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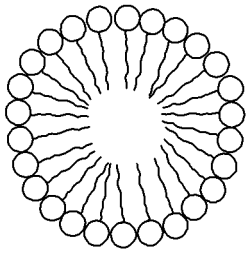
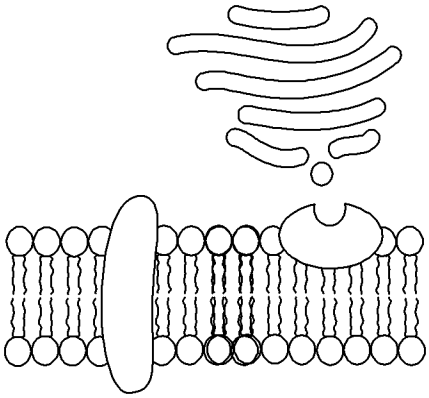


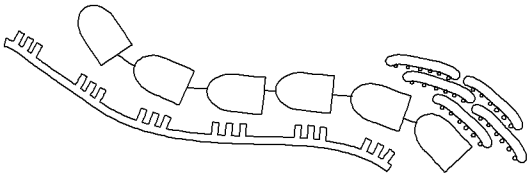
FOR CHEMISTRY 102

GENERAL, ORGANIC AND BIOLOGICAL CHEMISTRY



Thomas A. Olmstead, Ph.D

Grossmont College



3rd Edition

Grossmont College
Periodic Table of the Elements

	1 1A	2 2A	3 3B	4 4B	5 5B	6 6B	7 7B	8 8B	9 8B	10 8B	11 1B	12 2B	13 3A	14 4A	15 5A	16 6A	17 7A	18 8A
1	1 H 1.008																	2 He 4.003
2	3 Li 6.941	4 Be 9.012											5 B 10.811	6 C 12.011	7 N 14.007	8 O 15.999	9 F 18.998	10 Ne 20.180
3	11 Na 22.990	12 Mg 24.305											13 Al 26.982	14 Si 28.086	15 P 30.974	16 S 32.061	17 Cl 35.453	18 Ar 39.948
4	19 K 39.098	20 Ca 40.078	21 Sc 44.956	22 Ti 47.867	23 V 50.942	24 Cr 51.996	25 Mn 54.938	26 Fe 55.845	27 Co 58.933	28 Ni 58.693	29 Cu 63.546	30 Zn 65.382	31 Ga 69.723	32 Ge 72.640	33 As 74.922	34 Se 78.960	35 Br 79.904	36 Kr 83.798
5	37 Rb 85.468	38 Sr 87.62	39 Y 88.906	40 Zr 91.224	41 Nb 92.906	42 Mo 95.962	43 Tc (98)	44 Ru 101.07	45 Rh 102.906	46 Pd 106.42	47 Ag 107.868	48 Cd 112.411	49 In 114.818	50 Sn 118.710	51 Sb 121.760	52 Te 127.60	53 I 126.905	54 Xe 131.293
6	55 Cs 132.905	56 Ba 137.327	57 La 138.906	72 Hf 178.49	73 Ta 180.948	74 W 183.84	75 Re 186.207	76 Os 190.23	77 Ir 192.217	78 Pt 195.078	79 Au 196.967	80 Hg 200.59	81 Tl 204.383	82 Pb 207.2	83 Bi 208.980	84 Po (209)	85 At (210)	86 Rn (222)
7	87 Fr (223)	88 Ra (226)	89 Ac (227)	104 Rf (261)	105 Db (262)	106 Sg (266)	107 Bh (264)	108 Hs (277)	109 Mt (268)	110 Ds (281)	111 Rg (272)	112 Cn (285)	113 Uut (284)	114 Fl (289)	115 Uup (288)	116 Lv (293)	117 Uus (294)	118 Uuo (294)

6	58 Ce 140.116	59 Pr 140.908	60 Nd 144.24	61 Pm (145)	62 Sm 150.36	63 Eu 151.964	64 Gd 157.25	65 Tb 158.925	66 Dy 162.500	67 Ho 164.930	68 Er 167.259	69 Tm 168.934	70 Yb 173.04	71 Lu 174.967
7	90 Th 232.038	91 Pa 231.036	92 U 238.029	93 Np (237)	94 Pu (244)	95 Am (243)	96 Cm (247)	97 Bk (247)	98 Cf (251)	99 Es (252)	100 Fm (257)	101 Md (258)	102 No (259)	103 Lr (262)

rev. March 2013

Acknowledgment

Many thanks to friends and colleagues who contributed to this work. It is difficult to identify every contribution from every single member of the Grossmont Chemistry department, both past and present, but surely their input is part of this endeavor. For their expertise, kindness, and support, I am exceedingly grateful and fortunate to count them like kin.

I also want to thank my employer, the Grossmont Cuyamaca Community College District, for supporting me during my sabbatical leave and allowing me the opportunity to make this book a reality.

I dedicate this book to all students who turn these pages and to my Master.

Thomas Olmstead
2011

Prepared for printing on December 6, 2016

17-0003-328

Contents

POGIL ACTIVITY 1

All Numbers Big and Small: Power of Ten and Scientific Notation

A. The Power of Ten

Measurements vary over a wide range of magnitude, from very large to vanishingly small values. Numbers written in familiar decimal notation that contain a lot of zeros before or after the decimal point can be simplified by using a **power of ten**. Powers of ten are **exponential numbers** that result when 10 is multiplied by itself a number of times. The powers of ten can be abbreviated with a **prefix**. (Table 1.1).

TABLE 1.1 The Power of Ten and Exponential Notation

Prefix		Decimal number	Power of Ten	name
Tera	T	1,000,000,000,000	10^{12}	Trillion
Giga	G	1,000,000,000	10^{9}	Billion
Mega	M	1,000,000	10^{6}	Million
kilo	k	1,000 (1 x 10 x 10 x 10 = 10^{3})	10^{3}	Thousand
		1	10^{0}	One
centi	c	0.01 (1 x 1/10 x 1/10 = 10^{-2}	10^{-2}	Hundredth
milli	m	0.001	10^{-3}	Thousandth
micro	μ	0.000 001	10^{-6}	Millionth
nano	n	0.000 000 001	10^{-9}	Billionth
	Å	0.000 000 000 1	10^{-10}	Angstrom

Name _____

Critical Thinking Questions

CTQ:1.

Two units have non-English symbols. Write the symbol for these units.

CTQ:2.

Explain why the correct use of capital letters and lower-case letters must be observed for prefixes; provide a specific example to support your answer.

CTQ: 3.

Complete the table by placing an "x" in the correct box.

	decimal number greater than 10	decimal number less than one
pos. exponent		
neg. exponent		

CTQ: 4.

What is the decimal number that is equal to (1×10^0) ? _____

CTQ: 5.

(1 x 10 x 10 x 10 x 10 = 10^x) What is the value of the exponent? x = _____

CTQ: 6.

Match decimal numbers with powers of ten by placing an "x" in the correct box.

	10^{-6}	10^{-3}	10^{-2}	10^{-1}	10^0	10^1	10^2	10^3	10^4	10^5	10^6
1000 =											
0.1 =											
10,000 =											
0.001 =											
100,000 =											
0.000 001 =											
0.01 =											
10 =											
1 =											

B. Scientific Notation

A standard expression for writing numbers is **scientific notation**, an example of exponential notation. Any decimal number can be written in scientific notation using this form $a \cdot 10^x$ where a is called the **coefficient** and x is called the **exponent.** *By convention*, the coefficient is restricted to values of: $1 \leq a < 10$ (Table 1.2).

TABLE 1.2 Scientific Notation

Numbers ten or greater		Numbers less than one	
Decimal	Exponential	Decimal	Exponential
10	1×10^1	0.1	1×10^{-1}
127	1.27×10^2	0.045	4.5×10^{-2}
1000	1×10^3	0.001	1×10^{-3}
1500	1.5×10^3	0.002 57	2.57×10^{-3}
1,000,000	1×10^6	0.000 001	1×10^{-6}
999,000,000	9.99×10^8	0.000 000 087	8.7×10^{-8}
1,000,000,000	1×10^9	0.000 000 001 68	1.68×10^{-9}

Critical Thinking Questions

CTQ: 7.

In scientific notation, the value of any exponent (x) can be:

a. positive
b. negative
c. zero
d. all of the above

CTQ: 8.

For any number written in scientific notation, how is the sign of the exponent related to the size of that number?

a. a positive exponent indicates a number less than one
b. a positive exponent indicates a number greater than ten
c. a negative exponent indicates a number less than one
d. a negative exponent indicates a number greater than one
e. (b) and (c) are both correct
f. (a) and (d) are both correct

CTQ: 9.

The value of the coefficient must be:

a. less than zero
b. less than or equal to one, but greater than zero
c. greater than one
d. less than ten
e. greater than or equal to one, but less than ten

CTQ: 10.

To convert one-thousand (1000) into scientific notation, the decimal point is moved ___ to derive the coefficient …

a. one place to the right	b. one place to the left
c. two places to the right	d. two places to the left
e. three places to the right	f. three places to the left

… and the exponent (x) = (-4) (-3) (-2) (-1) (0) (1) (2) (3) (4)

CTQ: 11.

To convert one-thousandth (0.001) into scientific notation, the decimal point is moved ___ to derive the coefficient …

a. one place to the right	b. one place to the left
c. two places to the right	d. two places to the left
e. three places to the right	f. three places to the left

… and the exponent (x) = (-4) (-3) (-2) (-1) (0) (1) (2) (3) (4)

CTQ: 12.

To convert (1×10^{-2}) into a decimal number, the decimal point is moved _____ .

a. one place to the right	b. one place to the left
c. two places to the right	d. two places to the left
e. three places to the right	f. three places to the left

CTQ: 13.

Formulate a rule that describes how the value of the exponent relates to the movement of the decimal point when converting between decimal numbers and scientific notation.

Exercises

1. Convert the following decimal numbers into scientific notation.

a. 10,005	
b. 10,405	
c. 0.994	
d. 1776	
e. 78.9	
f. 0.5001	
g. 0.0068	
h. 93 million	
i. 5.2 billionths	
j. 7 tenths	

2. Convert the following exponential numbers into decimal numbers.

a. 4.4×10^{-2}	
b. 8.977×10^{4}	
c. 4.05×10^{-6}	
d. 3.01×10^{8}	
e. 2.31×10^{2}	
f. 7.00006×10^{-3}	
g. 1.975×10^{-1}	
h. 2.46×10^{1}	
i. 2.54×10^{-10}	
j. 6.02×10^{23}	

POGIL ACTIVITY 2

Units of Measurement and Dimensional Analysis

A. Units of Measurement- The SI System and Metric System

There are myriad units for measurement. For example, length is reported in miles or kilometers; mass is measured in pounds or kilograms and volume can be given in gallons or liters. To avoid confusion, scientists have adopted an international system of units commonly known as the **SI System**. Standard units are called **base units**.

TABLE 2.1 SI System *(Systéme Internationale d'Unités)*

Measurement	Base Unit	Symbol
mass	gram	g
length	meter	m
volume	liter	L
temperature	Kelvin	K
time	second	s
energy	joule	j
pressure	atmosphere	atm

The **metric system** combines the powers of ten and the base units from the SI System. Powers of ten are used to derive larger and smaller units, multiples of the base unit. Multiples of the base units are defined by a **prefix**. When metric units are

attached to a number, the **letter symbol** is used to abbreviate the prefix and the unit. For example,

2.2 kilograms would be reported as 2.2 **kg**. Plural units, i.e., (kgs) are incorrect.

TABLE 2.2 Common Metric Units

Power Of Ten	Decimal equivalent	Prefix (symbol)	Name of metric unit (and symbol)		
			length	volume	mass
10^3	1000	kilo (k)	kilometer (km)	**B**	kilogram (kg)
10^0	1	Base Unit	meter (m)	Liter (L)	gram (g)
10^{-1}	0.1	deci (d)	**A**	deciliter (dL)	**D**
10^{-2}	0.01	centi (c)	centimeter (cm)	**C**	**E**
10^{-3}	0.001	milli (m)	millimeter (mm)	milliliter (mL)	milligram (mg)
10^{-6}	0.000 001	micro (μ)	micrometer (μm)	microliter (μL)	microgram (μg)

Critical Thinking Questions

CTQ:1.

Consult Table 2.2 . The labels, **a, b, c, d** and **e** represent units that are not frequently encountered. Write the name and the (symbol) for each of these.

a. ( )	**b.** ( )
c. ( )	**d.** ( )
e. ( )	

CTQ:2.

Identify by name the metric unit and the prefix that use the same abbreviation.

CTQ:3.

Identify by name the two SI units that do not use a lower-case abbreviation.

CTQ:4.

Match each prefix (symbol) with its corresponding power of ten by placing an X in the appropriate box.

	10^{-6}	10^{-3}	10^{-2}	10^{-1}	10^{1}	10^{2}	10^{3}	10^{6}
d =								
m =								
k =								
μ =								
c =								

Mathematical Equivalency- A Useful Table of Metric Units

There exists a mathematical equivalency between the multiples of each base unit; equivalency is based on some power of ten. For example, since a kilogram is one-thousand times bigger than a gram, we could say that **one kilogram is equal to one-thousand grams**, and the mathematical equivalency is written as:

$$1 \text{ kg} = 1000 \text{ g} = 10^3 \text{ g}$$

Or, we could say that **one gram is equal to one-thousandth of a kilogram** and write the equivalency as:

$$1 \text{ g} = 0.001 \text{ kg} = 10^{-3} \text{ kg}$$

Another unit of volume is cubic centimeter ($cm^{3.}$) In the health science professions, cubic centimeter is frequently abbreviated with (cc). Since **one cubic centimeter is equal to one milliliter**, the equivalency is:

$$1 \text{ mL} = 1 \text{ cm}^3 = 1 \text{ cc}$$

CTQ:5.

Complete the Table of Metric Equivalents below:

TABLE 2.3 Metric Equivalents

Length	Volume	Mass
1 km = m	1 L = mL	1 kg = g
1 m = cm	1 L = dL	1 g = mg
1 m = mm	1 mL = μL	1 mg = μg
1 mm = μm	1 mL = cm^3 = cc	

CTQ:6.

The Table of Metric Equivalents does not include an equivalency between kilometers (km) and centimeters (cm). How do we convert (km) into (cm)? Your answer must be in the form of one or two grammatically correct sentences.

CTQ:7.

Explain why The Table of Metric Equivalents, as completed, is sufficient to derive an equivalency between any two mass units, any two volume units or any two length units.

B. Conversion Factors

A conversion factor is a ratio (fraction) of equivalent values that have different units. The mathematical equivalency between any two units can be used to derive a conversion factor between the units. For example, this equivalency **1 kg = 1000 g**, can be expressed as two different, but equivalent quotients or fractions. Notice the fractions are reciprocals:

$$\frac{1\text{ kg}}{1000\text{ g}} \quad \text{or} \quad \frac{1000\text{ g}}{1\text{ kg}}$$

These conversion factors say, **"one kilogram is equal to one thousand grams"** or **"one thousand grams is equal to 1 kg"**. Every equality in The Table of Metric Equivalents can be expressed as reciprocal fractions; in other words, two equivalent conversion factors can be derived from any equality.

Conversion factors are not restricted to metric units. Consider this equivalency of U.S. units: **twelve inches = 1 foot**. The conversion factors are derived in the same manner:

$$\frac{1\text{ ft}}{12\text{ in}} \quad \text{or} \quad \frac{12\text{ in}}{1\text{ ft}}$$

Notice that every conversion factor contains a number and a unit in the numerator as well as a number and a unit in the denominator.

Critical Thinking Questions

CTQ:8.

Using the Table of Metric Equivalents, write two reciprocal conversion factors for each pair of units. You may use decimal numbers or a power of ten for numerical values. Be sure each quotient contains a number and a unit in both numerator and denominator.

m and km			m and μm		
m and mm			m and cm		
L and dL			L and μL		
L and mL			mL and μL		
L and cc			cm^3 and μL		
g and mg			mg and μg		
g and μg			mg and kg		

CTQ:9.

Derive reciprocal conversion factors based on the following. Be sure each quotient contains a number and a unit in both the numerator and denominator.

One inch (in) equals 2.54 cm		
One kg equals 2.2 pounds (lb)		
One liter equals 1.06 qt		
Your car burns one gallon (gal) of gas every 18 miles (mi)		
One milliliter of mercury (Hg) has a mass of 13.6 grams		
There are 12 eggs in one dozen		

C. Unit Conversions or Dimensional Analysis

A **unit conversion** is a simple algebraic calculation used to switch a quantity in one particular unit into another unit. For example, mass units can be expressed in grams or milligrams. We can switch between units by choosing the appropriate conversion factor:

$$\frac{1\text{ g}}{1000\text{ mg}} \quad \text{or} \quad \frac{1000\text{ mg}}{1\text{ g}}$$

Which conversion factor to use depends on which unit we want in our final answer, grams or milligrams. For example, to convert 325 mg into grams, we need to set up an equation so that the given unit of (mg) is **algebraically canceled** and the desired unit of (g) remains:

$$325\ \cancel{\text{mg}} \times \left(\frac{1\text{ g}}{1000\ \cancel{\text{mg}}}\right) = 0.325\text{ g}$$

Conversely, to switch grams into milligrams, we use the reciprocal conversion factor. For example, 2.59 g is equal to 2590 mg:

$$2.59\ \cancel{\text{g}} \times \left(\frac{1000\text{ mg}}{1\ \cancel{\text{g}}}\right) = 2590\text{ mg}$$

Dimensional analysis is a technical term for unit conversion, often implying that a particular unit may undergo sequential conversions. For example, to express 525 mg in units of kilograms, one approach uses a two-step process to convert milligrams to grams followed by conversion of grams into kilograms.

Step 1 (mg into g)

$$525\ \cancel{\text{mg}} \times \left(\frac{1\text{ g}}{1000\ \cancel{\text{mg}}}\right) = 0.525\text{ g}$$

Step 2 (g into kg)

$$0.525\ \cancel{\text{g}} \times \left(\frac{1\text{ kg}}{1000\ \cancel{\text{g}}}\right) = 0.000525\text{ kg}$$

A more efficient approach to dimensional analysis makes use of the rules of algebra to combine both steps into a single equation:

$$525\ \cancel{mg} \times \left(\frac{1\ \cancel{g}}{1000\ \cancel{mg}}\right)\left(\frac{1\ kg}{1000\ \cancel{g}}\right) = 0.000525\ kg$$

starting unit | conversion factor(s) | final unit

Notice the **three elements of dimensional analysis**: a starting quantity, a desired quantity and conversion factors. The starting quantity and desired quantity are stated (or implied) in the word problem. The conversion factors must be derived base on knowledge of the units of measurement. The **key** to dimensional analysis is proficiency in recognizing these three elements.

When two or more conversion factors are needed, the rules of algebra are followed: $x \cdot \frac{a}{b} \cdot \frac{c}{d} = \frac{(x \cdot a \cdot c)}{(b \cdot d)} =$

Critical Thinking Questions

CTQ:10.

What are the three elements needed to set up a calculation for dimensional analysis?

CTQ:11.

For each calculation below, draw a **square** around the starting units, draw a **circle** around the conversion factor(s) and draw a **triangle** around the final unit.

$$22.4\ L \quad \frac{1000\ mL}{1\ L} = 22400\ mL$$

$$0.78\ cm \quad \frac{1\ m}{100\ cm} = 0.0078 = 7.8 \times 10^{-3}\ m$$

$$2.5\ ft \quad \frac{12\ in}{1\ ft} \quad \frac{2.54\ cm}{1\ in} \quad \frac{10\ mm}{1\ cm} = 762 = 7.62 \times 10^{2}\ mm$$

CTQ:12.

In all unit conversions, every number **must** include _____.

CTQ:13.

Read the word problems carefully. **Do not bother to calculate answers**. Instead, for each problem, **identify the three elements**: starting quantity, the desired (final) unit and the conversion factor(s). Be sure to include proper units with the starting quantity.

Word problem	starting quantity	final unit	conversion factor(s)
Convert 100 centimeters into millimeters.			
How many dL in 15 mL?			
Calculate the mg of gold in a wedding ring that has a mass of 17.5 g			
A 5.0 L vessel containing salt water is cooled to 10°C and the solution is transferred into a holding tank. How many mL of salt water are in the tank?			
Gas mileage for a late model truck is reported as 14 miles per gallon. What is this mileage in km per liter?			
Superman is faster than a speeding bullet which travels at 2700 feet per second. How fast is this in miles per hour?			

A doctor prescribes 1 L of saline solution to be administered intravenously over a two-hour period. How many mL per second is this?			

D. More About Dimensional Analysis and Conversion Factors

There are a number of ways to solve any word problem. In the previous example:

$$525\ \cancel{mg} \times \left(\frac{1\ \cancel{g}}{1000\ \cancel{mg}}\right)\left(\frac{1\ kg}{1000\ \cancel{g}}\right) = 0.000525\ kg$$

This calculation required two conversion factors, one quotient for (mg and g) and another for (g and kg) based on the equalities (1000 mg = 1g) and (1000 g = 1 kg), respectively.

However, if one recognizes this equality (1 kg = 1,000,000 mg), then the calculation can be done in a single step with one conversion factor:

$$525\ \cancel{mg} \left(\frac{1\ kg}{10^6\ \cancel{g}}\right) = 0.00525\ kg = 5.25 \times 10^{-3}\ kg$$

Notice the use of scientific notation which eliminates all place-holder zeros.

Both approaches to the word problem are correct since both calculations render the same answer. With complex, multi-step problems, it is recommended to do all calculations in a step-wise fashion unless you know your conversion facts are correct.

CTQ:14.

Write a grammatically correct definition of a place-holder zero.

CTQ:15.

Name _____

Convert 2459 km into micrometers. For each calculation, complete each conversion factor(s) and solve the equation.

1. $2459\ \text{km} \times \frac{\text{m}}{\text{km}} \times \frac{\text{cm}}{\text{m}} \times \frac{\text{mm}}{\text{cm}} \times \frac{\mu\text{m}}{\text{mm}} =$

2. $2459\ \text{km} \times \frac{\mu\text{m}}{\text{km}} =$

3. Write each answer above in scientific notation.

Exercises

Show calculations and fill in the blank after converting answer to scientific notation.

a. 97.5 m = _____μm

b. 345 m = _____cm

c. 2.3×10^{-1} L = _____μL

d. 1.05 km = _____mm

e. 24.2 cm^3 = _____μL

f. 8.89×10^{-6} mg = _____μg

g. 7.34 mg = _____kg

h. 75 mL = _____L

i. 6.53×10^{4} mL = _____μL

j. 3.5×10^{-4} mg = _____g

k. 0.25 dL = _____cc (mL)

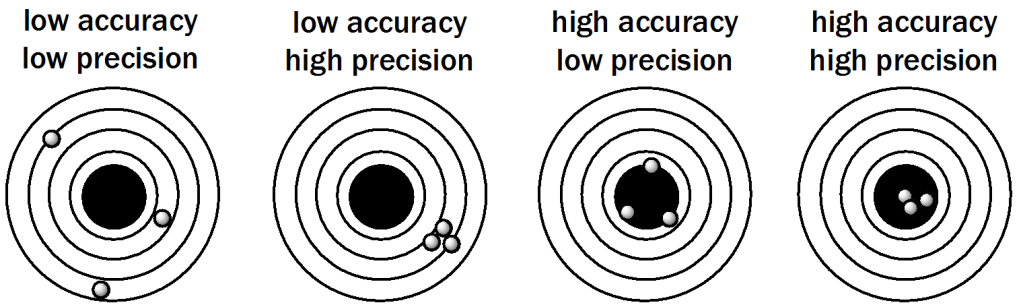
POGIL ACTIVITY 3

All Targets Near and Far: Accuracy, Precision and Significant Figures

A. Accuracy and Precision

All measurements are estimates of some true value. The validity of any measurement is primarily due to the nature of the device used to make the measurement and partly due to the manner in which data is collected.

MODEL 3.1 Accuracy and Precision



A measured value that matches the true value is a "Bull's-eye".

Critical Thinking Questions

CTQ:1.

Using **Model 2.1**, define accuracy using a grammatically correct sentence.

CTQ:2.

Define precision using a grammatically correct sentence.

CTQ:3.

High precision implies high accuracy, true or false?

CTQ:4.

High accuracy implies high precision, true or false?

According to the U.S. Mint, the mass of a U.S. quarter ($0.25) is **5.670 g**. Four students measured the same coin (Table 3.1).

TABLE 3.1 Mass of U.S. Quarter

I	II	III	IV
5.010 g	5.670 g	5.673 g	5.669 g
5.010 g	5.589 g	5.674 g	5.672 g
5.011 g	5.801 g	5.673 g	5.672 g
5.011 g	5.800 g	5.669 g	5.671 g
5.010 g	5.712 g	5.669 g	5.669 g

CTQ:5.

Which data set is the most precise? I II III IV

CTQ:6.

What information is required to determine the accuracy of any data set?

CTQ:7.

Explain how you could determine (mathematically) which set is the most accurate?

CTQ:8.

Which data set is the most accurate? I II III IV

B. Uncertainty (or Error)

Every measurement is an estimate of the actual value because every measurement contains a degree of **uncertainty** or **error**. In this context, error does not mean "mistake". Error (uncertainty) is a mathematically determined variance between individual measurements that arises when repeated measurements are made on the same sample or object. For example, four students weighed a U.S. dime ($0.10) multiple times using different types of balances (**Table 2**).

TABLE 3.2 Mass of U.S. Dime

I	II	III	IV
2.2 g	2.29 g	2.268 g	2.2681 g
2.1 g	2.26 g	2.269 g	2.2689 g
2.2 g	2.21 g	2.260 g	2.2683 g
2.3 g	2.23 g	2.267 g	2.2682 g
2.3 g	2.27 g	2.268 g	2.2680 g

The measurements in Set I contain two digits. The first digit (the one's place) is called the **reproducible digit** and the second digit in the tenth's place (0.1) is called the **doubtful digit**.

CTQ:9.

Formulate a definition for the term **reproducible digit**.

CTQ:10.

Formulate a definition for the term **doubtful digit**.

CTQ:11.

Identify the doubtful digit in each data set in Table 3.2 .

The doubtful digit is:					
data set	the one's place	one-tenth's place	hundredth's place	thousandth's place	ten-thousandth's place
I					
II					
III					
IV					

CTQ:12.

What is the uncertainty in each data set from Table 3.2 ?

Data Set	+/- 0.1 g	+/- 0.01 g	+/- 0.001 g	+/- 0.0001 g
I				
II				
III				
IV				

CTQ:13.

An increase in precision is:

a. an increase in uncertainty
b. a decrease in uncertainty

C. Significant Figures (significant digits, sig figs), Exact Numbers and Those Pesky Zeros

Significant figures are those digits in any number that designate the level of precision.

Sig figs include all reproducible digits plus the first doubtful digit.

TABLE 3.3 Mass of U.S. Nickel

I	II	III	IV
5.0 g	5.01 g	5.001 g	5.0001 g
5.0 g	5.00 g	5.002 g	5.0009g
5.0 g	5.01 g	5.002 g	5.0002 g
5.1 g	5.01 g	5.000 g	5.0006 g
5.0 g	5.02 g	5.002 g	5.0003 g

CTQ:14.

According to the definition above, indicate how many sig figs are in each measurement:

a. Set I_____
b. Set II_____
c. Set III_____
d. Set IV_____

Exact numbers contain no error (uncertainty) since these numbers are not measurements; in other words, an exact count is not an estimate. For example, the number of people in a family of four is an exact number (**Table 4**).

TABLE 3.4 Measurements versus Exact Numbers

Measurements (estimates)			Exact Numbers	
0.00024 kg	U.S. population		24 students in classroom	5 fingers each hand
2 cups of milk	volume of a 1-L water bottle		17 one-liter water bottles	1 dozen = 12
18 mph	9.3×10^6 miles		2.54 cm = 1 inch	100 cm = 1 meter

Non-zero digits are always significant but zeros may or may not be significant. In fact, zeros cause the most confusion when dealing with significant digits. Examine **Table 3.5** .

TABLE 3.5 Zeros are not always significant

1 sig fig	2 sig fig	3 sig fig	4 sig fig	5 sig fig
3 kg	2.9 kg	2.98 kg	2.982 kg	2.9824 kg
80 km	81 km	80.7 km	80.76 km	80.761 km
0.06 g	0.055 g	0.0550 g	0.05503 g	0.055039 g
200 L	2.0	20.0	200.0 L	200.00 L
3×10^8 m	3.0×10^8 m	3.00×10^8 m	3.008×10^8 m	3.0081×10^8 m

Using **Table 3.5** and the examples shown here, answer true or false:

	examples	T	F
Zeros between non-zero digits are significant	80.7 3.008×10^8		
Zeros at the beginning of a number are significant:	0.06 0.055		
Zeros in the coefficient for scientific notation are significant	3.0×10^8 1.00×10^{-3}		
Trailing zeros in numbers written with a decimal point are significant	200.0 8.750		
Trailing zeros in numbers written without a decimal point are significant	80 200		

D. Calculations Involving Sig Figs and Rounding Numbers

A calculation cannot change the level of uncertainty. There are two rules to observe, one for multiplication and one for addition:

Rule 1

When multiplying (or dividing) measurements, the answer must contain the same number of sig figs as the starting quantity with the fewest sig figs.

For example, calculate the mileage for an automobile based on the following data,

108.4 miles driven using 3.5 gallons of fuel:

$$\frac{108.4 \text{ mi}}{3.5 \text{ gal}} = 30.97142857 \text{ mpg} = 31 \text{ mpg}$$

Since the denominator has fewer sig figs than the numerator, the answer must be rounded to two sig figs.

Rule 2

When adding (or subtracting) measurements, the answer must contain the same number of decimal places as the starting quantity with the fewest decimal places.

Consider the addition of volume in this example:

7.6 mL + 125 mL = 132.6 mL = 133 mL *count decimal places, not sig figs*

In this case, one measurement (125 mL) does not have any digits past the one's place and the answer must be rounded to the nearest one milliliter.

When calculations generate trailing zeros, conversion to scientific notation clarifies the number of sig figs allowed in the answer:

730 cm + 880 cm = 1610 cm = 1.610×10^3 cm

Trailing zero is allowed since precision is to the nearest one's place.

525 g x 4 = 2100 g = 2×10^3 g

Trailing zeros are not allowed because the precision is limited to one sig fig.

Name _____

Rounding Numbers: Calculations often generate non-significant digits, especially calculations done with an electronic calculator; these values must be rounded to the correct number of sig figs. Once it is determined how many sig figs are allowed, all remaining digits to the right must be dropped. However, if the first digit to be dropped is 5 or greater, then the preceding digit is rounded up by one, then the extra digits are dropped.

In these examples, two sig figs are allowed in the answer:

2.1 x 3.5 = 7.35 = 7.4 round up the doubtful digit by one then truncate extra digit

2.1 x 3.4 = 7.14 = 7.1 do not round up, truncate extra digit

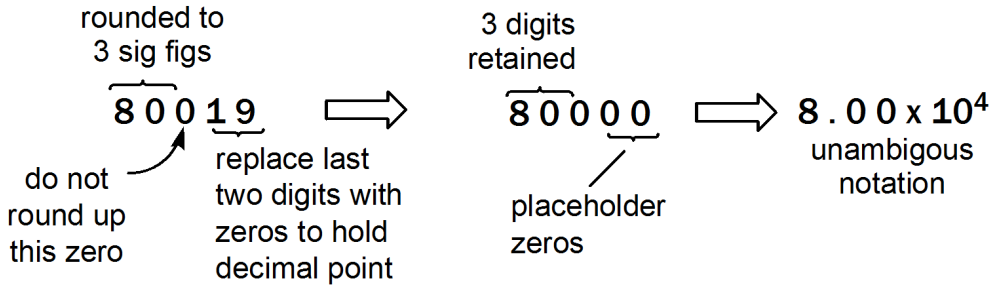
In this example, three sig figs are allowed in the answer:

252 / 1.401 = 179.8715203 = 180 = 1.80 x 10^2 round up and convert to sci. notation

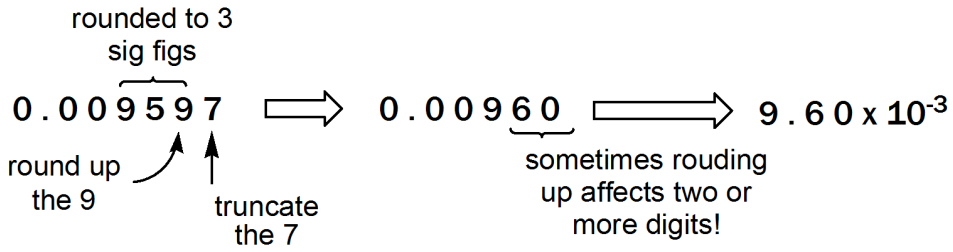
Notice the zero generated after rounding- this is the most ambiguous type of zero, a trailing zero with no decimal point. But inspection of the calculation reveals this to be a sig fig and should be included in the final answer. Conversion to scientific notation removes all doubt that this zero is significant and should be included in the final answer.

More about zeros. Frequently, rounding off numbers produces zeros which may or may not be significant. Scientific notation is the best method to remove all ambiguity and to eliminate placeholder zeros. Below are four more examples of how to deal with zeros.

1. **Zeros generated to the left of the decimal point after rounding off become placeholder zeros (to hold the decimal point) but are not significant digits.**



2. **Zeros generated to the right of the decimal point after rounding off may be significant depending on how many digits are allowed in the final answer.**



3. **Beware of Zeros that "disappear" from electronic calculators. Compare the addition problem below done by hand versus using a calculator.**

   Addition by pencil: **Addition by calculator:**

   87.72 + 2.28 = 90.00 (keep 2 decimal places)87.72 + 2.28 = 90

4. **Always include a "courtesy zero" for numbers that begin with a decimal point. Your instructor will love you for this!**

   Courtesy zeros are not significant digits.

   Examples: (0.01 not .01) (0.005 not .005) (0.100 not .100 and not.1)

Exercises With Sig Figs and Rounding

1. Assume each number is a measured value. How many sig figs are in each number?

a. 93 million	b. 300	c. 1.81×10^{-5}
d. 93,000,000	e. 300.0	f. 6.0×10^{0}
g. 9.30×10^{7}	h. 0.607	i. 0.00023
j. 93,125,479	k. 1.277	l. 23,004
m. 0.677	n. 6089	o. 873.20
p. 0.0677	q. 6.700×10^{-2}	r. 0.00500

2. Round each number to **3 sig figs**; write answers as decimal numbers and in scientific notation.

	decimal value	scientific notation
a. 30,010		
b. 30.54		
c. 609.7		
d. 5.2377		
e. 0.1278		

3. Solve each calculation and round the answer to the correct number of sig figs. Use good judgment and convert to scientific notation where appropriate- to preserve zeros that are significant or to eliminate placeholder zeros. Include units where indicated.

   a. 0.433 x 7.6889

   b. 7.22 x 19.4

   c. 989.17/23.1

   d. 9.94 + 0.05

   e. 6.94 - 0.072

   f. 134.9 - 0.05

   g. (2.21 + 0.09) x 12.75

   h. (2.43 + 0.07) x 34.5

   i. (2.5 cm x 0.65 cm)

   j. Convert 65.4 g into kg

POGIL ACTIVITY 4

Gas Laws and Temperature Scales

A. Units of Measurement for Quantity, Pressure and Temperature

1. Quantity

In scientific disciplines, the amount of substance is measured by **mass** or **moles**. To measure mass, common metric mass units are used. The other measurement for quantity is the **mole.** A mole is a collection of particles, similar to a dozen. Just as a dozen represents a number (12 items), a mole represents a number, a very large number. One mole is equal to **6.02×10^{23} particles**. For example, one mole of neon gas contains 6.02×10^{23} neon atoms; one mole of water contains 6.02×10^{23} water molecules.

Quantities are given using either unit, for example, one mole of water has a mass of 18 g. In other words, **amounts can be measured by weight or by counting the number of particles in the sample:**

18 g of water = 6 020 000 000 000 000 000 000 000 = 6.02×10^{23} molecules

The term **molar mass** embodies the relationship between mass and moles. For example, based on the example for water, the molar mass of water is 18 grams per mole (g/mol). *This activity will not explore the mole concept beyond the definitions stated above.*

2. Pressure

Pressure is defined as a force per unit area. SI units of pressure are atmospheres (atm). Other common units of pressure include: millimeters of mercury (mmHg), torr, inches of mercury (inHg) and pounds per square inch (psi).

Consider placing a 15-pound weight on the last digit of your thumb which has an area of about one square inch; you would experience a pressure of 15 psi. This is approximately the same pressure exerted by a column of air, from sea level to the top of the earth's atmosphere (one atm), under normal atmospheric conditions. More precisely, one atm is equal to 14.7 psi.

There are several units for pressure. The relationship between atm and the most common units are given here. Each mathematical relationship can be used to derive a conversion factor between the various units.

1 atm = 14.7 psi = 29.9 inHg 760 mmHg = 760 torr

3. Temperature

Temperature is a measure of the average kinetic energy of a system or sample. As sample particles collide with the bulb on a thermometer, their kinetic energy is transformed into heat which causes a column of liquid to expand. The liquid is usually mercury or alcohol, both of which expand with heat.

Critical Thinking Questions

CTQ:1.

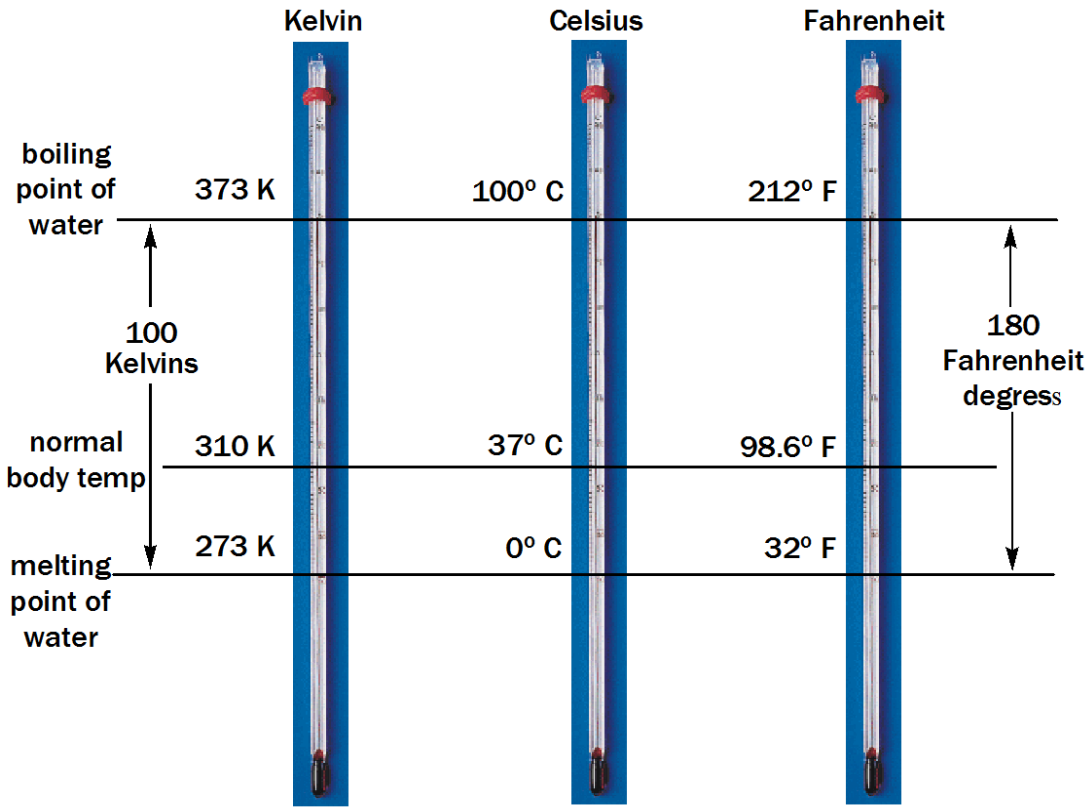
Indicate the type of equipment or device that can be used to measure the following:

a. Temperature	
b. Volume	
c. Pressure	
d. Moles	
e. Length	
f. Area	

B. Temperature Scales

Temperature is measured using three different scales: Fahrenheit, Celsius and Kelvin. Kelvin is the SI unit for temperature; Celsius is the most widely used temperature scale whereas Fahrenheit is mainly restricted to the U.S. and Britain.

FIGURE 4.1 1. Three Temperature Scales



CTQ:2.

Which temp scale does not use the degree sign (°)?

CTQ:3.

For each scale, how many degrees are there between m.p. and b.p. for water?

Celsius = _____ degrees

Fahrenheit = _____ degrees

Kelvin = _____ kelvins

CTQ:4.

How is the size of a single Kelvin related to the size of a single degree Celsius; is it larger, smaller, or the same? Answer using a grammatically complete sentence.

CTQ:5.

Derive an equation for converting from Kelvin to Celsius.

°C= _____

Information

There are 3 female students in room A and 7 male students in room B. The gender ratio is:

$$\frac{3\ F}{7\ M} \quad \text{or} \quad \frac{7\ M}{3\ F}$$

CTQ:6.

How is the size of a single degree Celsius related to the size of a single degree Fahrenheit; is it larger, smaller, or the same? Answer using a complete sentence.

CTQ:7.

Derive reciprocal ratios for the relationship between degrees Celsius and degrees Fahrenheit (This fraction can be used as a conversion factor.)

Information

To convert temperatures between Celsius and Fahrenheit, both temperatures must be at the same reference point; for example, the freezing point of water in Fahrenheit and Celsius is 32°C and 0°C, respectively.

To convert from °C to °F, first use the conversion factor, then add 32.
To convert from °F to °C, first subtract 32 from °F then use the conversion factor.

CTQ:8.

Derive an equation for converting from °C to °F

CTQ:9.

Derive an equation for converting from °F to °C

CTQ:10.

Convert the following:

a. Convert 23.5°C to °F

b. Normal body temperature is 98.6°F. Convert to °C

c. Convert -19.5 °F to °C

d. Convert -40°C to °F

C. Gas Laws

Any gas can be characterized by some combination of pressure **(P)**, volume **(V)**, temperature **(T)** and the amount of gas expressed in moles **(n)**. Moles can be readily calculated if the mass of a sample is known.

In the following discussion, a sample of gas refers to a fixed quantity of gas and if no gas is added or removed from the sample, then mathematically speaking, (n) is a constant (unchanged).

A mathematical constant, represented by a variable, is number whose value does not change; it is a constant value.

A constant may refer to any one of the characteristics of a gas (P, V, T, n) whose value remains unchanged. Or a constant may refer to a number that does not have a meaningful interpretation (such as k) and simply serves to facilitate rearranging a mathematical expression into a more useful form.

If the amount (n) of a sample of gas does not change, then a gas is described by only three variables, P,V and T.

Two empirical gas laws describe the change in volume when pressure is changed (**Boyle's Law)** or when temperature is changed (**Charles' Law**). **The Combined Gas Law** collects all three variables into one equation.

1. Boyle's Law

Boyle's Law states that volume (V) is inversely proportional to pressure (P) as long as T and n do not change. This inverse relationship is expressed as:

$V \sim 1/P$ (when n, T constant)

A mathematical constant is used to rearrange the two variables into an equality known as Boyle's Law:

$PV = k$ (n, T constant) Boyle's Law

If either variable is changed, the new PV value is still equal to the same constant (k); thus, we can set initial conditions (subscript 1) equal to final conditions (subscript 2):

$P_1V_1 = P_2V_2$ (n, T constant) another form of Boyle's Law

CTQ:11.

Consider this form of Boyle's Law, PV = k (n, T constant). Since k is a constant,

a. What is the change in volume if pressure is doubled?
V is unchangedV is doubledV decreases by one-half

b. What is the change in P if V is doubled?
P is unchangedP is doubledP decreases by one-half

CTQ:12.

Consider this form of Boyle's Law, $P_1V_1 = P_2V_2$ (n, T constant).

What is the change in P_2 if V_1 is doubled?

P_2 is unchangedP_2 is doubledP_2 decreases by half

CTQ:13.

What happens to k when:

a. P is increased and V is decreased? k increasesk decreasesk is unchanged

b. P is increased and V is increased? k increasesk decreasesk is unchanged

c. P is decreased and V is decreased? k increasesk decreasesk is unchanged

2. Charles' Law

Charles' Law states that volume (V) is directly proportional to temperature (T) as long as (n) and (P) do not change. This direct relationship is expressed as:

V ~ T (n, P constant)

A mathematical constant is used to rearrange the two variables into an equality known as Charles' Law:

V/T = k (n, P constant) Charles' Law

If either variable is changed, the new quotient is still equal to the same constant (k); thus, we can set initial conditions (subscript 1) equal to final conditions (subscript 2):

$$\frac{V_1}{T_1} = \frac{V_2}{T_2} \quad \text{(n, P constant)} \quad \text{Charles' Law}$$

CTQ:14.

Consider this form of Charles' Law, V/T = k (n, P constant). Since k is a constant,

a. What is the change in volume if temperature is doubled?
V is unchangedV is doubled V decreases by one-half

b. What is the change in T if V is doubled?
T is unchangedT is doubledT decreases by one-half

CTQ:15.

Consider this form of Charles' Law, $V_1/T_1 = V_2/T_2$ (n, P constant).

a. What is the change in V_2 if T_1 is doubled?
V_2 is unchangedV_2 is doubledV_2 decreases by half

b. What is the change in T_2 if V_1 is doubled?
T_2 is unchangedT_2 is doubledT_2 decreases by half

CTQ 16

What happens to k when:

a. V is increased and T is decreased? k increasesk decreasesk is unchanged

b. V is increased and T is increased? k increasesk decreasesk is unchanged

c. V is decreased and T is decreased? k increasesk decreasesk is unchanged

3. Combined Gas Law

Since the volume of a gas depends on the pressure and temperature, Boyle's and Charles' Law can be combined into one expression called the Combined Gas Law:

$\frac{PV}{T} = k$ and $\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$ (n constant) Combined Gas Law

CTQ:16.

What happens to P_2 when:

V_1 is doubled and T_1 is doubled?

P_2 is unchangedP_2 is doubledP_2 decreases by half

D. Application of Gas Laws

Any gas is characterized by some combination of P,V, T and n. Solving word problems involving gases requires using the proper units. For a sample of gas (constant n), pressure is measured in atmospheres (atm), volume is measured in liters (L) and temperature is measured in Kelvins (K).

If other units are given in a word problem, they must first be converted into atm, liters and kelvins before using a gas law equation.

EXAMPLE 4.1 Using Boyle's Law

A helium balloon at 298 K has a volume of 2.5 L at normal atmospheric pressure (1.0 atm). What is the volume when the balloon is released and floats to an altitude where the pressure is 0.875 atm? Assume the temperature remains constant.

Solution

a. Insert given values into Boyle's Law $P_1V_1 = P_2V_2$ (n, T constant):
$P_1 = 1.0$ atm$V_1 = 2.5$ L$P_2 = 0.875$ atm$V_2 =$ unknown
(1.0 atm) (2.5 L) = (0.875 atm) V_2

b. Rearrange equation to isolate unknown variable (simple algebra):
$\frac{(1.0\text{ atm})\,(2.5\text{ L})}{(0.875\text{ atm})} = V_2$

c. Solve for unknown variable:

$\frac{(1.0\cancel{\text{atm}})\,(2.5\text{ L})}{(0.875\,\cancel{\text{atm}})} = 2.85714\ldots = 2.9\text{ L}$ [two sig figs]

EXAMPLE 4.2 Using Charles' Law

A helium balloon at 298 K has a volume of 2.5 L at normal atmospheric pressure (1.0 atm). What happens to the volume if the balloon is cooled in dry ice to a temperature of 198 K? In the absence of any more information, assume pressure remains constant.

Solution

a. Insert given values into Charles' Law $V_1/T_1 = V_2/T_2$ (n, P constant):

$V_1 = 2.5\ L$ $T_1 = 298\ K$ $V_2 = \text{unknown}$ $T_2 = 198\ K$

$2.5\ L / 298\ L = V_2 / 198\ K$

b. Rearrange equation to isolate unknown variable:

$$\frac{2.5\ L \quad 198\ K}{298\ K} = V_2$$

c. Solve for unknown variable:

$$\frac{2.5\ L \quad 198\ \cancel{K}}{298\ \cancel{K}} = 1.66107\ldots = 1.7\ L$$

EXAMPLE 4.3 Converting units for Gas Law equation

A balloon filled with nitrogen gas has a volume of 3425 mL and a temperature of 25.5°C. What is the volume if the sun warms the balloon to 38.5°C?

Solution

V & T given; must be Charles' Law

a. Convert into proper units:

$V_1 = 3425\ mL = 3.425\ L$ $V_2 = \text{unknown}$

$T_1 = 25.5°C = 298.5\ K$ $T_2 = 38.5\ °C = 311.5\ K$

b. Rearrange and solve for unknown:

$$\frac{(3.425\ L)\ (311.5\ K)}{(298.5\ K)} = V_2 = 3.574\ L$$

CTQ:17.

Rearrange Charles' Law to solve for T_2

CTQ:18.

Rearrange the Combined Gas Law to solve for:

a. $P_2 =$

b. $V_2 =$

c. $T_2 =$

Exercises

1. A sample of chlorine gas has a volume of 0.765 L and exerts a pressure of 0.760 atm. What is the volume at constant temperature if the pressure is decreased to 0.625 atm?

2. A sealed syringe contains 2.00 cc of oxygen gas at a pressure of 14.7 psi. If the plunger is depressed and the volume is reduced to 1.75 cc, what is the pressure inside the syringe?

3. A cylinder fitted with a moveable piston has a volume of 2.5 L. What happens to the piston if the temperature of the gas inside the cylinder is increased? (Think about the engine in your automobile).

4. A sample of krypton gas with a volume of 10.00 L has a temp of 303 K and exerts a pressure of 2.47 atm. What is the final volume if the temp increases to 450 K and pressure remains constant?

EXPERIMENT 1

Eggsperience with Lab Measurements

Chemistry is an experimental science based on observations. Familiarity with equipment and glassware is essential for taking measurements which are the most routine type of observation. In this lab, students will make quantitative and qualitative measurements of the physical properties of an ordinary chicken egg.

Objectives

1. Learn how to select appropriate lab equipment for measuring length, mass, volume and temperature
2. Learn how to record the proper number of significant digits from various measuring devices.
3. Learn how to measure density using a hydrometer and by calculation.
4. Learn how to compare estimated results of varying precision.
5. Determine mass percent composition

The goal is to develop a method to separate the components of a chicken egg and determine its mass percent composition.

1. Lab Equipment

Measuring Temperature

Traditional thermometers are filled with a column of mercury which expands and contracts due to temperature changes. Since many environments prohibit the use of mercury, modern thermometers are filled with an alcohol colored with red or green dyes. The column of alcohol expands and contracts in the same manner as metallic mercury. The chances of recording an incorrect temperature can be avoided if the following procedures are kept in mind:

- Avoid contact between the thermometer bulb and the walls of a container.
- Keep the bulb immersed long enough to establish thermal equilibrium between the thermometer and the sample being measured.
- Mix the sample thoroughly but **do not use the thermometer as a stir rod.**

Record temperature to the nearest 0.1°C; *this requires an estimate of the tenths place.*

Measuring Length

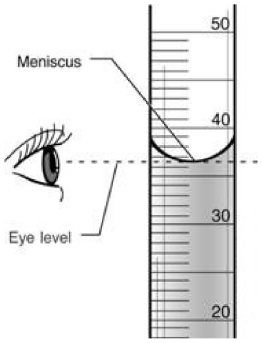
The most common units of length are meters (m), centimeters (cm) and millimeters (mm). Typical devices are ordinary meter sticks and calipers for precise measurements. If an English ruler is used, inches are converted into centimeters.

Measuring Liquid Volumes

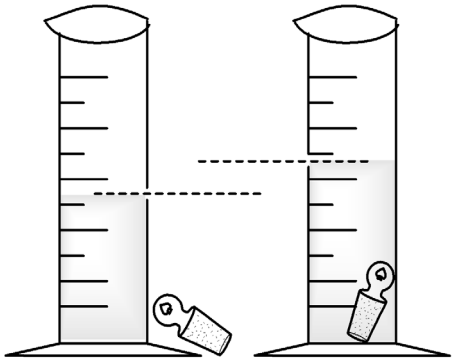
There are several types of glassware for measuring volume. The liquid level is determined by reading the bottom of the **meniscus curve** (Model 1.1). A concave meniscus is formed as a result of the liquid moving up the walls of the container. This behavior is true for most liquids including water. However, liquid mercury has a convex curve since there is essentially no attractive force between mercury and glass. For an irregular-shaped solid, the **volume can be determined by water displacement** (Model 1.2).

MODEL 1.1 MODEL 1.2

Meniscus Curve



Volume by Displacement

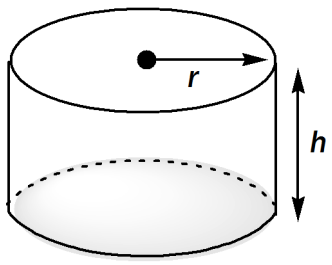


Measuring Volumes for Geometric Shapes

For geometrically-shaped solids, volume can be calculated by measuring dimensions (i.e., length x width x height) or using formulas (Model 1.3 and Model 1.4)

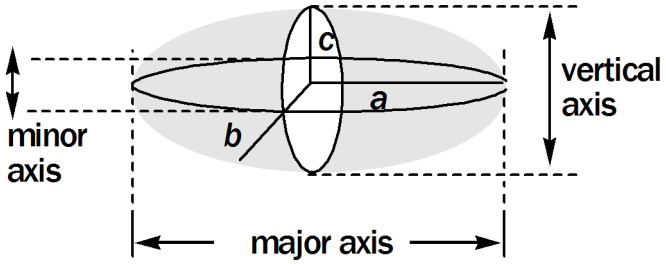
MODEL 1.3 Formula for Volume of a Cylinder

$$V = \pi r^2 h \qquad \text{(EQ 1.1)}$$



MODEL 1.4 Formula for Volume of a Regular Ellipsoid

$$V = 4/3\ \pi\ abc \qquad \text{(EQ 1.2)}$$



Measuring Mass

The unit of mass is the gram for most balances used in the laboratory. Beam balances are true balances like the scales held by Lady Liberty, the famous statue of the blindfolded Lady of Justice. The sample and counterweights are separated by a fulcrum. Triple and quad beam balances measure to the nearest centigram or milligram.

Electronic balances are also called pan balances because the sample is placed on a pan and the mass is observed on the digital display. Electronic balances measure to the nearest milligram (mg); analytical balances measure to four places past the decimal (one-tenth of a mg). Laboratory balances are not called scales- fish have scales, chemists have balances.

Your instructor will demonstrate the proper use of balances but there are a few procedures necessary to protect these delicate instruments.

- Never place any sample directly onto the pan of any balance; use weigh paper or weigh boats (small plastic tubs).
- Always use a flask, beaker or glass vial to weigh liquids.
- Close the glass doors on electronic balances when recording a mass.

There are two methods to obtain a mass:

1. Mass by subtraction

One method is to weigh and record the mass of weigh paper (or weigh boat or other container) then add the sample to the weigh paper and record the total mass. Subtracting the mass of weigh paper from the total mass gives the mass of the sample.

2. Tare mass

The other method is to place the weigh paper on the pan and "tare" the balance. Tare means to zero the balance. Then add the sample to the weigh paper and record the mass. The mass in the display represents the mass of the sample only, since the mass of the weigh paper is essentially subtracted when the balance is zeroed (tared).

2. Determining Density

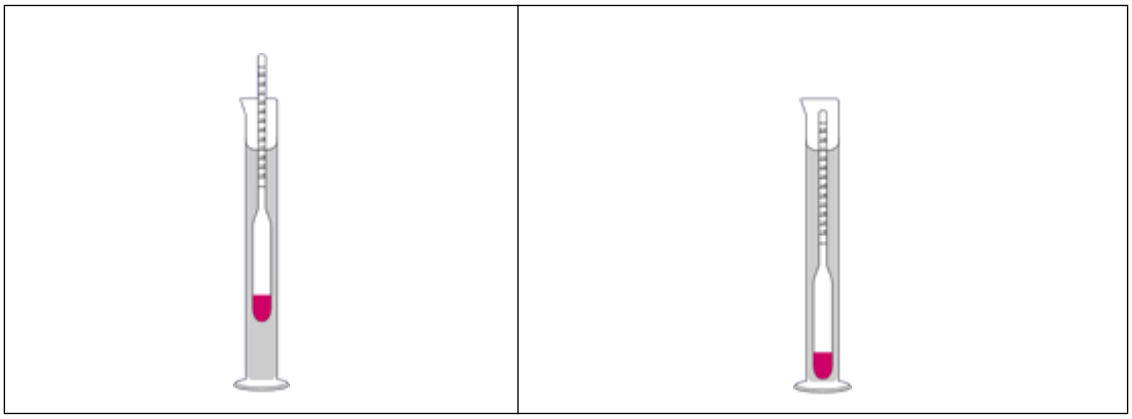
Density is defined as mass per volume (mass/volume). The most common units for density are grams per milliliter (g/mL) although units of grams per cubic centimeter (g/cm^3) are also used, especially for solids.

There are two general methods to determine density. The first method involves a simple calculation in which the mass is divided by the volume and the result is recorded using proper units. The volume for this calculation can be measured using a graduated cylinder for liquids; the volume for solids can be calculated with a formula or by water displacement. The second method uses a device called a **hydrometer.**

Density is useful in the clinical setting for determining the amount of a solid dissolved in a liquid. The more dissolved solids in a liquid, the more dense the liquid. The function of the kidneys is to filter waste products from the bloodstream. The filtered waste material is then excreted in the urine. If the kidneys are not functioning properly, the wastes are not collected and mixed into the urine and thus a urine sample will be less dense than normal.

The density of liquids such as urine is measured with an instrument called a **hydrometer** (Figure 1). The more dense the liquid, the less deep the hydrometer will drop into the liquid. (It stands higher in the denser liquid.) A hydrometer measures how dense the liquid is compared to water. Water has a density of 1, since 1 milliliter of water weighs 1 gram. Any liquid more dense than water will have a hydrometer reading greater than 1. Liquids that are less dense than water (i.e., alcohol) will have hydrometer readings less than 1.

FIGURE 1.5 Hydrometers measure density relative to water



The solution on the right is less dense than the solution on the left.

3. Determining Mass Percent Composition (mass %)

The mass percent of any component in a sample is the mass of that component divided by the total mass of the sample multiplied by 100%.

(EQ 1.3)

$$\text{mass \%} = \frac{\text{mass of component}}{\text{mass of sample}} \times 100\%$$

Notice the numerator is the mass of the smaller "part", the individual component. The denominator is the total mass of the sample Simply speaking, **mass percent is the part divided by the whole, times 100%.** The mass percent of all components should equal 100%.

For example, consider the mass percent composition of a 50 g sample of mixed nuts composed of 10 g of peanuts, 15 g of cashews and 25 g of almonds (Model 5):

MODEL 1.6 Calculating Mass Percent

Mass % peanuts	(10 g peanuts / 50 g mixed nuts) X 100% = 20%
Mass % cashews	(15 g cashews / 50 g mixed nuts) X 100% = 30%
Mass % almonds	(25 g almonds / 50 g mixed nuts) X 100% = 50%

Mass percent determination requires separation of the individual components which are then weighed. It is not necessary to measure the mass of each component: if the mass of all but one component is known, its mass can be found by subtracting the sum of all other masses from the sample weight.

To determine the mass percent of an egg in this experiment, the components must be separated and individually weighed.

PreLab Critical Thinking Questions

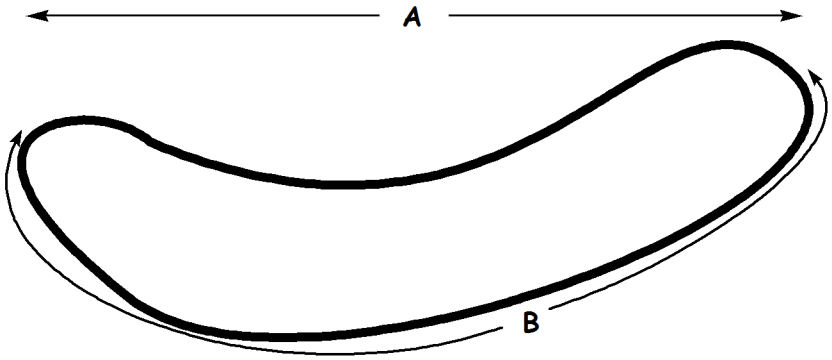
Name _____ Section _____ Date _____

CTQ:1.

What is the expected result of resting a thermometer on the bottom of a beaker used to measure the temperature of a solution being heated on a hotplate?

CTQ:2.

Using a flexible tape measure, explain which measurement, A or B, is the logical choice to determine if a zucchini will fit in your lunchbox.



CTQ:3.

For thermometer graduated to the nearest one degree Celsius, how many digits past the decimal point should be recorded in a data notebook?

CTQ:4.

For an electronic balance that measures to the nearest milligram, how many digits past the decimal would be shown on the electronic display?

CTQ:5.

A student observes the display on an analytical balance which reads 2.6070 g. Which of the following is the correct entry for the lab notebook?

a. 2.61 g	**b.** 2.6070 g
c. 3 g	**d.** 2.607 g

CTQ:6.

A lab procedure requires 2.35g of ethyl alcohol to be dispensed with a syringe. Show a calculation to determine how much volume is equal to 2.35g. The density of ethyl alcohol is 0.7893 g/mL.

CTQ:7.

a. Vitamin C, is an organic compound composed of carbon, hydrogen and oxygen. Analysis of a 10.58 g sample reveals that vitamin C is composed of 40.92% C and 4.58% H. What is the mass % of oxygen in vitamin C?

b. Using the sample mass, how many grams of C are present in the sa

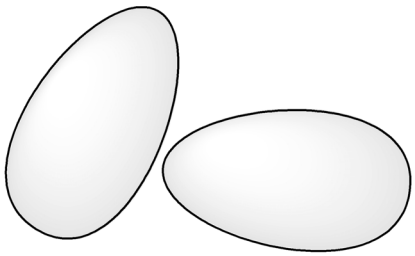
CTQ:8.

There are four components to a chicken egg; three *major* components and one *minor* component. List them.

Major components:			
Minor component:			

Experimental Procedure

Select a raw egg and inspect to be sure there are no cracks in the shell.



A. Measuring the Mass of an Egg

1. Mass
    a. **Tare Mass**

Using an electronic balance, weigh your egg to the nearest milligram and record in Table 1.1 . Do two trials and determine the average mass.

    b. **Mass by Subtraction**

Using a quad beam balance, weigh your egg and record your results in Table 1.2 . Do only one trial with beam balance.

B. Determining the Volume of an Egg

2. Make a sketch of your egg and label your measurements as length, width and height. Realize that there are only 3 dimensions for 3-D objects, regardless of whether the dimensions are labeled as (l, w, h) or labeled as variables in a geometric formula such as (a, b, c) or (r, h).

Before you begin, you must have your instructor initial your illustration.

    a. Measure the three dimensions of your egg using a caliper. Calculate the volume using your measurements. Enter the proper volume units in Table 1.3 .
    b. Using the caliper measurements from Table 1.3 , calculate the volume of your egg using the formula for the volume of a cylinder and record your result in Table 1.4 . Be sure to record which dimension from Table 1.3 , length or width, corresponds to variable r and which dimension corresponds to h in the formula.
    c. Using the caliper measurements from Table 1.3 , calculate the volume of your egg using the formula for the volume of a regular ellipsoid and

record your result in Table 1.5 . Be sure to record which dimensions from Table 1.3 correspond to variables a, b and c in the formula.

3. Measure the volume of your egg (in mL) by water displacement. Enter the proper volume units for volume in Table 1.6 .

C. Measuring Temperature

4. Measure the temperature of boiling water: use a 500 mL beaker to heat your sample on a hot plate. Measure the temperature of ice water: use a 100 ml beaker and prepare an ice/water mixture. Enter results in Table 1.7 .

D. Measuring the Density of Aqueous Solutions

5. Using the hydrometer provided, measure the density of three solutions provided. Enter your measurements in Table 1.8 .

E. Determining Mass Percent of an Egg

6. Devise a method to isolate the 4 components of an egg. Before you begin this step, weigh 4 beakers and record their mass. Designate one beaker for egg shell, one for egg yolk, one for albumin and the smallest beaker for the 4^{th} component. As you separate the components, place each constituent into its respective beaker then obtain the mass of each component. Depending on your method of separation, the *minor* component will most likely be attached to both the shell and the egg white. Isolate this minor component in the best manner possible. Enter your measurements in Table 1.9 .

Data

TABLE 1.1 Mass of Egg			TABLE 1.2 Mass of Egg	
	Electronic Balance			Beam Balance
Trial 1			Mass of weigh boat + Egg	
Trial 2			Mass of weigh boat	
Average mass from two trials			Mass of Egg	

Sketch of egg and dimension measurements

TABLE 1.3

Volume of Egg by Measuring Dimensions			
Length (l)	*width (w)*	*Height (h)*	Volume

TABLE 1.4

Volume of egg using formula for a cylinder	
r corresponds to which measurement, l, w or h?	h corresponds to which measurement, l, w or h?
r =	*h* =
Volume =	

TABLE 1.5

Volume of egg using formula for a regular ellipsoid		
a corresponds to which measurement, l, w or h?	b corresponds to which measurement, l, w or h?	c corresponds to which measurement, l, w or h?
a =	*b* =	*c* =
Volume =		

TABLE 1.6		
Volume by Displacement		
Initial Volume (mL)	Final Volume (mL)	Volume of Egg (mL)

TABLE 1.7	
Measuring Temperature °C	
Boiling water	Ice water

TABLE 1.8	
Hydrometer Measurements	
Sample	Density (g/cm^3)
NaCl (aq)	
$BaCl_2$ (aq)	
urine	

TABLE 1.9					
Mass of Egg Components					
	shell	yolk	albumin	4^{th} component	
sample + beaker (g)					
beaker (g)					Total mass
sample (g)					

Results

1. Volume

Complete the summary table for volume measurements below:

TABLE 1.10 Summary Table for the Volume of an Egg

Volume determined by:	
Measuring length x width x height (Table 1.3)	
Using the formula for a cylinder (Table 1.4)	
Using the formula for an ellipsoid (Table 1.5)	
Water displacement (Table 1.6)	

2. Density

a. Calculate the density of your egg using the mass from Table 1.1 and the volume from Table 1.3 . Show your calculations and include proper units.

b. Calculate the density of your egg using the mass from Table 1.1 and the volume from Table 1.6 . Show your calculations and include proper units.

3. Mass Percent

a. Briefly describe your method of separation of the components of an egg.

b. Calculate the mass percent of your egg using the measurements from Table 1.9 .

Mass %	
shell	
albumin	
yolk	
membrane	

Post Lab Critical Thinking Questions

CTQ:9.

Consider your results in the Volume Summary Table. Which method provides the most accurate determination of volume in your opinion? Explain your answer.

CTQ:10.

Consider your results in the Volume Summary Table. Which method provides the most precise determination of volume in your opinion? Be sure to address significant figures in your response.

CTQ:11.

Calculate the percent difference in volume from the volume determined by the cylinder formula (Table 1.4) versus volume determined by the ellipsoid equation (Table 1.5). Use this formula to calculate % difference:

$$\%\ \text{diff} = \frac{\text{difference between two measurements}}{\text{average of two measurements}} \times 100\% = \frac{|a - b|}{(a + b)/2} \times 100\% \qquad \text{(EQ 1.4)}$$

CTQ:12.

Assume the average mass of a chicken egg is 54.9 g. Based on your results, how many grams of yolk are contained in an average chicken egg? Show your calculation.

CTQ:13.

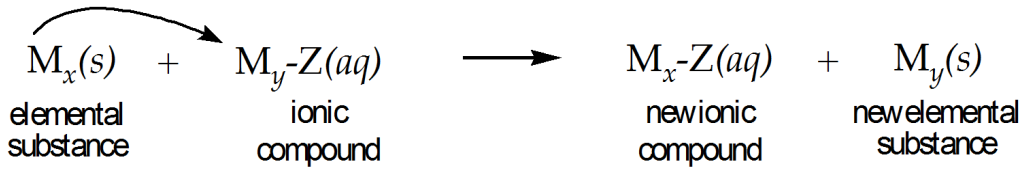
Assume that the average turkey egg contains 10% greater mass percent of yolk. How many grams of yolk are contained in a turkey egg that weighs 84.37 g?

EXPERIMENT 2

Single Displacement Reactions

A single displacement reaction occurs when one element of an ionic compound is replaced by another element. These reactions are studied by adding an elemental substance (for example, a small piece of metal) to an ionic solution. The pattern to observe for single displacement reactions is straightforward: as the metal dissolves, a new substance is formed, as a solid, liquid or gas (**Model 1**).

MODEL 2.1 General Representation of Single Displacement



There are 3 main objectives in this experiment:

1. To observe evidences for reaction

A reaction occurs when a new substance is formed. Formation of a new substance can be inferred when one of the following is observed**:**

- formation of a solid (precipitate or turbidity)
- formation of a liquid (observed as a heat exchange)
- formation of a gas (presence of bubbles)

2. To identify reduction and oxidation processes

- determine if a metal is oxidized or reduced

- assign oxidation numbers to all species involved in a redox process
- write half-reactions for the oxidation step and the reduction step
- write balanced chemical equations for single displacement reactions

3. To predict the relative reactivity of metals (including H)

The goal in this experiment is to construct an Activity Series for several elements.

Activity of Metals and Activity Series

The activity of a metal refers to its ability to become oxidized, that is, to lose one or more electrons. Experimentally, the activity of any metal is defined as its ability to displace another element from an ionic compound.

The element hydrogen is often classified as a metal since its chemical behavior is similar to other metallic elements. By observing the behavior of various metals in single displacement reactions, an activity series can be determined.

An activity series is a list of elements arranged according to their ability to displace another element in single displacement reactions.

Single displacement reactions provide a classical approach for studying chemical reactions, learning how to identify evidence for a reaction and becoming familiar with the phase changes that accompany some of these chemical changes. These reactions also afford a convenient mode to elucidate the features of oxidation and reduction.

Reduction and Oxidation (Redox)

There are many empirical definitions for reduction and oxidation but the formal definition can be condensed into a simple mnemonic device:

LEO (the lion) says GER

Loss of Electrons is Oxidation Gain of Electrons is Reduction

Any oxidation reaction must be accompanied by a reduction reaction. Because reduction and oxidation must occur simultaneously, the collective term **redox** is used to describe these two processes. A little reflection makes this apparent- if a species loses electrons, then another species must gain those electrons.

Oxidation State and Oxidation Number

The oxidation number refers to the number of electrons lost or gained by an atom. Since all atoms are electrically neutral, *all atoms and diatomic elements have an oxidation number of zero* **(zero oxidation state).** Oxidation state and oxidation number are interchangeable terms, for the most part. Likewise, for monatomic ions, the oxidation number corresponds to ionic charge **(Model 2).**

MODEL 2.2 Oxidation State and Ionic Charg

Oxidation Number (Oxidation State)					
+1	**+2**	**+3**	**0**	**-2**	**-1**
H^{+}	Mg^{+2}	Fe^{+3}	Cu*(s)*	O^{-2}	F^{-1}
Li^{+}	Ca^{+2}		Ni^{0}	S^{-2}	Cl^{-1}
Ag^{+}	Ti^{+2}		Sn		

Single Displacement Reactions- Redox Reactions

The activity of the elements varies greatly. Some elements like sodium and potassium are so reactive that they are not found in the free or uncombined state; in other words, these elements do not exist in nature as pure metals but only as cations combined in ionic compounds. Other elements like xenon and platinum are essentially inert (unreactive) and do not combine with other elements except when forced to react under laboratory conditions.

Consider the activity of two elements when a strip of metallic copper is immersed in a solution of mercury(II) chloride.

$$Cu\ (s) + HgCl_2\ (aq) \rightarrow Hg\ (l) + CuCl_2\ (aq) \qquad \textbf{(EQ 2.1)}$$

Within a few moments, evidence for reaction is observed as tiny droplets of silver/black liquid appear at the bottom of the solution; this is elemental mercury forming in the reaction as written in equation 1. **Since copper is displacing mercury from the ionic compound, we say that copper is more active than mercury.**

Now consider the reverse reaction in which a few drops of mercury metal are added to a solution of copper(II) chloride.

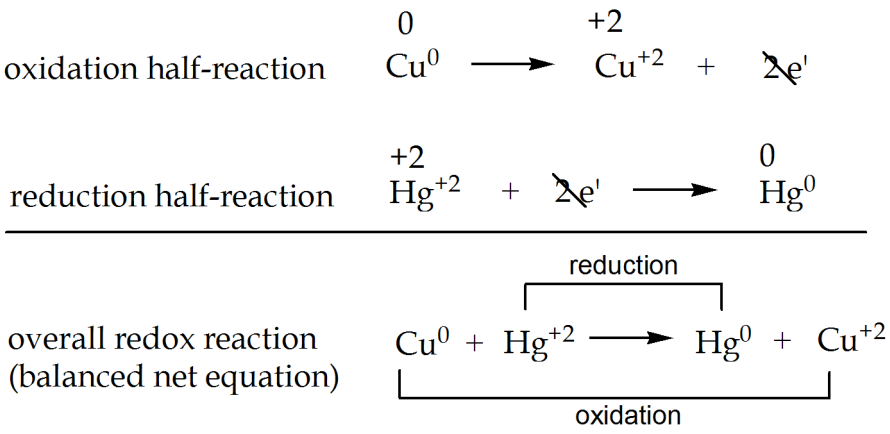
$$Hg\ (l) + CuCl_2\ (aq) \rightarrow \text{No reacton} \qquad \textbf{(EQ 2.2)}$$

No change is observed even after the solution has been standing for a prolonged period of time, and we conclude that there is no reaction. In this case, since mercury **does not** displace copper, we conclude that mercury is not more active than copper; or we can affirm once again, that **copper is more active than mercury.** *This is an important point- we can evaluate the activity of two elements regardless of whether or not a reaction occurs.*

Half-Reactions

A practical approach to understanding redox is to separate the reduction step from the oxidation step by writing half-reactions **(Model 2.3)**.

MODEL 2.3 Half-Reactions and Overall Redox For Equation 1



The oxidation numbers are written above each species in the half-reactions. Since the electrons appear as a product in the oxidation step and as a reactant in the reduction step, they "cancel out" in the balanced net equation. Of course the electrons do not simply disappear. Fundamentally, at the microscopic level, the electrons are transferred from copper atoms to mercury ions. This illustrates the principle that oxidation only occurs in synchronicity with reduction. Finally, notice that the **spectator ion**, chloride ion, is absent from the net equation.

One final point about redox terminology- in the example above, copper gets oxidized and is called the reducing agent. Mercury gets reduced and is called the oxidizing agent. This may seem confusing at first but, logic declares that the reducing agent is the species that loses electrons (donates electrons) and therefore increases its oxidation number. The oxidizing agent is the species that accepts electrons and decreases its oxidation number. To summarize**: the species that gets oxidized is**

called the reducing agent and the species that gets reduced is called the oxidizing agent.

Constructing an Activity Series for Metals (including H)

In single displacement reactions involving redox between metals, one metal displaces another metal from an ionic compound. Also, a metal may displace hydrogen from aqueous acids and from water. Note that when hydrogen is part of an acid or water its oxidation state is +1 and the pattern is the same as other metal cations in displacement reactions. Listed below are 4 reactions **(Model 2.4)** and the Activity Series generated from these observations **(Model 5)**.

MODEL 2.4 Laboratory Experiments

	Observations
Equation 1 $Cu(s) + HgCl_2(aq) \rightarrow Hg(l) + CuCl_2(aq)$	~~no reaction~~ liquid drops
Equation 2 $2\,Al(s) + 3\,Pb(NO_3)_2(aq) \rightarrow 2\,Al(NO_3)_3(aq) + 3\,Pb(s)$	black solid
Equation 3 $Cu(s) + 2\,HNO_3(aq) \rightarrow$	no reaction
Equation 4 $Pb(s) + 2\,HNO_3(aq) \rightarrow H_2(g) + Pb(NO_3)_2(aq)$	evolution of bubbles

MODEL 2.5 Results Table- Activity Series

Rxn	More active	Less active	explanation
1	Cu	Hg	copper oxidizes and displaces Hg
2	Al	Pb	aluminum displaces Pb
3	H	Cu	copper does not displace H
4	Pb	H	lead forms ion & H ion forms H2
Activity Series:	Al > Pb > H > Cu > Hg		

Study the reactions until you can identify the oxidizing agent, the reducing agent and the spectator ion. And pay close attention to the coefficients. Since the redox

partners are all metals (and H), the element produced as the cation (oxidized species) is the more active element. Also study the results until you understand how the activity series was produced based on the experiments.

PreLab Critical Thinking Questions

CTQ:1.

Choose oxidation, reduction or neither for the following scenarios:

a. An atom accepts (gains) one or more electrons:	oxid.	red.	neither
b. A cation donates (loses) one or more electrons:	oxid.	red.	neither
c. A cation accepts (gains) one or more electrons:	oxid.	red.	neither
d. An anion accepts one or more electrons:	oxid.	red.	neither
e. An anion donates (loses) one or more electrons:	oxid.	red.	neither

CTQ:2.

Using Model 2 as a guide, give the oxidation number for the following:

	Oxid. No.		Oxid. No.		Oxid. No.
a. N^{-3}		**b.** Se^{-2}		**c.** $Zn(s)$	
d. Ti^{+4}		**e.** I^{-1}		**f.** $Cl_2(g)$	

CTQ:3.

a. If a nickel atom donates 3 electrons, what is the oxidation number of the resulting ion? _____

b. Write the formula for this ion. _____

CTQ:4.

Circle <u>all</u> correct answers below. The spectator ion from **Equation 1**:

a. … is the species that undergoes oxidation

b. … is the species that gets reduced

c. … is the species that does not get oxidized or reduced

d. … is the mercury ion

e. … is the chloride ion

f. … is the copper ion

g. … does not undergo redox and is present only to balance charges

CTQ:5.

In a redox reaction, explain why the species that gets oxidized is called the reducing agent.

CTQ:6.

Write the formula for the spectator ion in these reactions:

a. Equation 4 spectator ion _____

$$2\ Al(s) + 3\ Pb(NO_3)_2(aq) \longrightarrow 2\ Al(NO_3)_3(aq) + 3\ Pb(s) \quad \textbf{(EQ 2.3)}$$

b. Equation 6 spectator ion _____

$$Cd\ (s) + CuBr_2\ (aq) \longrightarrow Cu(s) + CdBr_2(aq) \quad \textbf{(EQ 2.4)}$$

CTQ:7.

Write the oxidation half-reaction for the ionization of Zn atom to Zn^{+2} ion.

CTQ:8.

If cadmium displaces copper according to this reaction:

$$Cd\ (s) + CuBr_2\ (aq) \longrightarrow Cu(s) + CdBr_2(aq)$$ **Equation 6**

Where would you place cadmium in the activity series from Model 2.5?

a. Between Cu and Hg
b. Above Al (more active than Al)
c. Below Pb (less active than Pb)
d. Below Hg
e. Between H and Cu
f. Above Cu although its exact position relative to H is unknown based on only one experiment

Experimental Procedure

With a few of these reactions, the evidence for reaction is not immediately apparent. Before making a conclusion, be sure to observe the reaction mixture for approximately 10 minutes.

1. Obtain 3 pieces of zinc, 2 pieces of copper, and 1 piece of lead.
2. Clean the metal pieces with sandpaper to expose a fresh surface.
3. Place 6 test tubes in a rack, label tubes appropriately and mix the following reactants:

Tube 1: Copper strip and approximately 4 mL silver nitrate

Tube 2: Lead strip and about 4 mL copper(II) nitrate

Tube 3: Zinc strip and about 4 mL lead(II) nitrate

Tube 4: Zinc strip and about 4 mL magnesium sulfate

Tube 5: Copper strip and about 4 mL dilute (3*M*) sulfuric acid

Tube 6: Zinc strip and about 4 mL dilute (3*M*) sulfuric acid

4. Observe the contents of each of the test tubes for evidence of reaction.

For best results, try to use the same amount of solution in each test tube. The 4 mL of reagent solutions do not have to be measured precisely; you can estimate the volume of approximately 4 mL based on what you learned about measurements in a previous lab. Do your best to conserve reagents.

Results

A. For each test tube trial, record any evidence for reaction.

#	Observations
1	
2	
3	
4	
5	
6	

B. For each trial, write the reactants followed by the reaction arrow as shown for test tube #1. If no reaction occurs, write N.R. after the arrow; otherwise, complete the balanced chemical equation.

#	Balanced equation
1	$Cu + AgNO_3 \rightarrow$
2	
3	
4	
5	
6	

C. Complete the following table by writing the symbols of the two elements whose reactivity is being compared in each test.

trial #	1	2	3	4	5	6
Greater activity						
Lesser activity						

Post Lab Critical Thinking Questions

CTQ:9.

Arrange Pb, Mg, and Zn in order of their reactivity, listing the most active first. Explain how you determined this order.

CTQ:10.

Arrange Cu, Ag, and Zn in order of their activities, listing the most active first. Explain how you determined this order.

CTQ:11.

Arrange Mg, H, and Ag in order of their activities, listing the most active first. Explain how you determined this order.

CTQ:12.

Arrange all five of the metals (excluding hydrogen) in an activity series, listing the most active first. Explain how you determined this order.

CTQ:13.

On the basis of the reactions observed in the six tubes, explain why the position of the hydrogen cannot be fixed exactly with respect to the five metals listed in your activity series.

CTQ:14.

What addition tests would have to be done to establish the position of hydrogen in the activity series of the five metals?

CTQ:15.

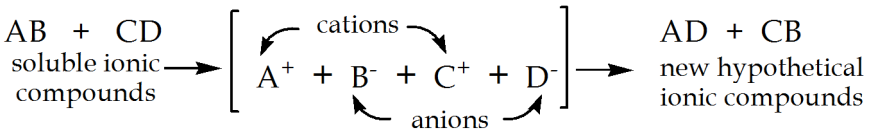
On the basis of the evidence developed in this experiment, would silver react with dilute sulfuric acid? Why or why not?

EXPERIMENT 3

Double Displacement Reactions

Double displacement reactions can be studied by simply mixing two aqueous solutions, both which contain an ionic compound (electrolyte). The pattern for all double displacement reactions is straightforward: the **cations and anions of two ionic compounds change partners** to produce two new "possible" products, as illustrated in the *"hypothetical"* reaction:

MODEL 3.1 General Representation of Single Displacement



The pattern for double displacement is an exchange of cations and anions

Why use the terms, "hypothetical" reaction, "possible" products? A chemical reaction is a process that produces a new substance, but simply mixing two ionic compounds does not guarantee that a new substance is actually formed. We must determine whether or not a "hypothetical" reaction produces a new solid, liquid or gas.

There are 3 main objectives in this experiment:

1. To observe evidences for reaction

A reaction occurs when a new substance is formed. Formation of a new substance can be inferred when one of the following is observed**:**

- formation of a solid (precipitate or turbidity)
- formation of a liquid (observed as a heat exchange)
- formation of a gas (presence of bubbles)

2. To learn how to write equations for a double displacement reaction

The method for writing chemical equations is developed in the following examples which illustrate:

- The balanced chemical equation
- The total ionic equation
- The net ionic equation

3. To learn solubility rules and assign phase labels for all reaction species

Solubility rules are used to select appropriate phase labels for all reactants and products (all species) in a reaction mixture. The phase label identifies the physical state of each species:

- Solid *(s)*
- Liquid *(l)*
- Gas *(g)*
- Aqueous *(aq)*

The goal in this experiment is to determine if a reaction occurs when various aqueous electrolytic solutions are mixed.

Any ionic compound that carries the (aq) phase label will dissociate into ions in water if it is a strong electrolyte. Strong electrolytes include all soluble ionic compounds, all strong acids and all strong bases. Consider the result of mixing aqueous solutions of sodium chloride and potassium nitrate as shown in example 3.1.

EXAMPLE 3.1 Sodium chloride plus potassium nitrate ($NaCl + KNO_3$)

By switching partners, the hypothetical products can be predicted from the **balanced chemical equation**:

$$NaCl\ (aq) + KNO_3\ (aq) \rightarrow KCl\ (aq) + NaNO_3\ (aq) \quad \text{(EQ 3.1)}$$

But notice the phase labels; both reactants and products are strong electrolytes. Strong electrolytes always dissociate into their respective ions. In other words, the reactants and products produce the same mixture of four ions. These ions are clearly illustrated by writing the **total ionic equation:**

$$Na^+(aq) + Cl^-(aq) + K^+(aq) + NO_3^-(aq) \rightarrow K^+(aq) + Cl^-(aq) + Na^+(aq) + NO_3^-(aq) \quad \textbf{(EQ 3.2)}$$

To reiterate, in this example, all of the possible combinations of cations and anions represent soluble compounds:

Possible combinations: $NaCl\ (aq)$ $KNO_3\ (aq)$ $KCl\ (aq)$ $NaNO_3\ (aq)$

And since no new substance is formed, we conclude that ***no reaction occurs***:

$$NaCl\ (aq) + KNO_3\ (aq) \rightarrow \text{No Reaction}$$

We are not chiefly concerned with "hypothetical" reactions like example 3.1.

Since formation of a new substance is the operational definition of a chemical reaction, our focus will be on double displacement patterns that actually produce a new precipitate (solid), or a small covalent molecule in the form of a gas or a liquid. Formation of these new substances is **physical evidence** that a reaction has occurred.

The following examples illustrate the objectives: observing evidences for reaction, using solubility rules to assign phase labels and writing ionic equations.

EXAMPLE 3.2 Sodium chloride plus silver nitrate ($NaCl + AgNO_3$)

The **balanced chemical equation** is written by simply switching the cations and anions. In this example, all the coefficients are one; of course, that is not always true.

Balanced Chemical Equation **(EQ 3.3)**

$$NaCl\ (aq) + AgNO_3\ (aq) \rightarrow NaNO_3\ (aq) + AgCl\ (s)$$

The **total ionic equation** is written by dissociating each strong electrolyte into their respective ions. But notice the phase label on silver chloride. This solid is written using its molecular formula. (Assigning phase labels will be discussed in the next section.)

Total Ionic Equation **(EQ 3.4)**

$$Na^+(aq) + Cl^-(aq) + Ag^+(aq) + NO_3^-(aq) \rightarrow Na^+(aq) + NO_3^-(aq) + AgCl\ (s)$$

The **net ionic equation** is the actual chemical reaction (chemical change) that occurs. The net equation includes only those species that participate in the reaction

Net Ionic Equation **(EQ 3.5)**

$$Ag^{+}\,(aq) + Cl^{-}\,(aq) \rightarrow AgCl\,(s)$$

Notice the difference between the total ionic equation and the net ionic equation. Those species present on both sides of the reaction arrow are eliminated in the net equation. These are often called **spectator ions** since they do not participate in the actual chemical change.

Net Ionic Equation

$$Na^{+}(aq) + NO_3^{-}\,(aq) + \mathbf{Ag^{+}(aq) + Cl^{-}\,(aq)} \rightarrow \mathbf{AgCl\,(s)} + Na^{+}(aq) + NO_3^{-}\,(aq)$$

spectator ions

spectator ions

Compared to example 3.1 in which no reaction takes place, this example does represent a chemical reaction since a new substance is formed as a precipitate.

EXAMPLE 3.3 Sodium sulfide plus hydrochloric acid (Na_2S + HCl)

Consider the **balanced chemical equation** between hydrochloric acid and sodium sulfide. One of the products is a gas:

(EQ 3.6)

$$Na_2S\,(aq) + 2\,HCl\,(aq) \rightarrow 2\,NaCl\,(aq) + H_2S\,(g)$$

The **ionic equation** is written by dissociating the strong electrolytes into ions:

(EQ 3.7)

$$\cancel{2\,Na^{+}}(aq) + S^{-2}\,(aq) + 2\,H^{+}(aq) + \cancel{2\,Cl^{-}}\,(aq) \rightarrow \cancel{2\,Na^{+}}(aq) + \cancel{2\,Cl^{-}}\,(aq) + H_2S\,(g)$$

Removing all spectator ion provides the **net ionic equation**:

(EQ 3.8)

$$S^{-2}\,(aq) + 2\,H^{+}(aq) \rightarrow H_2S\,(g)$$

Basic stoichiometry is required to give balanced equations and account for solution inventory.

Notice that when HCl dissociates, each ion carries the coefficient since two moles of HCl provide two moles of H^{+} ion and two moles of Cl^{-} ion. The same is true for NaCl. However, one mole of Na_2S provides two moles of Na^{+} ion but only one mole of S^{-2} ion.

EXAMPLE 3.4 **Lithium hydroxide plus sulfuric acid ($LiOH + H_2SO_4$)**

Sulfuric acid is a diprotic acid and dissociates to give 2 moles of H^+ ion. The **balanced chemical equation, ionic equation and net equation are shown:**

$$2\ LiOH\ (aq) + H_2SO_4\ (aq) \rightarrow Li_2SO_4\ (aq) + 2\ HOH\ (l) \quad \textbf{(EQ 3.9)}$$

$$\cancel{2\ Li}^+(aq) + 2\ OH^-\ (aq) + 2\ H^+(aq) + \cancel{SO}_4^{-2}\ (aq) \rightarrow \cancel{2\ Li}^+(aq) + \cancel{SO}_4^{-2}\ (aq) + 2\ HOH\ (l) \quad \textbf{(EQ 3.10)}$$

$$2\ OH^-\ (aq) + 2\ H^+(aq) \rightarrow 2\ HOH\ (l) \quad \textbf{(EQ 3.11)}$$

These last two examples may also be called acid/base reactions. **Acid/base reactions follow the same pattern for double displacement reactions:** cations and anions switch partners.

EXAMPLE 3.5 **Nitric acid plus sodium carbonate ($HNO_3 + Na_2CO_3$)**

Similar to Equation 3.6, this example is one of the few double displacement reactions that produce a gas. In this case, carbonic acid (H_2CO_3) is the product shown in Equation 3.12:

$$2\ HNO_3\ (aq) + Na_2CO_3\ (aq) \rightarrow H_2CO_3\ (aq) + 2\ NaNO_3\ (aq) \quad \textbf{(EQ 3.12)}$$

However, carbonic acid is unstable and decomposes to give CO_2 and water:

$$H_2CO_3\ (aq) \rightarrow HOH\ (l) + CO_2\ (g) \quad \textbf{(EQ 3.13)}$$

Therefore, the **balanced chemical reaction** is written to illustrate the decomposition:

$$2\ HNO_3\ aq) + Na_2CO_3\ (aq) \rightarrow HOH\ (l) + CO_2\ (g) + 2\ NaNO_3\ (aq) \quad \textbf{(EQ 3.14)}$$

EXAMPLE 3.6 Decomposition of sulfurous acid (H_2SO_3)

Another common gas is produced when sulfurous acid (H_2SO_3) is formed in water. Sulfurous acid undergoes decomposition (in a manner similar to carbonic acid) to form water and SO_2 gas:

$$H_2SO_3\ (aq) \rightarrow HOH\ (l) + SO_2\ (g) \quad \text{(EQ 3.15)}$$

Pay attention to reactions that produce carbonic acid or sulfurous acid. Remember to show the decomposition in the balanced chemical equation.

Evidence for Reaction Summary

From these examples it becomes apparent that if one of the products is a solid or a covalent liquid or gas, then a chemical reaction does occur.

Formation of liquids is accompanied by the evolution of heat which is often the only evidence for reaction. Some common covalent molecules include liquids such as water and alcohols (CH_3OH and CH_3CH_2OH).

Formation of a gas usually produces enough bubbles to make a definitive observation. Common gases include ammonia (NH_3), CO_2, SO_2, and H_2S.

Formation of solid may produce a precipitate or appear as a finely-divided suspension resulting in a cloudy, turbid dispersion.

Solubility Rules

The "missing link" at this point in our discussion of double displacement reactions is knowledge of solubility for ionic compounds. What is needed is a set of solubility rules to determine if a new combination of cation and anion produces an insoluble ionic compound. Here is an abbreviated set of **solubility rules**:

1. A compound is probably **soluble** if it contains the following cations:

- Group 1 metal ions (Li^{+1}, Na^{+1}, K^{+1}, etc.) or ammonium ions (NH_4^{+1})

2. A compound is probably **soluble** if it contains the following anions:

- Nitrates (NO_3^{-1})
- Perchlorates (ClO_4^{-1})
- Acetates (CH_3COO^{-1}) [often abbreviated as AcO^- or OAc^-]
- Sulfates (SO_4^{-2}) except when combined with these cations: Ba^{+2}, Pb^{+2}, Hg_2^{+2}

- Halide ions (F^-, Cl^-, Br^-, and I^-) except when combined with: Ag^+, Pb^{+2} and Hg_2^{+2} cations

3. A compound is probably **insoluble** if it contains the following polyatomic anions:

- Carbonates (CO_3^{-2})
- Hydroxides (HO^{-1})
- Oxides (O^{-2})
- Phosphates (PO_4^{-3})
- Sulfides (S^{-2})
- Chromates (CrO_4^{-2})

Table 3.7 illustrates how to apply the solubility rules. It should be noted that **if either the cation or the anion is soluble, then the compound is soluble.** In other words, insoluble anions can be made soluble by combining them with a soluble cation.

TABLE 3.7

insoluble		**soluble**	
$Ti(OH)_2$	*insoluble anion*	NaOH	*insoluble anion but soluble cation*
$CaCO_3$	*insoluble anion*	$(NH_4)_2CO_3$	*insoluble anion but soluble cation*
$PbSO_4$	*insoluble cation (with SO_4^{-2})*	K_2SO_4	*soluble cation soluble anion*
$Ba_3(PO_4)_2$	*insoluble anion*	$Ba(NO_3)_2$	*soluble anion*

The list of solubility rules is by no means exhaustive. There are many exceptions and "borderline" cases.

For example, $Mg(OH)_2$ is slightly soluble but based on the rules above, this would most likely be designated as insoluble. However, since $Mg(OH)_2$ is a strong base, this substance will dissolve readily when mixed with an acid to form water as shown here:

$$Mg(OH)_2\,(aq) + 2\,HCl\,(aq) \rightarrow 2\,HOH\,(l) + MgCl_2\,(aq) + \text{heat}$$

These solubility rules are not relevant for covalent compounds except for the strong acids. Students should know the appropriate phase labels for all substances

involved in double displacement reactions. Review the concepts of solvation if necessary.

The rules for assigning phase labels to strong, weak and non electrolytes in solution are essential for dealing with displacement reactions.

Vocabulary Alert

Double displacement reactions are also called double **replacement** reactions. Another general term for this type of reaction is **metathesis** (to transpose). Double displacement reactions are also named according to specific behavior such as precipitation reaction, neutralization reaction (acid/base reaction) and gas-forming reaction (a particular type of decomposition reaction). **Regardless of the name used, double displacement reactions are always identified by the pattern of switching partners.**

Experimental Procedure

Before you begin, use a graduated cylinder to measure 2 to 3 mL of DI water into a clean test tube. This will allow you to estimate your volumes throughout the experiment. It will not be necessary to use precise amounts but do be consistent with your volumes for each pair of solutions.

When writing your equations, be sure to **leave 3-5 spaces** on both sides of the addition sign that separates each chemical formula and **3-5 spaces** on both sides of the reaction arrow. Do not crowd your formulas and symbols; this will provide room for coefficients and for adding the phase labels.

There are 10 pairs of solutions in this experiment:

1	KCl and $AgNO_3$	6	$CuSO_4$ and $Zn(NO_3)_2$
2	Na_2CO_3 and $CaCl_2$	7	Na_2SO_3 and HCl
3	$CuSO_4$ and $CaCl_2$	8	$FeCl_3$ and NH_4OH
4	Na_2CO_3 and HCl	9	NH_4OH and H_2SO_4
5	NaOH and HCl	10	$BaCl_2$ and H_2SO_4

For each pair of solutions:

1. Mix equal volumes (2-3 mL) of each solution in a test tube and record your observations.
2. Write the balanced chemical equation and assign phase labels to all species.

Based on your observations, if you do not observe any evidence for reaction, then write *No Reaction* in the space provide for the ionic equation and go on to the next set of solutions.

3. Based on your observations, if you conclude that a chemical change has occurred, write the complete ionic equation including phase labels. Verify that your equation remains balanced.
4. Write the net ionic equation with phase labels. Verify that your equation is balanced.
5. List the spectator ions.

Be sure to leave spaces between formulas and symbols so that your equations are not crowded and messy.

PreLab Critical Thinking Questions

CTQ:1.

a. What observation would you record as evidence for reaction from Equation 3.16?

$$Na_2S\ (aq) + 2\ HCl\ (aq) \rightarrow 2\ NaCl\ (aq) + H_2S\ (g) \quad \textbf{(EQ 3.16)}$$

b. What observation would you record as evidence for reaction for Equation 3.17?

$$2\ LiOH\ (aq) + H_2SO_4\ (aq) \rightarrow Li_2SO_4\ (aq) + 2\ HOH\ (l) \quad \textbf{(EQ 3.17)}$$

CTQ:2.

Use solubility rules to determine the solubility of the following compounds:

compound	sol	insol	compound	sol	insol	compound	sol	insol
$MgCl_2$			Li_2SO_4			$ZnCO_3$		
KF			$CaSO_4$			$Cu(OH)_2$		
AgBr			K_2CO_3			NH_4OH		
$BaCl_2$			$Zn(NO_3)_2$			$Ni_3(PO_4)_2$		
PbI_2			$Al(NO_3)_3$			$AlPO_4$		
CaS			$Pb(NO_3)_2$			Na_3PO_4		
NaOAc			$Hg(OAc)_2$			$AgNO_3$		

CTQ:3.

The balanced chemical equation between nitric acid and sodium carbonate:

$$2\ HNO_3\ aq) + Na_2CO_3\ (aq) \rightarrow HOH\ (l) + CO_2\ (g) + 2\ NaNO_3\ (aq) \quad \textbf{(EQ 3.18)}$$

a. Write the total ionic equation including phase labels:

b. Write the net ionic equation including phase labels:

CTQ:4.

Which ions are spectator ions?

Results

1. KCl and $AgNO_3$ Observations								
Balanced Chemical Equation					2. Na_2CO_3 and $CaCl_2$ Observations			
Complete Ionic Equation			Spectator Ions		Balanced Chemical Equation			
Net Ionic Equation					Complete Ionic Equation			Spectator Ions
					Net Ionic Equation			

3. $CuSO_4$ and $CaCl_2$ Observations					4. Na_2CO_3 and HCl Observations		
Balanced Chemical Equation					Balanced Chemical Equation		
Complete Ionic Equation					Complete Ionic Equation		
Net Ionic Equation		Spectator Ions			Net Ionic Equation		Spectator Ions

5. NaOH and HCl Observations					6. $CuSO_4$ and $Zn(NO_3)_2$ Observations		
Balanced Chemical Equation					Balanced Chemical Equation		
Complete Ionic Equation					Complete Ionic Equation		
Net Ionic Equation		Spectator Ions			Net Ionic Equation		Spectator Ions

7. Na_2SO_3 and HCl Observations	
Balanced Chemical Equation	
Complete Ionic Equation	
Net Ionic Equation	Spectator Ions
8. $FeCl_3$ and NH_4OH Observations	
Balanced Chemical Equation	
Complete Ionic Equation	
Net Ionic Equation	Spectator Ions

9. NH_4OH and H_2SO_4 Observations				
Balanced Chemical Equation				
Complete Ionic Equation				
Net Ionic Equation			Spectator Ions	
10. $BaCl_2$ and H_2SO_4 Observations				
Balanced Chemical Equation				
Complete Ionic Equation				
Net Ionic Equation			Spectator Ions	

Post Lab Critical Thinking Questions

CTQ:5.

Complete and balance the equation including phase labels. Use solubility rules to determine if a reaction is probable; if so, write the formula for the expected product.

a. Balanced chemical equation: $K_2S + CuSO_4 \rightarrow$	
Does Rxn occur? Yes or no?	Formula for new product:

b. Balanced chemical equation: $Na_2CrO_4 + Pb(NO_3)_2 \rightarrow$	
Does Rxn occur? Yes or no?	Formula for new product:

c. Balanced chemical equation: $(NH_4)_2SO_4 + NaCl \rightarrow$	
Does Rxn occur? Yes or no?	Formula for new product:

d. Balanced chemical equation: $BiCl_3 + NaOH \rightarrow$	
Does Rxn occur? Yes or no?	Formula for new product:

e. Balanced chemical equation: $ZnBr_2 + K_3PO_4 \rightarrow$	
Does Rxn occur? Yes or no?	Formula for new product:

f. Balanced chemical equation: $Ca(ClO_3)_2 + NaBr \rightarrow$	
Does Rxn occur? Yes or no?	Formula for new product:

CTQ:6.

Write a balanced double displacement reaction that produces the following products. Include phase labels on all species.

a. Aluminum phosphate, $AlPO_4$ *(s)*

b. Lead (II) iodide, PbI_2 *(s)*

c. Potassium bromide, KBr *(aq)*

CTQ:7.

Cadmium metal (Cd) ionizes to Cd^{+2} ion. Since cadmium is not a Group 1 metal, which anion would you select to form a soluble ionic compound of Cd^{+2}? Write the correct formula for your answer.

CTQ:8.

Chromate (CrO_4^{-2}) is a polyatomic anion which is generally insoluble. Which cation would you select to form a soluble ionic compound of CrO_4^{-2}? Write the correct formula for your answer.

CTQ:9.

Analysis of municipal water supplies typically lists both nitrates (NO_3^-) and chromates (CrO_4^{-2}) as pollutants. Nitrates promote rampant growth of algae and aquatic plants in ecosystems but have relatively minor adverse health effects on human at low dosages. However, chromates are highly toxic even at low levels. Fortunately, removal of chromates from water is much easier than removal of nitrates. Explain why nitrates are more difficult to remove from water than chromates.

EXPERIMENT 4

Organic Structure and Molecular Modeling

An architect recognizes that a pile of wood, stone, steel and glass could be assembled into an office building using a set of blueprints. Even without blueprints, an experienced team of architects and engineers could envision a new functional structure and fashion the materials into a recognizable edifice with some degree of success. Likewise, trained chemists are molecular architects and engineers able to utilize a handful of substances to manufacture known compounds or envision a synthesis for a new molecule. It is certainly true that organic structure can be viewed as **molecular architecture**.

There are 3 Main Objectives in this Modeling Exercise

1. To reveal organic structure using drawings and molecular models
- Elements and patterns of construction
- Converting molecular formulas into structural drawings
- Bond angles and molecular geometry
- Cyclic structures

2. To understand the concept of a group
- Alkyl groups
- 1°, 2° and 3° labels
- Organic functional groups

3. To recognize 3-dimensional structure and understand isomerism

- Structural isomers
- Stereoisomers

The goal in this lab activity is to become proficient in drawing organic structures to illustrate structural features such as molecular shape, isomerism and stereochemistry.

A. Revealing Organic Structure

There are literally millions of organic compounds but the vast array is based on a small number of structural features. To the trained eye, a chemist views organic molecules much as an architect looks at the elements of an intricate suspension bridge or a massive skyscraper. Just as an architect recognizes common building materials and methods of construction in every building, a chemist distinguishes between a handful of elements and patterns of connectivity that are predictable in all molecules.

Elements of Construction

There are approximately eight elements used for all organic molecules, carbon and hydrogen plus six common heteroatoms, N, O, halogen, S, P and Si; the first five elements are the most common. **A heteroatom is any element besides carbon and hydrogen.** If metals are included in a formula, this generally indicates that the organic species is ionized.

Patterns of Construction (Bonding Patterns)

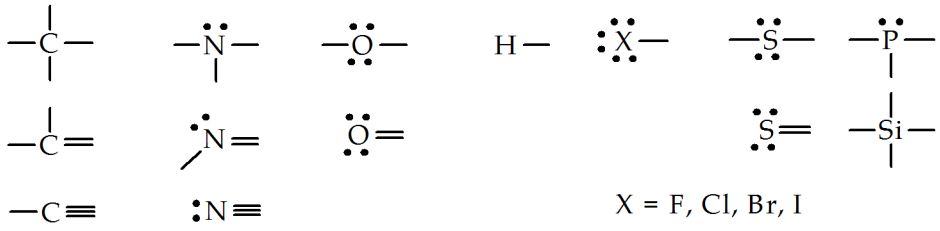
The connectivity of atoms in organic structures is quite predictable. In stable molecules, carbon always forms four bonds. There are several ways to distribute four bonds around carbon:

- four single bonds
- one double bond plus two single bonds
- one triple bond plus one single bond

Except for the smallest molecules, organic structures contain more than one carbon atom. The C atoms may be connected with single, double or triple bonds. Each C

atom is treated as a central atom in the sense that C atoms are connected in a chain and the remaining atoms are attached to carbon to fulfill the valence requirement of four bonds. This chain of C atoms provides the **carbon framework or skeleton** to which all other elements are attached. The carbon framework may have one or more branch points **(side chains)** or the ends of a chain may be connected to form a **ring**, the latter being the foundation for **cyclic compounds**. The bonding patterns for elements contained in organic compounds are shown below Model 4.1

MODEL 4.1 Common Bonding Patterns



Organic compounds that contain only carbon and hydrogen are called hydrocarbons. Classification of hydrocarbons is based on the types of bonds in these molecules:

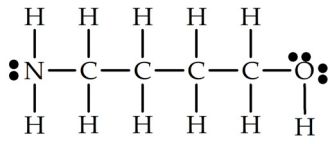
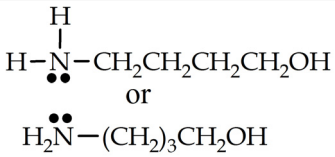
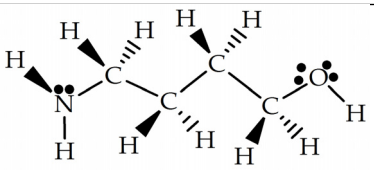
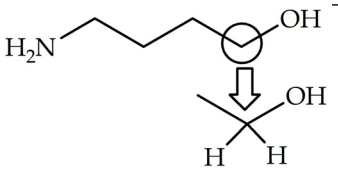
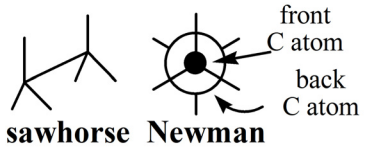
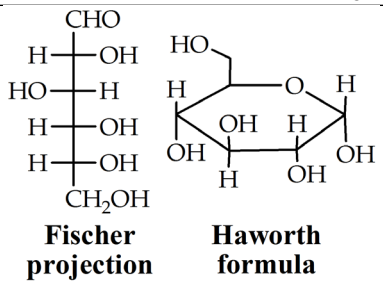
- **Alkanes** have all C-C single bonds
- **Alkenes** have at least one C-C double bond
- **Alkynes** have at least one C-C triple bond
- **Aromatics** have alternating single and double bonds in a six-membered ring.

Recognizing aspects of the hydrocarbon framework is an important first step in learning organic structure. Indeed, all organic molecules are built upon a foundation of some type of hydrocarbon skeleton.

Converting Molecular Formulas into Structures

A molecular formula is a list of elements that can be assembled into a variety of structural drawings. As you work through this course, you will be introduced to many additional structures. A summary of the different types of structural drawings is shown below. Compare the molecular formulas to the structures derived from common bonding patterns **(Model 4.2)**.

MODEL 4.2 Common Structural Formulas

Structures for 4-amino-1-butanol ($C_4H_{11}NO$)		
Structural formula (Lewis structure)		All atoms and all bonds are drawn.
Condensed structure		Structures can be condensed to varying degrees (some bonds are not drawn)
3-D or Perspective drawing		Wedges and dashed bonds illustrate 3-D. Solid lines show approximate bond angles
Bond line formula or Line drawing		No atom labels drawn except for heteroatoms. Each vertex represents a CH_2 group.
Structures for ethane (C_2H_6)		
Sawhorse and Newman projections		Used to illustrate rotation around single bonds.
Structures for glucose ($C_6H_{12}O_6$)		
Haworth formula And Fischer projection		Used to show stereochemistry. Commonly used for carbohydrates.
Nonbonding electrons are optional on all types of drawings		

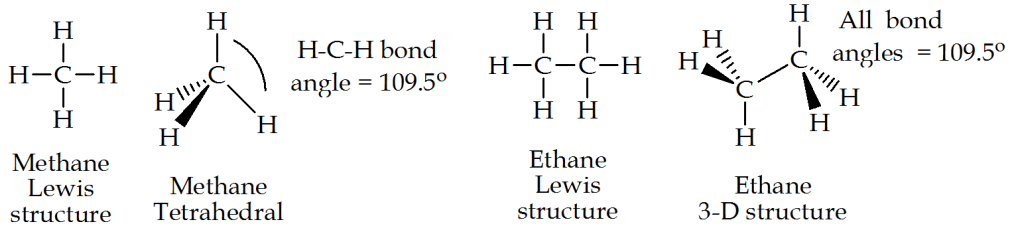
Bond Angles and Molecular Geometry

Recognizing the difference between single, double and triple bonds is a convenient way to determine molecular shape or geometry. A carbon atom that has four single bonds will always adopt a **tetrahedral geometry** around that carbon atom. A **trigonal planar geometry** is observed around carbon atoms that have a double

bond and a **linear geometry** is observed around carbon atoms that have a triple bond. Furthermore, there are only three bond angles expected for organic compounds: The tetrahedral geometry is produced from bonds angles of 109.5°; a trigonal planar geometry is associated with bond angles of 120° and a linear structure results from bond angles of 180°.

The Lewis structure for methane appears to be a square planar-shaped molecule. The actual bond angles in the 3-D structure are 109.5°, the ideal tetrahedral angle. Ethane contains all single bonds so we expect to find bond angles close to the tetrahedral angle **(Model 4.3)**.

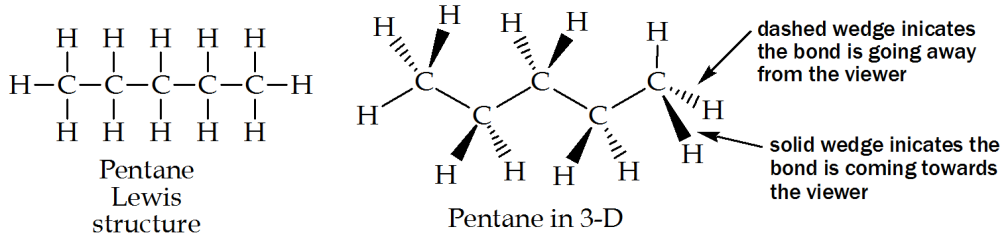
MODEL 4.3 Tetrahedral Geometry and Bond Angles for Alkanes



Molecular models are a great tool for visualizing the structures shown in these examples. As you work through this activity, models will help to elucidate the 3-D aspects of molecules.

For longer-chain alkanes, the bond angles remain 109.5° and using a molecular model, you can visualize the "zigzag" arrangement along the carbon backbone. In fact, this zigzag structure is a common type of structural drawing used to indicate molecular shape **(Model 4.4)**.

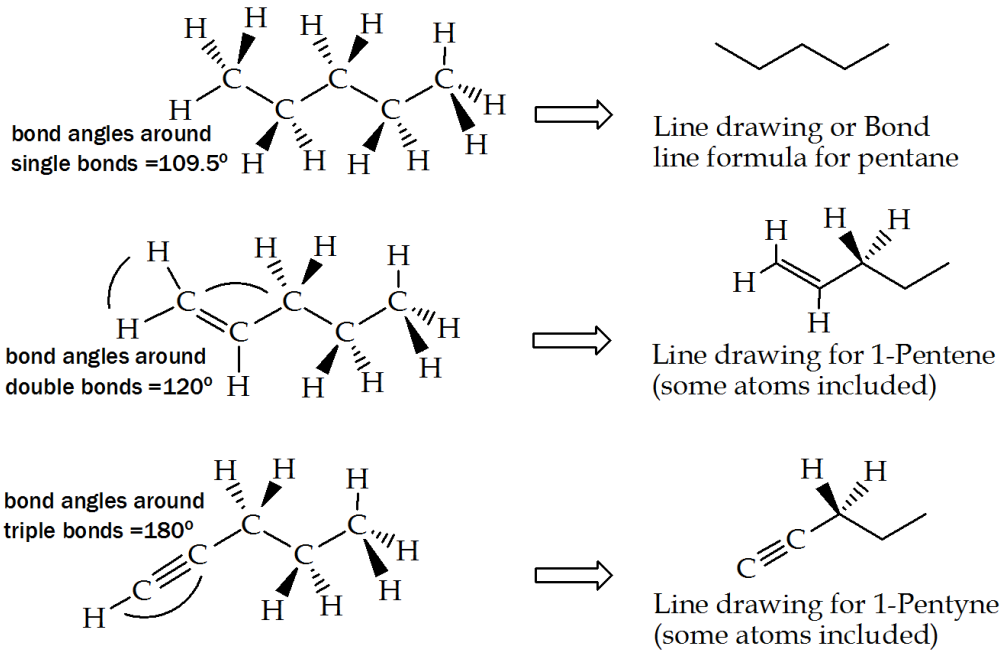
MODEL 4.4 Tetrahedral Angles Produce a Zigzag Carbon Skeleton



Since all bond angles are determined by the type of bonds around carbon, it is unnecessary to show all of the H atoms because their position is known based on the three geometry types, tetrahedral, trigonal planar and linear. The most economical organic structures are simply zigzag patterns (Bond line formulas) which show

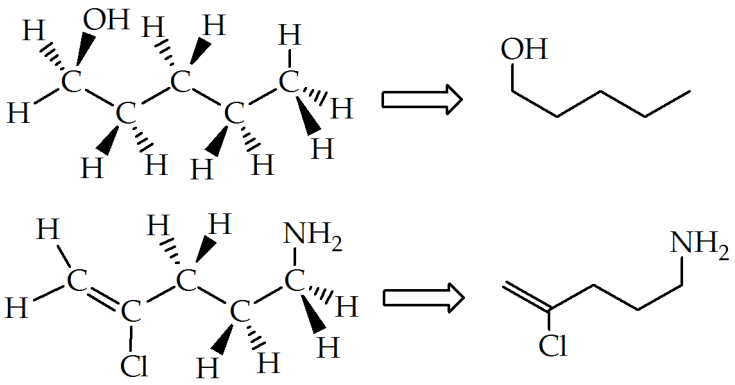
only the carbon framework. **Notice the bond angle associated with single, double and triple bonds.** (MODEL A5).

MODEL 4.5 Lewis Structures Condensed to Bond Line Formulas



Compounds that contain heteroatoms follow the same basic patterns for molecular shape. By (hypothetically) replacing a H atom with heteroatom, the carbon framework adopts a geometry determined by C-C bond angles and the position of any heteroatom is known. **Heteroatoms must be shown** in all condensed structures and bond line formulas; otherwise the assumption is that H atoms are present. (MODEL A6).

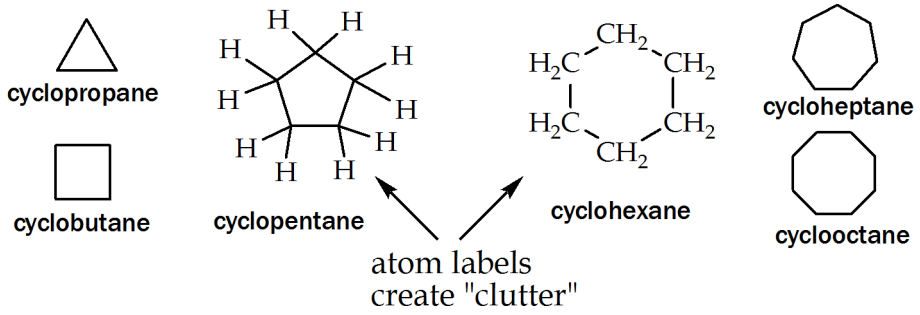
MODEL 4.6 Structures with Heteroatoms



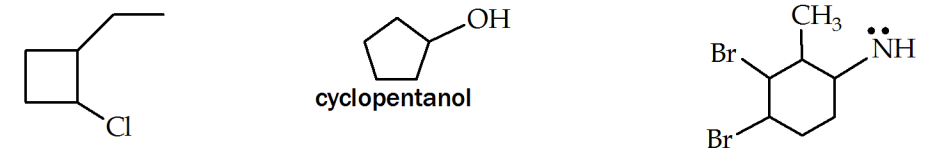
Cyclic Structures

Hydrocarbons that form rings are named according to the number of carbon atoms that comprise the ring. The smallest ring is cyclopropane and it is drawn using a triangle to represent the bond line type of structure. Cyclic structures can also be drawn as condensed or partially condensed structures but for clarity, the polygons are most common. **As with any structure, atom labels for all heteroatoms must be included** (Model 4.7, Model 4.8).

MODEL 4.7 Cyclic Structures



MODEL 4.8 Substituted Cycloalkanes



2-chloro-1-ethylcyclobutane

1,2-dibromo-3-methyl-4-aminocyclohexane

B. The Concept of a Group

A structural drawing represents either a compound or, in many cases, a single molecule. A group denotes a substructure of a particular molecule. Because molecules are the smallest unit of any organic substance, a group represents a ***hypothetical substructure*** and cannot be isolated and put into a container. The term group has different connotations depending on the context; the most common uses are listed here:

- To describe alkyl substituents
- To distinguish primary, secondary and tertiary centers
- To identify a functional group

Alkyl Groups

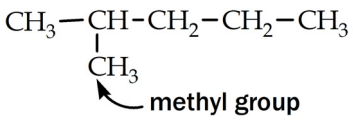
The side chains on branched structures are often comprised of alkyl groups. Alkyl groups are derivatives of alkanes formed by removing a H atom and using the empty bond to attach the group to the main carbon chain. Alkyl groups are often abbreviated using the letter R.

For example, a CH_3 group is derived from methane and is called a methyl group. Notice the **suffix changes from *ane* to *yl*** when writing alkyl groups. The dashed line is often included to indicate an empty valence which is the point of attachment for the alkyl group to the carbon chain **(Model 4.9)**.

MODEL 4.9 Common Alkyl Groups

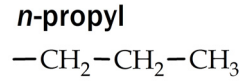
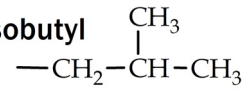
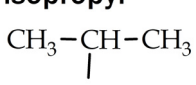
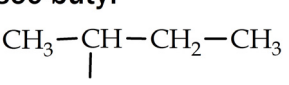
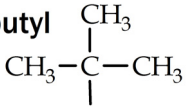
methyl	$-CH_3$
ethyl	$-CH_2-CH_3$
propyl	$-CH_2-CH_2-CH_3$
butyl	$-CH_2-CH_2-CH_2-CH_3$
pentyl	$-CH_2-CH_2-CH_2-CH_2-CH_3$

2-methylpentane



There are two alkyl groups derived from propane and four groups derived from butane that are very common and should be memorized. **(MODEL B2)**.

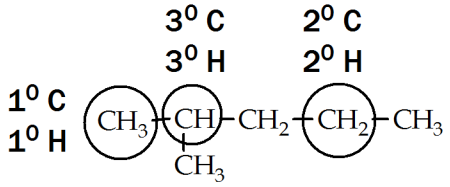
MODEL 4.10 Alkyl Groups to Memorize

propyl groups		butyl groups	
***n*-propyl** 		***n*-butyl** 	**isobutyl** 
isopropyl 		***sec*-butyl** 	***tert*-butyl** 

Primary, Secondary and Tertiary Centers

A carbon atom attached to one other C atom is called a primary carbon and identified with the symbol 1°. Likewise, a carbon atom attached to two other C atoms is a secondary (2°) center, and a carbon atom attached to three other C atoms is a tertiary (3°) center. The use of 1°, 2° and 3° can be used to identify either the type of carbon center or any group attached to those centers as shown in the example, 3-methylhexane (Model 4.11).

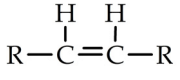
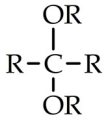
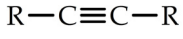
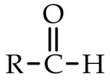
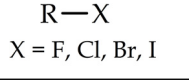
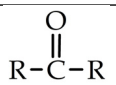
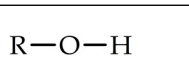
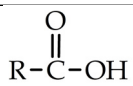
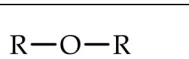
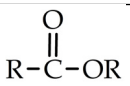
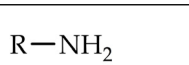
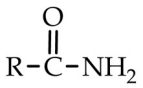
MODEL 4.11 1°, 2° and 3° Centers



Organic Functional Groups

Groups of atoms such as double and triple bonds and especially heteroatoms attached to a hydrocarbon skeleton constitute a functional group. A functional group defines the structure of a family of compounds and determines the properties of that family including the characteristic chemical reactions. In essence, replacing hydrogen with any heteroatom creates a functional group. Except for alkanes, all organic compounds are classified by their functional group. (Model 4.12).

MODEL 4.12 Some Common Functional Groups (R = alkyl group)

Non-Carbonyl groups		Carbonyl groups	
Alkene		Acetal	
Alkyne		Aldehyde	
Alkyl halide		Ketone	
Alcohol		Carboxylic Acid	
Ether		Ester	
Amine		Amide	
Acetals are derivatives of aldehydes and ketones			

The C=O double bond is a very important group called a carbonyl group. There are several functional groups that contain a carbonyl group. The concept of a "group" is being developed here- a group can refer to a particular functional group

or any defined subset of atoms such as a carbonyl group (C=O group); alkyl group (R group); hydroxy group (OH group); alkoxy group (OR group); amino group (NH_2 group); halo group (halogen), etc.

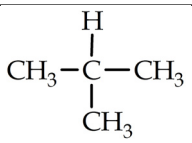
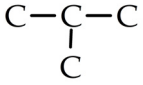
C. Three-Dimensional Structure and Isomerism

In the macroscopic world, objects are described by length, width and height. In the same manner, molecules are 3-dimensional objects described by their molecular shape. A crucial leap from 2-dimensional drawings on paper to 3-D molecules in your mind's eye is needed to appreciate the beauty found in nature and to fully understand organic structure. To develop this understanding, the concepts of isomerism and stereochemistry are needed to recognize molecular shape.

Isomerism

There are two basic kinds of isomers, structural isomers and stereoisomers. **Structural isomers are compounds that have the same molecular formula but different connectivity between the atoms, in other words, same formulas but different carbon skeletons.** There are no structural isomers for methane, ethane or propane, but with 4 C atoms in its skeleton, butane exists as two different structural isomers. Verify that both isomers have the same molecular formula but different connectivity **(Model 4.13)**.

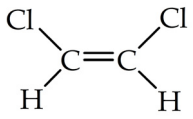
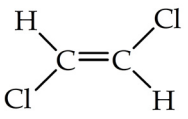
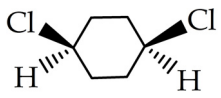
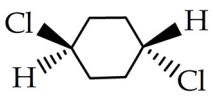
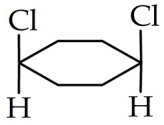
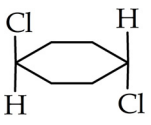
MODEL 4.13 Structural Isomers for Butane (C_4H_{10})

	structure	connectivity	Types of C atoms
***n*-butane**	$CH_3-CH_2-CH_2-CH_3$	C—C—C—C	**1° and 2°**
isobutane			**1° and 3°**

Stereoisomers are molecules that have the same molecular formula and the same connectivity but the atoms occupy different positions in 3-D space. There are many kinds of stereoisomers. However, in this lab activity, we will investigate only one type of stereoisomer called geometric isomers. **Geometric isomers are also called cis/trans isomers.** Because this type of stereoisomerism is only observed in alkenes and cyclic compounds, the presence of a **double bond or a ring is required** to produce cis/trans isomers.

At this point we must depart from simple 2-D structures on paper and develop a 3-dimensional view of molecular structure. When describing stereo-structures, it becomes commonplace to refer to the "top" and "bottom" or "left" and "right" sides of a molecule, depending on how the structure is drawn on paper. For cyclic structures, we must use some type of perspective drawing employing wedges and dashed bonds or draw a Haworth formula (**Model 4.14**).

MODEL 4.14 Geometric Isomers

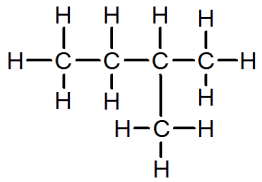
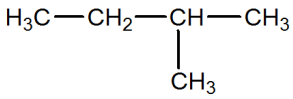
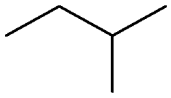
name	*cis*-isomer	*trans*-isomer	structure
1,2-dichloroethane			Lewis structure
1,4- dichlorocyclohexane			3-D drawing
			Haworth structure

Top/bottom, left/right are relative terms when describing *cis/trans* isomers. **The *cis*-isomer is the structure that has the same groups (in this case, Cl atoms) positioned on the same side of the molecule.** In the Lewis structures above, the *cis*-isomer has both Cl atoms on the top of the drawing; the *trans*-isomer has Cl atoms on opposite sides. The same top/bottom (*cis/trans)* stereochemical assignments are shown in the Haworth structures. In the 3-D drawings, the wedge represents a bond to a group on the top face of the ring and the dashed bond is connected to a group on the bottom face.

Prelab Questions

1. What is the definition of a heteroatom?

2. What basic information is given by a molecular formula?

3. There are only three bonding patterns between carbon atoms in every hydrocarbon skeleton, or carbon framework.
   a. What class of hydrocarbons contains at least one C-C triple bond? _____
   b. A hydrocarbon that contains a C-C double bond is called an_____.
   c. What class of hydrocarbons contains all C-C single bonds? _____
4. Write the approximate bond angle associated with each of the following:
   a. alkane skeleton (also called the carbon backbone or framework_____
   b. the alkene skeleton that includes a double bond_____
   c. the geometry of a triple bond_____
5. 


   a. For each structure, draw a triangle around the 3° carbon atom; a square around the 2° carbon atom and a circle around all 1° carbon atoms.
   b. Are these three structures the same or different compounds?_____
6. When drawing large molecules or complex structures, alkyl groups are often abbreviated. What is the common abbreviation for an alkyl group? _____

7. What is the definition of a structural isomer?

Critical Thinking Questions and Model Building Activity

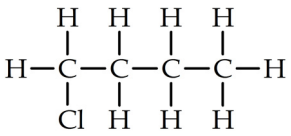
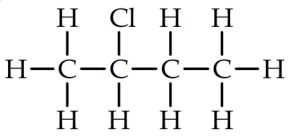
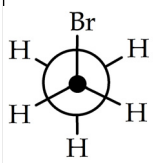
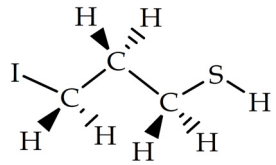
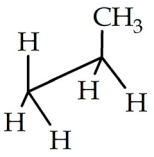
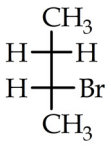
CTQ:1.

Convert the molecular formula (C_3H_8) into the following structural drawings

a. Lewis structure	**b.** Condensed structure
c. Bond line structure	**d.** 3-D drawing

CTQ:2.

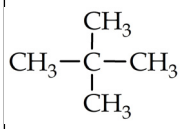
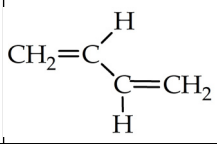
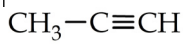
Write the molecular formula inside the box for each drawing:

a. 	**b.** 	**c.** 
d. 	**e.** 	**f.** 

g. Do any of the structures above have the same molecular formula? If yes, which ones represent structural isomers?

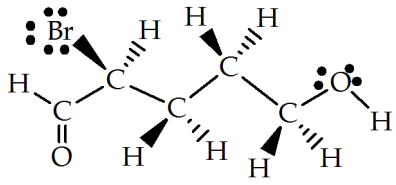
CTQ:3.

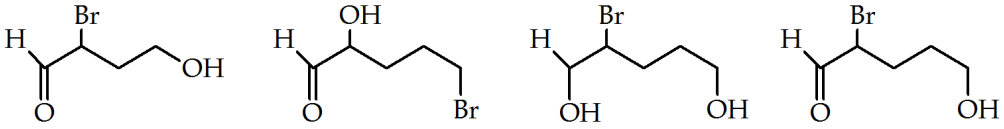
Based on the type of bonds in the carbon skeleton, choose one of the following approximate bond angles you would expect to find in each of the following molecules:109.5°120°180°

a.	b.	c.	d.
			

CTQ:4.

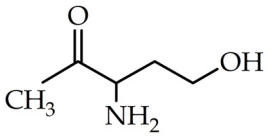
Circle the bond line drawing that matches the 3-D structure.





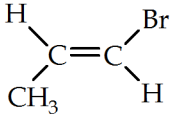
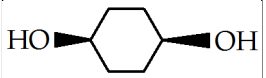
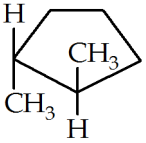
CTQ:5.

Circle the names for all the functional groups present in this molecule:

	Aldehyde Ketone Ester Carboxylic acid hydroxy group	Halide Alkoxy group Amino group Alkene Alkyne

CTQ:6.

Identify the structures below as *cis*-isomer or *trans*-isomer

a.	b.	c.
		

Molecular Model Building Activities

The molecular formulas indicate how many of each type of atom is required to build the molecule.

1. Ethane (C_2H_6)

Build a model of ethane and rotate around the C-C bond. You will discover that there are two major arrangements called conformations. One conformation is called eclipsed and the other is called staggered.

a. Draw a Newman projection for each conformation.

eclipsed	staggered

b. Are the C atoms 1°, 2° or 3° centers?

c. Explain why one conformation is more stable than the other.

2. Butane (C_4H_{10})

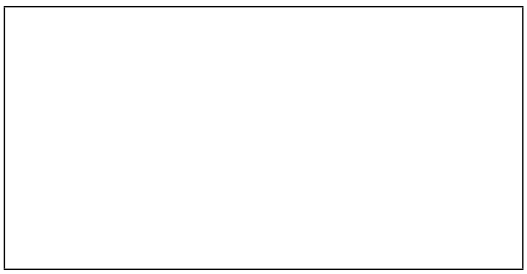
a. There are two structural isomers of butane. Build models of both isomers of butane then draw their Lewis structures and match with correct name.

n-butane	isobutane

b. Label the C atoms in both structures as 1°, 2° or 3° centers.

3. Propene (C_3H_6)

Build a model of propene then draw its Lewis structure.



a. What is the bond angle around the central carbon atom? _____

b. Is there free rotation around both C-C bonds? Explain.

c. If the C-C double bond is moved between the other two carbon atoms, does that represent a different structure; i.e., does propene have a structural isomer? Explain.

4. Butene (C_4H_8)

Recall your answer to a previous question; the isomers of butane exist as a straight-chain structure (*n*-butane) or as a branched skeleton (isobutane). Now consider the isomers of butene: There are 4 isomers with the molecular formula C_4H_8.

a. Build each molecule and draw each possible isomer as a condensed structure:

I	II

III	IV

b. Using the labels (I, II, III etc.) which are structural isomers? _____

c. Using the labels (I, II, III etc.) which are geometric isomers? _____

5. Hexane (C_6H_{14})

a. There are 5 isomers of hexane. Build a model and draw a bond line formula for each isomer.

b. Are these structural isomers or stereoisomers?

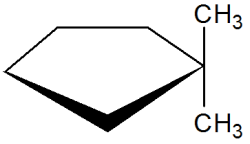
6. Cyclohexane (C_6H_{12})

Build a model of cyclohexane then draw these structures:

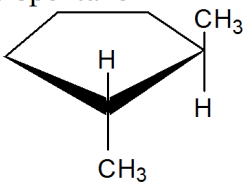
Haworth formula	bond line formula

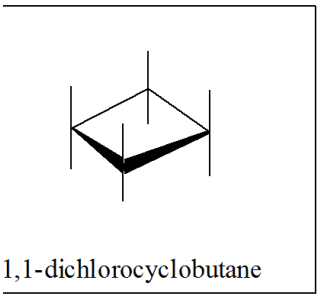
7. Dichlorocyclobutane ($C_4H_6Cl_2$)

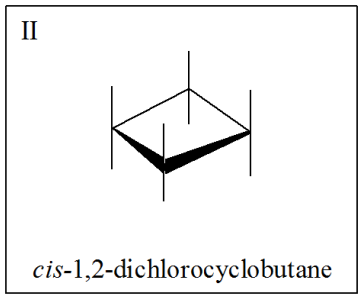
1,1-dimethylcyclopentane

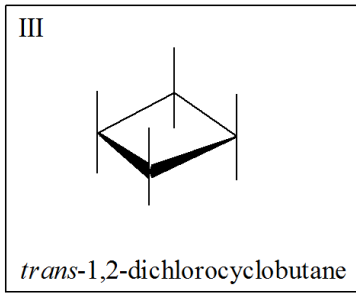


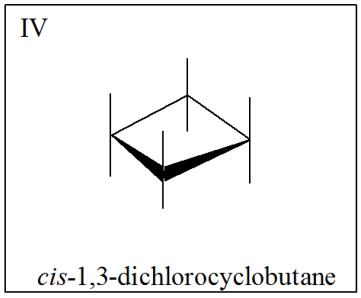
trans-1,2-dimethylcyclopentane

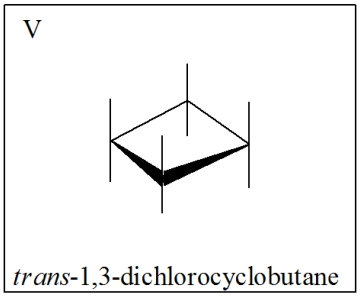












a. There are 5 isomers with this molecular formula, $C_4H_6Cl_2$. For each isomer, complete the structure from the name provided. As a guide, use the model shown below for the isomers of dimethylcyclopentane:

b. Using the labels (I, II, III, etc.) identify 2 pairs of geometric isomers and at least one pair of structural isomers.

Geometric isomers _____ & _____

Constitutional or structural isomers _____

8. Glucose and Fructose ($C_6H_{12}O_6$)

Use the index in your textbook to find structures for glucose and fructose. Build a model of each sugar in the **open-chain form** then draw bond line formulas so you can compare the location of the carbonyl group (C=O group).

bond line formula	
glucose	fructose

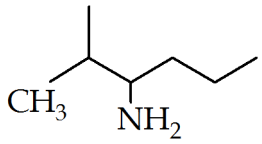
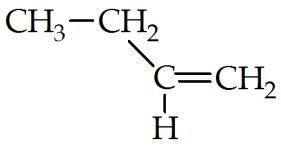
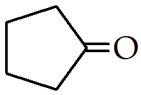
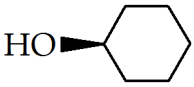
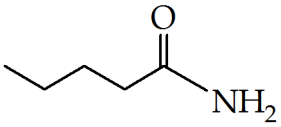
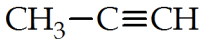
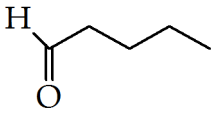
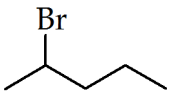
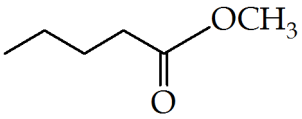
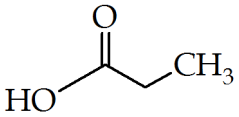
a. Which sugar contains an aldehyde functional group? _____

b. Which sugar contains a ketone? _____

c. Draw Haworth formulas for the **cyclized form** of each sugar.

Haworth formula	
glucose	fructose

9. Identify the functional group in the following structures.

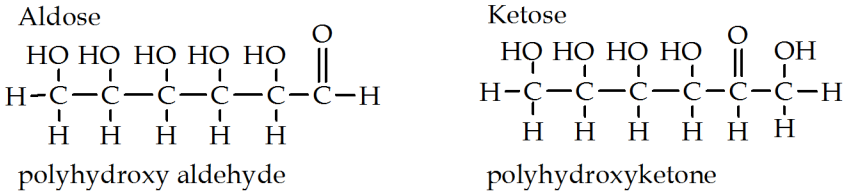
a. 	**b.** 
c. 	**d.** 
e. 	**f.** 
g. 	**h.** 
i. 	**j.** 

EXPERIMENT 5

Carbohydrates and Qualitative Organic Analysis

Carbohydrates are the most abundant class of organic compounds and the main energy source for most animals. They are products of photosynthesis in contrast to most other organic compounds which originate from crude oil. Carbohydrates are comprised of three elements (C, H, and O) and were originally viewed as "hydrates of carbon" since their empirical formula $C_m(H_2O)_n$ suggests that each carbon is combined with a water molecule. A more accurate description considers them as polyhydroxy compounds that contain an aldehyde or ketone.

FIGURE 5.1 **Figure 1 Carbohydrate Structures**



Carbohydrates are also called saccharides or referred to as sugars. The most important examples include glucose, fructose, cellulose, and starch.

There are 3 Main Objectives in this Lab

1. To learn about reduction/oxidation (redox) of organic compounds
- Common oxidation states for organic compounds

2. To interpret qualitative tests for carbohydrate functional groups

- Alcohols and Phenols
- Aldehydes and Ketones

3. To understand Carbohydrate Structure and Reactivity
- Acetals and Hemiacetals
- Classification of carbohydrates: mono-, di- and polysaccharides
- Reactions of carbohydrates: redox, hydrolyses, dehydration and condensation reactions

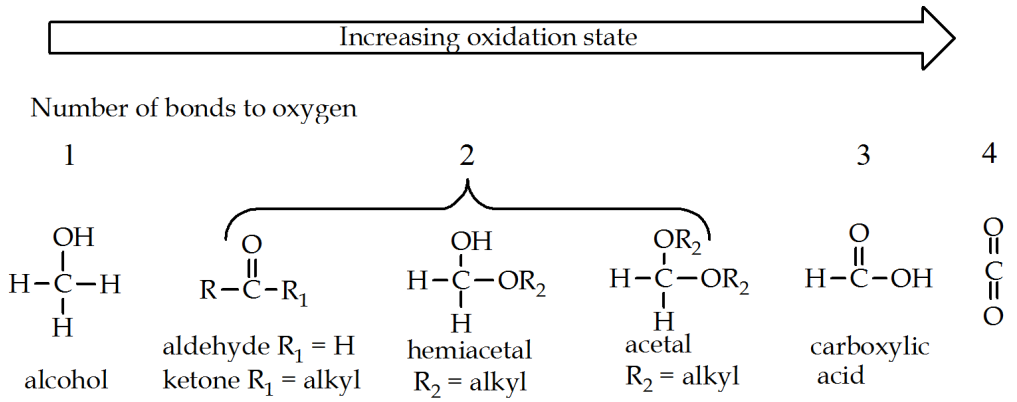
The goal in this lab activity is to determine the class and identify the functional groups present in an unknown carbohydrate by using classical chemical tests.

1. Redox of Organic Compounds

Redox refers to reduction/oxidation processes. A discussion of redox often includes assignment of oxidation numbers, especially when dealing with metal ions from ionic compounds. But for organic compounds, the focus is not on the oxidation number of carbon but rather the **oxidation state** of carbon atoms in the skeleton. Except for alkanes, alcohols have the lowest oxidation state followed by the **carbonyl oxidation state** (aldehyde/ketone), followed by the **carboxyl oxidation state** (carboxylic acids, esters and amides). Understanding that alcohols undergo oxidation to carbonyls is more important than knowing the actual oxidation numbers. The central concept says that reduction is the reverse of oxidation. Carboxyl compounds can be reduced to carbonyls which in turn can be reduced to alcohols.

There are two ways to identify an oxidation process involving carbon atoms: *increasing the oxygen content* on a particular carbon atom or *decreasing the hydrogen content* on a carbon atom. An easy way to determine oxygen content of carbon is to count the number of bonds between the carbon and oxygen atoms; **the greater the number of C-O bonds, the higher the oxidation state for that carbon atom**. In this manner both aldehyde/ketones and acetal/hemiacetals have two bonds between C and O and are thus in the same oxidation state.

MODEL 5.2 1 Oxidation States for Some Organic Functional Groups



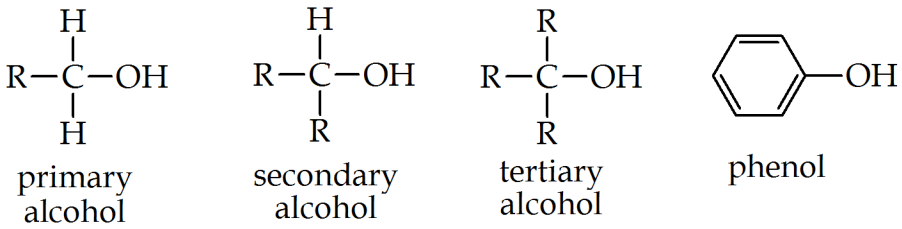
2. Qualitative Tests for Alcohols, Phenols, Aldehydes and Ketones

All carbohydrates contain hydroxy groups and either an aldehyde or ketone. In fact, all naturally occurring sugars have an oxygen atom attached to every carbon atom in the carbon skeleton. Qualitative tests are used to investigate the behavior of these common functional groups.

2a. Alcohols and Phenols

Alcohols and phenols contain a hydroxy group (O-H). The classification of alcohols is based on the degree of substitution of the carbon that bears the hydroxy group; this atom is called the **carbinol carbon**. The carbinol carbon can be labeled as a primary (1°), secondary (2°), or tertiary (3°) center; thus alcohols are classified as 1°, 2° or 3° alcohols. Molecules that have a hydroxy group attached directly to an aromatic ring (benzene ring) are called **phenols**.

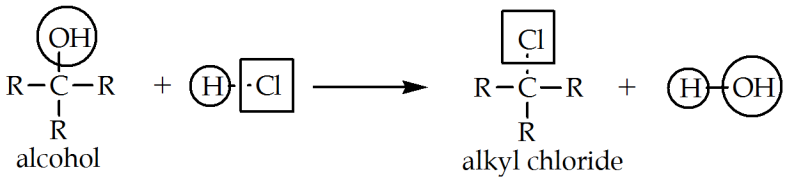
MODEL 5.3 Structures for Alcohols and Phenol



You will examine three qualitative tests for alcohols and phenols. These are described on the following pages.

The first test is the **Lucas test** in which a hydroxy group is substituted by chloride using aqueous hydrochloric acid:

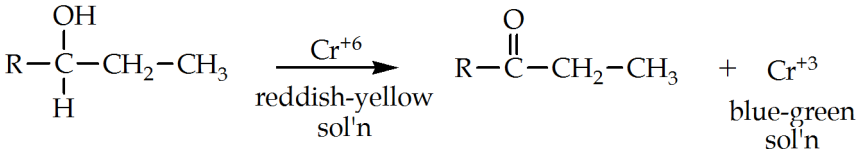
MODEL 5.4 3 Lucas Test for Alcohols



Conversion of an alcohol to a chloride produces an insoluble alkyl chloride that appears as a cloudy dispersion or as a separate layer in the reaction mixture. Appearance of the alkyl chloride is called a **positive test** meaning that the substrate does contain an alcohol.

The second test is the **Jones oxidation test** which converts some alcohols to ketones and some alcohols to aldehydes:

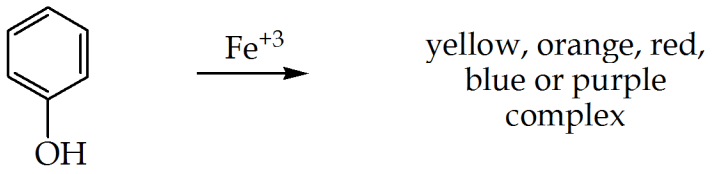
MODEL 5.5 4 Oxidation of Alcohols with Jones Reagent



An oxidation reaction is observed when the reddish-yellow Jones reagent begins to fade or disappears and a blue-green color is produced. This color change is a **positive test** which indicates that the alcohol group has been oxidized. Any aldehydes that form during this test are quickly oxidized further to carboxylic acids with the Jones Reagent.

The third test is for phenols and is called the **ferric chloride test.** Phenols react with ferric chloride solution to give a complex that varies in color from yellow to deep purple. A **positive test** is formation of a colored mixture.

MODEL 5.6 Formation of Colored Complex with Ferric Chloride



The Lucas test is used to distinguish between 1°, 2° and 3° alcohols. Not all alcohols undergo this reaction at the same rate. Some alcohols undergo this reaction very quickly, others are slower and some alcohols simply do not undergo substitution or do so very slowly under the conditions of the Lucas test. Therefore, how quickly the oily layer appears is used to determine the structure of the alcohol that is being tested. The **objective** here is to determine whether 1°, 2° or 3° alcohols undergo the reaction the fastest (and which type react the slowest).

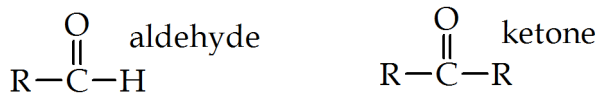
The Jones test is used to distinguish between 1° and 2° versus 3° alcohols because 3° alcohols cannot be oxidized. When the Jones test and Lucas test results are examined together, the alcohol type (1°, 2° or 3°) should be evident.

From a structural viewpoint, **notice the pattern of alcohol oxidation requires that two hydrogen atoms are removed**: the H atom from the OH group and one H atom from the carbinol carbon. Recall that one of the definitions of oxidation is decreasing the H content on carbon (the carbinol carbon). An alcohol oxidizes to progressively higher oxidation states in this order: alcohol → aldehyde/ketone → carboxylic acid, depending upon the structure of the alcohol (1°, 2°, 3°) and the reaction conditions (oxidizing reagent, temp, etc.). Because aldehydes are more easily oxidized than most alcohols, once an alcohol is converted into an aldehyde, it may be difficult to prevent the aldehyde from oxidizing further to the carboxylic acid state.

2b. Aldehydes and Ketones

Aldehydes and ketones contain a carbonyl group (C=O). The carbon atom that is double-bonded to oxygen is called the **carbonyl carbon**. Aldehydes have a H atom and an alkyl group bonded to the carbonyl carbon whereas ketones have two alkyl groups attached to the carbonyl carbon.

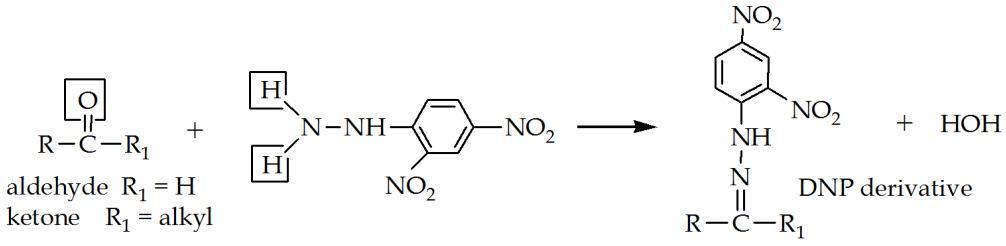
MODEL 5.7 Carbonyl Compounds



You will examine two qualitative tests for carbonyl compounds described below.

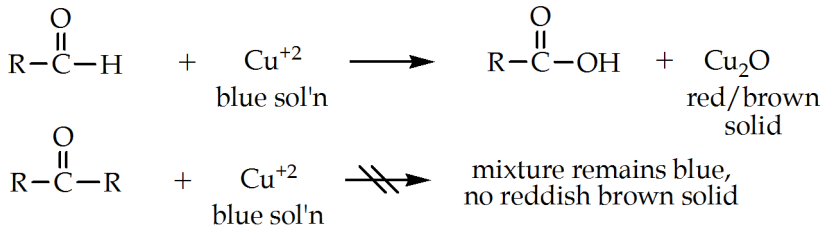
The first is called the **DNP test** in which both aldehydes and ketones react with a compound called 2,4-dinitrophenylhydrazine which produces brightly-colored compounds called 2,4-dinitrophenylhydrazone derivatives (DNP derivatives).

MODEL 5.8 DNP Test for Aldehydes and Ketones



The second test is called **Benedict's test** which oxidizes aldehydes to carboxylic acids. A redox reaction is observed when the blue-colored reagent begins to fade and a reddish-brown precipitate is produced. This color change and precipitate formation is a **positive test** which indicates the presence of an aldehyde group.

MODEL 5.9 Benedict's Test for Aldehydes and Ketones



Notice that the pattern of aldehyde oxidation requires removal of a H atom from the carbonyl carbon. Ketones give a **negative test** because they do not oxidize to carboxylic acids.

Simple sugars are classified as **reducing or non-reducing sugars** depending on their behavior towards mild oxidizing agents. All monosaccharides and many disaccharides are called reducing sugars because they reduce the copper ion present in Benedict's reagent ($Cu^{+2} \rightarrow Cu^{+1}$).

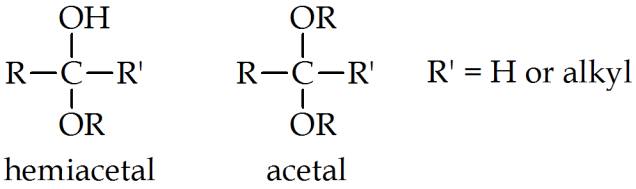
3. Carbohydrate Structure and Reactivity

In addition to hydroxy groups, all carbohydrates contain either an aldehyde or ketone functional group. However, these carbonyl groups are usually disguised as derivative functional groups called hemiacetals and acetals.

3a. Acetals and Hemiacetals

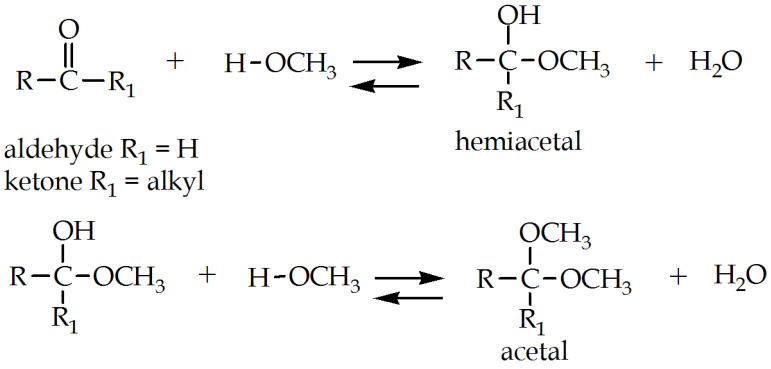
A hemiacetal contains a hydroxy group (OH) and an alkoxy group (OR) attached to the same carbon atom. An acetal contains two alkoxy groups attached to the same carbon atom.

MODEL 5.10 Acetal and Hemiacetal Structure



In simple terms, a hemiacetal is "half of an acetal" in the sense that addition of one molecule of alcohol forms the hemiacetal and addition of a second molecule of alcohol produces the acetal (Model 5.11).

MODEL 5.11 Formation and Hydrolysis of Hemiacetals and Acetals



Acetals and hemiacetals are "masked carbonyls" in the sense that they can be easily converted back to the parent aldehyde/ketone. Conversion of an acetal or hemiacetal back to the parent aldehyde/ketone is called **hydrolysis** since water is used to cleave the OR groups and regenerate the carbonyl group; hydrolysis is simply the reverse process of acetal formation.

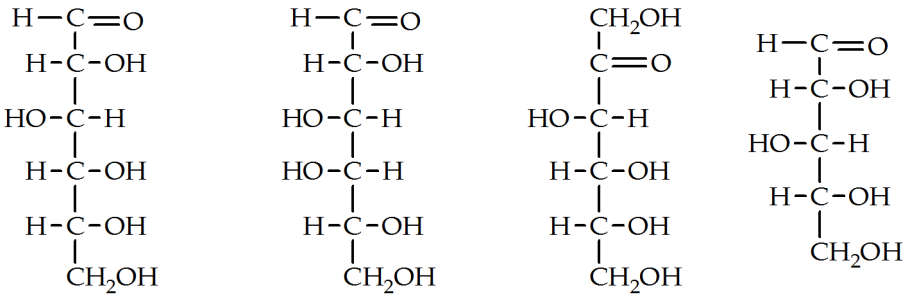
Hydrolysis is a major reaction involved in the qualitative determination of acetals and hemiacetals since these groups form the linkages between the monosaccharide units found in disaccharides and polysaccharides.

The functional groups determine the classification of simple sugars and are the basic components of repetitive substructures found throughout the carbohydrate domain.

3b. Classification and Structure of Carbohydrates

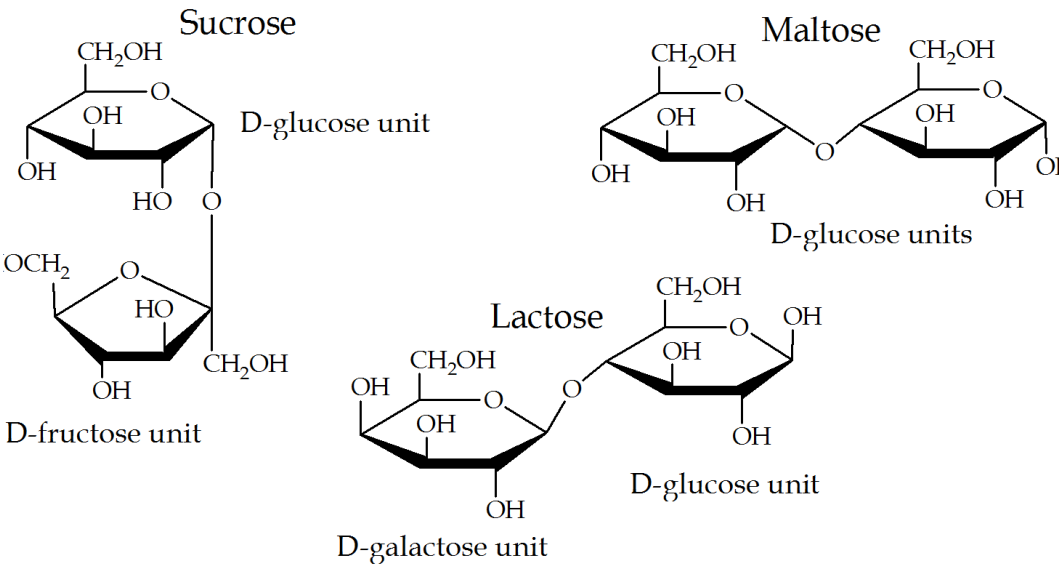
Carbohydrates are classified in various ways. **Monosaccharides** have three to six carbon atoms in their skeleton and are often referred to as simple sugars. Those that contain an aldehyde are called aldoses and sugars that contain a ketone are called ketoses. Some common monosaccharides are glucose, galactose, fructose and xylose, shown in Model 5.12.

MODEL 5.12 Monosaccharide Structures



Disaccharides are another class of sugars composed of two monosaccharides. Disaccharides are condensation products that contain at least one glucose unit linked by an acetal group to another monomer unit. Common examples include sucrose, maltose and lactose shown in Model 5.13.

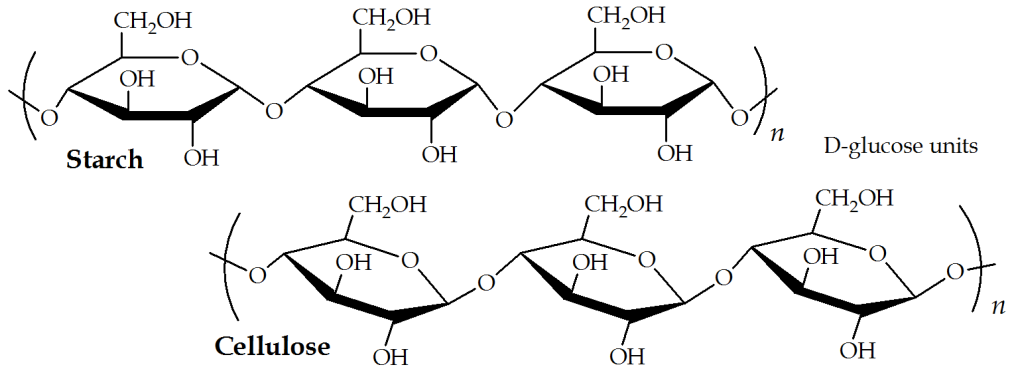
MODEL 5.13 Disaccharide Structures



Simple sugars are also classified as **reducing or non-reducing sugars** depending on their behavior towards mild oxidizing reagents. All monosaccharides and many disaccharides are called reducing sugars because they reduce the copper ion present in Benedict's Reagent ($Cu^{+2} \rightarrow Cu^{+1}$). Experimentally, a positive Benedict's test indicates that a carbohydrate contains an aldehyde (or a hemiacetal, since hemiacetals are hydrolyzed to the aldehyde). On the other hand, a ketose will give a negative Benedict's test.

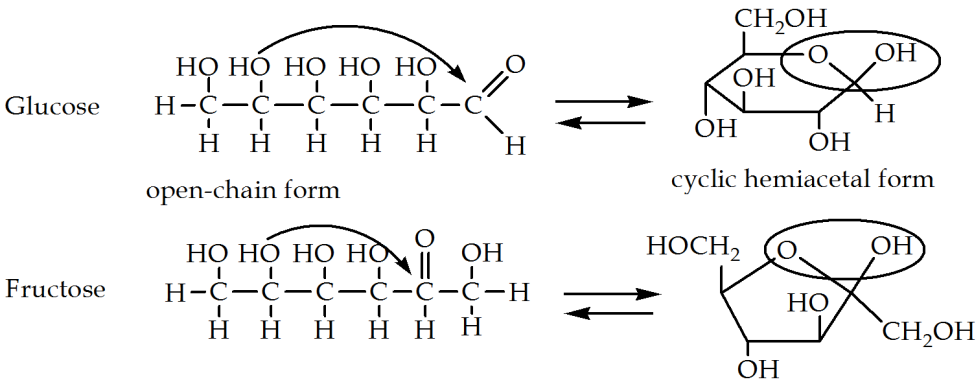
Polysaccharides are polymers; the two most important examples are starch and cellulose (Model 5.14). Both are polymers of glucose and differ only in the stereochemistry of the acetal linkage.

MODEL 5.14 Polysaccharide Structures



The most important behavior of monosaccharides involves the intramolecular cyclization reaction between the hydroxy group and the carbonyl group resulting in a cyclic hemiacetal structure (Model 5.15). **All monosaccharides are in equilibrium with their hemiacetal forms.**

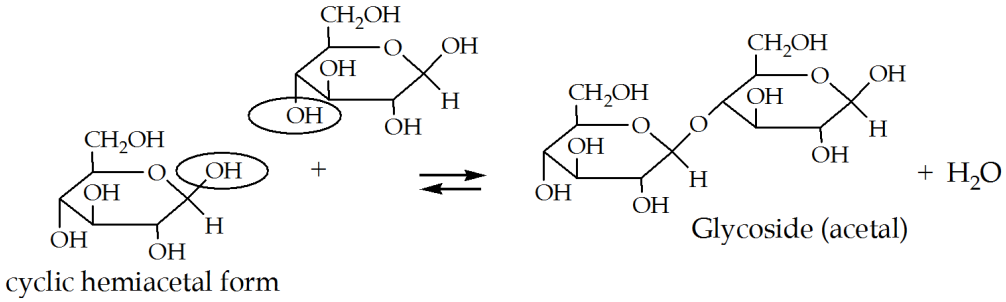
MODEL 5.15 Carbohydrate Hemiacetal Formation



Sugars that exist as the cyclic hemiacetal are reducing sugars due to this equilibrium between the hemiacetal and aldehyde.

A hemiacetal may react with a second molecule of alcohol to form an acetal. If the "second" alcohol is a hydroxy group from another sugar molecule, then two monosaccharides are linked to form a disaccharide. When sugars form acetals, they are called **glycosides** (Model 5.16).

MODEL 5.16 Glycoside linkage in Disaccharide



3c. Reactions of Carbohydrates

With some exceptions, the representative organic reactions of alcohols and carbonyl compounds are observed with carbohydrate substrates. Some of the qualitative organic tests previously introduced are suitable for elucidating the structure of carbohydrate compounds. However *a test for the presence of alcohols is not par-*

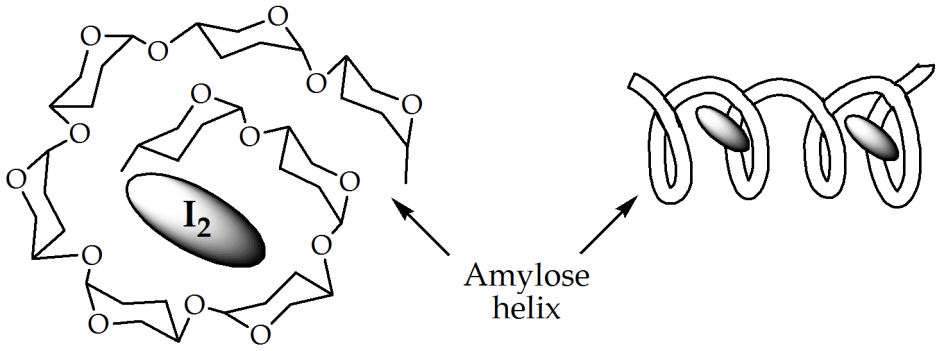
ticularly useful because sugars contain multiple hydroxy groups. On the other hand, careful oxidation will discriminate between reducing sugars and non-reducing sugars (hemiacetals and glycosides).

Descriptions of the classical qualitative tests for carbohydrates are listed below:

Iodine Test for Starch

Starch and cellulose are the most common polysaccharides which consist of glycosidic links between multiple glucose units. Starch includes the helical substructure of **amylose** which forms a purple complex with iodine. Some starches may produce a greenish color. A **positive test** is appearance of these colored complexes. Cellulose and simple sugars do not form colored complexes and there is little change in the reddish-brown color of iodine test solution (a negative test).

MODEL 5.17 Iodine/Starch Complex



Hydrolysis of Disaccharides and Polysaccharides

Carbohydrates are easily hydrolyzed by mixing with aqueous acid. Hydrolysis of disaccharides and polysaccharides ultimately produces monosaccharides. Although there is no definitive test for hydrolysis, the products are simple sugars which can be subjected to other tests such as Benedict's test, dehydration tests and the osazone test to determine the functional groups present in the original carbohydrate.

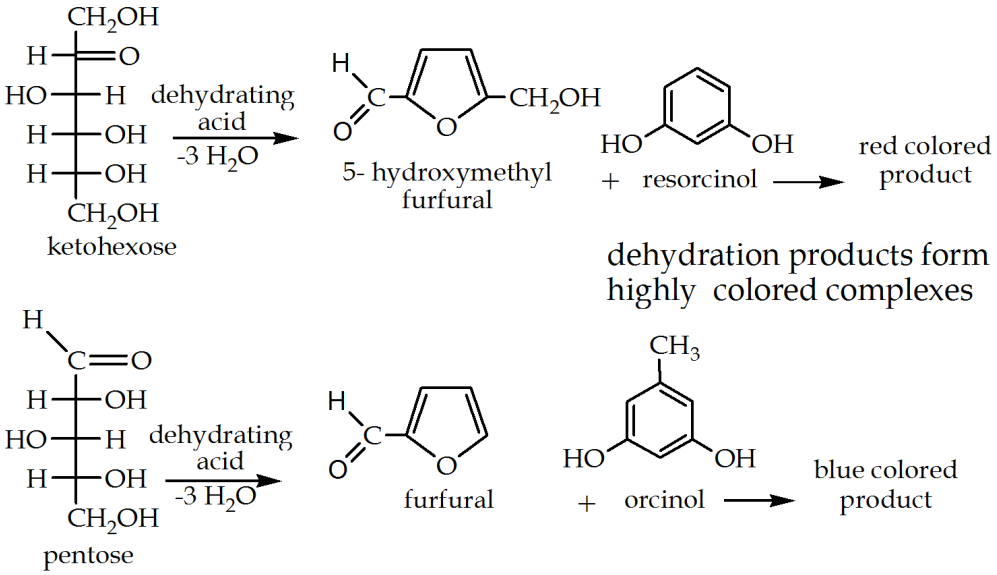
Benedict's Test for Reducing Sugars

Benedict's reagent can be used to determine if an unknown carbohydrate contains a monosaccharide.

Dehydration Tests

When exposed to strong acids, monosaccharides undergo dehydration to produce furfurals and substituted furfurals. These products react with phenol compounds to produce colored complexes. The two dehydration tests investigated in this experiment are Seliwanoff's test and Bial's test (Model 5.18).

MODEL 5.18 Dehydration of Monosaccharides



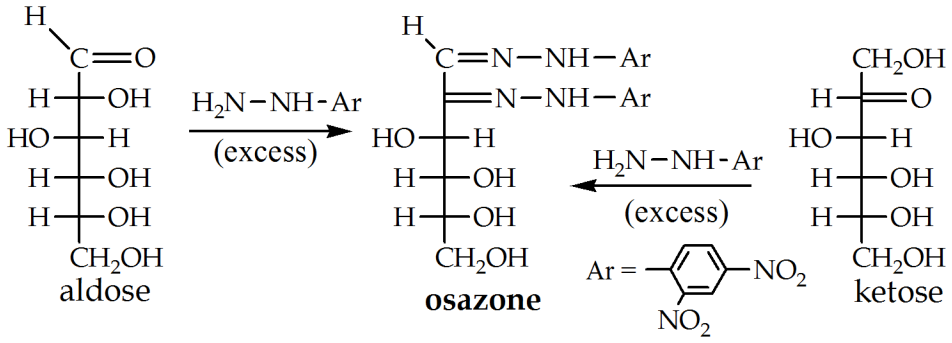
Seliwanoff's test is used to distinguish between an aldohexose and ketohexose. A **positive test** is the formation of a cherry-red product which indicates the presence of a ketohexose. The deep red color is the result of a complex formed with hydroxymethyl furfural and resorcinol. An aldohexose will develop a light pink color usually after a longer reaction time.

Bial's test is used to differentiate between a pentose and a hexose. A **positive test** is the formation of a blue product (sometimes green/blue) which indicates the presence of a pentose. The blue color is the result of a complex formed with furfural and orcinol. A hexose may form a gray or brown product.

Osazone Test for Carbohydrates

Hydrazine compounds react with monosaccharides in a condensation reaction that produces an **osazone**. This reaction is similar to hydrazone formation of aldehydes and ketones except that monosaccharides condense with two molecules of hydrazine to produce an osazone that has two C=N groups (Model 18).

MODEL 5.19 Formation of Osazone from Carbohydrates



PreLab Critical Thinking Questions

CTQ:1.

According to Model 5.2, an ester would be in the same oxidation state as:

a. an alcohol	**b.** a carboxylic acid
c. a ketone	**d.** carbon dioxide

CTQ:2.

According to Model 5.2, an ether would be in the same oxidation state as:

a. an alcohol	**b.** a carboxylic acid
c. a ketone	**d.** carbon dioxide

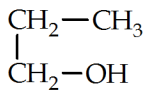
CTQ:3.

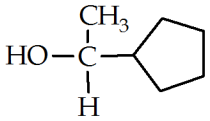
Analogous to the information in Model 5.2, an alkyl halide (R-Cl) would be in the same oxidation state as:

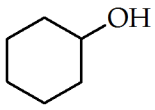
a. an alcohol	**b.** a carboxylic acid
c. a ketone	**d.** carbon dioxide

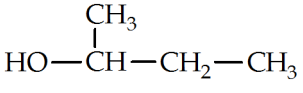
CTQ:4.

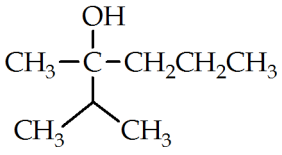
Label the following alcohols as 1°, 2° or 3°

a. 

b. 

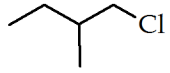
c. 

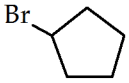
d. 

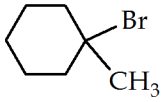
e. 

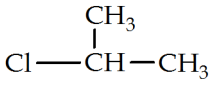
CTQ:5.

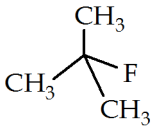
Alkyl halides are classified in the same manner as alcohols. Label the following halides as 1°, 2° or 3°

a. 

b. 

c. 

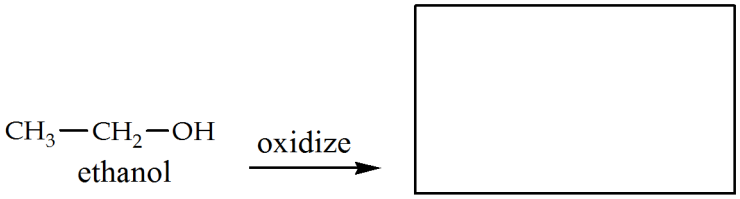
d. 

e. 

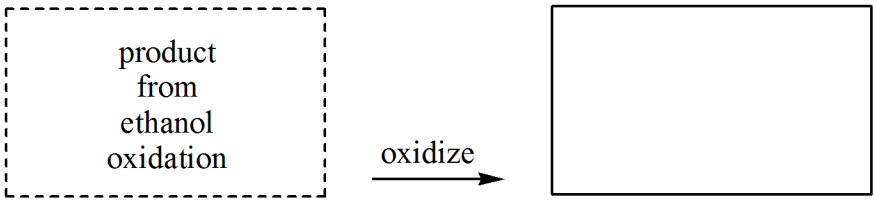
CTQ:6.

Fill in the boxes. Draw the structure for the molecule formed when-

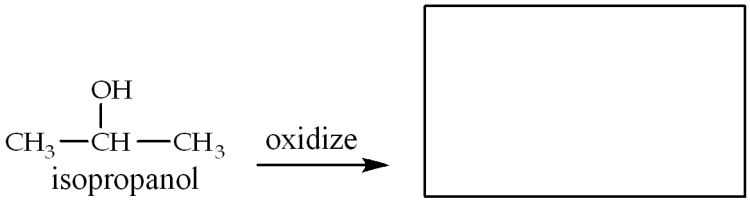
a. ethanol is oxidized to the next higher oxidation state:



b. the product from above is oxidized to the next higher oxidation state:



c. isopropanol is oxidized to the next higher oxidation state:



Lab Report

A. Lucas Test

Start with a clean test tube for each of the alcohols you will be testing.

Add 2 mL of Lucas reagent to a clean test tube. Add approximately 0.5 mL (10 drops) of the alcohol to be tested. Mix the contents by gently shaking, then record your observations and note the time required for the mixture to become cloudy or to separate into two layers. Enter results in Table .

Repeat the procedure for each of the remaining alcohols. If any of your results are uncertain, repeat the test on that alcohol as many times as needed until a definitive conclusion is reached.

TABLE 5.1 Alcohol type refers to 1° 2° or 3°

Alcohol	type	Reaction occurs? (Y/N)	Reaction time	Description of reaction before and after mixing
1-butanol				
2-butanol				
t-butyl alcohol				
isobutyl alcohol				
isoamyl alcohol				
cyclohexanol				
isopropyl alcohol				

CTQ:7.

Using your observations in Table 5.1 , briefly describe a positive result for the Lucas test.

CTQ:8.

Based on your results from Table 5.1 , which alcohol(s) reacted the fastest and which alcohol(s) reacted the slowest or did not react?

CTQ:9.

Using primary, secondary and tertiary labels, list the alcohols in order of reactivity, from fastest to slowest, towards Lucas reagent.

CTQ:10.

Use grammatically correct sentences to formulate a rule describing how the Lucas test can be employed as a qualitative organic test.

B. Oxidation of Alcohols with Jones Reagent

Start with a clean test tube for each of the alcohols you will be testing.

In a clean test tube, dissolve 5 drops of the alcohol to be tested in 1 mL of pure acetone. Add 1 drop of Jones reagent. Be sure the drop of reagent falls into the solution and does not run down the side of the tube; otherwise a false reaction time may result. Record your observations in Data Table 2 and note any color changes that occur. Disregard any color changes or precipitates that form after 10-12 seconds.

Repeat the procedure for each of the remaining alcohols. If any of your results are uncertain, repeat the test on that alcohol as many times as needed until a definitive conclusion is reached.

TABLE 5.2 Alcohol type refers to 1° 2° or 3°

Color change, cloudiness or precipitate in 10 s or less means reaction does occur			
Alcohol	type	Reaction occurs? (Y/N)	Description of reaction before and after mixing
1-butanol			
2-butanol			
t-butyl alcohol			
isobutyl alcohol			
isopropyl alcohol			
cyclohexanol			

CTQ:11.

Using your observations in Table 5.2 , briefly describe a positive result for the Jones test.

CTQ:12.

Based on your results from Table 5.2 , which alcohol(s) reacted the fastest and which alcohol(s) reacted the slowest or did not react?

CTQ:13.

Using primary, secondary and tertiary labels, list the alcohols in order of reactivity, from fastest to slowest, towards Jones reagent.

CTQ:14.

Use grammatically correct sentences to formulate a rule describing how the Jones test can be employed as a qualitative organic test.

c. Ferric Chloride Test for Phenols

Start with a clean test tube for each of the samples you will be testing. All samples are aqueous solutions; one sample is a commercial cleaning product. In a clean test tube, add approximately 1 mL of your first sample and then add 1-2 drops of 1% ferric chloride solution. If there is a change, note the color of the complex that is formed. Repeat the procedure for each of the remaining samples. If any of your results are uncertain, repeat the test on that sample as many times as needed until a definitive conclusion is reached. Since Lysol is already a colored solution, formation of a complex is indicated by a change in the original color. Enter results in Table 5.3 .

TABLE 5.3

sample	positive or negative test result?	Description of any color change
phenol		
p-cresol		
t-butyl alcohol		
1-butanol		
Lysol cleaner		

CTQ:15.

Using your observations in Table 5.3 , briefly describe a positive result for the ferric chloride test.

CTQ:16.

Based on your results from Table 5.3 , which sample(s) gave a positive test; which sample(s) gave a negative test?

CTQ:17.

Use grammatically correct sentences to formulate a rule describing how the ferric chloride test can be employed as a qualitative organic test.

D. Tests for Carbohydrates

For each substrate and unknown, you will need five separate test tubes, one tube for each test. It is recommended that five samples of DI water are mixed first and set aside for the duration of the experiment to serve as a control for each test reagent. Record the color of each control solution. Record the number for each unknown in Table 5.4 .

The substrates and unknown samples are provided as 2% aqueous solutions. The amounts of substrate and test solution to be used are given in the Table. Add each substrate to a clean test tube followed by the test solution. Place tube in water bath (except the iodine test) and record your observations within the time specified for each test.

TABLE 5.4

	Benedict's	Iodine	Seliwanoff's	Bial's	DNP
amt of → substrate	1 mL	1 mL	1 mL	1 mL	1 mL
test → reagent	2 mL	4-5 drops	2 mL	2 mL	
boiling → bath time	10 min		1 min	5 min	10 min
time at → room temp		> 1 min			
substrate ↓	Indicate positive or negative result (P/N) for each test for all samples				
DI water (color)					
starch					
glucose					
fructose					
sucrose					
lactose					
xylose					
unk _____					
unk _____					
unk _____					
unk _____					

CTQ:18.

Which of the samples from Table 5.4 are reducing sugars, which are non-reducing sugars?

CTQ:19.

Use grammatically correct sentences to formulate a rule describing how Benedict's test can be employed as a qualitative organic test.

E. Hydrolysis of Carbohydrates

You will need three test tubes, labeled A, B and C.

Add 2 mL of starch solution to A and B and 2 mL of sucrose solution to C. Add 2-3 drops of concentrated HCl (6M) to each of the test tubes and place them in a boiling water bath for 10 minutes. After 10 minutes, perform the iodine test on test tube A by adding 5-7 drops of iodine. To test tubes B and C, add 10% NaOH dropwise until the pH is just basic to litmus paper. Then perform Benedict's test on B and C. Record your results in Data Table 5. If you think hydrolysis of your unknown would be a useful test then follow the procedure given here. Be sure to neutralize the unknown with NaOH after the water bath before testing with Benedict's reagent. Repeat any test if needed.

TABLE 5.5 Hydrolysis of Di- and Polysaccharides

	Indicate P/N				Indicate P/N	
sample	Benedict's	Iodine		sample	Benedict's	Iodine
Test tube A starch						
Test tube B starch						
Test tube C sucrose						
unknown						

CTQ:20.

According to Table 5.5 , was there any indication that the starch solution was hydrolyzed after heating with acid? Explain your answer and provide evidence for your conclusion.

CTQ:21.

According to Table 5.5 , was there any indication that the glucose solution was hydrolyzed after heating with acid? Explain your answer and provide evidence for your conclusion.

CTQ:22.

What is the identity of your unknown carbohydrate? Be sure to provide ample evidence and reasoning based on your results from Table 5.4 . If hydrolysis was part of the investigation of your unknown, include results from Table 5.5 .

Unknown number _____

EXPERIMENT 6

Why Does Lipstick Stick to Lips

Sticky Lips may or may not be considered attractive. But lips must be sticky enough to hold the color of a lip gloss or the soothing ingredients of a lip balm. Lipstick is a mixture of pigments in a wax base that includes fragrant oils and usually an anti-oxidant (vitamin E) to keep the product from going rancid. There is considerable affinity between the skin and a layer of wax but mechanical stress (eating, kissing, talking) wears away the wax after a period of time. Some formulations use a base of silicon which has superior staying power compared to most waxes due to its greater attraction towards skin. Silicon also encapsulates pigments and other ingredients to prevent them from being absorbed by the skin, prolonging the time between applications.

Developing a long-lasting, wear-resistant product is the goal of producing a high-quality lipstick. Chapstick is a very similar product that does not contain pigments. This lab activity examines the properties of the ingredients used in modern lip care products. Students will make their own lipstick or lip balm by following a general recipe that can be modified to accommodate a variety of colors and fragrances.

There are 2 Main Objectives in this Lab Activity

1. To learn the structure of diverse substances used in the cosmetic industry
2. To investigate some of the physical properties of waxes, fatty esters and other lipids

The goal in this lab activity is to manufacture a tube of lipstick or chapstick.

Cosmetic Ingredients

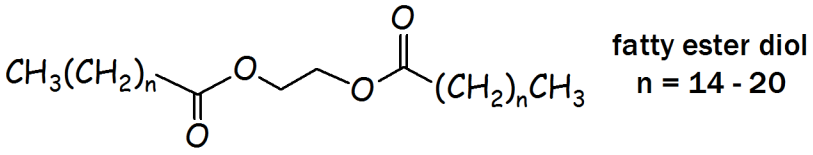
Cosmetic ingredients include waxes, oils, lanolin, fragrant esters and materials called D&C colors (Drug & Cosmetic colors). D&C colors are not suitable for lip products since they are generally water-soluble dyes and will not last in any formulation that is in contact with moisture. The colors found in most lipsticks and gloss come from pearlescent micas which are finely-ground granitic silicate minerals. Mica pigments are commercially available in many colors and tints. The structures of the other main components are shown below.

Waxes

Many different waxes have been used for centuries to make skin products. The two most popular types are beeswax and plant waxes, obviously due to their availability in nature.

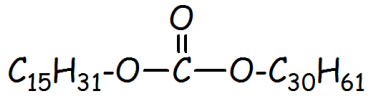
Carnauba wax

Carnauba wax is a yellowish-brown, durable substance produced by the Brazilian palm tree. Carnauba wax is a complex mixture of saturated fatty acid esters and fatty acid ester diols.

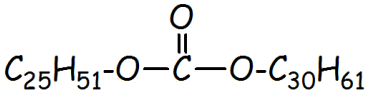


Beeswax

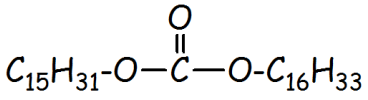
Beeswax is soft, pliable and usually carries a yellow tint due to contamination by pollen grains. This wax is also a mixture of various esters and fatty acids.



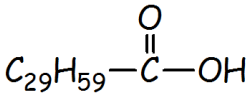
ester of palmitic acid and myricyl alcohol



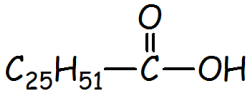
ester of hexaeicosanic acid and myricyl alcohol



ester of palmitic acid and cetyl alcohol



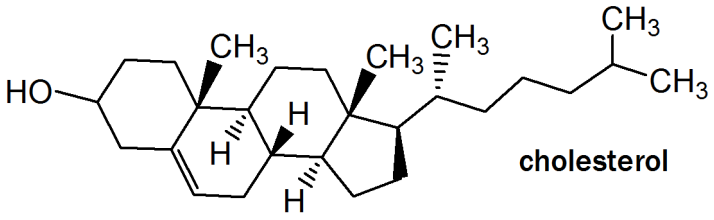
melissic acid



cerotinic acid

Lanolin

Lanolin is a complex mixture of cholesterol, fatty acid esters and other minor substances.

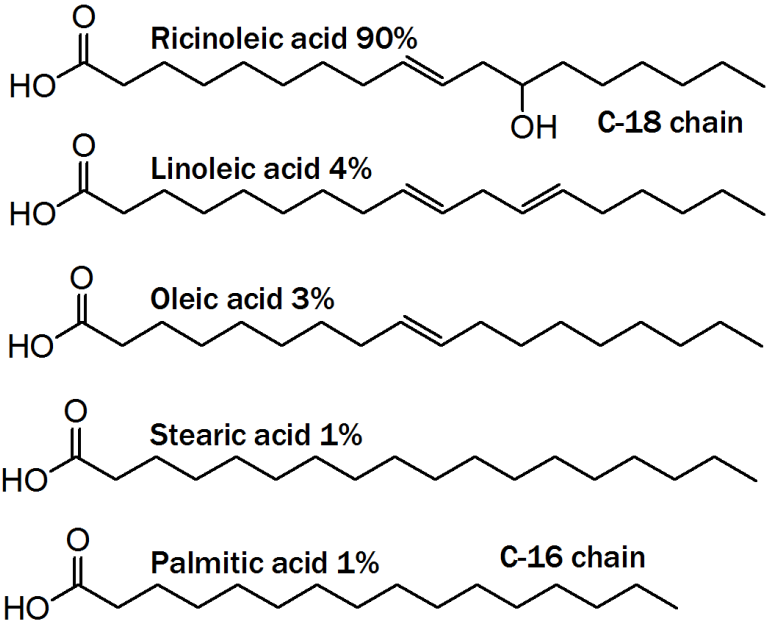


cholesterol

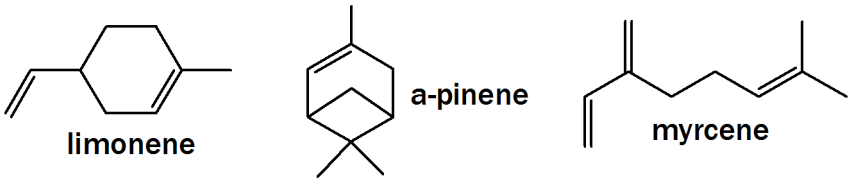
Oils

Several different oils provide the texture, fragrance and anti oxidant properties found in the better quality formulations. The oils include castor oil fruit oils vitamin E plus others.

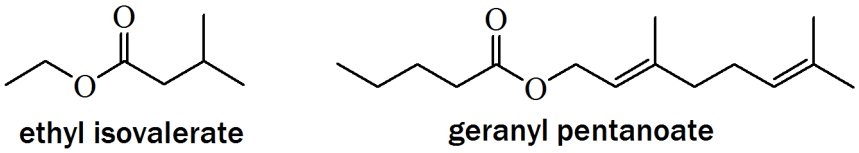
Castor oil is a mixture of fatty acids.



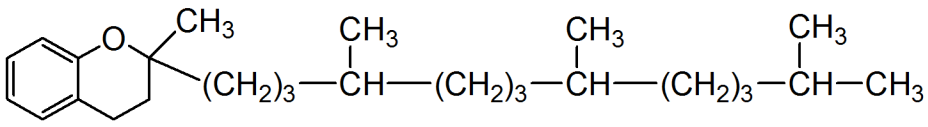
Grapefruit oil fragrance is most likely due to a mixture of terpenes



Apple oil fragrance most likely due to a mixture of esters



Vitamin E oil



Experimental Procedure

The following recipe makes approximately 5 grams of product. This is sufficient to fill one lipstick tube or chapstick container.

Ingredients

Part I

1. 4.0 grams Castor Oil
2. 0.6 grams Iron Oxide/Mica Powder/D&C color
3. Choose one color or mix and match for a total mass of 0.6 g

- Dusty Rose Mica
- Pearl Pink Mica

Part II

1. 0.7 grams Beeswax
2. 0.5 g Carnauba Wax
3. 3 drops Vitamin E Oil
4. 3 drops Lanolin

Part III

Add fragrant oil or a mixture of oils for a total amount of 3-4 drops

3-4 drops of Apple Extract

3-4 drops of Grapefruit Oil

Procedure

1. Place Castor oil and Mica powder from Part I into a small container over very low heat. Stir well.
2. Add the Beeswax, Carnauba wax, Vitamin E oil, and Lanolin from Part II into the container and heat until the mixture until fully melted (approx. 80°).
3. Remove from heat, then add the apple extract and grapefruit oil from Part III, stir, and ***quickly*** pour into lipstick tubes or lip pots. You can use a rubber policeman to help transfer the lipstick liquid into your container. Reheat if necessary to re-melt.
4. Place lipstick tube into ice bath to solidify.

Critical Thinking Questions

CTQ:1.

Would you describe a mixture of wax, oils and mica as a solution, a colloid or a suspension? Explain your answer.

CTQ:2.

Why is there an attraction between lipids and skin? *(Why does lipstick stick to lips?)*

CTQ:3.

Industry insiders claim that beauty pageant contestants cover their teeth with Vaseline to prevent lipstick from sticking to their front teeth. Explain how this strategy might actually be effective.

CTQ:4.

Are you satisfied with the lipstick or lip balm that you manufactured in lab? What changes, if any, would you make in your next batch?

EXPERIMENT 7

Chicken Egg Membrane Osmosis

Osmosis is the passive movement of water across a semipermeable membrane. All cell membranes are permeable to water. The water in our bodies is found in solutions both inside and outside the cells. Under normal conditions, the concentration of all these solutions is the same on both sides of the membrane; these solutions are called **isotonic** relative to each other meaning, same concentration. Osmosis occurs when the concentrations are not equal; water molecules diffuse across a membrane from a region of low solute concentration to a region of high solute concentration. A solution in which the concentration of solutes is lower than the normal cellular concentration is called a **hypotonic solution** (*hypo* means under). A solution in which the concentration of solutes is higher than the normal cellular concentration is called a **hypertonic solution** (*hyper* means over). Osmosis is simply passive diffusion when the water molecules migrate from a hypotonic environment to a hypertonic environment.

Without trying to answer the question of whether an egg is one big cell or one tiny cell with lots of protein, a chicken egg without its shell provides a great model of a cell and its membrane. The first step in this experiment will be to remove the egg shell with minimum disturbance to the other components inside the shell. Underneath the egg shell is a double-layered membrane composed primarily of proteins. Although a protein membrane is quite different from the lipid bilayer membrane found in typical cells, the egg membrane is permeable to water and provides a great model to investigate osmosis. By placing the shell-less egg into solutions of various concentrations, qualitative determinations will indicate which solutions are hypotonic and which are hypertonic compared to the solute concentration inside the egg.

There are Three Main Objectives in this Lab Activity

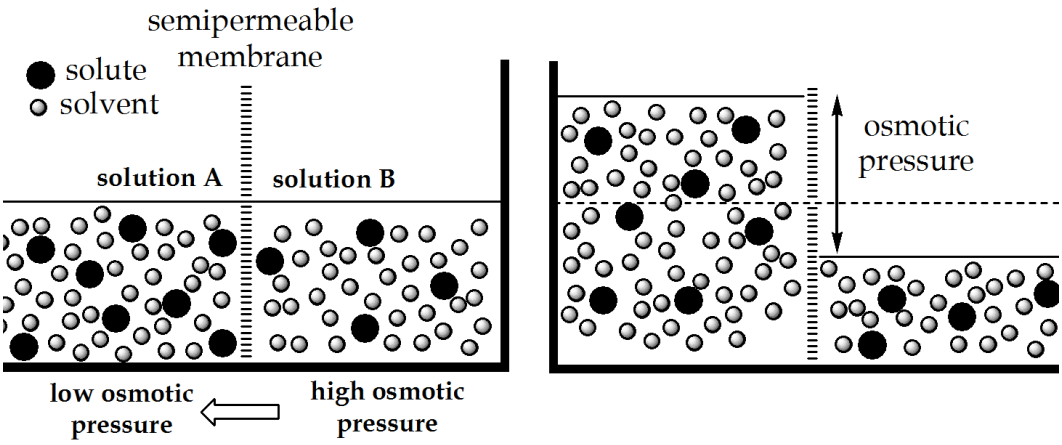
1. Measure the changes in egg mass and changes in solution volume when osmosis occurs through the membrane
2. Learn how to construct x,y graphs to illustrate correlation between two variables
3. Determine if various glucose solutions are hypotonic or hypertonic compared to a chicken egg

The Goal is to Determine the Isotonic Concentration in a Chicken Egg Based on Graphical Data

Osmosis and Osmotic Pressure

Consider a membrane that separates two solutions with different concentrations (**Model 7.1**). As the water molecules approach the membrane, a pressure is exerted on both sides of the membrane. The solution with a greater number of water molecules exerts the greater osmotic pressure. The dilute solution (solution B) has the greater osmotic pressure because it contains more solvent (more water molecules) than the concentrated solution (more solute molecules). Thus, water migrates from the dilute to the concentrated region faster than migration in the opposite direction. Eventually the concentrated solution becomes more dilute and its osmotic pressure increases until equilibrium is established. At equilibrium, water moves through the membrane in both directions at the same rate.

MODEL 7.1 Osmotic Pressure



The formal definition of osmotic pressure is the pressure exerted on a solution to prevent water molecules in that solution from migrating through the membrane. In

Model 7.1, osmotic pressure is represented as the height of a column of liquid, very similar to a schematic diagram representing gas pressure. In other words, if this osmotic pressure were applied to solution A on the left side of Model 7.1, then there would be no migration of water through the membrane.

Osmosis Through the Egg Membrane

Once the egg shell is removed from a raw egg and the egg is placed into a solution, osmosis will begin if the solution concentration is different from the concentration inside the egg membrane. If the solution is hypertonic (relative to the egg concentration) then water will migrate from the egg to the solution and the mass of the egg will decrease. At the same time, the volume of solution will increase.

Removal of Egg Shell to Expose the Membrane

Egg shells are composed of calcium carbonate which undergoes an acid base reaction to produce carbonic acid; carbonic acid is unstable and decomposes to carbon dioxide and water:

MODEL 7.2 Carbonate Reaction with Acids

$$CaCO_3 + 2\,H^+ \longrightarrow H_2CO_3 + Ca^{+2}$$

$$H_2CO_3 \longrightarrow CO_2 + H_2O$$

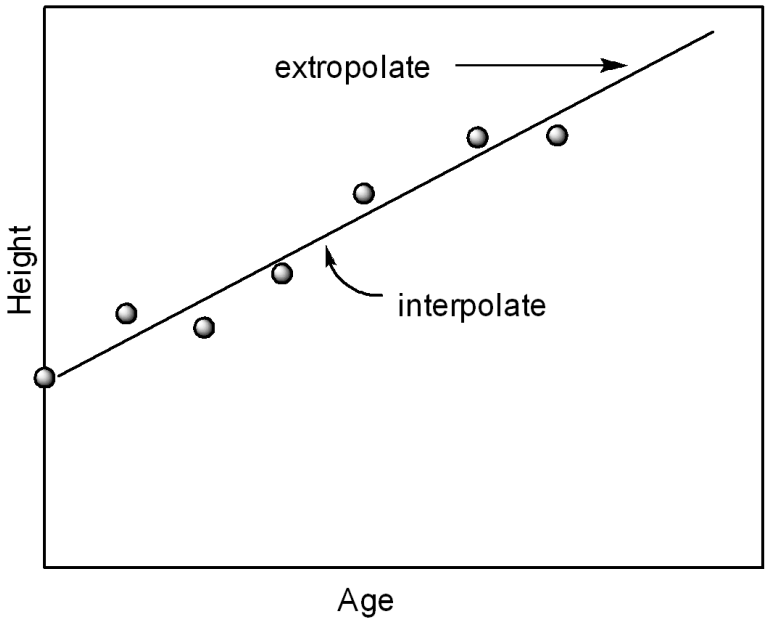
Any acid will react with carbonates, thus there are many choices for this experiment. Vinegar is a 5% solution of a weak acid, acetic acid, and is the classical method used for pickling eggs and making "rubber" chicken bones. However, in this experiment 3*M* HCl is used so that the shells are dissolved in about an hour.

Once the egg shell is removed, the egg obviously becomes more delicate. Care must be taken not only to prevent messy accidents from rough handling but also the danger of ***Salmonella* contamination** is an issue. Be sure to keep hands away from face after handling raw eggs and wash frequently after each encounter with the raw eggs.

Interpretation of Graphs

The x,y graphs to be constructed from your data show results within an interval defined by the values on the axes. Predicting values that extend *beyond the limits of the axes* is called **extrapolation**. Predicting values *between the data points* is called **interpolation.** Shown below is an example of a height vs age chart illustrat-

ing these terms. Notice a best-fit curve (the straight line) is added to the data points to aid with predicting x-values between and beyond y-values.



Experimental Procedure

Students will be working as part of a team. Each team will collect data on six eggs and six solutions of varying concentration. There are six egg/solution combinations to be studied including DI water:

a. DI water
b. 10% sucrose solution
c. 20% sucrose solution
d. 30% sucrose solution
e. 40% sucrose solution
f. 50% sucrose solution

Each student will be assigned one or more combinations (a-f) depending on how many members are in each team.

1. Place a raw egg into a 500 mL beaker and cover with 3M HCl. Carefully place a smaller beaker over the egg; the beaker should contain enough water to keep the egg fully submerged in the acid. It will take approximately one hour for the entire shell to be dissolved.

2. After shell is completely dissolved, remove egg and carefully dry with paper towels. Weigh and record the mass of egg without its shell. This will be your initial mass (weight at time zero). Enter mass in Data table 1

You must use a weigh boat to weigh your eggs. Under no circumstances should you weigh any eggs without a secondary container.

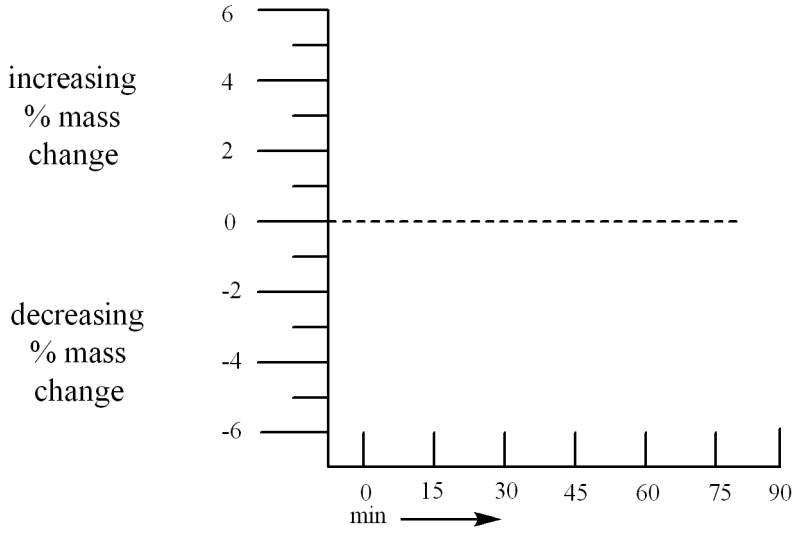
3. Place your egg into the solution that has been assigned to you. After 15 minutes, remove the egg, dry and weigh; enter mass in Data Table 1. Complete this step as quickly as possible and return egg to solution. Mass can be positive (increasing) or negative (decreasing) values.
4. Repeat step 3 every 15 minutes for the next 90 minutes. You will record a total of 7 measurements for each egg/solution combination.

During wait times, for Table 1 enter the **change in mass (Δ) and** the **percent change in mass (%** Δ) for each egg. The delta values are obtained by subtracting initial mass from mass at 15 min, 30 min, etc. Percent change is calculated by dividing the change in mass **(Δ)** by the initial mass and multiplying by 100%.

Graphing Procedure

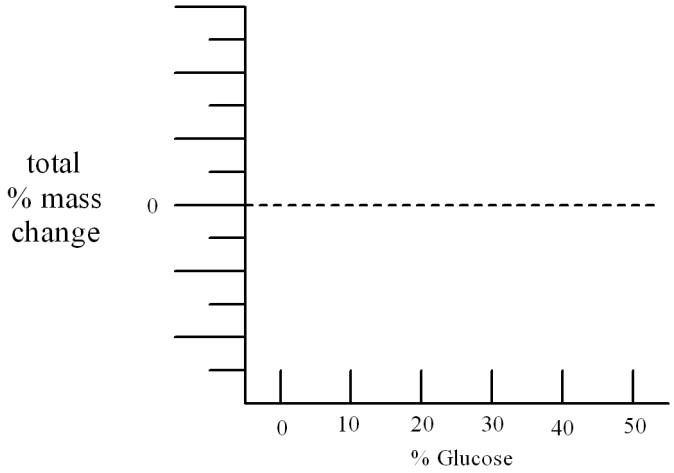
Graph 1 Plot of Total Mass Change vs Time

Use data from Table 7.1 to construct a graph of the % change in mass (vertical axis) versus time (horizontal axis). There will be six lines on the graph, one curve for each solution. Label each curve appropriately.



Graph 2 Plot of Total Mass Change vs Solution Concentration

Use data from Table 7.1 to construct a graph of the total % mass change for each egg (vertical axis) versus its solution concentration. Connect the data points.



Your graphs should resemble the examples shown above; be sure to use a full sheet of graph paper for each plot. Include complete labels for all axes and provide a title for each plot. Decide whether landscape or portrait mode works best for your data.

Lab Report

TABLE 7.1 Initial Mass (g), Change in Mass (Δ), % Change in Mass (%Δ)for Each Solution

	initial mass	mass at 15 min	mass at 30 min	mass at 45 min	mass at 60 min	mass at 75 min	mass at 90 min
DI							
Δ							
% Δ							
10%							
Δ							
% Δ							
20%							
Δ							
% Δ							
30%							
Δ							
% Δ							
40%							
Δ							
% Δ							
50%							
Δ							
% Δ							

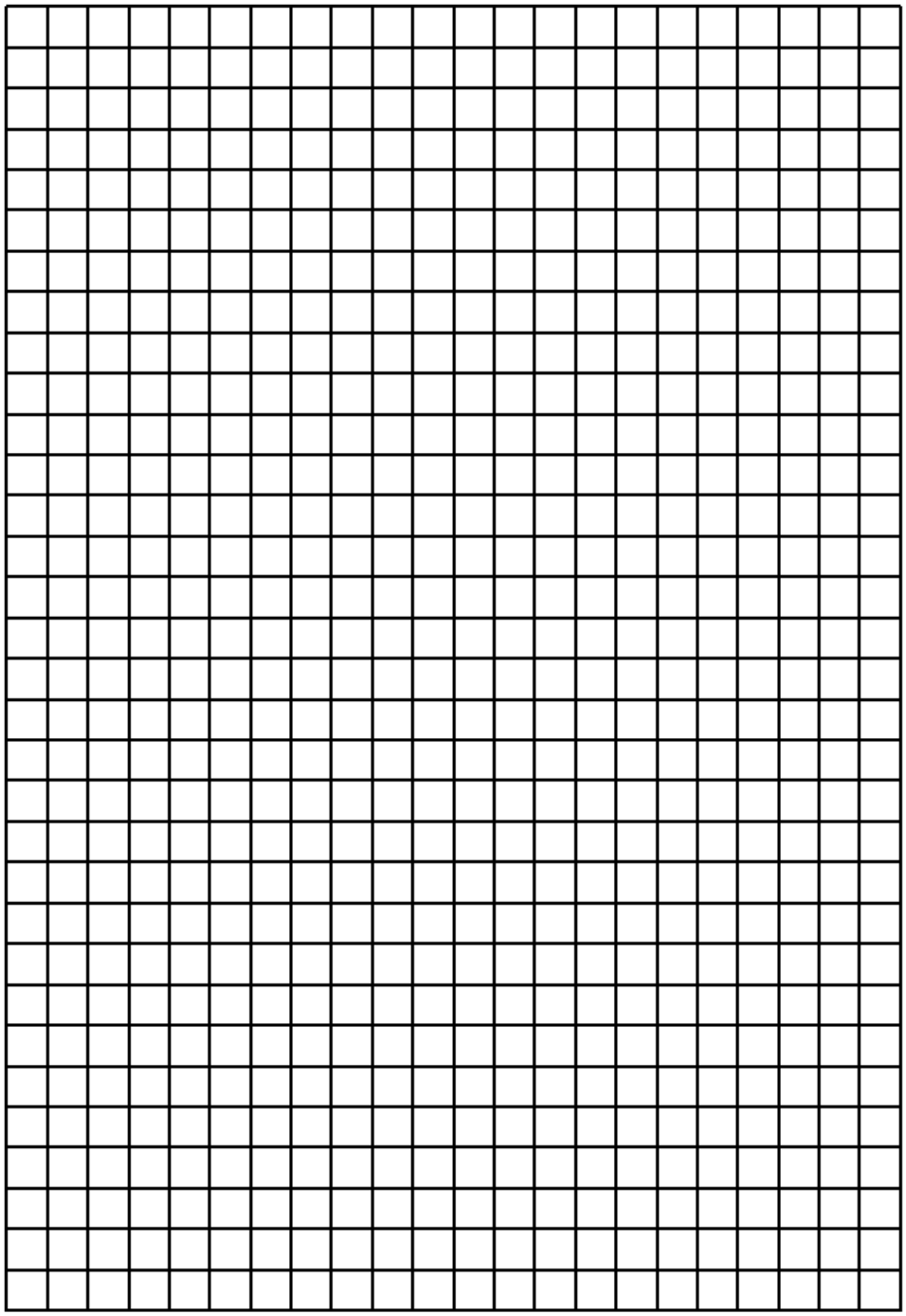
Change in mass (Δ) = [mass - initial mass]

% Change in mass (% Δ) = [Δ / initial mass * 100%]

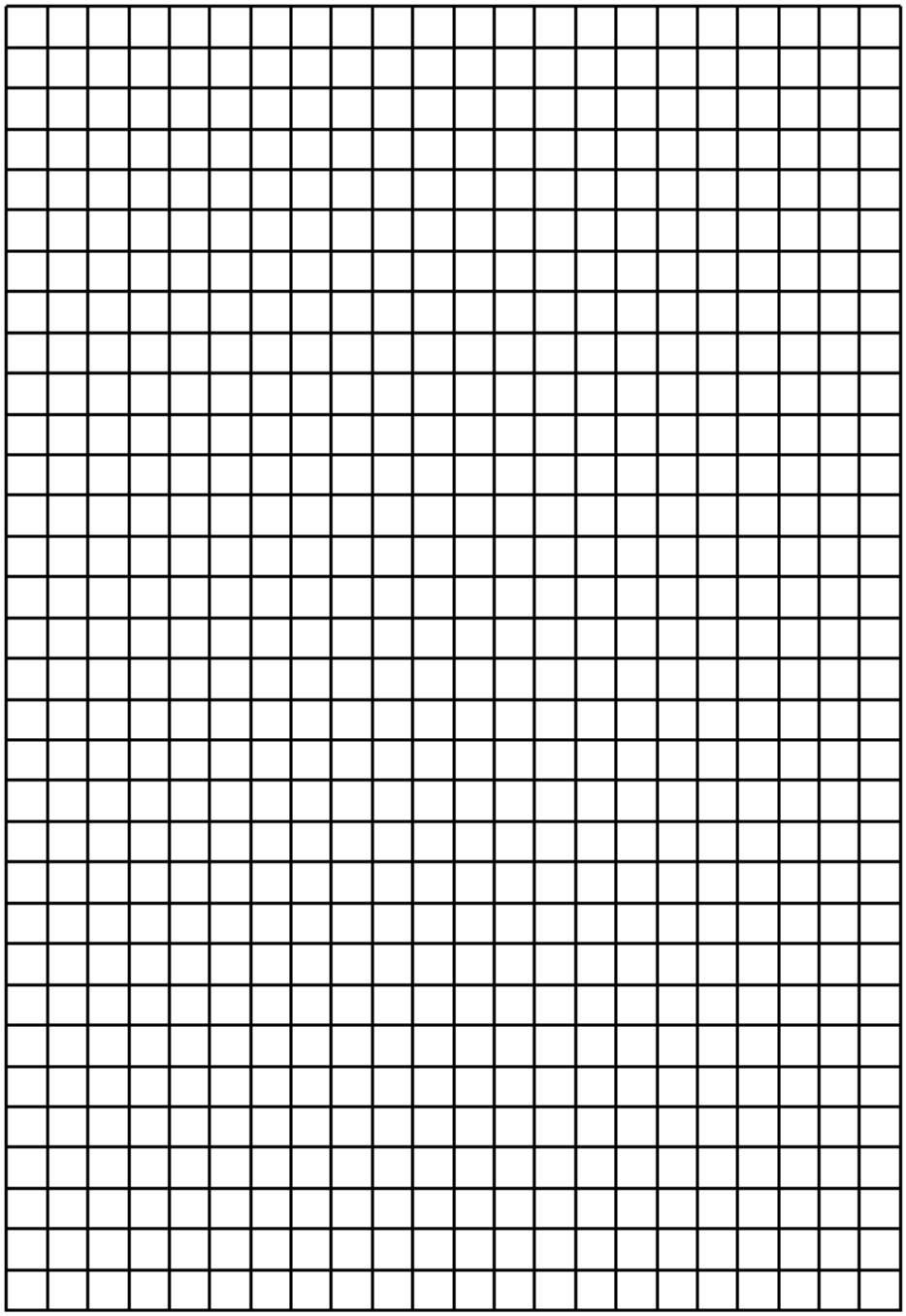
All Table values must be 3 places past decimal point.

Be sure graph values also have 3 places past decimal point.

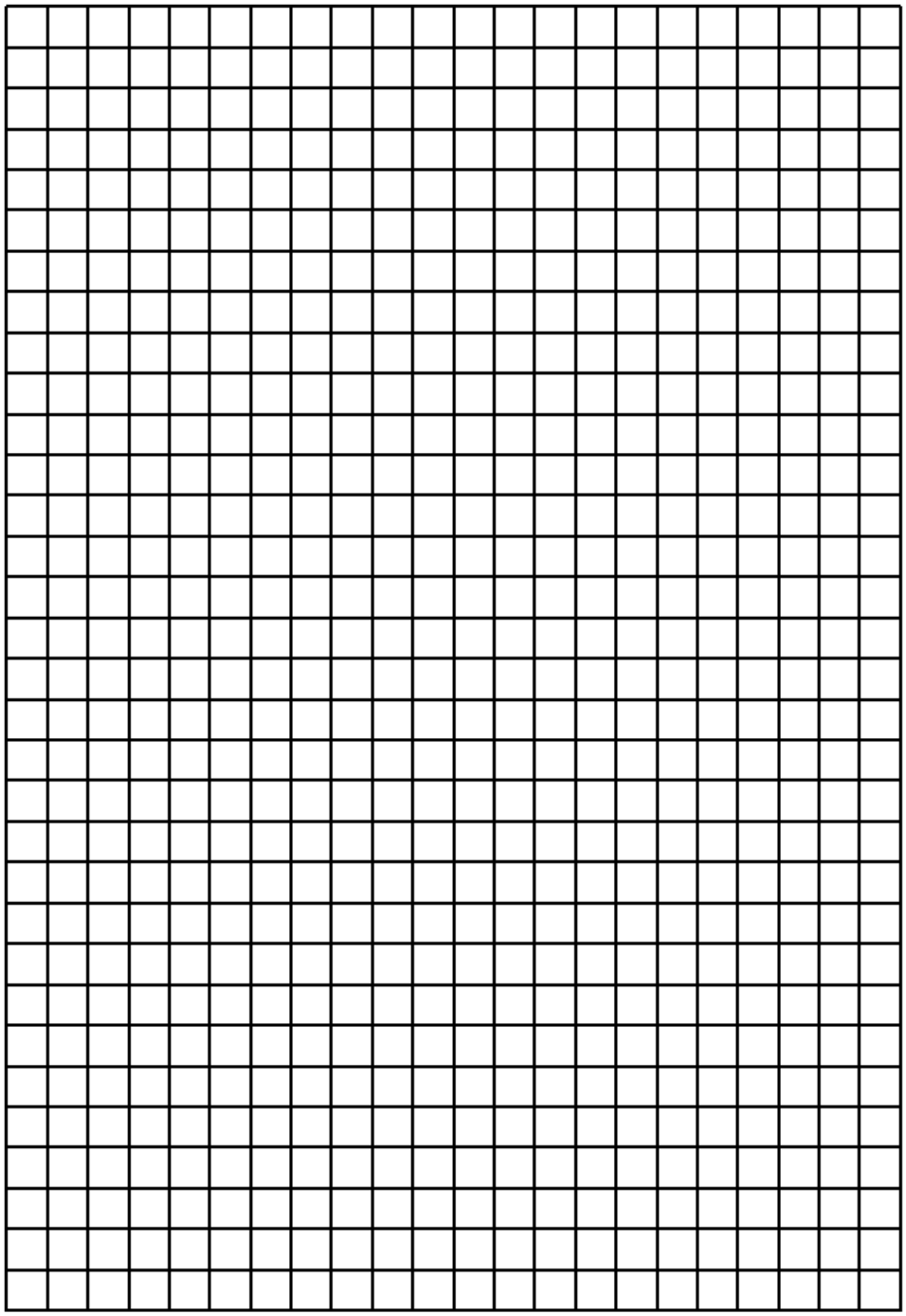
Practice Graph #1



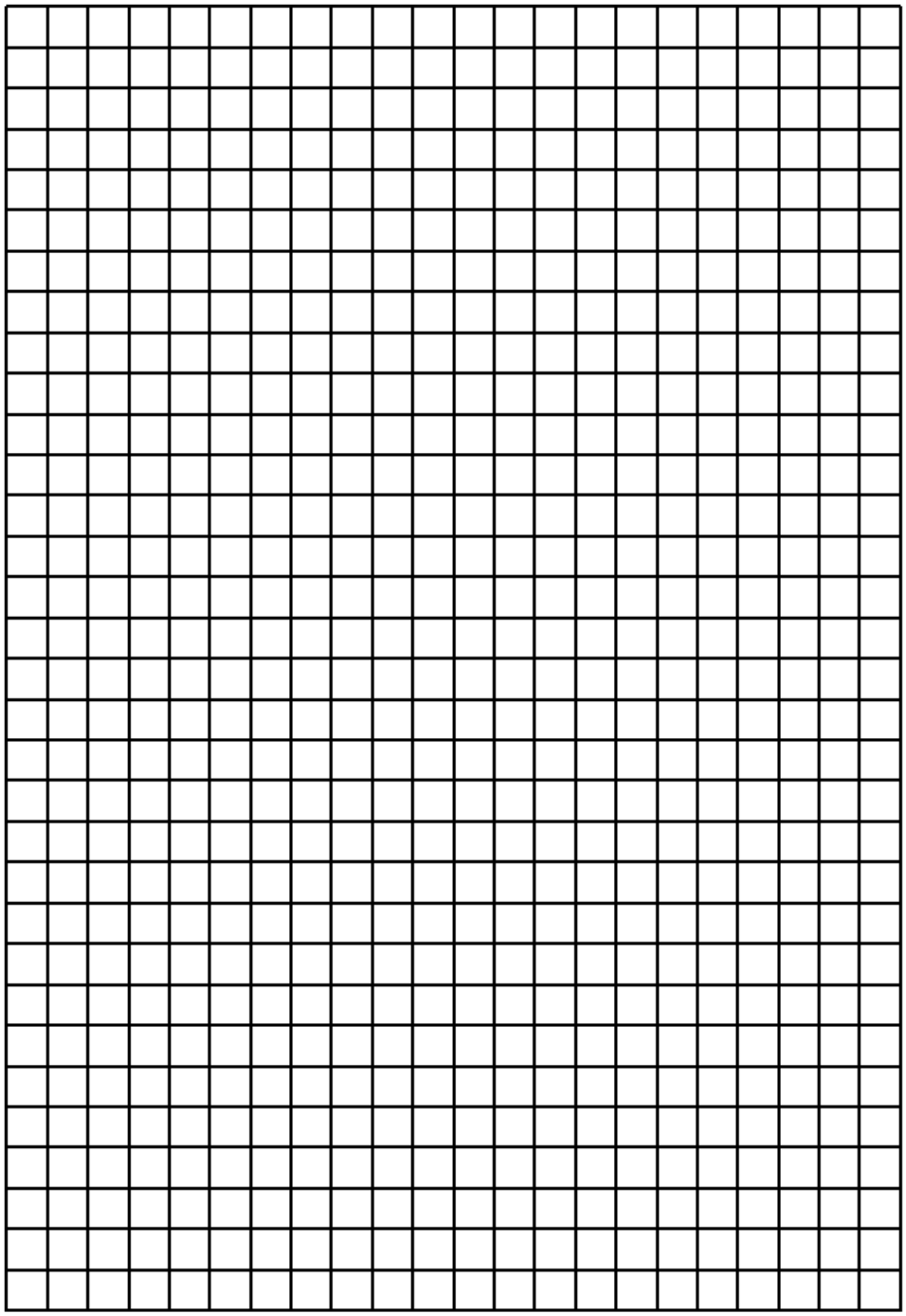
Graph #1 to be submitted with report



Practice Graph #2



Graph #2 to be submitted with report



Critical Thinking Questions

CTQ:1.

Why is change in mass graphed as a percent change rather than the actual mass in grams?

CTQ:2.

If a 5*M* solution and a 2*M* solution are separated by a semipermeable membrane, which direction will the water molecules move?

CTQ:3.

Snails excrete a mucus trail to facilitate mobility; mucus is mostly water. One method to keep snails out of garden areas is to lay down a barrier of table salt. Explain what happens to a snail when it comes into contact with NaCl.

CTQ:4.

Based on your results, is the egg membrane permeable to sugar molecules?

Determine the Isotonic Concentration from Your Graph

Interpolate your results from Graph 2 to determine the isotonic concentration of a chicken egg. What is this value according to your results? Explain briefly.

CTQ:5.

Based on Graph 1, how would you characterize each solution with respect to the egg contents (hypotonic, hypertonic or isotonic)?

DI water	
10%	
20%	
30%	
40%	
50%	

EXPERIMENT 8

Measuring Food Energy by Calorimetry

Organic compounds combine with oxygen to produce heat. This type of reaction is called a **combustion reaction**.

$CH_{4\,(g)} + 2\ O_{2\,(g)} \rightarrow CO_{2\,(g)} + 2\ H_2O_{\,(g)} + \text{heat}$

All combustion reactions are exothermic reactions. A reaction that produces energy is called an **exothermic** reaction. Exothermic reactions produce heat and warm their surroundings. There are many familiar examples of combustion reactions, including the burning of wood. A reaction that absorbs energy is called an **endothermic** reaction. Endothermic reactions absorb heat, and cool their surroundings. Cold Packs used to treat sports injuries utilize an endothermic reaction. The study of heat exchange associated with chemical reactions and physical changes is called **thermochemistry**. The method that measures heat exchange is called **calorimetry**.

Perhaps the most remarkable example of combustion is digestion. The main difference between a fire and digestion is the rate of reaction. Metabolic processes occur in a controlled fashion as opposed to rapid consumption of fuel in a typical fire (or explosion!). Foods produce the same amount of energy regardless of whether they are burned in a campfire or broken down by the metabolic processes of digestion. One method to determine the total energy content of food is to burn the food in a special container and measure the heat produced. This special container is called a **calorimeter**. Like a *speed*ometer that measures speed, or a *thermo*meter that measures temperature, a *calori*meter measures calories which are units of energy.

There are 3 main Objectives in this Lab Activity

1. To understand the fundamentals of thermochemistry

2. To identify the organic substances that provide food energy
3. To use calorimetry to measure food energy

The goal in this lab activity is to determine the caloric content of peanuts.

1. Fundamentals of Thermochemistry

Energy Units

There are standard units of measurement adopted by the scientific community called S.I. units. The standard unit of energy is called the **joule (J)**. A more common energy unit for measuring energy content of food is the **calorie (cal)**. There are 4.184 joules in 1 calorie. By definition: **one calorie is the energy required to raise the temperature of one gram of water by one degree Celsius**. Remember, 1000 calories = 1 kilocalorie (kcal).

It is important to recognize the difference between calories as defined above and the calories recorded on food packaging. It is common to list the energy content in foods as **dietary calories (Cal)**. Notice that this abbreviation uses a capital "C". One dietary calorie (1 Cal) is equal to 1 kilocalorie. That is, when a food label for a soft drink shows that one serving contains 280 Cal, it actually contains 280 kcal or 280,000 calories.

Heat Capacity and Specific Heat Capacity

Heat capacity is a physical property that literally means the ability to store heat without a change in temperature. Heat capacity is a measure of the amount of heat required to change its temperature. Imagine you place a container of water and a metal block in full sunshine on a hot day. After a short time, the metal block will feel warm to the touch whereas the water temperature will not change nearly as much. The reason behind this observation is that water has a much larger heat capacity than metals. A large heat capacity means a substance can absorb more heat than a substance with a low heat capacity before a temperature change is observed. **Specific heat capacity is the amount of heat required to raise the temperature of a (specific) substance by one degree Celsius.** The relationship between heat exchange and temperature change is expressed in Equation 1, where Q is heat (cal), c is the specific heat for that substance (cal/g • °C), m is mass (g) and ΔT is temperature change in degrees Celsius.

$$Q = c \bullet m \bullet \Delta T \qquad \text{(EQ 8.1)}$$

According to Equation 8.1, the amount of heat (Q) exchanged in any chemical or physical process depends on three factors: (1) the specific heat of that substance; (2) the amount of substance; and (3) the temperature change.

(1) As stated previously, the heat exchange will be big for substances with a large heat capacity (large specific heat) because these substances are able to hold and therefore transfer a large amount of heat.

(2) A large amount of sample will transfer more heat than a smaller sample. A bathtub of water holds more heat than a small bucket of water.

(3) Obviously, if the temperature change is big then a big amount of heat must be transferred.

The unknown variable is Q, the value to be determined which represent the amount of heat produced from combustion. If the amount of heat released from combustion is absorbed by water, then the specific heat of water can be used to calculate the calories of heat produced from the combustion reaction.

$$Q \text{ from combustion} = Q \text{ absorbed by water} \qquad \text{(EQ 8.2)}$$

Equation 8.2 simply embodies the concept of conservation of energy. Heat released by combustion is captured by its surroundings.

2. Organic Substances that Provide Food Energy

Not all of the chemical energy in food is available for our body during metabolism. Carbohydrates, fats and proteins are the primary constituents that are converted into food energy. Many foods contain fiber which is a collective term for several non-digestible substances including non-starch polysaccharides and lignin which is a complex polymer in the matrix of cell walls. Lignin provides the crunchy texture of most fruits and vegetables.

On average, only 97% of ingested carbohydrates, 95% of fats, and 92% of proteins are broken down and absorbed by our intestines. The average net or **physiological energy values** for the major energy-yielding nutrients are listed in the following Table. The caloric values listed on food labels usually reflect physiological, not total, energy values. This value is also referred to as **food energy**.

TABLE 8.1 Physiological Energy Values

Nutrient	Cal/g
Fat	9.0
Protein	4.0
Carbohydrate	4.0

Caloric Content of Nuts

Peanuts are an excellent source of protein, energy, vitamins, and minerals. They are low in salt and saturated fats (no cholesterol), and contain dietary fiber. The lipid (fat) portion of peanuts is commonly known as peanut oil, and is responsible for approximately 50% of the peanut's mass, and approximately 75% of the food energy provided by a peanut. Since peanut oil is combustible, we can estimate the food energy of a peanut by measuring the heat released from the combustion reaction when a peanut is burned. The energy value obtained in this experiment is an *estimate* due to many factors. However, this energy value is a useful measure of caloric content since comparisons can be made between different types of food items that contain a substantial amount of fats and oils, greasy snack foods like chips for example.

3. Using Calorimetry to Measure Food Energy

Calorimetry is a measure of the heat exchange in any process. The Law of Conservation states that energy cannot be created nor destroyed only transferred from one substance to another. This is the fundamental principle of calorimetry: heat released from one substance is absorbed by another substance **(Equation 8.2).** The function of a calorimeter is to absorb the heat released by combustion. Corrections may be included to account for the small amount of heat absorbed by the container itself but for our purposes, we assume that all the heat released from combustion is absorbed by the water in the device.

Peanuts burn because the oil is readily combustible. The fat will also ignite some of the other components in the peanut. The heat is absorbed by the water in our crude calorimeter and since the specific heat of water is a known value, we can calculate the amount of energy released (Q) from combustion of one peanut using Equation 8.3.

(EQ 8.3)

$$\textbf{energy released from peanut (cal)} = [\underbrace{\text{mass of water (g)}}_{\text{determine using density of water}}] \times [\underbrace{\text{temp increase (°C)}}_{\text{measured with thermometer}}] \times [\underbrace{\text{1 cal/g °C}}_{\text{specific heat of water}}]$$

Some of the peanut will not burn so we must calculate the energy released per gram by dividing the energy released by the mass of peanut consumed by the flame, Equation 8.4.

(EQ 8.4)

$$\textbf{energy released per gram (cal/g)} = \frac{\text{energy released from peanut}}{\text{mass of peanut burned}}$$

We can compare our experimental results with the theoretical value. The food label will provide the theoretical amount of food energy, Equation 8.5.

(EQ 8.5)

$$\textbf{theoretical amount of energy released (cal/g)} = \frac{\text{number of calories per serving}}{\text{mass of one serving (g)}}$$

Finally, we can calculate our % error which is the difference between the theoretical value and our experimental value, Equation 8.6.

(EQ 8.6)

$$\textbf{\% difference} = \frac{\left[\text{average amount of energy released (cal/g)}\right] - \left[\text{theoretical amount of energy released (cal/g)}\right]}{\text{theoretical amount of energy released (cal/g)}} \times 100\ \%$$

Experimental Procedure

Check out a calorimeter from the instructor. Some assembly may be required.

1. Use a graduated cylinder to measure 200.0 mL of tap water into the can; water should be close to room temperature. Record the amount of water on your data sheet. Cover the calorimeter and insert thermometer into the can. Record the initial temperature of water.
2. Weigh a whole peanut and record its mass and type on the data sheet.
3. Ignite the peanut with a match. As soon as peanut begins to burn, position it underneath the can.
4. As soon as peanut stops burning, carefully swirl the water in the can and record its temperature immediately.
5. Allow peanut to cool then weigh the residue on the balance.
6. Repeat all steps using the same brand of peanut. You may need to run a third trial to improve your technique.

Data Sheet

	trial 1	trial 2	trial 3
mass of water in calorimeter			
brand or type of peanut			
initial mass of peanut			
mass of peanut reside			
mass of peanut combusted			
final water temp			
initial water temp			
change in water temp			

Select your two best trials for calculations A and B.

Calculations and Report

A. Energy released from peanut

sample #1	
sample #2	

B. Energy released per gram of peanut

sample #1	
sample #2	

C. Average amount of energy released per gram

D. Theoretical amount of energy released per gram

E. % Difference

Post Lab Critical Thinking Questions

CTQ:1.

Based on your results and using the table below, how many grams of peanuts would provide enough energy for a 150 lb. person to golf for two hours?

Activity	kcal/kg min
bicycling (racing)	0.127
cross-country skiing	0.099
driving a car	0.015
playing golf	0.065
jogging (fast)	0.173

CTQ:2.

A student purchased a package of cookies from a vending machine and had the snack analyzed for total fat content by Pretty Good Food Labs Inc. Lab results indicate the mass % of fat is 14.8%.

a. How many grams of fat are in a 3.75 g sample of cookie?

b. According to the nutrition label, one serving is 3 cookies which is 3 ounces. How many grams of fat are in one serving? (1 oz. = 28.3 g)

c. The USDA recommends a daily fat intake of 65g for a 2000 calorie diet. How many cookies are equal to the RDA of fat?

EXPERIMENT 9

Investigating the Enzyme Activity of Catalase

Hydrogen peroxide, H_2O_2, is a toxic by-product of metabolism which must be eliminated before damage occurs to tissue cells. Fortunately, peroxide is easily reduced to water and oxygen in the presence of the enzyme Catalase.

$$H_2O_2 \xrightleftharpoons{Catalase} H_2O + O_2$$

Catalase is found in almost all plant and animal tissues. Plants that have fleshy storage organs such as fruits and potatoes contain large amounts of catalase which makes isolation of this enzyme relatively easy. Since pure enzyme is not essential to study its catalytic activity, crude extract from potatoes will be used in this experiment.

The enzyme must be capable of catalyzing several thousand reactions per second in order to carefully regulate toxic peroxides. In fact, Catalase is responsible for both decomposition and formation of hydrogen peroxide since various human immune cells actually produce H_2O_2 to kill foreign bacteria and viruses. White blood cells produce a flash of peroxide at the site of flesh wounds presumably for similar purpose.

Three aspects of enzyme activity will be studied in this experiment, the effect of pH on reaction rate, temperature effects and inhibition by metal ion contamination. A solution of hydrogen peroxide will be used as substrate and reaction rates will be determined by measuring the time for a small paper disk to rise through the peroxide solutions. The disks will be treated with the enzyme and then submerged into a peroxide solution. As the reaction proceeds and oxygen is formed, the gas bubbles will be trapped by the paper disk and rise to the surface.

There are Four Main Objectives in this Lab Activity

1. To prepare an active enzyme extract from raw potatoes
2. To measure the effects of temperature and pH on enzyme activity and determine the optimum pH and temperature for catalyase
3. To observe enzymatic inhibition by heavy metal contamination
4. To interpret graphs for determination of enzyme activity

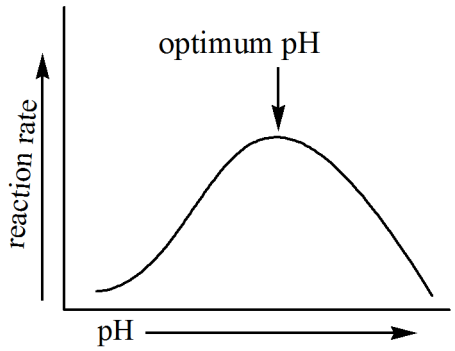
The goal in this lab is to determine the optimum pH and optimum temperature for the catalase enzyme.

Factors that Influence Enzymatic Activity

pH Effects

Enzymes are affected by pH. The pH value at which an enzyme is most active is called the optimum pH. As the hydrogen ion concentration deviates from the optimum pH, enzymatic activity becomes sluggish and will cease when pH changes significantly from the optimum value. Large changes in pH disrupt the salt bridges and ion forces that maintain the secondary and tertiary structure of proteins and results in denaturation.

MODEL 9.1 pH Effect on Enzyme Reaction Rate

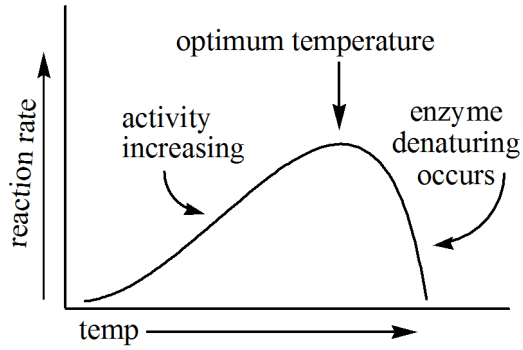


Temperature Effects

The rate of most reactions will increase as the temperature is raised. A rule of thumb is that a temperature increase of ten degrees will double the reaction rate. However, most enzyme-catalyzed reactions are adversely affected by temperature

changes that deviate from normal body temperature. At high temperatures, enzymes start to denature. Below body temperature, there may not be sufficient energy to overcome the activation energy of reaction. Lab experiments involving enzymes are often carried out within a temperature range of about 5° - 25°C to preserve the integrity of the enzyme.

MODEL 9.2 Temperature Effect on Enzyme Reaction Rate

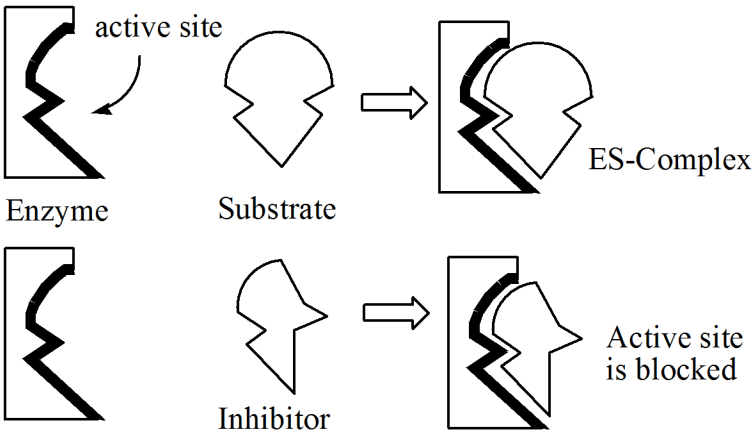


Inhibitors

Enzyme catalysis is greatly inhibited by the presence of metal ions. For example, one mode of action that has been characterized in some detail is the binding effect of metal ions to the –SH groups in the polypeptide side chains. Disruption of the disulfide bridges results in destruction of the tertiary structure of the enzyme. Another mode of action is simply displacement of the common native metal ions of sodium and calcium (enzyme cofactors) by any other metal ion such as mercury, lead, copper, chromium, cadmium and a host of other environmental contaminates.

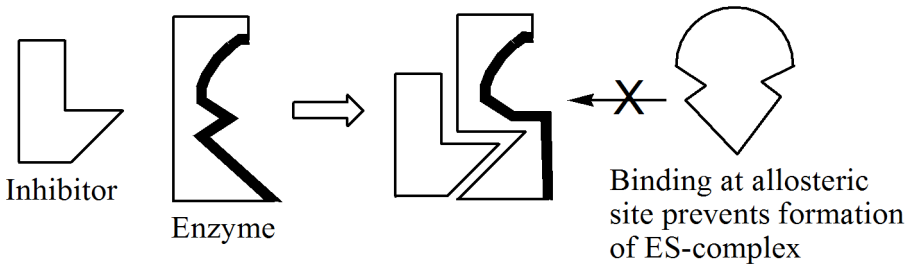
The two main types of inhibitors are referred to as competitive or non-competitive. Competitive inhibitors resemble the structure of the substrate and thus, compete for the active site because both the inhibitor and the substrate satisfy the "lock-and-key" requirements for the enzyme-substrate complex (ES complex).

MODEL 9.3 Enzyme-Substrate Complex and Competitive Inhibition



Non-competitive inhibitors bind to allosteric sites on the enzyme and alter the enzyme in some manner that prevents the substrate from locking into the active site. It is generally understood that non-competitive inhibitors cause a conformational change in the native structure of the enzyme.

MODEL 9.4 Non-Competitive Inhibition Alters the Active Site



Substrate concentration studies may elucidate the type of inhibition. Competitive inhibition can be overcome by increasing the concentration of substrate. Higher concentrations will increase the number of encounters between substrate and active site and return the enzyme to normal activity. On the other hand, a non-competitive inhibitor is not competing for the active site, thus, increasing the substrate concentration will not alter the enzyme activity.

Either type of inhibition may be reversible or irreversible. An irreversible inhibitor dissociates very slowly (or not at all) from the enzyme regardless of whether the inhibitor is bound to the active site (competitive) or an allosteric site (non-competitive). Reversible inhibition involves rapid dissociation of the inhibitor from the enzyme.

Graphing Reaction Rates

Rates are typically stated in reciprocal seconds (s-1). For example, Superman's speed (faster than a speeding bullet) can be expressed in miles per second. The units for speed may be written as a quotient or a mathematical product:

Speed = mi/s = mi · s-1

The rate of an enzymatic reaction is the amount of substrate converted to product per second which is illustrated by this equation:

Enzyme reaction rate = amount of substrate converted to product seconds

Since you will be recording time in seconds, the rate at various pH values and the rate at different temperatures will be graphed in reciprocal seconds. Thus, in some fashion, your graphs should resemble the examples shown in Model 9.1 and Model 9.2.

Experimental Procedure

Extraction of Catalase from Potatoes

1. Remove the skin from a fresh potato and cut into small pieces. Place a 50 gram sample of potato into a blender and add 50 mL of ice-cold DI water.
2. Pulverize the sample for 15-20 seconds at high speed.
3. Filter the extract with cheese cloth to remove large particulate matter.
4. Do a second filtration with filter paper and collect in a 100 mL beaker. At this point, you should have a fairly homogeneous mixture of potato extract.
5. Add 25 mL of ice-cold DI water to your extract and place contents in an ice bath for the remainder of the experiment.

Practice measuring volume with a pipet. Squeezing the pipet bulb, withdraw a sample of water into the pipet and dispense into a 10 mL graduated cylinder. Repeat several times and note the volume that is transferred after each trial. This should be approximately 1 mL for every squeeze of pipet bulb. The actual amount is not crucial but should be consistent each time you transfer liquid. Repeat the transfer 3-5 times until you become consistent at using a pipet to transfer the same volume each time.

Using a single-hole paper punch, create several paper disks from a filter paper. Collect 12-15 disks. Avoid excess handling to prevent oil from your hands absorbing onto the paper.

You will be recording time (in seconds) and calculating reaction rate (in reciprocal seconds). As you tabulate your results in the Data Tables to follow, round each entry to 2 sig. figs.

Experimental Procedure

Part A

pH Effects on Enzyme Activity

Obtain a sample of hydrogen peroxide in sufficient quantity to complete Part A (approximately 30 mL). This may sit at room temperature for the duration of Part A.

1. Place five large test tubes in a rack and label as samples #1a - #5a. Test tubes must all be the same size and diameter. Be sure test tubes are not leaning but standing vertical in the rack. Add approximately 2 mL of 3% hydrogen peroxide to each tube. The exact amount is not crucial as long as you have the same amount in each tube.
2. Add 2 mL of buffer to samples 1-4 as follows:

Sample #1a Add 2 mL buffer pH =3

Sample #2a Add 2 mL buffer pH = 5

Sample #3a Add 2 mL buffer pH = 9

Sample #4a Add 2 mL buffer pH = 10.5

Sample #5a is the control- no buffer is added

3. Use DI water and fill each test tube to about 1 inch from the top. Be sure the volumes are the same for each sample. Cover each tube with small piece of parafilm and mix contents by shaking. Remember sample #5 contains only DI water.
4. Measure the temperature of sample #5 and use this as the temperature for all of Part A of the experiment. Record temperature in Table 9.1 .
5. Use clean forceps and dip a paper disk into the catalase extract for 3-5 seconds. Use caution and try not to wet the forceps excessively with the enzyme extract. Drain excess liquid from the disk by touching the disk to the side of the beaker. Immediately drop the disk into sample #1a. The paper should sink to the bottom of the test tube. As the reaction begins to produce oxygen gas, the gas bubbles will lift the disk. Record the time it takes for the disk to float to the surface; enter reaction times in Table 9.1 . Start your time clock as soon as the disk

reaches the bottom of the test tube. If the disk starts to rise before reaching the bottom, start your clock as soon as it starts to rise.

6. Add a paper disk to samples #2a-5a and record reaction times as before.
7. Empty each sample into a waste container, rinse tubes with DI water and repeat the procedure two more times. Test tubes for the second set should be labeled as samples as #1b - 5b and the third set labeled as #1c - 5c. The temperature for the second and third sets must be within 2°C (or less) of the first sample.
8. You should end up with 3 trials for each sample. Calculate the average for the five samples and record in Table 9.2 .

Experimental Procedure

Part B

Temperature Effects on Enzyme Activity

Obtain a sample of hydrogen peroxide in sufficient quantity to complete Part B (approximately 12 mL). This may sit at room temperature for the duration of Part B.

1. Place three large test tubes in a rack and label as samples #6a, #7a, #8a. Test tubes must all be the same size and diameter. Be sure test tubes are not leaning but standing vertical in the rack. Add approximately 2 mL of 3% hydrogen peroxide to each tube. The exact amount is not crucial as long as you have the same amount in each tube.
2. Use DI water and fill each test tube to within 1 inch from the top and mix contents according to previous instructions.
3. Measure the temperature of sample #6 (should be approx. room temp) then quickly add a paper disk containing catalase extract according to previous instructions. Measure the time it takes for disk to float to the surface. This will be your control sample. Record temp and reaction time in Table 9.3 .
4. Place sample #7 into an ice bath and cool to approximately 4°C. Measure the temperature of your solution with a thermometer to be sure contents have reached 4°C, then quickly add a paper disk soaked with catalase as before. Measure the time it takes for disk to float to the surface; record in Table 9.3 .
5. Place sample #8 into a hot water bath and heat to approximately 80°C. Measure the temperature of your solution with a thermometer to be sure contents have reached 50°C, then quickly add a paper disk soaked with catalase as before. Measure the time it takes for disk to float to the surface (Table 9.3).
6. Empty each sample into a waste container, rinse tubes with DI water and repeat the procedure once more. The temperature for the second set must be within 2°C (or less) of the previous sample. Test tubes for the second set should be labeled as samples as #6b - 8b.

7. You should end up with 2 trials of each sample. Calculate the average for the three samples and record values in Table 9.4 .

Experimental Procedure

Part C

Effect of Copper Sulfate on Enzyme Activity

Obtain a sample of hydrogen peroxide in sufficient quantity to complete Part C (approximately 20 mL). This may sit at room temperature for the duration of Part C.

1. Place five large test tubes in a rack and label as samples #9a, - 13a. Test tubes must all be the same size and diameter. Be sure test tubes are not leaning but standing vertical in the rack. Add approximately 2 mL of 3% hydrogen peroxide to each tube. The exact amount is not crucial as long as you have the same amount in each tube.
2. Add the following amounts of 0.1 M $CuSO_4$ to each sample:

#9 none this will be your control sample)

#10 2 drops

#11 10 drops

#12 20 drops

#13 25 drops

3. Use DI water and fill each test tube to within 1 inch from the top and mix contents according to previous instructions.
4. To each test tube, add a paper disk containing catalase extract according to previous instructions. Measure the time it takes for disk to float to the surface. Record temp and reaction time in Table 9.5 .
5. Empty each sample into a waste container, rinse tubes with DI water and repeat the procedure once more. The temperature for the second set must be within 2°C (or less) of the previous sample. Test tubes for the second set should be labeled as samples as #9b - 13b.
6. You should end up with 2 trials of each sample. Calculate the average for each sample and record values in Table 9.5 .

Graphing Your Results

You will construct 3 separate graphs using your experimental data.

Graph A Reaction rate vs. pH (Use results from Table 9.2)

Graph B Reaction rate vs. Temperature (Use results from Table 9.4)

Graph C Reaction Rate vs. Amount of Inhibitor (Use results from Table 9.5)

Be sure to implement best practices for making your graphs:

- Provide a title for each graph
- Label each axis
- Use the appropriate scale for each axis so that you utilize the entire graph

Lab Report

Part A

TABLE 9.1

Temperature _____

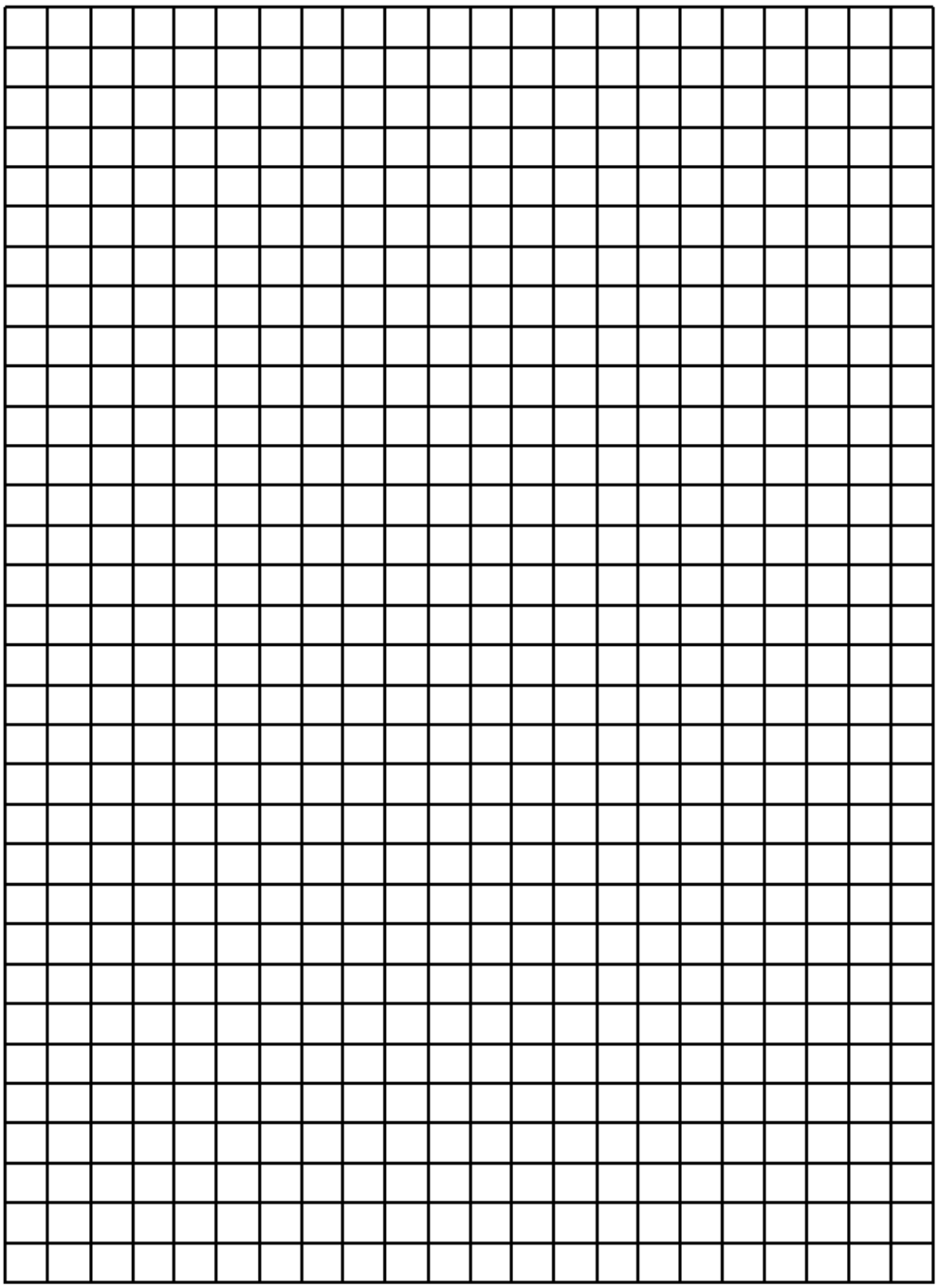
sample	pH	Reaction time (s)	Reaction rate (s^{-1})
1a			
2a			
3a			
4a			
5a			
1b			
2b			
3b			
4b			
5b			
1c			
2c			
3c			
4c			
5c			

TABLE 9.2

samples	pH	Average reaction time (s)	Average rate (s^{-1})
1a, 1b, 1c			
2a, 2b, 2c			
3a, 3b, 3c			
4a, 4b, 4c			
5a, 5b, 5c			

Graph from Part A

Use average data values from Part A and construct a graph of reaction rate vs. pH. Include Title and label both axes and draw a best-fit curve to connect data points.



Part B

TABLE 9.3

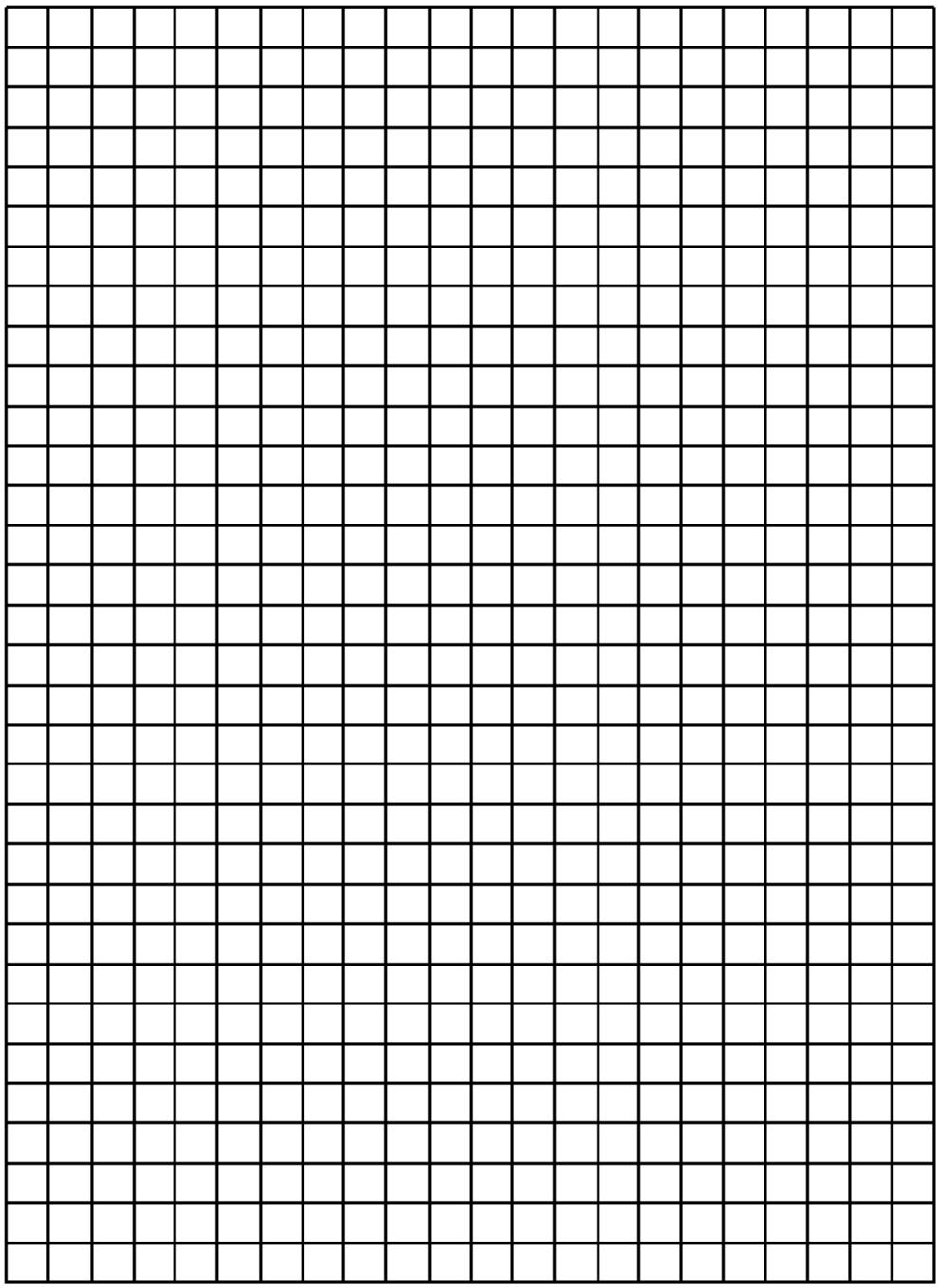
sample	temp	Reaction time (s)	Reaction rate (s^{-1})
6a			
7a			
8a			
6b			
7b			
8b			

TABLE 9.4

samples	average temp	Average reaction time (s)	Average rate (s^{-1})
6a, 6b			
7a, 7b			
8a, 8b			

Graph from Part B

Use average data values from Part B and construct a graph of reaction rate vs. temp. Include Title and axes labels.



Part C

TABLE 9.5

Temperature _____

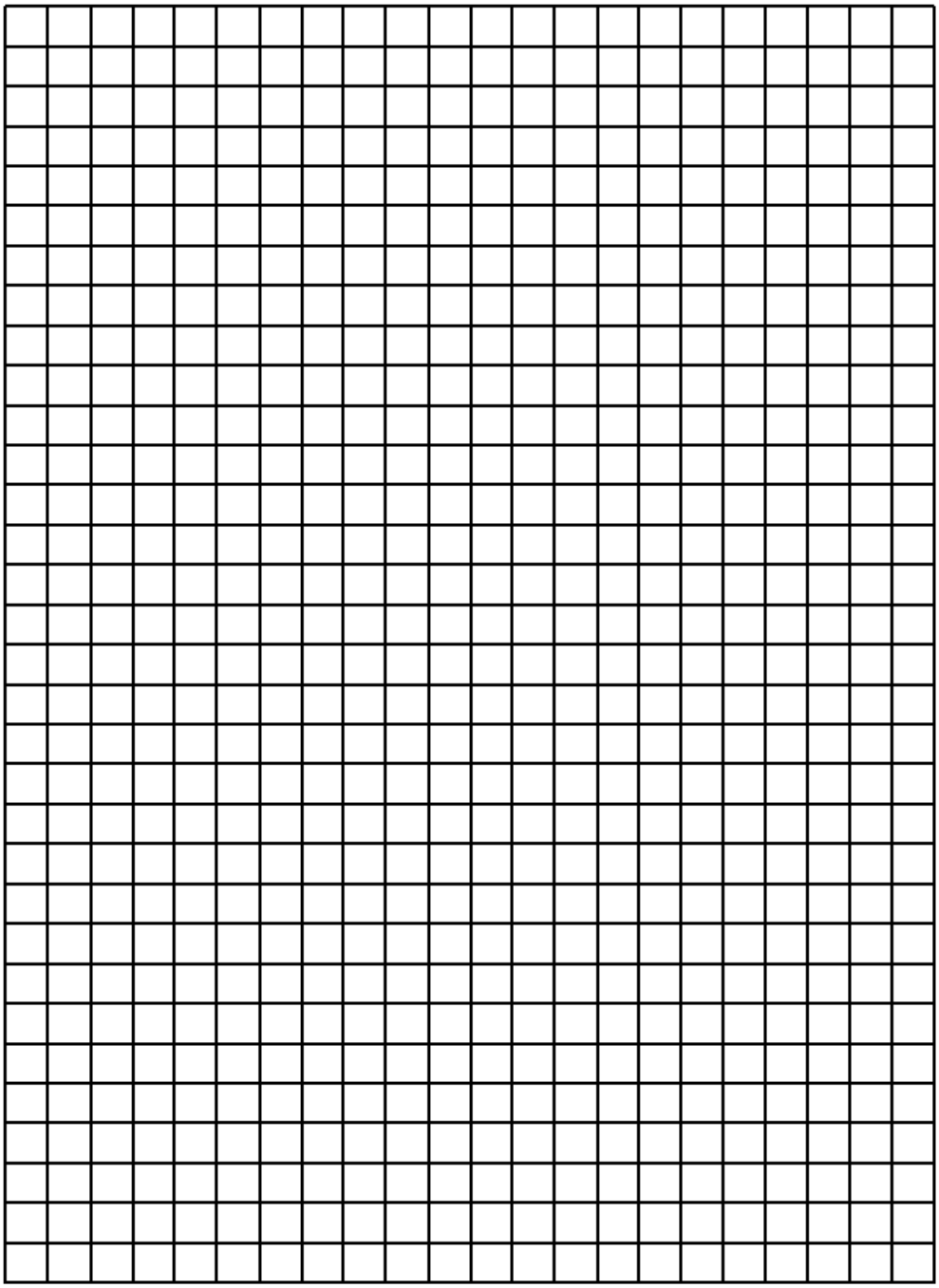
sample	Drops of $CuSO_4$	Reaction time (s)	Reaction rate (s^{-1})
9a			
10a			
11a			
12a			
13a			
9b			
10b			
11b			
12b			
13b			

TABLE 9.6

samples	average number of drops	Average reaction time (s)	Average rate (s^{-1})
9a, 9b			
10a, 10b			
11a, 11b			
12a, 12b			
13a, 13b			

Graph from Part C

Use average data values from Part C and construct a graph of reaction rate vs. amount of $CuSO_4$. Include Title and axes labels.



Critical Thinking Questions

CTQ:1.

Write the balanced chemical reaction for the decomposition of hydrogen peroxide.

CTQ:2.

Use grammatically correct sentences to explain the movement of the paper disk.

CTQ:3.

According to your results, what is the optimum pH for the enzyme catalase?

CTQ:4.

According to your results, what is the optimum temperature value for the enzyme catalase?

CTQ:5.

What is the substrate in this experiment?

CTQ:6.

What is the inhibitor used in this experiment?

CTQ:7.

Examine the graph from Part C. By interpolation (or extrapolation), how many drops of $CuSO_4$ would stop all enzymatic activity? Provide a brief explanation for your answer.

CTQ:8.

Examine the graph from Part B. Describe the part of the graph that most likely corresponds to enzyme denaturing.

EXPERIMENT 10

Extraction of Nucleic Acids from Strawberries

Extraction of nucleic acids is an important laboratory technique that provides DNA samples for a variety of purposes such as screening of newborns for genetic diseases, studying cancer genes and as an investigation tool in forensic science. In theory, DNA can be extracted from any plant or animal tissue. This experiment uses strawberries as a source of DNA because the fruit has a relatively large genome. Strawberries are octoploid (eight copies of each chromosome), which means their cells are relatively larger than other plant cells and contain copious amounts of nucleic acids. The nucleic acid component of the cells is collectively referred to here as DNA, although nucleic acids include both DNA and RNA. In this experiment, no effort is made to distinguish between the two types of nucleic acids.

There are 3 Main Objectives in this Lab Activity

1. To understand how cell components can be separated by exploiting solubility behavior
2. To understand the properties of nucleic acids
3. To observe the effect of heat on strands of DNA

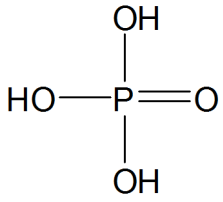
The goal in this lab activity is to extract a sample of DNA from strawberries and study the effects of heat on nucleic acids.

Properties of Nucleic Acids

Acid/Base Properties of DNA

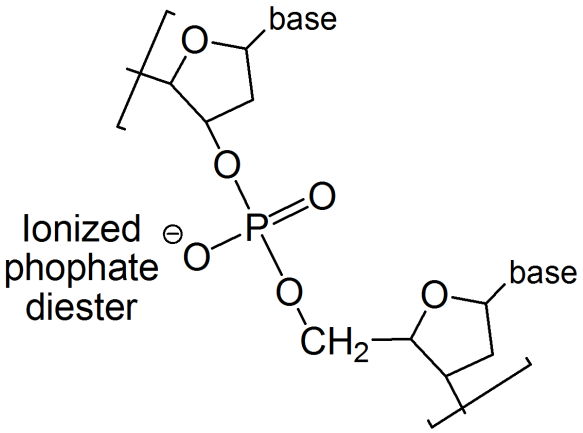
DNA is usually characterized by the four different bases that it contains, although the basic properties of the purines and pyrimidines are diminished by the hydrogen bonds between the base pairs. However, DNA does have acidic properties due to the phosphate groups which are in fact, derivatives of triprotic phosphoric acid.

FIGURE 10.1 Phosphoric Acid, H_3PO_4



When two of the acidic protons are exchanged for the carbon atoms of ribose, a phosphate diester is formed and the remaining proton is very acidic- DNA phosphate groups have pKa values close to zero. At physiological pH, the DNA backbone is deprotonated at the phosphate groups and carries multiple negative charges. The acidic properties of DNA dominate its behavior and explain why they are named nucleic acids; in a sense, they are derivatives of phosphoric acids. Indeed the ionic nature of DNA greatly influences important properties such as solubility.

FIGURE 10.2

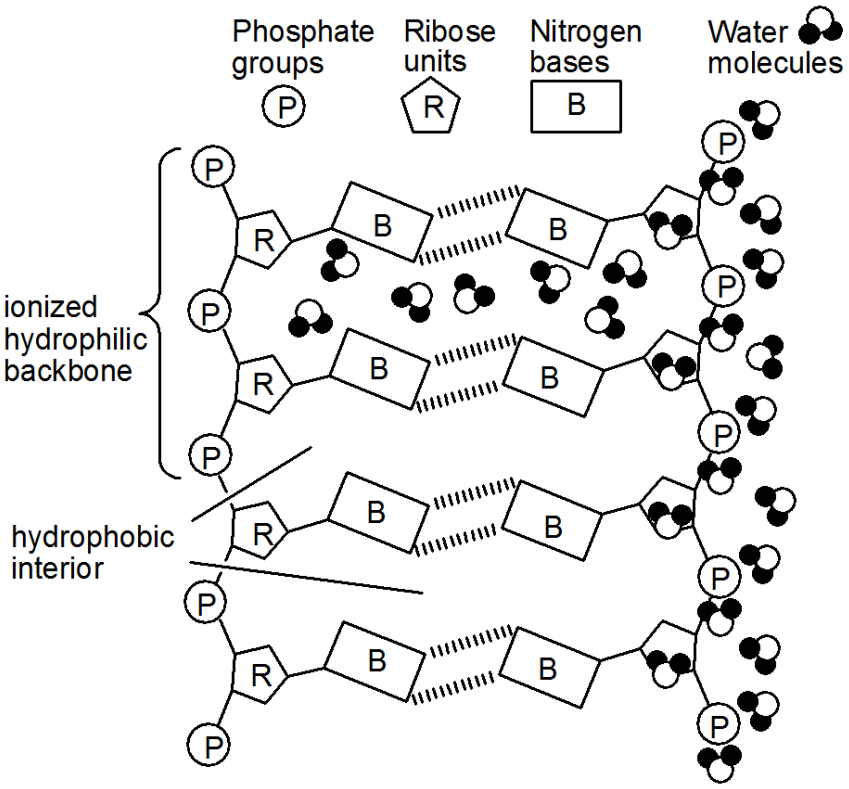


Solubility of DNA

DNA is soluble in water. Its solubility is determined by the nature of the three main components- the polyhydroxy sugars and highly ionic phosphate groups are water soluble but the nitrogen bases are not. When these three groups are bonded together, the resulting nucleotide is water soluble due to the overwhelming hydrophilic nature of the sugar-phosphate backbone. Nucleic acids are simply amplified structures, polymers, of these water-soluble nucleotides. Since most of the volume inside a cell consists of water, DNA provides an interesting study in intermolecular attractions and repulsions.

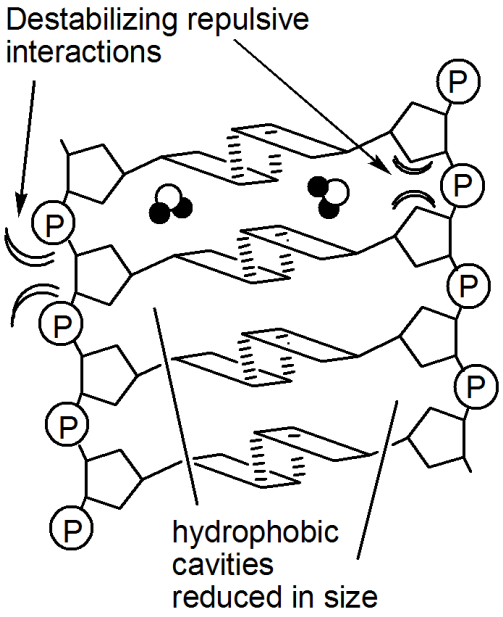
The sugar-phosphate backbone is readily solvated by water molecules whereas the bases tend to self-associate in a manner similar to the pooling of oil droplets dispersed in water. This self-association forms a double-stranded, ladder-like structure that creates a hydrophobic concentration of bases within the interior. However, small water molecules are able to penetrate the spaces between the closely associated base pairs. The presence of water in the hydrophobic region is destabilizing and increases the energy of the system due to repulsive forces between the water molecules and lipophilic bases (See Model 10.3).

MODEL 10.3 Solvation of DNA Segment



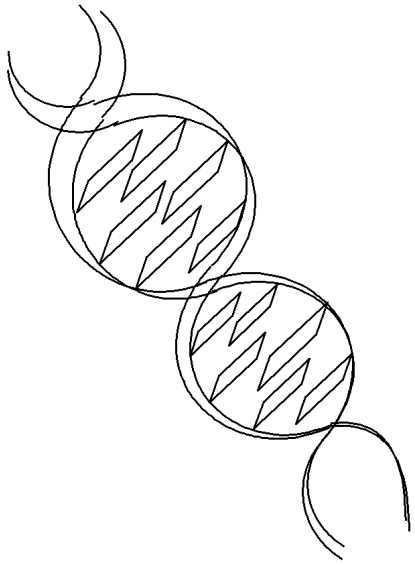
To reduce the spaces between the base pairs and hence, the energy of the system, the nitrogen bases rotate so that the planar rings can stack closer together, squeezing out most of the water molecules from the hydrophobic interior. However, this creates destabilizing Van der Waal repulsions as the sugar and phosphate groups are crowded together (Model 10.4).

MODEL 10.4 Steric Crowding



The final adjustment involves twisting the entire ladder-like structure into a helical shape to reduce these unfavorable steric interactions. The ultimate result is the well-known double helix (Model 10.5).

MODEL 10.5 Double Helix



DNA is soluble in water because it closely resembles a polyionic species. The charged phosphate backbone is readily solvated by water molecules as shown in Model 1. However, its solubility in less polar solvents such as alcohols and other organic liquids is expected to be much less due to its highly ionic character. This behavior towards organic solvents can be exploited as a method to precipitate pure DNA from an aqueous environment. An aqueous solution of DNA will precipitate nucleic acids as a cottony fibrous mass when the polarity of solution is reduced by carefully adding a layer of ethanol on top of the water phase.

Isolating DNA from the Cellular Environment

Pure nucleic acids are soluble in water but in their native environment they are surrounded by many water-insoluble components. These lipophilic components include cell membranes and membrane-associated proteins and carbohydrates. The DNA strands are spooled around specialized proteins called **histones** which are the major component of chromatin, the compacted contents of the cell nucleus. In order to isolate DNA, these lipophilic fractions must be separated from the nucleic acids.

The extraction buffer consists of a detergent mixed with strong electrolytes, NaCl and sodium bicarbonate. The detergent breaks apart the membranes and dissolves the lipids and membrane proteins. The electrolytes maintain pH and provide the ions needed to facilitate solvation of membrane proteins.

Histones are alkaline (basic) proteins closely associated with DNA strands and stabilize the charges on the phosphate groups. An enzyme is added to digest the his-

tones into water-soluble peptides and amino acids. This enzyme is a protease called papain which can be obtained from commercial meat tenderizers or pineapple juice. Once the histones are removed from the DNA coils, the extraction buffer provides cations to stabilize the phosphate groups of the naked DNA strands. Without this ion exchange, in water, DNA has a tendency to unravel into single-stranded nucleic acids.

Extraction of DNA involves three main steps.

1. Breaking the cell membranes to expose the nucleic acids inside the nucleus.
2. Separation of DNA from membrane components and DNA-bound proteins
3. Precipitating DNA using alcohol as a co-solvent.

The cell membrane and the nuclear envelope are similar structures. Both consist of a lipid bilayer with embedded proteins and carbohydrate moieties. These are fragile components which are easily compromised by pulverizing with a food blender or simply squishing by hand. Once the membranes are breached, an extraction buffer solution is used to sequester the membrane lipids. The extraction buffer also contains ionic compounds which facilitate solvation of membrane proteins and DNA-bound proteins. At this stage, the protease enzyme is added to digest the histones. In the final step, cold alcohol is added to precipitate DNA from the buffer solution since DNA is not soluble in alcohol. Careful addition of alcohol provides two liquid layers and DNA precipitates in large aggregates which make it visible in the mixture. Strands of DNA can be wrapped around a glass stir rod or wooden stick and removed from the interface of the layers as a white gelatinous mass.

Laboratory Procedure

Fresh or frozen strawberries may be used in this experiment. Thaw to room temperature if using frozen fruit. Remove the green sepals if necessary.

Extraction Buffer A

Prepare your extraction buffer solution before working with fruit. Dissolve approximately 1g NaCl and 3 g $NaHCO_3$ in 100 mL of DI water. After solids are completely dissolved, add approximately 5 mL of dish soap that contains sodium lauryl sulfate. Gently stir without generating soap bubbles. Label as extraction buffer solution A

Extraction Buffer B

Prepare a second buffer solution that does not contain any soap. Use the same ratio of NaCl, $NaHCO_3$ and water. Label as buffer solution B. Set this mixture aside to be used later in Part B of the experiment.

A. Isolating DNA

1. Place 2 or 3 strawberries into a Ziploc bag and carefully squish fruit until completely pulverized, about 2 minutes. Add 10-20 mL of extraction buffer A and squish baggie gently to mix contents but avoid making soap bubbles.
2. Separate the pulp from the strawberry juice by gravity filtration. Use a two-step filtration process: filter the extract with cheese cloth then perform a second filtration with filter paper. You should obtain a fairly homogeneous extract if done properly; otherwise repeat the filtration process until you obtain an acceptable extract mixture. Collect extract in a 50-mL beaker. **Test tube must be no more than a third full**. If there is sufficient extract, collect a second sample.
3. Add the papain enzyme to your filtered sample. Add approximately 0.5 g of powdered meat tenderizer and mix gently. Excessive agitation will break the DNA strands. After mixing, let contents stand about 5 minutes before proceeding to the next step. Alternatively, instead of meat tenderizer, add approximately 1 mL of pineapple juice or papaya juice, both of which contain papain enzyme. Mix gently, let stand for 5 minutes then carefully transfer approximately 10-15 mL of extract to a large test tube. **Test tube should be no more than a third full**.
4. Add approximately 2 volumes of ice cold alcohol to the extract in your test tube. Carefully pour the alcohol down the side of container so that two layers form.
5. Observe for a few minutes. When a white mass becomes visible at the liquid interface, gently insert a glass rod or wooden stick into the DNA and remove a

sample from the mixture. Treat DNA sample with care and process immediately in part B after removing a small portion for examination under microscope.

Laboratory Procedure

B. Effects of heat on DNA

1. Measure approximately 10 mL of buffer solution B into a clean test tube or small beaker. Insert the stir rod with DNA sample from Part A into buffer solution B. Swirl gently until DNA dissolves then divide the buffer into two equal portions.
2. Set aside one portion as a control and place the other portion into a boiling water bath for a minimum of 10 minutes.
3. Allow the heated sample to cool to room temperature (use an ice bath to decrease temperature). Add ice-cold alcohol to both portions forming two layers as before to induce precipitation of DNA.
4. Using the same technique from Part A, extract DNA from both samples and compare the amount of DNA from each portion.

PreLab Critical Thinking Questions

CTQ:1.

List the three major components of DNA molecules.

CTQ:2.

Why are DNA and RNA called acids?

a. Exactly which proton on DNA is the acidic proton? (A sketch may be helpful.)

b. Indicate whether the acidic groups of DNA are expected to be protonated or deprotonated (ionized) at the following pH values:

pH = 1.0 pH = 7.2 pH = 12.5

CTQ:3.

Is pure DNA water soluble? Explain in detail why it is or why it is not soluble.

CTQ:4.

Is DNA soluble in ethanol? Explain your answer.

CTQ:5.

List the lipophilic cellular components that surround and are associated with DNA.

Lab Report

Describe your results from Part A.

1. Approximately how much extract did you obtain from your strawberries?

2. What did you observe when alcohol was added to your DNA extract?

3. Approximately how much nucleic acid did you obtain from your extract?

4. Describe and sketch your DNA after observing with a microscope.

Describe your results from Part B.

5. Did your DNA obtained from Part A re-dissolve into buffer solution B?

6. Were you able to isolate the control sample from Part B?

7. Did you isolate any material from the sample that was heated in the water bath? Approximately how much material did you obtain from this sample?

Post Lab Critical Thinking Questions

CTQ:6.

The relatively simple composition of extraction buffer A performs a rather complex function in this experiment. *List the main components* of extraction buffer A and briefly *describe the purpose of each ingredient* in terms of their physical properties.

CTQ:7.

Although the cell membrane and nuclear envelope are destroyed during the pulverizing step, how are these membrane molecules separated from the nucleic acids. What happens to these components after being separated from DNA?

CTQ:8.

There are specialized proteins embedded in the strands of nucleic acids.

a. What are these proteins called?

b. How are these specialized proteins separated from DNA?

c. What happens to these proteins after being separated from DNA?

CTQ:9.

In deionized water, DNA will denature into single-stranded nucleic acids. However, if salts are added, the DNA will retain its double helical structure. Explain these observations in terms of intermolecular forces. Consider both attractive and repulsive forces. *(Of course water is no longer DI water once electrolytes have been added!)*

CTQ:10.

RNA is more water soluble than DNA. Provide a reason for this observation.

EXPERIMENT 11

Simulation of Food Digestion

Digestion of large biomolecules represents the first stage of metabolism. Digestion involves the hydrolysis of complex carbohydrates, fats and proteins into smaller molecules. There are specific enzymes used to carry out the hydrolysis of each large food molecule into smaller units or monomers. In one sense, digestion refers to the metabolic steps needed to convert complex food molecules into smaller monomers for delivery to the tissues to be catabolized by individual cells.

There are 3 Main Objectives in this Lab Activity

1. To learn the chemistry involved in the first stage of metabolism
2. To carry out hydrolysis reactions of food molecules
3. Use qualitative tests to identify hydrolysis products

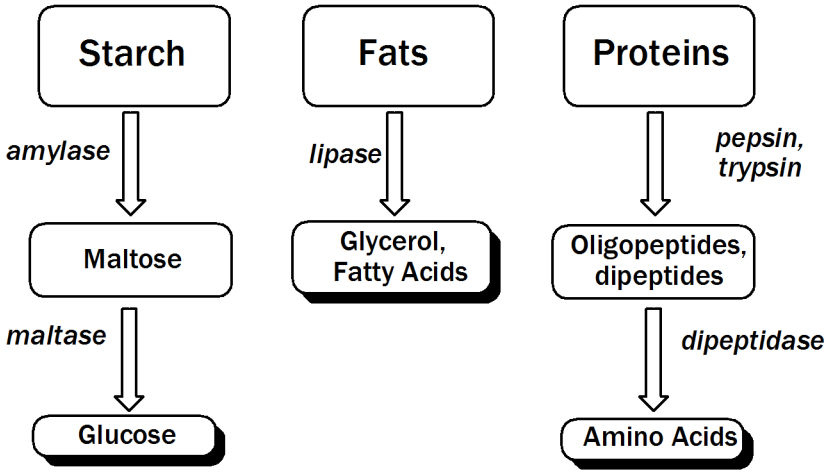
The Goal in this lab activity is to simulate digestion of food molecules and identify hydrolysis products.

Digestion- First Stage of Metabolism

Starch is the major carbohydrate in our diet. Digestion of starch begins in the mouth with the enzyme **amylase**. Complete hydrolysis continues in the gut with the enzyme **maltase**. Glucose is the end product of starch digestion.

Fats are hydrophobic and must be emulsified with bile salts in the stomach before hydrolysis occurs with the enzyme **lipase**. Triglycerides (fats) are hydrolyzed to fatty acids and glycerol.

Protein digestion begins in the stomach where the low pH serves to denature (unfold) the proteins and expose the peptide bonds to enzymes like pepsin and trypsin. Proteins are ultimately hydrolyzed to amino acids.



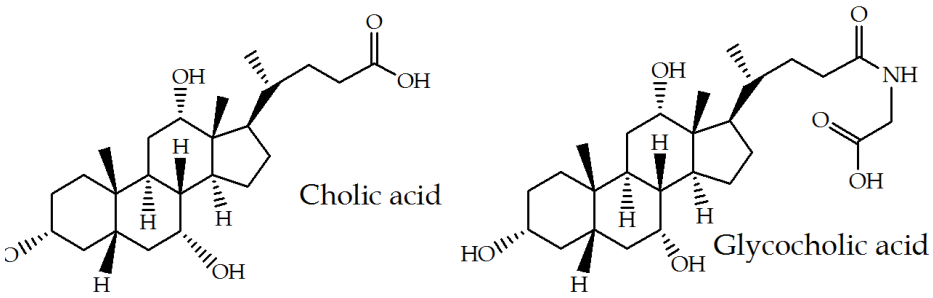
A. Digestion of Carbohydrates

The digestion of starch begins in the mouth since amylase is present in saliva. Amylase hydrolyzes the 1,4-α-D-glycosidic linkages in starch which cleaves some glucose monomers from the large biomolecules amylose and amylopectin. Other products from amylase hydrolysis include the disaccharide maltose and larger oligosaccharides which are passed into the small intestine. Only monosaccharides are small enough to pass through the intestines into the blood system. Gastric juices in the stomach facilitate additional hydrolyses of various sugars. But complete digestion of starch and other carbohydrates occurs in the small intestines where additional enzymes are secreted for hydrolysis of specific glycosidic linkages.

B. Digestion of Fats

Fats are considerably hydrophobic and must be solubilized with bile secreted by the gall bladder. The action of bile salts resembles the formation of micelles. Bile is a substance composed of amphipathic steroidal (fatty) acids which act as surfactants to emulsify triglycerides and facilitate hydrolysis.

MODEL 11.1 Bile Acids



Hydrolysis cleaves the ester bond of triglycerides. Fats are hydrolyzed in the stomach with a pancreatic enzyme called lipase to fatty acids and monoglycerides which are then absorbed through the intestines into the blood. The fatty acids and monoglycerides are then reassembled into triglycerides and bound with cholesterol for transport to the tissues.

All cells require fats and cholesterol for membrane construction; both of these are packaged together as lipoproteins called chylomicron for transport through the vascular system. Lipoproteins also carry lipids synthesized in the liver to the body cells and transport cholesterol where needed. Fats are usually not digested immediately; they are transported and stored in adipose tissue. Digestion occurs when needed, for example a low carbohydrate intake will eventually stimulate the metabolism of fats.

C. Digestion of Proteins

Digestion of proteins starts in the stomach where gastric juices denature proteins and activate an enzyme called pepsin which hydrolyzes the peptide bonds. Proteins are reduced to smaller peptides or amino acids. Polypeptides must be broken down into tetrapeptides or smaller units in order to pass into the small intestine where two more enzymes, trypsin and chymotrypsin, complete the hydrolysis to amino acids.

Experimental Procedure

This procedure will simulate enzymatic reactions involved in digestion of food in the mouth, stomach and small intestine. Pancreatin is a commercial mixture of enzymes produced by the pancreas. Pancreatin contains amylase, lipase and protease. Amylase hydrolyzes starch into oligosaccharides, maltose and some glucose. Lipase hydrolyzes triglycerides into fatty acids and glycerol. Protease hydrolyzes proteins into polypeptides and some amino acids. Trypsin, pepsin and peptidase are examples of protease enzymes.

You will need two water baths. Use two 500 mL beakers containing approximately 150 mL of water. Heat one bath to 37°C and the other bath should be boiling.

Materials

Substrates

- 2% starch solution
- boiled egg whites
- corn oil

Enzymes and bile

- 2% pancreatin solution
- 5% sodium choleate solution

Test solutions

- Benedict's solution
- Iodine solution

Other reagents

- 0.2*M* $NaHCO_3$
- 0.2*M* HCl
- 0.1 *M* NaOH
- pH paper

Except for water baths, use DI water throughout the experiment.

Experimental Procedure

A. Digestion of Starch

A1. Human Saliva

Collect approximately 10-12 mL of human saliva in a large test tube or suitable container. Add 0.5 - 1.0 mL of DI water to reduce any bubbles if necessary.

1. Label four test tubes as samples #1, #2, #3, #4 and add 2 mL of 2% starch solution to each.
2. Add 2 mL of saliva to samples #1 and #2. Samples #3 and #4 will serve as controls. Place all four samples into the 37°C water bath. Carefully mix samples #1 and #2 by stirring with a clean glass rod or by gently shaking.
3. After 30 minutes at 37°C, transfer samples to a test tube rack and add 2 drops of iodine solution to samples #2 and #4. Record your observations.
4. Add 5 mL of Benedict's solution to samples #1 and #3 and heat these samples in a boiling water bath for 10 minutes. Record any color changes and note whether a precipitate forms.

A2. Commercial Amylase Solution

1. Label four test tubes as samples #5, #6, #7, #8 and add 2 mL of 2% starch solution to each.
2. Add 4 mL of DI water to sample #5. This will be your control.
3. Add 2 mL of pancreatin solution and 2 mL of DI water to sample #6.
4. Add 2 mL of pancreatin solution and 2 mL of 0.2*M* $NaHCO_3$ solution to sample #7.
5. Add 2 mL of pancreatin solution and 2 mL of 0.2*M* HCl to sample #8.
6. Gently mix all four samples then heat for 30 minutes at 37°C.
7. After 30 minutes, divide each sample into two equal portions. Pour half of each sample into a new test tube and label these as samples #9, #10, #11, #12.
8. Add 2 drops of iodine solution to samples #9, #10, #11, #12. Record your observations.
9. Add 5 mL of Benedict's solution to samples #5, #6, #7, #8 and heat these samples in a boiling water bath for 10 minutes. Record any color changes and note whether a precipitate forms.

B. Digestion of Protein

1. Label three test tubes as samples #13, #14, #15. To each tube add a small piece of egg white (approximately 1 cm^2).

2. To sample #13, add 4 mL of DI water and 1 mL of 0.2*M* HCl. This will be your control sample.
3. To sample #14, add 4 mL pancreatin solution and 1 mL of 0.2*M* HCl.
4. To sample #15, add 4 mL pancreatin solution and 1 mL of DI water.
5. Place samples in 37°C water bath for 30-40 minutes. Record any changes in egg white.

C. Digestion of Triglyceride

C1 Emulsion with Bile Salt

1. Label two test tubes as samples #16 and #17. To each tube add about 1 mL of corn oil.
2. To sample #16, add 4 mL of DI water.
3. To sample #17, add 2 mL of DI water and 2 mL of bile solution.
4. Periodically mix both samples for 15 minutes. Record your observations.

C2 Hydrolysis by Lipase

1. Label three test tubes as samples #18,# 19 and #20.
2. To sample #18 mix 2 mL of bile and 10 drops of DI water.
3. To sample #19, mix 2 mL of pancreatin solution and 10 drops of DI water.
4. To sample # 20, mix 2 mL of pancreatin solution, 2 mL of sodium choleate solution and 10 drops of DI water.
5. To samples #18 and #19, add 0.1*M* NaOH dropwise until pH = 7. Then add DI water (approx. 2mL) until the volume is equal to the volume in sample # 20.
6. Add 5 drops of corn oil to each sample and heat in 37°C water bath. Test the pH of each sample after 5 minutes. Repeat pH test at 10 minutes and 15 minutes. Record your observations.

Prelab Critical Thinking Questions

CTQ:1.

Briefly explain how to interpret the Iodine test and Benedict's test: explain color changes/precipitates; explain what is meant by a positive result; explain what is meant by a negative result.

a. Iodine test

b. Benedict's test

CTQ:2.

Explain the change in pH when a solution of triglyceride is hydrolyzed.

CTQ:3.

Identify the monomers or hydrolysis products formed by digestion of the following food molecules. Provide the name of the enzyme in each case.

Substrate	Enzyme	Monomer(s)
protein		
maltose		
triglyceride		
lactose		
sucrose		
starch		

CTQ:4.

Explain why sugars must be hydrolyzed to monosaccharides in order to be absorbed through the intestinal wall, whereas, fatty acids pass through the intestines even though they are much larger molecules.

CTQ:5.

Provide a sketch of emulsification of a triglyceride by bile. Label all parts.

Lab Report

A. Digestion of Starch

A1 Human Saliva

sample	Iodine test	Benedict's test
1		
2		
3		
4		

A2 Commercial Amylase

sample	Iodine test	Benedict's test
5		
6		
7		
8		
9		
10		
11		
12		

B. Digestion of Protein

sample	changes in egg white
13	
14	
15	

C. Digestion of Fats

C1 Emulsion with Bile Salts

sample	changes in oil/water mixture
16	
17	

C2 Hydrolysis with Lipase

sample	changes in pH after addition of corn oil
18	
19	
20	

Postlab Critical Thinking Questions

CTQ:6.(samples 1-4)

What evidence did you record to support the conclusion that starch was hydrolyzed by saliva?

CTQ:7.(samples 5-12)

What evidence did you record to support the conclusion that starch was hydrolyzed by pancreatin?

CTQ:8.(samples 13-15)

What evidence did you record to support the conclusion that protein was hydrolyzed by pancreatin?

CTQ:9.(samples 13-15)

What effect, if any, does low pH have on protein hydrolysis?

CTQ:10.(samples 16, 17)

Is the action of bile salts towards triglycerides a physical or enzymatic (chemical) process? Explain.

CTQ:11.(samples 18-20)

What evidence did you record to support the conclusion that corn oil was hydrolyzed by pancreatin?

Name _____ Section_____ Date _____

WORKSHEET 1 # *Dimensional Analysis*

1. Use Dimensional Analysis to solve the following problems.
   a. How many seconds old are you? (Express with 2 sig figs in scientific notation.)
   b. Convert your distance from school to home from miles to inches. (Express with 2 sig figs in scientific notation.)
   c. How many kilometers is it from school to home? (Express with 2 sig figs in scientific notation.)
   d. A person's weight is 154 pounds. Convert this to kilograms. (1 lbs. = 454 grams)
2. Solve using the conversion factors that are listed in the table below.
   a. Your cruise ship is leaving for a 610-league adventure. How many nautical miles is this?
   b. Later the ship is discovered at 38 fathoms deep under water. Convert this to meters.
   c. Fortunately you survived! You are stranded on a deserted island that is located 12.5 degrees north of the equator. How many kilometers is this?
   d. If you are rationed to 32 gills of fresh water a day, how many liters is this?
   e. To reach the top of a palm tree for a coconut you will have to climb 7.4 meters. How many hands is this?
   f. The island is rich with hot chile peppers. You can collect 1.6 pecks a day. How many liters could you collect in **1 week**?

Some Interesting Units of Measure

Length		Volume
1 nautical mile = 6076 feet		4 gills = 1 pint
1 inch = 2.54 cm		2 pints = 1 quart
1 league = 5 280 yards		1 liter = 1.0567 quarts
1 cable = 120 fathoms		1 bushel = 4 pecks = 32 quarts
1 fathom = 6 feet		1 gallon = 4 quarts
1 degree = 69.047 miles		
1 mile = 5280 feet		
1 hand = 4 inches		

Name _____ Section_____ Date _____

WORKSHEET 2 # *Significant Digit*

1. Give the number of significant digits in each of the following measurements:

a. 1278.50	**b.** 8.002	**c.** 43.050
d. 120000	**e.** 823.012	**f.** 0.147
g. 9.30×10^{7}	**h.** 0.607	**i.** 0.00023
j. 93,125,479	**k.** 1.277	**l.** 23,004
m. 0.677	**n.** 6089	**o.** 873.20
p. 0.0677	**q.** 6.700×10^{-2}	**r.** 0.00500

2. Round off the following numbers to three significant digits:

a. 120904	**b.** 4.53619
c. 5.457	**d.** 43.659
e. 0.0008769	**f.** 876493

3. Perform the following operations giving the proper number of significant figures in the answer:
   - **a.** 23.4 x 14 =
   - **b.** 0.005 - 0.0007 =
   - **c.** 7.895 + 3.4 =
   - **d.** 7.895 / 34 =
   - **e.** 0.0945 x 1.47 =
   - **f.** 0.2 / 0.0005 =

g. $(8.71 \times 0.0301)/0.056 =$

h. $(7.6 \times 10^{4})\ (5.8 \times 10^{-3}) =$

4. Write each number in scientific notation.

0.07882 =	
87200 =	
450 =	
0.0000085 =	
0.00000272338 =	
62360 =	
500260 =	

5. Write each number in standard format.

1.21×10^{4} =	
5.8×10^{-7} =	
6.58157×10^{7} =	
3.443×10^{-3} =	
7.141×10^{-5} =	

Name _____ Section_____ Date _____

WORKSHEET 3 *Isoptopes and Subatomic Particles*

Fill in the blanks

Atomic symbol	Atomic number	Protons	Neutrons	Electrons	Isotope mass
B			6		
	11				24
		31	37		
				39	89
	29		35		
		43			100
Pb					207
			102	70	
		89			225
Mo			53		
	81				206
	100		159		
No					261
Yb					172
		106	159		

Name _____ Section_____ Date _____

WORKSHEET 4 # *Electron Configuration*

1. Write the complete electron configuration for the following elements:
   a. sodium_____
   b. carbon _____
   c. bromine _____
   d. iron _____
   e. barium _____

2. Write the abbreviated electron configurations for the following elements:
   a. cobalt_____
   b. silver_____
   c. cesium_____
   d. tellurium_____
   e. radium_____

3. Identify the element based on the electron configuration:

   a. $1s^2 2s^2 2p^6 3s^2 3p^4$ _____

   b. $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^6 5s^1$ _____

   c. [Kr] $5s^2 4d^{10} 5p^3$ _____

   d. [Xe] $6s^1$ _____

   e. [Ne] $3s^2 3p^5$ _____

Name _____ Section_____ Date _____

WORKSHEET 5 # *Valence Electrons*

1. Write the shell number of the valence shell for the following atoms:

Li		N	
Sr		F	
C		O	
Ne		H	

2. Indicate the number of valence electrons in each of the following atoms:

H		P	
Ba		S	
C		N	
Kr		O	

3. Draw a Lewis Dot structure for the following atoms:

C H O Ne Br N B

4. For Main Groups Elements, how does the group number (from the Periodic Table) correspond to the Lewis Dot structure?

Name _____ Section_____ Date _____

WORKSHEET 6 # Nuclear Equations

Fill in the missing daughter isotopes and the missing radiation particles (a, b, g particles and the positron)

Alpha Decay

$^{256}_{103}Lr$	$\rightarrow$	$^{252}_{101}Md$	+	
$^{231}_{91}Pa$	$\rightarrow$		+	$^{4}_{2}He$
$^{225}_{89}Ac$	$\rightarrow$	$^{4}_{2}\alpha$	+	
$^{211}_{87}Fr$	$\rightarrow$		+	$^{4}_{2}\alpha$
$^{185}_{79}Au$	$\rightarrow$	$^{4}_{2}He$	+	

Beta Decay

$^{6}_{2}He$	$\rightarrow$		+	$^{0}_{-1}e$	+	$^{0}_{0}\bar{\nu}$
$^{24}_{11}Na$	$\rightarrow$		+	$^{0}_{-1}\beta$	+	$^{0}_{0}\bar{\nu}$
$^{201}_{79}Au$	$\rightarrow$	$^{0}_{-1}\beta$	+		+	$^{0}_{0}\bar{\nu}$
$^{52}_{26}Fe$	$\rightarrow$	$^{0}_{0}\bar{\nu}$	+		+	
$^{42}_{19}K$	$\rightarrow$	$^{0}_{-1}e$	+		+	

Positron Decay

$^{8}_{5}B$	$\rightarrow$	$^{8}_{4}Be$	+		+	$^{0}_{0}\bar{\nu}$
$^{45}_{22}Ti$	$\rightarrow$	$^{45}_{21}Sc$	+		+	$^{0}_{+1}e$
$^{27}_{14}Si$	$\rightarrow$	$^{0}_{+1}e$	+		+	
$^{30}_{15}P$	$\rightarrow$	$^{0}_{+1}e$	+		+	$^{0}_{0}\bar{\nu}$

$^{75}_{35}Br$	$\rightarrow$		+		+	

Name _____ Section_____ Date _____

WORKSHEET 7

Molar Mass and Mole Conversions

1. Calculate the molar mass:

CH_4 methane	$MgSO_4$
CH_3CH_2OH ethanol	$NaHCO_3$
$AlCl_3$	Li_3PO_4

2. Convert mass to moles:

24.5 g CH_4 to moles of CH_4	0.578 g of ethanol to moles of ethanol
87.6 g of NaCl to moles of NaCl	425 mg of KCl to moles of KCl

3. Convert moles to mass:

0.245 moles of CH_4 to grams of CH_4	1.55 moles of ethanol to grams of ethanol
1.00×10^{-3} moles of NaCl to grams of NaCl	45.8 moles of KCl to grams of KCl

Name _____ Section_____ Date _____

WORKSHEET 8 *Writing Formulas and Name for Monoatomic Ionic Compounds*

Write the formula and name for the ionic compound formed when the metal combines with the nonmetal. For example sodium combines with chlorine to give NaCl because sodium forms a sodium (1^+) cation and chlorine forms a chloride (1^-) ion. Since the ion charges are the same magnitude; i.e., +1 and -1, the ratio of cation to anion is one-to-one (1:1).

elements	cation (charge)	anion (charge)	formula	name
Na and Cl	Na+	Cl-	NaCl	sodium chloride
Li and I				
Ca and O				
Mg and F				
K and S				
Na and N				
Al and Br				
Be and Cl				
Rb and I				
Sr and O				

Polyatomic ions:

$(NH_4)^{+1}$	**ammonium ion**		$(CN)^{-}$	cyanide
$(OH)^{-1}$	hydroxide		$(CH_3CO_2)^{-1}$	acetate
$(CO_3)^{-2}$	carbonate		$(NO_3)^{-1}$	nitrate
$(HCO_3)^{-1}$	hydrogen carbonate (aka bicarb)		$(NO_2)^{-1}$	nitrite
$(PO_4)^{-3}$	phosphate		$(SO_4)^{-2}$	sulfate
$(HPO_4)^{-2}$	hydrogen phosphate		$(HSO_4)^{-1}$	hydrogen sulfate
$(H_2PO_4)^{-1}$	dihydrogen phosphate		$(SO_3)^{-2}$	sulfite
			$(HSO_3)^{-1}$	hydrogen sulfite

Write formulas for:

Na and sulfate ion	Sr and dihydrogen phosphate
Ca and nitrate ion	K and acetate
Mg and sulfite ion	Na and bicarb
Al and phosphate ion	ammonium and nitrate
K and cyanide ion	ammonium and carbonate
Li and hydroxide ion	Ba and phosphate

Name _____ Section_____ Date _____

WORKSHEET 9 # *Lewis Structures*

Indicate the normal bonding pattern for these elements:

element	# bonds	# lone pairs
C		
N		
O		
H		
F, Cl, Br, I		
S		
P		

Draw Lewis Structures for the following molecules including all lone pairs.

CH_4 v.e.=	NH_3 v.e.=	H_2O v.e.=
N_2 v.e.=	O_2 v.e.=	Br_2 v.e.=

C_3H_8 v.e.=	C_2H_6O v.e.=	CH_5N v.e.=
HCN v.e.=	SeO_2 v.e.=	CCl_4 v.e.=
CS_2 v.e.=	PBr_3 v.e.=	$C_2H_2Cl_2$ v.e.=
C_2H_2 v.e.=	C_2H_7N v.e.=	N_2H_4 v.e.=

Name _____ Section_____ Date _____

WORKSHEET 10 *Drawing Lewis Structures and Determining Molecular Shape*

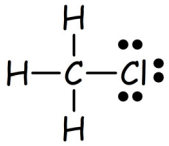
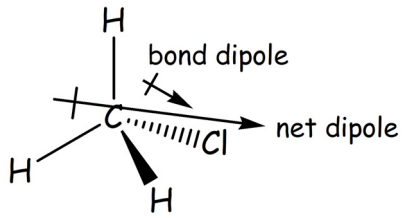
Once you have a correct Lewis structure, use this Chart to determine molecular shape.

A = central atomX = atoms bonded to central atom

e' clouds on central atom	Lone pairs	Bonding pairs	General Formula	Orbital geometry **(electron geometry)**	Approx. bond angles	Molecular geometry **(molec. shape)**
2	0	2	AX_2	Linear	180	Linear
3	0	3	AX_3	Trigonal Planar	120	Trigonal Planar
3	1	2	$\ddot{A}X_2$	Trigonal Planar	<120	Bent
4	0	4	AX_4	Tetrahedral	109	Tetrahedral
4	1	3	$\ddot{A}X_3$	Tetrahedral	<109	Trigonal Pyramidal
4	2	2	$:\ddot{A}X_2$	Tetrahedral	<109	Bent

For each molecular formula, complete the Table. The first formula is done as an example.

To illustrate polarity, **Redraw** Lewis structure in 3-D with individual bond dipoles, then shown net dipole for the molecule. You may omit lone pairs in this final structure.

formula	Lewis structure v.e. = **?**	*Bonding groups	*Lone pairs	Electronic geometry	Molecular shape	Polar or Nonpolar (3-D Structure required)
CH_3Cl	 v.e. = **14**	4	0	tetrahedral	tetrahedral	**polar** 

* Consider bonding groups and lone pairs on central atoms only.

formula	Lewis structure	Bonding groups	Lone pairs	Electronic geometry	Molecular shape	Polar or Nonpolar (3-D Structure required)
AlF_3	**v.e.** =					
CH_2Br_2	**v.e.** =					
NH_3	**v.e.** =					
SO_3	**v.e.** =					
H_2O	**v.e.** =					
PH_3	**v.e.** =					

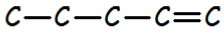
formula	Lewis structure	Bonding groups	Lone pairs	Electronic geometry	Molecular shape	Polar or Nonpolar (3-D Structure required)
NCl_3						
CO_2						
$BeCl_2$						
SO_2						
CCl_4						
$CHCl_3$						
SiH_3Br						

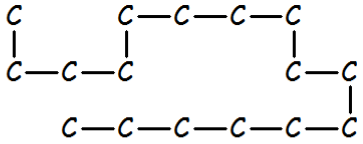
Name _____ Section_____ Date _____

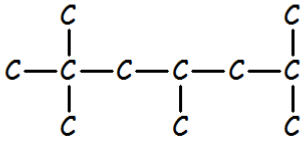
WORKSHEET 11

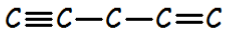
Drawing Organic Structures

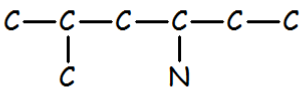
1. Below are partial structures for hydrocarbons; some of these contain oxygen and nitrogen. Complete the structures by adding all hydrogen atoms and lone pairs on heteroatoms.

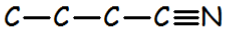
a. 

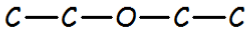
b. 

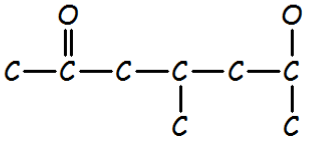
c. 

d. 

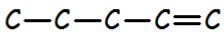
e. 

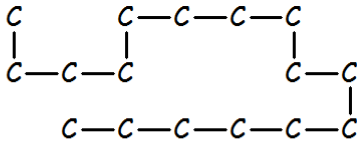
f. 

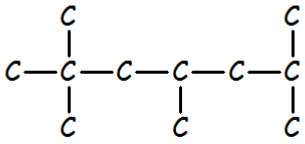
g. 

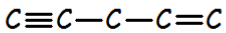
h. 

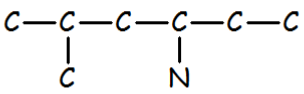
2. Convert each structure to a molecular formula.

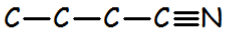
a. 

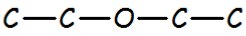
b. 

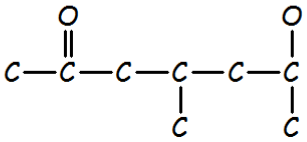
c. 

d. 

e. 

f. 

g. 

h. 

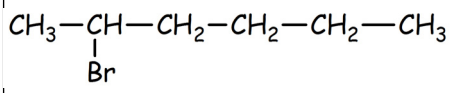
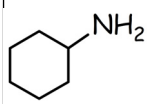
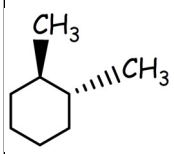
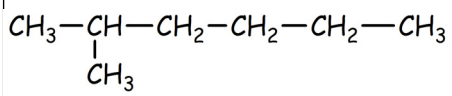
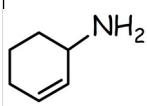
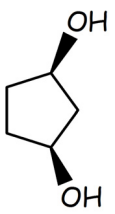
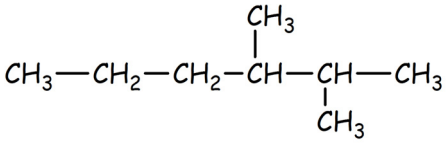
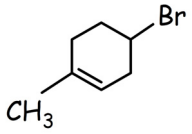
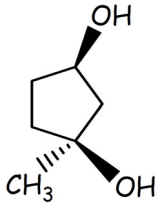
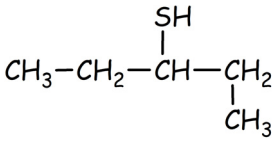
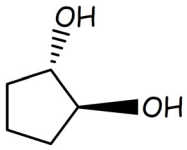
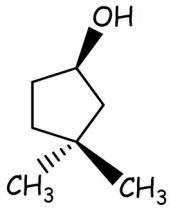
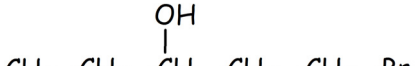
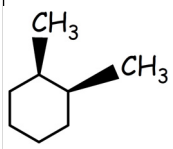
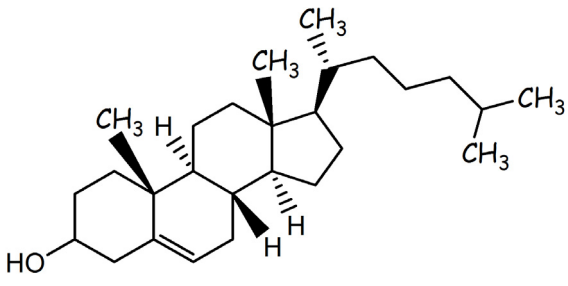
Name _____ Section_____ Date _____

WORKSHEET 12

Identifying Stereocenters and Chirality

For each molecule:

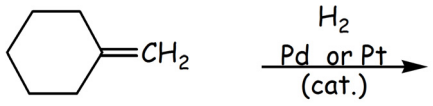
1. Place an asterisk (*) next to each asymmetric center; some may contain more than one chiral center.
2. Indicate whether or not each molecule is chiral.

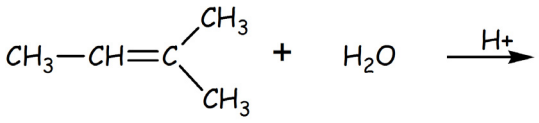
		
		
		
		
		

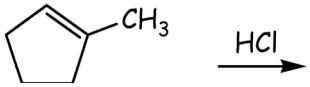
Name _____ Section_____ Date _____

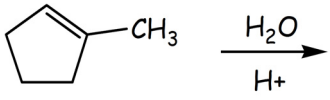
WORKSHEET 13 # *Addition Reactions*

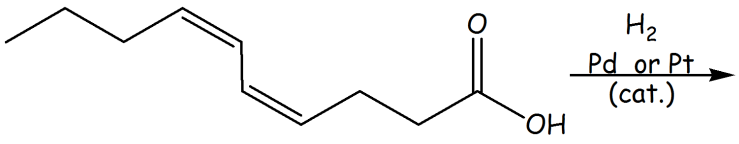
1. Draw the expected product for each reaction:

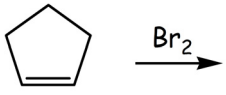
a. 

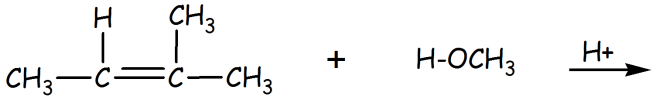
b. 

c. 

d. 

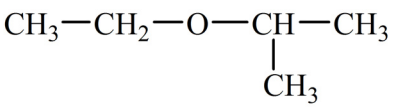
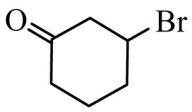
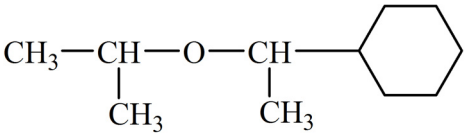
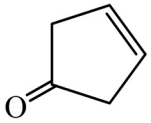
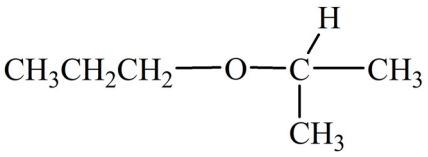
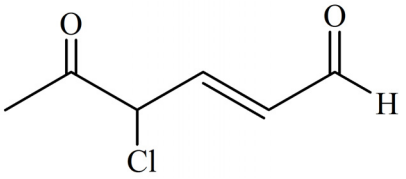
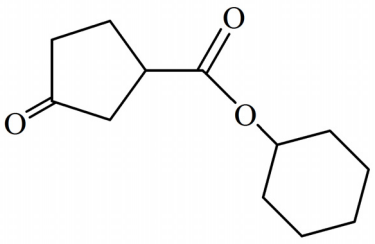
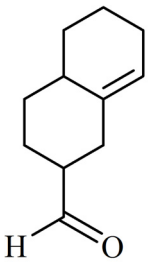
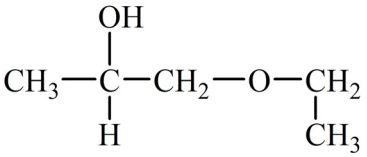
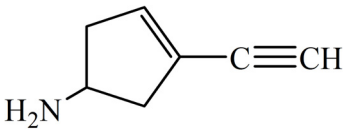
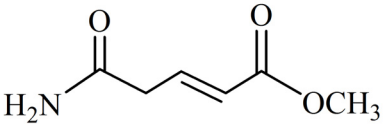
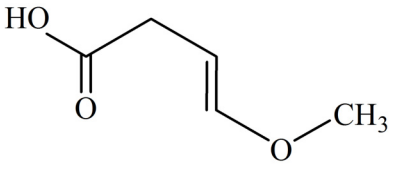
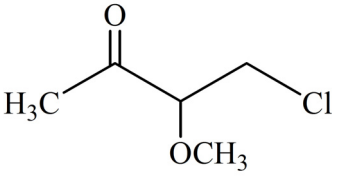
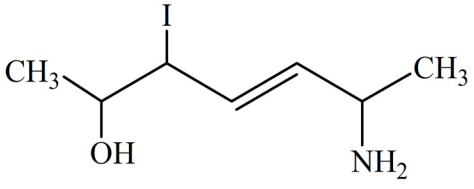
e. 

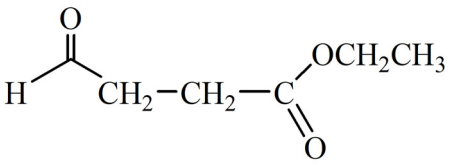
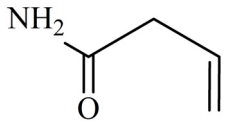
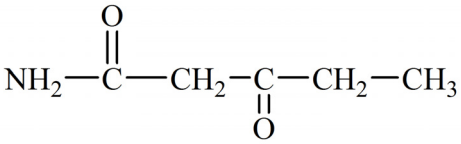
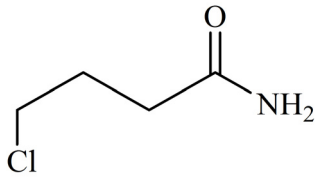
f. 

g. 

Name _____ Section_____ Date _____

WORKSHEET 14 # *Functional Groups*

List all the functional groups in each structure. Some molecules have more than one functional group.			
functional groups	structures		functional groups
			
			
			
			
			
			
			

Name _____ Section_____ Date _____

WORKSHEET 15 # *Fatty Acid Notation*

Consult the Table to answer the questions below.

Notation	common name	systematic name	structure
12:0	Lauric acid	dodecanoic acid	$CH_3(CH_2)_{10}COOH$
14:0	Myristic acid	tetradecanoic acid	$CH_3(CH_2)_{12}COOH$
16:0	Palmitic acid	Hexadecanoic acid	$CH_3(CH_2)_{14}COOH$
18:0	Stearic acid	Octadecanoic acid	$CH_3(CH_2)_{16}COOH$
$16:1^{\Delta 9}$	Palmitoleic acid	Hexadecenoic acid	$CH_3(CH_2)_5CH{=}CH\text{-}(CH_2)_7COOH$
$18:1^{\Delta 9}$	Oleic acid	9-Octadecenoic acid	$CH_3(CH_2)_7CH{=}CH\text{-}(CH_2)_7COOH$
$18:2^{\Delta 9,12}$	Linoleic acid	9,12-Octadecadienoic acid	$CH_3(CH_2)_4(CH{=}CHCH_2)_2(CH_2)_6COOH$
$18:3^{\Delta 9,12,15}$	α-Linolenic acid	9,12,15-Octadecatrienoic acid	$CH_3CH_2(CH{=}CHCH_2)_3(CH_2)_6COOH$
$20:4^{\Delta 5,8,11,14}$	arachidonic acid		you draw it!

1. What information is given by the notation in the left column (12:0, 16:0, etc.)?

2. What information is given by the delta sign and superscripts in the left column ($\Delta^{9,\,12,\,15}$ etc.)?

   a. Draw a bond line structure for Oleic acid (eliminate the parentheses).

b. Draw a bond line structure for Linoleic acid (eliminate the parentheses).

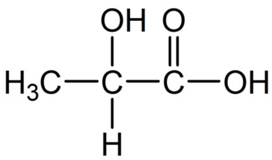
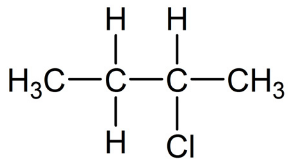
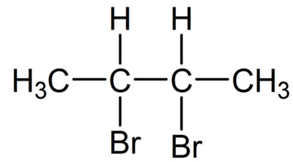
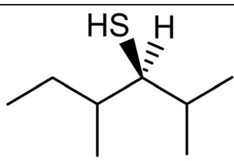
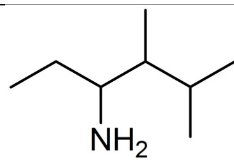
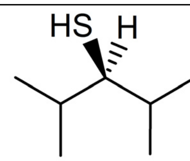
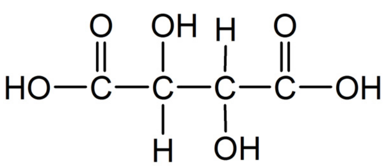
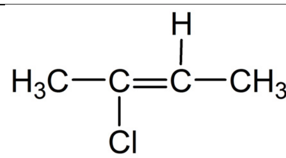
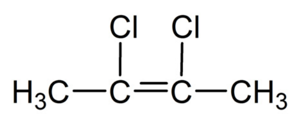
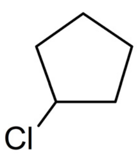
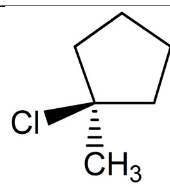
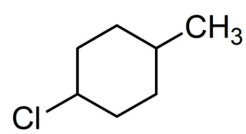
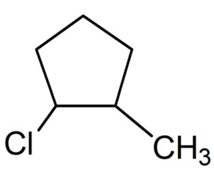
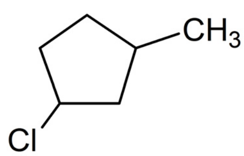
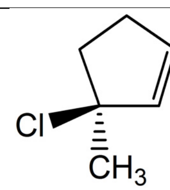
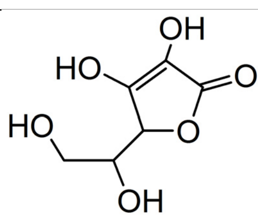
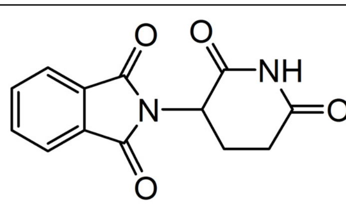
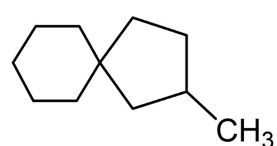
c. Draw a bond line structure for α- Linoleic acid (eliminate the parentheses).

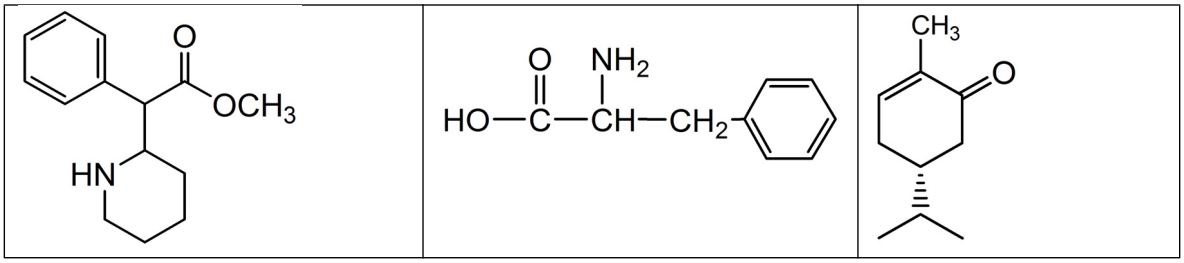
3. Draw the structure of arachidonic acid based on the notation from the left column.

Name ______________________ Section__________ Date ___________

WORKSHEET 16 *Chirality*

Determine if the following molecules are chiral. If so, then label the chiral centers with an asterisk (*). Some molecules may have more than one chiral center.

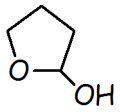
		
		
		
		
		
		

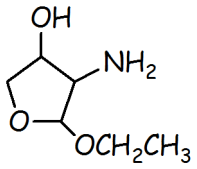

O
OCH3
HN
O
NH2
HO
C
CH
CH2
CH3
O

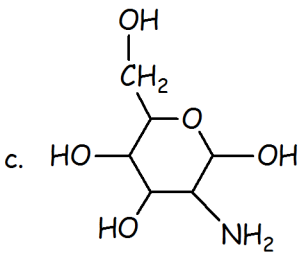
Name _____ Section_____ Date _____

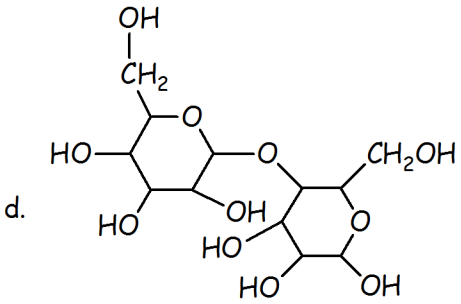
WORKSHEET 17 # *Acetals and Hemiacetals*

1. Identify the acetal or hemiacetal in each structure:

a. 

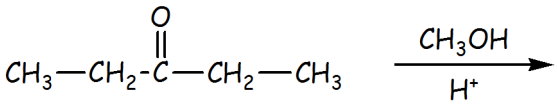
b. 

c. 

d. 

2. Draw the hemiacetal <u>intermediate</u> formed in these reactions:

a.



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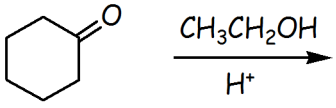
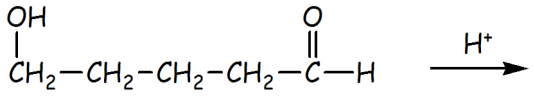
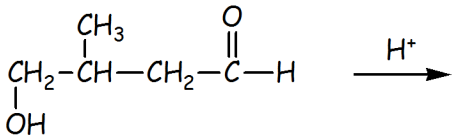


c.

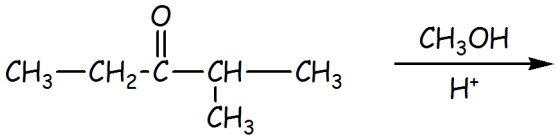


d.

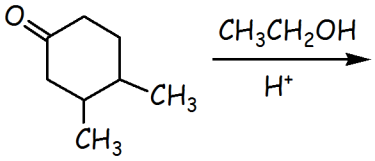


3. Draw the acetal formed in these reactions:

a.

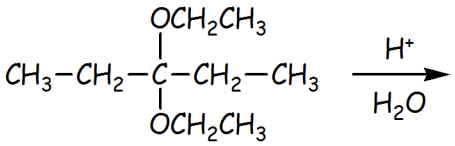


b.

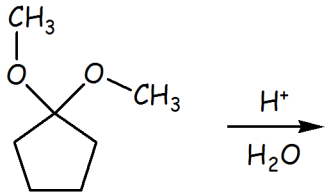


4. Draw the aldehyde or ketone produced from hydrolysis in these reactions:

a.



b.

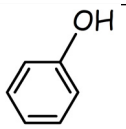
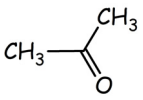
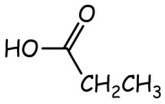
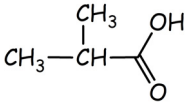
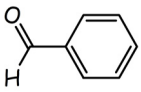
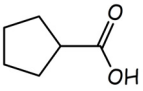


Name _____ Section_____ Date _____

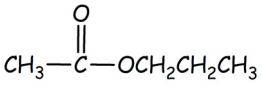
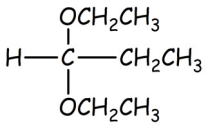
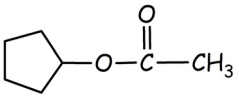
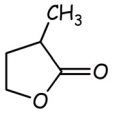
WORKSHEET 18

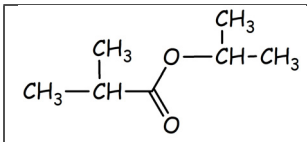
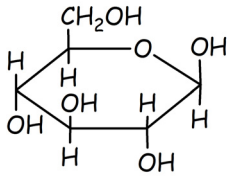
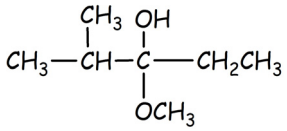
Acetals, Redox, and Hydrolysis

1. Draw the condensation product for each combination of alcohol and carbonyl compound. Where appropriate, assume the acetal is formed not the hemiacetal.

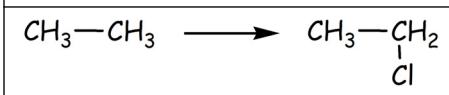
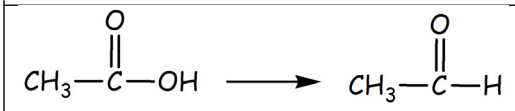
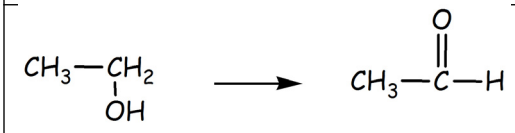
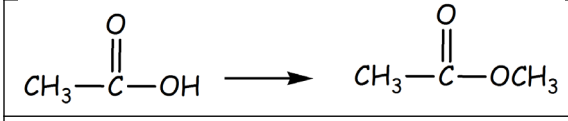
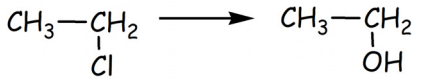
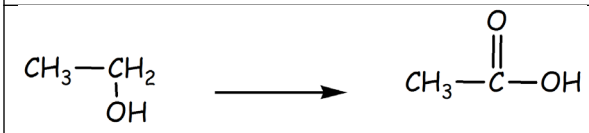
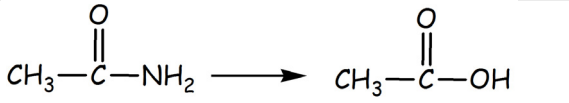
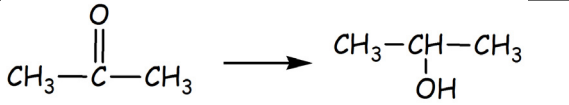
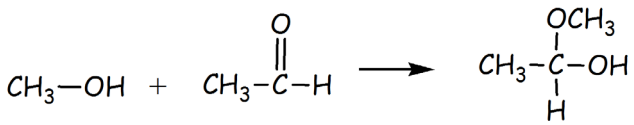
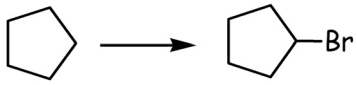
	CH_3-OH	$CH_3-\underset{\displaystyle OH}{\underset{|}{CH}}-CH_2$	$CH_3-\underset{\displaystyle CH_3}{\underset{|}{CH}}-OH$	
				
				
				
				
				

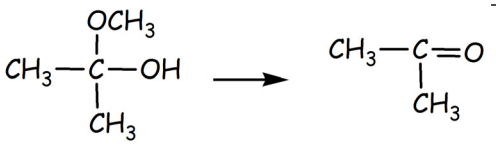
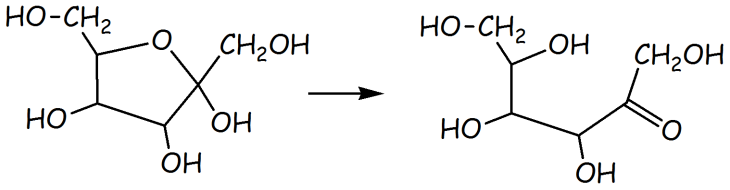
2. Draw the hydrolysis product for each.

3. Indicate whether each reaction is an oxidation, a reduction, a hydrolysis or neither. Some of these are challenging- do your best to answer the examples you have seen.

Reaction	Oxid / Red / Hydrolysis / None
	
	
	
	
	
	
	
	
	
	

	
	
$Mg^{+2} \rightarrow Mg\ (s)$	
$FeO \rightarrow Fe_2O_3$	
$Mn^{+2} \rightarrow Mn^{+5}$	
$Cu^{+2} \rightarrow Cu^{+1}$	

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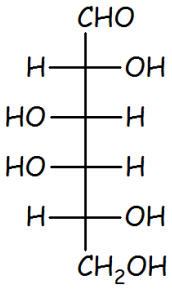
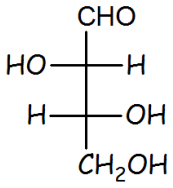
WORKSHEET 19

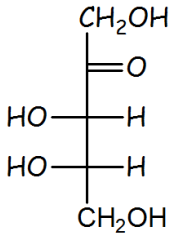
Carbohydrates - Monosaccharides

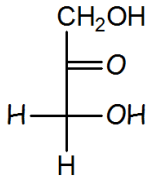
1. Complete the following:
   a. Classify the following as ketose or aldose; ie. aldoheptose, ketohexose, etc:



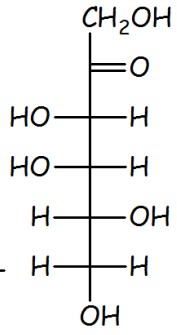


B _____





D _____



A _____ C _____ E _____

   b. How many chiral centers for each structure?

A __ B __ C__ D __ E __

   c. Which sugars, if any, are structural isomers?

2. Identify the following as D or L-sugars:

3. Draw the cyclic hemiacetal form using a Haworth structure for the sugars A and E above.

Name _____ Section_____ Date _____

WORKSHEET 20

Carboyhydrates - Glycosides, Glycosamines

1. Drawing Fischer projections and hemiacetals for monosaccharides

- draw the Fischer projection for each carbohydrate below
- label Fishcer structure as a ketose or aldose
- draw both stereoisomers for the cyclic hemiacetal
- label each hemiacetal as
- α or β anomer

a. Glucose

Fischer projection	hemiacetal α or β anomer?	hemiacetal α or β anomer?

b. Galactose

Fischer projection	hemiacetal α or β anomer?	hemiacetal α or β anomer?

c. **Fructose**

Fischer projection	hemiacetal α or β anomer?	hemiacetal α or β anomer?

2. Drawing the glycoside bond of disaccharides and polysaccharides.

Draw the cyclic hemiacetal of glucose and number the carbon atoms (remember which carbon is C-1).

Now form the glycosidic bond between the anomeric hydroxy group of one glucose unit and the C-4 hydroxy group of another glucose unit (this is an acetal bond). There are two ways to make this bond; draw both possibilities and label each as α or β glycoside.

α **glycoside**

β **glycoside**

Examine your two glycosides. One of them is the disaccharide maltose, the other is the same substructure found in cellulose. Identify which is which.

3. **Draw the disaccharide formed from glucose and fructose**.

The glycosidic link is between the anomeric hydroxy group of glucose and the C-2 hydroxy group (anomeric center) of fructose; the stereochemistry of the glucose, fructose link is (α,β).

4. Explain this terminology:
   a. sucrose contains an α,β-1,2-glycosidic bond.

b. cellulose contains a β-1,4-glycosidic bond.

5. Glycosamines

When the C-2 hydroxy group of glucose is converted to an amino group the result is called a glucosamine. Draw the cyclic form of D-glucosamine

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WORKSHEET 21

Polysaccharides and Derivatives

Use the figures on page 49 and 50 to answer the following:

1. Identify each structure by name:

A _____D _____

B _____E _____

C _____

2. Examine structure B.
   a. What is the parent aldose? _____

   b. What functional group distinguish this structure from one of the 8 aldoses?

3. Provide the numbering notation for each glycoside link in these structures and indicate whether each link is (a) or (b).

A _____D _____

C _____E _____

4. Explain the major features of amylose and amylopectin:

   a. What is the parent monosaccharide for each type of starch?

b. What type of glycosidic link exists in each type?

c. Which one contains a linkage other than 1,4 and what is the numbering of the linkage between branches?

d. Is the branch linkage an acetal linkage? If no, what type of linkage is it?

FIGURE 21.1

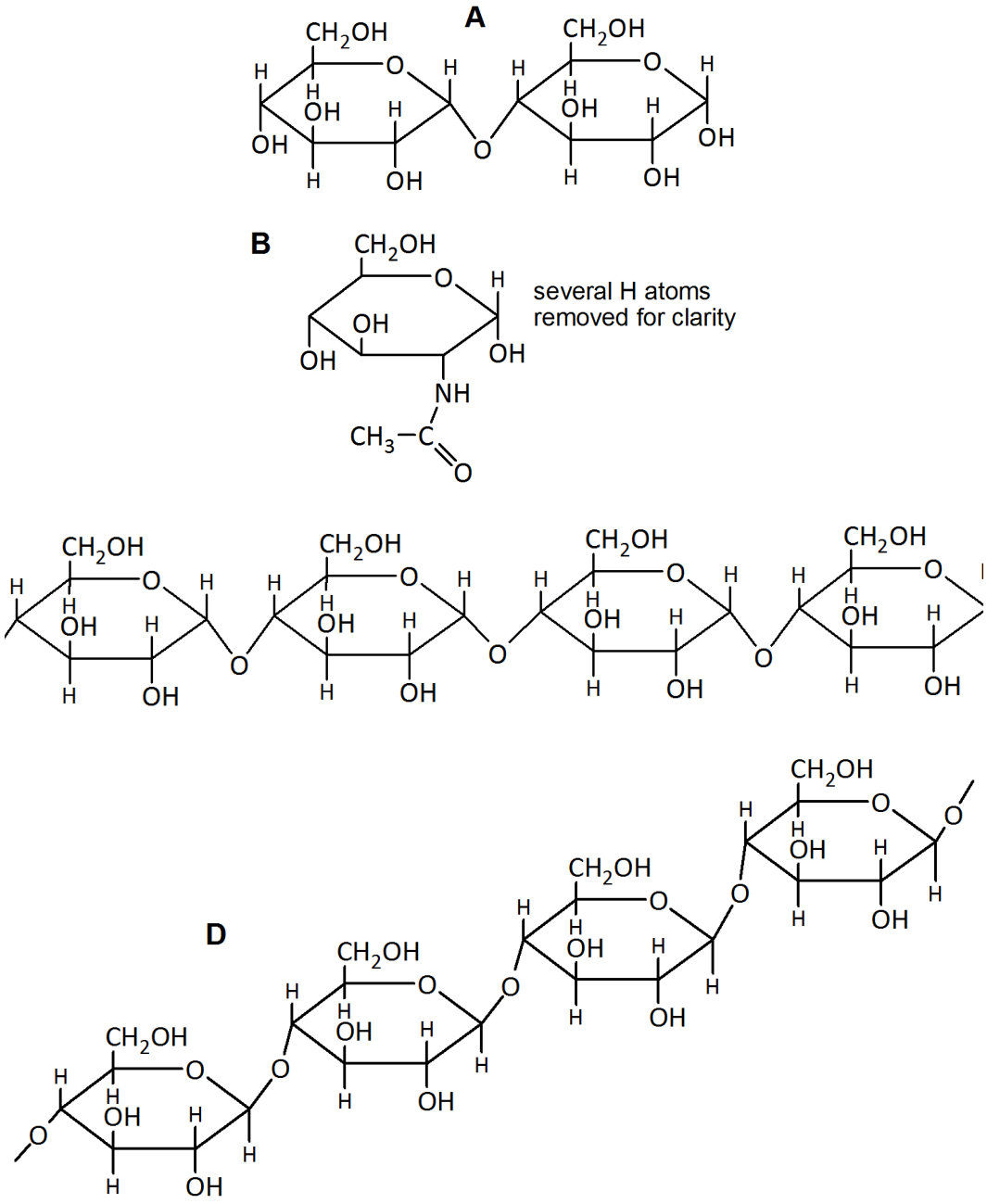
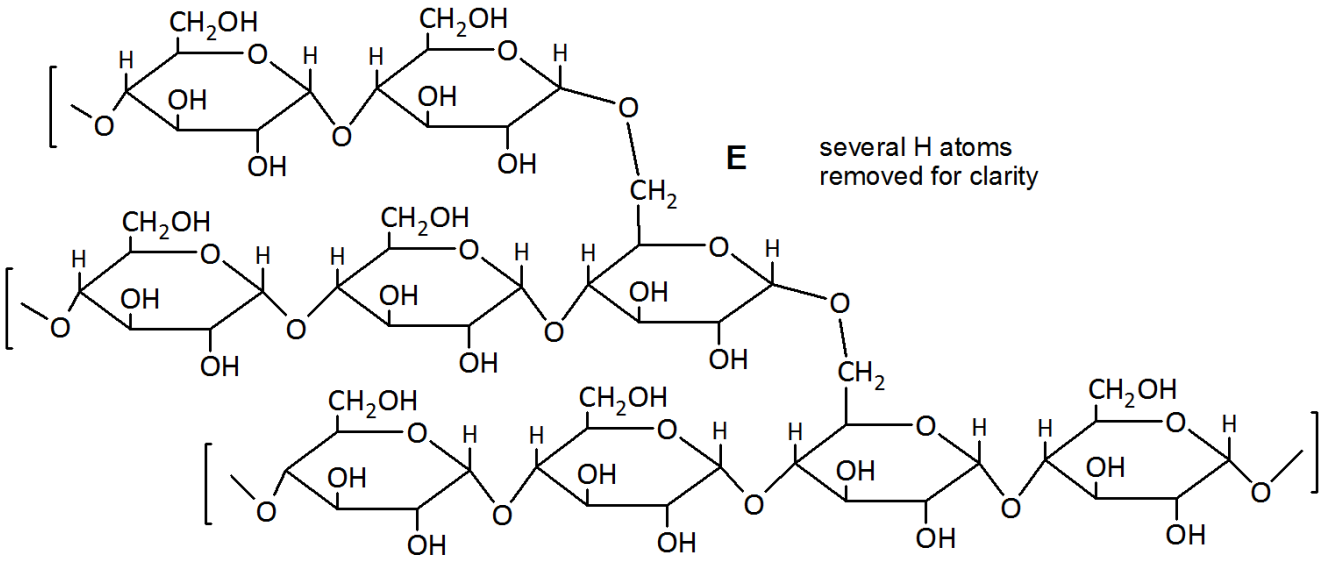


FIGURE 21.2



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WORKSHEET 22 # *Intermolecular Forces*

For each compound:

1. Indicate whether molecule is polar (P) or nonpolar (N)
2. Draw a 3-D Lewis structure and include the dipole symbol, if any.
3. Identify all types of IM forces from strongest to weakest.

Compound	P/N	3-D structure	IM forces (strongest to weakest)
H—O—H water			
H_3C—O—H methanol			
CH_2Cl_2 dichloromethane			
H_3C—CH_2—CH_3 propane			
HS—CH_2—CH_3 ethane thiol			
H_2N—CH_3 methyl amine			

Name _____ Section_____ Date _____

WORKSHEET 23 # *Intermolecular forces*

Part A: Correlation between Molecular Shape, IM Forces and Polarity

Group 1

	H_2S	CCl_4	HOH	CH_3OH
For each molecule, draw the Lewis structure then predict the shape of each molecule				
List all types of IM forces that exists in each molecule				
Indicate whether each molecule is polar or nonpolar				

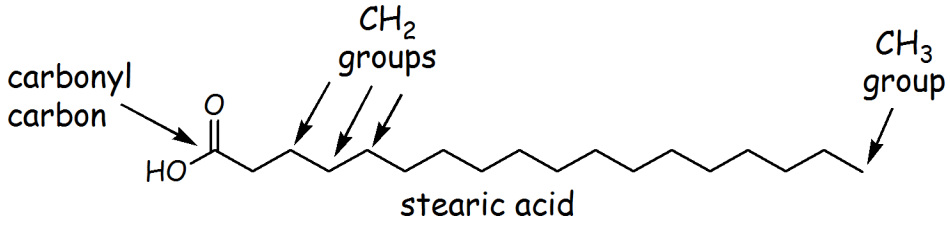
Group 2

	CH_3COCH_3 ketone	CH_3CO_2H Carboxylic acid	CH_3CONH_2 amide	$CH_3CO_2CH_3$ Carboxylic ester
For each molecule, draw the Lewis structure then predict the shape around the carbonyl carbon atom				

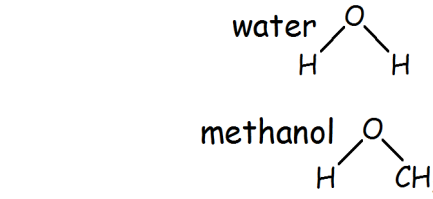
List all types of IM forces that exists in each molecule				
Indicate whether each molecule is polar or nonpolar				

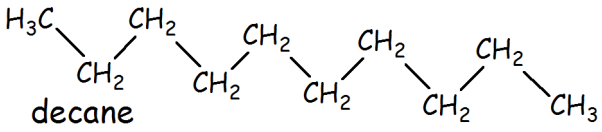
Part B: Correlation between Polarity and Solubility

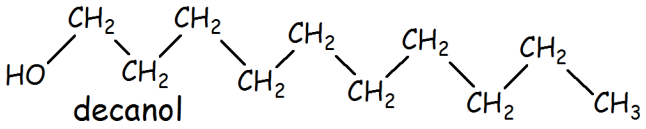
a. Stearic acid is a fatty acid composed of an 18-carbon backbone:



Think of the liquids below as solvents and stearic acid as the solute:



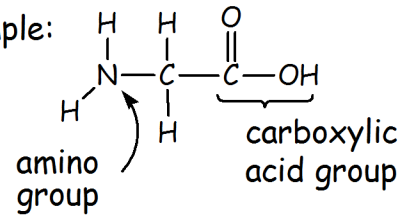




Stearic acid would be the most soluble in which solvent? Which solvent would it be least soluble? Explain in terms of IM forces.

b. Amino acids are composed of a carboxylic acid group and an amino group.

Glycine is an example:



Consider the 4 solvents above; which environment would it be most soluble? Explain.

Name _____ Section_____ Date _____

WORKSHEET 24

Solutions and Solubility Terminology

1. Do the following represent a saturated solution? Provide a short answer for each:
   a. A piece of rock salt does not change in size when added to a salt solution.

   b. A teaspoon of honey dissolves in hot tea.

2. Fill in the blanks with these choices: "increase", "decrease" or "stay the same".
   a. If the temp of a solution increases, the solubility of most solid solutes will _____.

   b. If the temp of a solution increases, the solubility of a gaseous solute will _____.

   c. If the pressure above a solution increases, the solubility of a gaseous solute will _____.

3. Explain what is happening in the following situations in terms of solubility. Provide short answers:
   a. Fish die in a lake that gets heated with water from a power plant cooling tower.

   b. Crystals form in a jar of honey that has been sitting for several months on a shelf.

4. Provide definitions for the following terms:
    a. strong electrolyte
    b. weak electrolyte
    c. non electrolyte
    d. osmosis
    e. active transport
    f. facilitated transport
    g. passive diffusion
    h. hydration

Name _____ Section_____ Date _____

WORKSHEET 25

Electrolyte Solutions and Molarity

1. Predict whether the following will fully dissociate, partially dissociate or not ionize when dissolved in water:
   a. sodium sulfate, $Na_2SO_4(s)$; a strong electrolyte
   b. ethyl alcohol $CH_3CH_2OH(l)$; a nonelectrolyte
   c. phosphoric acid $H_3PO_4(s)$; a weak electrolyte

2. Provide a balanced equation for the hydration of each compound in problem # 1.
   a.
   b.
   c.

3. For the following ionic compounds, write a balanced equation for their hydration:
   a. $FeCl_3$
   b. $NaHCO_3$
   c. K_2SO_4
   d. $Ca(NO_3)_2$

4. Calculate the molarity of:
   a. 750.0 mL of solution containing 2.10 moles of Na_2S

   b. 500.0 mL of solution containing 0.45 moles of $NaHSO_4$

Name _____ Section_____ Date _____

WORKSHEET 26

Molarity and Concentration Units

Molarity as a conversion factor:

1. How many moles of NaCl in 50.0 mL of a 1.25 M solution?

2. How many grams of $CaCl_2$ are present in 25.0 mL of a 0.500 M solution?

Percent Concentration Units:

3. Calculate the % mass/volume for the solute in each of the following solutions:
   a. 75 g of Na_2SO_4 in 250 mL of Na_2SO_4 aqueous soluti
   b. 39.0 g of sucrose in 335 mL of a carbonated drink.

4. What is the concentration in % (m/m) of a solution prepared by mixing 10.0 g of KCl with100.0 g of distilled water?

Concentration used as a conversion factor:

5. How many grams of NaCl must be dissolved in water to prepare 500.0 mL of a 0.90% (m/v) saline solution?

Name _____ Section_____ Date _____

WORKSHEET 27 # *Molarity Problems*

Calculate the molarity of the following solutions:

1. 2.3 moles of sodium chloride in 0.45 liters of solution.

2. 1.2 moles of calcium carbonate in 1.22 liters of solution.

3. 0.090 moles of sodium sulfate in 12 mL of solution.

4. 0.75 moles of lithium fluoride in 65 mL of solution.

5. 0.80 moles of magnesium acetate in 5.0 liters of solution.

For the following, notice you are starting with grams, not moles.

6. 120.0 grams of calcium nitrate, $Ca(NO_3)_2$, in 241 mL of solution.

7. 98 grams of sodium hydroxide, NaOH, in 2.2 liters of solution.

8. 1.2 grams of hydrochloric acid, HCl, in 25 mL of solution.

9. 45 grams of ammonia, NH_3, in 0.75 L of solution.

Name _____ Section_____ Date _____

WORKSHEET 28

Acid/Base, pH, and Zwitterions

A. Calculating pH when given either $[H_3O^+]$ or $[HO^-]$

If hydronium ion concentration is given, simply use your calculator and take the negative log of $[H_3O^+]$

$[H_3O^+] = 3.5 \times 10^{-3}$ M

$-\log(3.5 \times 10^{-3})$

pH = 2.46

If hydroxide ion concentration is given, First use Kw expression to calculate $[H_3O^+]$ and then take the negative log of $[H_3O^+]$ Given: $[HO^-] = 3.5 \times 10^{-3}$ M First use Kw expression to determine $[H_3O^+]$ $K_w = [H_3O^+][HO^-]$ $1.0 \times 10^{-14} = [H_3O^+][HO^-]$ $1.0 \times 10^{-14} = [H_3O^+](3.5 \times 10^{-3})$ Now rearrange and solve for $[H_3O^+]$ $\frac{1.0 \times 10^{-14}}{3.5 \times 10^{-3}} = [H_3O^+] = 2.9 \times 10^{-12} M$ Finally, take –log of $[H_3O^+]$ $-\log(2.9 \times 10^{-12})$ pH = 11.54	There is a faster method: Take the –log of $[HO^-]$, this is called the pOH Use the Kw expression in log form and rearrange: $pOH = -\log(3.5 \times 10^{-3}) = 2.46$ pOH = 2.46 $K_w = [H_3O^+][HO^-]$ $pK_w = pH + pOH$ 14 = pH + 2.46 pH = 14 - 2.46 = 11.54

Calculating pH when strong acid or strong base concentration is given

Remember, strong electrolytes completely dissociate, thus the concentration of H_3O^+ or OH^- is equal to the starting concentration given in the problem.

Example:	Example:
0.15 *M* HCl gives H_3O^+concentration of 0.15 *M* Take the –log to get pH: -log (0.15) = 0.82 pH = 0.82	0.25 *M* KOH gives HO^- concentration of 0.25 *M* Take the –log to get pOH: -log (0.25) = 0.60 pOH = 0.60 pH = 14 – pOH pH = 13.40

B. Calculating H_3O^+ from pH

$[H_3O^+]$ = INV log (-pH)

pH = 3.50

INV log (-3.50) = 3.2×10^{-4}

$[H_3O^+] = 3.2 \times 10^{-4}$ M

1. In the following equation which is the proton donor and which is the proton acceptor?

CO_3^{-2} (aq) + H_2O (l) → HCO_3^- (aq) + OH^- (aq)

   a. Donor: CO_3^{-2}; acceptor: H2O
   b. Donor: H2O; acceptor: CO_3^{-2}
   c. Donor: HCO_3^-; acceptor: OH-
   d. Donor: OH-; acceptor: HCO_3^-

2. Which of the following cannot act as a Bronsted acid?

   a. HSO_4^-
   b. H_2O
   c. CO_3^{-2}
   d. HS^-

3. According to the equation,

$NH_3 + HCN \rightarrow NH_4^+ + CN^-$

which of the following is a conjugate pair?

   a. NH_3 and HCN
   b. HCN and NH_4^+
   c. NH_4^+ and CN^-
   d. NH_3 and NH_4^+

4. Which of the following is <u>not</u> a strong acid?
   a. HCl (aq)
   b. HNO_3
   c. HOAc
   d. HBr

5. Which of the following is <u>not</u> a strong base?
   a. NaOH
   b. $Al(OH)_3$
   c. KOH
   d. $Ca(OH)_2$

6. Which of the following is a weak acid?
   a. H_3PO_4
   b. HNO_3
   c. NH_3
   d. OH^-

7. Which of the following is a correct balanced equation for the neutralization reaction that occurs between $Al(OH)_3$ and HCl (aq)?
   a. $Al(OH)_3 + 3\ HCl\ (aq) \rightarrow AlCl_3 + 3\ H_2O$
   b. $Al(OH)_3 + HCl\ (aq) \rightarrow AlCl_3 + H_2O$
   c. $Al(OH)_3 + 3\ HCl\ (aq) \rightarrow AlCl_3 + H+ + OH-$
   d. $Al^{+3} + OH^- + H^+ + Cl^- \rightarrow AlCl_3 + H_2O$

8. Which of the following compounds will form CO_2 and H_2O when it reacts with an acid?
   a. $Mg(OH)_2$
   b. $CaCO_3$
   c. NH_3
   d. NaOAc

9. Given the following reaction,

$$4\ CuO\ (s) + CH_4\ (g) \rightleftharpoons CO_2(g) + 4\ Cu\ (s) + 2\ H_2O\ (g)$$

the equilibrium expression will be:
   a. $K = [CuO]/[Cu]$
   b. $K = [CuO]^4/[Cu]^4$
   c. $K = [Cu]^4/[CuO]^4$
   d. $K = [CO_2][H_2O]^2/[CH_4]$

10. The following reaction is *exothermic*. Which of the following will drive the reaction to the right (towards products)?

$$CH_4\ (g) + 2\ O_2\ (g) \rightleftharpoons CO_2\ (g) + 2\ H_2O\ (g)$$

   a. A decrease in temperature
   b. An increase in temperature
   c. The removal of CH_4
   d. The addition of CO_2

11. Which one is the strongest acid?
   a. HCN ($Ka = 4.9 \times 10^{-10}$)
   b. HClO ($Ka = 3.0 \times 10^{-8}$)
   c. HNO_2 ($Ka = 4.5 \times 10^{-4}$)
   d. HF ($Ka = 6.8 \times 10^{-4}$)

12. When a system is at equilibrium:
    a. the reaction rate of the forward reaction is equal to the rate of the reverse.
    b. the reaction rate of the reverse reaction is small compared to forward.
    c. the reaction rate of the forward reaction is small compared to the reverse.
    d. the amount of product and reactant is exactly equal.

13. Which one is the weakest acid?
    a. HCN ($K_a = 4.9 \times 10^{-10}$)
    b. HClO ($K_a = 3.0 \times 10^{-8}$)
    c. HNO_2 ($K_a = 4.5 \times 10^{-4}$)
    d. HF ($K_a = 6.8 \times 10^{-4}$)

14. What is the conjugate base of water?
    a. H_2O
    b. OH^-
    c. O_2
    d. O^{-2}

15. Which of the following does <u>not</u> represent a conjugate acid-base pair?
    a. H_3O^+/H_2O
    b. HCN/CN^-
    c. HCl/Cl^-
    d. $HOAc/OH^-$

16. Calculate the pH of 0.00756 M HNO_3.
    a. 11.879
    b. 7.091
    c. 2.121
    d. 12.947

17. In an *acidic* solution, pH is _____ and $[H_3O^+]$ is _____.
    a. = 7 and $[H_3O^+] = 1 \times 10^{-7}$ M
    b. > 7 and $[H_3O^+] < 1 \times 10^{-7}$ M
    c. < 7 and $[H_3O^+] > 1 \times 10^{-7}$ M
    d. < 7 and $[H_3O^+] < 1 \times 10^{-7}$ M

18. What is the pH of a solution that has a $[H_3O^+] = 1.2 \times 10^{-3}$?
    a. 1.20
    b. 2.92
    c. 11.08
    d. 12.80

19. What is the $[H_3O^+]$ concentration of a solution that has a pH = 2.34?
    a. 2.3×10^{-3} M
    b. 4.6×10^{-3} M
    c. 2.2×10^{-12} M
    d. 1.2×10^{1} M

20. What is the $[H_3O^+]$ concentration of a solution that has a pH = 11.61?
    a. 1.2×10^{1} M
    b. 1.0×10^{-14} M
    c. 2.5×10^{-12} M
    d. 4.1×10^{11} M

21. Consider the weak acid HCO_3^- whose pKa = 10.32, which form will predominate when the pH of the solution is 8.5?
    a. HCO_3^-
    b. CO_3^{-2}
    c. H_2CO_3
    d. All of these

22. Consider the weak acid HCO_3^- whose pKa = 10.32, which form will predominate when the pH of the solution is 12.00?

a. HCO_3^-

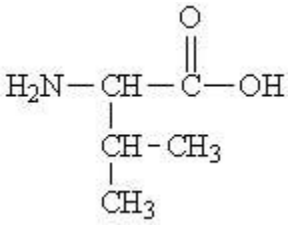
b. CO_3^{-2}

c. H_2CO_3

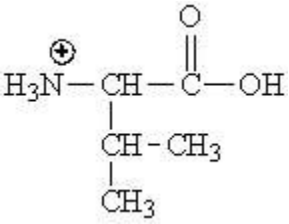
d. All of these

23. Which of the following represents the zwitterion form of the amino acid valine?

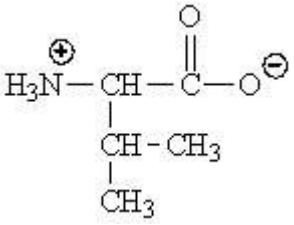
a.



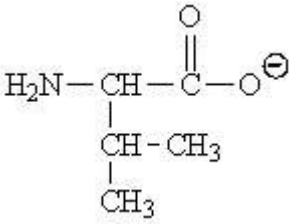
b.



c.



d.



24. The isoelectric point of an amino acid is defined as:
    a. the pH at which the amino acid exits in the zwitterion form
    b. the pH at which it exists in the basic form
    c. the pH at which it exists in the acidic form
    d. the pH equals the pKa

25. Which of the following substances, when added to a solution of nitrous acid (HNO_2), could be used to prepare a buffer solution?
    a. HCl
    b. NaCl
    c. AcOH
    d. $NaNO_2$

26. Which of the following blood buffers is the one we studied in this class?
    a. HOAc/AcO-
    b. NH_4^+ / NH_3
    c. H_2CO_3/HCO_3^-
    d. HPO_4^{-2}/PO_4^{-3}

Not a multiple choice question:

27. Identify the acid *(A)*, base *(B)*, conjugate acid *(CA)* and conjugate base *(CB)* in each of the following reactions:
    a. HSO_4^- (aq) + ClO^- (aq) → HClO (aq) + SO_4^{-2} (aq)
    b. $H_2C_2O_4$ (aq) + NH_3 (aq) → $HC_2O_4^-$ (aq) + NH_4^+ (aq)
    c. CN^- (aq) + $HC_2H_3O_2$ (aq) → HCN (aq) + $C_2H_3O_2^-$
    d. H_2S (aq) + NH_3 (aq) → HS^- (aq) + NH_4^+ (aq)

Not a multiple choice question:

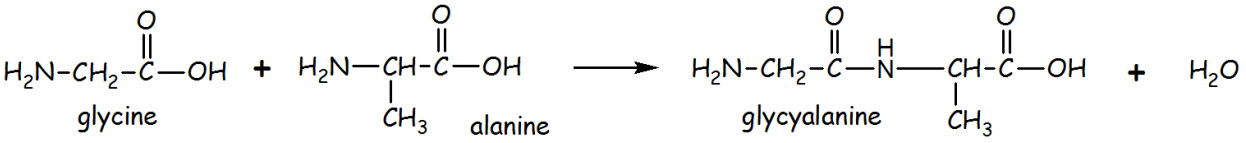
28. Indicate whether the following solutions are acidic, basic or neutral, **and,** for each concentration calculate the pH of the solution.
    a. $[H^+] = 1.1 \times 10^{-3}$ M
    b. $[H^+] = 6.0 \times 10^{-11}$ M

Name _____ Section_____ Date _____

WORKSHEET 29 # *Amino Acids*

The amino group of one amino acid and the acid group of another can undergo a condensation reaction to form a new bond called a peptide bond (an amide bond). The new molecule is called a dipeptide. More condensation reactions can form tripeptides, tetrapeptides and polypeptides.

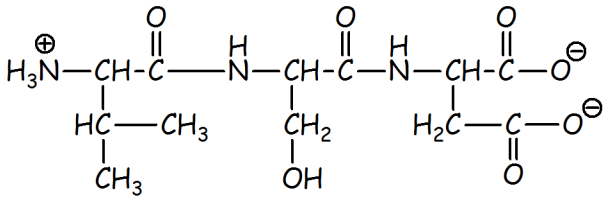
MODEL 29.1



1. Draw a box around the substructure of glycylalanine that corresponds to alanine.
2. Draw a dotted-box around the substructure of glycylalanine that corresponds to glycine.
3. Draw an arrow to the bond formed in the condensation reaction (the peptide bond).
4. Would the dipeptide Ala-Gly (alanylglycine) be the same molecule as Gly-Ala? Explain.

MODEL 29.2

Model 2
Tripeptide



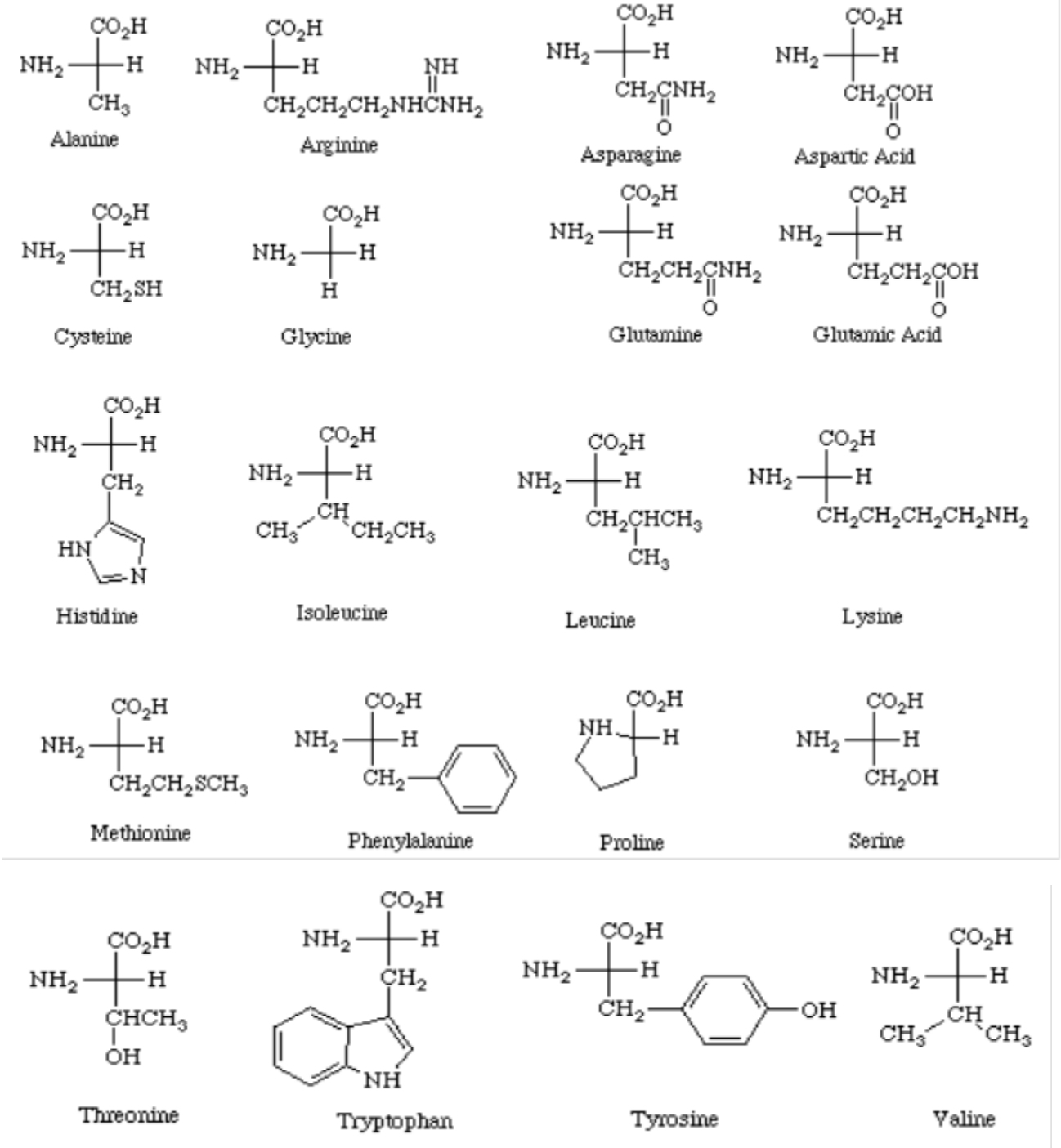
5. Circle the three side chains (R groups) in Model 29.2.
6. What three amino acids condensed to make this tripeptide? (see Figure 29.3 on page 75)

7. Construct an explanation for why the central amino acid in Model 29.2 is called an amino acid residue.

For each amino acid in Figure 29.3 on page 75:

1. Draw a circle around the carboxylic acid group
2. Draw a triangle around the α-amino group
3. Draw a box (or rectangle or polygon) around the R group in each amino acid
4. Use hi-lighters or colored pencils on each name to classify the amino acids as one of the following:
    a. Nonpolar
    b. Polar neutral
    c. Polar acidic
    d. Polar basic

FIGURE 29.3


Alanine
Arginine
Asparagine
Aspartic Acid
Cysteine
Glycine
Glutamine
Glutamic Acid
Histidine
Isoleucine
Leucine
Lysine
Methionine
Phenylalanine
Proline
Serine
Threonine
Tryptophan
Tyrosine
Valine

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WORKSHEET 30 *Oxytocin*

Oxytocin is a polypeptide that acts as a hormone. Its structure is shown below.

1. If oxytocin undergoes complete hydrolysis, how many amino acids would be produced?

2. Notice that the polypeptide chain is cyclized; two cysteine residues form a covalent bond between their sulfur atoms (a disulfide bond). When the disulfide bond is broken, each S atom will gain a hydrogen atom (to become a thiol alcohol). Break the disulfide bond and draw the uncyclized polypeptide chain. Follow the convention and draw the polypeptide with the N-terminus on the left and C-terminus on the right.

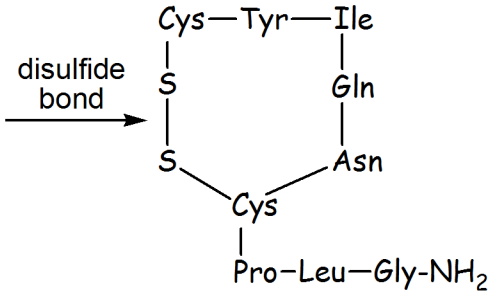
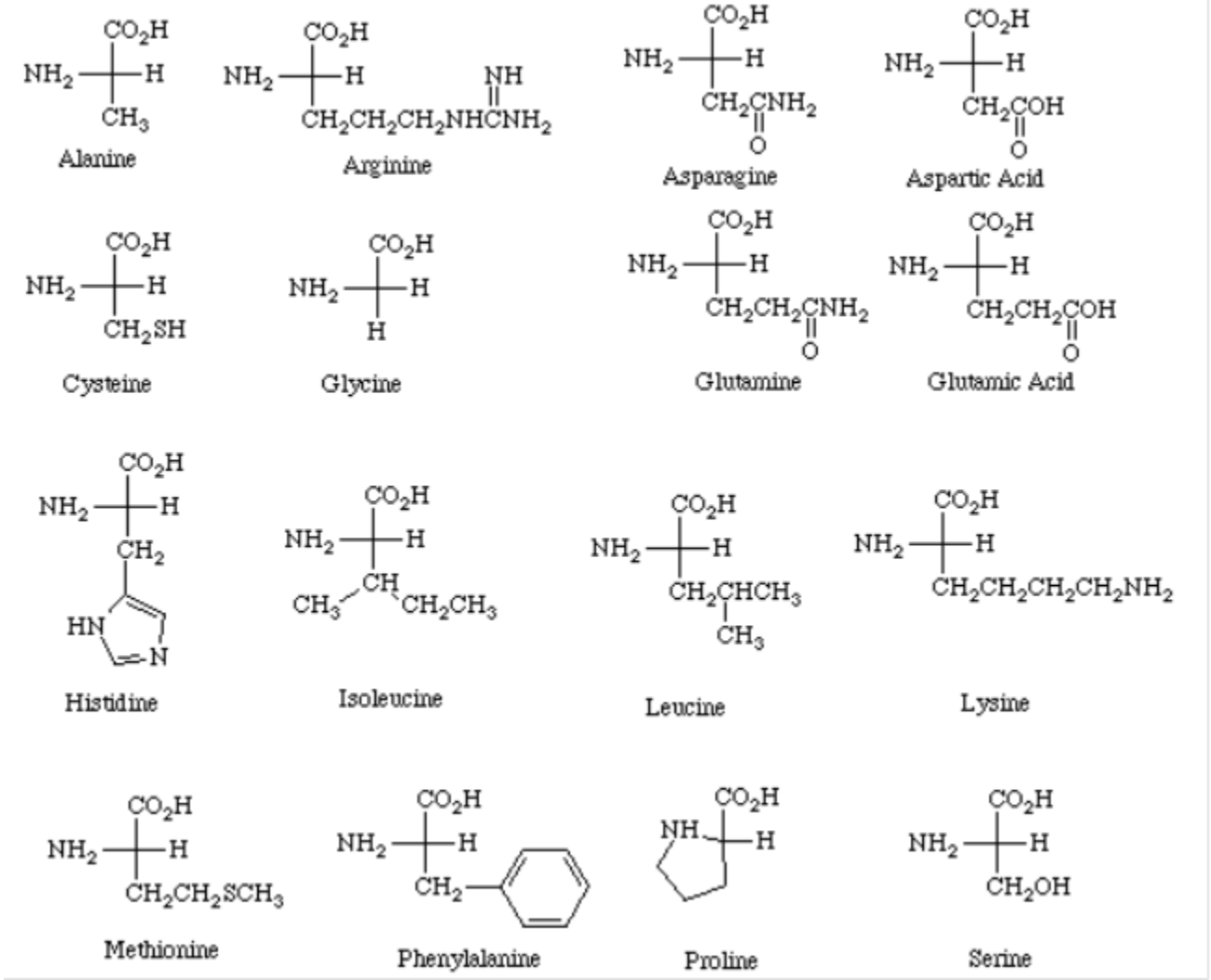


FIGURE 30.1

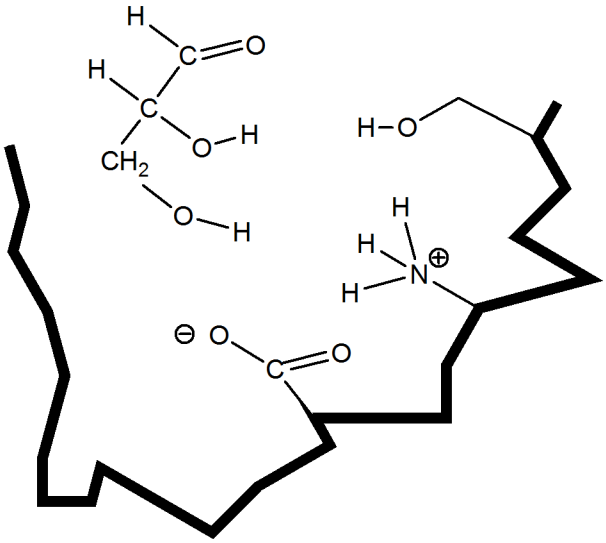

Alanine
Arginine
Asparagine
Aspartic Acid
Cysteine
Glycine
Glutamine
Glutamic Acid
Histidine
Isoleucine
Leucine
Lysine
Methionine
Phenylalanine
Proline
Serine
Threonine
Tryptophan
Tyrosine
Valine

Name _____ Section_____ Date _____

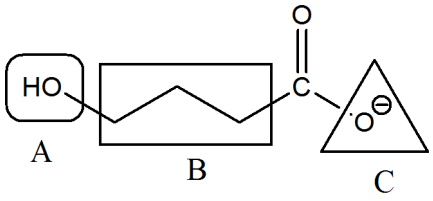
WORKSHEET 31

Enzyme-Substrate Complex

1. Illustrate intermolecular forces between this hypothetical model of a substrate molecule bound in the active site of an enzyme.



2. A substrate is locked into place in the active site of an enzyme by intermolecular forces between the substrate and amino acid side chains. Examine the three regions of the substrate molecule which are labeled as A, B and C.
   a. For each region, describe a possible intermolecular force that could form in the active site.
   b. For each region, name an amino acid whose side chain could provide the intermolecular force you described above.



Name _____ Section_____ Date _____

WORKSHEET 32 # *Nucleic Acids*

Nucleic acids resemble other biomolecules in the sense that they are polymers of smaller building blocks. The monomers of nucleic acids are called nucleotides which are assembled into a polymer by phosphate ester linkages. There are two types of nucleic acids, DNA and RNA. DNA has two main functions: replication of genetic information during mitosis and translation of genetic information into protein synthesis. RNA serves as the carrier of genetic information from DNA to protein synthesis sites within the cells.

Nucleic acid building blocks, **nucleotides**, consist of three units: a carbohydrate, an organic base and a phosphate group. There are two differences between RNA and DNA:

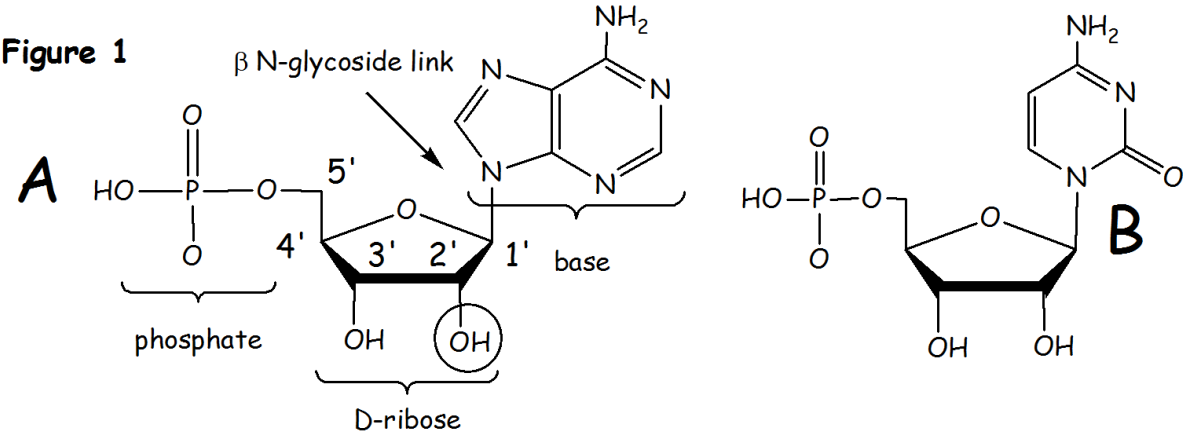
1. RNA uses D-ribose as the carbohydrate component; DNA uses D-2-deoxyribose
2. RNA uses 4 organic bases- adenine, guanine, cytosine and uracil; DNA use the same bases except thymine replaces uracil.

The ribose unit is connected to the base through a nitrogen glycosidic link at the anomeric carbon and the phosphate group is connected to C-5. There are two classes of organic bases, pyrimidine bases (one six-membered ring) and purine bases (6-membered ring fused to a 5-membered ring).

Nucleotides are connected by a phosphate diester link between the 5′ position of one nucleotide and the 3′ position of the neighboring nucleotide. The hydroxyl groups at both 5′ and 3′ are lost as water molecules when substituted with a phosphate group.

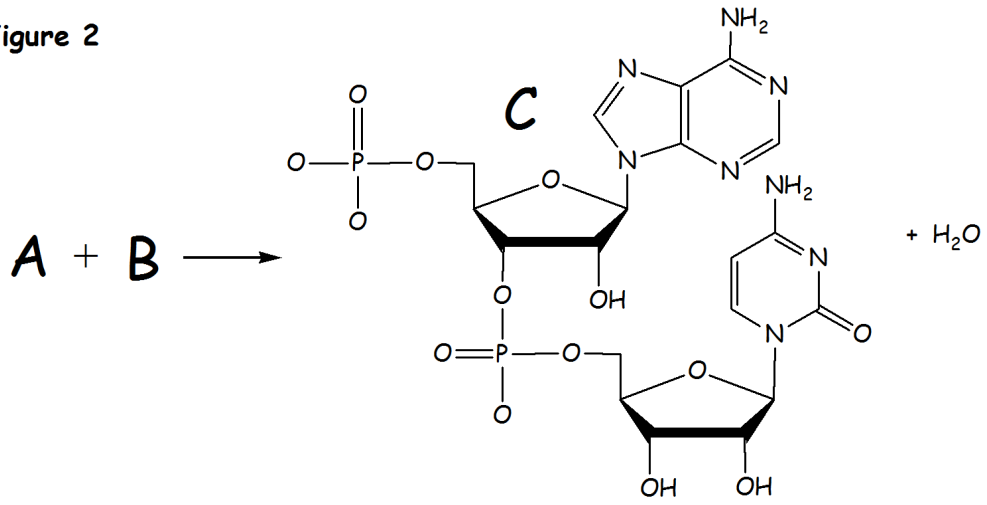
Representative nucleotides (A, B) are shown below including the prime numbering system of the ribose unit.

Figure 1

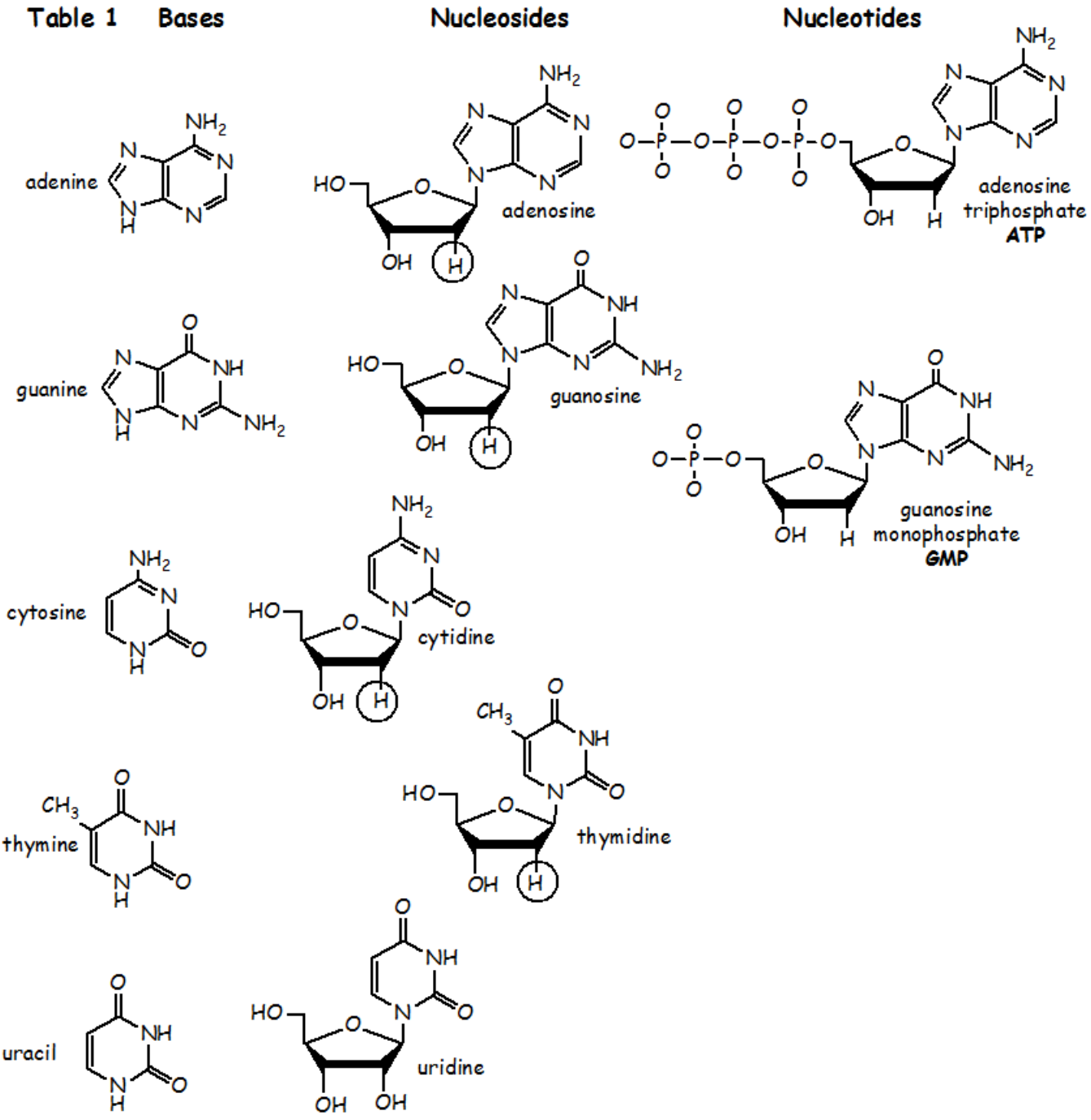


The condensation of A and B produces water:

Figure 2



A nucleotide that does not contain a phosphate group is called a nucleoside. The name of nucleosides is derived from the name of the base; notice the suffix changes when the base is bonded to a ribose (or deoxyribose) unit. Study the table below to see how nomenclature is applied to nucleosides and nucleotides.



The different bases distinguish one polynucleotide from another; the **primary structure** of polynucleotides is the identity and order of the bases. Nucleic acids (polynucleotides) are named by the sequence of bases beginning at the 5′ end using one-letter abbreviations for each base. The abbreviations used are G, C, A, T and U (RNA).

I. Critical Thinking Questions

1. What is the significance of the circle around one of the hydroxyl groups in Figure 1?

2. Are the nucleotides in Figure 1 and Figure 2 possible units for RNA or DNA? Explain.

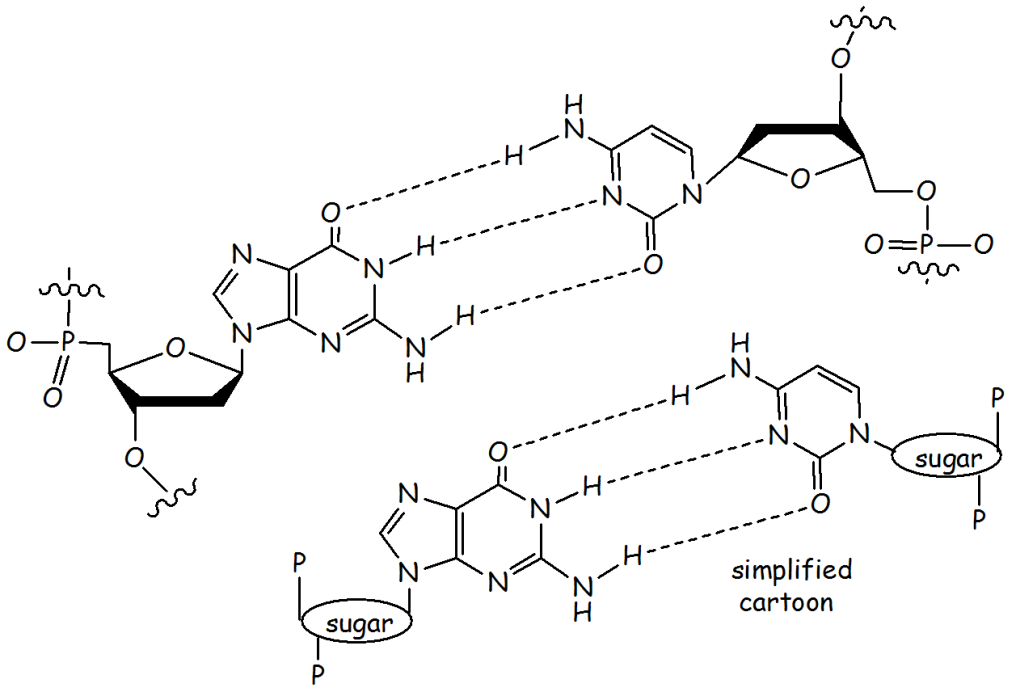
3. Provide the full name and 3-letter abbreviation for A and B (Figure 1).

Abbr.	Name
a.	
b.	

4. Provide the full name and 3-letter abbreviation for the nucleotide formed from uracil bonded to two phosphate units.

Abbr.	Name
a.	
b.	

Figure 3 Hydrogen Bonding in DNA Double Helix



II. Critical Thinking Questions

1. Two conditions for hydrogen bonding:

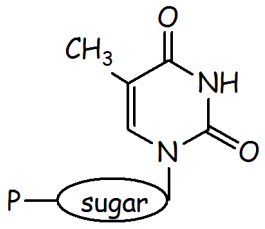
   a. There must be a hydrogen atom bonded to a _____ or _____ atom.

   b. There must be a _____ to accept the hydrogen atom.

2. The nucleotide complementary pair in Figure 3 can be abbreviated as (choose one):
   a. AT
   b. GC
   c. AU

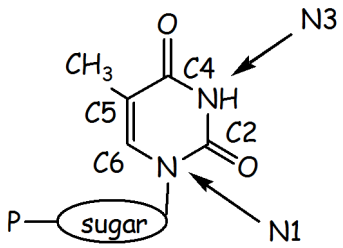
3. Draw the complementary nucleotide for the nucleotide in Figure 4a and illustrate hydrogen bonds.

Figure 4a



4. Explain why the sugar unit in Figure 4b is connected to atom N1 and not atom N3. To answer this question, redraw the nucleotide with the sugar connected to N3 then examine the relationship to its complementary nucleotide.

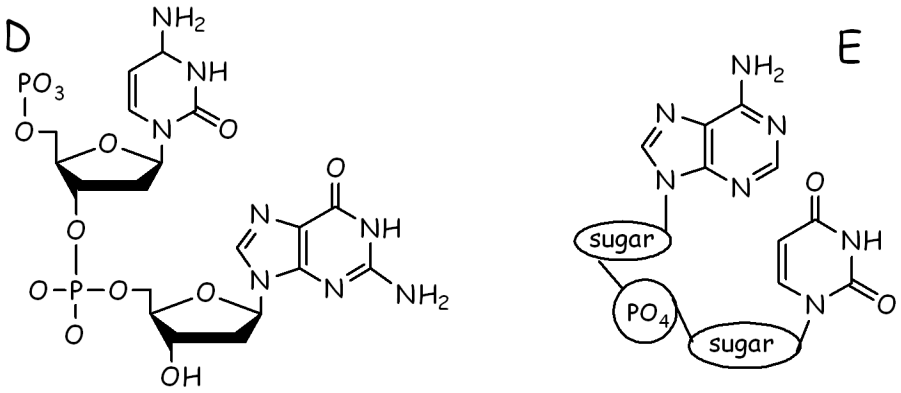
Figure 4b



5. High temperature destabilizes DNA helices; the helix begins to unwind and degrade. Consider two DNA double helices, A and B. Helix A has 75% CG content and 25% AT content. Helix B has 35% CG content and 65% AT content. Which helix is more stable to heat? Explain.

III. Critical Thinking Questions

Figure 5



1. Examine the structures in Figure 5.
   a. Is structure D a dinucleotide for RNA or DNA? Explain.

   b. Is structure E a dinucleotide for RNA or DNA? Explain.

IV. Critical Thinking Questions

1. Examine the notation shown here for a strand of DNA:
   5' - A T T G C T G C C A - 3'
   a. Explain what 5' and 3' refer to.

   b. Explain what the letter abbreviations refer to.

   c. Draw the complementary strand using similar notation.

The sequences of nucleotides in DNA correspond to the sequences of amino acids in proteins. DNA is too large to move through the cell nucleus membrane; in order to transmit genetic information into the cytosol of a cell, DNA directs the formation of RNA which can migrate from the nucleus to the site of protein synthesis. **Protein synthesis** consists of two major steps:

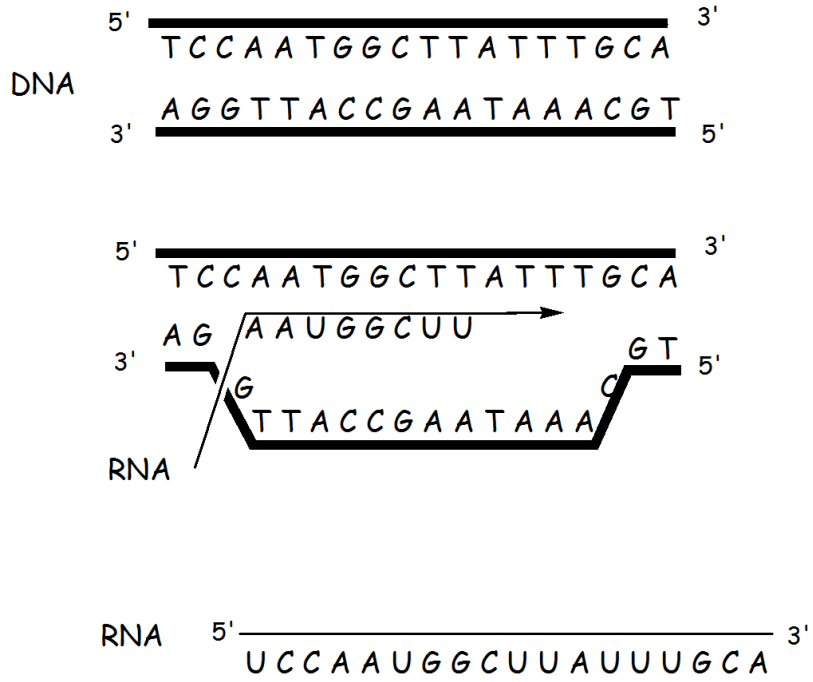
1. Transcription- synthesis of RNA from DNA. There are 3 types of RNA:

Messenger RNA (mRNA), transfer RNA (tRNA) and ribosomal RNA (rRNA).

2. Translation- synthesis of polypeptides using the nucleotide sequence from nucleic acids

DNA helix unwinds to form a transcription bubble which has a **template strand** and **nontemplate strand**. RNA polymerase is the enzyme which "reads" the base sequence of the template strand and assembles the complementary nucleotides in the developing RNA strand. Base pairing determines the sequence of nucleotides from DNA to RNA (uracil replaces thymine in RNA). Consequently, RNA synthesized from the template strand has the same base sequence as the nontemplate strand, except for uracil in place of thymine.

Figure 6



V. Critical Thinking Questions

1. Write the base sequence in the RNA strand synthesized from DNA whose template strand has this sequence 5'- ACATGC-3'

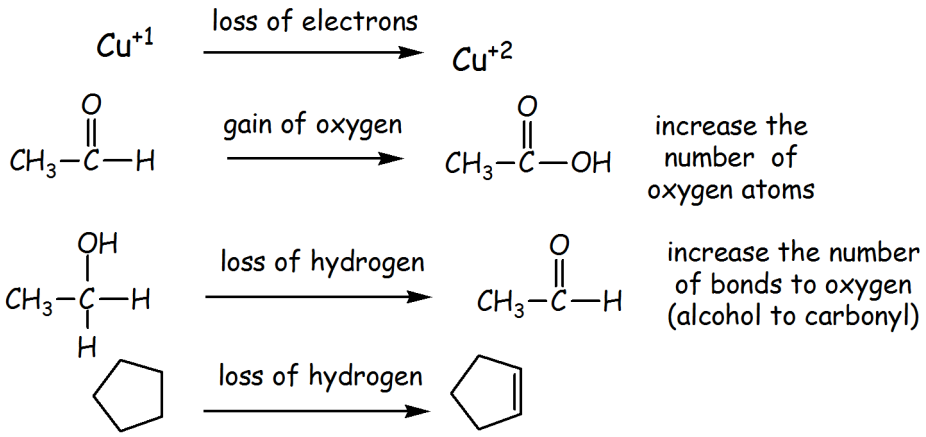
Name _____ Section_____ Date _____

WORKSHEET 33 # *Metabolism Redox*

What is Redox? What does oxidation look like?

Oxidation is defined as loss of electrons by an atom (or group of atoms). For organic molecules, oxidation is loosely defined as an increase of oxygen content or a decrease in the hydrogen content. In the oxidation of an aldehyde to an acid, obviously the number of oxygen atoms increases. But for oxidation of an alcohol to an aldehyde, the number of oxygen atoms does not increase, however, the number of bonds to oxygen does increase. If using the decrease in hydrogen content as the criterion, then oxidation of an alcohol to an aldehyde does show a decrease in the number of hydrogen atoms. Study the examples of oxidation in Figure 33.1.

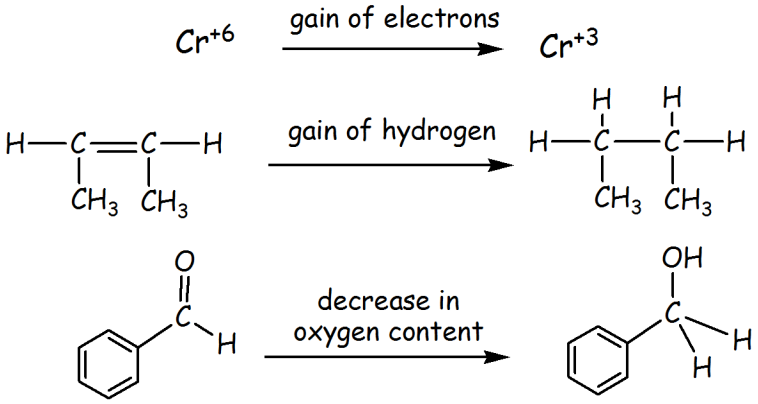
FIGURE 33.1 Oxidation Half-Step Reactions



What does reduction look like?

The easy answer is, reduction looks like oxidation in reverse. In fact each reaction in Figure 1 written backwards, would be an example of reduction. **Reduction is defined as a gain of electrons** by an atom (or groups of atoms). For organic molecules, an increase in the hydrogen content or a decrease in the oxygen content would be reduction. See Figure 33.2 for examples.

FIGURE 33.2 Reduction Half-Step Reactions



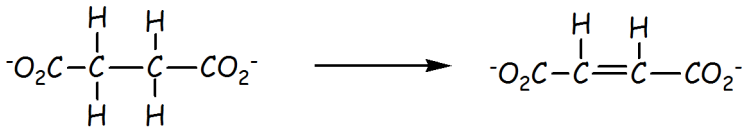
Whenever a species gets oxidized, some other species must get reduced. Since redox is defined as gain or loss of electrons, in actual systems, a reducing agent transfers electrons to an oxidizing agent. In any redox process, there is a structure which provides and a structure which accepts electrons. A **half-reaction** refers to either the oxidation or reduction step.

Some reactions are often confused with redox. There are many examples of hydrolysis of organic functional groups and biomolecules: hydrolysis of carboxylic acid derivatives, hydrolysis of hemiacetals and acetals, hydrolysis of peptides bonds, etc. None of these are redox. Other common reactions in biosystems involve isomerization, the movement of an atom or group of atoms from one location to another within the same molecule. Isomerization reactions are not redox.

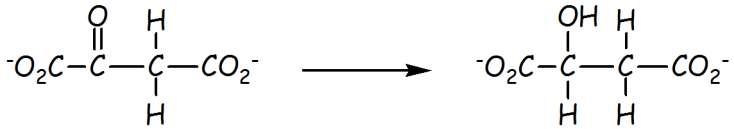
A. Critical Thinking Questions.

1. Label the following reactions as reduction, oxidation or neither (not redox).

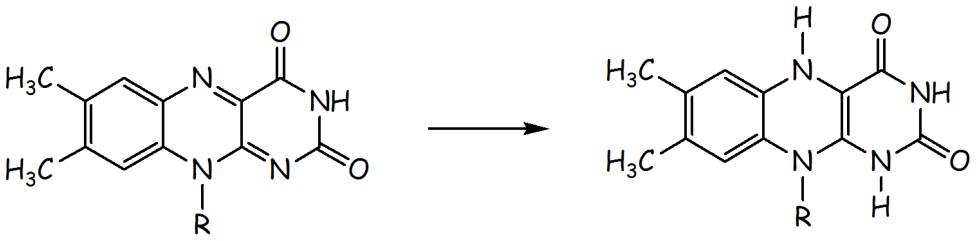
a.



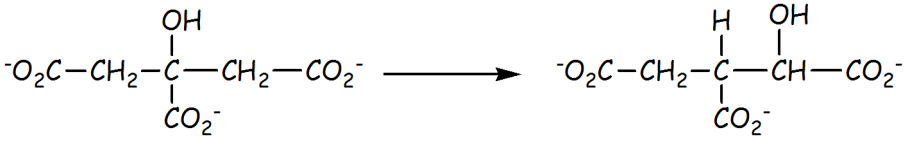
b.



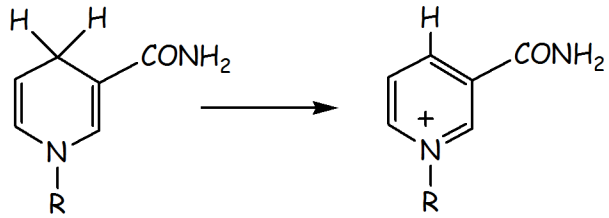
c.



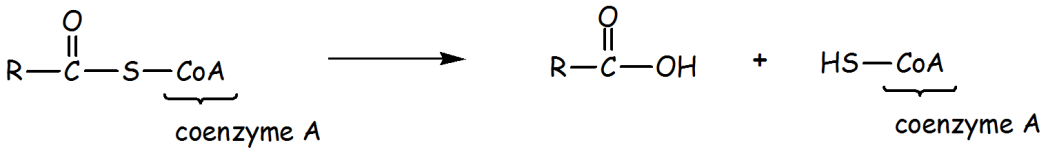
d.



e.



f.



2. Which of the reactions (a-f above) if any, are:
   a. hydrolysis reactions
   b. isomerization reactions

Name _____ Section_____ Date _____

WORKSHEET 34 *Glycolysis*

Using Figure 34.1 on page 97 answer the following questions:

1. Identify the steps of glycolysis that are referred to as:
    a. Energy-investment phase

    b. Energy-generating phase

2. Step 4 of glycolysis produces two products, glyceraldehyde-3-phosphate and dihydroxyacetone phosphate. What happens to dihydroxyacetone phosphate before it proceeds through the glycolytic pathway?

3. Examine Steps 6-10 of glycolysis.

Why is there a "2" preceding each substrate (e.g., "2" 1,3-bisphosphoglycerate)?

4. ATP is used up in two steps (1 and 3) and generated in two other steps (7 and 10). If this is the case, explain how glycolysis gives a net yield of 2 ATP molecules.

5. Which step in glycolysis is an oxidation step? Explain how you can determine this.

6. Identify the enzyme needed for each of the following steps in glycolysis:
   a. Step 1 _____
   b. Step 3 _____
   c. Step 6 _____

7. The net chemical equation for the first step of glycolysis is:

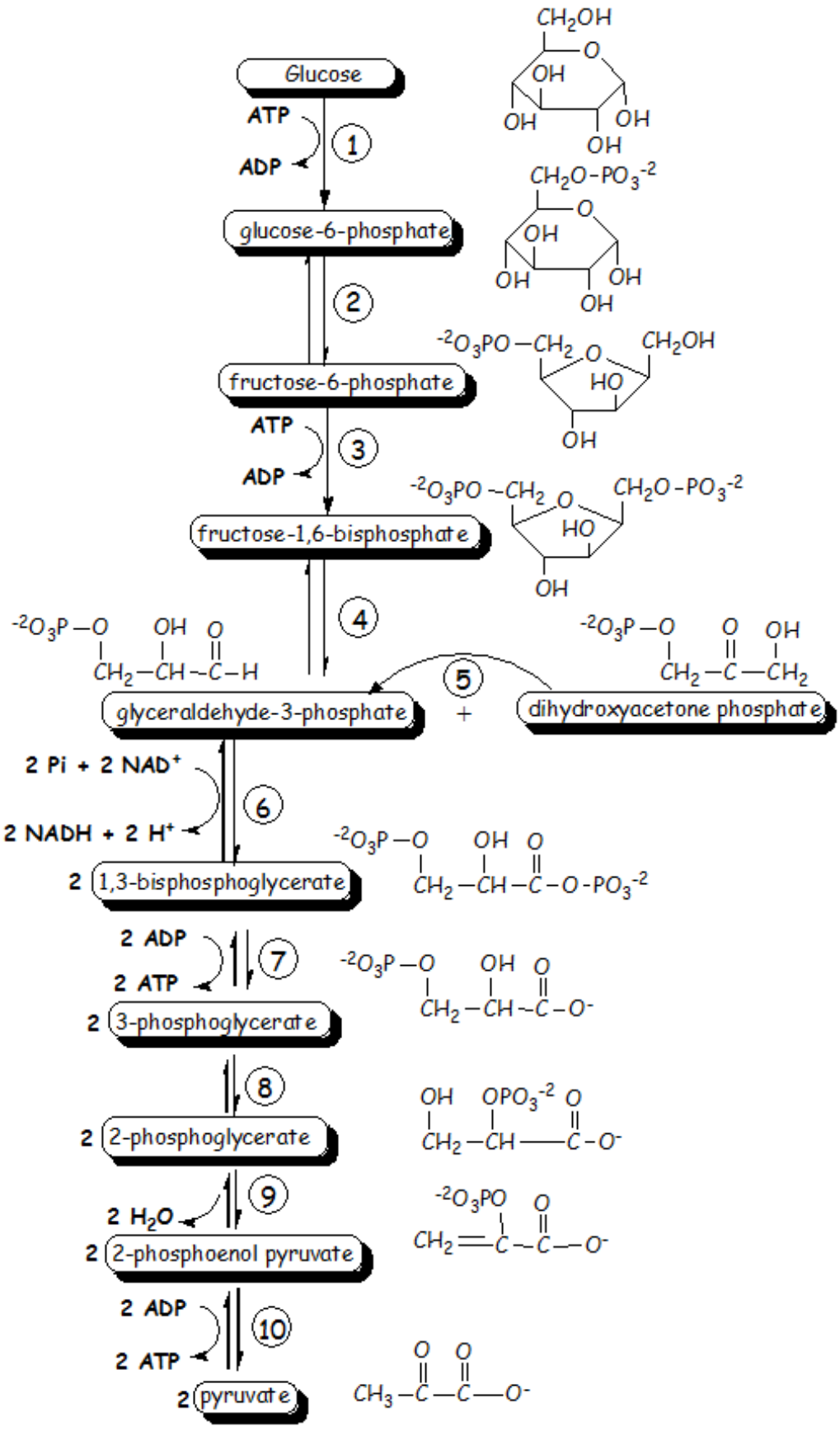
glucose + ATP ⇌ glucose-6-phosphate + ADP

Write a similar equation for these steps of glycolysis:

   a. Step 7

   b. Step 4

FIGURE 34.1 Glycolysis Pathway



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WORKSHEET 35 # *Citric Acid Cycle*

Using Figure 35.1 on page 100 answer the following questions:

1. Consider one of the reactants in Step 1 and the product from Step 8 then explain why the CAC is called a cyclic pathway.

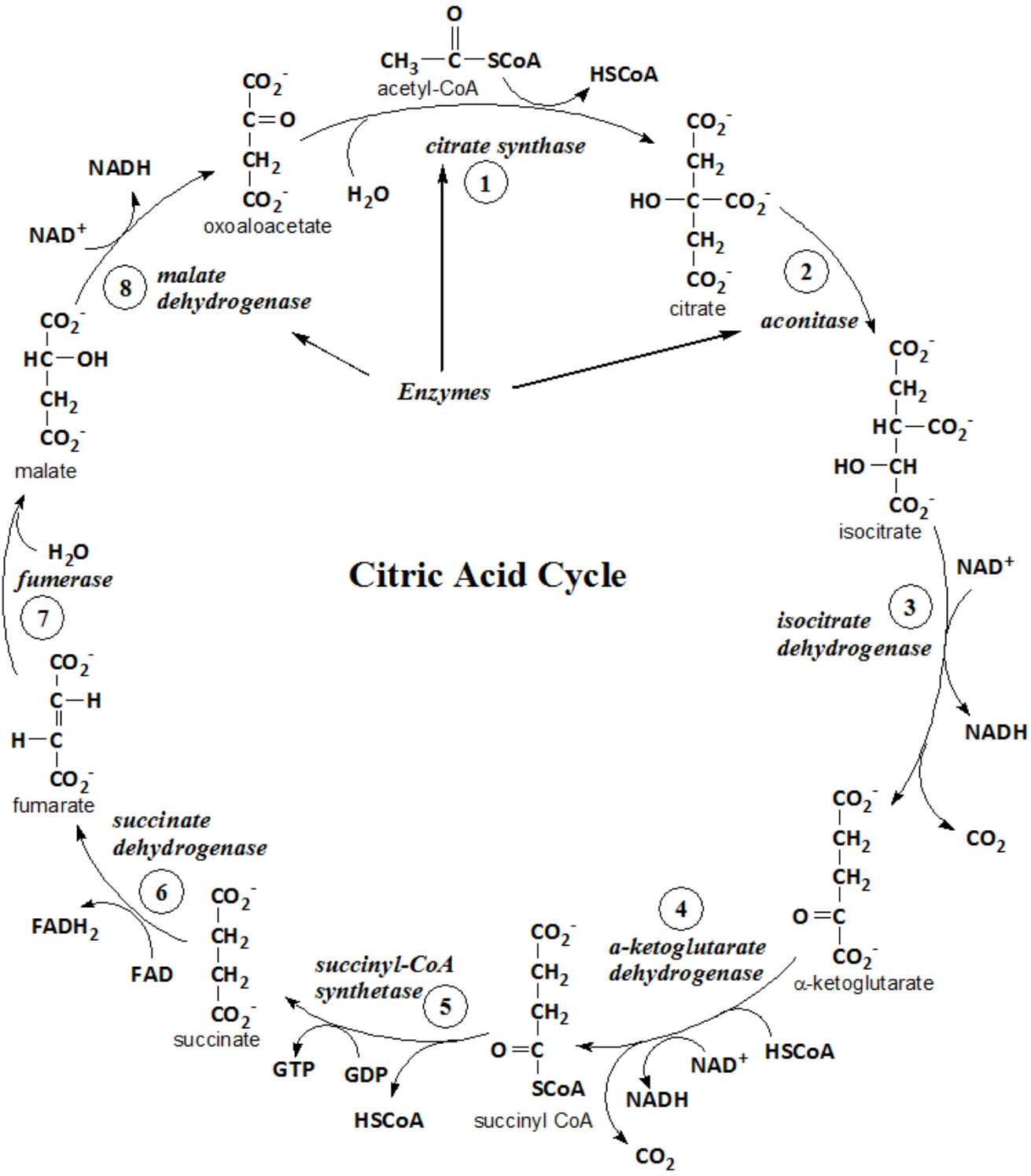
2. For each cycle, two molecules of CO_2 are released. In which steps is CO_2 produced?

3. Four of the eight steps are oxidations; identify the oxidation steps.

4. In one of the early steps in the CAC, an alcohol is oxidized. Why is it necessary that this step is preceded by an isomerization reaction?

5. The only reaction in the citric-acid cycle in which a carbon-carbon bond is formed is catalyzed by which enzyme?

FIGURE 35.1 Citric Acid Cycle (CAC) oxidizes acetyl-coenzymeA to CO_2 and H_2O



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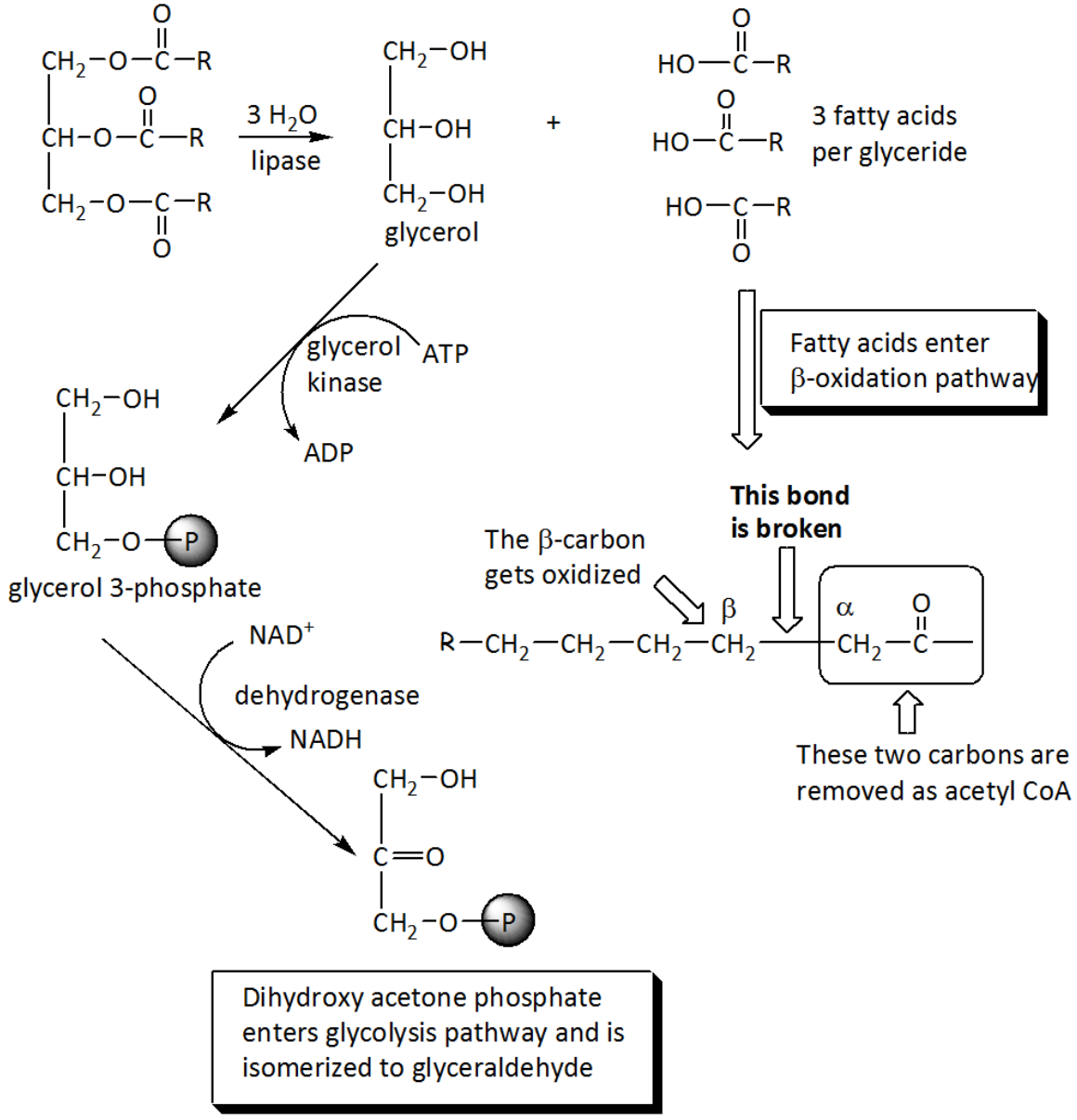
WORKSHEET 36

Metabolism of Fats via β-Oxidation of Fatty Acids

Triglyceride Catabolism

Triglycerides are hydrolyzed to give glycerol and fatty acids:

- Glycerol is converted to dihydroxyacetone and enters the glycolysis pathway. (Dihydroxyacetone is the same intermediate formed in glycolysis.)
- Fatty Acids enter the β-oxidation pathway



β-*Oxidation Pathway*

1. How many high-energy phosphate bonds are hydrolyzed during fatty acid activation?

2. Which steps in the β-oxidation pathway are oxidation steps? (how can you tell?)

3. What is the first substrate that enters the CAC?_____

4. What is the final substrate from the CAC? _____

5. If glucose is not available, how does the CAC continue during a "low carb" diet?

6. Are ketone bodies expected to be water soluble?

7. A doctor is monitoring a patient on a "low carb" diet. Why would the doctor sniff the patient's breath?