Measurements in Chemistry

Measurements are part of our daily lives. We measure our weight, driving distances and gallons of gasoline. A health professional might measure blood pressure, temperature and pulse rate or calculate drug dosage. A **measurement** contains a *number* and a *unit*. The *unit* specifies the physical property and the size of the measurement, while the *number* indicates how many units are present. A number without a unit is usually meaningless. *Measurements* made with instruments such as rulers, balances and graduated cylinders that are recorded with numbers and units are **quantitative** observations that are made in science. Observations that are *descriptions* made using the five senses are called **qualitative** observations.

Section 1: International System of Units

In the United States most measurements are made with the English system of units which usually contain fractions. The **metric system** is a decimal-based system of units of measurement which is used most often worldwide. Around 1960, the international scientific organization adopted a modification of the metric system call the **International System of Units** or SI. Table 1 outlines five of the seven base units for the SI system. Not included in the table are the units for electric current (ampere) and luminous intensity (candela) because we will not be using them in this course.

Physical Quantity	Name of Base Unit	Symbol of base unit
Length	meter	m
Mass	kilogram	kg
Time	seconds	s
Temperature	Kelvin	K
Amount of substance	mole	mol

Table 1: SI base units and their symbols

The units of every measurement in the SI system, no matter how simple or complex should be derived from one or more of the seven base units. For example, the preferred unit for volume is the cubic meter (m^3) because volume has units of length cubed and the SI unit for length is the meter. However, volume is often expressed in scientific works in the unit of liters or milliliters. Because of this, a number of units that are not strictly acceptable under the SI conventions are still used. Some common non-SI units in chemistry summarized in Table 2.

Physical Quantity	Name of Base Unit	Symbol of base unit
Volume	Liter	L
Temperature	Degrees Celsius	ºC
Concentration	Molarity	M
Pressure	Atmosphere	atm

Table 2: Non-SI units in common use

PRACTICE: Identify the physical quantity measured based on the the measurement and units provided.

Measurement	Physical Quantity
1.33 m	
298 K	
3.4 L	

Measurement	Physical Quantity
1.5 atm	
2.0 M	
22.8 kg	

**NOTE: NYS Reference Table D includes selected physical quantities and their associated units.

Section2: Scientific Notation

Scientific notation is a common method used to conveniently represent very small or very large numbers. There are two parts to any number expressed in scientific notation, a coefficient and a power of 10. The number 375 is written in scientific notation as 3.75×10^2. The coefficient is 3.75 and 10^2 shows the power of 10 (the superscript 2 is called an exponent). A number less than one would contain a negative exponent. For example: the number 0.0075 is written as 7.5×10^{-3} (note the negative exponent.) The coefficient must always be a number greater than or equal to 1 but less than 10.

> ***NOTE:***
> *A* positive exponent *indicates that the first factor is* multiplied by a power of 10
>
> Ex. $2 \times 10^2 = 2 \times 100 = 200$
>
> $4.5 \times 10^4 = 4.5 \times 10000 = 45000$
>
> *A* negative exponent *indicates that the first factor is* divided by a power of 10
>
> *Ex.* $3 \times 10^{-1} = 3 \times 0.1 = 3/10 = .3$
>
> $5.6 \times 10^{-3} = 5.6 \times 0.001 = 5.6/1000 = .0056$

Scientific Notation and Calculators

Numbers in scientific notation can be entered into most calculators using the EE or EXP key. As an example try 9.7×10^3.

1. Enter the coefficient (9.7) into the calculator.
2. Push the EE (or EXP) key. DO NOT use the times (x) button.
3. Enter the exponent (3).

Number to enter	**Method**	**Display Reads**
9.7×10^3	9.7 EE 3	9.7E3 or 9700

Calculating with Numbers in Scientific Notation

When numbers expressed in scientific notation are **added** or **subtracted**, the base and the ***exponent must be the same.***

Sample Problem 1: Add 2.52×10^4 and 2.43×10^3

Solution:
First change 2.43×10^3 to 0.243×10^4
***The exponents must be the same.*
Then add 2.52 and 0.243
The answer is 2.763×10^4

Sample Problem 2: Subtract 5.2×10^{-4} and 2.7×10^{-3}

Solution:
First change 5.2×10^{-4} to 0.52×10^{-3}
***The exponents must be the same.*
Then subtract 0.52 from 2.7.
The answer is 2.18×10^{-3}

Sample Problem 3: Add 3.1×10^{-2} and 2.7×10^{-2}

Solution:
Since the exponents are the same -
Add 3.1 and 2.7
The answer is 5.8×10^{-2}

*Note: Once calculated, be sure that the final answer is in proper scientific notation.

The mathematical operation typically results in proper scientific notation if numbers are expressed to the larger exponent.

When numbers expressed in scientific notation are **multiplied** or **divided**, the bases are the same but the ***exponents can be different***. When **multiplying**, *exponents will be added*; when **dividing**, *exponents will be subtracted.*

Sample Problem 4

Multiply 4×10^2 and 5×10^3

Solution: Multiply the coefficients
Add the exponents
$(4x10^2)(5x10^3) = 20 \times 10^{(3+2)} = 20 \times 10^5$

Answer (in Scientific Notation) = 2.0×10^6

Sample Problem 5

Divide 7.5×10^6 by 2.5×10^2

Solution: Divide the coefficients
Subtract the exponents
$(7.5x10^6)(2.5x10^2) = 3.0 \times 10^{(6+2)} = 3.0 \times 10^4$

*Make sure the answer is in scientific notation.

PRACTICE:

EXPRESS EACH OF THE FOLLOWING NUMBERS IN PROPER SCIENTIFIC NOTATION:

1. 0.000033 = ______________________
2. 50,000. = ______________________
3. 230,000 = ______________________
4. 465 = __________________
5. 236,000,000,000 = __________________
6. 0.000000000000236 = __________________

EXPRESS EACH OF THE FOLLOWING IN STANDARD FORM.

9. 3.7×10^5 = ______________________
10. 3.21×10^{-4} = ______________________
11. 6×10^5 = ______________________
12. 1.99×10^{-3} = ______________________

PERFORM EACH OF THE FOLLOWING OPERATIONS USING THE RULES FOR CALCULATING WITH SCIENTIFIC NOTATION. YOUR ANSWERS SHOULD BE EXPRESSED IN SCIENTIFIC NOTATION AND ROUNDED TO THE PROPER SIGNIFICANT FIGURES. CHECK YOUR WORK USING THE SCIENTIFIC NOTATION FUNCTION ON YOUR CALCULATOR.

13. $(9.6 \times 10^{-1})(5.2 \times 10^2)$

14. $(2.56 \times 10^4)+(4.6 \times 10^3)$

15. $(1.76 \times 10^3) - (5.8 \times 10^2)$

16. $\dfrac{6.7 \times 10^2}{1.3 \times 10^3}$

17. $7.19 \times 10^{-8} - 4.9 \times 10^{-8}$

18. $\dfrac{8.1 \times 10^4}{9.0 \times 10^{-3}}$

Section 3: Metric Prefixes

The **metric system** is a decimal-based system of units of measurement used by most scientists worldwide. Selected metric prefixes and the associated factor are listed on NYS Chemistry Reference Table C. In the metric system, a prefix can be attached to a unit to increase or decrease its size by factors (powers) of 10.

Prefix	Symbol	Factor	Value
kilo-	k	10^3	1000
deci-	d	10^{-1}	$0.1 = \frac{1}{10}$
centi-	c	10^{-2}	$0.01 = \frac{1}{100}$
milli-	m	10^{-3}	$0.001 = \frac{1}{1000}$
micro -	µ	10^{-6}	$0.000001 = \frac{1}{1000000}$
nano -	n	10^{-9}	$0.000000001 = \frac{1}{1000000000}$
pico -	p	10^{-12}	$0.000000000001 = \frac{1}{1000000000000}$

Base unit (ex. m, g, L) have a factor of 10^o

Notes:
"milli" means one-thousandth; so a milliliter (symbol: mL) is one thousandth of a liter. That means it takes 1000 mL to make 1 L.

"kilo" means one thousand; so a kilogram (symbol: kg) means 1000 grams [1 kg = 1000g]

PRACTICE:

1. Give the metric prefix that corresponds to each of the following.
   a. $\frac{1}{1000000000}$ ___________
   b. 10^{-6} ___________
   c. 1000 ___________
   d. 0.01 ___________

2. Compare the values given using <, >, or =.
   a. 60 m ◯ 60 cm
   b. 200 mL ◯ 200 L
   c. 5 g ◯ 5 µg
   d. 8.6 mm ◯ 8.6 km

Section 4: Converting Between Units

Many problems in chemistry require converting a quantity from one unit to another. To perform this conversion, you must use a **conversion factor** or a series of conversion factors that relate two units. This method is called **dimensional analysis.**

Any equality can be written in the form of a fraction called a conversion factor. A conversion factor is easily distinguished from all other numbers because it is always a fraction that contains different units in the numerator and denominator.

In the United States we may need to convert inches to feet. Since we know the equality is 12 inches = 1 foot, two different conversion factors can be written as seen below. Note the difference units in the numerator and denominator, a requirement for all conversion factors.

Conversion factors: $\frac{Numerator}{Denominator}$ $\frac{1\ foot}{12\ inches}$ **OR** $\frac{12\ inches}{1\ foot}$

PRACTICE:

Write the two conversion factors possible for each of the following equalities.

a. 1 g = 1000 mg

b. 1 dozen = 12 eggs

c. 60 minutes = 1 hour

Section 5: Problem Solving with Dimensional Analysis

Dimensional Analysis is a general method for solving numerical problems in chemistry. In this method we follow the rule that when multiplying or dividing numbers, we must also multiply or divide units.

Solving problems with dimensional analysis is a three-step process.

1. Write down the given measurement; number *with* units
2. Multiply the measurement by one or more conversion factors. The unit in each denominator of the conversation factor must cancel (or match) the preceding unit in each numerator.
3. Perform the calculation and report the answer to proper number of significant figures based on numbers given in the question (data record), not conversion factors used.

Sample Problem 6 [SINGLE STEP CONVERSION]

Convert 0.455 km to meters

Solution:
To convert kilometers to meters, we must use the following equality

1 km = 1000 m

The corresponding conversion factors would be:

$\frac{1\ km}{1000\ m}$ or $\frac{1000\ m}{1\ km}$

Select the conversion factor to cancel kilometers, leaving units of meters.

0.455 km x $\frac{1000\ m}{1\ km}$ = 455 m

NOTE: The final answer is rounded to the significant figures represented in measured value given in the problem. The conversion factor was not used when determining the number of significant figures for the final answer.

Sample Problem 7 [MULTIPLE STEP CONVERSION]

Convert 2.5 weeks to minutes

Solution:
To convert weeks to minutes, we must use the following equalities

1 week = 7 d 1 d = 24 h 1 h= 60 min

The corresponding conversion factors would be:

$\frac{1 week}{7\ d}$ or $\frac{7\ d}{1\ week}$ $\frac{1\ d}{24\ h}$ or $\frac{24\ h}{1\ d}$ $\frac{1\ h}{60\ min}$ or $\frac{60\ min}{1\ h}$

Select the conversion factors that cancel units.

2.5 weeks x $\frac{7\ d}{1\ week}$ x $\frac{24\ h}{1\ d}$ x $\frac{60\ min}{1\ h}$ = 25200 min Rounded to sig figs = 25000 min

PRACTICE:

Complete each of the following conversions using dimensional analysis. All work must be shown in order to receive credit.

1) 300 mg to g
2) 4 L to mL
3) 12 cm to mm
4) 365 g to kg
5) 56 cm to m
6) 7.6 km to mm

Compare the following values using the symbols <,>, or =.
NOTE: You may have to convert in order to solve.

7) 75 cm ◯ 7.5 m
8) 9 g ◯ 900 mg
9) 2.4 m ◯ 240 cm
10) 754 mL ◯ 7.54 dL
11) 6 s ◯ 60 ms
12) 25 μg ◯ 0.25 mg

Make the following conversions. Express your answer in proper scientific notation.

13) 5×10^3 mm to m

14) 1.57×10^3 mg to dg

15) 125 days to seconds