints
  – 1 gallon = 128 ounces
Commonly Used Prefixes

- **Mega**, M – $10^6$ – 1,000,000 times the base
- **Kilo**, k – $10^3$ – 1,000 times the base
- **Centi**, c – $10^{-2}$ – 1/100th of the base
- **Milli**, m – $10^{-3}$ – 1/1000th of the base

- *See Appendix 1 for complete listing*
Liter – Nonstandard Metric Unit

- **Liter** – volume of liquid in a 0.1m (10 cm) cube (10cm x 10cm x 10cm = 1000 cm$^3$)
- A liter of pure water has a mass of 1 kg or 1000 grams.
- Therefore, 1 cubic cm (cc) of water has a mass of 1 gram.
- By definition 1 liter = 1000 milliliters (ml)
- So, 1 ml = 1 cc = 1 g of pure water.
- 1 ml = 1 cc for all liquids, but other liquids do not have a mass of 1 g
Liter & Quart

- A Liter is slightly more than a quart.
  - 1 quart = .946 liter
  - 1 liter = 1.06 quart
The Kilogram

- \(1 \text{ kg} = 2.2046 \text{ lb on earth}\)

- The amount of water in a 0.10m (10 cm) cube (0.10m\(^3\))
Metric Ton

- Metric ton -- mass of 1 cubic meter (1 m$^3$) of water
- 1 m = 100 cm
- (100cm)$^3$ = 1,000,000 cm$^3$
- Remember that 1000 cm$^3$ = liter
- Therefore, there are 1000 liters in 1 m$^3$ of water.
- Each liter has a mass of 1 kg.
- 1 kg x 1000 = 1 metric ton
Derived Units and Conversion Factors

• It is difficult to make all measurements with only the 7 fundamental units.
• Derived units are therefore used, these are multiples/combinations of fundamental units.
• Volume -- We’ve already used derived unit → length$^3$, m$^3$, cm$^3$
• Area → length$^2$, m$^2$, ft$^2$, etc.
• Speed → length/time, m/s, miles/hour, etc.
Density

- **Density** \( (\rho) \) = mass per unit volume
- \( \rho = \frac{m}{v} \) [or \( m/\text{length}^3 \) (since \( v = \text{length}^3 \)]
- How “compact” a substance is
- Typical Units used – \( \text{g/cm}^3 \), \( \text{kg/m}^3 \)
- \( \text{Al} = 2.7 \text{ g/cm}^3 \), \( \text{Fe} = 7.8 \text{ g/cm}^3 \), \( \text{Au} = 19.3 \text{ g/cm}^3 \)
- Average for solid earth = 5.5 g/cm\(^3\)
Liquid Densities

- **Hydrometer** – a weighted glass bulb
- The higher the hydrometer floats the greater the density of the liquid
- Pure water = 1 g/cm$^3$
- Seawater = 1.025 g/cm$^3$
- Urine = 1.015 to 1.030 g/cm$^3$
- Hydrometers are used to ‘test’ antifreeze in car radiators – actually measuring the density of the liquid
Unit Combinations

• When a combination of units becomes complex and frequently used –
• It is given a name
  – newton (N) = kg x m/s²
  – joule (J) = kg x m²/s²
  – watt (W) = kg x m²/s³
Conversion Factors

• Relates one unit to another unit
• Convert British to Metric (1in → cm)
• Convert units within system (1kg → g)
• We use “conversion factors” – many are listed on inside back cover of book
• 1 inch **is equivalent to** 2.54 centimeters
• Therefore **“1 in = 2.54 cm”** is our conversion factor for inches & centimeters
Easy Conversion Example

• **Question:** How many centimeters are there in 65 inches?

• Since $1 \text{ in} = 2.54 \text{ cm} \Rightarrow \frac{1 \text{ inch}}{2.54 \text{ cm}} = 1$

• Or $\frac{2.54 \text{ cm}}{1 \text{ in}} = 1$

• $65 \text{ in.} \times \frac{2.54 \text{ cm}}{1 \text{ in}} = 165 \text{ cm}$ *(the inches cancel out!!)*
Steps to Convert

• **Step 1** - Choose/Use a Conversion Factor, generally can be looked up.

• **Step 2** – Arrange the Conversion Factor into the appropriate form, so that unwanted units cancel out.

\[
\frac{1\text{ inch}}{2.54 \text{ cm}} \quad \text{or} \quad \frac{2.54 \text{ cm}}{1\text{ inch}}
\]

for example

• **Step 3** – Multiply or Divide to calculate answer.

• **Use common sense** – anticipate answer!
50 km/h → ?? mi/h

• How fast in mi/h is 50 km/h?
• Conversion Factor is \(1\text{km/h}=0.621\text{mi/h}\)

\[
\begin{align*}
50 \text{ km/h} \times \frac{0.621 \text{mi/h}}{1 \text{km/h}} &= 31.05 \text{ mi/h}
\end{align*}
\]
$50 \text{ km/h} \rightarrow ?? \text{ mi/h}$

Starting Value $\times \frac{0.621 \text{ mi/h}}{1 \text{ km/h}} = 31.05 \text{ mi/h}$

Result
50 mi/h → ?? km/h

• Either Conversion Factor can be used:
  • $1 \text{km/h} = 0.621 \text{mi/h}$  or  $1 \text{mi/h} = 1.61 \text{km/h}$
• How fast in km/h is 50 mi/h?

\[
50 \text{ mi/h} \times \frac{1 \text{ km/h}}{0.621 \text{ mi/h}} = 80.5 \text{ km/h}
\]

\[
50 \text{ mi/h} \times \frac{1.61 \text{ km/h}}{1 \text{ mi/h}} = 80.5 \text{ km/h}
\]

Starting Value  Conversion Factor  Same Result
50 mi/h $\rightarrow$ ?? km/h

\[50 \text{ mi/h} \times \frac{1 \text{ km/h}}{0.621 \text{ mi/h}} = 80.5 \text{ km/h}\]

Starting Value  Conversion Factor  Same Result
Multi-Step Conversion
No Problem!

• 22 inches = ?? Meters
• Inches $\rightarrow$ centimeters $\rightarrow$ meters

\[
22 \text{ in} \times \frac{2.54 \text{ cm}}{1 \text{ in}} \times \frac{1 \text{ m}}{100 \text{ cm}} = 0.56 \text{ m}
\]
Multi-Step Conversion
No Problem!

\[
22 \text{ in} \times \frac{2.54 \text{ cm}}{1 \text{ in}} \times \frac{1 \text{ m}}{100 \text{ cm}} = 0.56 \text{ m}
\]

Starting Value  Conv. Factor #1  Conv. Factor #2  Result

\( \text{in} \rightarrow \text{cm} \)  \( \text{cm} \rightarrow \text{m} \)
How high is this road in feet?
Peruvian Road Solution

\[
4843 \text{ m} \times \frac{3.28 \text{ ft}}{1 \text{ m}} = 15,885 \text{ feet above SL}
\]

(1775 feet higher than the top of Pikes Peak!)
Significant Figures

• Significant figures (“SF”) – a method of expressing measured numbers properly

• A mathematical operation, such as multiplication, division, addition, or subtraction cannot give you more significant figures than you start with.

• For example, 6.8 has two SF and 1.67 has three SF.
• When we use hand calculators we may end up with results like: 6.8/1.67 = 4.0718563

• Are all these numbers “significant?”
Significant Figures

• General Rule: Report only as many significant figures in the result as there are in the quantity with the least.

• $6.8 \text{ cm}/1.67 \text{ cm} = 4.1$ (round off $4.0718563$)
  – $6.8$ is the limiting term with two SF

• $5.687 + 11.11 = 16.80$ (round up $16.797$)
  – $11.11$ is the limiting term with four SF
Significant Figures - Rules

• All non-zero digits are significant
  – Both 23.4 and 234 have 3 SF

• Zeros are significant if between two non-zero digits (‘captive’) – 20.05 has 4 SF, 407 has 3 SF

• Zeros are not significant to the left of non-zero digits – used to locate a decimal point (leading zeros) – 0.0000035 has 2 SF

• To the right of all non-zero digits (trailing zeros), must be determined from context – 45.0 has 3 SF but 4500 probably only has 2 SF
Significant Figures

• Exact Numbers – numbers of people, items, etc. are assumed to have an unlimited number of SF

• In the process of determining the allowed number of significant figures, we must generally also ‘round off’ the numbers.
Rounding Off Numbers

- If the first digit to be dropped is less than 5, leave the preceding digit unchanged.
  - Round off to 3 SF: 26.142 → 26.1
- If the first digit to be dropped is 5 or greater, increase the preceding digit by one.
  - Round off to 3 SF: 10.063 → 10.1
Rounding off Numbers – Examples

• Round off 0.0997 to two SF
  0.0997 \rightarrow 0.10

• What about this? 5.0 \times 356 = 1780
  Round off 1780 to 2 SF
  1780 \rightarrow 1800
Powers-of-10 Notation
(Scientific Notation)

• Many numbers are very large or very small – it is more convenient to express them in ‘powers-of-10’ notation

• $1,000,000 = 10 \times 10 \times 10 \times 10 \times 10 \times 10 = 10^6$

\[
\frac{1}{1,000,000} = \frac{1}{10^6} = 0.000001 = 10^{-6}
\]
Examples of Numbers Expressed in Powers-of-10 Notation

<table>
<thead>
<tr>
<th>Number</th>
<th>Powers-of-10 Notation*</th>
</tr>
</thead>
<tbody>
<tr>
<td>247</td>
<td>$2.47 \times 10^2$</td>
</tr>
<tr>
<td>186,000</td>
<td>$1.86 \times 10^5$</td>
</tr>
<tr>
<td>4,705,000</td>
<td>$4.705 \times 10^6$</td>
</tr>
<tr>
<td>9,000,000,000</td>
<td>$9 \times 10^9$</td>
</tr>
<tr>
<td>30,000,000,000</td>
<td>$3 \times 10^{10}$</td>
</tr>
<tr>
<td>602,200,000,000,000,000,000,000,000</td>
<td>$6.022 \times 10^{23}$</td>
</tr>
<tr>
<td>0.025</td>
<td>$2.5 \times 10^{-2}$</td>
</tr>
<tr>
<td>0.0000408</td>
<td>$4.08 \times 10^{-5}$</td>
</tr>
<tr>
<td>0.00000010</td>
<td>$1.0 \times 10^{-7}$</td>
</tr>
<tr>
<td>0.000000000000000000000000000000016</td>
<td>$1.6 \times 10^{-19}$</td>
</tr>
</tbody>
</table>
Scientific Notation

• The distance to the sun can be expressed many ways:
  – 93,000,000 miles
  – 93 x 10^6 miles
  – 9.3 x 10^7 miles
  – 0.93 x 10^8 miles

• All four are correct, but 9.3 x 10^7 miles is the preferred format.
Rules for Scientific Notation

- The exponent, or power-of-10, is increased by one for every place the decimal point is shifted to the left.
  \[-360,000 = 3.6 \times 10^5\]

- The exponent, or power-of-10, is decreased by one for every place the decimal point is shifted to the right.
  \[-0.0694 = 6.94 \times 10^{-2}\]
Example
Rounding/Scientific Notation

• $5.6256 \times 0.0012 = 0.0067507$
• $\rightarrow$ round to 2 SF
• 0.0067507 rounds to 0.0068
• $\rightarrow$ change to scientific notation
• 0.0068 = 6.8 \times 10^{-3}$
Example
Rounding/Scientific Notation

• $0.0024/8.05 = 0.0002981$
• $\rightarrow$ round to 2 SF
• $0.0002981 \text{ rounds to } 0.00030$
• $\rightarrow$ change to scientific notation
• $0.00030 = 3.0 \times 10^{-4}$

• **Note that the “trailing zero” is significant**
Problem Solving

• Read the problem, and identify the chapter principle that applies to it. Write down the given quantities w/ units. Make a sketch.

• Determine what is wanted – write it down.

• Check the units, and make conversions if necessary.

• Survey equations – use appropriate one.

• Do the math, using appropriate units, round off, and adjust number of significant figures.
Problem Example

- The earth goes around the sun in a nearly circular orbit with a radius of 93 million miles. How many miles does Earth travel in making one revolution about the sun?
Problem Example

- The earth goes around the sun in a nearly **circular orbit** with a **radius of 93 million miles**. **How many miles does Earth travel** in making **one revolution** about the sun?

- Determine what parts of the question are important and how to attack the problem.
Problem Example

- The earth goes around the sun in a nearly **circular orbit** with a **radius of 93 million miles**. How many **miles does Earth travel** in making **one revolution about the sun**?

- In order to solve this problem notice that you need an equation for a circular orbit (circumference).

- The radius of 93,000,000 miles is given.

- Our answer also needs to be in miles (convenient!)

- Equation: \( c = 2\pi r \) \( (\pi = 3.14159...) \)
Problem Solving

- Circumference = \( c = 2\pi r \) \( (\pi = 3.14159\ldots) \)
- \( c = 2 \times 3.14159 \times 93,000,000 \) miles
- or
- \( c = 2 \times 3.14159 \times 9.3 \times 10^7 \) miles
- \( c = 58.433574 \times 10^7 \) miles
- round off and adjust to two SF
- \( c = 5.8 \times 10^8 \) miles
- \( 5.8 \times 10^8 \) miles = distance that the earth travels in one revolution around the sun
Equations at the end of the chapter with which the student needs to be familiar

- Density: \( \rho = \frac{m}{V} \)
- Circumference of a Circle: \( c = 2\pi r \)