CHAPTER 1
CHEMISTRY: THE STUDY OF CHANGE

This chapter reviews two topics basic to the study of chemistry that most of you learned in first year chemistry:

- The classification of matter and its changes
- Measurement and significant figures

The classification of matter and its changes

The simplest form of matter is an **element**. **Compounds** are combinations of elements that have a definite composition. Elements and compounds can exist in three states of matter: solids, liquids, and gases. The state in which matter exists depends on the temperature.

Matter can undergo physical and chemical changes. **Physical changes** *are those that do not alter the identity of that substance; for example, melting or freezing*. **Chemical changes** *do alter the identity of the substance; for example, rusting or burning*. To determine whether a physical or chemical change has occurred, observations must be made and measurements must be taken. Color, odor, and state are some of the common observations that can be made. Mass, volume, and temperature are the most frequently taken measurements. It is important to distinguish between **extensive properties**, *properties such as mass that depend on how much matter is being considered*, and **intensive properties**, *properties such as density that do not depend on how much matter is being considered.*

Measurement and significant figures

An understanding of **precision**, *how closely two or more measurements of the same quantity agree with one another*, and **accuracy**, *how close a measurement is to the true value of the quantity that was measured*, is important to laboratory measurement and data assessment. You should be very familiar with **SI units**, **scientific notation**, and **significant figures** in order to handle the calculations associated with chemical change.

> **Take Note:** *All calculations on the AP exam require that the rules for significant figures be obeyed. Credit will be given on the AP exam for the correct number of significant figures and for one more or one less than the correct number of significant figures. If a numerical answer is outside this range in the Free Responses section, a point will be deducted from your score.*

Significant figures are the *meaningful digits in a measured or calculated quantity*. A simplified version of significant figure rules is:

- **All nonzero digits are significant**. Thus 845 has three significant figures and 1.234 has four.
- **All zeroes to the right of nonzero digits are significant**. Thus 2.0 has two significant figures and 0.0000320 has three significant figures.*
- **All zeroes between nonzero digits are significant**. Thus 606 has three significant figures and 40,501 has five significant figures.
- **Exact numbers obtained from definitions or counting have an infinite number of significant figures**. One meter contains 1000 millimeters and thus one and 1000 have an infinite number of significant figures.

* There is one exception: for numbers that do not contain decimal points, the trailing zeroes (i.e., zeroes after the last nonzero digit) may or may not be significant. If there is no decimal, as in the case of the number 400, this implies that the quantity is approximately, but not exactly, 400; in this case, there is only one significant figure.

The mathematical operations with significant figures are the same for addition and subtraction but different than operations involving multiplication and division. In addition and subtraction, the answer is controlled by the number with the fewest decimal places and the answer should contain that number of decimal places (see Example 1). In a multiplication or division operation, the total number of significant figures in the answer is governed by the number with the least number of significant figures regardless of where the decimal point is (see Example 2). Answers that do not contain the correct number of significant figures must be rounded off.

Example 1. Subtraction with significant figures**.**

Consider the following experimental data:

mass of precipitate and filter paper	14.1 g
mass of filter paper	0.1983 g

Determine the mass of the precipitate.

General Strategy	**Solution to Example 1**
Perform the subtraction.	14.**1** g precipitate + filter paper – 0.**1983** g filter paper 13.9017 g precipitate
The 14.**1** g has the fewest decimals. Subtraction answers are governed by the number with the fewest decimal points. The answer must be rounded to one decimal place.	13.9017 g = 13.9 g final answer

Example 2. Division with significant figures.

Laboratory measurements were performed to determine the density of an unknown liquid. The following data were obtained in the lab:

mass of the graduated cylinder empty	10.0500 g
mass of the graduated cylinder + the unknown liquid	91.5900 g
volume of the liquid in the graduated cylinder	88.3 mL

Determine the density of the unknown liquid.

General Strategy	**Solution to Example 2**
The mass and volume of the liquid must be known in order to calculate the density. The volume is given as 88.3 mL (three significant figures).	Determination of the mass of the liquid: $\begin{array}{r} 91.5900\ \text{g} \\ -10.0500\,\text{g} \\ \hline 81.5400\,\text{g} \end{array}$ (six significant figures)
Calculate the density of the unknown liquid being the mass and volume of the liquid are known.	$D = \dfrac{m}{V}$ $D = \dfrac{81.5400\,\text{g}}{88.3\,\text{mL}} = .9234428086\ \dfrac{\text{g}}{\text{mL}}$
There are six significant figures in **81.5400** g and three significant figures in **88.3** mL. The number with fewest significant figures governs the answer in division. The answer should have three significant figures and must be rounded off.	$0.\mathbf{923}\ \dfrac{g}{mL}$

SAMPLE MULTIPLE CHOICE QUESTIONS

1. When the following calculation is performed, the number of significant figures in the answer is:

$$(74.0/23.60) + 15.000$$

   A. 6
   B. 3
   C. 2
   D. 4
   E. 7

2. What is the volume of a sample of gold having a mass of 20.0 g? The density of gold is 19.3 g/mL.

   A. 0.731 mL
   B. 0.893 mL
   C. 1.04 mL
   D. 0.751 mL
   E. 280. mL

3. The term that describes the ability of an instrument to produce the same measurement on repetition is:

   A. quantity
   B. qualitative
   C. accuracy
   D. precision
   E. property

4. Which is an example of an extensive property?

   A. odor
   B. color
   C. melting point
   D. density
   E. mass

5. A temperature of 245 K corresponds to which of the following Celsius temperatures?

   A. $-28°C$
   B. $-100°C$
   C. $0°C$
   D. $273°C$
   E. $-73°C$

6. Copper is a trace element and nutrient required in the diet of newborn babies, who require 80.0 µg per kg of body weight per day. Formula contains 0.48 µg/mL. How many mL of formula does a 6.60 lb baby require per day? (1 kg = 2.2 lb)

A. 5.00×10^2 mL
B. 5.0×10^2 mL
C. 50. mL
D. 50.0 mL
E. 5.00 mL

7. Which of the following is a chemical property?

A. copper sulfate crystals are blue
B. water boils at 100 °C
C. chlorine is a gas at room temperature
D. sodium reacts with oxygen in the air to form a white oxide
E. magnesium is malleable

8. In which of the following does a chemical change occur?

A. $2Ag\ (s) + O_2\ (g) \rightarrow 2Ag_2O\ (s)$
B. $NaCl\ (s) \rightarrow NaCl\ (aq)$
C. $I_2\ (s) \rightarrow I_2\ (g)$
D. $Mg\ (s) \rightarrow Mg\ (l)$
E. $H_2O\ (g) \rightarrow H_2O\ (l)$

9. The number of significant figures in 0.00000640301 is:

A. 6
B. 4
C. 11
D. 2
E. 5

10. 453 mm expressed in meters is:

A. 0.0453
B. 0.453
C. 4.53
D. 45.3
E. 0.00453

Comprehension Questions

1) Classify the following as either physical or chemical changes, and provide a brief explanation for each choice:

a) A tire's tread wears down with use.
b) An iron poker in a fire begins to glow red.
c) A mixture of amino acids is combined to create a protein.
d) White, mineral-like deposits form at the end of a faucet.
e) Antacid tablets "fizz" when dropped into a glass of water.

2) Human core body temperature is 98.6 ºF. Convert this temperature to both Kelvin and Celsius. Record your answers to the correct number of significant figures.

3) 39.95 g of argon gas, 1 mol, contains approximately 6.022×10^{23} atoms of argon. This quantity of argon will occupy a volume of 22.4 L at 0 ºC and 1.00 atm of pressure. Assuming the atoms to be roughly spherical with a radius of 98 pm, calculate the percentage of the volume occupied by the gas that is occupied by the atoms themselves, and the percentage of the total volume that is empty space (i.e., the amount of space between the atoms).

4) A student wishes to determine the density of an irregularly shaped fishing weight to determine if it is made from a pure metal, lead in this case, or an alloy. Describe a practical process, utilizing common lab equipment, by which this measurement could be made. The student discovers that the density of the object is 11.30 g/cm^3, and concludes that it is indeed made from pure lead (lead's density is reported to be 11.34 g/cm^3 at room temperature). Discuss the validity of the claim and possible sources of error that would invalidate the conclusions made.

5) Explain why the Kelvin temperature is considered an absolute temperature scale whereas Celsius is not.

ANSWERS TO MULTIPLE CHOICE QUESTIONS

1. D

Division requires that the least number of significant figures govern the number of significant figures in the answer. Since 74.0 has only three significant figures, then the answer to the division will be 3.14 (three significant figures).

Significant figures in addition (or subtraction) are governed by the number of decimal places, with the number containing the least number of decimal places controlling the number of significant figures in the answer. The addition of 3.14 (two decimal places) and 15.000 (three decimal places) yields 18.14, which contains two decimal places.

2. C

$$20.0 \text{ g} \times \frac{1 \text{ mL}}{19.3 \text{ g}} = 1.036 \text{ mL} = 1.04 \text{ mL} \text{ (three significant figures)}$$

3. D

Precision refers to how closely two or more measurements of the same quantity agree with one another.

4. E

An extensive property depends on how much matter is being considered. Since mass is the quantity of matter in a given sample, it is an extensive property.

5. A

The relationship between the Kelvin temperature scale and the Celsius scale is K = C + 273. Consequently 245 = C + 273 or $C = 245 - 273$. $C = -28°C$.

6. B

Dimensional analysis yields the following solution:

$$6.60 \text{ lb} \times \frac{1\,kg}{2.2\,lbs} \times \frac{80.0\,\mu g}{1\,kg} \times \frac{1\,mL}{0.48\,\mu g} = 500 \text{ mL or } 5.0 \times 10^2\ mL$$

Since 0.48 µg contains two significant figures, the answer requires two significant figures.

7. D

Silvery sodium reacting with oxygen gas to form a white powdery solid describes a chemical property because a chemical change must occur to observe this property. The reaction is $4Na\ (s) + O_2\ (g) \rightarrow 2Na_2O\ (s)$.

8. A

The formation of silver oxide from silver and oxygen is the only change resulting in a new substance. All other choices involve only a change in state.

9. A

The answer is *0.00000640301*. All nonzero digits are significant and only zeroes to the right of nonzero digits are significant. Zeroes to the left of nonzero digits are not significant.

10. B

$$453 \text{ mm} \times \frac{1\,m}{1000\,mm} = 0.453 \text{ meters}$$ (three significant figures since the conversion factor is an absolute number)

Answers to Comprehension Questions

1a) The wearing down of tread is a physical change that occurs through physical contact and friction with the road surface. Although there is the possibility of chemical change when rubber is subjected to atmospheric oxidants and sunlight, a great deal of this change would be the physical removal of rubber by abrasion.

b) This also represents a physical change. As the iron is heated, energy is added to its outermost electrons and they move to higher energy levels. When they spontaneously move back to lower energy levels, they emit the excess energy that they possessed. Some of this energy can be seen as visible light in the red portion of the electromagnetic spectrum.

c) Formation of a protein, either as part of a living organism's metabolic processes or in a lab, represents a chemical transformation. Chemical bonds are both broken and formed in this process, and the chemical and physical characteristics of the protein will be different than those of the amino acids.

d) This formation of mineral deposits is a physical process involving a change of state. Dissolved minerals, for example, $CaCO_3$, in tap water have limited solubility in water and therefore form a solid precipitate at the end of a faucet as the water evaporates. It is possible for these deposits to react with metal materials in the faucet if they are left in place for an extended period, however, they will form even at the end of a plastic faucet.

e) The antacids that "fizz" or produce a gas, carbon dioxide, do so by a chemical reaction. The antacids contain a carbonate salt, for example, $CaCO_3$, and a solid acid such as citric and/or acetyl salicylic acid. Upon addition to water, the tablets dissolve and begin to react in an acid-base neutralization reaction as shown. The gas produced is CO_2.

$$C_5H_8O_7 + CaCO_3 \rightarrow CaC_5H_7O_7 + H_2O + CO_2$$

2) Conversion from Celsius to Kelvin is straightforward, and therefore it is common to convert from Fahrenheit to Celsius and then to Kelvin. ºC = (ºF × 1.8) + 32. Substituting, ºC = (98.6 ºF × 1.8) + 32 = **37.0 ºC**. Kelvin = ºC + 273.15 = 37.0 ºC + 273.15 = **310.2 K.**

3) Since the question states that the total volume occupied by the gas is 22.4 liters, the calculation that remains is to determine the volume of the gas particles themselves. The atoms can be treated as extremely small spheres with a volume equal to $4/3\Pi r^3$. Substituting a radius of 98×10^{-12} m into the equation:

$$4/3\Pi r^3 = 4/3\Pi(98 \times 10^{-12}\ \mathrm{m})^3 = 4/3\pi 9.4 \times 10^{-31}\ \mathrm{m}^3 = 3.9 \times 10^{-30}\ \mathrm{m}^3$$

Multiplying by the conversion 1000 L / m^3 gives a volume of 3.9×10^{-27} L. This value is the volume of a single Ar atom, and must be multiplied by the total number of atoms present, 6.022×10^{23}, to arrive at the volume occupied by all of the atoms in the sample.

$$3.9 \times 10^{-27}\ \text{L/atom} \times 6.022 \times 10^{23}\ \text{atoms} = 2.4 \times 10^{-3}\ \text{L}$$

Calculating the percentage of the space occupied by the atoms:

$(2.4 \times 10^{-3}\ \mathrm{L} / 22.4\,\mathrm{L}) \times 100\% =$ **0.011% of the space is occupied by the atoms themselves,** or, subtracting from 100%, a sample of argon gas is **99.99% empty space**.

4) Density is the ratio between mass and volume for a given object or substance, so it is necessary to determine both the mass and volume of the object, a fishing weight in this case. The mass can be determined with a lab balance. In this case, because of the question that is being asked about the object itself, a balance that reads to the nearest 1/100th of a gram would be a good choice. The volume of an irregularly shaped object can be easily measured to a reasonable precision by displacement. This procedure usually involves the use of a graduated cylinder that is partially filled with water. The volume of the water is noted before and after the object is submerged into the water, and the difference in volumes is equal to the volume of the object.

The student's claim that the object is made from pure lead based on a density measurement is a reasonable, but not definitive conclusion. It is assumed that other physical characteristics of the object were taken into account, that is, metallic properties such as luster, malleability, etc. However, the object could have been made from an alloy, a mixture of metals, that just happened to have the same density as lead. A chemical analysis would have to be performed to be sure. The student should have conducted several trials of this measurement to get some idea of the precision of the data generated. Sources of error in this type of measurement include bubbles sticking to the outside of the object being submerged into the water, water splashing out of the graduated cylinder as the object is introduced, weighing the object after its volume is determined (sometimes there is residual water left on the object), and other random errors that would not be detected if a single trial were performed.

5) Commonly used temperature scales such as Fahrenheit and Celsius use arbitrary values for their zero point such as the freezing point of water, etc. Therefore, these scales have negative temperature values. These negative values correlate with situations in which there is still molecular motion, that is, a positive amount of "temperature" (temperature is proportional to motion of particles). The Kelvin scale is the only one that sets its zero point at the temperature where all molecular motion has ceased, that is, that situation in which there is no "temperature." This is the only case in which a doubling of the measured temperature corresponds with a doubling of molecular motion.