Chapter 3  “Scientific Measurement”

Section 3.1 Measurements and Their Uncertainty

• OBJECTIVES:
  – Convert measurements to scientific notation.

Section 3.1 Measurements and Their Uncertainty

• OBJECTIVES:
  – Distinguish among accuracy, precision, and error of a measurement.

Section 3.1 Measurements and Their Uncertainty

• OBJECTIVES:
  – Determine the number of significant figures in a measurement and in a calculated answer.

Measurements

• Qualitative measurements are words, such as heavy or hot
• Quantitative measurements involve numbers (quantities), and depend on:
  1) The reliability of the measuring instrument
  2) the care with which it is read – this is determined by YOU!
• Scientific Notation
  • Coefficient raised to power of 10
  • Reviewed earlier this semester!

Accuracy, Precision, and Error

• It is necessary to make good, reliable measurements in the lab
• Accuracy – how close a measurement is to the true value
• Precision – how close the measurements are to each other (reproducibility)
Precision and Accuracy

Accuracy, Precision, and Error

- **Accepted value** = the correct value based on reliable references
- **Experimental value** = the value measured in the lab

Accuracy, Precision, and Error

- **Error** = accepted value – exp. value
  - Can be positive or negative
- **Percent error** = the **absolute value** of the error divided by the accepted value, then multiplied by 100%
  \[ \% \text{ error} = \left( \frac{\text{error}}{\text{accepted value}} \right) \times 100\% \]

Why Is there Uncertainty?

- Measurements are performed with instruments, and no instrument can read to an infinite number of decimal places
- *Which of the balances shown has the greatest uncertainty in measurement?*

Significant Figures in Measurements

- **Significant figures** in a measurement include all of the digits that are known, plus one more digit that is estimated.
- Measurements must be reported to the correct number of significant figures.

**Figure 3.5 Significant Figures - Page 67**

Which measurement is the best?
**Rules for Counting Significant Figures**

**Non-zeros** always count as significant figures:

- 3456 has 4 significant figures

**Zeros** Leading zeroes do not count as significant figures:

- 0.0486 has 3 significant figures

**Rules for Counting Significant Figures**

**Zeros** Captive zeroes always count as significant figures:

- 16.07 has 4 significant figures

**Rules for Counting Significant Figures**

**Zeros** Trailing zeroes are significant only if the number contains a written decimal point:

- 9.300 has 4 significant figures

**Rules for Counting Significant Figures**

**Two special situations** have an *unlimited* number of significant figures:

1. Counted Items
   - a) 23 people, or 425 thumbtacks
2. Exactly defined quantities
   - b) 60 minutes = 1 hour

**Sig Fig Practice #1**

How many significant figures in the following?

- 1.0070 m → 5 sig figs
- 17.10 kg → 4 sig figs
- 100,890 L → 5 sig figs
- $3.29 \times 10^3$ s → 3 sig figs
- 0.0054 cm → 2 sig figs
- 3,200,000 → 2 sig figs
- 5 dogs → unlimited

These come from measurements

This is a counted value
**Significant Figures in Calculations**

- In general a calculated answer cannot be more precise than the least precise measurement from which it was calculated.
- Ever heard that a chain is only as strong as the weakest link?
- Sometimes, calculated values need to be rounded off.

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**Rounding Calculated Answers**

- **Rounding**
  - Decide *how many* significant figures are needed (more on this very soon)
  - Round to that many digits, counting from the left
  - Is the next digit less than 5? Drop it.
  - Next digit 5 or greater? Increase by 1

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**SAMPLE PROBLEM 3.1 - Page 69**

**Rounding Measurements**

Round off each measurement to the number of significant figures shown in parentheses. Write the answers in scientific notation.

- a. 3147.21 meters (four)
- b. 0.001 773 meter (two)
- c. 0.792 meters (two)

Be sure to answer the question completely!

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**SAMPLE PROBLEM 3.2 - Page 70**

**Significant Figures in Addition**

Calculate the sum of the three measurements. Give the answer to the correct number of significant figures.

\[ 12.32 \text{ meters} + 3.49 \text{ meters} + 8.24 \text{ meters} \]

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**Rounding Calculated Answers**

- **Addition and Subtraction**
  - The answer should be rounded to the same number of decimal places as the least number of decimal places in the problem.

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**Rounding Calculated Answers**

- **Multiplication and Division**
  - Round the answer to the same number of significant figures as the least number of significant figures in the problem.
SAMPLE PROBLEM 3.3 - Page 71

**Significant Figures in Multiplication and Division**

Perform the following operations. Give the answers to the correct number of significant figures.

- a. 7.55 meters \( \times \) 0.04 meter
- b. 2.10 meters \( \times \) 0.70 meter
- c. 2.4528 meters \( \div \) 8.4

**Analyse Identify the relevant concepts.**

Perform the required math operation and then analyze each of the original numbers to determine the correct number of significant figures required in the answer.

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**Sig Fig Practice #2**

<table>
<thead>
<tr>
<th>Calculation</th>
<th>Calculator says:</th>
<th>Answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.24 m ( \times ) 7.0 m</td>
<td>22.68 m²</td>
<td>23 m²</td>
</tr>
<tr>
<td>100.0 g ( \div ) 23.7 cm³</td>
<td>4.219409283 g/cm³</td>
<td>4.22 g/cm³</td>
</tr>
<tr>
<td>0.02 cm ( \times ) 2.371 cm</td>
<td>0.04742 cm²</td>
<td>0.05 cm²</td>
</tr>
<tr>
<td>710 m ( \div ) 3.0 s</td>
<td>236.6666667 m/s</td>
<td>240 m/s</td>
</tr>
<tr>
<td>1818.2 lb ( \times ) 3.23 ft</td>
<td>5872.786 lb-ft</td>
<td>5870 lb-ft</td>
</tr>
<tr>
<td>1.030 g ( \times ) 2.87 mL</td>
<td>2.9561 g/mL</td>
<td>2.96 g/mL</td>
</tr>
</tbody>
</table>

---

**Sig Fig Practice #3**

<table>
<thead>
<tr>
<th>Calculation</th>
<th>Calculator says:</th>
<th>Answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.24 m + 7.0 m</td>
<td>10.24 m</td>
<td>10.2 m</td>
</tr>
<tr>
<td>100.0 g - 23.73 g</td>
<td>76.27 g</td>
<td>76.3 g</td>
</tr>
<tr>
<td>0.02 cm + 2.371 cm</td>
<td>2.391 cm</td>
<td>2.39 cm</td>
</tr>
<tr>
<td>713.1 L - 3.872 L</td>
<td>709.228 L</td>
<td>709.2 L</td>
</tr>
<tr>
<td>1818.2 lb + 3.37 lb</td>
<td>1821.57 lb</td>
<td>1821.6 lb</td>
</tr>
<tr>
<td>2.030 mL - 1.870 mL</td>
<td>0.16 mL</td>
<td>0.160 mL</td>
</tr>
</tbody>
</table>

*Note the zero that has been added.

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**Rules for Significant Figures in Mathematical Operations**

- **Multiplication and Division:** # sig figs in the result equals the number in the *least precise* measurement used in the calculation.
  
  - 6.38 \( \times \) 2.0 =
  
  - 12.76 \( \rightarrow \) 13 (2 sig figs)

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**Rules for Significant Figures in Mathematical Operations**

- **Addition and Subtraction:** The number of decimal places in the result equals the number of decimal places in the *least precise* measurement.

  - 6.8 + 11.934 =
  
  - 18.734 \( \rightarrow \) 18.7 (3 sig figs)

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**Section 3.3 The International System of Units**

- **OBJECTIVES:**
  - List SI units of measurement and common SI prefixes.
Section 3.3
The International System of Units

- **OBJECTIVES:**
  - Distinguish between the *mass* and *weight* of an object.

International System of Units

- Measurements depend upon *units* that serve as reference standards
- The standards of measurement used in science are those of the Metric System

The Fundamental SI Units (Le Système International, SI)

<table>
<thead>
<tr>
<th>Physical Quantity</th>
<th>Name</th>
<th>Abbreviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>Meter</td>
<td>m</td>
</tr>
<tr>
<td>Mass</td>
<td>Kilogram</td>
<td>kg</td>
</tr>
<tr>
<td>Temperature</td>
<td>Kelvin</td>
<td>K</td>
</tr>
<tr>
<td>Time</td>
<td>Second</td>
<td>s</td>
</tr>
<tr>
<td>Amount of substance</td>
<td>Mole</td>
<td>mol</td>
</tr>
</tbody>
</table>

*Not commonly used in chemistry:

<table>
<thead>
<tr>
<th>Physical Quantity</th>
<th>Name</th>
<th>Abbreviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Luminous intensity</td>
<td>Candela</td>
<td>cd</td>
</tr>
<tr>
<td>Electric current</td>
<td>Ampere</td>
<td>A</td>
</tr>
</tbody>
</table>

Nature of Measurements

Measurement - quantitative observation consisting of 2 parts:

- Part 1 – **number**
- Part 2 - scale (unit)

Examples:

- **20 grams**
- **6.63 x 10⁻³** Joule seconds
International System of Units

- Sometimes, non-SI units are used
  - Liter, Celsius, calorie
- Some are derived units
  - They are made by joining other units
  - Speed = miles/hour (distance/time)
  - Density = grams/mL (mass/volume)

Length

- In SI, the basic unit of length is the **meter** (m)
- Length is the distance between two objects – measured with **ruler**
- We make use of **prefixes** for units larger or smaller

SI Prefixes – Page 74
Common to Chemistry

<table>
<thead>
<tr>
<th>Prefix</th>
<th>Unit Abbreviation</th>
<th>Meaning</th>
<th>Exponent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kilo-</td>
<td>k</td>
<td>tuane</td>
<td>$10^3$</td>
</tr>
<tr>
<td>Deci-</td>
<td>d</td>
<td>umin</td>
<td>$10^1$</td>
</tr>
<tr>
<td>Centi-</td>
<td>c</td>
<td>finche</td>
<td>$10^{-2}$</td>
</tr>
<tr>
<td>Milli-</td>
<td>m</td>
<td>millim</td>
<td>$10^{-3}$</td>
</tr>
<tr>
<td>Micro-</td>
<td>μ</td>
<td>microm</td>
<td>$10^{-6}$</td>
</tr>
<tr>
<td>Nano-</td>
<td>n</td>
<td>nanim</td>
<td>$10^{-9}$</td>
</tr>
</tbody>
</table>

Volume

- The space occupied by any sample of matter.
- Calculated for a solid by multiplying the length x width x height; thus derived from units of length.
- SI unit = **cubic meter** (m³)
- Everyday unit = Liter (L), which is non-SI. (Note: 1mL = 1cm³)

Devices for Measuring Liquid Volume

- Graduated cylinders
- Pipets
- Burets
- Volumetric Flasks
- Syringes

The Volume Changes!

- Volumes of a solid, liquid, or gas will generally increase with temperature
- Much more prominent for **GASES**
- Therefore, measuring instruments are calibrated for a specific temperature, usually 20 °C, which is about room temperature
Units of Mass

- **Mass** is a measure of the quantity of matter present
  - *Weight* is a force that measures the pull by gravity; it changes with location
  - Mass is constant, regardless of location

Working with Mass

- The SI unit of mass is the **kilogram (kg)**, even though a more convenient everyday unit is the gram
- Measuring instrument is the balance scale

Units of Temperature

- Temperature is a measure of how hot or cold an object is. *(Measured with a thermometer.)*
- Heat moves from the object at the higher temperature to the object at the lower temperature.
- We use two units of temperature:
  - **Celsius** – named after Anders Celsius
  - **Kelvin** – named after Lord Kelvin

Units of Temperature

- **Celsius scale** defined by two readily determined temperatures:
  - Freezing point of water = 0 °C
  - Boiling point of water = 100 °C
- **Kelvin scale** does not use the degree sign, but is just represented by K
  - absolute zero = 0 K *(thus no negative values)*
  - formula to convert: $K = °C + 273$

SAMPLE PROBLEM 3.4 - Page 78

**Converting Between Temperature Scales**

Normal human body temperature is 37°C. What is that temperature in kelvins?

1. **Analyze** List the known and the unknown.
   - Known
     - Temperature in °C = 37°C
   - Unknown
     - Temperature in K
   - Use the known value and the equation $K = °C + 273$ to calculate the temperature in kelvins.

Units of Energy

- Energy is the capacity to do work, or to produce heat.
- Energy can also be measured, and two common units are:
  1. **Joule (J)** = the SI unit of energy, named after James Prescott Joule
  2. **calorie (cal)** = the heat needed to raise 1 gram of water by 1 °C
Units of Energy

- Conversions between joules and calories can be carried out by using the following relationship:
  \[ 1 \text{ cal} = 4.184 \text{ J} \]

Section 3.3 Conversion Problems

- OBJECTIVE:
  - Construct conversion factors from equivalent measurements.

Section 3.3 Conversion Problems

- OBJECTIVE:
  - Apply the techniques of dimensional analysis to a variety of conversion problems.

Section 3.3 Conversion Problems

- OBJECTIVE:
  - Convert complex units, using dimensional analysis.

Conversion factors

- A “ratio” of equivalent measurements
- Start with two things that are the same: one meter is one hundred centimeters
- Write it as an equation
  \[ 1 \text{ m} = 100 \text{ cm} \]
- We can divide on each side of the equation to come up with two ways of writing the number “1”
Conversion factors

\[
\frac{1 \text{ m}}{100 \text{ cm}} = \frac{100 \text{ cm}}{100 \text{ cm}}
\]

\[
\frac{1 \text{ m}}{100 \text{ cm}} = 1
\]

\[
\frac{1 \text{ m}}{1 \text{ m}} = \frac{100 \text{ cm}}{1 \text{ m}}
\]

\[
1 = \frac{100 \text{ cm}}{1 \text{ m}}
\]

Conversion factors

- A unique way of writing the number 1
- In the same system they are defined quantities so they have an unlimited number of significant figures
- Equivalence statements always have this relationship:
  \[
  \text{big # small unit} = \text{small # big unit}
  \]
  \[
  1000 \text{ mm} = 1 \text{ m}
  \]

Practice by writing the two possible conversion factors for the following:

- Between kilograms and grams
- Between feet and inches
- Using 1.096 qt. = 1.00 L
What are they good for?

- We can multiply by the number "one" creatively to change the units.
- Question: 13 inches is how many yards?
- We know that 36 inches = 1 yard.
- \[13 \text{ inches} \times \frac{1 \text{ yard}}{36 \text{ inches}} = 0.36 \text{ yards}\]

Conversion factors

- Called **conversion factors** because they allow us to convert units.
- really just multiplying by 
  - **one**, in a creative way.

Dimensional Analysis

- A way to analyze and solve problems, by using units (or dimensions) of the measurement
  - **Dimension** = a unit (such as g, L, mL)
  - **Analyze** = to solve
    - Using the units to solve the problems.
  - If the units of your answer are right, chances are you did the math right!

Dimensional Analysis

- Dimensional Analysis provides an alternative approach to problem solving, instead of with an equation or algebra.
- A ruler is 12.0 inches long. How long is it in cm? (1 inch = 2.54 cm)
- How long is this in meters?
- A race is 10.0 km long. How far is this in miles, if:
  - 1 mile = 1760 yards
  - 1 meter = 1.094 yards

Converting Between Units

- Problems in which measurements with one unit are converted to an equivalent measurement with another unit are easily solved using dimensional analysis
- Sample: Express 750 dg in grams.
- Many complex problems are best solved by breaking the problem into manageable parts.
Converting Between Units

- Let's say you need to clean your car:
  1) Start by vacuuming the interior
  2) Next, wash the exterior
  3) Dry the exterior
  4) Finally, put on a coat of wax
- What problem-solving methods can help you solve complex word problems?
  - Break the solution down into steps, and use more than one conversion factor if necessary

Converting Complex Units?

- Complex units are those that are expressed as a ratio of two units:
  - Speed might be meters/hour
  - Sample: Change 15 meters/hour to units of centimeters/second
  - How do we work with units that are squared or cubed? (cm$^2$ to m$^2$, etc.)

Section 3.4 Density

- OBJECTIVES:
  - Calculate the density of a material from experimental data.

SAMPLE PROBLEM 3.9 - Page 86

Converting Ratios of Units

The mass per unit volume of a substance is a property called density. The density of manganese, a metallic element, is 7.21 g/cm$^3$. What is the density of manganese expressed in units of g/m$^3$?

1. Analyze: List the knowns and the unknown.

   Known:
   - density of manganese = 7.21 g/cm$^3$
   - 1$^0$ g = 1 kg
   - 1$^0$ cm$^3$ = 1 m$^3$

   Unknown:
   - density of manganese = ? g/m$^3$

   The desired conversion is g/cm$^3$ → g/m$^3$. The mass unit in the numerator must be changed from grams to kilograms: g → kg. In the denominator, the volume unit must be changed from cubic centimeters to cubic meters: cm$^3$ → m$^3$. Note that the relationship between cm and m. Cubing the relationship $10^2$ cm = 1 m yields $(10^2$ cm$^3$ = 1 m$^3)$, or $10^6$ cm$^3$ = 1 m$^3$.

Section 3.4 Density

- OBJECTIVES:
  - Describe how density varies with temperature.

Density

- Which is heavier - a pound of lead or a pound of feathers?
  - Most people will answer lead, but the weight is exactly the same
  - They are normally thinking about equal volumes of the two
  - The relationship here between mass and volume is called Density
Density

- The formula for density is: \[ \text{Density} = \frac{\text{mass}}{\text{volume}} \]
- Common units are: \( \text{g/mL} \), or possibly \( \text{g/cm}^3 \), (or \( \text{g/L} \) for gas)
- Density is a physical property, and does not depend upon sample size

Density and Temperature

- What happens to the density as the temperature of an object increases?
  - Mass remains the same
  - Most substances increase in volume as temperature increases
- Thus, density generally decreases as the temperature increases

Density and Water

- **Water** is an important exception to the previous statement.
- Over certain temperatures, the volume of water increases as the temperature decreases (Do you want your water pipes to freeze in the winter?)
  - Does ice float in liquid water?
  - Why?

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**SAMPLE PROBLEM 3.10 - Page 91**

Calculating Density

A copper penny has a mass of 3.1 g and a volume of 0.55 cm\(^3\). What is the density of copper?

1. **Analyze** List the knowns and the unknown.
   - **Knowns**
     - mass = 3.1 g
     - volume = 0.55 cm\(^3\)
   - **Unknown**
     - density = ? g/cm\(^3\)

2. Use the known values and the following definition of density:
   \[ \text{Density} = \frac{\text{mass}}{\text{volume}} \]