ChemQuest 1

Numbers in Chemistry

Name: ____________________________
Date: _______________
Hour: _____

Information: Qualitative vs. Quantitative

The following observations are qualitative.

The building is really tall.
It takes a long time for me to ride my bike to the store.
I live really far away.

The following observations are quantitative.

The river is 31.5 m deep.
The cheese costs $4.25 per pound.
It is 75^{o} F outside today.

Critical Thinking Questions

1. What is the difference between qualitative and quantitative observations? (Your answers should reveal an understanding of the definitions for qualitative and quantitative.)

2. Write an example of a quantitative observation that you may make at home or at school.

3. Why are instruments such as rulers, scales (balances), thermometers, etc. necessary?

Information: Units

The following tables contain common metric (SI) units and their prefixes.

Table 1: metric base units

Quantity	Unit	Unit Symbol
Length	meter	m
Mass	kilogram	kg
Time	second	s
Temperature	Kelvin	K
Volume	Liter	L
Amount of substance	mole	mol

Table 2: prefixes for metric base units.

Prefix	Symbol	Meaning
Mega	M	million
Kilo	k	thousand
Deci	d	tenth
Centi	c	hundredth
Milli	m	thousandth
Micro	μ	millionth
Nano	n	billionth
Pico	p	trillionth

Note the following examples:

- "milli" means thousandth so a milliliter (symbol: mL) is one thousandth of a Liter and it takes one thousand mL to make one L.
- "Mega" means million so "Megagram" (Mg) means one million grams NOT one millionth of a gram. One millionth of a gram would be represented by the microgram (μg). It takes one million micrograms to equal one gram and it takes one million grams to equal one Megagram.
- One cm is equal to 0.01 m because one cm is "one hundredth of a meter" and 0.01 m is the expression for "one hundredth of a meter"

Critical Thinking Questions

4. How many milligrams are there in one kilogram?

5. How many meters are in 21.5 km?

6. Is it possible to answer this question: How many mg are in one km? Explain.

7. What is the difference between a Mm and a mm? Which is larger one Mm or one mm?

Information: Scientific Notation

"**Scientific notation**" is used to make very large or very small numbers easier to handle. For example the number 45,000,000,000,000,000 can be written as "4.5×10^{16}". The "16" tells you that there are sixteen decimal places between the right side of the four and the end of the number.

Another example: $2.641 \times 10^{12} = 2,641,000,000,000$ → the "12" tells you that there are 12 decimal places between the right side of the 2 and the end of the number.

Very small numbers are written with negative exponents. For example, 0.00000000000000378 can be written as 3.78×10^{-15}. The "-15" tells you that there are 15 decimal places between the right side of the 3 and the end of the number.

Another example: 7.45 x 10^{-8} = 0.0000000745 → the "-8" tells you that there are 8 decimal places between the right side of the 7 and the end of the number.

In both very large and very small numbers, the exponent tells you how many decimal points are between the right side of the first digit and the end of the number. If the exponent is positive, the decimal places are to the right of the number. If the exponent is negative, the decimal places are to the left of the number.

Critical Thinking Questions

8. Two of the following six numbers are written incorrectly. Circle the two that are incorrect.

   a) 3.57 x 10^{-8} b) 4.23 x 10^{-2} c) 75.3 x 10^{2} d) 2.92 x 10^{9} e) 0.000354 x 10^{4} f) 9.1 x 10^{4}

   What do you think is wrong about the two numbers you circled?

9. Write the following numbers in scientific notation:

   a) 25,310,000,000,000,000 = ________________ b) 0.000000003018 = ________________

10. Write the following scientific numbers in regular notation:

   a) 8.41 x 10^{-7} = _________________ b) 3.215 x 10^{8} = ______________________

Information: Multiplying and Dividing Using Scientific Notation

When you multiply two numbers in scientific notation, you must add their exponents. Here are two examples. Make sure you understand each step:

$(4.5\text{x}10^{12})$ x $(3.2\text{x}10^{36})$ = (4.5)(3.2) x 10^{12+36} = $14.4\text{x}10^{48}$ → $1.44\text{x}10^{49}$

$(5.9\text{x}10^{9})$ x $(6.3\text{x}10^{-5})$ = (5.9)(6.3) x $10^{9+(-5)}$ = $37.17\text{x}10^{4}$ → $3.717\text{x}10^{5}$

When you divide two numbers, you must subtract denominator's exponent from the numerator's exponent. Here are two examples. Make sure you understand each step:

$$\frac{2.8x10^{14}}{3.2x10^{7}} = \frac{2.8}{3.2}x10^{14-7} = 0.875x10^{7} = 8.75x10^{6}$$

$$\frac{5.7x10^{19}}{3.1x10^{-9}} = \frac{5.7}{3.1}x10^{19-(-9)} = 1.84x10^{19+9} = 1.84x10^{28}$$

Critical Thinking Questions

11. Solve the following problems.

    a) $(4.6x10^{34})(7.9x10^{-21}) =$

    b) $(1.24x10^{12})(3.31x10^{20}) =$

12. Solve the following problems.

    a) $\frac{8.4x10^{-5}}{4.1x10^{17}} =$

    b) $\frac{5.4x10^{32}}{7.3x10^{14}} =$

Information: Adding and Subtracting Using Scientific Notation

Whenever you add or subtract two numbers in scientific notation, you must make sure that they have the <u>same</u> exponents. Your answer will them have the same exponent as the numbers you add or subtract. Here are some examples. Make sure you understand each step:

$4.2x10^6 + 3.1x10^5$ → make exponents the same, either a 5 or 6 → $42x10^5 + 3.1x10^5 = 45.1x10^5 = 4.51x10^6$

$7.3x10^{-7} - 2.0x10^{-8}$ → make exponents the same, either -7 or -8 → $73x10^{-8} - 2.0x10^{-8} = 71x10^{-8} = 7.1x10^{-7}$

Critical Thinking Questions

13. Solve the following problems.

    a) $4.25x10^{13} + 2.10x10^{14} =$

    b) $6.4x10^{-18} - 3x10^{-19} =$

    c) $3.1x10^{-34} + 2.2x10^{-33} =$

ChemQuest 2

Significant Figures

Name: ______________________________
Date: _______________
Hour: _____

Information: Significant Figures

We saw in the last ChemQuest that scientific notation can be a very nice way of getting rid of unnecessary zeros in a number. For example, consider how convenient it is to write the following numbers:

$$32{,}450{,}000{,}000{,}000{,}000{,}000{,}000{,}000{,}000{,}000{,}000 = 3.245 \times 10^{34}$$

$$0.000000000000000127 = 1.27 \times 10^{-16}$$

There are a whole lot of zeros in the above numbers that are not really needed. As another example, consider the affect of changing units:

21,500 meters = 21.5 kilometers
0.00582 meters = 5.82 millimeters

Notice that the zeros in "21,500 meters" and in "0.00582 meters" are not really needed when the units change. Taking these examples into account, we can introduce three general rules:

1. Zeros at the beginning of a number are **never** *significant* (important).
2. Zeros at the end of a number are not significant **unless**… (you'll find out later)
3. Zeros that are between two nonzero numbers are always significant.

Therefore, the number 21,500 has *three* **significant figures**: only three of the digits are important—the two, the one, and the five. The number 10,210 has four significant figures because only the zero at the end is considered not significant. All of the digits in the number 10,005 are significant because the zeros are in between two nonzero numbers (Rule #3).

Critical Thinking Questions

1. Verify that each of the following numbers contains four significant figures. Circle the digits that are significant.

   a) 0.00004182 b) 494,100,000 c) 32,010,000,000 d) 0.00003002

2. How many significant figures are in each of the following numbers?

   _____ a) 0.000015045 _____ b) 4,600,000 _____ c) 2406

   _____ d) 0.000005 _____ e) 0.0300001 _____ f) 12,000

Information: The Exception to Rule #2

There is one exception to the second rule. Consider the following measured values.

It is **1200 miles** from my town to Atlanta.

It is **1200.0 miles** from my town to Atlanta.

The quantity "1200.0 miles" is more precise than "1200 miles". The decimal point in the quantity "1200.0 miles" means that it was measured very precisely—right down to a tenth of a mile. Therefore, the complete version of Rule #2 is as follows:

Rule #2: Zeros at the end of a number are not significant **unless there is a decimal point in the number.** A decimal point anywhere in the number makes zeros at the end of a number significant.

Not significant because these are at the beginning of the number!

This zero is significant because it is at the end of the number and there is a decimal point in the number.

$$0.\underbrace{000000}_{}7290$$

Critical Thinking Questions

3. Verify that each of the following numbers contains five significant figures. Circle the digits that are significant.

   a) 0.00030200 b) 200.00 c) 2300.0 d) 0.000032000

4. How many significant figures are there in each of the following numbers?

   _____ a) 0.000201000 _____ b) 23,001,000 _____ c) 0.0300

   _____ d) 24,000,410 _____ e) 2400.100 _____ f) 0.000021

Information: Rounding Numbers

In numerical problems, it is often necessary to round numbers to the appropriate number of significant figures. Consider the following examples in which each number is rounded so that each of them contains 4 significant figures. Study each example and make sure you understand why they were rounded as they were:

42,008,000 → 42,010,000
12,562,425,217 → 12,560,000,000
0.00017837901 → 0.0001784
120 → 120.0

Critical Thinking Questions

5. Round the following numbers so that they contain 3 significant figures.

   a) 173,792 b) 0.0025021 c) 0.0003192 d) 30

   _________ ___________ __________ __________

6. Round the following numbers so that they contain 4 significant figures.

   a) 249,441 __________   b) 0.00250122 __________   c) 12,049,002 __________   d) 0.00200210 __________

Information: Multiplying and Dividing

When you divide 456 by 13 you get 35.0769230769… How should we round such a number? The concept of significant figures has the answer. When multiplying and dividing numbers, you need to round your answers to the correct number of significant figures. To round correctly, follow these simple steps:

1) Count the number of significant figures in each number.
2) Round your answer to the least number of significant figures.

Here's an example:

3 significant figures

$$\frac{4560}{14} = 325.714285714 = 330$$

2 significant figures

Final rounded answer should have only 2 significant figures since 2 is the least number of significant figures in this problem.

Here's another example:

$$13.1 \times 1.2039 = 15.77109 = 15.8$$

3 significant figures

5 significant figures

Final rounded answer should have 3 significant figures since 3 is the least number of significant figures in this problem.

Critical Thinking Questions

7. Solve the following problems. Make sure your answers are in the correct number of significant figures.

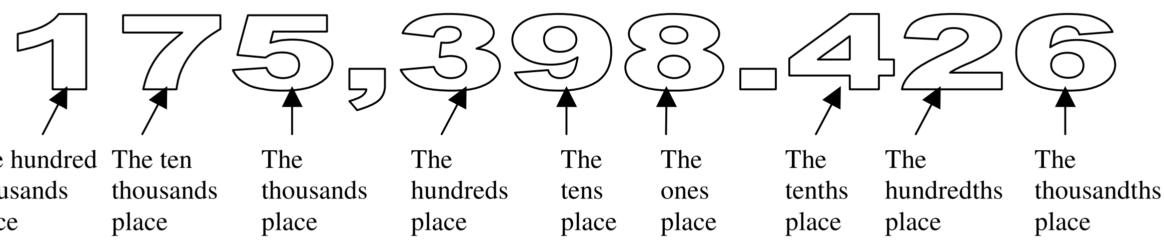
   a) (12.470)(270) = ______________   b) 36,000/1245 = ______________

   c) (310.0)(12) = ______________   d) 129.6/3 = ______________

   e) (125)(1.4452) = ______________   f) 6000/2.53 = ______________

Information: Rounding to a Decimal Place

As you will soon discover, sometimes it is necessary to round to a decimal place. Recall the names of the decimal places:



If we rounded the above number to the hundreds place, that means that there can be no significant figures to the right of the hundreds place. Thus, "175,400" is the above number rounded to the hundreds place. If we rounded to the tenths place we would get 175,398.4. If we rounded to the thousands place we would get 175,000.

Critical Thinking Questions

8. Round the following numbers to the tens place.

   a) 134,123,018 = _______________ b) 23,190.109 = _________________

   c) 439.1931 = _________________ d) 2948.2 = _____________________

Information: Adding and Subtracting

Did you know that 30,000 plus 1 does not always equal 30,001? In fact, usually 30,000 + 1 = 30,000! I know you are finding this hard to believe, but let me explain…

Recall that zeros in a number are not always important, or *significant*. Knowing this makes a big difference in how we add and subtract. For example, consider a swimming pool that can hold 30,000 gallons of water. If I fill the pool to the maximum fill line and then go and fill an empty one gallon milk jug with water and add it to the pool, do I then have exactly 30,001 gallons of water in the pool? Of course not. I had approximately 30,000 gallons before and after I added the additional gallon because "30,000 gallons" is not a very precise measurement. So we see that sometimes 30,000 + 1 = 30,000!

Rounding numbers when adding and subtracting is different from multiplying and dividing. In adding and subtracting you round to the least specific decimal place of any number in the problem.

Example #1: Adding

```
  350.04
+720
 1070.04
 1070
```

The hundredths place contains a significant figure.

The tens place contains a significant figure.

The answer gets rounded to the *least* specific place that has a significant figure. In this case, the tens place is less specific than the hundredths place, so the answer is rounded to the tens place.

Example #2: Subtracting

```
  7000
- 1770
  5230
  5000
```

The tens place contains a significant figure.

The thousands place contains a significant figure.

The answer gets rounded to the *least* specific place that has a significant figure. In this case, the thousands place is less specific than the tens place, so the answer gets rounded to the thousands place.

Critical Thinking Questions

9. a) 24.28 + 12.5 = ________________ b) 120,000 + 420 = ________________

   c) 140,100 – 1422 = ______________ d) 2.24 – 0.4101 = ________________

   e) 12,470 + 2200.44 = ____________ f) 450 – 12.8 = ____________________

10. The following are problems involving multiplication, dividing, adding, and subtracting. Be careful of the different rules you need to follow!

    a) 245.4/120 = _________________ b) 12,310 + 23.5 = _________________

    c) (31,900)(4) = _________________ d) (320.0)(145,712) = ________________

    e) 1420 – 34 = _________________ f) 4129 + 200 = ____________________

ChemQuest 3

Changes and Matter

Name: ____________________________

Date: ______________

Hour: _____

Information: Changes in Matter

Books are made of matter. You are made of matter. "Matter" is a fancy word for the "stuff" of which all objects are made. Every day, matter is changed in different ways. For example, paper can be changed in many ways—it can be torn, folded, or burned.

A chemical change is any alteration that changes the identity of matter. For example, by passing electricity through water it can be broken down into hydrogen and oxygen. Burning paper is a chemical change because after the change takes place, the paper has been changed into different substances (like ash, carbon dioxide, etc.).

A physical change is any alteration that does not change the identity of the matter. Shredding paper does not change the paper into a different substance. Dissolving salt in water is a physical change because after the change, the salt and water are both still there.

Critical Thinking Questions

1. Explain why each of the following is a physical change.
   a) boiling water until no water remains

   b) mixing sugar with coffee

2. Explain why each of the following is a chemical change.
   a) a car rusting

   b) food digesting

3. Identify each of the following changes as chemical or physical by placing a C or P in each blank.

_____ a) acid rain corroding the statue of liberty

_____ b) dissolving salt in water

_____ c) boiling salt water until just salt remains

_____ d) melting steel

_____ e) dissolving steel in acid

_____ f) cracking ice

Information: Elements, Compounds, Mixtures

Examine the following tables. Following the name of each element or compound is the "chemical formula" of the element or compound; please see the periodic table for the meaning of some of the symbols (i.e. Na = sodium). *Italics* tell you that substance is organic.

Elements	**Compounds**
Sodium (Na)	Water (H_2O)
Chlorine (Cl)	*Methane (CH_4)*
Carbon (C)	Sodium chloride, salt (NaCl)
Oxygen (O)	*Carbon dioxide (CO_2)*
Hydrogen (H)	Hydrogen Peroxide (H_2O_2)

Pure Substances	**Mixtures**
Salt (NaCl)	Salt water (NaCl and H_2O)
Hydrogen (H)	Sand
Carbon dioxide (CO_2)	Hydrogen (H) and Oxygen (O)
Water (H_2O)	Sodium (Na) and Chlorine (Cl)
Aluminum (Al)	Kool-aid (sugar, water, etc.)

Critical Thinking Questions

4. How are elements different from compounds?

5. How are compounds different from mixtures?

6. How are pure substances different from mixtures?

7. Can something be both a mixture and a pure substance? Explain using examples from the tables.

8. Is it always possible to identify something as an element, compound, pure substance or mixture just by looking at it? Explain using examples from the tables.

9. Formulate a definition for each of the following terms.
   a) element:

   b) compound:

   c) mixture:

   d) pure substance:

10. Categorize each of the following as an element, compound, mixture, or pure substance. If more than one label applies, then include both labels. (You will need more than one label sometimes.)

    a) ____________________ Popsicle   c) ______________________ Gold

    b) ____________________ Sugar   d) ______________________ Dishwater

11. If you have a container with hydrogen gas and oxygen gas in it do you have water? Why or why not?

12. Give an example of something that is an element. Your example should not already be on this sheet.

13. Give an example of something that is a compound. Your example should not already be on this sheet.

14. Give an example of something that is a mixture. Your example should not already be on this sheet.

15. What do all <u>organic</u> substances have in common?

Information: Homogeneous and Heterogeneous Mixtures

Examine the following table.

Example of Mixture	# of phases in mixture	How many kinds of states in mixture	Homogeneous or heterogeneous?
Salt water	1	2	Homogeneous
Oil and water	2	1	Heterogeneous
Sugar and salt (no water)	2	1	Heterogeneous
Sugar and salt in water	1	2	Homogeneous
Sand and water	2	2	Heterogeneous
Carbon dioxide, water, and ice	3	3	Heterogeneous
14 kt. gold (mixture of silver and gold)	1	1	Homogeneous

Critical Thinking Questions

16. What is the difference between a "phase of matter" and a "state of matter"? Define each term as best you can.

17. What relationship exists between a homogeneous mixture and the number of phases in the mixture?

18. What is the difference between homogeneous and heterogeneous mixtures?

19. If you had to categorize elements as homogeneous or heterogeneous, what category would you put them in?

20. If you had to categorize compounds as homogeneous or heterogeneous, what category would you put them in?

21. Categorize each of the following as homogeneous or heterogeneous.

______________ a) salad ________________ b) ice water

______________ c) dishwater ________________ d) 14 kt. Gold

ChemQuest 4

Phase Diagrams

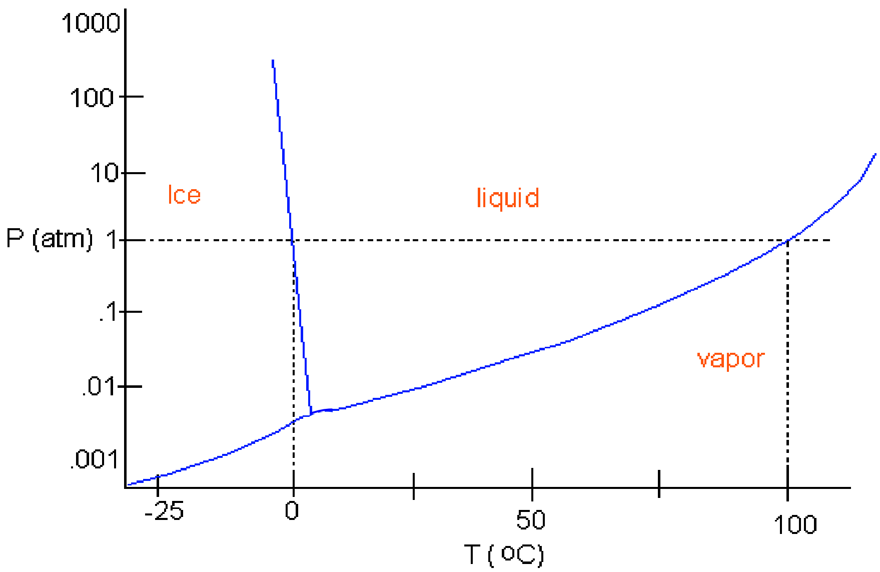
Name: ____________________________

Date: _______________

Hour: _____

Information: Phase diagrams

Figure 1: Phase diagram for water. Note that the unit for pressure on the diagram is atmospheres (atm). Another unit is the kilopascal (kPa). Standard pressure is the pressure at sea level and it is equal to 1 atm, which is equivalent to 101.325 kPa. Standard temperature is 273 Kelvin (K), which equals 0^oC. The abbreviation STP is used for "standard temperature and pressure" and it denotes a temperature of 0^oC and 1 atm (or 273K and 101.325 kPa).



A phase diagram is a graph that illustrates under what conditions the states of matter exist. For example, in the phase diagram of water above, it should be noted that at 1 atm (which equals 101.325 kPa) of pressure and 50 ^oC, H_2O exists as a liquid. The dark solid lines represent the boundaries between different states. The term "vapor" is used instead of "gas" because vapor describes a substance that is normally a liquid at STP. The line that divides the liquid area from the vapor area has a special name: the vapor pressure curve. (The vapor pressure of water at any given temperature can be found looking at the vapor pressure curve.) To the left of the line, liquid exists. To the right of the line, vapor (gaseous H_2O) exists. Right on the line, for example when the pressure is 1 atm and the temperature is 100^oC, both liquid and vapor exist at the same time. When two or more things coexist at the same time it is called "equilibrium". During equilibrium, liquid changes to vapor and vapor changes to liquid all at the same time and rate.

Critical Thinking Questions

1. When a substance melts, what happens to the motion of the molecules of the substance?

2. What is the freezing point and boiling point of water when the pressure on the water is 1 atm? (I.e. at what temperature will the water freeze and boil when the pressure is 1 atm?)

3. How does lowering the pressure affect the boiling point?

4. Estimate the boiling point of water when the pressure on the water is 0.1 atm.

5. The triple point of a substance is the conditions under which a solid, liquid and gas all exist in equilibrium. On the phase diagram of water, label the location of the triple point.

6. Dry ice sublimes; that is, it changes directly from a solid to a gas. Is it ever possible for ice to sublime? If so, describe the conditions necessary for sublimation to occur.

7. What is meant by the "vapor pressure" of water?

8. From the phase diagram, estimate the vapor pressure of water at 25 ^{o}C.

9. What is the vapor pressure of water when the temperature is 100 ^{o}C?

10. When the atmospheric pressure equals 1 atm, what is the boiling point of water?

11. From your answers to questions 10 and 11, formulate a definition for boiling point in terms of atmospheric pressure and vapor pressure of the liquid.

12. Is it ever possible for solid H_2O to exist at a temperature above 0 ^{o}C?

13. Is it ever possible for solid H_2O to exist at a temperature above 25 ^{o}C?

14. Describe the region where a solid-liquid equilibrium exists.

15. Why might an equilibrium situation be described as a "reversible change"?

ChemQuest 5

Specific Heat

Name: ______________________________
Date: ________________
Hour: _____

Information: Heat and Temperature

When a substance absorbs heat energy, the temperature of the substance increases. There are a number of factors (such as mass of the substance) that affect *how much* the temperature of a substance changes.

Critical Thinking Questions

1. Consider two pots of water. Each pot has the same diameter, but pot A is deeper than pot B and so there is more water in pot A. If both of the pots are exposed to exactly the same amount of heat for five minutes on a stove, which pot will contain the hottest water after heating?

2. Considering question 1, propose an explanation for the fact that even though both pots were exposed to the same amount of heat, one got hotter.

3. Fill in the blank: *The greater the mass of a substance (like water in questions 1 and 2), the*

   ______________________ *the temperature change when heat is applied.*
   greater or lower

4. Consider the metal hood of a car on a warm sunny day. Next to the car is a large puddle of water. The puddle of water is so large that it has the same mass as the hood of the car. Assume that the hood of the car and the puddle are exposed to the same amount of sunlight. Which will be hotter after two hours—the hood of the car or the puddle?

5. Propose an explanation for the fact that even though both the hood and the puddle were exposed to the same amount of heat energy and their masses were the same, one still got much warmer than the other.

6. In general is it harder to change the temperature of metal (like on a car hood) or of water? In other words, would it require more heat energy to change the temperature of metal or of water?

7. In one of the following blanks you will need to write "400" and in the other blank you will need to write "200".
If we wanted to change the temperature of water by 4 ^oC, then _______ Joules of heat energy are required, but to change the temperature of metal by 4^oC, then ________ Joules of heat energy are required.(Note: a Joule is the standard unit of energy.)

Information: Specific Heat

In questions 1 and 2 above you probably recognized that the temperature change of a substance depends on the mass of the substance. You also have probably experienced the fact that different substances heat at different rates as was discussed in questions 3 and 4 above. Each substance has its own specific heat capacity, or just "specific heat". The specific heat capacity is a measure of the amount of energy needed to change the temperature of the substance. The higher the specific heat, the more energy is required to change the temperature of the substance.

Critical Thinking Questions

8. Which substance has a higher specific heat—water or a metal like the aluminum in a car hood?

9. Consider 200 Joules (J) of heat energy applied to several objects and fill in the blank: *The higher the specific heat of the object, the ___________________ the temperature change of the object.*
lower or higher

10. Given the following symbols and your answers to the above questions, which of the following equations is correct. Make sure you have the correct answer before proceeding to the next questions!

ΔT = temperature change of a substance
C_p = specific heat capacity
m = mass of the substance
q = amount of heat energy applied to the substance

A) $\Delta T = qmC_p$ B) $\Delta T = \dfrac{q}{(m)(C_p)}$ C) $\Delta T = \dfrac{(q)(m)}{C_p}$ D) $\Delta T = \dfrac{(C_p)(m)}{q}$

HINT: Equation D is not correct because according to that equation, a large mass (m) will lead to a large temperature change (ΔT), but this is not consistent with question 3. Apply this same reasoning to the other equations to see if which equation is logical.

11. If ΔT is measured in ^oC, m is measured in grams (g), and q is measured in Joules (J), what are the units for specific heat capacity?

12. What is the temperature change of a 120 g piece of aluminum whose specific heat is 1.89 J/g^{o}C after 1800 J of heat energy is applied?

13. A beaker containing 250.0 g of water is heated with 1500.0 J of heat energy. If the temperature of the water changed from 22.0000^{o}C to 23.4354^{o}C, what is the specific heat of water?

14. Heat energy equal to 25,000 J is applied to a 1200 g brick whose specific heat is 2.45 J/g^{o}C.
    a) What is the change in temperature of the brick?

    b) If the brick was initially at a temperature of 25.0^{o}C, what is the final temperature of the brick?

ChemQuest 6

Energy and Changes in Matter

Name: ____________________________
Date: _______________
Hour: _____

Information: Specific Heat Constants Depend on the State of Matter

Recall that specific heat is the energy necessary to raise the temperature of one gram of a substance by one degree Celsius. The specific heat of liquid water is a constant equal to 4.18 J/(g-^{o}C). This means that it takes 4.18 Joules (J) of heat energy to raise the temperature of each gram of water by one degree Celsius. For ice, the specific heat is 2.06 J/g^{o}C. Steam's specific heat is 2.02 J/g^{o}C. You will want to remember the three different specific heat values for H_2O.

Critical Thinking Questions

1. How much energy is required to heat 32.5g of water from 34^{o}C to 75^{o}C?

2. How many J of energy are needed to heat 45.0g of steam from 130^{o}C to 245^{o}C? Why don't you use 4.18 J/g^{o}C in this calculation?

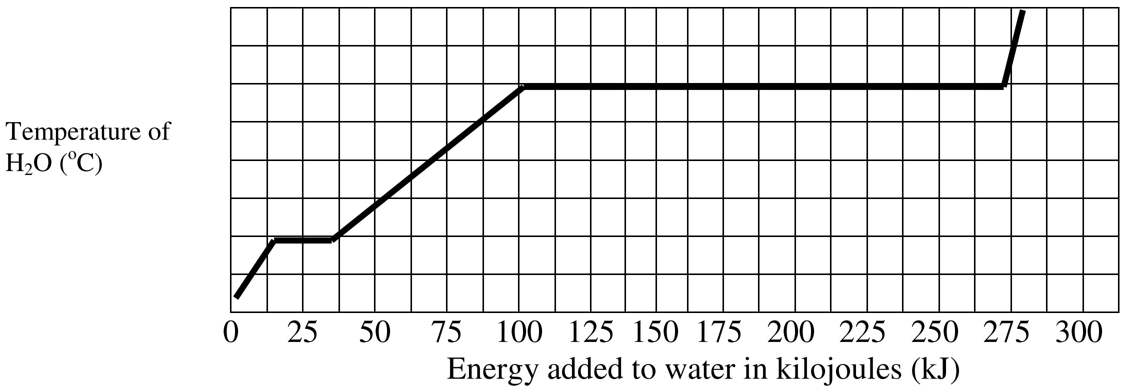
3. Why is it impossible for you to answer the following question right now: How much energy is required to heat 35g of H_2O from 25^{o}C to 150^{o}C?

Information: Energy Involved in Changing State

Obviously, it takes energy to heat a substance such as water. There is also an energy change when a substance changes state. For example, when water freezes, energy is taken away from the water and when water boils, energy is being added to the water.

When water is heated up to 100^{o}C, it will NOT automatically boil unless more energy is added. Once water is at the correct temperature (100^{o}C), it will boil IF you add energy to change it from a liquid to a gas. The extra energy is needed to separate the molecules from one another. Note: **at the boiling point of a liquid energy is added to the liquid, but the temperature of the liquid does NOT change.** The temperature of H_2O will increase above 100^{o}C only after all of the water has been changed to steam. After the phase change, if more energy is applied, the temperature will go up.

Figure 1: Graph of the temperature of H_2O vs. energy added to the water.



Critical Thinking Questions

4. What is the significance of the horizontal portions of the graph? What is going on during those times?

5. Label the temperature scale on the graph.

6. Does it require more energy to "vaporize" water at the boiling point or to melt water at the melting point? Explain.

Information: Mathematics of Changes of State

Recall the equation: $q = (m)(C_p)(\Delta T)$ where q is the heat energy, C_p is the specific heat of the substance, m is the mass of the substance, and ΔT is the change in the temperature. This equation works ONLY when there is **no phase change**. You use it to find how much energy is required to change the temperature of a certain substance as long as you know the specific heat of the substance and as long as no change in state occurs.

Now for when there is a change in state: The energy required for a change of state is given a special name called enthalpy. So the "enthalpy of vaporization" (symbolized by ΔH_{vap}) of water is the energy needed to vaporize (or boil) one gram of water when the water is already at its boiling point. The ΔH_{vap} of water is 2260 J/g. So for each gram of hot (100°C) water, 2260 J are required to vaporize it. Similarly, the enthalpy of fusion (ΔH_{fus}) of H_2O is 334 J/g. So each gram of ice at 0°C there are 334 J of energy required to melt it. (Fusion is melting.)

Critical Thinking Questions

7. Verify that it takes 4140.7 J of energy to heat 12.7 g of water from room temperature (22^{o}C) to the boiling point (100^{o}C). Recall that the specific heat (C_p) of water is 4.18 J/(g-^{o}C).

8. Given the fact that the ΔH_{vap} of water is 2260 J/g we know that 2260 J of energy is required to vaporize 1 gram of water. To vaporize 2 grams of water it requires 4520 J. For 3 grams, 6780 J are needed. Verify that it takes 28,702 J of energy to vaporize 12.7 g of water, when the water is already at its boiling point.

9. Verify that it takes 1513.6 J of energy to heat 12.7 g of steam from 100^{o}C to 159^{o}C. Note: the specific heat of steam (C_p) is 2.02 J/(g-^{o}C).

10. Using only your answers to questions 7-9, calculate how many Joules of energy it takes to change 12.7 g of water at 22^{o}C to steam at 159^{o}C.

11. Calculate how many Joules of energy would be required to change 32.9 g of water at 35^{o}C to steam at 120^{o}C. You will need to break this problem into four steps.
    a) Find the Joules needed to heat the water to the boiling point.

    b) Find the Joules needed to vaporize the water.

    c) Find the Joules needed to heat the vapor (steam) from the boiling point to 120^{o}C.

    d) Add your answers to steps a, b, and c.

12. How much heat energy would be required to change the temperature of 125g of ice from -32.9^{o}C to liquid water at 75^{o}C?

ChemQuest 7

Density, Mass and Weight

Name: ______________________________
Date: _______________
Hour: _____

Information: Density

Object	Mass of Object (g)	Volume of Object (mL)	Density of Object (g/mL)
1	21.50	18.40	1.168
2	12.6	14.7	0.857
3	41.90	31.60	1.326
4	32.90		2.560
5	59.5	61.7	
6		0.574	1.035
7	17.23	21.67	

Critical Thinking Questions

1. Consider the data for objects 1, 2 and 3. Which of the following equations correctly show the relationship(s) between mass (M), volume (V) and density (D)? There may be more than one answer.

   A) $D = \frac{V}{M}$ B) $M = \frac{V}{D}$ C) $D = \frac{M}{V}$ D) $V = \frac{D}{M}$ E) $V = \frac{M}{D}$

   F) $V = DM$ G) $M = DV$ H) $D = MV$

2. For objects 4, 5, 6 and 7 there are blanks in the table. Using your answers to question 1, fill in the blanks.

3. What are the units for density if the mass of an object was measured in kilograms and the volume in liters?

4. In your own words, define "density".

5. Calculate the density of an object that has a mass of 45.0 kg and a volume of 20.0 L. Include units.

<u>Information</u>: Mass and Weight

The following is a table that relates the mass of an object and the weight of the same object. The pull of gravity is a constant. As long as you stay in the same place, the pull of gravity (g) does not change. For example, at sea level g is always equal to 9.8 m/s^2.

Object	**Place**	**Mass**	**Pull of Gravity**	**Weight**
1	Earth, sea level	42 kg	9.8 m/s^2	411.6 N
2	Earth, sea level	29 kg	9.8 m/s^2	284.2 N
3	Earth, Mt. Everest	38 kg	9.1 m/s^2	345.8 N
4	Moon	51 kg	1.6 m/s^2	81.6 N

<u>Critical Thinking Questions</u>

6. What is the relationship between mass (M), the pull of gravity (g) and weight (W)?

   A) M = gW B) g = MW C) W = Mg

7. What is the weight of a 42 kg object (like object 1) if the object was on the moon where g is always 1.6 m/s^2?

8. <u>**Mass**</u> **measures how much matter an object has.** It is an indication of how much "stuff" is in the object. It does not describe the size of the object or the weight of the object. What is the difference between mass and weight?

9. In question 7, you calculated the weight of object 1 on the moon. How did that weight compare to the object's weight on Earth?

ChemQuest 8

Structure of the Atom

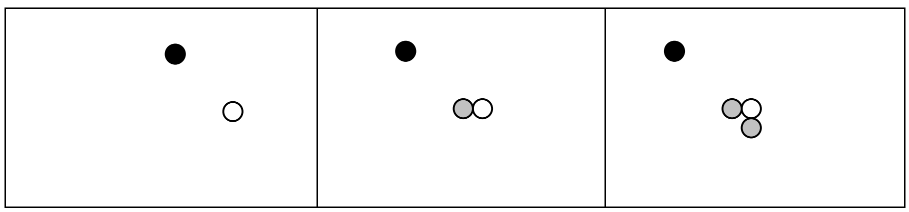
Name: ______________________________
Date: _______________
Hour: _____

Information: Structure of the Atom

Note the following symbols: (they are not to scale)

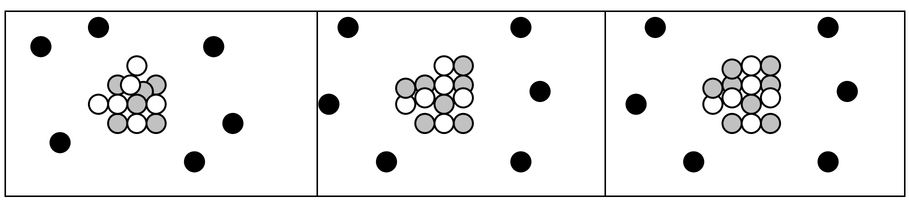
○ = proton (positive charge)
● = electron (negative charge)
◍ = neutron (no charge)

The following three diagrams are hydrogen atoms:



${}^{1}_{1}H$ ${}^{2}_{1}H$ ${}^{3}_{1}H$

The following three diagrams are carbon atoms:



${}^{12}_{6}C$ (6 protons, 6 neutrons) ${}^{13}_{6}C$ (6 protons, 7 neutrons) ${}^{14}_{6}C$ (6 protons, 8 neutrons)

Notice the type of notation used for atoms: ${}^{A}_{Z}X$

X = chemical symbol of the element
Z = "atomic number"
A = "mass number"

${}^{12}_{6}C$, ${}^{13}_{6}C$, and ${}^{14}_{6}C$ are notations that represent **isotopes** of carbon.

${}^{1}_{1}H$, ${}^{2}_{1}H$ and ${}^{3}_{1}H$ are notations that represent **isotopes** of hydrogen.

The part of the atom where the protons and neutrons are is called the **nucleus**.

Critical Thinking Questions

1. How many protons are found in each of the following: ${}^{1}_{1}H$? in ${}^{2}_{1}H$? in ${}^{3}_{1}H$?

2. How many neutrons are found in each of the following: ${}^{1}_{1}H$? in ${}^{2}_{1}H$? in ${}^{3}_{1}H$?

3. How many electrons are found in each of the following: ${}^{1}_{1}H$? in ${}^{2}_{1}H$? in ${}^{3}_{1}H$?

4. What structural characteristics do all hydrogen atoms have in common?

5. What structural characteristics do all carbon atoms have in common?

6. What does the mass number tell you? Can you find the mass number of an element on the periodic table?

7. What does the atomic number tell you? Can you find the atomic number of an element on the periodic table?

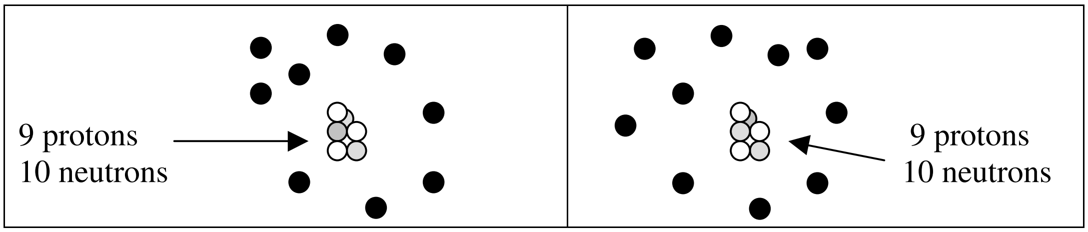
8. Define the term **isotope**.

9. How does one isotope of carbon differ from another isotope of carbon?

Information: Atoms, Ions, Masses of Subatomic Particles

The atomic mass unit (amu) is a special unit for measuring the mass of very small particles such as atoms. The relationship between amu and grams is the following: 1.00 amu = 1.66×10^{-24}g
Note the following diagrams comparing atoms and ions.

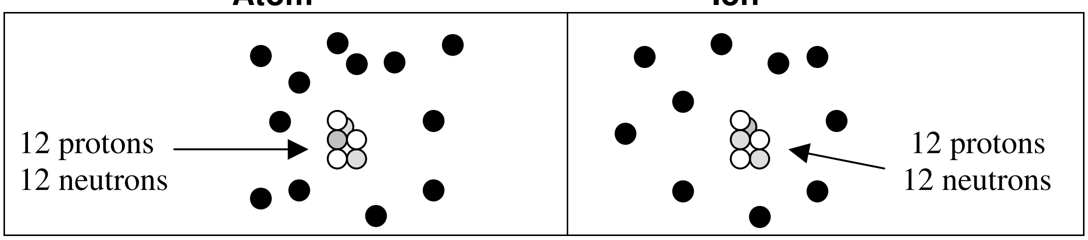
Atom **Ion**



${}^{19}_{9}F$ mass = 18.9980 amu

${}^{19}_{9}F^{-1}$ mass = 18.9985 amu

Atom **Ion**



${}^{24}_{12}Mg$ mass = 23.9978 amu

${}^{24}_{12}Mg^{+2}$ mass = 23.9968 amu

Critical Thinking Questions

10. What is structurally different between an atom and an ion? Note: This is the ONLY structural difference between an atom and an ion.

11. In atomic mass units (amu), what is the mass of an electron?

12. Is most of the mass of an atom located in the nucleus or outside the nucleus? How do you know?

13. If protons and neutrons have the same mass, what is the approximate mass of a proton and neutron in atomic mass units (amu)?

14. The mass of $^{14}_{6}C$ is about 14 amu. Does this agree with what you determined in questions 11 and 13?

15. The charge (in the upper right hand corner of the element symbol) is –1 for a fluorine ion. Why isn't it +1 or some other number?

16. What is the charge on every <u>atom</u>? Why is this the charge?

17. How do you determine the charge on an ion?

18. An oxygen ion has a –2 charge. (Use your periodic table if necessary)
    a) How many protons does the oxygen ion have?

    b) How many electrons does the oxygen ion have?

ChemQuest 9

Average Atomic Mass

Name: ______________________________
Date: ________________
Hour: _____

Information: Weighted Averages

Examine the table of student test scores for five tests they have taken.

Test	Student A	Student B
1	95	76
2	74	88
3	82	90
4	92	81
5	81	72
Average Grade		

Critical Thinking Questions

1. Calculate the average grade for students A and B and enter the average in the table above.

2. If you know a student's average grade can you tell what the student's individual test scores were? Explain.

3. Suppose student C had an average of 83%. On each of his five tests he scored either 65% or 95%. Which score occurred more often? Explain.

4. What if the teacher decided that test five would count for 40% of the final grade and test four would count for 30% of the final grade and each of the other tests would count for 10%. Calculate the new average for each student. Note: this is called the <u>weighted average</u>.

   Student A's new average: ______________ Student B's new average: ________________

Information: Average Atomic Mass

On the periodic table you can find the average atomic mass for an element. This average is a weighted average and it tells you the average mass of all the isotopes of an element. The periodic table does not contain mass numbers for individual atoms, instead you can find the average mass of atoms. The average atomic mass is calculated just how you calculated the weighted average in question 4 above.

Critical Thinking Questions

5. Neon has three different isotopes. 90.51% of neon atoms have a mass of 19.992 amu. 0.27% of neon atoms have a mass of 20.994 amu. 9.22% of neon atoms have a mass of 21.991 amu. What is the average atomic mass of neon?

6. Chlorine-35 is one isotope of chlorine. (35 is the mass number.) Chlorine-37 is another isotope of chlorine. How many protons and how many neutrons are in each isotope of chlorine?

7. Of all chlorine atoms, 75.771% are chlorine-35. Chlorine-35 atoms have a mass of 34.96885 amu. All other chlorine atoms are chlorine-37 and these have a mass of 36.96590. Calculate the average atomic mass of chlorine.

8. Do your answers for questions 5 and 7 agree with the average atomic masses for neon and chlorine on the periodic table?

Skill Practice

9. Complete the following table.

Symbol	# of neutrons	# of protons	# of electrons	Atomic #	Mass #
$^{31}_{15}P$					
$^{28}_{13}Al^{+3}$					
			38	38	80
$^{119}_{50}Sn$					
		84	84		210
	8	7	10		

10. A certain element has two isotopes. One isotope , which has an abundance of 72.15% has a mass of 84.9118 amu. The other has a mass of 86.9092 amu. Calculate the average atomic mass for this element.

11. Given the following data, calculate the average atomic mass of magnesium.

Isotope	**Mass of Isotope**	**Abundance**
Magnesium-24	23.985	78.70%
Magnesium-25	24.986	10.13%
Magnesium-26	25.983	11.17%

ChemQuest 10

Bohr's Atomic Model

Name: ____________________________

Date: _______________

Hour: _____

Information: Bohr's Solar System Model of the Atom

All the planets are attracted to the sun by gravity. The reason that the Earth doesn't just float out into space is because it is constantly attracted to the sun. Similarly, the moon is attracted to the Earth by Earth's gravitational pull. So all of the planets are attracted to the sun but they never collide with the sun.

Negative charges are attracted to positive ones. Therefore the negative electrons in an atom are attracted to the positive protons in the nucleus. In the early 1900's scientists were looking for an explanation to a curious problem with their model of the atom. Why don't atoms collapse? The negative electrons should collapse into the nucleus due to the attraction between protons and electrons. Why doesn't this happen? Scientists were at a loss to explain this until Neils Bohr proposed his "solar system" model of the atom.

Critical Thinking Questions: Bohr's reasoning

1. Consider swinging a rock on the end of a string in large circles. Even though you are constantly pulling on the string, the rock never collides with your hand. Why is this?

2. Even though the Earth is attracted to the sun by a very strong gravitational pull, what keeps the Earth from striking the sun?

3. Why doesn't the moon strike the Earth?

4. How could it be possible for electrons to not "collapse" into the nucleus?

Information: Light

Recall that light is a wave. White light is composed of all the colors of light in the rainbow. All light travels at the same speed (c), 3.00×10^8 m/s. (The speed of all light in a vacuum is always equal to 3.0×10^8 m/s.) Different colors of light have different frequencies (f) and wavelengths (λ). The speed (c), frequency (f) and wavelength (λ) of light can be related by the following equation:

$$c = f \bullet \lambda$$

It is important that the wavelength is always in meters (m), the speed is in m/s and the frequency is in hertz (Hz). Note: 1 Hz is the inverse of a second so that 1 Hz = 1/s.

Critical Thinking Questions

5. As the frequency of light increases, what happens to the wavelength of the light?

6. What is the frequency of light that has a wavelength of 4.25×10^{-8} m?

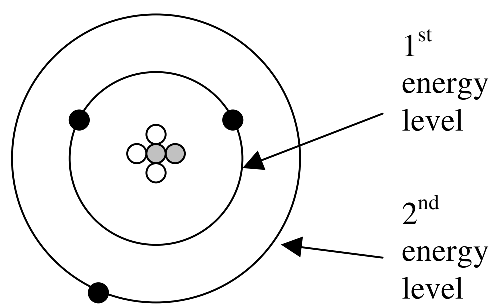
7. What is the wavelength of light that has a frequency of 3.85×10^{14} Hz?

Information: Energy levels

After Bohr proposed the Solar System Model (that electrons orbit a nucleus just like planets orbit the sun), he called the orbits "energy levels".

Consider the following Bohr model of a Boron atom:

○ = proton (positive charge)
● = electron (negative charge)
◎ = neutron (no charge)



Higher energy levels are further from the nucleus. For an electron to go into a higher energy level it must gain more energy. Sometimes the electrons can absorb light energy. (Recall that different colors of light have different frequencies and wavelengths.) If the right color (and therefore, frequency) of light is absorbed, then the electron gets enough energy to go to a higher energy level. The amount of energy (E) and the frequency (f) of light required are related by the following equation:

$$E = h \bullet f$$

E is the energy measured in Joules (J), f is the frequency measured in Hz, and h is Planck's constant in units of J/Hz which is the same as J-second. Planck's constant, h, always has a value of 6.63×10^{-34} J-s.

An electron that absorbs energy and goes to a higher energy level is said to be "excited." If an excited electron loses energy, it will give off light energy. The frequency and color of light depends on how much energy is released. Again, the frequency and energy are related by the above equation. When an excited electron loses energy, we say that it returns to its "ground state". Since not all electrons start out in the first energy level, the first energy level isn't always an electron's ground state.

Critical Thinking Questions

8. Does an electron need to absorb energy or give off energy to go from the 2nd to the 1st energy level?

9. How is it possible for an electron go from the 3rd to the 4th energy level?

10. Red light of frequency 4.37 x 10^{14} Hz is required to excite a certain electron. What energy did the electron gain from the light?

11. The energy difference between the 1st and 2nd energy levels in a certain atom is 5.01 x 10^{-19} J. What frequency of light is necessary to excite an electron in the 1st energy level?

12. a) What is the frequency of light given off by an electron that loses 4.05 x 10^{-19} J of energy as it moves from the 2nd to the 1st energy level?

    b) What wavelength of light does this correspond to (hint: use $c = f\,\lambda$)?

13. Do atoms of different elements have different numbers of electrons?

14. If all of the electrons in atom "A" get excited and then lose their energy and return to the ground state the electrons will let off a combination of frequencies and colors of light. Each frequency and color corresponds to a specific electron making a transition from an excited state to the ground state. Consider an atom from element "B". Would you expect the excited electrons to let off the exact same color of light as atom "A"? Why or why not?

ChemQuest 11

An Electron's Address

Name: ______________________________

Date: ________________

Hour: _____

Information: Energy Levels and Sublevels

As you know, in his solar system model Bohr proposed that electrons are located in energy levels. The current model of the atom isn't as simple as that, however.

Sublevels are located inside energy levels just like subdivisions are located inside cities. Each sublevel is given a name. Note the following table:

TABLE 1

Energy Level	Names of sublevels that exist in the energy level
1st energy level	s
2nd energy level	s and p
3rd energy level	s, p, and d
4th energy level	s, p, d, and f

Note that there is no such thing as a "d sublevel" inside of the 2nd energy level because there are only s and p sublevels inside of the 2nd energy level.

Critical Thinking Questions

1. How many sublevels exist in the 1st energy level?

2. How many sublevels exist in the 2nd energy level?

3. How many sublevels exist in the 3rd energy level?

4. How many sublevels would you expect to exist in the 5th energy level?

5. Does the 3f sublevel exist? (Note: the "3" stands for the 3rd energy level.)

Information: Orbitals

So far we have learned that inside energy levels there are different sublevels. Now we will look at orbitals. **Orbitals** are located inside sublevels just like streets are located inside subdivisions. Different sublevels have different numbers of orbitals.

TABLE 2

Sublevel	# of Orbitals Possible
s	1
p	3
d	5
f	7

Here's an important fact: only two electrons can fit in each orbital. So, in an s orbital you can have a maximum of 2 electrons; in a d orbital you can have a maximum of 2 electrons; in any orbital there can only be two electrons.

Since a d sublevel has 5 orbitals (and each orbital can contain up to two electrons) then a d sublevel can contain 10 electrons (= 5 x 2). Pay attention to the difference between "sublevel" and "orbital".

Critical Thinking Questions

6. How many orbitals are there in a p sublevel?

7. How many orbitals are there in a d sublevel?

8. a) How many total sublevels would be found in the entire 2nd energy level?

   b) How many orbitals would be found in the entire 2nd energy level?

9. a) How many electrons can fit in an f sublevel?

   b) How many electrons can fit in an f orbital?

10. How many electrons can fit in a d orbital? in a p orbital? in any kind of orbital?

11. In your own words, what is the difference between a sublevel and an orbital?

12. How many electrons can fit in each of the following energy levels:

    1st energy level =

    2nd energy level =

    3rd energy level =

    4th energy level =

Information: Representing the Most Probable Location of an Electron

The following is an "address" for an electron—a sort of shorthand notation. The diagram below represents an electron located in an orbital inside of the p sublevel in the 3rd energy level.

EXAMPLE #1:

$$\mathbf{3p}\ \underline{\uparrow}\ \ \underline{\quad}\ \ \underline{\quad}$$

Some important facts about the above diagram:

- The arrow represents an electron.
- The upward direction means that the electron is spinning clockwise.
- "3p" means that the electron is in the p sublevel of the 3rd energy level.
- Each blank represents an orbital. Since there are three orbitals in a p sublevel, there are also three blanks written beside the p.
- In the diagram, the electron is in the first of the three p orbitals.

Here's another example:

EXAMPLE #2:

$$\mathbf{4d}\ \underline{\downarrow}\ \ \underline{\quad}\ \ \underline{\quad}\ \ \underline{\quad}\ \ \underline{\quad}$$

Critical Thinking Questions

13. In example #2, why are there 5 lines drawn next to the d?

14. In example #2, what does it mean to have the arrow pointing down?

15. Write the notation for an electron in a 2s orbital spinning clockwise.

16. Write the notation for an electron in the first energy level spinning clockwise.

17. What is wrong with the following notation? You should find two things wrong.

$$\mathbf{2d}\ \underline{\downarrow}\ \ \underline{\quad}\ \ \underline{\quad}\ \ \underline{\quad}$$

18. Write the notation for an electron in the 4th energy level in an f sublevel spinning clockwise.

ChemQuest 12

Quantum Numbers

Name: ____________________________

Date: _______________

Hour: _____

Information: Quantum Numbers

Quantum mechanics is a set of complex mathematics that is used to describe the most probable location of an electron. Shortly after Bohr, a man by the name of Heisenberg proposed an **uncertainty principle**, which stated that it is impossible to know both the exact position and the exact velocity of a small particle at the same time. The location of an electron in an atom is based on **probability**—the most likely location for an electron.

To locate the most probable location of a person you need 4 things. If you know 4 things: state, city, street and house number then you know the most probable location of the person. You also need 4 things, called "**quantum numbers**", to describe the most probable location for an electron. Each "number" is actually symbolized by a letter:

TABLE 1

Quantum number	What the Quantum number tells us
Principal quantum number, **n**	which energy level the electron is in
Azimuthal quantum number, ***l***	which sub-level within the energy level the electron is in
Magnetic quantum number, $\mathbf{m}_l$	which orbital within the sub-level the electron is in
Spin quantum number, $\mathbf{m_s}$	direction of electron spin (clockwise or counterclockwise)

The four quantum numbers—n, l, m_l and m_s—come from a very complex equation. Together all four of them (n, l, m_l, m_s) will describe the most probable location of an electron kind of like how (x, y, z) describes the location of a point on a graph.

TABLE 2: Rules governing what values quantum numbers are allowed to have.

Quantum number	Possible values
n	1, 2, 3, 4, …integer values
l	0, 1, 2, …integers up until n-1
m_l	$-l$, ..., 0, …, $+l$
m_s	+½ or -½

Examples:

- If n = 3, then the electron is in the 3rd energy level and l is allowed to have only a value of 0, 1, or 2. It cannot equal anything higher than 2 because n-1=2.
- If l = 1, then m_l is allowed to have a value of -1, 0, 1.
- If l = 2, then m_l is allowed to have a value of -2, -1, 0, 1, or 2.
- m_s can only be +½ meaning that the electron is spinning clockwise or -½ meaning that the electron is spinning counterclockwise.

Critical Thinking Questions

1. Using the quantum numbers (n, *l*, m_l, m_s) explain why each of the following is not an allowed combination of quantum numbers. The first one is done for you.

   a) (3, 4, 1, +½) Here n = 3 and so *l* can only have values of 0, 1, or 2. Here, however, *l* has a value of 4, which is impossible.

   b) (2, 1, -2, -½)

   c) (1, 0, 0, -1)

2. If n=4, what are the possible values of *l*?

3. If *l* = 3, what are the possible values for m_l?

4. Fill in the blanks in the following table.

Principle Quantum Number (n)	Sublevels that are possible	Possible values for *l*
n = 1		
n = 2	s and p	0 or 1
n = 3		0, 1, or 2
n = 4	s, p, d and f	

5. Given the above table and remembering that the quantum number *l* tells us which sublevel (s, p, d, or f), complete the following statements. The first is done for you.
   - For an s sublevel, *l* equals ____0____.
   - For a p sublevel, *l* equals ________.
   - For a d sublevel, *l* equals ________.
   - For an f sublevel, *l* equals ________.

Information: Correlating quantum numbers and sublevels

TABLE 3

Azimuthal Quantum Number (*l*)	Sublevel	# of Orbitals Possible in the sublevel	Possible m_l values
0	s	1	0
1	p	3	-1, 0, +1
2	d	5	-2, -1, 0, +1, +2
3	f	7	-3, -2, -1, 0, 1, 2, 3

The same as Table 2 from ChemQuest 11

Critical Thinking Questions

6. How many m_l values are possible for a d sublevel?

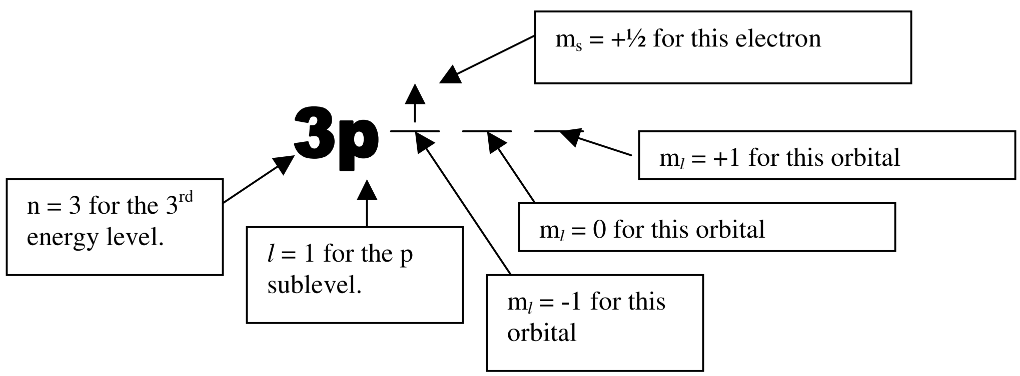
7. How many orbitals are there for a d sublevel?

8. How many m_l values are possible for an f sublevel?

9. How many orbitals are there for an f sublevel?

10. Comparing your answers for 6 and 7 and your answers for 8 and 9, what correlation exists between the number of orbitals and the number of m_l values possible?

Information: Correlating quantum numbers to what you already know

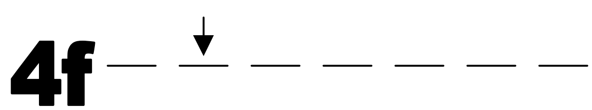


The quantum numbers (n, l, m_l, m_s) for the above diagram are: (3, 1, -1, +½).

- n = 3 indicating the third energy level
- l = 1 indicating the p sublevel
- m_l = -1 indicating that the electron is the first of the three orbitals.
- m_s = +½ indicating a spin in the clockwise direction.

Critical Thinking Questions

11. Explain why the set of quantum numbers (n, l, m_l, m_s) is (4, 3, -2, -½) for the following electron.



12. Draw an orbital diagram for an electron whose quantum numbers are (5, 2, 0, +½).

ChemQuest 13

Electron Configurations

Name: ______________________________
Date: ________________
Hour: _____

Information: Energy of Sublevels

Each sublevel has a different amount of energy. For example, orbitals in the 3p sublevel have more energy than orbitals in the 2p sublevel. The following is a list of the sublevels from lowest to highest energy:

1s, 2s, 2p, 3s, 3p, 4s, 3d, 4p, 5s, 4d, 5p, 6s, 4f, 5d, 6p, 7s, 5f, 6d…

To help you, here is the above list with the orbitals included. Recall that each blank represents an orbital:

1s -, 2s -, 2p - - -, 3s -, 3p - - -, 4s -, 3d - - - - -, 4p - - -, 5s -, 4d - - - - -, 5p - - -, 6s -, 4f - - - - - - -

Note that d and f sublevels appear to be out of place. This is because they have extra high energies. For example, the 3d sublevel has a higher energy than a 4s sublevel and the 4f sublevel has a higher energy than the 6s sublevel.

When electrons occupy orbitals, they try to have the lowest amount of energy possible. (This is called the ***Aufbau Principle***.) An electron will enter a 2s orbital only after the 1s sublevel is filled up and an electron will enter a 3d orbital only after the 4s sublevel is filled. Recall that only two electrons can fit in each orbital. (This is called the ***Pauli Exclusion Principle***.) When two electrons occupy the same orbital they must spin in opposite directions—one clockwise and the other counterclockwise.

Critical Thinking Questions

1. a) How many electrons would an atom need to have before it can begin filling the 3s sublevel?

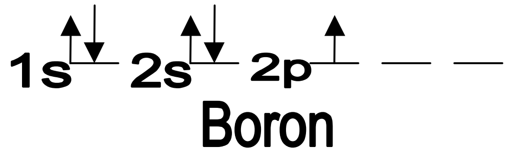
   b) What is the first element that has enough electrons to have one in the 3s sublevel? (Use your periodic table.)

2. a) How many electrons would an atom need to have before it can begin filling the 3d sublevel?

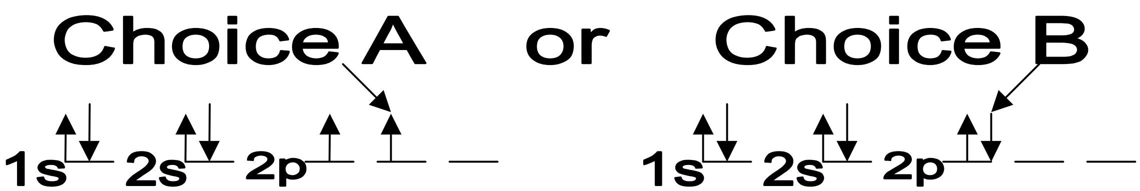
   b) What is the first element that has enough electrons to begin placing electrons in the 3d sublevel?

Information: Hund's Rule

Electrons can be "paired" or "unpaired". Paired electrons share an orbital with their spins parallel. Unpaired electrons are by themselves. For example, boron has one unpaired electron. Boron's <u>orbital diagram</u> is below:

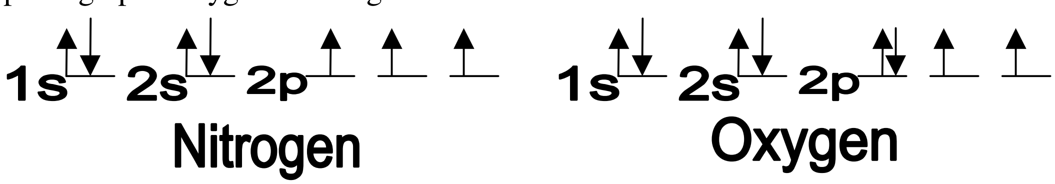


If we added one more electron to boron's orbital diagram we will get carbon's orbital diagram. One important question is: where does the next electron go? The electron has a choice between two equal orbitals—which of the 2p orbitals will it go in?



Hund's rule tells us which of the above choices is correct. **Hund's rule** states: when electrons have a choice of entering two equal orbitals they enter the orbitals so that a maximum number of unpaired electrons result. Also, the electrons will have parallel spins. Therefore Choice A is carbon's actual orbital diagram because the p electrons are in separate orbitals and they have parallel spins!

The following are the electron orbital diagrams for the next elements, nitrogen and oxygen. Notice that nitrogen's 2p electrons are all unpaired to obey Hund's Rule. The 2p electrons are forced to begin pairing up in oxygen's configuration.



Critical Thinking Questions

3. How many "unpaired" electrons are in a nitrogen atom?

4. Why does carbon's sixth electron have to go into another p orbital? Why can't it go into a 2s orbital? Why can't it go into a 3s orbital?

5. Write the electron orbital diagram for phosphorus.

6. Write the electron orbital diagram for arsenic.

7. Compare the orbital diagrams for nitrogen (see information section above), phosphorus (question 5) and arsenic (question 6). What is similar about the electrons in the last sublevel for each of them?

Information: Electron Configurations vs. Orbital Diagrams

The electron orbital diagram of an atom can be abbreviated by using what is called **electron configurations**. The following is the electron configuration for carbon: $1s^2 2s^2 2p^2$. The following is the electron configuration for several elements whose orbital diagrams are given above:

Carbon: $1s^2 2s^2 2p^2$ nitrogen: $1s^2 2s^2 2p^3$ oxygen: $1s^2 2s^2 2p^4$

Critical Thinking Questions

8. What are the small superscripts (for example, the ^{4} in oxygen) representing in an electron configuration?

9. What information is lost when using electron configurations instead of orbital diagrams? When might it be more helpful to have an orbital diagram instead of an electron configuration?

10. How many unpaired electrons are in a sulfur atom? What did you need to answer this question—an orbital diagram or an electron configuration?

11. Write the electron configuration for zirconium (atomic # = 40).

12. Write the configuration for argon (atomic # = 18).

13. Write the electron configuration for calcium (atomic # = 20). Notice that calcium has all of argon's electrons plus two additional ones in a 4s orbital.

ChemQuest 14

Lewis Dot Structures

Name: ____________________________
Date: _______________
Hour: _____

Information: Valence Electrons

The electrons in the highest energy level are called valence electrons. Valence electrons are the electrons located farthest from the nucleus. Valence electrons are *always* in the highest energy level. The valence electrons are the most important electrons in an atom because they are the electrons that are the most involved in chemical reactions and bonding.

The electron configuration for thallium (#81) is:

$$1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^6 5s^2 4d^{10} 5p^6 \mathbf{6s^2} 4f^{14} 5d^{10} \mathbf{6p^1}$$

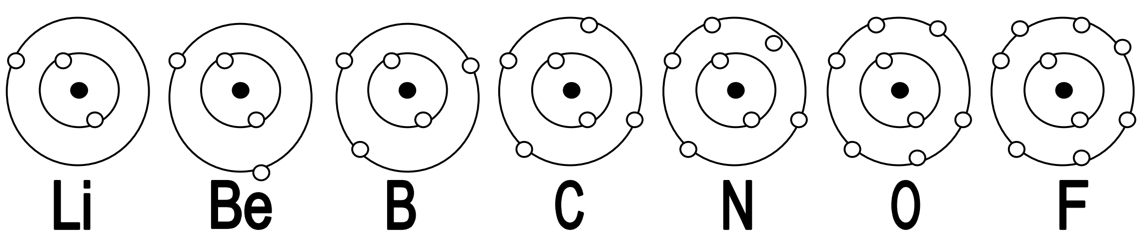
The outermost energy level (not sublevel) is the 6^{th} energy level. How many total electrons does thallium have in the sixth level? 3, they are in boldfaced type above. Therefore, thallium has 3 valence electrons.

Critical Thinking Questions

1. Write the electron configurations for
   a) oxygen:
   b) sulfur:
2. How many valence electrons does oxygen have?
3. How many valence electrons does sulfur have?
4. Verify that selenium (atomic number = 34) has six valence electrons by drawing an electron configuration and giving a brief explanation.

Information: Bohr Diagrams

Below are seven "Bohr diagrams" for atoms #3-9.
FIGURE 1:



Critical Thinking Questions

5. In each of the Bohr diagrams in Figure 1, the first energy level only has two electrons drawn in it. Why is this?

6. What is the maximum number of electrons that the second energy level can have? How many electrons can the 3rd energy level have?

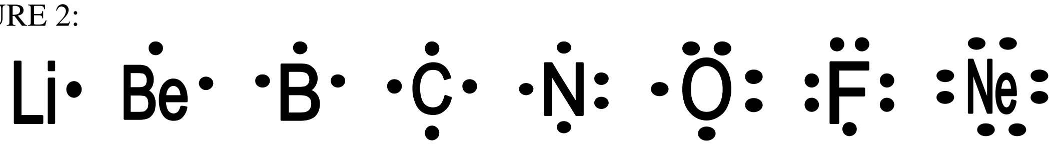
7. Draw Bohr diagrams for the following atoms.

   a) magnesium b) phosphorus c) argon

Information: Electron Dot Diagrams

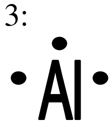
Below are electron dot diagrams, also known as "Lewis Structures" for atoms #3-10.

FIGURE 2:



The position of the dots is important. For example, another atom that has three dots in its Lewis structure is aluminum. Aluminum's three dots must be positioned the same way as boron's. Thus, aluminum's Lewis structure is:

FIGURE 3:



Critical Thinking Questions

8. What relationship exists between an atom's valence electrons and the number of dots in the Lewis structure of the atom?

9. Why does nitrogen's Lewis Structure has five dots around it while nitrogen's Bohr diagram contains 7 dots around it.

10. Recall from questions 1-4 that oxygen, sulfur and selenium all have the same number of valence electrons (6). They also are in the same column of the periodic table. Predict how many valence electrons tellurium (Te) will have.

11. Comparing Figure 2 and Figure 3 we see that boron and aluminum have the same number of dots in their Lewis structures. Notice they are in the same column of the periodic table. Write the Lewis structure for gallium (Ga).

12. Write the Lewis structure for sulfur and selenium. Compare the structures you write with oxygen's Lewis structure from Figure 2.
    a) Sulfur b) Selenium

13. In question seven, you drew the Bohr diagram for magnesium. Now write the Lewis Structure for magnesium. What similarities exist between the Lewis Structures for magnesium and beryllium?

14. Complete this statement: If elements are in the same column of the periodic table, they must

    have Lewis Structures that are ________________.
    similar or different

15. Why does sodium have the same Lewis structure as lithium?

16. Lewis structures are easier to draw than Bohr diagrams, but what information is lost by drawing a Lewis structure instead of a Bohr Diagram?

17. Draw the Lewis structure for the following elements.
    a) germanium b) bromine c) xenon d) potassium e) arsenic

18. You should be able to tell how many valence electrons an atom has by which column of the periodic table the element is in. How many valence electrons are in each of the following atoms?
    a) bromine b) tin c) krypton d) rubidium

ChemQuest 15

Electron Configurations and the Periodic Table

Name: ______________________________
Date: _______________
Hour: _____

Information: Relating Electron Configurations to the Periodic Table

In this section you will see how the periodic table serves as a road map for writing electron configurations. Get your periodic table out and get ready. Remember that a row on the periodic table goes horizontally from left to right. Columns are vertical (up and down).

Critical Thinking Questions

1. Write the electron configurations for Li, Na and K. (Remember for electron configurations, arrows are not necessary.)

2. What is similar about the electron configurations of all of the elements in question 1? Look at the very end of their configurations.

3. Lithium (Li) is in row 2 of the periodic table, sodium (Na) is in row 3, and potassium is in row 4. How do their row numbers affect how their electron configurations end?

4. Write the electron configurations for Be, Mg, and Ca.

5. What is similar about the ending of the electron configurations for all of the elements in question 4?

6. Beryllium (Be) is in row 2 of the periodic table, magnesium (Mg) is in row 3, and Calcium (Ca) is in row 4. How do their row numbers affect how their electron configurations end?

7. Given what you have done in questions 1-6, complete the following statement.

   Elements ending in s^1 are in column number _____ and those ending in s^2 are in column number _____ of the periodic table.

8. Name the element that have an electron configuration ending with… (the first is done for you)
   a) $5s^1$ _Rubidium (Rb)__ b) $6s^2$ _______________ c) $7s^1$ _________________

9. Write the electron configurations for B, Al, and Ga and note their similarities.

10. Write the electron configurations for N, P and As and note their similarities.

11. Complete the following statement: Elements ending in p^1 are in column number _________ of the periodic table and elements ending in p^3 are in column number __________ of the periodic table. Therefore, elements ending in p^2 must be in column __________ of the periodic table.

12. Name the elements that have an electron configuration ending with…(the first is done for you)

    a) $3p^4$ __Sulfur (S)__ b) $5p^6$ ________________ c) $6p^5$ __________________

13. Write the electron configurations for Ti, Zr, and Hf and note their similarities.

14. Write the electron configurations for Cr, Mo, and W and note what is similar about them.

15. Complete the following: Elements ending in d^2 are in column number ________ and those ending in d^4 are in column number ______. Therefore, elements ending in d^3 are in column number ______. Elements ending in d^7 must be in column number _______.

16. Notice from question 6 that an element that ends in 3s is in the 3rd row. Also, from questions 9-12 it should be clear that an element that ends in 3p is in the 3rd row. However, notice that an element that ends in 3d is in the 4th row instead of the 3rd row. Offer an explanation for this.

17. Name the elements that have an electron configuration ending with…(the first is done for you)
    a) $4d^3$ _Niobium (Nb)_ b) $5d^8$ _________________ c) $3d^6$ _____________________

18. There are three major divisions on the periodic table: the "s block", the "d block" and the "p block". Where are these blocks of elements located? Give the column numbers of their locations. (Yes, there is also an "f block" but we won't consider that now.)

    s block: columns _______ d block: columns ______ p block: columns ______

Information: Abbreviating the Electron Configurations

Electron configurations can be shortened using a special group of elements called the noble gases. They are found in the column furthest to the right on the periodic table: helium, neon, argon, krypton, xenon, and radon. These gases are very non-reactive. All of the noble gases have electron configurations that end in p^6. Because of their unique non-reactivity, they are often used to abbreviate long electron configurations.

Take note of krypton's electron configuration: $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^6$.

Now notice that strontium's electron configuration is the same as krypton's except that strontium has 38 electrons instead of 36. Strontium's electron configuration is $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^6 5s^2$. Strontium has the same electron configuration as krypton and then two additional electrons in the 5s orbital. Therefore strontium's electron configuration can be abbreviated as $[Kr]5s^2$. This notation means that strontium has all of krypton's electrons plus two more in the 5s sublevel.

As another example, consider iodine. Instead of writing a long electron configuration, we can abbreviate it. Follow these steps:

1. Going backward from iodine on the periodic table, find the previous noble gas. It is krypton.
2. Take note of what krypton's electron configuration ends with. It ends with $4p^6$ since it is in the 4th row and in the p^6 column.
3. Iodine has 17 more electrons than krypton and so you can begin by writing [Kr] followed by orbitals for 17 more electrons. After $4p^6$ comes $5s^2$…

$$\text{Iodine} = [Kr]5s^2 4d^{10} 5p^5$$

Any of the noble gases can be used for abbreviations. Here are a few more examples:

$$\text{iron} = [Ar]4s^2 3d^6 \qquad \text{cesium} = [Xe]6s^1 \qquad \text{phosphorus} = [Ne]3s^2 3p^3$$

Study the above examples and make sure you understand why they are written that way.

Critical Thinking Questions

19. Write abbreviated electron configurations for the following elements:
    a) Ruthenium (Ru)

    b) Arsenic (As)

    c) Tellurium (Te)

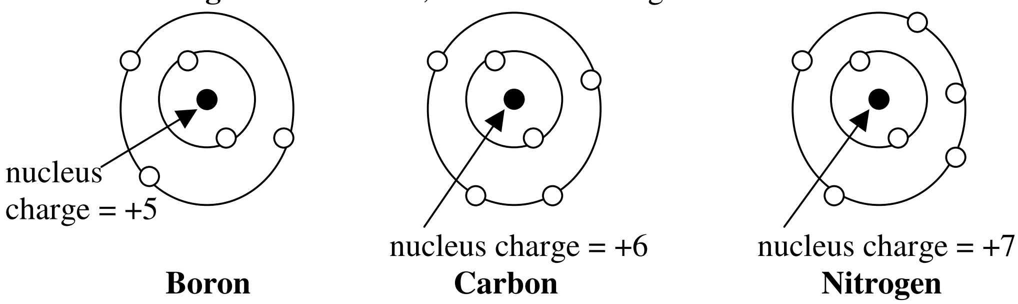
ChemQuest 16

Trends in Size

Name: ______________________________
Date: ________________
Hour: _____

Information: Shielding

FIGURE 1: "**Bohr Diagrams**" of boron, carbon and nitrogen



Because the nucleus is positively charged, it exerts an attractive force on the electrons. However, the three electrons in boron's outer energy level do not feel the full +5 attraction from the 5 protons in boron's nucleus. Before the +5 attraction gets to the outer energy level it gets partially cancelled (or "**shielded**") by the two electrons in the first energy level. The two electrons in the first energy level weaken the attractive force by two. Therefore to the outer energy level it only "feels" like a +3 charge rather than a +5 charge from the nucleus.

Consider the diagram of carbon. An electron in the outer energy level only "feels" a charge of +4 coming from the nucleus because the two electrons in the first energy level shield two of the positive charges from the nucleus.

Critical Thinking Questions

1. How large is the charge that the second energy level of nitrogen "feels" from the nucleus?

2. Why does the first energy level in each of the three above diagrams only contain two electrons?

3. How many electrons can fit in the second energy level of any atom?

4. How many electrons can fit in the third energy level?

5. How many energy levels does aluminum have? How many electrons should be in each energy level?

6. Draw a Bohr diagram for aluminum similar to those above.

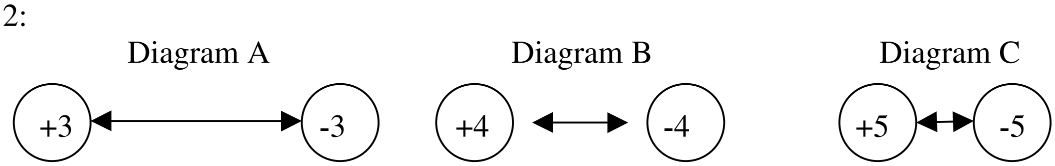
7. Explain why the second energy level of aluminum only feels a +11 attraction instead of a +13 attraction from aluminum's electrons.

8. How large is the charge that the third energy level of an aluminum atom "feels" from the nucleus?

Information: Charge and Distance

As you know, opposite charges attract. Examine the following diagrams of charged metal spheres.

FIGURE 2:



The attraction between the two charged metal spheres in each diagram is represented by an arrow. The metal spheres are pulled closer together in diagram C because of the +5 to -5 attraction is stronger than the +4 to -4 attraction in Diagram B and the +3 to -3 attraction in Diagram A.

Electrons behave the same way as the metal spheres are depicted in Figure 2. Consider the Bohr diagrams of boron, carbon and nitrogen in Figure 1. Recall that Boron's outer electrons feel a +3 attraction from the nucleus. Carbon's outer electrons feel a +4 attraction. In question 1, you found out that nitrogen's outer electrons feel a +5 attraction.

This attraction between the nucleus and outer energy level determines the size of the atom. If the attraction is strong the atom is small; if the attraction is weak, the atom spreads out and is larger.

Critical Thinking Questions

9. Which atom is larger: nitrogen or carbon? Why?

10. In a silicon atom, the force of attraction from the nucleus to the outer energy level is +4. Using a Bohr diagram of a silicon atom as an illustration, explain in detail why this is true.

11. Draw Bohr diagrams for sulfur and chlorine.

12. a) Find the size of the charge attraction between the nucleus and outer energy level for sulfur and for chlorine.

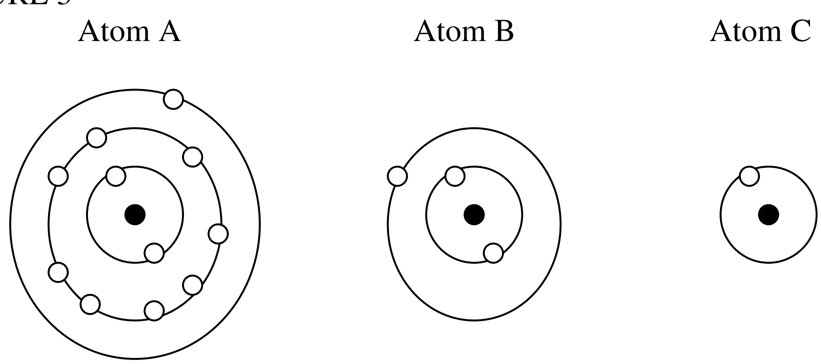
    b) Which atom do you predict to be larger: sulfur or chlorine?

    c) Explain, in detail, your reasoning to part b.

13. Notice and compare the locations of boron, carbon and nitrogen on the periodic table. Now compare their sizes. Do the same with sulfur and chlorine. There is a general trend in size as you proceed from left to right across the periodic table. What is this trend? In other words, how do atoms in the same row of the periodic table compare to each other in size?

Information: Bohr Diagrams and the Size of Atoms

Examine the following "Bohr Diagrams" of three atoms from the periodic table.
FIGURE 3



Critical Thinking Questions

14. Give the name and atomic number of each atom from Figure 3.

	Atom A	**Atom B**	**Atom C**
Name of the element			
Atomic number			

15. a) Concerning atoms A, B and C, what is similar about their location in the periodic table?

    b) In atoms A, B, and C compare the force of attraction from the nucleus to the outer level of electrons.

16. Draw Bohr diagrams for neon and argon.

17. a) What is similar about the location of neon and argon in the periodic table

    b) Compare the force of attraction between the outer level electrons and the nucleus for neon and argon.

    c) Using your answers to 15b and 17b, what can be said about elements in the same column and the force of attraction between their outer energy level and nucleus?

18. Atom A is larger than atom B. The attraction between the nucleus and outer level electrons is equal in atoms A and B, so what other reason could there be for Atom A's larger size? Propose an explanation based on that <u>structure</u> of atoms A and B.

19. Which is larger—neon or argon? Why is this atom the largest?

20. In general, there is a trend in the sizes of atoms as you move down a column of the periodic table.
    a) What is this trend?

    b) Why does this trend exist? (Explain the basis for the trend.)

21. Order the following lists of elements in order from smallest to largest.
    a) K, As, Br   b) P, Sb, N   c) S, Ca, Mg, Cl

ChemQuest 17

Ionization Trends

Name: ______________________

Date: ______________

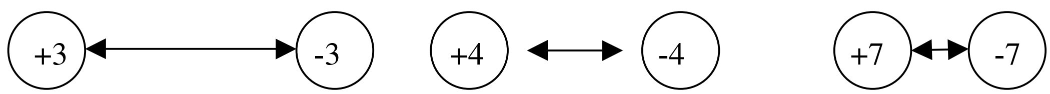
Hour: _____

Information: Separating Charges

Examine Figure 1 below where there are three pairs of metal spheres that have different amounts of charge on them. The spheres in diagram C are closer than the others because they have the strongest attraction.

FIGURE 1: Attraction between metal spheres.

Diagram A Diagram B Diagram C



Critical Thinking Questions

1. Which would be harder to separate: the two spheres in Diagram A or the two spheres in Diagram B? Why?

2. Draw Bohr diagrams of the following atoms: lithium, nitrogen and fluorine.

3. For each of the atoms in question two compare the attraction between the nucleus and the outer level of electrons. Which atom has the strongest attraction between the nucleus and outer electrons?

4. Which would be more difficult: if you wanted to remove an electron from an atom of fluorine or from an atom of nitrogen?

5. Would it be easier to remove an electron from lithium or nitrogen?

Information: Ionization Energy

The amount of energy that it takes to completely remove an electron from an atom is called **ionization energy**. The first ionization energy is the energy required to remove one electron from an atom's outer energy level. The second ionization energy is the energy needed to remove a second electron from the energy level. The second ionization energy is always higher than the first ionization energy. Because noble gases have eight electrons in their outer energy level, they are very stable and therefore it takes a very high amount of energy to remove an electron from a noble gas.

Critical Thinking Questions

6. Which would have a higher first ionization energy: phosphorus or aluminum? (You may want to draw a Bohr diagram to help you determine the answer.)

7. a) Phosphorus and aluminum are in the same row of the periodic table. Lithium, nitrogen and fluorine are also in the same row. Using your answers to questions 3, 4 and 6 what do you notice about the ionization energy of elements proceeding from left to right across a row of the periodic table? Does the ionization energy increase or decrease as you go across a period?

   b) Explain **why** you believe this trend exists.

8. Draw a Bohr diagram of sodium. Do you expect the first ionization energy to be high or low for sodium?

9. The second ionization energy of all elements is higher than the first ionization energy, but in sodium the second ionization energy is extra large. Considering the structure of the sodium atom explain why this might be. (HINT: after one electron is removed, what is sodium's electron arrangement like?).

10. A certain atom in the third period has a third ionization energy that is unusually high. Using the same reasoning you used for question 9, name this atom.

Information: Trend in Ionization Energy in Groups

Consider the following figure of diagrams of two magnets that you wish to separate.

FIGURE 2: Separating Magnets

Critical Thinking Questions

11. Would it be easier to separate the magnets in Diagram D or those in Diagram E in Figure 2? Assume that each magnet is attracted to the other and that the size of the attraction is the same. Take only the distance between magnets into consideration.

12. How does the distance between the outer level of electrons and the nucleus in phosphorus compare to the distance between the outer level of electrons and the nucleus in nitrogen?

13. Based on your answer to question 12, would it be easier to remove an electron from nitrogen or from phosphorus?

14. Nitrogen and phosphorus are in the same column on the periodic table. From your answers to questions 12 and 13 what happens to the ionization energy as you move down a column in the periodic table?

ChemQuest 18

Forming Ions

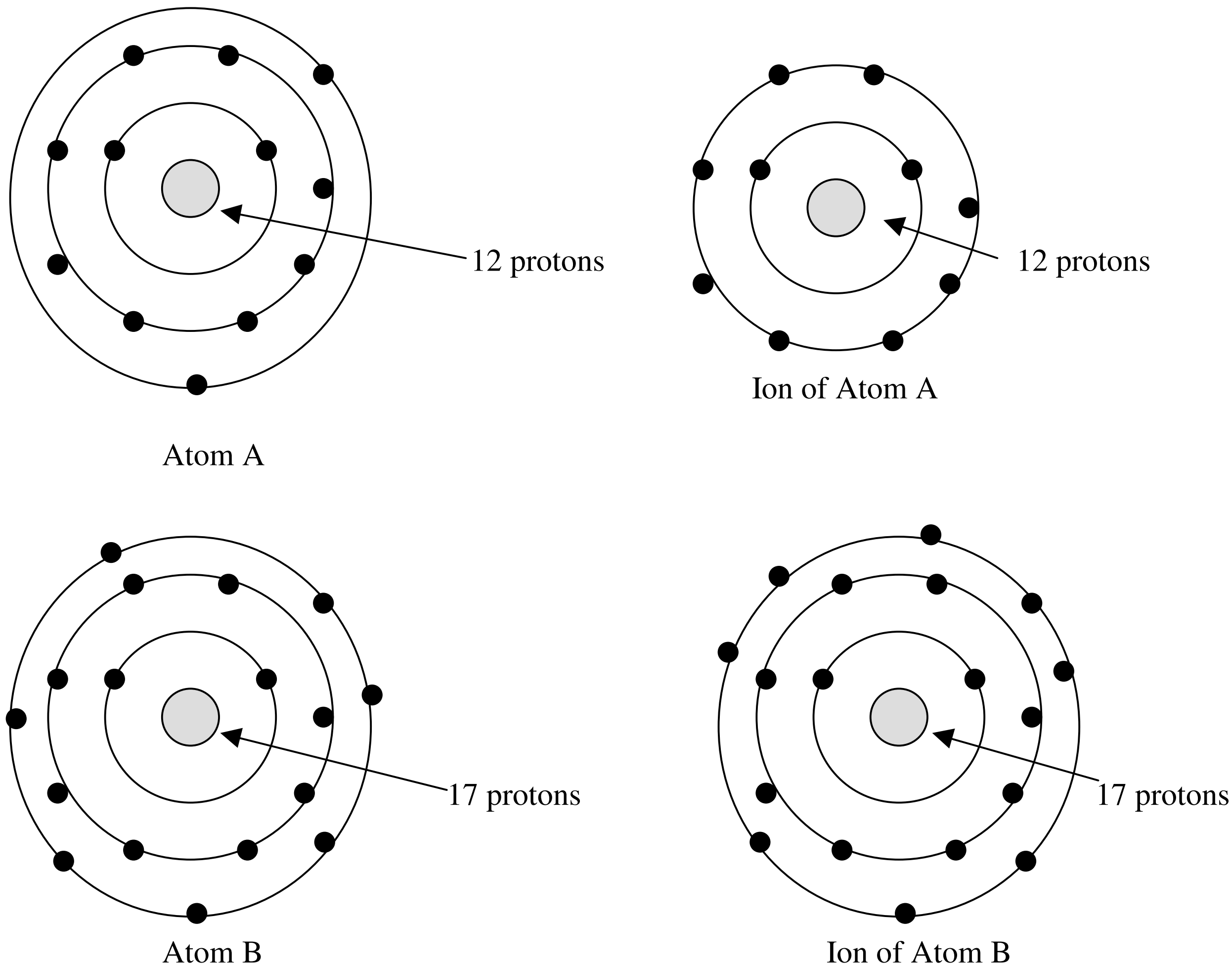
Name: ______________________________

Date: ________________

Hour: _____

Information: Ions

Figure 1: Below are four Bohr diagrams of atoms and ions. The two diagrams on the left are atoms; the two on the right are ions.



Critical Thinking Questions

1. Prove that both Atom A and Atom B are neutral (have a charge of zero).

2. What is the identity of Atom A and of Atom B?

3. Given the above diagrams, how does an atom become an ion?

4. What is the charge on Ion A? What is the charge on Ion B?

5. Write the electron configuration (ex: $1s^2 2s^2 2p^6$….) for each ion and atom shown in the Bohr diagrams.

   Atom A: ____________________________ Ion A: ________________________________

   Atom B: ____________________________ Ion B: ________________________________

6. Consider the electron configuration that you wrote for Ion A. What atom has the same electron configuration as this ion?

7. Consider the electron configuration that you wrote for Ion B. What atom has the same electron configuration as this ion?

8. Bromine atoms always gain one electron when they become an ion. Which atom has the same number of electrons as a bromine ion?

9. Cesium atoms always lose one electron to become an ion. Which atom has the same number of electrons as a cesium ion?

10. Consider your answers to questions 6-9. What do all of the atoms you named have in common?

11. Knowing what you know about the atoms that you named in questions 6-9, why do you think atoms want to form ions the way they do?

Information: Ions

As you know, all of the noble gases are very stable. Ions form in such a way so that the ion will have the same number of electrons as a noble gas. Take oxygen, for example. Oxygen has 8 electrons. To become like a noble gas it could either gain two to become like neon or it could lose six to become like helium. So what will oxygen do—gain two or lose six? As a general rule, atoms will gain or lose the fewest number of electrons possible.

Critical Thinking Questions

12. What does an oxygen atom do when becoming an ion? (Does it gain or lose electrons and how many?)

13. An oxygen atom has an overall neutral charge because it has an even number of protons and electrons. What is the overall charge on an oxygen ion?

14. Consider an aluminum atom.
    a) To become like argon, would aluminum have to gain or lose electrons? How many?

    b) To become like neon, would aluminum have to gain or lose electrons? How many?

    c) Considering your answers to parts a and b, what does an aluminum atom do to become an ion?

    d) What is the charge on an aluminum ion?

15. When each of the following atoms becomes an ion, what will the charge be? (Your answer should include the sign and magnitude such as +1, +2, -2, etc…)

    a) Ca b) Cl c) N d) K e) S f) B g) P

ChemQuest 19

Ionic Bonding

Name: ______________________
Date: ______________
Hour: _____

Information: Naming Ions

To write an ion, you write the symbol of the atom and put the charge in the upper right corner. Consider the following examples: Al^{3+}, O^{2-}, Mg^{2+}. You should verify that each of the charges is correct.

Positive and negative ions are named differently. Positive ions retain the same name as the parent atom. For example, Al^{3+} is called the "aluminum ion" and Mg^{2+} is called the "magnesium ion." Negative ions are named a little differently. For negative ions, you change the ending of the name to "-ide". Therefore, O^{2-} is named ox<u>ide</u> and P^{3-} is named phosph<u>ide</u>.

Critical Thinking Questions

1. Write the symbol (including the charge) and name for each of the ions for each of the following:
   a) Ca b) Cl c) N d) K e) S f) B g) P

Information: Ionic Bonding and Formulas

There are two ways in which atoms can "bond" to each other and form a <u>compound</u>. The means of bonding that we will consider now is called <u>ionic bonding</u>, which <u>occurs between a metal and a nonmetal</u>. As you know, opposite charges attract. Ionic bonding is when two ions of opposite charge attract and bond to each other forming an <u>ionic compound</u>. Consider the following examples of <u>formulas</u> for ionic compounds:

- One Na^{+} (sodium ion) and one Cl^{-} (chloride ion) bond to make NaCl, "sodium chloride."
- One Mg^{2+} (magnesium ion) and two F^{-} (fluoride ion) bond to make MgF_2, "magnesium fluoride."
- Three Ca^{2+} (calcium ion) and two N^{3-} (nitride ion) bond to make Ca_3N_2, "calcium nitride."
- One Al^{3+} (aluminum ion) and one N^{3-} (nitride ion) bond to make AlN, "aluminum nitride."

The small numbers at the bottom right of each symbol in a formula are called "subscripts". <u>Subscripts</u> tell us how many of each type of atom are present. For example in the formula Mg_3N_2 there are three magnesium ions and two nitride ions.

Critical Thinking Questions

2. Consider the formula NaCl in the above example. It tells us that one Na^{+} ion is bonded to one Cl^{-} ion. What is the overall charge for NaCl? Is it positive, negative, or neutral?

3. Consider MgF_2. This formula tells us that one Mg^{2+} ion bonds with two F^- ions. What is the overall charge on MgF_2?

4. What is the overall charge on any ionic compound?

5. Why is calcium nitride written like Ca_3N_2 and not something like CaN_2 or Ca_2N_3? In other words why do exactly three calcium ions bond with exactly two nitride ions?

6. The formula Ca_3N_2 can never be written as N_2Ca_3. To find out why, take note of each of the four example formulas given above.
   a) In terms of charge, what do the first ions named all have in common?

   b) In terms of charge, what do the second ions named all have in common?

   c) Now, why can't Ca_3N_2 ever be written like N_2Ca_3?

7. There are two rules to follow when writing formulas for ionic compounds. One has to do with charges (see questions 4 and 5) and the other has to do with which atom to write first and which one to write second (see question 6). What are these two rules?

8. What is wrong with the following formulas?
   a) Al_2S b) PNa_3 c) Mg_2S_2

9. Write the formula and name for the compound that forms when the following atoms form ionic compounds. The first is done for you.
   a) nitrogen and sodium b) barium and sulfur c) magnesium and iodine
   Na_3N
   sodium nitride

   d) oxygen and aluminum e) calcium and phosphorus f) sodium and sulfur

10. Given the following compounds, determine the charge on the unknown ion "X".
    a) X_2S b) MgX c) X_3P_2

ChemQuest 20

Ionic Bonding Advanced

Name: ______________________________
Date: _______________
Hour: _____

Information: Polyatomic Ions

The word, "polyatomic" means "many atoms". A polyatomic ion, therefore, is an ion that is made of more than one atom. An example of a polyatomic ion is the sulfate ion, SO_4^{2-}. Sulfate is composed of one sulfur atom and four oxygen atoms and overall sulfate has a negative two charge.
Some polyatomic ions:

Sulfate: SO_4^{2-}	Phosphate: PO_4^{3-}	Nitrate: NO_3^-
Cyanide: CN^-	Ammonium: NH_4^+	Chlorate: ClO_3^-
Acetate: $C_2H_3O_2^-$	Hydroxide: OH^-	Carbonate: CO_3^{2-}

Critical Thinking Questions

1. What do all of the polyatomic ions that have the suffix "-ate" have in common?

2. Which two atoms do you think compose the polyatomic ion called "silicate"?

3. What is the difference between calcium nitride and calcium nitrate?

Information: Writing Formulas With Polyatomic Ions

First of all, you must remember that you can never change the formula for a polyatomic ion. Sulfate is always SO_4^{2-} and never $S_2O_8^{4-}$ or something else. Following are some examples of chemical formulas that contain polyatomic ions.

Ammonium chloride is formed from one ammonium ion (NH_4^+) and one chloride ion (Cl^-) to give the formula: NH_4Cl. Sodium sulfate requires two sodium ions (Na^+) because sulfate (SO_4^{2-}) has a negative two charge; the formula is: Na_2SO_4.

Consider calcium hydroxide. Calcium has a positive two charge (Ca^{2+}) and hydroxide has a negative one charge (OH^-). We need two hydroxide ions to combine with one calcium ion so that the overall charge ends up being zero. We write calcium hydroxide like $Ca(OH)_2$.

Following are some more examples:

potassium acetate: $KC_2H_3O_2$	magnesium nitrate: $Mg(NO_3)_2$
barium phosphate: $Ba_3(PO_4)_2$	calcium carbonate: $CaCO_3$

Critical Thinking Questions

4. As mentioned above, calcium hydroxide is written like $Ca(OH)_2$. Why can't it be written like $CaOH_2$?

5. As mentioned above, barium phosphate is written as $Ba_3(PO_4)_2$. Why can't it be written like Ba_3PO_{42}?

6. Name the following compounds. Each includes at least one polyatomic ion.
   a) Na_3PO_4 b) $(NH_4)_2SO_4$ c) $Mg(C_2H_3O_2)_2$

   d) $(NH_4)_2S$ e) $CaCO_3$ f) $Ba(NO_3)_2$

7. Write formulas for the following ionic compounds. Note that each includes a polyatomic ion.
   a) lithium phosphate b) ammonium oxide c) barium hydroxide

   d) calcium cyanide e) sodium chlorate f) potassium sulfate

8. In question 3, you were asked the difference between calcium nitride and calcium nitrate. Now write the formula for each of them.

   calcium nitride: calcium nitrate:

Information: Formulas for Acids

Acids are compounds that contain positive hydrogen ions (H^+) bonded to a negative ion. For example, carbonic acid is formed when the carbonate ion (CO_3^{2-}) bonds with two hydrogen ions (H^+) to give H_2CO_3. Other common acids are listed below:

Hydrochloric acid: HCl
Sulfuric acid: H_2SO_4
Nitric Acid: HNO_3
Acetic Acid: $HC_2H_3O_2$

Critical Thinking Questions

9. Why do carbonic and sulfuric acid require two H^+ ions to bond, but HCl and HNO_3 only have one H^+?

10. Phosphoric acid is made from the phosphate ion and H^+ ions. Write the formula for phosphoric acid.

ChemQuest 21

Transition Metals

Name: ____________________________

Date: _______________

Hour: _____

Information: Charges of Some Transition Elements

So far you have learned that you can predict the charge that an ion will have based on its location on the periodic table. However, the transition elements are not easy to predict. A few common transition elements are listed below. You should memorize their charges.

Silver: Ag^{+} Zinc: Zn^{2+} Cadmium: Cd^{2+}

Critical Thinking Questions

1. Write the formulas for the following compounds:

   a) silver nitrate b) zinc phosphate c) cadmium chloride

Information: More Than One Possible Charge

Many transition elements can have more than one charge when they become an ion. Copper ions, for example, can be Cu^{+} or Cu^{2+}. As another example, iron ions are sometimes Fe^{2+} and sometimes Fe^{3+}.

Critical Thinking Questions

2. Copper and iron are in the "d block" and so you need to calculate their charge by comparing what bonds to them. Find the charge on copper and iron in each of the following compounds.

   a) $CuCl_2$ b) $CuCl$ c) $FeSO_4$ d) $Fe_2(SO_4)_3$

3. Give your best attempt at naming the compounds from question 2. (They are rewritten below.)

   a) $CuCl_2$ b) $CuCl$ c) $FeSO_4$ d) $Fe_2(SO_4)_3$

Information: Formulas Containing Roman Numerals

You probably put the same name for the compounds in question 3a and 3b. You may also have put the same name for the compounds in 3c and 3d. BUT these are not the same compound! You cannot have the same name for two different compounds. Here are the correct names for the compounds in questions 2 and 3:

a) $CuCl_2$	b) $CuCl$	c) $FeSO_4$	d) $Fe_2(SO_4)_3$
copper(II) chloride	copper(I) chloride	iron(II) sulfate	iron(III) sulfate

Critical Thinking Questions

4. Compare your answers for questions 2 &3 with the names of the compounds given in the information section. What do the Roman numerals stand for?

5. Why is MnO_2 called manganese(IV) oxide?

6. Name the following compounds. *Note: assume that anytime you have a transition element (d block element) you must use a Roman numeral unless the element is silver, zinc, or cadmium.* (The first one is done for you.)

   a) $NiNO_3$ b) $Cr_2(CO_3)_3$ c) $FeNO_3$ d) $CoCl_2$

   nickel(I) nitrate

   e) $Cu_3(PO_4)_2$ f) MnS   g) $ZnCl_2$ h) $AgNO_3$

7. Write the formulas for the following compounds. (The first one is done for you.)

   a) mercury(II) acetate   b) chromium(III) sulfate   c) iron(I) carbonate

   $Hg(C_2H_3O_2)_2$

   d) potassium carbonate   e) strontium nitride   f) manganese(IV) chlorate

ChemQuest 22

Covalent Bonding

Name: ______________________________

Date: _______________

Hour: _____

Information: Terminology

Recall that an ionic bond results from the combination of a metal and a nonmetal. A covalent bond is the type of bond between two nonmetals. Covalent bonds are formed by neutral atoms that share electrons rather than by charged ions. When a compound is formed by sharing electrons, the compound is called a molecule or molecular compound. It is important to note that ionic compounds are not called molecules. The largest class of molecules are called organic molecules. Carbon is the distinguishing mark of organic compounds.

Critical Thinking Questions

1. Circle any of the following compounds that would properly be called a "molecule".

a) H_2O b) CO_2 c) NaCl d) Mg_3P_2 e) N_2O_5

Information: Naming Covalent Compounds

There are several prefixes used to name molecules. The name "carbon oxide" is not sufficient because carbon and oxygen sometimes form CO_2 and sometimes CO. Prefixes are necessary to distinguish between them.

Formula	Name
N_2O_4	dinitrogen tetraoxide
SF_6	sulfur hexafluoride
$XeCl_5$	xenon pentachloride
SO_3	sulfur trioxide
CO	carbon monoxide

Critical Thinking Questions

2. Fill in the table to indicate which prefix is used to represent the numbers. The first one is done for you.

Number	Prefix
1	mono
2	
3	
4	
5	
6	

3. Name each of the following molecules using the appropriate prefixes.
   a) N_2O_5 b) CF_4 c) SCl_3 d) SO

4. Which of the above compounds would be classified as "organic"?

Information: Empirical Formulas

Molecules can be represented by using either a molecular formula or an empirical formula. The molecular formula tells you exactly how many atoms of each element are in the compound. For example, in the table below, compound #2 has exactly 4 carbons and 8 hydrogens in each molecule. Observe the table below that shows four organic molecules along with a molecular and empirical formula for each one:

Molecule	Molecular Formula	Empirical Formula
#1	C_2H_4	CH_2
#2	C_4H_8	CH_2
#3	C_3H_8	C_3H_8
#4	C_8H_{18}	C_4H_9

Critical Thinking Questions

5. What is an empirical formula?

6. How can molecules #1 and #2 have the same empirical formula even though they are different molecules?

7. Given the empirical formula for a compound is it possible to determine the molecular formula? If so, explain how.

8. Given the molecular formula for a compound is it possible to determine its empirical formula? If so, explain how.

9. Give the empirical formula for each of the molecules below:
   a) N_2O_6 b) $C_2H_4O_2$ c) C_4H_{14} d) C_3H_5

ChemQuest 23

Lewis Structures

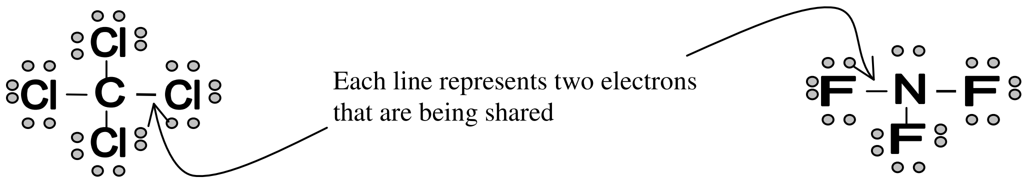
Name: ______________________________

Date: ________________

Hour: _____

Information: Drawing Covalent Compounds

For covalent bonding, we often want to draw how the atoms share electrons in the molecule. For example, consider CCl_4 and NF_3 as drawn below:



Notice that the atoms share electrons so that they all have 8 electrons. If you count the electrons around carbon, you will get a total of eight (each line is two electrons). If you count the electrons around each chlorine atom, you will find that there are eight of them.

Critical Thinking Questions

1. How many valence electrons does a carbon atom have (before it bonds)? Hint: find this based on carbon's column on the periodic table.

2. How many valence electrons does a chlorine atom have (before it bonds)?

3. Since CCl_4 is made up of one carbon and four chlorine atoms, how many total valence electrons does CCl_4 have? Hint: add your answer to question 1 and four times your answer to question 2.

4. Verify that there are 32 electrons pictured in the drawing of CCl_4.

5. Find the sum of all the valence electrons for NF_3. (Add how many valence electrons one nitrogen atom has with the valence electrons for three fluorine atoms.)

6. How many electrons are pictured in the drawing of NF_3 above?

7. In CCl_4 carbon is the "central atom". In NF_3 nitrogen is the "central atom". What is meant by "central atom"?

8. In SF_3 sulfur is the central atom. You can tell which atom is the central atom simply by looking at the formula. How does the formula give away which atom is the central atom?

9. Identify the central atom in each of the following molecules:
   A) CO_2 B) PH_3 C) SiO_2

10. For each of the compounds from question 9, add up how many valence electrons should be in the bonding picture. A is done for you.
    A) CO_2 B) PH_3 C) SiO_2

    4+2(6)=16

11. The number of electrons that should appear in the bonding picture for CO_3 is 22. The number of electrons that appear in the picture for CO_3^{2-} is 24. Offer an explanation for why CO_3^{2-} has 24 electrons instead of 22. (Where did the extra two electrons come from?)

12. The number of electrons that should be included in the picture of NH_4 is 9. The number of electrons in the picture for NH_4^+ is 8. Offer an explanation for why NH_4^+ has 8 electrons instead of 9.

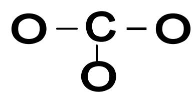
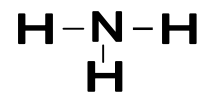
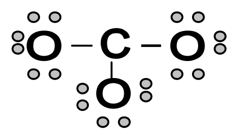
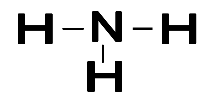
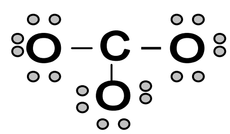
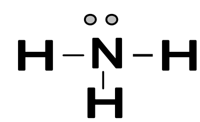
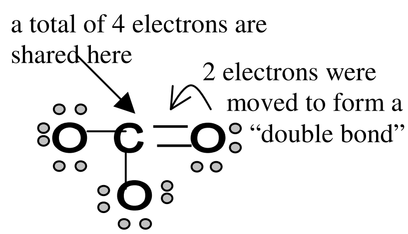
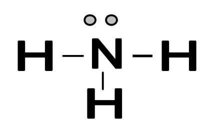
13. Considering questions 11 and 12, we can formulate a rule: For each negative charge on a polyatomic ion, we must ______________ (add or subtract) an electron and for each positive charge we must ______________ (add or subtract) an electron.

14. For each of the polyatomic ions or molecules below, determine the total number of valence electrons.

    a) NO_3^- b) SCl_4 c) H_3O^+ d) PO_4^{3-}

Information: Steps for Drawing Lewis Structures for Covalent Compounds

Study the two examples in the table of how to write structures for CO_3^{2-} and NH_3. Make sure you understand each of the five steps.

	CO_3^{2-}	NH_3
Step #1: Add up the number of valence electrons that should be included in the Lewis Structure.	4 + 3(6) + 2 = **24** (carbon has four and each oxygen has six; add two for the -2 charge)	5 + 3(1) = **8** (nitrogen has five; each hydrogen has one)
Step #2: Draw the "skeleton structure" with the central atoms and the other atoms, each connected with a single bond.		
Step #3: Add six more electron dots to each atom *except* the central atom. Also, never add dots to hydrogen.		 (no change)
Step #4: Any "leftover" electrons are placed on the central atom. Find the number of leftovers by taking the total from Step #1 and subtracting the number of electrons pictured in Step #3.	24 – 24 = 0 leftover electrons  (no change)	8 – 6 = 2 leftover electrons; placed around nitrogen 
Step #5: If the central atom has 8, then you are done. If not, then move two electrons from a different atom to make a multiple bond. Keep making multiple bonds until the central atom has 8 electrons.		(no change) 

Critical Thinking Questions

15. Write the Lewis Structure for nitrate, NO_3^{-1}. Hint: when you are done it should look very similar to CO_3^{2-} in the table above.

16. Draw the Lewis Structure for SO_2.

ChemQuest 24

More Lewis Structures

Name: ____________________
Date: ____________
Hour: _____

Introduction Questions

1. Draw the Lewis structures for the following molecules. Part c is done for you.
   a) H_2O (oxygen is central)   b) SO_2 c) N_2

   $:N\equiv N:$

2. In question 1 above you should see three different kinds of bonds. Define each of these kinds of bonds as best you can.
   a) single bond:

   b) double bond:

   c) triple bond:

3. In general, which kind of bond do you think would be harder to break—a single, double or triple bond? Why?

Information: Bond Order, Bond Length and Bond Energy

Study the following table relating bond order, bond length, and bond energy. Note that **bond length** is the distance between two bonding atoms in picometers and **bond energy** is the amount of energy (in kilojoules) required to break one mole of bonds.

Carbon—Carbon Bonds (note: these are drawings of bonds, not entire molecules)	**Bond Order for C—C bonds**	**C—C Bond Length (pm)**	C—C Bond Energy (kJ/mole)
$C-C$	1	150	350
$C=C$	2	130	600
$C\equiv C$	3	120	830

Critical Thinking Questions

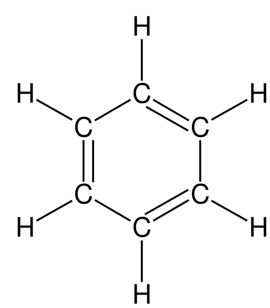
4. Is your answer to question 3 consistent with the data in the table?

5. What is the relationship between bond order and single, double, and triple bonds?

6. What relationship exists between bond length and bond energy?

7. Which bonds are shortest—single, double or triple?

8. A structure for benzene is given below.



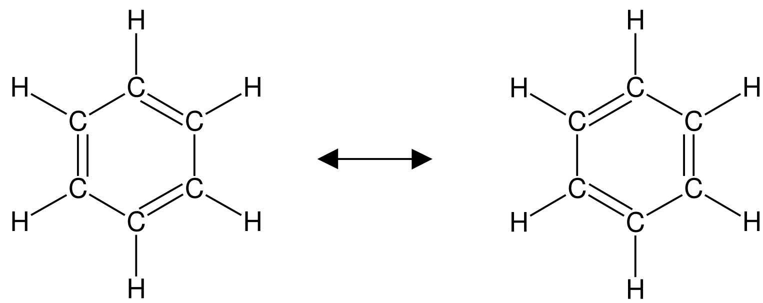
   a) Based on the Lewis structure, what is the bond order for each C—C bond? Label your predictions on the structure above.

   b) What would be the approximate lengths of the carbon-carbon bonds? Label these predictions on the structure also.

Information: Resonance Structures

Experimentally, all of the carbon-carbon bonds in benzene are exactly the same length. All of the bonds also require the same energy to break. This would indicate that all of the carbon-carbon bonds are identical. The bond order of each of the C—C bonds is approximately 1.5. The bonds have characteristics in between those of first order and second order bonds. Therefore, the structure of benzene is best represented by what is called a **resonance structure**. The structure is given at the top of the next page.

The resonance hybrid representation of benzene:



Note: the only difference in the resonance structures is the position of the double bonds.

Critical Thinking Questions

9. a) The nitrate ion, NO_3^-, is best represented by three resonance structures. Draw the three structures below. Note: the only difference between the three structures you draw will be the position of the double bond.

   b) Why were three structures required instead of two?

   c) Describe in general terms what you think nitrate's nitrogen-oxygen bonds are like in terms of bond order, bond length, and bond energies.

ChemQuest 25

Formal Charge

Name: ______________________________

Date: ________________

Hour: _____

Information: More than one possible Lewis Structure.

Sometimes when you draw a Lewis structure you discover that there is more than one possible way to draw it. For example, consider the following Lewis Structures for sand, which is silicon dioxide:

Diagram #1:

Structure A Structure B

Critical Thinking Questions

1. What is the total number of electrons allowed in the Lewis structure for SiO_2? Do both of the above Lewis structures have the correct number of electrons pictured?

2. Is each of the proposed structures above a legitimate Lewis structure for SiO_2? (In other words, in each of the proposed structures are all of the "rules" that you know followed?) Explain.

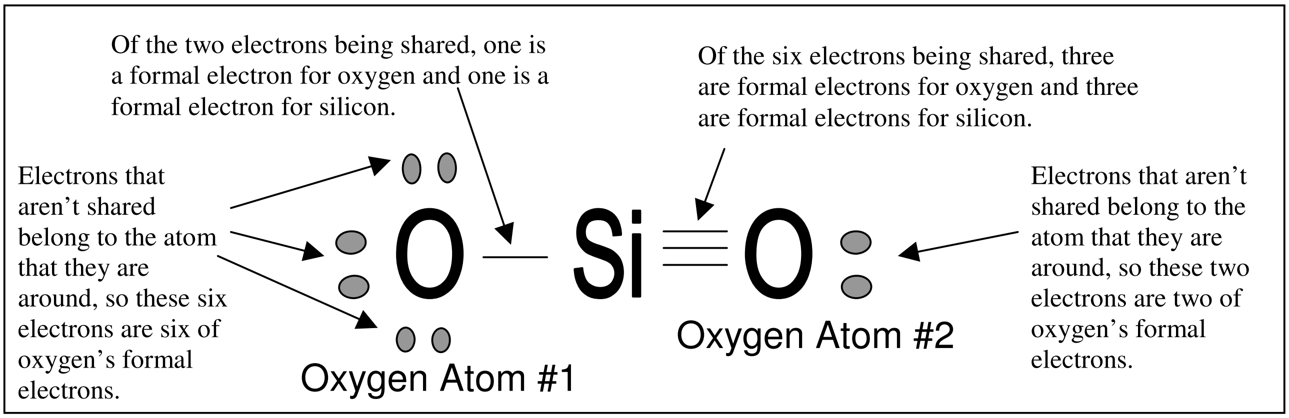
3. According to a large number of experiments, both of the silicon-oxygen bonds in SiO_2 are identical. Given this information, which Lewis structure, A or B, is a better description of the bonding in SiO_2. Explain.

Information: Formal Charges

When there are two structures that are possible for a compound, then scientists in a lab can determine which one is the correct one. Other than laboratory work, there is another way to determine which Lewis structure is correct—using “formal charges”.

Let’s examine Structure B for SiO_2. In the structure that was drawn, each atom has the eight electrons that they need. Let’s look at how many **formal electrons** each atom has. To understand “formal electrons” study the diagram of Structure B below:

Diagram #2:



You should see from the above diagram that the silicon atom has a total of four formal electrons, oxygen atom #1 has 7 formal electrons, and oxygen atom #2 has 5 formal electrons. Now we can calculate the **formal charge** of each atom.

Found from the column of the periodic table that the atom is in

Formal charge = (# of valence electrons) – (# of formal electrons)

Here are the formal charges for each of the atoms in structure B for SiO_2.

Si = 4 – 4 = 0 Oxygen atom #1: 6 – 7 = -1 Oxygen atom #2: 6 – 5 = 1

Critical Thinking Questions

4. Verify that the formal charge for each of the atoms is zero in Structure A from Diagram #1.

5. Consider questions 3 and 4. If two different structures are possible, does the best structure have the fewest or the most formal charges?

6. Draw a Lewis structure for the carbonate ion, CO_3^{2-}. On your drawing label the formal charge of each atom.

7. Add up all of the formal charges for all the atoms from question 6.

8. Draw the Lewis structure for the ammonium ion, NH_4^+ and label the formal charge of each atom.

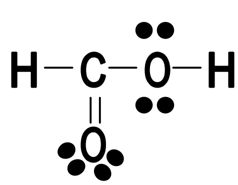
9. Add up all of the formal charges for the atoms from question 8.

10. Draw the Lewis structure for SO_3 and label the formal charge of each atom.

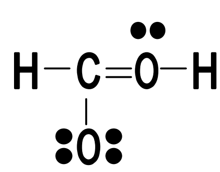
11. Add up all of the formal charges for the atoms from question 10.

12. Consider questions 6-11 and then fill in the blanks: The SUM of the formal charges for all the atoms in a structure always equals the _________ of the molecule or ion. For example, the charge on CO_3^{2-} is ________ and the sum of the formal charges (question 6) is ________.

13. Which of the following is the best structure for CH_2O_2? Explain your reasoning.



Structure #1



Structure #2

ChemQuest 26

Electronegativity

Name: ______________________________

Date: ________________

Hour: _____

Information: Definition of Electronegativity

Electronegativity is a measure of how much an atom attracts an electron. The higher the electronegativity, the greater the atom's attraction for electrons. Atoms that become negative ions have a much greater electronegativity than atoms that become positive ions. Below is a table of the electronegativities of many elements from the periodic table.

1 **H** 2.20								2 **He** —
3 **Li** 0.97	4 **Be** 1.47		5 **B** 2.01	6 **C** 2.50	7 **N** 3.07	8 **O** 3.50	9 **F** 4.10	10 **Ne** —
11 **Na** 1.01	12 **Mg** 1.23		13 **Al** 1.47	14 **Si** 1.74	15 **P** 2.06	16 **S** 2.44	17 **Cl** 2.83	18 **Ar** —
19 **K** 0.91	20 **Ca** 1.04		31 **Ga** 1.82	32 **Ge** 2.02	33 **As** 2.20	34 **Se** 2.48	35 **Br** 2.74	36 **Kr** —

Critical Thinking Questions

1. Why do you think there are no values for the noble gases?

2. In terms of electrons, what is the difference between a covalent bond and an ionic bond?

3. What type of bond (covalent or ionic) would you expect to form between an atom with a high electronegativity and an atom of low electronegativity. Explain and give an example.

4. What type of bond (covalent or ionic) would you expect to form between two atoms of somewhat high electronegativity? Explain and give an example.

5. Consider the ionic compound, sodium chloride (NaCl). Which atom has a greater attraction for electrons—sodium or chlorine? Which atom forms the negative ion?

6. In an ionic bond, the atom with the highest electronegativity will always form a

   _________________________ ion.
   (positive or negative)

7. Consider the covalent compound, carbon monoxide (CO).
   a) Draw the Lewis dot structure for carbon monoxide.

   b) In the Lewis structure you drew, you should see that there is a triple bond between carbon and oxygen. The carbon and oxygen share 6 electrons. All 6 electrons are not shared equally, however, because carbon and oxygen don't have equal attraction for electrons. The 6 electrons spend a little more time near one of the atoms—predict which one and explain.

8. Why are the electrons in a nitrogen-phosphorus covalent bond NOT shared equally? Which atom do the electrons spend more time around? Explain.

9. True or false: In an ionic bond, the difference in electronegativities between the two bonding atoms is greater than the difference in a covalent bond.

10. In terms of electronegativity, explain why this statement is true: "Carbon monoxide is more 'ionic' than carbon monosulfide".

11. Which bond is more like an ionic bond—a nitrogen-oxygen bond or a carbon-oxygen bond? Explain.

12. Which compound is more like an ionic compound—NH_3 or PH_3? Explain.

<u>**Information**</u>: "Polar" Bonds

In critical thinking questions 10, 11, and 12 we used the term "ionic" when describing covalent bonds. This can get confusing and so instead of the term "ionic" we will use the term "**polar**". A **polar covalent bond** then is a covalent bond in which the electrons are not shared equally by the two atoms involved in the bond. For example, in carbon monoxide the electrons spend more time near oxygen than carbon because oxygen has a greater electronegativity. Because of oxygen's greater electronegativity, it attracts the electrons more than carbon.

Critical Thinking Questions

13. Which bond is more polar—a phosphorus-chlorine bond or a phosphorus-fluorine bond? Explain why.

14. Consider a carbon-fluorine bond. One atom in the bond is "partially negative" and the other atom is "partially positive". Which atom is which? Explain how you know.

15. In your own words explain what you think the term "partially negative" means and explain why an atom might be partially negative when it bonds covalently. (I.e. What makes it partially negative?)

16. In your own words explain what you think the term "partially positive" means and explain why an atom might be partially positive when it bonds covalently. (What makes it partially positive?)

Information: Polar vs. Nonpolar

Not all covalent compounds are categorized as polar. For example, a carbon-hydrogen bond is made up of two atoms that have very similar electronegativities. Because of this, carbon and hydrogen share the electrons just about equally and we say that a carbon-hydrogen bond is "nonpolar". As a general measure, if the difference in electronegativity between two bonding atoms is less than about 0.5, then the bond is nonpolar.

Critical Thinking Questions

17. For the following bonds, indicate whether they are ionic (I), polar covalent (P), or nonpolar covalent (NP).

_____ a) C—P   _____ b) S—O   _____ c) Fe—O   _____ d) N—H

18. What are the three most electronegative atoms on the periodic table?

ChemQuest 27

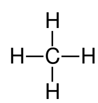
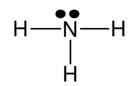
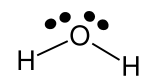
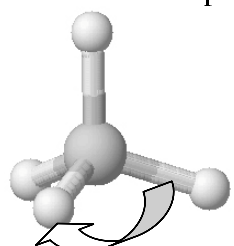
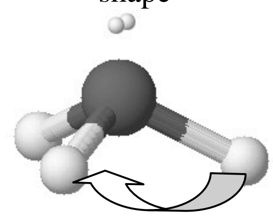
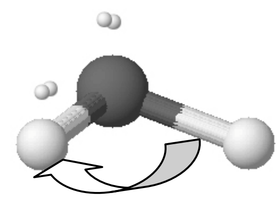
Molecular Geometry

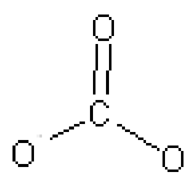
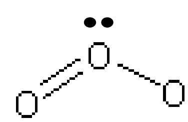
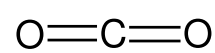
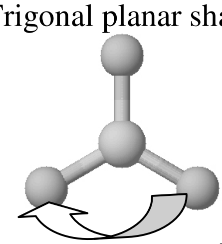
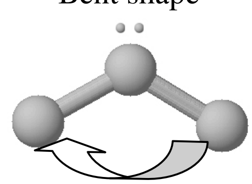
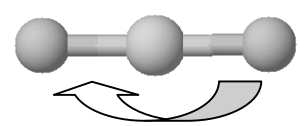
Name: ______________________

Date: ______________

Hour: _____

Information: Shapes of Molecules

Name	Methane, CH_4	Ammonia, NH_3	Water, H_2O
Lewis Structure			
3-D Shape	Tetrahedral shape  Bond angle =109.5°	Trigonal pyramidal shape  Bond angle =106.5°	Bent shape  Bond angle =104.5°
Total # of electron regions	4	4	4
# of Bonding electron regions	4	3	2
# of lone pair electron regions	0	1	2

Name	Carbonate, CO_3^{2-}	Ozone, O_3	Carbon dioxide, CO_2
Lewis Structure			
3-D Shape	Trigonal planar shape  Bond angle =120°	Bent shape  Bond angle =118.6°	Linear shape  Bond angle =180°
Total # of electron regions	3	3	2
# of bonding electron regions	3	2	2
# of lone pair electron regions	0	1	0

Critical Thinking Questions

1. What is an electron region?

2. What is a "lone pair electron region"?

3. What is a "bonding electron region"?

4. *The number of electron regions determines the bond angle.* With this in mind, complete the following sentence: "Any molecule that has bond angles of <u>approximately</u> 105-109^o will have

   ____________ total electron regions; any molecule that has bond angles of <u>approximately</u> 120^o
   how many?

   will have ___________ total electron regions; and any molecule with bond angles of
   how many?

   <u>approximately</u> 180^o will have ___________ total electron regions."
   how many?

5. The molecules in the above table are representative of many other molecules. Therefore, it can be said that any molecule with 3 bonding electron regions and 1 lone pair electron region has a geometrical shape called "trigonal pyramidal". Draw Lewis dot structures for the following structures and name the geometrical shape.
   A) NO_3^- B) NF_3 C) CF_4

6. A certain molecule has a bent shape with bond angles of about 119^o. Is the molecule SO_2 or SH_2? Explain. (Hint: draw the Lewis structures for SO_2 and SH_2.)

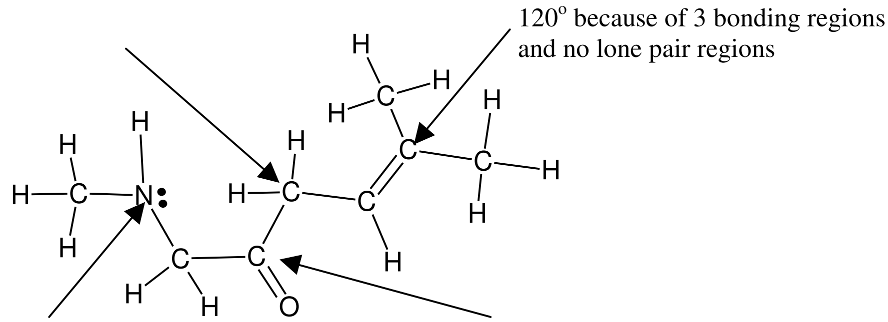
<u>Information</u>: VSEPR

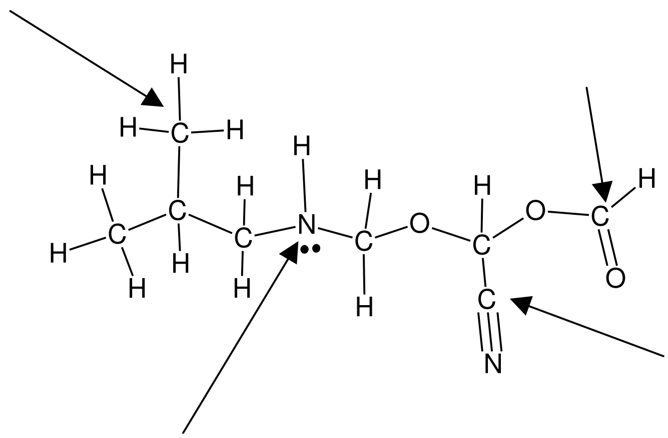
The geometry of molecules is based on a theory called "**V**alence **S**hell **E**lectron **P**air **R**epulsion" (VSEPR) theory. The word "repulsion" is the key word because this theory states that all the electron pairs repel each other and so they want to get as far away from each other as possible. The atoms in a tetrahedral molecule are as far apart as geometrically possible at bond angles of 109.5^o. There is no way that the atoms can get farther apart.

Critical Thinking Questions

7. In the tables above, there are 3 molecules that have a total of 4 electron regions. The bond angles are slightly different because of lone pair electrons. What takes up more room--a lone pair of electrons or a bonding pair of electrons? Offer proof from the table above.

8. If you know how many bonding regions and lone pair regions surround an atom you can predict the bond angles around the atom, even in complex situations. Examine the following "big" molecules. By each arrow that points to an atom, write the bond angle for that atom; you should write 109°, 120°, or 180° to represent the *approximate* bond angle. One of them is done for you.





ChemQuest 28

Chemical Reactions!

Name: ____________________________
Date: _______________
Hour: _____

Information: Introduction to Reactions

During a chemical reaction, new substances are formed. Reactants are transformed into different products. Atoms are never created or destroyed, but they are rearranged. A chemical equation represents what happens during a reaction. The following is an example of a chemical equation:

Example Equation: $Ca + HNO_3 \rightarrow Ca(NO_3)_2 + H_2$

This equation describes the reaction of calcium (Ca) with nitric acid (HNO_3) to produce calcium nitrate ($Ca(NO_3)_2$) and hydrogen gas (H_2). You may notice that there are more total atoms on the right side than there are on the left side of the equation. If this seems strange to you, don't worry about it now; we'll fix this later.

Note in the above equation that hydrogen gas is written as H_2 and not simply as H. There are a few elements that exist as diatomic molecules. If a substance is diatomic then the substance must always be bonded to something. A hydrogen atom is diatomic and so it must be bonded to something else like in HCl or HNO_3. If nothing is available for it to bond to, it will bond to itself by forming H_2. All of the diatomic substances are listed below:

Br I N Cl H O F

When by themselves these elements exist as Br_2, I_2, N_2, Cl_2, H_2, O_2, and F_2. By the way, you can remember these by recalling a made-up name: Mr. Brinclhof.

Critical Thinking Questions

1. Consider the bromine atoms in this reaction: $LiBr + P \rightarrow Li_3P + Br_2$.
   a) Why is bromine written as Br_2 on the right side?

   b) Why is it not necessary for LiBr to be written as $LiBr_2$?

2. What are the reactants in the example equation in the above information section?

3. Answer the questions that follow based on this chemical equation: $Na + MgCl_2 \rightarrow NaCl + Mg$.
   a) Why can't NaMg be produced?

   b) Why can't $NaCl_2$ be produced?

   c) Are NaCl and Mg the only products that can be produced?

4. Given the following equation: $Li + Ca_3(PO_4)_2 \rightarrow Li_3PO_4 + Ca$.
   a) Why can't $CaLi_2$ be produced?

   b) Why can't Li_3P be produced?

   c) Are Li_3PO_4 and Ca the only substances that can be produced?

5. Write chemical equations for the following reactions.
   a) Aluminum sulfate reacts with barium to produce barium sulfate and aluminum.

   b) Magnesium reacts with copper(I) nitrate to produce magnesium nitrate and copper.

   c) Sodium reacts with calcium phosphide to produce sodium phosphide and calcium.

   d) Phosphorus reacts with sodium chloride to produce sodium phosphide and chlorine.

6. Each of the reactions you wrote in question 5 follows a similar pattern. The same pattern is followed by the equations in questions 3 and 4. Describe this pattern.

7. a) How are reactions 5c and 5d different?

   b) How are reactions 5c and 5d similar?

8. Complete the following reactions:

   a) $NaCl + Ag \rightarrow$

   b) $Li + Ca_3(PO_4)_2 \rightarrow$

Information: Single and Double Replacement Reactions

Each of the equations that you looked at in the above section is called a single replacement reaction. Notice that in each of them, a single atom replaces an ion from another reactant. Study what happens in the following reactions. They are called double replacement reactions.

$$MgCl_2 + NaF \rightarrow NaCl + MgF_2$$
$$Al_2S_3 + Na_2O \rightarrow Al_2O_3 + Na_2S$$
$$Ca(NO_3)_2 + Na_3P \rightarrow NaNO_3 + Ca_3P_2$$

Critical Thinking Questions

9. What is the difference between single replacement reactions and double replacement reactions?

10. Complete the following reactions by providing the formulas for the missing compound(s).

    a) $Cu(NO_3)_2$ + ____________________ $\rightarrow NaNO_3 + CuCl_2$

    b) ZnI_2 + ____________________ $\rightarrow ZnSO_4 + AlI_3$

    c) $K_2O + MgBr_2 \rightarrow$ __________________ + _________________

11. Name the two products in the reaction between calcium phosphate and sodium iodide.

12. Explain why when you mix the following reactants, no reaction occurs: $Na_2SO_4 + NaCl \rightarrow$

Information: Combustion, Synthesis, and Decomposition Reactions

Another type of reaction is a combustion reaction. During combustion, a hydrocarbon reacts with oxygen. The products for complete combustion are always the same—water and carbon dioxide and energy. The following equation is an example of the combustion of a hydrocarbon.

$$C_3H_8 + O_2 \rightarrow CO_2 + H_2O$$

Two other types of reactions are synthesis and decomposition. During a synthesis reaction, several reactants combine to make a single product. During a decomposition, one reactant *decomposes* into two or more products. The following table shows some examples of these types of reactions.

Synthesis	Decomposition
$H_2 + O_2 \rightarrow H_2O$	$H_2O \rightarrow H_2 + O_2$
$Na + Cl_2 \rightarrow NaCl$	$NaCl \rightarrow Na + Cl_2$

Critical Thinking Questions

13. Categorize each of the following reactions as single replacement (SR), double replacement (DR), synthesis (S), decomposition (D) or combustion (C).

_____ a) $Ca + O_2 \rightarrow CaO$

_____ b) $Mg(NO_3)_2 + Cu \rightarrow CuNO_3 + Mg$

_____ c) $C_4H_{10} + O_2 \rightarrow CO_2 + H_2O$

_____ d) $Al_2O_3 \rightarrow Al + O_2$

_____ e) $SrCl_2 + F_2 \rightarrow SrF_2 + Cl_2$

_____ f) $BaF_2 + Na_2O \rightarrow BaO + NaF$

14. Write an equation for the combustion of C_3H_6.

15. Write an equation for the decomposition of calcium oxide.

Practice Problems

1. Complete the following reactions.

a) $Na_2CO_3 + AlN \rightarrow$

b) $BaCl_2 + F_2 \rightarrow$

c) $CuNO_3 + Ag \rightarrow$

2. Fill in the blanks for the missing reactant or product and then in the blank to the left of each equation indicate whether the reaction is a single replacement (SR), double replacement (DR), synthesis (S), decomposition (D) or combustion (C).

_____ a) $LiCl +$ ____________ $\rightarrow ZnCl_2 + LiNO_3$

_____ b) ____________ $+ CaBr_2 \rightarrow NaBr + Ca$

_____ c) $K + Cl_2 \rightarrow$ ______________

ChemQuest 29

Balancing Equations

Name: ____________________________

Date: _______________

Hour: _____

Introduction Questions

1. Write the equation for the reaction of sodium and chlorine (diatomic) to form sodium chloride.

2. Write the equation for the reaction of calcium nitride and sodium chloride to produce calcium chloride and sodium nitride.

Information: Subscripts and Coefficients

A subscript is a small number that tells you how many atoms are in a compound. For example, in $CaCl_2$ the two is the subscript and it tells us that there are two chloride ions bonded to one calcium.

A coefficient tells also tells us how many atoms or compounds there are, but in a different way. For example in the expression "3 H_2O" the three is the coefficient. The three tells us that there are three molecules of water present. In the expression "3 H_2O" there are a total of 6 hydrogen atoms and 3 oxygen atoms.

Critical Thinking Questions

3. Verify that in $4Ca_3(PO_4)_2$ there are 32 oxygen atoms present.

4. How many oxygen atoms are in each of the following:

_____ a) Al_2O_3 _____ b) 3 Na_2O _____ c) 4 Na_2SO_4 _____ d) 5 $Mg(NO_3)_2$

Information: How To Balance Equations

Consider the reaction of sodium and chlorine to produce sodium chloride from question one:

$$Na + Cl_2 \rightarrow NaCl$$

Remember that when chlorine is by itself it is always written as Cl_2. On the reactant side of the reaction (left side) there are a total of two atoms of chlorine, but on the product side there is only one atom of chlorine. Atoms cannot simply disappear. In order for the equation to make sense, we need to balance the equation. This can be done, first, by adding a "2" to the product side:

$$Na + Cl_2 \rightarrow 2\ NaCl$$

Now the equation reads that one atom of Na reacts with one molecule of Cl_2 to produce two units of NaCl. However, now the Na atoms are not balanced because there is one atom of the reactant side, but two atoms of Na on the product side. This can be fixed by adding another two:

$$2\ Na + Cl_2 \rightarrow 2\ NaCl$$

Let us consider another example, the equation you wrote in question two above:

$$Ca_3N_2 + NaCl \rightarrow CaCl_2 + Na_3N$$

Notice that none of the atoms are "balanced". There are three calcium atoms on one side and only one on the other. There are two nitrogen atoms on one side and one on the other. How can we fix this? Begin by "balancing" one atom at a time:

1. First, let's balance the calcium atoms by placing a three in front of $CaCl_2$:
$$Ca_3N_2 + NaCl \rightarrow 3\ CaCl_2 + Na_3N$$
2. Next, let's balance the nitrogen atoms, by placing a 2 in front of Na_3N:
$$Ca_3N_2 + NaCl \rightarrow 3\ CaCl_2 + 2\ Na_3N$$
3. Now we will balance the sodium atoms by placing a 6 in front of NaCl.
$$Ca_3N_2 + 6\ NaCl \rightarrow 3\ CaCl_2 + 2\ Na_3N$$
4. Finally, examine the chlorine atoms and notice that they are already balanced.
5. Double check each atom to make sure there are equal numbers of each on both sides of the equation.

When balancing equations you NEVER change subscripts. Only change the coefficients.

Critical Thinking Questions

5. Which of the following equations are properly and completely balanced? (Circle as many as apply.)
   A) $2\ NaCl + Cu \rightarrow CuCl_2 + Na$
   B) $C_3H_8 + 3\ O_2 \rightarrow 3\ CO_2 + H_2O$
   C) $MgCl_2 + F_2 \rightarrow MgF_2 + Cl_2$
   D) $FeCl_2 + O_2 \rightarrow 2\ FeO + Cl_2$

6. Balance each of the following equations by inserting the correct coefficient in each blank. Remember to balance one atom at a time. If the number "one" belongs in the blank you may either leave it blank or insert the number one.

   A) _____ $CaCl_2$ + _____ Li_2O → _____ CaO + _____ $LiCl$

   B) _____ Al_2S_3 + _____ Cu → _____ CuS + _____ Al

   C) _____ Na_3P + _____ $MgBr_2$ → _____ Mg_3P_2 + _____ $NaBr$

7. Here are the answers to question 6. Double check your answers to question 6:
   A) $CaCl_2 + Li_2O \rightarrow CaO + 2\ LiCl$
   B) $Al_2S_3 + 3\ Cu \rightarrow 3\ CuS + 2\ Al$
   C) $2\ Na_3P + 3\ MgBr_2 \rightarrow Mg_3P_2 + 6\ NaBr$

Information: Balancing Equations Containing Polyatomic Ions

When an equation contains polyatomic ions, it may look a little more difficult to balance. But balancing an equation containing polyatomic ions is really not much different from the ones you just did. In the equations above, you kept in mind that you must balance only one atom at a time. With polyatomic ions, keep in mind that you balance *one polyatomic ion* at a time. For example, consider the following unbalanced equation.

$$Na_2SO_4 + Ca_3(PO_4)_2 \rightarrow Na_3PO_4 + CaSO_4$$

The first thing you should do is take note of which atoms/ions are not balanced. Keep the polyatomic ions together. In other words, do not balance the phosphorus and oxygen atoms separately; instead, balance the phosphate ions on each side of the reaction. Follow these steps:

1. Balance the sodium so that there are 6 sodium atoms on each side of the reaction:
$$3\ Na_2SO_4 + Ca_3(PO_4)_2 \rightarrow 2\ Na_3PO_4 + CaSO_4$$

2. Now there are three sulfate ions on the left and one on the right. Add a three to the right.
$$3\ Na_2SO_4 + Ca_3(PO_4)_2 \rightarrow 2\ Na_3PO_4 + 3\ CaSO_4$$

3. Take inventory of all the atoms and ions to make sure they are balanced. The equation is now balanced.

Critical Thinking Questions

8. Which of the following equations are properly balanced?
   A) $Ba(NO_3)_2 + Fe_2SO_4 \rightarrow 2\ FeNO_3 + BaSO_4$
   B) $3\ SrCl_2 + Al(NO_3)_3 \rightarrow 3\ Sr(NO_3)_2 + AlCl_3$
   C) $Ca_3(PO_4)_2 + 3\ Na_2CO_3 \rightarrow 2\ Na_3PO_4 + 3\ CaCO_3$
   D) $Fe(NO_3)_2 + Mg \rightarrow Mg(NO_3)_2 + Fe$

9. Balance each of the following equations by inserting the correct coefficient in each blank. Remember to balance one atom/ion at a time. If the number "one" belongs in the blank you may either leave it blank or insert the number one.

   A) _____ $Ca(NO_3)_2$ + _____ $Na \rightarrow$ _____ $NaNO_3$ + _____ Ca

   B) _____ $Al_2(CO_3)_3$ + _____ $MgCl_2 \rightarrow$ _____ $AlCl_3$ + _____ $MgCO_3$

   C) _____ $Ba_3(PO_4)_2$ + _____ $Na_2CO_3 \rightarrow$ _____ Na_3PO_4 + _____ $BaCO_3$

10. Make sure you got the following answers for question 9:
    - A) $Ca(NO_3)_2$ + 2 Na → 2 $NaNO_3$ + Ca
    - B) $Al_2(CO_3)_3$ + 3 $MgCl_2$ → 2 $AlCl_3$ + 3 $MgCO_3$
    - C) $Ba_3(PO_4)_2$ + 3 Na_2CO_3 → 2 Na_3PO_4 + 3 $BaCO_3$

11. Complete and balance the following equations.

    A) HCl + Mg →

    B) Na_2S + $Be(OH)_2$ →

    C) BaF_2 + $NaNO_3$ →

    D) $Ca_3(PO_4)_2$ + K_2SO_4 →

    E) $Zn(NO_3)_2$ + Mg →

    F) $Ca(NO_3)_2$ + $Al_2(CO_3)_3$ →

ChemQuest 30

Intro to Moles

Name: ____________________________

Date: _______________

Hour: _____

Information: Atomic Mass Using Atomic Mass Units (amu) and Grams (g)

One atomic mass unit (amu) is equal to 1.6611×10^{-24} grams.

Critical Thinking Questions

1. According to the periodic table, a single carbon atom has a mass of 12.011 amu. What is the mass of a single carbon atom in grams?

2. How many carbon atoms does it take to equal 12.011 grams?

3. According to the periodic table, a single phosphorus atom has a mass of 30.973 amu. What is the mass of a single phosphorus atom in grams?

4. How many phosphorus atoms does it take to equal 30.973 grams?

5. Compare your answers to questions 2 and 4.

Information: What is a Mole?

Hopefully, you found that your answers to questions 2 and 4 were about the same. Both answers should be about 6.02×10^{23}. The quantity, 6.02×10^{23} is Avogadro's constant and we call it the "mole". Just like the quantity "12" is called a "dozen", so the quantity 6.02×10^{23} is called a "mole".

By definition, a mole is the quantity of atoms necessary to equal the element's atomic mass in grams. So, according to the periodic table, one atom of sodium has an atomic mass of about 22.99 amu. If you weighed out 22.99 grams on a balance, you would have 6.02×10^{23} atoms of sodium present.

Look at your periodic table and find gold (atomic number = 79). What is the mass of one gold atom? You should note that one gold atom has a mass of 196.97 amu. How many gold atoms would you need to get 196.97 grams? You would need to put 6.02×10^{23} atoms of gold on the balance before you would have 196.97 grams of gold. One mole of an atom will always equal the atom's atomic mass in grams.

Critical Thinking Questions

6. What is the mass of one atom of aluminum? (include units)

7. If you had 6.02×10^{23} atoms of aluminum, what mass of aluminum would you have? (include units)

8. What is atomic mass?

9. If you had one mole of pennies, how many pennies would you have?

10. If you had 3 moles of sand, how many grains of sand would you have?

Information: Molecular Mass (also known as Formula Mass) and Molar Mass

Just as atomic mass is the mass of an atom, molecular mass is that mass of a molecule. It is found by adding up all of the masses of the atoms in the molecule. Because ionic compounds are not properly called molecules, the term formula mass is used in place of molecular mass for ionic compounds. Consider the following examples:

1. The atomic mass of hydrogen 1.0 amu and the atomic mass of oxygen is 16.0 amu. One molecule of water (H_2O) has a molecular mass of 18.0 amu. This number is obtained by adding the masses of two hydrogens (each at 1.0 amu) and the mass of one oxygen (16.0 amu).
2. Aluminum chloride ($AlCl_3$) has a formula mass of about 133.5 amu. This is found by adding the mass of one aluminum atom (27.0 amu) to the mass of three chlorine atoms (3 x 35.5 amu). Verify this on your calculator.

Just as one mole of atoms equals the atomic mass of an atom in grams, so also one mole of molecules equals the molar mass of the molecule in grams. Molar mass is the mass (in grams per mole) of one mole of a substance. Therefore we expect that 6.02×10^{23} molecules of water will have a mass of 18.0 g and 6.02×10^{23} formula units of $AlCl_3$ will have a mass of 133.5 g. We say, then, that the molar mass of water is 18.0 g/mol and the molar mass of $AlCl_3$ is 133.5 g/mol. (g/mol is read grams per mole where mol is the abbreviation for mole.)

Critical Thinking Questions

11. Verify using a periodic table and calculator that the molecular mass of N_2O_5 is approximately 108 amu.

12. How many molecules of N_2O_5 are required to equal 108 grams?

13. Why is the term "molecular mass" applied to water, but the term "formula mass" applied to aluminum chloride?

14. Find the molecular or formula mass for each of the following (include units):
 a) magnesium phosphide
 b) sodium sulfate
 c) $Ca(NO_3)_2$
 d) C_4H_8

15. Find the molar mass of each of the following (include units):
 a) $CaCl_2$
 b) barium nitrate

16. What is the difference between the terms molecular mass and molar mass.

Information: Beginning Mole Conversions

The mole (often abbreviated as mol) is the link between the microscopic (atoms and molecules) and the macroscopic (things measured in grams). If you know how many grams of a substance you have and you know the molar mass, you can find out how many molecules you have. Two examples of how to do this using a method similar to converting units is shown below:

1. How many atoms of carbon does it take to equal 23.5 g?

$$23.5g \bullet \frac{1mol}{12.0g} \bullet \frac{6.02x10^{23}\ atoms}{mol} = 1.18x10^{24} \text{atoms}$$

molar mass of carbon, from the periodic table

2. How many molecules of carbon monoxide gas does it take to equal 50.0 g?

$$50.0\text{g} \bullet \frac{\text{mol}}{28.0\text{g}} \bullet \frac{6.02\text{x}10^{23}\text{ molecules}}{\text{mol}} = 1.08\text{x}10^{24}\text{ molecules}$$

molar mass of carbon monoxide found by adding molar mass of C and of O

Critical Thinking Questions

17. Using your calculator, verify that if you have 125 g of gold, you have about 3.82×10^{23} atoms of gold. Show the calculations below.

18. Consider 210 g of N_2O_5. How many molecules are present?

19. If you exhale 7.25×10^{24} molecules of CO_2…
    a) How many moles of CO_2 do you exhale? (Hint: use the conversion factor that one mole = 6.02×10^{23} molecules)

    b) How many grams of CO_2 do you exhale? (Hint: find how many grams are in a mole by finding the molar mass of CO_2. Use this as a conversion factor.)

20. In a bag full of pennies, you may have 2.15 moles of copper. How many grams do you have?

ChemQuest 31

Using Moles with Formulas

Name: ______________________________

Date: ________________

Hour: _____

Information: Percent Composition

Sometimes it is needful to know the composition of a compound. For example, 39.3% of the mass of sodium chloride is due to sodium. The other 60.7% of the mass is from chlorine. So, in a 100 g sample of sodium chloride, there are 39.3 g of sodium and 60.7 g of chlorine. This type of data is known as percent composition. The percent composition tells you the percentage by mass of an element in a compound. There is a convenient formula for finding the percent composition of an element in a compound:

(obtained from periodic table)

$$\text{percent composition of element "X"} = \frac{\text{mass of x in one mole of the compound}}{\text{mass of one mole of the compound}} \bullet 100$$

(obtained from periodic table)

Let us look at how the percent composition of calcium (Ca) in calcium chloride ($CaCl_2$) was determined.

$$\text{percent composition of Ca} = \frac{\text{mass of Ca in one mole of } CaCl_2}{\text{mass of one mole of } CaCl_2} \bullet 100$$

$$\text{percent composition of Ca} = \frac{40.1\text{ g}}{111.1\text{ g}} \bullet 100 = 36.1\%$$

from periodic table for calcium

from periodic table for calcium + 2 chlorines;
40.1 + 2(35.5) = 111.1

As another example, consider calculating the percent composition of nitrogen in Ca_3N_2:

From periodic table for 2 nitrogen atoms: 2(14.0)=28.0

$$\text{percent composition of N} = \frac{28.0\text{ g}}{148.3\text{ g}} \bullet 100 = 18.9\%$$

from periodic table for 3 calcium + 2 nitrogen atoms
3(40.1) + 2(14.0) = 148.3

Critical Thinking Questions

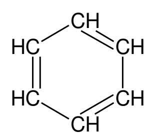
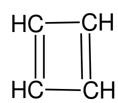
Note: For the following questions use 12.0 g/mol for the molar mass of carbon and 1.01 g/mol for the molar mass of hydrogen. These values can be found on the periodic table.

1. Verify that in C_4H_{10} the percent composition of carbon is approximately 82.6%.

2. Calculate the percent composition of sodium in Na_2S.

Information: Formulas and Percent Composition

Table 1: Percent composition and formulas of some compounds.

Name	Structural Formula	Molecular Formula	% Comp. of H	% Comp. of C
Hexene	$H_2C{=}CH{-}CH_2{-}CH_2{-}CH_2{-}CH_3$	C_6H_{12}	14.4	85.6
Propene	$H_2C{=}CH{-}CH_3$			
Benzene		C_6H_6		
Cyclobutadiene			7.8	
1,5-hexadi-yne	$HC{\equiv}C{-}CH_2{-}CH_2{-}C{\equiv}CH$			

Critical Thinking Questions

3. Verify that the percent composition of C and H given for hexene in Table 1 are correct.

4. Fill in the blanks in Table 1 by determining the percent composition and the molecular formulas of each compound.

5. Can you determine a compound's structural formula if you are given the molecular formula? Explain.

6. What is true about the percent composition of two different compounds that each have the same ratio of carbon to hydrogen?

7. Can you determine a molecule's molecular formula solely from the percent composition? Explain.

8. It is possible to complete the following table using only the information in Table 1 without the aid of a calculator or periodic table. Try it! (Hint: consider question #6.)

Molecular Formula	% Composition of H	% Composition of C
C_8H_8		
$C_{10}H_{20}$		

Information: Empirical Formulas

An empirical formula is a formula that describes the lowest whole-number ratio of elements in a compound. An example of an empirical formula is CH, which is the empirical formula for benzene whose molecular formula was given in Table 1.

Critical Thinking Questions

9. What is the empirical formula of a compound whose percent composition is 92.2% carbon and 7.8% hydrogen? (See question 8 and Table 1)

10. Verify that the empirical formula for hexene (see Table 1) is CH_2.

Information: Calculating the Empirical Formula

When you know the percent composition of each element in a compound, you can calculate the empirical formula of that compound. The following example will illustrate how to do this.

Example 1: A certain compound is 30.4% nitrogen and 69.6% oxygen by mass. What is the empirical formula of the compound?

Step #1: Divide each percentage by the molar mass from the periodic table:

For Nitrogen: $\frac{30.4}{14.0} = 2.17$ For Oxygen: $\frac{69.6}{16.0} = 4.35$

From the periodic table for nitrogen and oxygen

Step #2: Find the ratio of nitrogen to oxygen. To do this, find the smallest answer obtained in step #1. In this example, the smallest answer is 2.17. Now divide each of your answers to step #1 by this smallest number. In this example, you should divide each answer by 2.17:

For Nitrogen: $\frac{2.17}{2.17} = 1.00$ For Oxygen: $\frac{4.35}{2.17} = 2.00$

Step #3: Write the formula. The answers from step #2 are the subscripts in the formula! The formula is NO_2.

If in step #2 you get something like Nitrogen = 1.00 and Oxygen = 2.50 then the formula you write in step #3 would be $NO_{2.5}$. This doesn't make sense because all subscripts must be whole numbers. You would need to double *each* subscript. The formula would be $N_{1x2}O_{2.5x2}$ = $\mathbf{N_2O_5}$.

Critical Thinking Questions

11. Find the empirical formula for a compound that contains 82.4% nitrogen and 17.6% hydrogen.

Information: Calculating the Molecular Formula from the Empirical Formula

Remember that the empirical formula is just a simplification of the molecular formula. For example, consider the empirical formula NO. There are several possible molecular formulas including: N_2O_2, N_3O_3, N_4O_4, etc. Which one is it? Notice that the possible formula N_2O_2 is made up of two of the empirical formulas, NO. Similarly, N_3O_3 is made up of three of the empirical formulas, NO. How do we know which empirical formula is correct? All you need is the molar mass or molecular mass of the molecular formula.

Critical Thinking Questions

12. The empirical formula for a certain compound is NO. The molar mass of the compound is 60.0 g/mol.
    a) What is the molar mass of the empirical formula? (Use the periodic table.)

    b) Divide the molar mass of the compound (given in the question) by the molar mass of the empirical formula found in part a.

    c) Your answer to part b tells you how many empirical formulas are in the molecular formula. You now should be able to write the correct molecular formula, which is N_2O_2. Verify that the correct molecular formula is N_2O_2.

13. a) What is the empirical formula of a compound whose percent composition by mass is 85.7% carbon and 14.3% hydrogen?

    b) If the compound has a molar mass of 56 g/mol, what is the molecular formula? (Follow the steps from question 12abc.)

ChemQuest 32

Moles and Reactions

Name: ____________________________

Date: _______________

Hour: _____

Information: Mole Ratios in Equations

Propane is burned in many rural homes for heat in the winter. Below is the balanced equation for the combustion of propane (C_3H_8).

$$C_3H_8 + 5\ O_2 \rightarrow 3\ CO_2 + 4\ H_2O$$

For each molecule of propane that is burned, there needs to be five molecules of oxygen present. Likewise, if there were a dozen molecules of propane, five dozen molecules of oxygen would be required. Similarly, for each **mole** of propane, five **moles** of oxygen are needed. Also, for each mole of propane burned three moles of carbon dioxide and 4 moles of water are produced. **The numbers of moles of each substance in a chemical equation are related by the ratio of the coefficients of each substance.**

Critical Thinking Questions

Note: For questions 1-6, refer to the balanced equation for the combustion of propane.

1. a) How many moles of water are produced when 1.45 moles of propane are combusted?

   b) How many molecules of water is this? (Remember each mole has 6.02×10^{23} molecules.)

2. If 2.35 moles of CO_2 are produced in a reaction, how many moles of H_2O would be produced?

3. Why is this statement false: “If 10 grams of propane burn, you need 50 grams of oxygen.”

4. a) If 27.3 moles of carbon dioxide are produced during the combustion of a certain amount of propane, how many moles of propane were combusted?

   b) How many grams of propane was this?

5. If you have 410 grams of propane and want to know how many grams of oxygen are required to burn it, you can follow these steps…
   a) Find the number of moles of propane that you have. Convert grams to moles!

   b) The moles of propane are related to the moles of oxygen by the ratio of coefficients in the balanced chemical equation. Find the number of moles of oxygen you need given the moles of propane from part a.

   c) Find the grams of oxygen from the moles of oxygen. Convert the moles of oxygen (answer to part b) to grams of oxygen (O_2)! (Note: use the molar mass for O_2, not just O. You should get approximately 1490 g of oxygen.)

6. Verify that this statement is correct: If 315 grams of propane combusts, then approximately 515 grams of water are produced.

7. Consider the decomposition of ammonia: $2\ NH_3 \rightarrow 3\ H_2 + N_2$. If you start with 425 g of NH_3, how many grams of H_2 and N_2 can be produced?

ChemQuest 33

Limiting Reactants

Name: ___________________________
Date: _______________
Hour: _____

Information: Limiting Reactant

Again consider the combustion of propane: $C_3H_8 + 5\ O_2 \rightarrow 3\ CO_2 + 4\ H_2O$. If you had 10 moles of propane to burn, you would need 50 moles of oxygen according to the ratio in the balanced equation. If you only had 20 moles of oxygen you could not combust all 10 moles of propane. The reaction has been **limited** by the amount of oxygen you have—you don't have enough oxygen to burn all of the propane. In this case, oxygen is called the "limiting reactant" because it limits how much propane can react. Notice that the limiting reactant isn't always the substance that is present in the fewest number of moles. In this example, propane (C_3H_8) is the "excess reactant" because after the reaction there will be some of it left over. It is important to remember that everything in a chemical equation is related by mole ratios. If you only know the mass (grams) of the substances, you need to convert to moles.

Critical Thinking Questions

8. a) In the above discussion, it was evident that 20 moles of oxygen was not sufficient to combust 10 moles of propane. How many moles of the propane can be combusted with 20 moles of oxygen?

   b) How many moles of carbon dioxide will be produced? (Base the answer to this question on the number of moles of propane that actually get combusted—which is your answer to part a.)

   c) Verify that if 12.5 moles of propane and 63.2 moles of oxygen were present, then propane is the "limiting reactant" and oxygen is the excess reactant.

9. Consider the following chemical reaction: $3\ MgCl_2 + 2\ Na_3PO_4 \rightarrow 6\ NaCl + Mg_3(PO_4)_2$. Assume that 0.75 mol of $MgCl_2$ and 0.65 mol of Na_3PO_4 are placed in a reaction vessel.
   a) Verify that Na_3PO_4 is the excess reactant and $MgCl_2$ is the limiting reactant.

   b) How many moles of the excess reactant are left over after the reaction stops?

   c) How many moles of NaCl will be produced in this reaction? (Remember—you must base this answer on how many moles of the <u>limiting</u> reactant that reacted.)

10. Consider the double replacement reaction between calcium sulfate ($CaSO_4$) and sodium iodide (NaI). If 34.7 g of calcium sulfate and 58.3 g of sodium iodide are placed in a reaction vessel, how many grams of each product are produced? (Hint: Do this problem in the steps outlined below.)
   a) Write the <u>balanced</u> chemical equation for the reaction.

   b) Find the limiting reactant. First, convert 34.7g and 58.3g from grams to moles using the molar masses from the periodic table. Next, compare the number of moles of each reactant. Ask yourself: Do I have enough NaI to use up all of the $CaSO_4$? Do I have enough $CaSO_4$ to use up all of the NaI? Whichever one will get used up is the limiting reactant.

   c) Use the number of moles of the limiting reactant to calculate the number of moles of each product produced using the coefficients from the balanced chemical equation in part a.

   d) In part c you found the moles of each product produced. Now convert moles to grams using the molar mass from the periodic table. You have now answered the question.

11. If 181.1g of $Al(NO_3)_3$ react with 102.1g of CaO in a double replacement reaction, how many grams of each product will be produced? (Note: this is just like the last question, but parts a-d are not spelled out for you.)

ChemQuest 34

Percent Yield

Name: ____________________
Date: ____________
Hour: _____

Information: Sources of Error in the Real World

When we perform experiments in the laboratory we never get all of the product we theoretically could get. Reactions in the laboratory are not ideal. For example, consider the reaction of sodium metal and chlorine gas to produce salt:

$$2\ Na + Cl_2 \rightarrow 2\ NaCl$$

If we react 23.0g of sodium metal with plenty of chlorine gas, calculations tell us that we should get about 58.5g of sodium chloride. However, if you tried this in the lab and then took the mass of your final product on a balance, you would usually get somewhat less than 58.5g. The more careful you are, the closer you can get to the mark of 58.5g, but you will never be able to make 58.5g of sodium chloride.

Critical Thinking Questions

1. What are some practical things—some "sources of error"—that can happen in the lab and in a reaction that would cause us to get less than 100% of the product that we are trying to produce?

2. The information section above made it sound like we always would get less than 58.5 g of salt. However, it is possible that after the reaction we could take the mass of the product and find that it is greater than 58.5g. According to our calculations this should be impossible, but what "sources of error" may cause this?

3. When 40.5 g of sodium metal reacts with plenty of chlorine gas, how many grams of sodium chloride should be produced?

Information: Calculating Percent Yield

Percent yield is a measure of how much of a product you actually obtained in a reaction compared to the amount that you *could have* obtained according to calculations. There is a handy formula for calculating percent yield:

$$\text{percent yield} = \frac{\text{actual yield}}{\text{theoretical yield}} \bullet 100$$

"Theoretical yield" is the amount of a product that we should be able to make. You calculated the theoretical yield of sodium chloride in question 3; hopefully your answer was about 103g. Now let's say that you actually attempted this experiment in a lab with 40.5g of sodium and when you were finished you collected 84.0g of sodium chloride—this amount is your "actual yield", the amount of product you actually collected in the lab.

Using the formula given above, we can calculate our percent yield:

$$\text{percent yield} = \frac{84.0\text{g}}{103\text{g}} \bullet 100 = 81.6\%$$

Critical Thinking Questions

4. Consider the combustion of 215.0g of butane, C_4H_{10} with plenty of oxygen. If you are able to collect 295.3g of water in the laboratory, what was your percent yield. Hint: first calculate your theoretical yield using the balanced equation and mole ratios!

5. Consider the double replacement reaction of excess sodium chloride with 203.9g of silver nitrate. If you are able to produce 150.4g of silver chloride what was your percent yield?

6. If you make 46.8g of calcium carbonate by reacting 87.5g of calcium nitrate with plenty of sodium carbonate, what is your percent yield?

ChemQuest 35

Intro. to Gases

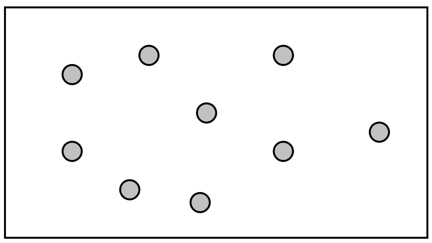
Name: ______________________

Date: ____________

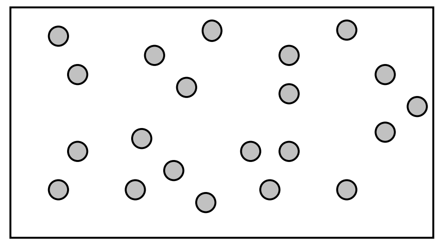
Hour: _____

Information: Gas Pressure

Figure 1: Two containers of gas molecules



Container 1



Container 2

Gas molecules move randomly in their containers, colliding with the walls of their containers causing "gas pressure." Pressure can be defined as the force pushing on an area. It can be described with the equation:

$$P = \frac{F}{A}$$ where P is pressure (in kPa), F is force (in N) and A is area (in m^2).

The more molecules collide with the wall and the faster the molecules are going when they strike the wall, the greater the force on the wall and therefore, the higher the pressure.

Critical Thinking Questions

1. Use the pressure equation to explain why it would be more likely for an ice skater to fall through the ice on a lake than it would be for someone walking across the lake with regular shoes on.

2. Which container in Figure 1 has the highest pressure? Explain.

3. If I heated container 1 and did not heat container 2, could I get the pressure in container 1 to equal container 2? Explain.

4. If container 2 was made of an elastic material and if I expanded container 2, could I make the two containers have equal gas pressures? Explain.

Information: Gas Laws

Observe the following experimental data concerning a container of gas. The pressure, volume and temperature of a gas are all related. The table of data was obtained by making measurements of the pressure, volume and temperature of a sample of a gas. Several different kinds of gases were used and all had identical results. The variable that was not changed was the amount of gas present. The number of moles of gas always remained the same during these trials.

Table 1: Experimental Data for Gases

Trial	**Pressure (P)** Units: kPa	**Volume (V)** Units: L	**Temperature (T)** Units: K
A	120	3.2	324.3
B	135	2.5	285.0
C	195	2.3	378.7
D	150	2.0	254.4
E	135	4.2	480.8
F	100	3.0	254.4
G	225	3.2	608.0
H	262	2.8	620.4

Critical Thinking Questions

5. Verify that this equation is true when the volume is unchanged: $\frac{P_1}{T_1} = \frac{P_2}{T_2}$
   (Hint: You must use two sets of data where the volume does not change like in trials A and G. Note: the subscript 1 refers to the pressure and temperature for the first trial you select and the subscript 2 refers to the pressure and temperature for the second trial you select.)

6. Scientists often look for relationships between variables. If you wanted to see how the volume and pressure are related you would need to compare data from different trials when the temperature does not change. Why?

7. Find two sets of data in the table that have constant temperature. Which of the following mathematical relationships is true (there may be more than one) when the temperature remains unchanged? This relationship is known as "Boyle's Law", named after the person who first discovered it.
   a) $\frac{P_1}{V_1} = \frac{P_2}{V_2}$ b) $(P_1)(V_1) = (P_2)(V_2)$ c) $P_1 + V_1 = P_2 + V_2$ d) $\frac{P_1}{P_2} = \frac{V_1}{V_2}$

8. At <u>constant pressure</u>, which of the following equations is/are true? This relationship is known as "Charles' Law", named after the person who first discovered it.
   a) $\frac{V_1}{T_1} = \frac{V_2}{T_2}$ b) $(T_1)(V_1) = (T_2)(V_2)$ c) $P_1 + V_1 = P_2 - V_2$

9. Complete the following. You may want to consider the equations from questions 5, 7 and 8.

   a) At constant volume, as the temperature increases, the pressure always ________________.

   b) At constant temperature, as the volume increases, the pressure always ________________.

   c) At constant pressure, as the temperature increases, the volume always ________________.

10. If the volume is not constant, is the statement you completed in 9a always true? Justify your answer by citing experimental data from the data table.

11. If the temperature or pressure is not constant are your statements in 9b and 9c correct? Justify your answer.

12. Would the equations you discovered still be true if the temperature was measured in degrees Celsius (^{o}C) instead of Kelvin (K)? Recall that $K = {}^{o}C + 273$ or ${}^{o}C = K - 273$.

13. Which of the following quantities is a constant?
    a) $\frac{PV}{T}$ b) $PV + T$ c) $\frac{PT}{V}$

14. Based on your answer to question 13, verify that this equation is true: $\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$ This equation is called the "Combined Gas Law". Notice that it contains all of the equations combined into one!

15. What needs to remain constant in order for equation 14 to be true? (You may need to refer to the information section.)

16. Prove that when the temperature remains constant, the combined gas law becomes Boyle's Law.

17. Prove that when the pressure remains constant, the combined gas law becomes Charles's Law.

18. You have discovered several new mathematical relationships among gases. Now is your chance to practice using these equations!

    a) At constant temperature, the volume of a gas expands from 4.0 L to 8.0 L. If the initial pressure was 120 kPa, what is the final pressure?

    b) At constant pressure, a gas is heated from 250 K to 500 K. After heating, the volume of the gas was 12.0 L. What was the initial volume of the gas? Notice: as the temperature doubled, what happened to the volume?

    c) The volume of a gas was originally 2.5 L; its pressure was 104 kPa and its temperature was 270K. The volume of the gas expanded to 5.3 L and its pressure decreased to 95 kPa. What is the temperature of the gas?

19. At constant temperature, if you increase the volume by a factor of two (doubling the volume), the pressure _______________ by a factor of ______________. (Refer to 18a for a hint.)
    increases or decreases what number

ChemQuest 36

Gases and Moles

Name: ______________________________

Date: ________________

Hour: _____

Information: The Gas Constant

We previously examined the fact that $\frac{PV}{T}$ is a constant as long as the number of moles of a gas remains unchanged.

This means that any time you measure a gas, the pressure times the volume divided by the temperature (in Kelvin) will always equal the same number unless the amount of gas in the container changes. We are now going to explore how the pressure, volume and temperature depend on the number of moles of gas that are present.

Table 1: Experimental Data for Three Different Samples of Gas That Contain the Same Amount of Gas (# of moles of gas is constant)

Gas	# of moles of Gas in container (mol)	Volume of Container (L)	Temperature of Gas (K)	Pressure of Gas (kPa)
A	0.3008	14.0	672.0	120.0
B	0.3008	16.0	1280	200.0
C	0.3008	10.0	340.0	85.0

Table 2: Experimental Data for Three Different Samples of Gases That Contain Different Amounts of Gas (# of moles of gas is not constant)

Gas	# of moles of Gas in container	Volume of Container (L)	Temperature of Gas (K)	Pressure of Gas (kPa)
D	3.3485	40.0	230.0	160.0
E	0.7306	22.5	315	85
F	0.85950	16.0	280	125

Critical Thinking Questions

1. Prove that $\frac{PV}{T}$ is a constant for the data in Table 1, but not a constant for the data in Table 2.

2. Why is $\frac{PV}{T}$ a constant in Table 1, but not in Table 2?

3. Which of the following is a constant for Table 1 and Table 2? (Note that "n" means **n**umber of moles of gas in the container.)

   A) $\frac{PT}{nV}$ B) $\frac{PTn}{V}$ C) $(n^2)PV+T$ D) $\frac{PV}{nT}$

4. Consider your answer to question 3. Compute the numerical value of the constant by putting values into the equation indicated by your answer to question 3. This constant is given a special name, "The Ideal Gas Constant" and it has the symbol "R".

5. Which of the following equations is true? The equation is known as the "Ideal Gas Law".

   A) PT = nRV B) PV = nRT C) TV = nRP

6. At 215 kPa of pressure and a temperature of 318 K, 2.35 mol of a gas has what volume? (Use the ideal gas law and the ideal gas constant, R, to calculate V. Your answer should be 28.9 L.)

7. What is the temperature of a gas if 4.11 mol of a gas has a pressure of 315 kPa and a volume of 12.5 L?

8. 23.5 g of CO_2 gas is at a temperature of 45°C and a pressure of 125 kPa. What is the volume of the container? (Hint: change grams to moles and 45°C to Kelvin.)

Information: Molar Volume

Molar volume: the volume of one mole of a gas. Depending on the temperature and pressure a mole of gas may have different volumes. Whenever we are speaking of molar volume, we can assume that we are talking about one mole of the gas. Thus, whenever we need to calculate the molar volume, n=1.

Critical Thinking Questions

9. What is the molar volume of oxygen gas if the gas has a pressure of 120 kPa and a temperature of 38°C? Use the ideal gas law (from question 5) with n=1 for one mole of gas and solve for V; remember to use Kelvin temperature and that R always equals 8.31.

10. Prove that if two different gases are at the same pressure and temperature, each gas has the same molar volume.

11. What is the molar volume of any gas at STP? Recall that STP is standard temperature (273 K) and standard pressure (101.325 kPa).

12. Why do you think <u>all</u> gases have the same molar volume at STP?

Information: Using the Ideal Gas Law to Calculate Molar Mass

You should know that to find the number of moles (n) of a substance, you take the mass (m) of the substance and divide it by its molar mass (M) according to the following equation:

$$\#\ of\ \ moles = \frac{mass}{Molar\ mass} \quad \Rightarrow \quad n = \frac{m}{M}$$

Now consider the Ideal Gas Law, PV=nRT. Since n=m/M we can replace n with m/M in the ideal gas law to get:

$$\mathrm{PV} = \frac{\mathrm{m}}{\mathrm{M}}\mathrm{RT}$$

By rearranging it a bit, we can get a more useful form of the equation: MPV = mRT.

This equation can then be used when you are dealing with grams and molar mass instead of moles.

Critical Thinking Questions

13. If 128g of a certain gas in a container with a volume of 21.5 L has a pressure of 132 kPa and a temperature of 45^{o}C, what is the molar mass of the gas?

14. How many grams of CO_2 are in a 5.0 L container if the pressure in the container is 101 kPa and the temperature is 280 K?

15. If 4.0 L of a gas were produced at STP and the mass of the gas was found to be 12.8g, then what is the molar mass of the gas?

ChemQuest 37

Gas Stoichiometry

Name: ______________________
Date: ______________
Hour: _____

Critical Thinking Questions

1. How many moles and how many grams of hydrogen gas can be produced by reacting 32.8 g of magnesium according to the following balanced equation?
$$Mg\ (s) + 2\ HCl\ (aq) \rightarrow MgCl_2\ (aq) + H_2\ (g)$$

2. Considering your answer to question 1, what volume of hydrogen gas was produced if this reaction was carried out at STP?

3. Nitrogen gas can be produced by reacting Na_3N with chlorine gas. If the reaction was carried out at STP with 34.8 g of Na_3N, what volume of nitrogen gas can be produced? (Hint: first use stoichiometry to calculate the number of moles of nitrogen produced and then use the ideal gas law.)

Information: Mole Ratios in Chemical Equations and Volume

As you know, the coefficients in balanced equations relate the number of moles of reactants to each other. For gaseous reactions, the coefficients relate not only the moles but also the number of liters of reactants and products to each other. For example, consider the following reaction, noting that "(g)" means that the substances are gaseous:

$$N_2\ (g) + 2\ O_2\ (g) \rightarrow 2\ NO_2\ (g)$$

The coefficients tell you that for every mole of N_2, two moles of O_2 react and two moles of NO_2 are produced. It also tells you that for each liter of N_2, two liters of O_2 react and two liters of NO_2 are produced.

Critical Thinking Questions

4. Verify that for the following reaction to be completed, 4 liters of hydrogen would require at least 2 liters of oxygen gas at the same pressure and temperature.

$$2\ H_2\ (g)\ +\ O_2\ (g)\ \rightarrow\ 2\ H_2O\ (g)$$

5. In a certain combustion reaction involving propane, 34.4 L of CO_2 was produced. How many liters of propane (C_3H_8) were combusted? Assume the reaction took place at STP.

6. How many grams of sodium are required to produce 31.9 L of H_2 at 97 kPa and 290 K according to the following balanced equation? $2\ HNO_3\ +\ 2\ Na\ \rightarrow\ 2\ NaNO_3\ +\ H_2$

7. At room temperature (25^{o}C) and pressure (100 kPa), 381g of octane (C_8H_{18}) was burned in an atmosphere of plenty of oxygen gas. How many liters of each product were produced?

ChemQuest 38

Partial Pressures

Name: ______________________
Date: ____________
Hour: _____

Information: Collecting Gas Over Water

When gas is collected in a container, it is often collected using a technique called, "water displacement." In water displacement, a container is filled with water and then gas is bubbled into the container. In this way, the container can be filled with relatively pure gas without air in it.

Figure 1A: A beaker is filled with water and then turned upside down in a bucket of water. Rubber tubing is attached to a source of gas so that the gas is bubbling up through the water in the beaker. These gas bubbles force some of the water out of the beaker.

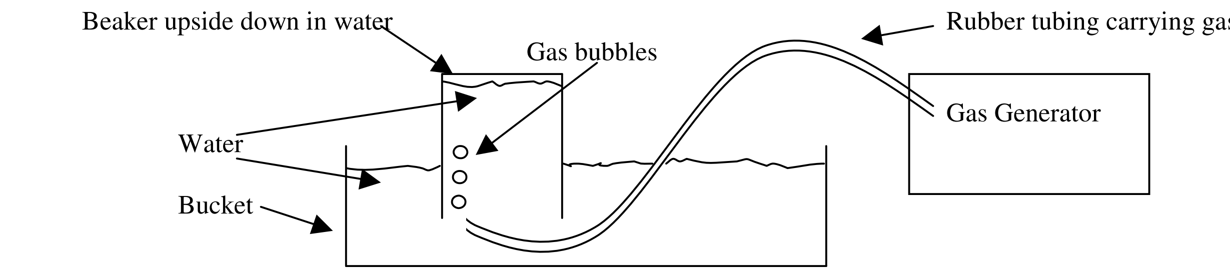
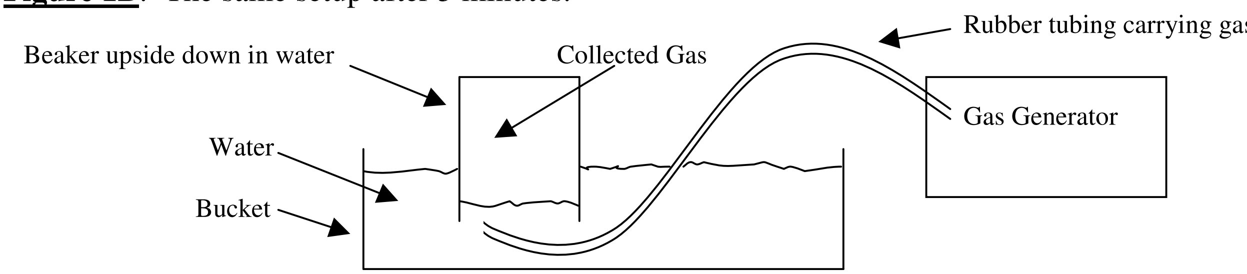


Figure 1B: The same setup after 5 minutes.



Critical Thinking Questions

1. To collect the gas, why is the beaker first filled completely with water? What purpose does the water serve?

2. Examine the beaker in Figure 1A and 1B. What causes the water level to go down after 5 minutes?

3. In Figure 1B, is the gas in the beaker pure? Explain.

Information: Dry Gas

The gas that is collected is not “dry” because there is some water vapor left behind in the beaker. If you attempt to collect pure oxygen, you will actually get mostly pure oxygen with a little water vapor. You can get an idea of how much water is left behind by examining the water vapor pressure at various temperatures.

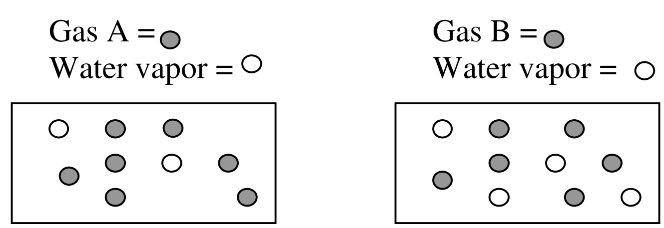
Table 1: Vapor pressure of water at various temperatures.

Temperature (^{o}C)	Vapor Pressure (kPa)
0	0.6
5	0.9
10	1.2
15	1.6
20	2.3
25	3.2
30	4.2
35	5.6
40	7.4
45	9.8

Critical Thinking Questions

4. Why is it logical to expect that the vapor pressure of water would increase as the temperature increases?

5. Examine the two containers below. Both contain gases that were collected over water. Which one was collected at the higher temperature—gas A or gas B? Explain your answer.



6. Consider Gas A from question 5. The total pressure in the container is 104 kPa. If the temperature of the container is 20^{o}C, calculate the pressure of Gas A when it is “dry”. Hint: find the vapor pressure of water at 20^{o}C from Table 1 and then subtract it from the total pressure in the container.

7. Consider Gas B from question 5. The total pressure in the container is 110 kPa. If the temperature of the container is 35^{o}C, calculate the pressure of Gas B when it is “dry”.

Information: Dalton's Law of Partial Pressures

John Dalton was one of the first scientists to quantitatively state a mathematical relationship involving the total gas pressure in a container and the individual gases in the container. Dalton's law states that the total pressure of any mixture of gases in a container is the sum of all the individual gas's partial pressures. In equation form, Dalton's law can be written as:

$$P_{Total} = P_{Gas\ A} + P_{Gas\ B} + P_{Gas\ C} + \ldots$$

Critical Thinking Questions

8. A container of gas with a pressure of 450 kPa contained three different gases—hydrogen, oxygen and nitrogen. If the partial pressure of hydrogen was 210 kPa and the partial pressure of oxygen was 125 kPa, what was the partial pressure of nitrogen?

9. A tank held neon gas at a pressure of 350 kPa, helium at a pressure of 275 kPa and argon at a pressure of 410 kPa. What was the pressure in the tank?

10. A certain gas was collected over water. The total pressure of the container was 100.0 kPa. The pressure of the dry gas was 94.4 kPa. At what temperature was the gas collected?

11. Hydrogen gas was collected over water at a pressure of 102.5 kPa and a temperature of 25°C. After sealing the container, it was heated to 210°C. What is the final pressure of the dry hydrogen gas? (Hints: You must first find P_1 for the gas by subtracting out the water vapor from the given pressure; solve for P_2 using the combined gas law with constant volume.)

12. Oxygen gas was collected over water at 30°C. The pressure in the 2.5 L container was 110 kPa. If the container was allowed to expand to 7.0 L and if the temperature was decreased to -30°C, what is the final pressure of the dry oxygen gas?

13. A quantity of oxygen gas was collected over water at 30°C in a 475 mL container. The pressure in the container was measured to be 105 kPa. How many grams of oxygen gas were collected?

ChemQuest 39

Concentration

Name: ______________________________
Date: ________________
Hour: _____

Information: Molarity

Concentration is a term that describes the amount of solute that is dissolved in a solution. Concentrated solutions contain a lot of dissolved solute, but dilute solutions contain only a little.

Critical Thinking Questions

1. Consider the terms "concentrated" and "dilute". Are these qualitative or quantitative terms?

2. One way of quantitatively measuring solution concentration is with units of molarity, symbolized by M. You see 1.7 liters (L) of a sodium chloride and water solution. The label on the bottle reads "1.5 M NaCl". You don't know what molarity is, but you decide to find out. After evaporating the water out of the solution you discover that there are about 149 grams of salt. Using this information, which of the following formulas is/are correct for finding molarity?

   A) $\text{Molarity} = \dfrac{\text{grams of solute}}{\text{moles of solute}}$ B) $\text{Molarity} = \dfrac{\text{moles of solute}}{\text{liters of solution}}$

3. Using the equation you discovered in question two, calculate the molarity of each of the following solutions.
   A) A solution is prepared by dissolving 24.9 g of $CaCl_2$ in 210 mL (which 0.210 L) of solution.

   B) A solution contains 12.9 g of Na_2SO_4 in 325 mL of solution.

4. Verify that I need 2.15 moles of $Ca(NO_3)_2$ to make 358 mL of a 6.00 molar solution.

5. Verify that it takes 80.8 g of sodium chloride to make 425 mL of a 3.25 M solution.

6. Consider 670 mL of a 4.10 M solution of $Mg(NO_3)_2$ setting in a beaker. If you evaporate all 670 mL of the solution, how many grams of solute would be left in the beaker?

Information: Molality

Molality is another way of expressing solution concentration. The symbol for molality is m. Whereas molarity (M) represents the ratio of moles solute to liters of solution, the molality (m) is the ratio of moles solute to kilograms of solvent. It can be expressed using the following formula:

$$\text{molality} = \frac{\text{moles of solute}}{\text{kg solvent}}$$

Critical Thinking Questions

7. Consider a solution that is prepared by adding 1.34 moles of sodium nitrate to 2.5 kg of water. What is the molality of the solution?

8. Considering the data given in question 7, is this enough data to find the molarity? If so, calculate the molarity. If not, explain why not.

9. What is the molality of a solution that is made by dissolving 32.6 g of Na_2SO_4 in 475 g of water?

10. Consider 2.35 moles of sodium chloride are dissolved in 1.21 kg of solution to make 1.29 liters. Calculate and compare the molarity and molality.

11. If 26.45g of Na_2SO_4 are dissolved in 1.10 kg of solution to make 1.24 L, calculate both the molarity and the molality of the resulting solution.

Information: Mole Fraction

Another way of expressing solution concentration is called “mole fraction”. The mole fraction (symbolized by X) of the solute or of the solvent can be calculated using the following equations:

$$X_{solute} = \frac{mol_{solute}}{(mol_{solute} + mol_{solvent})} \qquad X_{solvent} = \frac{mol_{solvent}}{(mol_{solute} + mol_{solvent})}$$

Note: both the solute and the solvent must be converted to moles when finding the mole fraction!

Critical Thinking Questions

12. Prove that the mole fraction of salt (X_{NaCl}) equals 0.049 when 14.25 g of NaCl is dissolved in 85.0 g of H_2O.

13. Find the mole fraction of water (X_{water}) for the solution described in question 12.

14. Prove that $X_{solute} + X_{solvent} = 1$.

15. In a certain salt water solution, the mole fraction of salt is 0.18. Find the mole fraction of water.

Information: Mass Percent Composition

Mass percent composition is similar to the mole fraction except the amounts of solute and solvent are in grams instead of moles. Here is the formula for finding the mass percent of a solute:

$$mass\%_{solute} = \frac{mass_{solute}}{(mass_{solute} + mass_{solvent})} \bullet 100$$

Critical Thinking Questions

16. Prove that the mass percent of salt is 14.36% in the solution described in question 12.

17. Calculate the mass percent of sodium phosphate if 12.5g of it are dissolved in 250 mL of water. (Note: 1 mL of water has a mass of 1 g.)

ChemQuest 40

Colligative Properties

Name: ____________________________
Date: ______________
Hour: _____

Introduction Question: Melting Ice

1. In colder climates during the winter, people put salt on the roads and walkways to melt ice. Why do people do this? Why does salt melt the ice?

Information: Dissociation and Total Molality of Particles

When you dissolve a solute in a solvent, the resulting solution has slightly different properties than the original solvent. For example, salt water has a different freezing point and boiling point than pure water. The salt interferes with water's ability to freeze and boil. A solution, therefore, will always have a *higher* boiling point and a *lower* freezing point than the pure solvent.

When ionic compounds dissolve, they dissociate. When an ionic compound dissociates that means that it breaks up into ions. For example, salt (sodium chloride) breaks up into sodium ions and chloride ions. This process is represented in the following balanced equation:

$$NaCl \rightarrow Na^{+} + Cl^{-}$$

Note for the above equation that Cl^{-} does not need to be written as Cl_2 because Cl^{-} is a chloride ion and not a lone chlorine atom.

Since calcium nitrate is an ionic compound it also dissociates as shown below:

$$Ca(NO_3)_2 \rightarrow Ca^{2+} + 2\ NO_3^{-}$$

Covalent molecules do not dissociate. Although they may dissolve, they do not break up into ions.

Critical Thinking Questions

2. Write the balanced equation for the dissociation of magnesium chloride.

3. Write the balanced equation for the dissociation of ammonium sulfate.

4. Consider calcium nitrate. Each calcium nitrate breaks up into one calcium ion and two nitrate ions according to the balanced equation given in the information section. If you take one mole of calcium nitrate and put it in water, it will dissociate.
   a) How many moles of calcium ions and how many moles of nitrate ions will there be in the solution?

   b) What is the total number of moles of all ions in the solution?

5. A solution is made so that it is 2.5 M $Ca(NO_3)_2$. Therefore the concentration of Ca^{2+} is 2.5 M and the concentration of NO_3^- is 5.0 M. The total concentration of all particles is 7.5 M. Explain.

6. A solution is made so that the concentration is 3.0 m $MgCl_2$. What is the molality of Mg^{2+} and Cl^- ions? What is the total molality of all particles in the solution?

   Mg^{2+} ________ Cl^- _________ Total molality of all particles: ____________

7. A solution is prepared by dissolving 45.7 g of sodium carbonate in 200 g of water.
   a) What is the molality of the sodium carbonate?

   b) What is the total molality of all particles in the solution?

8. Consider sugar ($C_6H_{12}O_6$) , a covalent molecule. If a solution is made so that the concentration is 3.5 m in sugar, then what is the total molality of particles?

Information: Total Molality of Particles and Changes in Boiling/Freezing Points

You may be wondering how all of this ties together. We have seen that adding a solute changes the boiling and freezing points of solvents. The amount of the change depends on how much solute is added. Equations relating the change in boiling or freezing point and the molality is shown below:

$\Delta T_{bp} = (m_T)(K_{bp})$ for boiling point $\Delta T_{fp} = (m_T)(K_{fp})$ for freezing point

Note: m_T is the total molality of particles. K_{bp} and K_{fp} are constants called the molal boiling point elevation constant and the molal freezing point depression constant respectively. K_{bp} for water is 0.515 $^oC/m$ and K_{fp} for water is 1.853 $^oC/m$.

Critical Thinking Questions

9. What is the freezing point of a 2.5 m solution of salt water. Hints: first find ΔT_{fp} and then subtract the change from the original freezing point (0^oC for water). Also, remember m_T is not 2.5 m in this problem.

10. Find the boiling point of a 3.7 m solution of calcium chloride.

11. What is the freezing point of a sugar solution in which the concentration of sugar is 2.25m? Note: sugar is covalent so it dissolves but it does <u>not</u> dissociate.

Information: Raoult's Law

A solution will almost always have a lower vapor pressure than the pure solvent. For example, salt water will have a lower vapor pressure than pure water. The vapor pressure of a solution ($P_{solution}$) is related to the vapor pressure of the pure solvent ($P_{solvent}$) by the mole fraction of the solvent ($X_{solvent}$) in an equation known as Raoult's Law:

$$P_{solution} = (X_{solvent})(P_{solvent})$$

Critical Thinking Questions

12. The vapor pressure of water at 20^oC is 2.3 kPa. What is the vapor pressure of a solution formed by dissolving 21.5g of LiCl in 84.3g of H_2O at 20^oC?

ChemQuest 41

Using Colligative Properties to Find Molar Mass

Name: ____________________________

Date: _______________

Hour: _____

Information: Molar Mass

As you know, the molar mass of any substance is how much mass (measured in grams) one mole of a substance has. The units for molar mass are g/mol. If you know that 2.0 moles of water have a mass of 36.0 g, you can find the molar mass of water by dividing 36.0 g by 2.0 moles to get 18.0 g/mol.

Critical Thinking Questions

1. If 2.75 moles of a certain compound has a mass of 125.9 g, what is the molar mass of the compound?

2. If you put 2.53×10^{24} molecules of an unknown compound on a balance you will discover that the mass is 757.8 g. What is the identity of the unknown compound? (Hint: find the molar mass and then calculate the molar masses of the following compounds.)

   A) $C_{10}H_{12}O$ B) $C_6H_{12}O_6$ C) C_8H_{18} D) $C_{10}H_8NO$

Information: Relating Molar Mass and Colligative Properties

One of the ways to determine the molar mass of a compound is by experiments involving colligative properties. By measuring the temperature changes of solutions, it is possible to calculate the molality of the solution and from the molality you can determine the molar mass. The following calculations walk you through the process. Please note that the process used here is valid only for covalent compounds.

Critical Thinking Questions

3. When 135 g of an unknown covalent compound is dissolved in 450 g of water, the freezing point of the solution is –3.21°C. Find the molar mass of the covalent compound. Follow these steps…

   a) What is the molality of the solution? (Use $\Delta T_{fp} = m_T K_{fp}$ and solve for m_T. Note that since this is a covalent compound m_T equals the molality of the solute because covalent compounds don't dissociate.)

   b) How many moles of solute were dissolved? (Multiply your answer to part a by the *kilograms* of solvent.)

   c) Calculate the molar mass of the compound. (Take the mass of the solute given in the problem and divide by your answer to part b.)

4. Find the molar mass of a covalent compound if 210 g of the substance is dissolved in 810 g of water changes the boiling point of the solution to 101.3 °C.

5. Find the molar mass of a covalent compound if 38.5 g dissolves in 520 g of water to give a freezing point of –2.15°C.

6. When 282.5 g of a covalent compound is dissolved in 630 g of water, the vapor pressure lowers from 3.2 kPa to 2.1 kPa. What is the molar mass of the compound? Use the following steps…

   a) Use Raoult's Law to find the mole fraction of the water. (Solve for $x_{solvent}$.)

   b) Convert grams of water to moles of water.

   c) Use the mole fraction equation (below) and your answer to part b to solve for mol_{solute}.

$$x_{solvent} = \frac{mol_{solvent}}{(mol_{solvent} + mol_{solute})}$$

   d) Divide the mass of the compound given in the question by your answer to part c to find the molar mass.

7. Find the molar mass of a covalent solute if when 371 g of the solute are added to 650 g of water, the vapor pressure changes from 4.2 kPa to 2.8 kPa.

8. 230 g of a covalent solute are dissolved in 520 g of water. The vapor pressure changes from 3.5 kPa to 2.9 kPa. What is the freezing point of the solution? Hint: first find the moles of solute using Raoult's Law and then find the molality and use $\Delta T_{fp} = m_T K_{fp}$.

ChemQuest 42

Rates of Reactions Introduction

Name: ____________________

Date: ____________

Hour: _____

Information: Average Rate of Reaction

Recall that during a chemical reaction reactants are transformed into products: A + B → C + D. A very important question is: how fast do such processes happen? For example, we need to know how long it will take for a medicine to work in our bodies and how long will it take to produce chemicals in industry.

How fast do reactants A and B disappear? How fast do products C and D form? We can express such questions in the form of an equation as shown below.

$$\text{rate of disappearance of reactant A} = -\frac{\text{change in molarity of reactant A}}{\text{change in time}} = -\frac{\Delta[\text{reactant A}]}{\Delta\text{time}}$$

Keep in mind that all rates are written as positive numbers; thus, the function for the negative sign in the above equation is to yield a positive result for the rate.

Critical Thinking Questions

1. What is molarity?

2. What do the symbols Δ and [ ] mean in the above equation?

3. What units would you expect for the rate of disappearance of a reactant? (Assume time is measured in seconds.)

4. How is the change in molarity of a reactant calculated? Would this be a positive or a negative number?

5. How is the change in molarity of a product calculated? Would this be a positive or a negative number?

6. When writing the equation for the rate of formation of a product, the negative sign in the above equation is not needed. Explain why.

Information: Stoichiometry and Average Rate

Consider the decomposition of N_2O_5 and the experimental data for the reaction taking place inside a container that has a volume of 3.0 L.

$$2\ N_2O_5\ (g) \rightarrow 4\ NO_2\ (g)\ +\ O_2\ (g)$$

Time (s)	**Moles N_2O_5**	**Moles NO_2**	**Moles O_2**
0	0.4320	0	0
600	0.4194	0.0252	0.0063
1200	0.4104	0.0432	0.0108
1800			0.0144

Critical Thinking Questions

7. Calculate the change in moles of each reactant and product between 600 and 1200 seconds.

   change in moles of N_2O_5:   change in moles of NO_2:   change in moles of O_2:

8. Compare your answers in question 7. What is the relationship between the coefficients in the balanced chemical equation and the number of moles used up or produced in a reaction?

9. Fill in the missing blanks in the table above.

10. Calculate the following values. Be sure to use molarity in your calculations.

    a) Rate of disappearance of N_2O_5 between time 0 and 600 s.

    b) Rate of appearance of NO_2 between time 0 and 600 s.

    c) Rate of appearance of O_2 between time 0 and 600 s.

11. Compare each of the rates. What relationship exists between the rates and the coefficients in the balanced chemical equation?

12. Calculate the following values. Be sure to use molarity in your calculations.

    a) Rate of disappearance of N_2O_5 between time 600 and 1200 s.

    b) Rate of appearance of NO_2 between time 600 and 1200 s.

    c) Rate of appearance of O_2 between time 600 and 1200 s.

13. As the reaction proceeds are the rates constant? What affects the rate?

ChemQuest 43

Rate and Concentration

Name: ______________________________

Date: _______________

Hour: _____

Information: Reaction Order

Below is a table of data corresponding to the following balanced equation:

$$2\ ClO_2\ (aq) + 2\ OH^-\ (aq) \rightarrow ClO_3^-\ (aq) + ClO_2^-\ (aq) + H_2O\ (l)\ .$$

Six experiments were carried out with differing concentrations of ClO_2 and OH^- in each experiment. The measurement of how quickly ClO_2 disappears is given in the table for each of the six experiments. How quickly a reactant disappears (or how quickly a product forms) is a good measurement of how fast a reaction takes place.

Table 1: Experimental data for the reaction of ClO_2

Experiment	Initial [ClO_2]	Initial [OH^-]	Initial Rate of disappearance of ClO_2 (M/s)
1	0.020	0.030	0.00276
2	0.040	0.030	0.01104
3	0.020	0.060	0.00552
4	0.040	0.060	0.02208
5	0.040	0.090	0.03312
6	0.120	0.030	0.09936

Critical Thinking Questions

1. What happens to the rate of a reaction as the concentrations of the reactants increases? Justify your answer with data from the table above.

2. Consider the molecular level of what is happening when ClO_2 reacts with OH^- to form products. Offer an explanation for why changing the concentration of reactants changes the rate of a reaction.

3. Does the reaction depend on the concentration of ClO_2 and the concentration of OH^- equally? In other words, is the rate more dependent on ClO_2, on OH^-, or is it equally dependent on the concentration of both. Justify your answer.

4. If you wanted to know how the rate of reaction depends on the concentration of ClO_2 you could compare experiments 1 and 2. But if you compared experiments 1 and 4, you would not be able to accurately see how the reaction depends on the concentration of ClO_2. Why?

5. Which two experiments would you want to compare to determine how much the rate of reaction depends upon the concentration of OH^-?

   A) 1 and 4 B) 5 and 6 C) 1 and 6 D) 1 and 3

6. Considering [ClO_2] in experiments 1 and 2, complete the following sentence.

   When [ClO_2] increases by a factor of 2, the rate of reaction increases by a factor of 2 to the ____ power.

7. Considering [OH^-] in the two experiments you identified in question 5, complete the following sentence.

   When [OH^-] increases by a factor of 2, the rate of reaction increases by a factor of 2 to the ____ power.

8. Considering [ClO_2] in experiments 2 and 6, complete the following sentence.

   When [ClO_2] increases by a factor of 3, the rate of reaction increases by a factor of 3 to the ____ power.

9. Considering [OH^-] in experiments 2 and 5, complete the following sentence.

   When [OH^-] increases by a factor of 3, the rate of reaction increases by a factor of 3 to the ____ power.

10. The rate dependence with respect to [ClO_2] is said to be <u>second order</u>. Given your answers to questions 6 and 8, explain what "second order" means.

11. The rate dependence with respect to [OH^-] is said to be <u>first order</u>. Given your answers to questions 7 and 9, explain what "first order" means.

12. Can you find the order for a reactant just by looking at the balanced equation?

13. The overall "order" of the reaction for this reaction is <u>third order</u>. Explain how the overall order of a reaction is found.

Information: Rate Law

Once you know the order with respect to each reactant, you can determine the "rate law" for the reaction. Each reaction has a different rate law. The rate law is a convenient way of expressing how the rate of a reaction depends upon concentration. The rate law for the reaction we have been considering so far is

$$\text{Rate} = k[ClO_2]^2[OH^-]^1$$

Each reaction has a rate constant, given the symbol k. As you will soon see, the rate constant can be determined from experiments in a similar fashion to how you determined the orders for reactants.

Critical Thinking Questions

14. What is the relationship between the order of the reactant and the exponent for the reactant in the rate law?

15. Using the data from any of the six experiments in Table 1, verify that the rate constant is 230 $1/(M^2s)$. For example, let's pick experiment 3 to use. The rate is given and so are the concentrations of ClO_2 and OH^-. Plug these given data into the rate law and solve for k. Use units in your calculation to verify that the units for k are $1/(M^2s)$.

16. Now that you know the rate constant, you can calculate the rate for any concentration of reactants. For example, calculate the rate of reaction when the concentration of ClO_2 is 0.32 and the concentration of OH^- is 0.42.

Skill Practice

17. In a certain reaction, it is discovered that if the concentration of a reactant is tripled, then the rate of the reaction increases from 0.0670 M/s to 1.809 M/s. What is the order with respect to this reactant?

18. Given the following data, write the rate law for the reaction. Then find the rate constant (include units).

$$H_2O_2 + 2\,HI \rightarrow 2\,H_2O_2 + I_2$$

Experiment	$[H_2O_2]$	[HI]	Rate (M/s)
1	0.1	0.1	0.0076
2	0.1	0.2	0.0608
3	0.2	0.2	0.2432

ChemQuest 44

Concentration and Time

Name: ______________________________

Date: ________________

Hour: _____

Information: First Order Reactions with One Reactant

As we consider what affects the rate of reactions it is desirable to examine how the concentration of a reactant changes with time. Let us consider reactions that have only one reactant and we will further restrict our considerations to first order reactants. As an example, consider the following reaction:

$$SO_2Cl_2 \rightarrow SO_2 + Cl_2$$

Table 1: Experimental data for the decomposition of SO_2Cl_2

Time (s)	**$[SO_2Cl_2]$**
0	0.0250
60	0.0228
120	0.0208
180	0.0190

It can be shown that the natural log of the concentration of a first order reactant varies directly with the time. So in this case $\ln[SO_2Cl_2]$ varies in direct proportion to the time.

1. Using the above data, prove on the graph below that $\mathbf{\ln[SO_2Cl_2] = -kt + \ln[SO_2Cl_2]_0}$ is a straight line when graphed. Note the expression $[SO_2Cl_2]_0$ is the concentration of SO_2Cl_2 at a time of zero seconds. **Label the axes**.

2. Given this relationship between concentration and time ($\ln[SO_2Cl_2] = -kt + \ln[SO_2Cl_2]_0$), find the rate constant k

3. Find the half-life for this reaction. What this means is that you need to find the time it takes for half of the reactant to get used up.

Information: Second Order Reactions with One Reactant

Consider the following reaction: 2 NO_2 → 2 NO + O_2. The following experimental data was gathered for this reaction:

Table 2: Experimental data for the decomposition of NO_2

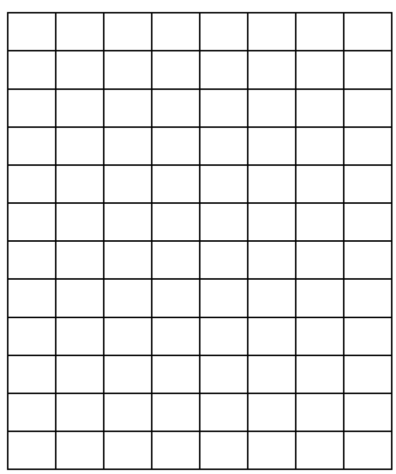
Time (s)	**[NO_2]**
0	0.0370
45	0.0338
90	0.0311
135	0.0288

If you attempted a plot of ln vs. t as you did in question 2 above you would not get a straight line. Instead, for second order reactants, the inverse of the concentration varies directly with time.

Critical Thinking Questions

4. Using the following graph and the above data, prove that the following equation yields a straight line.

$$\frac{1}{[NO_2]} = kt + \frac{1}{[NO_2]_0}$$



5. What is the value of the rate constant, k, for this reaction?

6. Find the half-life for this reaction.

Skill Practice Question

7. Given the following reaction and table of experimental data, answer the following questions.

$$2\ N_2O_5 \rightarrow 4NO_2 + O_2$$

Time (s)	**[N_2O_5]**
0	0.0200
100	0.0169
200	0.0142
300	0.0120
400	0.0101
500	0.0086
600	0.0072
700	0.0061

a) Is the reaction 1st order or second order with respect to N_2O_5? How do you know?

b) What is the value for the rate constant?

c) What is the half life for this reaction?

d) How many seconds are required for the concentration of N_2O_5 to reach a level of 0.0025 M?

ChemQuest 45

Intro. to Equilibrium

Name: ______________________

Date: ______________

Hour: _____

Information: Forward and Reverse Processes

When most people think of chemical reactions, they think of reactants being transformed into products. For example, take the reaction of carbon monoxide with hydrogen gas to form methane gas and water vapor:

$$CO\ (g) + 3\ H_2\ (g) \rightarrow CH_4\ (g) + H_2O\ (g)$$

If you were watching the molecules of this reaction, you would see that at the very beginning, there is no methane and no water in the container. Soon methane and water would begin to form and then the reaction would appear to stop. **However**, at this point there would still be some carbon monoxide and hydrogen present.

What happens at the molecular level is this: as the products (methane and water) begin to form, they react with each other and begin forming the reactants (carbon monoxide and hydrogen) again. There is a forward reaction and a reverse reaction. The forward reaction is written above. The reverse reaction is below:

$$CH_4\ (g) + H_2O\ (g) \rightarrow CO\ (g) + 3\ H_2\ (g)$$

The best way to represent the reaction, then, is as follows:

$$CO\ (g) + 3\ H_2\ (g) \leftrightarrow CH_4\ (g) + H_2O\ (g)$$

The reaction *appears* to stop when the rate of the forward reaction equals the rate of the reverse reaction. At this point we say that the reaction has reached **equilibrium**. The reaction is still occurring, but the products and reactants are being formed at the same time so there is no net change in their amounts.

Critical Thinking Questions

1. Consider the reaction above involving carbon monoxide and hydrogen. At the beginning of the reaction, there are 2.50 moles of carbon monoxide and 5.10 moles of hydrogen gas placed in a 5.0 L container. Of course, at the very beginning there is no methane or water in the container. When equilibrium is reached, there are 1.02 moles of water in the container. Calculate the number of moles of methane, hydrogen and carbon monoxide in the container.

   Hint: Calculate the *change* in the number of moles of water; by how many moles did the water *increase*? The number of moles of methane increased by this same amount. The number of moles of carbon monoxide *decreased* by this same amount. The number of moles of hydrogen decreased by *three times* this amount. We know this because of the coefficients in the balanced chemical equation.

2. Consider the following reaction: N_2 (g) + 3 H_2 (g) $\leftrightarrow$ 2 NH_3 (g). Initially, 4.25 moles of nitrogen gas and 6.33 moles of hydrogen gas are placed in a 3.35 L container. At equilibrium, 2.15 moles of NH_3 (ammonia) was present. Calculate the number of moles of nitrogen and hydrogen at equilibrium.

3. As mentioned already, equilibrium occurs when the rate of the forward reaction equals the rate of the reverse reaction. Assume that all reactions discussed so far are *elementary* reactions. This means that the exponents in the rate law are the same as the coefficients in the balanced equation.
   a) Write the rate law for the forward reaction of carbon monoxide and hydrogen. Use k_f to symbolize the rate constant for the forward reaction.

   b) Write the rate law for the reverse reaction of carbon monoxide and hydrogen. Use k_r to symbolize the rate constant for the reverse reaction.

4. Now divide the reverse rate law by the forward rate law and complete the following equation.

$$\frac{\text{rate}_{\text{reverse}}}{\text{rate}_{\text{forward}}} = \underline{\hspace{6cm}}$$

5. At equilibrium, the reverse rate equals the forward rate. What does the left side of the equation in question 4 equal?

6. Taking into account your answer to question 5, rearrange the equation that you wrote in number four and get k_f and k_r on the left side of the reaction and everything else on the right side.

<u>Information</u> The Equilibrium Constant

The <u>equilibrium constant</u> is a constant that allows us to compare the concentrations of products and reactants in a chemical reaction. The equilibrium constant (K) is defined as k_f/k_r.

Critical Thinking Questions

7. Given your answer to question 6 and also the information above, write the expression for the equilibrium constant for the reaction of carbon monoxide with hydrogen.

   K =

8. Calculate the equilibrium constant for the reaction using your answers to question number 1. You will first need to find the molarity of each reactant and product. You should get a value of 2.07.

9. Verify that the equilibrium constant expression for the reaction described in question two can be written as

$$K = \frac{[NH_3]^2}{[N_2][H_2]^3}$$

10. Calculate the numeric value of the equilibrium constant from question 9 using your answers and the data in question 2.

11. Considering questions 7 and 9, what relationship exists between the coefficients in the balanced chemical equation and the expression for the equilibrium constant?

12. Write the equilibrium constant expression for each of the following reactions.

    a) $2\ HI \leftrightarrow H_2 + I_2$

    b) $2\ CO_2 \leftrightarrow 2\ CO + O_2$

Information: Calculating Equilibrium Constants

Consider a 100 L container that holds 80 moles of hydrogen iodide. Over time, the hydrogen iodide decomposes into hydrogen and iodine. At equilibrium, there are 8.84 moles of iodine. The balanced equation for this process is: $2\ HI \leftrightarrow H_2 + I_2$

Critical Thinking Questions

13. Find the initial concentration of HI and the equilibrium concentration of I_2.

14. Consider the balanced equation for a moment. How will the change in iodine concentration compare to the change in hydrogen iodide? (Hint: it depends on the coefficients in the balanced equation.)

15. What was the initial concentration of I_2? Note: "initial" means *before* any reaction takes place.

16. What was the initial concentration of H_2?

17. What was the change in concentration for I_2? (Remember that *change* in concentration is simply the final minus the initial concentration.)

18. Calculate the change in H_2 and the change in HI concentration.

Δ in $[H_2]$ = ___________________ Δ in [HI] = ___________________

19. What is the equilibrium concentration (i.e. concentration at equilibrium) of HI? Note the equilibrium concentration of HI is equal to the initial concentration of HI minus the change in concentration.

20. What is the equilibrium concentration of H_2? Note the equilibrium concentration of H_2 is equal to the initial concentration of H_2 plus the change in concentration of H_2.

21. In question 19, you subtracted the change in concentration, but in question 20, you added it. Why?

22. Write the equilibrium constant expression for this reaction.

23. Calculate the equilibrium constant for this reaction.

24. This problem combines all of the previous eleven questions and asks you to find the equilibrium constant for a reaction. Consider the following reaction: $2\ NO + O_2 \rightarrow 2\ NO_2$. 5.25 moles of NO and 3.15 moles of O_2 are combined in a 12.0 L container. At equilibrium 3.20 moles of NO_2 are in the container. Verify that the equilibrium constant for this reaction is 18.88. Don't forget to use molarity instead of moles!

ChemQuest 46

Equilibrium Extensions

Name: ______________________________
Date: _______________
Hour: _____

Information: Equilibrium Constant for Gas Pressure

So far we have looked at equations involving gases in terms of the molarity of the gas. For example, if 3 moles of a gas was in a 1.5 L container we used the value 2.0 M in calculating the equilibrium constant. The equilibrium constant, K, when dealing strictly with molarity actually has the symbol K_c. It has been unnecessary to write K_c until now.

Molarity is not the only way to express the concentration of a gas in a container. Pressure, for example, may also be used. We know that for a 1.5 L container, the higher the pressure the greater the concentration. When only pressure information about a gaseous reaction we can still calculate an equilibrium constant, K_p. It is calculated in a very similar way as K_c is calculated. Consider the following reaction.

$$N_2\,(g) + 3\,H_2\,(g) \leftrightarrow 2\,NH_3\,(g)$$

The equilibrium constant expression, K_p for this reaction is:

$$K_p = \frac{p\mathrm{NH_3}^2}{p\mathrm{N_2}\,p\mathrm{H_2}^3}$$

Critical Thinking Questions

1. Consider the following reaction: $2\,NO\,(g) + Br_2\,(g) \leftrightarrow 2\,NOBr\,(g)$. Write the expression for K_p.

Information: Relating K_c and K_p

The values K_c and K_p are related by the following equation:

$$K_p = K_c(RT)^{\Delta n}$$

R = 0.0821 (L-atm)/(mol-K) or 8.31 (L-kPa)/(mol-K). It is customary to use atmospheres (atm) to measure pressure, so <u>we will use the value 0.0821 for R</u>.
T = Kelvin temperature
Δn = the change in the number of moles of gas as the reaction proceeds.

Critical Thinking Questions

2. Verify that $\Delta n = -1$ for the reaction in question 1. (Show how you can obtain -1.)

3. Verify that $\Delta n = -2$ for the reaction N_2 (g) + 3 H_2 (g) $\leftarrow\rightarrow$ 2 NH_3 (g).

4. For the reaction referred to in questions 1 and 2 K_c equals 0.45 at 650°C. What is K_p at this temperature? You should get a value of about 0.00594.

5. For the reaction in question 3, it was found that K_p equals 1.25×10^{-4} at 425°C. What is K_c at this temperature?

Information: Equilibrium Constants from the Sum of Chemical Equations

Consider the following two reactions for which the equilibrium constants are known:

Reaction 1: $CO + 3\,H_2 \leftarrow\rightarrow CH_4 + H_2O$; $K_1 = 3.92$

Reaction 2: $CH_4 + 2\,H_2S \leftarrow\rightarrow CS_2 + 4\,H_2$; $K_2 = 3.3 \times 10^4$

Now consider the following reaction for which the equilibrium constant is unknown:

Reaction 3: $CO + 2\,H_2S \leftarrow\rightarrow CS_2 + H_2O + H_2$; K_3 = ?

It is possible to obtain the equilibrium constant K_3 from K_1 and K_2. The following questions will show you how.

Critical Thinking Questions

6. Which of the following is the relationship between reaction 3 and reactions 1 and 2?
   A) Reaction 3 = Reaction 1 + Reaction 2 B) Reaction 3 = Reaction 2 – Reaction 1

7. Write the equilibrium constant expressions for K_1 and K_2.

   K_1 = K_2 =

8. Now write the equilibrium constant expression for K_3.

9. Consider your answers to questions 6 through 8. Which of the following equations is true:

   A) $K_3 = K_2/K_1$ B) $K_3 = K_1 + K_2$ C) $K_3 = K_1K_2$ D) $K_3 = K_1/K_2$

10. Calculate the equilibrium constant K_3.

ChemQuest 47

The Reaction Quotient

Name: ______________________________
Date: ________________
Hour: _____

Critical Thinking Questions

1. If K_c for a given reaction is very large would there be a large amount of products or reactants in the mixture?

2. If K_c for a given reaction is very small would there be a large amount of products or reactants in the mixture?

3. Offer a mathematical explanation for your answers to questions 1 and 2.

Information: The Reaction Quotient

The reaction quotient, Q_c, is calculated in the same way as you would calculate the equilibrium constant. For the reaction $aA + bB \leftarrow\rightarrow cC + dD$, the reaction quotient is:

$$Q = \frac{[C]^c[D]^d}{[A]^a[B]^b}$$

It is important to keep in mind that the reaction quotient does not involve equilibrium concentrations. The concentrations used to calculate Q_c are at <u>any time</u>, not just at equilibrium.

Critical Thinking Questions

4. Consider the following reaction: $CO + 3H_2 \leftarrow\rightarrow CH_4 + H_2O$. While carrying out a reaction between carbon monoxide and hydrogen, a scientist analyzed the mixture and found that in the 3.5 L container there were 0.35 moles of CO, 0.42 moles of H_2, 0.29 moles of CH_4, and 0.38 moles of H_2O. What is the reaction quotient for this mixture?

Information: What Q_c Tells Us

As a reaction proceeds it will always tend to go toward equilibrium. For example, the equilibrium constant for the reaction described in question 4 is 3.92. The concentration of products and reactants will adjust themselves so that as the reaction progresses until the products divided by reactants (raised to the appropriate power) will equal 3.92.

Critical Thinking Questions

5. Given your answer to question 4 and the fact that K_c equals 3.92 for the reaction, what must happen for the reaction to reach equilibrium?

   A) more products must form   B) more reactants must form

6. At a certain time during a reaction whose equilibrium constant was 12.5, it was found that the reaction quotient was 4.2. Predict what will happen to the concentration of reactants and products as the reaction progresses.

7. At a certain time during a reaction whose equilibrium constant was 0.45, it was found that the reaction quotient was 2.1. Predict what will happen to the concentration of products and reactants as the reaction progresses.

8. Given your answers to questions 6 and 7, complete the following sentences.

   If Q_c is greater than K_c, then the concentration of products needs to ________________________.

   If Q_c is less than K_c, then the concentration of products needs to ________________________.

9. Consider the equilibrium reaction of hydrogen gas reacting with nitrogen gas to produce ammonia, NH_3. K_c for the reaction is 0.500. A 50.0 L reaction vessel contains 1.00 mol N_2, 3.00 mol H_2, and 0.500 mol of NH_3. Will more NH_3 be formed or will more N_2 and H_2 form as the reaction proceeds?

ChemQuest 48

Intro to Acids and Bases

Name: ________________________
Date: ______________
Hour: _____

Information: Definitions of Acids and Bases

Arrhenius definitions

1) acid: substance that when dissolved in water increases $[H^+]$; (note: H^+ exists bonded to water as the hydronium ion, H_3O^+, so $[H^+]$ and $[H_3O^+]$ are equivalent expressions)
2) base: substance that when dissolved in water increases $[OH^-]$

Bronsted-Lowry definitions

1) acid: substance that donates a proton, H^+, in a reaction
2) base: substance that accepts a proton, H^+, in a reaction

Table 1: Equilibrium constants (at 25°C) for some acid-base equilibrium reactions.

Reaction	K_c
1. $C_2H_3O_2^- + H_2O \leftrightarrow HC_2H_3O_2 + OH^-$	1.07×10^{-11}
2. $HCN + SO_4^{2-} + H_2O \leftrightarrow HSO_4^- + CN^- + H_2O$	4.9×10^{-11}
3. $HC_2H_3O_2 + H_2O \leftrightarrow H_3O^+ + C_2H_3O_2^-$	3.09×10^{-7}
4. $H_2CO_3 + H_2O \leftrightarrow H_3O^+ + HCO_3^-$	7.82×10^{-9}
5. $HCl + H_2O \leftrightarrow H_3O^+ + Cl^-$	2.0×10^{4}

Critical Thinking Questions

1. List all of the reactants in Table 1 that are Arrhenius acids.

2. List all of the reactants in Table 1 that are Arrhenius bases.

3. List all of the reactants in Table 1 that are Bronsted-Lowry acids.

4. List all of the reactants in Table 1 that are Bronsted-Lowry bases.

5. Is it possible for an ion to act as a base? Explain.

6. Can a substance act as both an acid and a base under different conditions? Explain.

7. Is this statement true: "All substances that are Arrhenius acids are also Bronsted-Lowry acids"? Explain.

8. If a substance is a Bronsted-Lowry acid, can we conclude that the substance is also an Arrhenius acid? Explain.

9. a) What is the strongest acid among the reactants in reactions 3-5 inTable 1? Explain.

   b) What is the weakest acid among the reactants in reactions 3-5 inTable 1? Explain.

10. Consider Reaction 3.
    a) What substance is formed (by the acid) after the acid loses a proton?

    b) Is this substance an acid or a base? (Hint: look at reaction 1.)

11. Drawing a conclusion from question 10, what can be said about a substance after it loses a proton? Is the substance formed acidic or basic?

Information: Conjugate Acid-Base Pairs

After an acid loses a proton in a reaction, the substance formed behaves like a base. Verify this by examining Reactions 3 and 1 in Table 1. Notice from reaction 3 that $HC_2H_3O_2$ is an acid. After it loses a proton it becomes the acetate ion, $C_2H_3O_2^-$. The acetate ion is a base, as seen in reaction 1; there is a special name for this base: it is a conjugate base. So, $C_2H_3O_2^-$ is the conjugate base of $HC_2H_3O_2$. Similarly, HSO_4^- is the conjugate acid of SO_4^{2-}. Verify this by examining Reaction 2.

Critical Thinking Questions

12. Describe how a conjugate base is formed.

13. How is a conjugate acid formed?

14. For each of the acids below, write the reaction of the acid with water and circle the formula of the conjugate base in your reaction.
    a) H_2SO_4

    b) HCO_3^-

    c) HF

15. For each of the bases below, write the reaction of the base with water and circle the formula of the conjugate acid in your reaction.
    a) NH_3

    b) OH^-

    c) NO_3^-

ChemQuest 49

pH and pOH

Name: ___________________________

Date: _______________

Hour: _____

Information: Measuring Acidity

Many people have heard of "pH", and many people know that it probably refers to acidity, but not very many understand what exactly it measures. The pH is a measure of the concentration of hydrogen ions (H^+) in a solution. Recall that in water H^+ ions bond to water to form H_3O^+ (hydronium ions). Keep this in mind because hydrogen (H^+) and hydronium (H_3O^+) are often used interchangeably.

The pH of a solution can range from 0-14. The equation for calculating pH is:

$$pH = -\log[H^+]$$

Critical Thinking Questions

1. A certain solution has a concentration of hydrogen ions of 2.5×10^{-3} M. What is the pH?

2. The same solution as question 1 has a concentration of hydroxide ions of 4.0×10^{-12}. What is the pOH?

3. A certain solution has a pH of 5.2. What is the concentration of hydrogen ions?

4. The same solution as question 3 has a pOH of 8.8. What is the concentration of hydroxide ions?

5. Use the information given and your answers to questions 1 and 2 to find the following:
   a) Divide the pH by the pOH of the solution.

   b) Multiply the pH by the pOH of the solution.

   c) Add the pH and the pOH together.

   d) Multiply $[H^+]$ and $[OH^-]$ together.

   e) Divide $[H^+]$ by $[OH^-]$.

6. Use the information given and your answers to questions 3 and 4 to find the following:
   a) Divide the pH by the pOH of the solution.

   b) Multiply the pH by the pOH of the solution.

   c) Add the pH and the pOH together.

   d) Multiply $[H^+]$ and $[OH^-]$ together.

   e) Divide $[H^+]$ by $[OH^-]$.

7. Consider your answers to questions 5 and 6. Were there any that gave the same answer (or just about the same answer)? If so, which ones?

8. Given your answer to number 7, you should be able to answer the following questions.
   a) Find the pH of a solution that has a pOH of 4.6.

   b) The $[H_3O^+]$ of a solution is $2.55\text{x}10^{-3}$ M. What is the $[OH^-]$?

9. What is the pOH of a solution that has a $[H^+] = 4.22 \text{ x } 10^{-3}$ M.

10. A certain solution has a pH of 3.25.
    a) Find the pOH of the solution.

    b) Find the $[H^+]$ of the solution.

    c) Find the $[OH^-]$ of the solution.

11. Find the pH of a 0.035 M solution of HNO_3. (Hint: First find the $[H^+]$ by realizing that nitric acid dissociates according to this balanced equation: $HNO_3 \rightarrow H^+ + NO_3^-$. If the concentration of HNO_3 is 0.035, then $[H^+]$ is also 0.035.)

12. Find the pH of a 0.16 M solution of HCl.

13. Find the pH of a 0.045 M solution of NaOH. ($NaOH \rightarrow Na^+ + OH^-$)

14. Find the pH of a 0.0045 M solution of LiOH.

15. If 14.5 g of NaOH is dissolved in 720 mL of water, what is the pH?

16. A certain solution contains 0.35 mol of HCl in 1200 mL of water.
    a) Find the pH and pOH of the solution.

    b) Find the $[H^+]$ and the $[OH^-]$ in the solution.

ChemQuest 50

Acid/Base Calculations

Name: ______________________________
Date: ________________
Hour: _____

Information: Constants and Equations

You have discovered two fundamental constants represented by the following equations:

1. $pH + pOH = 14$
2. $[OH^-][H^+] = 1x10^{-14}$

A third equation is related to equation 2 above:

3. $(K_a)(K_b) = 1x10^{-14}$

This equation holds true for any conjugate acid-base pair. The K_a for the acid multiplied by the K_b for the conjugate base will always equal $1x10^{-14}$.

The following questions will give you some practice using the above three relationships combined with the equations for pH and pOH that you should already be familiar with.

Critical Thinking Questions

1. The K_a for a certain weak acid is $1.8x10^{-9}$. What is the K_b for the conjugate base of this acid?

2. The K_b for NH_3 is $1.8x10^{-5}$. Write the formula for and calculate the K_a for the conjugate acid of NH_3.

3. The pH of a certain solution was 1.45. What was the pOH?

4. If the hydroxide ion concentration of a certain solution was $2.6x10^{-4}$ M, what is the pH?

Information: Strong Acids and Bases

Acids and bases are called "strong" if they dissociate completely (or almost completely) in water. For example, hydrochloric acid (HCl) exists almost completely as H^+ ions and Cl^- ions in water. Therefore HCl is a strong acid. If you put 2.0 moles of HCl in water, the HCl will dissociate and you will end up having about 2.0 moles of H^+ and 2.0 moles of Cl^- in the water. Each HCl molecule breaks up into two ions when dissolved: $HCl \rightarrow H^+ + Cl^-$. For every mole of HCl added to water, you will get one mole of H^+.

Critical Thinking Questions

5. Consider a strong acid like HCl. If the concentration of the acid is 0.025 M, what is the concentration of hydrogen ions? Explain your reasoning.

6. Consider a strong base such as NaOH. If the concentration of the base is 0.75 M, what is the concentration of the hydroxide ions? Explain.

7. What is the pH of a solution that has a concentration of HCl equal to 0.0049 M?

8. If 2.5 moles of HCl were dissolved in 42 L of water, what would the pH be? What would the pOH be?

9. The strong base, NaOH, was dissolved in water. If 4.2 moles of NaOH was dissolved in 245 L of water, what is the pH of the solution?

Information: Weak Acids and Bases

Weak acids and bases do not dissociate completely in water. For example, consider acetic acid ($HC_2H_3O_2$):

$$HC_2H_3O_2 \leftrightarrow H^+ + C_2H_3O_2^- \,;\; K_a = 1.7\text{x}10^{-5}$$

For HCl, the concentration of HCl equaled the concentration of H^+ so finding the pH was easy. However, for acetic acid, $[HC_2H_3O_2]$ does not equal $[H^+]$ because not all of the $HC_2H_3O_2$ dissociates into H^+ ions. To find the pH of a solution of acetic acid, you first must calculate the $[H^+]$ using the K_a. This will be an equilibrium problem! Once you know $[H^+]$, you calculate pH using pH = -log$[H^+]$.

Critical Thinking Questions

10. What is the pH of a solution that was 0.75 M acetic acid? (Note: 0.75 M is the initial concentration of acetic acid.)
    a) Find the equilibrium concentration of H^+ using the equilibrium constant, K_a, as shown below. Recall that $[C_2H_3O_2^-]$ and $[H^+]$ will equal "x" and $[HC_2H_3O_2]$ will equal 0.75-x.

$$K_a = \frac{[C_2H_3O_2^-][H^+]}{[HC_2H_3O_2]}$$

    b) Now that you know the equilibrium concentration of H^+, calculate the pH.

11. Find the pH of a 0.85 M solution of hydrocyanic acid, HCN, whose $K_a = 4.9x10^{-10}$.

12. Find the pH of a 0.5 M solution of ammonia, NH_3, whose K_b is $1.8x10^{-5}$.

ChemQuest 51

Mixing Acids and Bases

Name: ___________________________
Date: _______________
Hour: _____

Information: Dilutions

When water is added to a solution, the concentration decreases. It is often desirable to be able to calculate the concentration of solutions that have been diluted. For doing this, keep in mind that molarity is equal to the moles of solute divided by the total liters of solution. Therefore, the following equations are valid where M is molarity, $L_{solution}$ is liters of solution and mol_{solute} is the moles of solute:

Equation #1:

$$M = \frac{mol_{solute}}{L_{solution}}$$

Equation #2:

$$mol_{solute} = (M)(L_{solution})$$

Critical Thinking Questions

For the following questions, assume that liquid volumes are additive.

1. A certain solution is prepared by dissolving 4.0 moles of salt (NaCl) in enough water to make 400 mL of solution. Later, the solution was diluted with enough water so that the volume of the solution was 650 mL. Calculate the molarity of the solution before and after dilution.

2. A 6.0 M solution of salt has a volume of 500 mL. Later, 275 mL of water is added. Confirm that the molarity of the resulting is approximately 3.87 M. (Hint: first find the moles of salt present before the additional 275 mL of water was added by using equation #2 and then find the new molarity using equation #1.)

3. Calculate the molarity of the solution formed by taking 350 mL of 2.25 M HCl and adding 420 mL of water.

4. Imagine that you have 300 mL of a stock solution of 2.8 M HCl solution. Describe how I could prepare 50 mL of 1.2 M HCl solution by using some of stock solution and diluting it with water. Be specific.

Information: Mixing Strong Acids and Strong Bases

Usually when we speak of "salt" we mean table salt, which is sodium chloride (NaCl). A salt is a general term for an ionic compound formed when an acid and a base mix. Whenever an acid and a base react, water and a salt are formed. For example consider the following reactions in which nitric acid (HNO_3) and hydrochloric acid (HCl) react with the base sodium hydroxide (NaOH):

$$HCl + NaOH \rightarrow NaCl + H_2O$$
$$HNO_3 + NaOH \rightarrow NaNO_3 + H_2O$$

Notice that in each reaction water and a salt (sodium chloride one reaction and sodium nitrate in another) were formed.

If equal moles of strong acid and strong base react, then they neutralize each other and form a solution of salt water. If there are more moles of acid than base then the resulting solution will be acidic. If there are more moles of base than acid, then the resulting solution will be basic.

Critical Thinking Questions

5. Consider the reaction of 2.5 moles of hydrochloric acid with 1.9 moles of sodium hydroxide.
   a) If this reaction took place in 2.0 L of solution, what is the concentration of leftover hydrochloric acid after the reaction?

   b) From your answer to part a, verify that the pH of the solution after the reaction is approximately 0.52.

6. Question 5 could be rewritten like this: *Consider the reaction of 1.0 L of _____ M hydrochloric acid with 1.0 L of _____ M sodium hydroxide.* Fill in the blanks with the appropriate numbers indicating the molarity.

7. 320 mL of 3.1 M HCl is mixed with 240 mL of 4.1 M NaOH. Use the following steps to find the pH of the resulting solution.
   a) Calculate the moles of HCl and the moles of NaOH that are reacting using Equation #2.

   b) Find out which substance is left over and find out how many moles of this substance is left over.

   c) Divide the moles left over by the total volume in liters to get the concentration of the left over substance.

   d) Your answer to part c is also the concentration of H^+ (if the acid is left over) or the concentration of OH^- (if the base is left over). From this information calculate the pH of the solution. You should get approximately 1.85 for your answer.

8. Calculate the pH of a solution formed by mixing 450 mL of 0.79 M HCl with 430 mL of 1.2 M NaOH. Hint: this is very similar to question 7.

9. Calculate the pH of a solution formed by mixing 820 mL of 1.2 M HNO_3 with 700 mL of 0.9 M NaOH.

10. Consider 400 mL of a 2.5 M HCl solution. How many milliliters of 1.25 M NaOH will be needed to neutralize the HCl?

ChemQuest 52

Acidic Properties of SALTS

Name: ____________________________

Date: ______________

Hour: _____

Information: Review Definitions of Acids and Bases

Recall the definitions of acids and bases according to Bronsted-Lowry:

1) acid: substance that donates a proton, H^+, in a reaction
2) base: substance that accepts a proton, H^+, in a reaction

Recall also, that we have seen that it is possible for ions to act as acids or bases. We will now examine the acidity or basicity of ions.

Critical Thinking Questions

1. If the chloride ion (Cl^-) or the cyanide ion (CN^-) were dissolved in water, would you expect the ions act as acids or bases? Ask yourself: could it accept a H^+? Does it have a H^+ to give away? Explain.

2. If the ammonium ion (NH_4^+) were dissolved in water, would you expect it to act as an acid or base? Explain.

3. Although <u>not all ions act as acids or bases</u>, we can generalize from the above two questions that **IF** an ion acts as an acid or a base the following rules will be observed:

   a) When in water, positive ions may act like _________________.

   b) When in water, negative ions may act like _________________.

Information: Determining Whether an Ion Affects the pH

It was mentioned above that not all ions will act as an acid or a base. Some, in fact, will not affect the pH of a solution at all. We are now going to look at what determines whether an ion affects the pH or not.

Consider the chloride ion. If it affects the pH, it will react with water in the following way:

Equation 1: $Cl^- + H_2O \leftrightarrow HCl + OH^-$

Now consider the cyanide ion. If it affects the pH, it will react with water in the following way:

Equation 2: $CN^- + H_2O \leftrightarrow HCN + OH^-$

Hopefully, these equations confirm what you wrote for the questions above: negative ions, if they affect the pH, will act like bases because they produce OH^- ions. In fact, the cyanide ion (CN^-) is the conjugate base of the weak acid HCN. The base ionization constants (K_b) for equations 1 and 2 are shown below:

$$K_{b1} = \frac{[HCl][OH^-]}{[Cl^-]} \qquad K_{b2} = \frac{[HCN][OH^-]}{[CN^-]}$$

Critical Thinking Questions

4. The expression for K_{b1} assumes that HCl exists in the solution without breaking into ions completely. Similarly, the expression for K_{b2} assumes that HCN exists in solution without breaking into ions completely. However, one of these—HCl or HCN—completely breaks up into ions when dissolved. Which substance breaks up completely into ions? Explain.

5. One of the ions—Cl^- or CN^-—does not affect the pH because it will not react as depicted in equation 1 or 2 above. Given your answer to question 4, which ion do you think will not affect the pH of a solution?

6. Complete the following sentence: The negative ions formed from a ____________ (strong/weak) acid will not affect the pH, but the negative ion formed from a ____________ (strong/weak) acid will raise the pH and act like a(n) ____________ (acid/base).

7. Similar reasoning applies to the positive ions formed from strong and weak bases. Using question six as a pattern, complete the following sentence:

   The positive ions formed from a ____________ (strong/weak) base will not affect the pH, but the positive ion formed from a ____________ (strong/weak) base will lower the pH and act like a(n) ____________ (acid/base).

8. Determine whether each of the following will act like an acid (A) or a base (B). If the ion will not affect the pH, place an X in the blank.

_____ a) Na^+ (from the strong base NaOH)   _____ b) NO_3^- (from the strong acid HNO_3)

_____ c) NH_4^+ (from the weak base NH_3)   _____ d) K^+ (from the strong base KOH)

_____ e) NO_2^- (from the weak acid HNO_2)   _____ f) $C_2H_3O_2^-$ (from the weak acid $HC_2H_3O_2$)

9. Write the chemical equation for acetic acid dissociating.

10. From the K_a of acetic acid ($1.7x10^{-5}$), calculate the K_b for the acetate ion.

11. When ammonia (NH_3) reacts with water, the ammonium ion is formed (NH_4^+). Write the chemical equation for this process.

12. Given the K_b for ammonia ($1.8x10^{-5}$), calculate the K_a for the ammonium ion.

Information: Salts

Salts are ionic compounds. They are similar to strong acids and bases because they dissociate completely in water. However, not all salts affect the pH. Consider the salt sodium acetate ($NaC_2H_3O_2$). If you place 2.0 moles of sodium acetate in 1.0 L of water, it will dissociate completely as follows:

$$NaC_2H_3O_2 \rightarrow Na^+ + C_2H_3O_2^-$$

Each mole of $NaC_2H_3O_2$ breaks up into a mole of Na^+ and a mole of $C_2H_3O_2^-$. Therefore, because you started out with 2.0 moles of $NaC_2H_3O_2$ in 1.0 L of water, the concentration of Na^+ is 2.0 M and the concentration of $C_2H_3O_2^-$ is 2.0 M. We have seen already that Na^+ will not affect the pH since it is derived from the strong base NaOH. $C_2H_3O_2^-$ (derived from the weak acid $HC_2H_3O_2$) will affect the pH by producing OH^- ions: $C_2H_3O_2^- + H_2O \leftrightarrow HC_2H_3O_2 + OH^-$.

Critical Thinking Questions

13. Determine whether each of the following salts will act like an acid (A) or a base (B). If the salt will not affect the pH, place an X in the blank.

_____ a) NaCl   _____ b) NH_4Cl _____ c) NaCN   _____ d) KNO_3

14. What is the pH of a 0.45 M solution of $NaC_2H_3O_2$? (Follow the following steps.)
    a) Will Na^+ or will $C_2H_3O_2^-$ affect the pH?

    b) Hopefully your answer to part a is $C_2H_3O_2^-$. Find the concentration of $C_2H_3O_2^-$ in the solution. (Note: remember that salts dissociate completely.)

    c) Now that you know $[C_2H_3O_2^-]_{initial}$ complete the necessary equilibrium calculations using the K_b for $C_2H_3O_2^-$ (see question 10) to calculate $[OH^-]$.

    d) Calculate the pOH of the solution.

    e) From the pOH, verify that the pH is 9.2.

15. Find the pH of a 0.32 M solution of NH_4NO_3.

ChemQuest 53

The First Law of Thermodynamics

Name: ____________________________
Date: _______________
Hour: _____

Information: Internal Energy

Thermodynamics involves the study of the energy and disorder of a system. Every system has "internal energy". Internal energy is the total amount of all the potential and kinetic energy that a system has. For an example of a "system" let's take a car. A car has kinetic energy (the energy of motion) ***if*** it is moving and it has potential energy (chemical energy of the gasoline) ***if*** it has gas in the tank. A car always has a certain amount of energy associated with it. A car has more total energy (chemical potential energy) with a full tank of gas than with a half full tank. Therefore, after driving a car for a while the total amount of energy (called the internal energy) that the car has decreases.

Critical Thinking Questions

1. If we use KE to symbolize kinetic energy and PE to symbolize potential energy, and U to symbolize internal energy, then write an equation for internal energy.

2. Consider a car as described in the table below. Fill in the blanks in the table with the hypothetical values for kinetic energy, potential energy, and internal energy. (Assume that the overall mass of the car stays the same even though the amount of gasoline in the tank decreases.)

	A car is setting in the driveway before a long road trip. The gas tank is full.	The car has set out on the trip and has been driving for a while. Cruise control is set for a constant speed.	The car is still driving at the same speed.	The car ran out of gas and is parked along the highway.
Kinetic Energy		20		
Potential Energy	100		30	
Internal Energy		90		

3. The Law of the Conservation of Energy states that energy isn't created or destroyed. The car in question 2, lost energy. If the energy was not destroyed, hypothesize what happened to it.

4. What would be the internal energy of the car in question 2 if someone brought enough gas to fill the tank back up completely while the car was stranded at the side of the highway?

Information: First Law of Thermodynamics

As you saw in question 2 above, the internal energy of a system can change. What happens to the energy? The energy merely changes form. In the car example, the internal energy was changed into heat energy as the gasoline burned. Also, some of the internal energy was used to do work by moving the car. The First Law of Thermodynamics states that the change in internal energy of a system equals the sum of the heat and the work. Internal energy of a system can increase or decrease. If a system is heated, it gains internal energy, but if the system loses heat then it decreases in internal energy. If a system does work it loses internal energy, but if work is done on the system then it gains internal energy.

Critical Thinking Questions

5. For each of the following, state what the "system" is and also state whether the internal energy of the system would increase or decrease in each situation.
   a) Lifting a ball from the ground and holding it six feet off the ground.

   b) Heating up a piece of pizza in the microwave.

   c) The logs in the fireplace are burning.

   d) An ice cube is melting while it sets on the kitchen counter.

   e) Two molecules bond together and heat energy is released (exothermic).

Information: Enthalpy

Heat energy is a large factor in how much the internal energy of a system changes. We will now turn our attention to chemical reactions. In your answer to question 5e above you should have identified the two molecules as the "system" and you should have noted that their overall internal energy decreased since they lost heat. Verify that this is correct. The heat energy involved in a chemical reaction is given the name "enthalpy". The change in heat energy for a reaction is called the change in enthalpy and it is given the symbol ΔH and it has units of kilojoules (kJ). An example of 5e taking place is when one mole of hydrogen molecules reacts with ½ mole of oxygen molecules:

Example Reaction 1: $H_2\ (g) + \frac{1}{2}\ O_2\ (g) \rightarrow H_2O\ (g)$; $\Delta H_f = -241.8$ kJ

In the following reaction, energy is absorbed by the system (endothermic) instead of being released.

Example Reaction 2: $C\ (s) + 2\ S\ (s) \rightarrow CS_2\ (g)$; $\Delta H_f = 117$ kJ

Critical Thinking Questions

6. Give the definition for the following terms.
   a) endothermic:

   b) exothermic:

7. In the above examples, Example Reaction 1 ΔH is negative and in Example Reaction 2 ΔH is positive. What does the sign on ΔH tell you?

8. In Example Reaction 1, compare the amount of energy that the product has compared to the reactants.

9. In Example Reaction 2, compare the amount of energy that the product has compared to the reactants.

Information: Enthalpy of Formation

In Example Reaction 1 and 2, one substance was formed out of two. Whenever one substance is made from elements in their standard states, the accompanying enthalpy change is called the enthalpy of formation, given the symbol ΔH_f. Note the following two example reactions:

Example Reaction 3: H_2 (g) + S (s) → H_2S (g); ΔH_f = -20 kJ

Example Reaction 4: C (s) + O_2 (g) → CO_2 (g); ΔH_f = -393.5 kJ

Notice that in the previous 4 example reactions, each substance formed is involved in the following reaction:

Example Reaction 5: 2 H_2O (g) + CS_2 (g) → 2 H_2S (g) + CO_2 (g); ΔH = ?

The ΔH for Example Reaction 5 can be calculated from the data for Example Reactions 1-4 as follows:

$$\Delta H = [2(-20 \text{ kJ}) + (-393.5 \text{ kJ})] - [2(-241.8 \text{ kJ}) + (117 \text{ kJ})] = -66.9 \text{ kJ}$$

Critical Thinking Questions

10. In Example Reactions 1-4, the enthalpy value was given the symbol ΔH_f, but in Example Reaction 5, the enthalpy value was given the symbol ΔH. Why the difference?

11. In calculating the ΔH for Example Reaction 5, why was –20kJ multiplied by 2? Why was the –241.8kJ multiplied by 2?

12. Using a table for standard enthalpies of formation (ΔH_f), verify that ΔH for the following reaction is approximately –91.4 kJ.

$$2\ NaF + CaCl_2 \rightarrow CaF_2 + 2\ NaCl$$

13. Again using a table of standard enthalpy values calculate ΔH for each of the following reactions.

    a) $LiCl + NaBr \rightarrow NaCl + LiBr$

    b) $MgCO_3 + 2\,NaCl \rightarrow Na_2CO_3 + MgCl_2$

    c) $CH_4 + Cl_2 \rightarrow HCl\,(g) + CH_3Cl$

14. In 13c, you should have noted that ΔH_f for Cl_2 is zero. ΔH_f is also zero for O_2, Na (s), Mg (s), and other substances. Why do you think ΔH_f is zero for these substances?

15. Compare the ΔH_f for O_2 (g) and for O (g). Why is ΔH_f equal to zero for O_2, but not for O?

16. Calculate ΔH for the following reaction using a table for standard enthalpy values:
    $2\,CO + O_2 \rightarrow 2\,CO_2$.

17. Consider the following reactions and ΔH values

$$C + O_2 \rightarrow CO_2 \;;\; \Delta H_f = -393.5 \text{ kJ}$$
$$2\,CO \rightarrow CO_2 + C \;;\; \Delta H = -172.5$$

    a) Using only the above two ΔH values, how can you calculate ΔH for the reaction in question 16?

    b) What is the relationship between the two reactions above and the reaction in question 16?

18. In question 17a, you used Hess's Law to find the ΔH for a reaction even though you didn't know what Hess's Law is. In your own words, state what you believe is Hess's Law.

19. Consider the following reaction: $N_2 + 2\ O_2 + 2\ NO \rightarrow 2\ NO + 2\ NO_2$. Use Hess's Law along with the following information to find the ΔH for this reaction.

    reaction #1 $N_2 + O_2 \rightarrow 2\ NO$; $\Delta H = 181$ kJ
    reaction #2 $2\ NO + O_2 \rightarrow 2\ NO_2$; $\Delta H = -113$ kJ

20. Consider the following reaction: $2\ NO \rightarrow N_2 + O_2$; $\Delta H = -181$ kJ. What relationship exists between this reaction and reaction #1 in question 19? How could the □H for this reaction be determined?

21. Using only the information presented in question 12, find the ΔH for the following reaction.

    $CaF_2 + 2\ NaCl \rightarrow 2\ NaF + CaCl_2$

ChemQuest 54

The Second Law of Thermodynamics

Name: ___________________________

Date: ______________

Hour: _____

Information: Spontaneity

It is often desirable to know if a process will occur all by itself or if you need to supply energy for a process to occur. If a process occurs naturally, all by itself without outside help, it is said to be spontaneous. Examples of spontaneous processes include iron rusting and a ball rolling down a hill.

Critical Thinking Questions

1. Which of the following processes are spontaneous?
   a) a rock rolling uphill b) a leaf falling c) water boiling at $100^{o}C$

Information: Entropy

It is important to consider the amount of disorder in a system when determining whether a reaction will occur spontaneously. Just as the energy change is given a special name and symbol (change in enthalpy, ΔH), the change in the amount disorder or randomness is also given a special name, "change in entropy", which has the symbol ΔS. Entropy, S, is a measure of the amount of disorder in a system. When disorder increases, ΔS is positive.

Critical Thinking Questions

2. When $\Delta H_{reaction}$ is negative that means that the reaction loses energy to become less energetic. When $\Delta S_{reaction}$ is negative, what is that telling us?

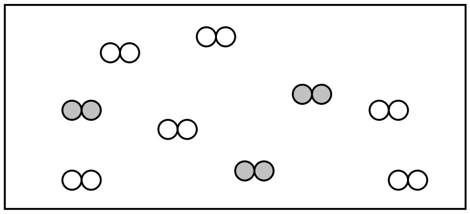
3. Does disorder (entropy) increase or decrease for the formation of gaseous water?

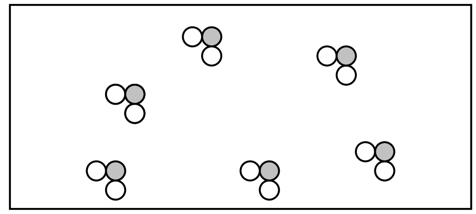
$$2\ H_2\ (g)\ +\ O_2\ (g) \rightarrow 2\ H_2O\ (g)$$

Note the diagrams below in which every molecule is moving randomly. Explain your answer using the diagrams.

= O_2 molecule
= H_2 molecule

= H_2O molecule





4. Indicate whether for each of the following processes ΔS will be positive or negative. Explain each answer. (Hint: think in terms of the disorder or randomness of molecules and molecular motion.)
   a) an ice cube melting

   b) water vaporizing

   c) cleaning your room

   d) folding paper into a paper airplane

<u>Information</u>: Comparing Entropy and Enthalpy

It was once thought that for a chemical reaction to be spontaneous that it also had to be exothermic ($\Delta H<0$). Now, however, we recognize that some endothermic reactions are spontaneous. When deciding whether a reaction is spontaneous, you need to consider both entropy and enthalpy. Note that for any reaction you will have the reaction itself and its surroundings. Both the reaction and its surroundings together are called the universe so that $\Delta S_{universe} = \Delta S_{reaction} + \Delta S_{surroundings}$. Consider the following table:

Reaction	sign of $\Delta H_{reaction}$	Sign of $\Delta S_{reaction}$	Sign of $\Delta S_{surroundings}$	Sign of $\Delta S_{universe}$	Spontaneous?
#1 exothermic, entropy increase	-	+	+	+	yes
#2 endothermic, entropy increase	+	+	-	+ or -	depends
#3 exothermic, entropy decrease	-	-	+	+ or -	depends
#4 endothermic, entropy decrease	+	-	-	-	no

Critical Thinking Questions

5. For reaction #2, according to the table, it says that there is an entropy increase. What entropy is it referring to—$\Delta S_{reaction}$, $\Delta S_{surroundings}$, or $\Delta S_{universe}$?

6. Why can $\Delta S_{universe}$ be + or – for reactions two or three?

7. What is the correlation between the sign of $\Delta H_{reaction}$ and the sign of $\Delta S_{surroundings}$?

8. The sign of $\Delta H_{reaction}$ ***determines*** the sign of $\Delta S_{surroundings}$. Explain why this is true. (Hint: think about what happens to the motion of molecules in the surroundings when $\Delta H_{reaction}$ is positive and when it is negative.)

9. On the table above, the sign of one value determines whether the reactions are spontaneous or not. Which value's sign determines the spontaneity of a reaction?

10. Use your answer to question 9 to fill in the blanks. This is a statement of the Second Law of Thermodynamics!

    For any spontaneous reaction, the amount of ________________ in the universe must
    (enthalpy or entropy)

    ________________.
    (increase or decrease)

11. In the above information section, the statement was made that "When deciding whether a reaction is spontaneous, you need to consider both entropy and enthalpy." If only one value (answer to question 9) is needed to determine spontaneity, then why do you still need to consider the enthalpy?

Information: Predicting and Calculating Entropy Changes

Consider question 3 along with the diagrams of oxygen, hydrogen and water molecules.

$$2\ H_2\ (g)\ +\ O_2\ (g)\ \rightarrow\ 2\ H_2O\ (g)$$

When the two gaseous reactants (oxygen and hydrogen) combined to form gaseous water, hopefully you concluded that entropy decreased. Notice that in the balanced chemical equation, there are a total of three moles of gaseous reactants ($2\ H_2 + O_2$) and only two moles of gaseous products ($2H_2O$). In general, then, whenever the number of moles of gaseous products is less than the number of moles of gaseous reactants entropy will decrease. If there are more moles of gaseous products than gaseous reactants, entropy has increased.

Critical Thinking Questions

12. Explain why ΔS is negative for the following reaction.

$$2\ Ca\ (s) + O_2\ (g) \rightarrow 2\ CaO\ (s)$$

13. For each of the following reactions, predict if the entropy change is positive or negative. If you cannot tell, explain why.

 A) $C_2H_2\ (g) + 2\ H_2\ (g) \rightarrow C_2H_6\ (g)$

 B) $CH_3NH_2\ (g) \rightarrow HCN\ (g) + 2\ H_2\ (g)$

 C) $N_2\ (g) + O_2\ (g) \rightarrow 2\ NO\ (g)$

14. Entropy values can be calculated in much the same was as enthalpy values. Using a table of standard entropies, calculate the entropy change for the following reactions.

 A) $N_2\ (g) + O_2\ (g) \rightarrow 2\ NO\ (g)$

 B) $CS_2\ (g) + 4\ H_2\ (g) \rightarrow CH_4\ (g) + 2\ H_2S\ (g)$

 C) $2\ H_2\ (g) + O_2\ (g) \rightarrow 2\ H_2O\ (g)$

ChemQuest 55

Free Energy

Name: ____________________________
Date: ______________
Hour: _____

Information: Free Energy

So far in our study of thermodynamics, we have seen that in order to determine if a reaction is spontaneous we must examine the entropy change (ΔS) and the enthalpy change (ΔH) associated with the reaction. A single quantity that combines both of these ideas is called the Gibbs Free Energy, which is given the symbol G. The change in free energy is related to the change in ethalpy for a reaction and the change in entropy for a reaction according to the following equation:

$$\Delta G = \Delta H - T\Delta S$$

- T is the temperature in units of Kelvin
- ΔH is $\Delta H_{reaction}$ (in Joules or kilojoules)
- ΔS is $\Delta S_{reaction}$ (in Joules or kilojoules)
- Note: $\Delta H_{reaction}$ and $\Delta S_{reaction}$ must either both be Joules or both kilojoules

Recall the following table:

Reaction	sign of $\Delta H_{reaction}$	Sign of $\Delta S_{reaction}$	Sign of $\Delta S_{surroundings}$	Sign of $\Delta S_{universe}$	Spontaneous?
#1 exothermic, entropy increase	-	+	+	+	yes
#2 endothermic, entropy increase	+	+	-	+ or -	depends
#3 exothermic, entropy decrease	-	-	+	+ or -	depends
#4 endothermic, entropy decrease	+	-	-	-	no

Critical Thinking Questions

1. What units must ΔS have if it is to be used in the above equation for free energy?

2. For a spontaneous reaction, what is the sign of ΔG—positive or negative?

3. For a nonspontaneous reaction, what is the sign of ΔG—positive or negative?

4. In the table above, under "Spontaneous" for reactions #2 and #3 it says, "depends". What does this mean? In other words, what does the spontaneity depend on in reaction #2 and reaction #3?

5. You have seen that $\Delta H_{reaction}$ can be calculated by the following:

   $$\Delta H_{reaction} = [\text{sum of } \Delta H_f \text{ of products}] - [\text{sum of } \Delta H_f \text{ of reactants}]$$

   The ΔS and ΔG for reactions can be calculated in the same way using values from a table of standard values. Use the information in a table of standard values and the following balanced equation to prove that $\Delta G = \Delta H - T\Delta S$. Pay special attention to units and note that each value in the table was determined at 25°C (298 K).

   $$CaCO_3\ (s) \rightarrow CaO\ (s) + CO_2\ (g)$$

6. Is the reaction from question 5 spontaneous at 25°C? Explain.

7. By varying the temperature, is it possible to change the spontaneity of the reaction from question 5? Explain.

<u>Information</u>: Coupling Reactions

Sometimes in industry we need to carry out nonspontaneous reactions. An example of a nonspontaneous reaction is isolating iron from iron ore. The equation and free energy are given below:

$$2\ Fe_2O_3\ (g) \rightarrow 4\ Fe\ (s) + 3\ O_2\ (g)\ ;\ \Delta G = 1487\ kJ$$

To get this reaction to proceed spontaneously, you can "couple" it with another reaction. One such reaction would be the conversion of carbon monoxide to carbon dioxide. This equation and its free energy is given below:

$$6\ CO\ (g) + 3\ O_2\ (g) \rightarrow 6\ CO_2\ (g)\ ;\ \Delta G = -1543\ kJ$$

By "coupling" the reactions, we essentially carry out both reactions at the same time and use the spontaneous reaction to drive the nonspontaneous one. The overall ΔG for the process then becomes -56 kJ (found by adding -1543 + 1487). The overall final balanced equation is then:

$$2\ Fe_2O_3\ (g) + 6\ CO\ (g) \rightarrow 4\ Fe\ (s) + 6\ CO_2\ (g)\ ;\ \Delta G = -56\ kJ$$

Critical Thinking Questions

8. In the overall final balanced equation above, why isn't O_2 written?

9. Consider the following reaction to obtain pure aluminum from aluminum ore:

$$Al_2O_3\ (s)\ +\ 2\ Fe\ (s)\ \rightarrow\ Fe_2O_3\ (s)\ +\ 2\ Al\ (s)$$

Which of the following two reactions would prove beneficial when coupled with the above reaction?

a) $CH_4\ (g)\ +\ 2\ O_2\ (g)\ \rightarrow\ CO_2\ (g)\ +\ 2\ H_2O\ (g)$

OR

b) $2\ CH_3OH\ (l)\ +\ 3\ O_2\ (g)\ \rightarrow\ 2\ CO_2\ (g)\ +\ 4\ H_2O\ (l)$

10. Given your answer to question 9, write the overall equation (after coupling) and calculate the ΔG for this overall reaction.