Chapter 1: Introduction to Chemistry/Analyzing Data

Read and study the following information to help you prepare for the Practice Problems Assignment. You are responsible for understanding this material. Keep a log of questions/concepts that you don't understand and bring it with you on your first day of class. If you do well on the Practice Problems, it will be assumed that you understand the material.

1.1 The Stories of Two Chemicals A chemical is any substance that has a definite composition. Ozone is a chemical that is made up of three particles of oxygen. Ozone forms a thick blanket above the clouds in the stratosphere. This layer of ozone protects Earth from overexposure to ultraviolet radiation from the Sun. You are probably familiar with the damage that exposure to ultraviolet radiation can do to your skin in the form of sunburn. Ultraviolet radiation can also harm other animals and plants. In the 1980s, scientists documented that the ozone layer around Earth was becoming measurably thinner in some spots. In the 1970s, scientists had observed that large quantities of chlorofluorocarbons (CFCs) had accumulated in Earth's atmosphere. CFCs are chemicals that contain chlorine, fluorine, and carbon. CFCs were used as coolants in refrigerators and air conditioners and as propellants in spray cans because they were considered relatively nonreactive. Some scientists hypothesized that there might be a connection between the concentration of CFCs in the atmosphere and the thinning of the ozone layer.

1.2 Chemistry and Matter Chemistry is the study of matter and the changes that it undergoes. Matter is anything that has mass and takes up space. Mass is a measurement of the amount of matter in an object. Everything, however, is not made of matter. For example, heat, light, radio waves, and magnetic fields are some things that are not made of matter. You might wonder why scientists measure matter in terms of mass, and not in terms of weight. Your body is made of matter, and you probably weigh yourself in pounds. However, your weight is not just a measure of the amount of matter in your body. Your weight also includes the effect of Earth's gravitational pull on your body. This force is not the same everywhere on Earth. Scientists use mass to measure matter instead of weight because they need to compare measurements taken in different locations.
Matter is made up of particles, called atoms, that are so small they cannot be seen with an ordinary light microscope. The structure, composition, and behavior of all matter can be explained by atoms and the changes they undergo. Because there are so many types of matter, there are many areas of study in the field of chemistry. Chemistry is usually divided into five branches, as summarized in the table below.

Branch	Area of Emphasis	Examples
Organic Chemistry	Most carbon-containing chemicals	Pharmaceuticals, plastics

Inorganic Chemistry	In general, matter that does not contain carbon	Minerals, metals and nonmetals, semi-conductors
Physical Chemistry	The behavior and changes of matter and the related energy changes	Reaction rates, reaction mechanisms
Analytical Chemistry	Components and composition of substances	Food nutrients, quality control
Biochemistry	Matter and processes of living organisms	Metabolism, fermentation

1.3 Scientific Methods

A **scientific method** is a systematic approach used to answer a question or study a situation. It is both an organized way for scientists to do research and a way for scientists to verify the work of other scientists. A typical scientific method includes making observations, forming a hypothesis, performing an experiment, and arriving at a conclusion. Scientific study usually begins with observations. Often, a scientist will begin with **qualitative data**—information that describes color, odor, shape, or some other physical characteristic that relates to the five senses. Chemists also use **quantitative data**. This type of data is numerical. It tells how much, how little, how big, or how fast.

A **hypothesis** is a possible explanation for what has been observed. Based on the observations of ozone thinning and CFC buildup in the atmosphere, the chemists Mario Molina and F. Sherwood Rowland hypothesized that CFCs break down in the atmosphere due to the Sun's ultraviolet rays. They further hypothesized that a chlorine particle produced by the breakdown of CFCs could break down ozone. An **experiment** is a set of controlled observations that test a hypothesis. In an experiment, a scientist will set up and change one variable at a time. A **variable** is a quantity that can have more than one value. The variable that is changed in an experiment is called the **independent variable**. The variable that you watch to see how it changes as a result of your changes to the independent variable is called the **dependent variable**. For example, if you wanted to test the effect of fertilizer on plant growth, you would change the amount of fertilizer applied to the same kinds of plants. The amount of fertilizer applied would be the independent variable in this experiment. Plant growth would be the dependent variable. Many experiments also include a **control**, which is a standard for comparison; in this case, plants to which no fertilizer is applied.how much, how little, how big, or how fast.

A **conclusion** is a judgment based on the data obtained in the experiment. If data support a hypothesis, the hypothesis is tentatively affirmed. Hypotheses are never proven; they are always subject to additional research. If additional data do not support a hypothesis, the hypothesis is discarded or modified. Most hypotheses are not supported by data. Whether the hypothesis is supported or not, the data collected may still be useful. Over time, data from many experiments can be used to form a visual, verbal, and/or mathematical explanation—called a model—of the phenomenon being studied.

A **theory** is an explanation that has been supported by many experiments. Theories state broad principles of nature. Although theories are the best explanations of phenomena that scientists have at any given time, they are always subject to new experimental data and are modified to include new data. A **scientific law** describes a relationship in nature that is supported by many experiments and for which no exception has been found. Scientists may use models and theories to explain why this relationship exists.

Chapter 2: Analyzing Data

You probably know your height in feet and inches. Most people outside the United States, however, measure height in meters and centimeters. The system of standard units that includes the meter is called the metric system. Scientists today use a revised form of the metric system called the Système Internationale d'Unités, or SI.

Base units There are seven base units in SI. A base unit is a unit of measure that is based on an object or event in the physical world. Table 2-1 lists the seven SI base units, their abbreviations, and the quantities they are used to measure. SI is based on a decimal system. So are the prefixes in Table 2-2, which are used to extend the range of SI units. ▲

SI Base Units

Quantity	Base Unit
Time	Second(s)
Length	Meter(m)
Mass	Kilogram(kg)
Temperature	kelvin(K)
Amount of Substance	Mole(mol)
Electric Current	Ampere(A)
Luminous Intensity	Candela(cd)

SI is based on a decimal system. So are the prefixes in Table 2-2, which are used to extend the range of SI units.

Prefix	Symbol	Factor	Scientific Notation	Example
giga	G	1,000,000,000	10^9	Gigameter (Gm)
mega	M	1,000,000	10^6	Megagram (Mg)
kilo	k	1000	10^3	Kilometer (km)

deci	d	1/10	10^-1	Deciliter (dL)
centi	c	1/100	10^-2	Centimeter (cm)
milli	m	1/1000	10^-3	Milligram (mg)
nano	n	1/1000000000	10^-9	Nanometer (nm)
pico	p	1/1000000000000	10^-12	Picometer (pm)

Example Problem 2-1
Using Prefixes with SI Units How many picograms are in a gram? The prefix pico- means 10 ^-12 , or 1/1 000 000 000 000. Thus, there are 10^12 , or 1 000 000 000 000, picograms in one gram.
Derived units Not all quantities can be measured using SI base units. For example, volume and density are measured using units that are a combination of base units. An SI unit that is defined by a combination of base units is called a **derived unit**. The SI unit for volume is the liter. A liter is a cubic meter, that is, a cube whose sides are all one meter in length. Density is a ratio that compares the mass of an object to its volume. The SI units for density are often grams per cubic centimeter (g/cm^ 3) or grams per milliliter (g/mL). One centimeter cubed is equivalent to one milliliter.
Example Problem 2-2
Calculating Density
A 1.1-g ice cube raises the level of water in a 10-mL graduated cylinder 1.2 mL. What is the density of the ice cube? To find the ice cube's density, divide its mass by the volume of water it displaced and solve.
density mass/volume density= 0.92 g/mL
Example Problem 2-3
Using Density and Volume to Find Mass
Suppose you drop a solid gold cube into a 10-mL graduated cylinder containing 8.50 mL of water. The level of the water rises to 10.70 mL. You know that gold has a density of 19.3 g/cm^ 3 , or 19.3 g/mL. What is the mass of the gold cube? To find the mass of the gold cube, rearrange the equation for density to solve for mass.
density= mass/volume
mass= volume x density
Substitute the values for volume and density into the equation and solve for mass.
mass= 2.20 ~~mL~~ x 19.3 g/~~mL~~= 42.5 g

Temperature The temperature of an object describes how hot or cold the object is relative to other objects. Scientists use two temperature scales—the Celsius scale and the Kelvin scale—to measure temperature. You will be using the Celsius scale in most of your experiments. On the Celsius scale, the freezing point of water is defined as 0 degrees and the boiling point of water is defined as 100 degrees.

A **kelvin** is the SI base unit of temperature. On the Kelvin scale, water freezes at about 273 K and boils at about 373 K. One kelvin is equal in size to one degree on the Celsius scale. To convert from degrees Celsius to kelvins, add 273 to the Celsius measurement. To convert from kelvins to degrees Celsius, subtract 273 from the measurement in kelvins.

2.2 Scientific Notation and Dimensional Analysis

Extremely small and extremely large numbers can be compared more easily when they are converted into a form called scientific notation. **Scientific notation** expresses numbers as a multiple of two factors: a number between 1 and 10; and ten raised to a power, or exponent. The exponent tells you how many times the first factor must be multiplied by ten. When numbers larger than 1 are expressed in scientific notation, the power of ten is positive. When numbers smaller than 1 are expressed in scientific notation, the power of ten is negative. For example, 2000 is written as 2 10^ 3 in scientific notation, and 0.002 is written as 2 x10 ^ 3 .

Example Problem 2-4

Expressing Quantities in Scientific Notation The surface area of the Pacific Ocean is 166 000 000 000 000 m^ 2 . Write this quantity in scientific notation. To write the quantity in scientific notation, move the decimal point to after the first digit to produce a factor that is between 1 and 10. Then count the number of places you moved the decimal point; this number is the exponent (n). Delete the extra zeros at the end of the first factor, and multiply the result by 10^ n. When the decimal point moves to the left, n is positive. When the decimal point moves to the right, n is negative. In this problem, the decimal point moves 14 places to the left; thus, the quantity is written as 1.66x 10^14 in scientific notation.

Adding and subtracting using scientific notation To add or subtract quantities written in scientific notation, the quantities must have the same exponent. For example, 4.5 x 10^14 m + 2.1 x10^14 m = 6.6 x10^14 m. If two quantities are expressed to different powers of ten, you must change one of the quantities so that they are both expressed to the same power of ten before you add or subtract them.

Example Problem 2-5

Adding Quantities Written in Scientific Notation Solve the following problem. 2.45 x 10^14 kg+ 4.00 1012 kg. First express both quantities to the same power of ten. Either quantity can be changed. For example, you might change 2.45 x 10^14 to 245 x 10^12. Then add the quantities: 245 x 10^12 kg + 4.00 x 10^12 kg = 249 x 10^12 kg. Write the final answer in scientific notation: 2.49 x 10^14 kg.

Multiplying and dividing using scientific notation When multiplying or dividing quantities written in scientific notation, the quantities do not have to have the same exponent. For multiplication, multiply the first factors, then add the exponents. For division, divide the first factors, then subtract the exponents.

Example Problem 2-6

Multiplying Quantities Written in Scientific Notation Solve the following problem. (2 x 10^14 cm) (4 x 10^12 cm)

To solve the multiplication problem, first multiply the factors: 2x 4= 8. Then add the exponents: 14 + 12= 26. Combine the factors: 8 x10^26. Finally, multiply the units and write your answer in scientific notation: 8x 10^26 cm^ 2 .

Dimensional analysis Dimensional analysis is a method of problem solving that focuses on the units that are used to describe matter. Dimensional analysis often uses conversion factors. A conversion factor is a ratio of equivalent values used to express the same quantity in different units. A **conversion factor** is always equal to 1. Multiplying a quantity by a conversion factor does not change its value—because it is the same as multiplying by 1—but the units of the quantity can change.

Example Problem 2-7

Converting From One Unit to Another Unit How many centigrams are in 5 kilograms? Two conversion factors are needed to solve this problem. Remember that there are 1000 grams in a kilogram and 100 centigrams in a gram. To determine the number of centigrams in 1 kilogram, set up the first conversion factor so that kilograms cancel out. Set up the second conversion factor so that grams cancel out.

$$5\cancel{kg} \times \frac{1000\cancel{g}}{1\cancel{kg}} \times \frac{100cg}{1\cancel{g}} = 500,000cg$$

2.3 How reliable are measurements?

When scientists look at measurements, they want to know how accurate as well as how precise the measurements are. **Accuracy** refers to how close a measured value is to an accepted value. **Precision** refers to how close a series of measurements are to one another. Precise measurements might not be accurate, and accurate measurements might not be precise. When you make measurements, you want to aim for both precision and accuracy.

Percent error Quantities measured during an experiment are called experimental values. The difference between an accepted value and an experimental value is called an error. The ratio of an error to an accepted value is called **percent error**. The equation for percent error is as follows.

$$\text{Percent error} = \frac{\text{error}}{\text{Accepted value}} \times 100$$

When you calculate percent error, ignore any plus or minus signs because only the size of the error counts.

Example Problem 2-8

Calculating Percent Error Juan calculated the density of aluminum three times.

Trial 1: 2.74 g/cm ^3

Trial 2: 2.68 g/cm^ 3

Trial 3: 2.84 g/cm^ 3

Aluminum has a density of 2.70 g/cm 3. Calculate the percent error for each trial.

First, calculate the error for each trial by subtracting Juan's measurement from the accepted value (2.70 g/cm^3).

Trial 1: error 2.70 g/cm^ 3 - 2.74 g/cm^ 3 = - 0.04 g/cm^ 3

Trial 2: error 2.70 g/cm^ 3 -2.68 g/cm^ 3= 0.02 g/cm^ 3

Trial 3: error 2.70 g/cm^ 3 - 2.84 g/cm^ 3 = - 0.14 g/cm^ 3

Then, substitute each error and the accepted value into the percent error equation. Ignore the plus and minus signs.

Trial 1: $\text{percent error} = \frac{0.04 \cancel{g/cm^3}}{2.70 \cancel{g/cm^3}} \times 100 = 1.48\%$

Trial 2: $\text{percent error} = \frac{0.02 \cancel{g/cm^3}}{2.70 \cancel{g/cm^3}} \times 100 = 0.741\%$

Trial 3: $\text{percent error} = \frac{0.14 \cancel{g/cm^3}}{2.70 \cancel{g/cm^3}} \times 100 = 5.19\%$

Significant figures The number of digits reported in a measurement indicates how precise the measurement is. The more digits reported, the more precise the measurement. The digits reported in a measurement are called significant figures. **Significant figures** include all known digits plus one estimated digit. These rules will help you recognize significant figures.
1. Nonzero numbers are always significant.
45.893421 min has eight significant figures
2. Zeros between nonzero numbers are always significant.
2001.5 km has five significant figures
3. All final zeros to the right of the decimal place are significant.
6.00 g has three significant figures
4. Zeros that act as placeholders are not significant. You can convert quantities to scientific notation to remove placeholder zeros.
0.0089 g and 290 g each have two significant figures
5. Counting numbers and defined constants have an infinite number of significant figures.

Example Problem 2-9
Counting Significant Figures How many significant figures are in the following measurements?
a. 0.002 849 kg
b. 40 030 kg
Apply rules 1–4 from above. Check your answers by writing the quantities in scientific notation.
a. 0.002 849 kg has four significant figures; 2.849×10^{3}
b. 40 030 kg has four significant figures; 4.003×10^{4}

Rounding off numbers When you report a calculation, your answer should have no more significant figures than the piece of data you used in your calculation with the fewest number of significant figures. Thus, if you calculate the density of an object with a mass of 12.33 g and a volume of 19.1 cm^3, your answer should have only three significant figures. However, when you divide these quantities using your calculator, it will display 0.6455497—many more figures than you can report in your answer. You will have to round off the number to three significant figures, or 0.646.

Here are some rules to help you round off numbers.

1. If the digit to the immediate right of the last significant figure is less than five, do not change the last significant figure.
2. If the digit to the immediate right of the last significant figure is greater than five, round up the last significant figure.
3. If the digit to the immediate right of the last significant figure is equal to five and is followed by a nonzero digit, round up the last significant figure.
4. If the digit to the immediate right of the last significant figure is equal to five and is not followed by a nonzero digit, look at the last significant figure. If it is an odd digit, round it up. If it is an even digit, do not round up.

Whether you are adding, subtracting, multiplying, or dividing, you must always report your answer so that it has the same number of significant figures as the measurement with the fewest significant figures.

Example Problem 2-10
Rounding Off Numbers Round the following number to three significant figures: 3.4650.
Rule 4 applies. The digit to the immediate right of the last significant figure is a 5 followed by a zero. Because the last significant figure is an even digit (6), do not round up. The answer is 3.46.