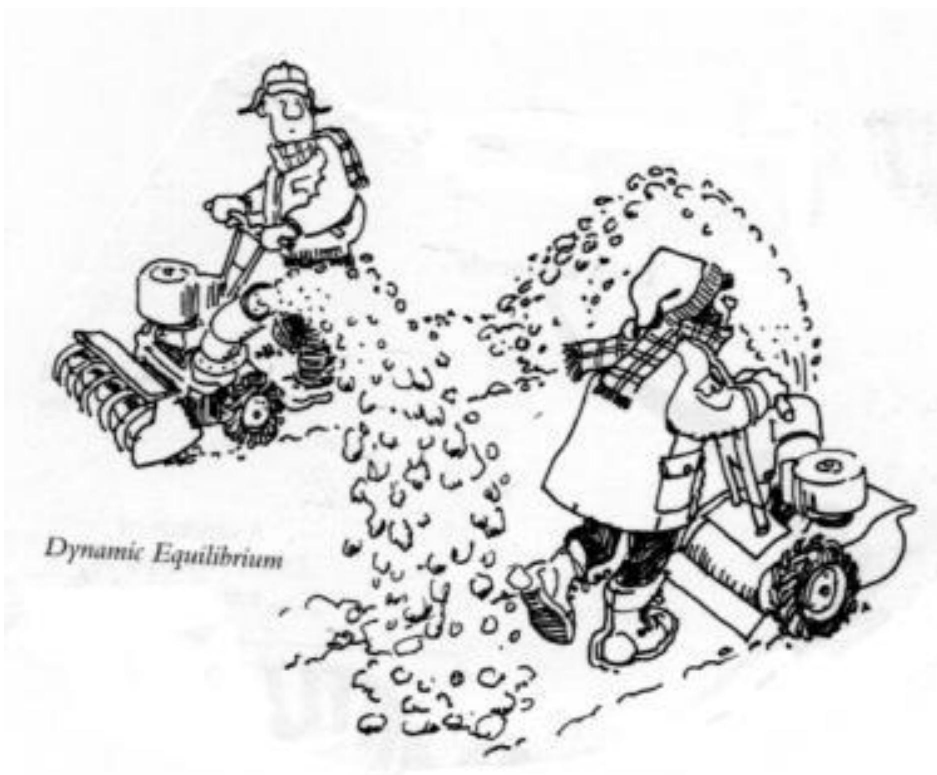
CHEMISTRY 40S

The Alchemist's Cookbook

UNIT 3 – CHEMICAL EQUILIBRIUM



NAME:____________________________________

It is expected that the activities in this book are completed as they are performed in class. This book will be collected at the end of the unit and a mark will be given.

LET'S GET STARTED!

By the end of this unit, you should be able to:

- ✓ Explain the concept of equilibrium as it relates to physical and chemical systems.
- ✓ Use an ICE table to determine equilibrium concentrations of reactants and products from initial concentrations.
- ✓ Interpret and sketch concentration vs time graphs of reactions proceeding towards equilibrium.
- ✓ Write equilibrium expressions from a balanced chemical equation.
- ✓ Calculate the equilibrium constant of a reaction from initial concentrations and one final concentration using an ICE table.
- ✓ Use the value of an equilibrium constant (K) to explain how far a system at equilibrium has gone towards completion.
- ✓ Use Le Chatelier's Principle to predict and explain shifts in equilibrium systems.
- ✓ Perform a lab activity demonstrating Le Chatelier's principle.
- ✓ Describe the Haber Process as a practical application of Le Chatelier's principle.
- ✓ Calculate the equilibrium concentrations of reactants and products from the initial concentrations and the K value for the reaction.
- ✓ Use the reaction quotient (Q) to predict whether a reaction is at equilibrium or not and how it will shift to reach equilibrium.
- ✓ Write solubility product (Ksp) expressions from balanced dissociation equations of salts with low solubility.
- ✓ Calculate Ksp from the solubility of a saturated salt solution using an ICE table.
- ✓ Calculate the solubility of a salt from the Ksp value using an ICE table.
- ✓ Describe the effect of a common ion on the solubility of a salt.
- ✓ Perform a lab activity to determine the Ksp of a salt with low solubility.

This unit will take approximately 20 lessons to complete and will comprise 18% of your mark in this class.

ACTIVITY #1 – WELCOME TO EQUILIBRIUM ISLAND!

Fantasy Island was a 70's television drama. In the show, the island was run by the mysterious Mr. Roarke and his assistant Tattoo. People from all walks of life would come and live out their fantasies, albeit for a price. In many episodes, people would find true love on the island, while in others, struggling couples would split up. The goal of this activity is for you to explore how an equilibrium can be established in a human population on Equilibrium Island (a cheap knock-off of Fantasy Island). You will be dealing with populations of humans, but all the general ideas can be carried forward to deal with populations of molecules.

Equilibrium Island is a small semi-tropical island out in the Pacific, and onto this island, we put **one thousand single men** and **one thousand single women** (assume all are heterosexual for the simplicity of our calculations). There is a single office on the island that performs marriages, and a single office that conducts no-fault divorces. Both offices can handle up to 600 couples per day. We will assume that the people on this island are very impulsive and make major decisions (such as whether to get married or divorced) on a whim. Basically, if a single gal meets a single guy who seems compatible, they'll run off to the marriage office in a jif, whereas a married couple that has a couple of arguments will be headed for the divorce office. There is a law that you can't get married and divorced on the same day (it's known as the "One Day Cool Off" law). Both offices are closed between 11:00 pm and 7:00 am.

QUESTIONS:

1. Let us assume that the Islanders are pretty friendly people, so that **60%** of the single people will get **married** on a given day. Another way of looking at it is that if you are single, you have a 60% chance of getting married that day.

    a. How many weddings will take place on the first day?

    b. How many weddings will take place on the second day? *Hint: it's not the same answer as (a) because there are fewer single people out there to get married! Only **60%** of the* SINGLE *people will get married. . .*

2. On the first day, there will be no divorces, but starting on the second day, couples will be breaking up. Let's assume that **20%** of the couples will break up on a given day. That is, if you started the day married, you will have a 20% chance of ending the day single.

    a. How many DIVORCES will there be on the second day? *Hint: this number will be **20%** of the* COUPLES. *That means you have to calculate 20% of 600. . .*

    b. At the end of the second day, there will be **720 COUPLES** on the island. **Explain** (with the use of mathematics) why there will be 720 couples at the end of the second day. *Note: some of these couples will be "brand new" while others will be "leftovers" from day one.*

3. Complete the table shown below. Starting on day 4, you will get decimal values. You should **use these decimal values up until the last line ("Equilibrium") in which you should round to the nearest whole number.** *Note: I have inserted some numbers into the table. Don't try to change these numbers—instead use them as check points to assist you in getting the right answers for the other blanks in the table.*

Day	Number of **COUPLES** at the start of the day	Number of ***SINGLE*** women (or single men) at the start of the day	Number of additional couples formed on that day (i.e. number of weddings) *60% OF* ***SINGLES*** *GET MARRIED*	Number of couples that break up (i.e. number of divorces) 20% OF **COUPLES** BREAK UP	Number of **couples** at the end of the day
1	0	1000		0	
2	600	400			
3					744
4 *use decimal values here!*					
5					
6					
7					
Equilibrium (round the value for # of couples to a WHOLE number)					

4. As you have seen in the table, after ~7 days, the number of couples on the island will reach a STEADY DAY-TO-DAY VALUE (for example 750 couples today, 750 couples tomorrow, 750 couples the day after, etc.). **Explain why** the number of couples reaches a "plateau" that remains stable day after day. *Note: this is asking you to define how an EQUILIBRIUM works.*

ACTIVITY #2 – ANALYZING EQUILIBRIUM

1. When dinitrogen tetroxide gas, $N_2O_4(g)$, is placed in a sealed container at 100°C, it decomposes into nitrogen dioxide gas, $NO_2(g)$, according to the following balanced equation:

$$N_2O_4(g) \leftrightarrow 2\ NO_2(g)$$

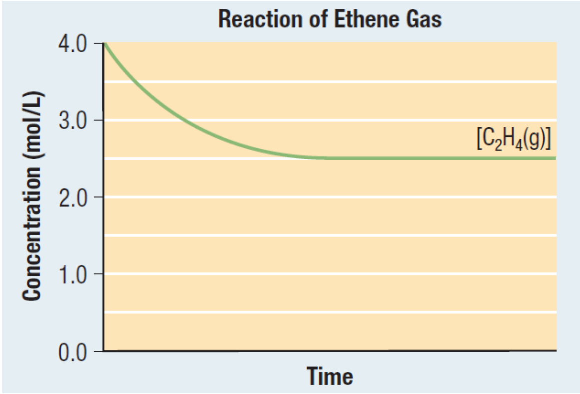
   A lab technician places 0.25 mol of dinitrogen tetroxide in a 1.0 L closed container. At equilibrium, the concentration of nitrogen dioxide is 0.25 mol/L. Use an ICE table to determine the equilibrium concentration of dinitrogen tetroxide.

2. At 35°C, 3.00 mol of pure nitrosyl chloride gas, NOCl(g), is contained in a sealed 3.00 L flask. The nitrosyl chloride gas decomposes into nitrogen monoxide gas, NO(g), and chlorine gas, $Cl_2(g)$, until equilibrium is reached.

$$2\ NOCl(g) \leftrightarrow 2\ NO(g) + Cl_2(g)$$

   At equilibrium, the concentration of nitrogen monoxide is 0.043 mol/L. Use an ICE table to determine the equilibrium concentrations of each chemical.

3. A chemist places 2.00 mol of ethene gas, $C_2H_4(g)$, and 1.25 mol of bromine gas, $Br_2(g)$, in a sealed 0.500 L container. The graph to the right shows the concentration of ethen gas over time. The balanced chemical equation for the reaction is as follows:



$$C_2H_4(g) + Br_2(g) \leftrightarrow C_2H_4Br_2(g)$$

a) Determine the equilibrium concentrations of all three chemicals in the reaction.

b) Sketch lines on the graph for the change in concentration of bromine gas and $C_2H_4Br_2(g)$ over time.

4. Sulphuric acid is an important industrial chemical that is usually produced by a series of chemical reaction. One of these reactions involves an equilibrium between gaseous sulphur dioxide, oxygen, and sulphur trioxide.

$$2\ SO_2(g) + O_2(g) \leftrightarrow 2\ SO_3(g)$$

If 2.5 mol of $SO_2(g)$ and 2.0 mol of $O_2(g)$ are placed in a 1.0 L sealed container aand allowed to reach equilibrium, 0.75 mol of sulphur dioxide will remain. Use an ICE table to determine the concentration of the other gases at equilibrium.

5. Phosphorus pentachloride, $PCl_5(g)$, will decompose to phosphorus trichloride, $PCl_3(g)$, and chlorine gas, $Cl_2(g)$, at 160°C. In a sealed vessel, the reaction will proceed to equilibrium:

$$PCl_5(g) \leftrightarrow PCl_3(g) + Cl_2(g)$$

A chemist places 3.00 mol of $PCl_5(g)$ into a sealed 1.50 L flask at 160°C. After 7.0 minutes, equilibrium is reached, and he observes there is 0.300 mol of $PCl_3(g)$ and some chlorine gas.

a) Calculate the equilibrium concentrations of $PCl_5(g)$ and $Cl_2(g)$.

b) Create and sketch a graph on the grid below showing the changes in concentration over time of all three chemicals involved in the reaction.

ACTIVITY #3 – "EXPRESS" YOURSELF…THE EQUILIBRIUM WAY!

A chemist was studying the decomposition of methanol, CH_3OH at a high temperature. She placed 1.0 mol of methanol into a 5.0-L flask and allowed it to decompose for 30 min at the high temperature. After 20 min, the concentration of CH_3OH had fallen to 0.050-M where it remained for the remainder of the experiment.

$$CH_3OH\ (g) \leftrightarrow CO\ (g) + 2\ H_2\ (g)$$

1. On a separate piece of paper, create an ICE table to determine the equilibrium concentrations of each of the gases involved in the reaction. List the equilibrium values below:

   $[CH_3OH(g)]$ = ______________ $[CO(g)]$ = _______________ $[H_2(g)]$ = __________________

2. Sketch a **concentration vs time** graph that would accurately reflect the data from the experiment above. Show how the concentrations of all three species in the reaction would have changed over the 30 min interval.

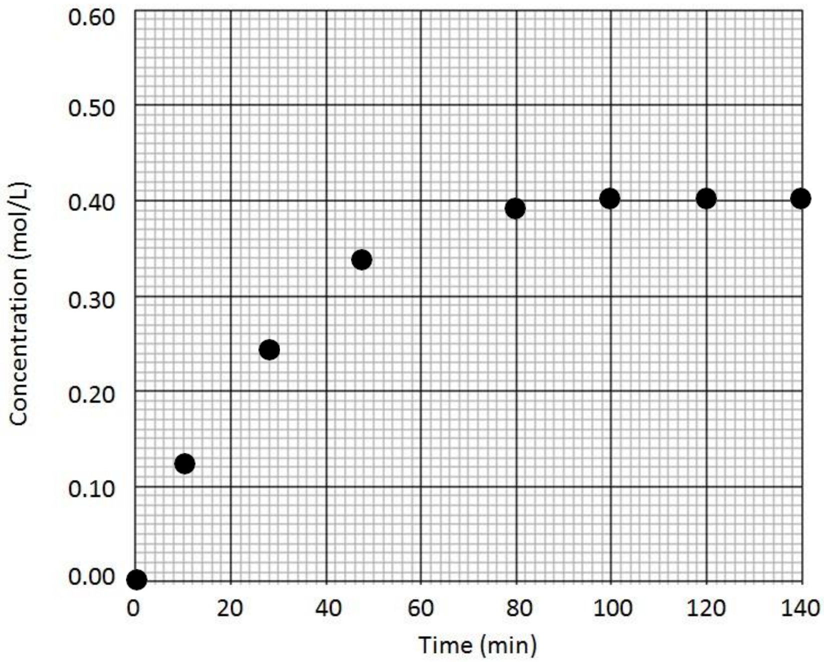
3. Write the **equilibrium (K) expression** for the reaction.

4. Based on the information from your graph above, **calculate K** for the experiment. Is this reaction reactant or product favoured.

A chemist was studying the reaction below at room temperature:

$$2\ SO_2\ (g) + O_2\ (g) \leftrightarrow 2\ SO_3\ (g)$$

She placed 3.0 mol of SO_2 and 2.0 mol of O_2 into a 5.0-L flask. During the reaction, she measured the change in $[SO_3]$ over time and obtained the following graph:



1. At what time does it appear that the system reached equilibrium? How can you tell?

2. On a separate piece of paper, create an ICE table to determine the equilibrium concentrations of each of the gases involved in the reaction. List the equilibrium values below:

   $[SO_2(g)]$ = ______________ $[O_2(g)]$ = _______________ $[SO_3(g)]$ = __________________

3. Sketch and label two curves on the graph above showing the change in $[SO_2]$ and $[O_2]$ during the experiment.

4. Write the K expression for the reaction based on the balanced equation and calculate its value at the temperature for this experiment. Is this reaction reactant or product favoured? Why?

5. Write equilibrium expressions for each of the following reactions:

$CaCO_3(s) \rightleftharpoons CaO(s) + CO_2(g)$

$Ni(s) + 4CO(g) \rightleftharpoons Ni(CO)_4(g)$

$5CO(g) + I_2O_5(s) \rightleftharpoons I_2(g) + 5CO_2(g)$

$Ca(HCO_3)_2(aq) \rightleftharpoons CaCO_3(s) + H_2O(l) + CO_2(g)$

$AgCl(s) \rightleftharpoons Ag^+(aq) + Cl^-(aq)$

6. In the following system:

$$CH_3COOH(aq) + C_2H_5OH(aq) \leftrightarrow CH_3COOC_2H_5(aq) + H_2O(aq)$$

The K value for this reaction is 4.10 at 25°C. If the equilibrium concentrations of $[CH_3COOH]$ = 0.210mol/L, $[H_2O]$ = 0.00850 mol/L and $[CH_3COOC_2H_5]$ = 0.910 mol/L, what is the $[C_2H_5OH]$?

ACTIVITY #4 – DEMO LAB: OOOHHH…PRETTY COLOURS!

In this activity, you will be introduced to Le Chatelier's Principle. Simply put, the principle states that anytime a system at equilibrium is disturbed, the reaction adjusts in such a way as to counteract the disturbance and re-establish equilibrium. You will investigate this by observing the changes in colour of a complex equilibrium system.

Safety:

Working with chromate and dichromate compounds always requires the user to wear gloves and eye protection. If you get any solution on your skin, wash the area with water immediately.

Pre-Lab:

Chromate ion has the formula ___________ and has the color of ____________

Dichromate ion has the formula ___________ and has the color of ____________

Chemical equation showing the equilibrium reaction is:

$\leftrightarrows$

We will apply the following chemical stresses to this reaction by doing the following:

a) Addition of $H^+(aq)$ by adding a strong acid. Remember…strong acids fully ionize to produce solutions with a high concentration of $H^+(aq)$

b) Removal of $H^+(aq)$ by adding $OH^-(aq)$. Remember…$H^+(aq)$ reacts with $OH^-(aq)$ to form liquid water according the reaction below.

$\leftrightarrows$

Observations:

1. Addition of HCl:

2. Addition of NaOH:

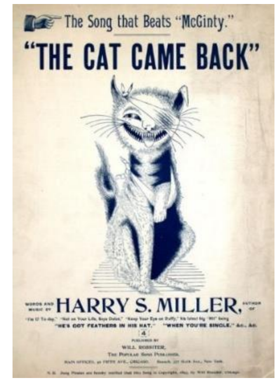
Conclusions:

STRESS	*Colour Change*	*Equilibrium Shifted…*
Add H^+		
Add OH^-		

I think that the addition of $H^+(aq)$ to the equilibrium caused the reaction to shift the way it did because:

I think that the addition of $OH^-(aq)$ to the equilibrium caused the reaction to shift the way it did because:

ACTIVITY #5 – LE CHAT CAME BACK, THE VERY NEXT DAY!!



1. Describe the changes that occur in the moments **after** each stress is applied to the equilibrium. Use an up arrow to show increase, a down arrow to show decrease, and left and right arrows to signify a rate shift in each direction.

   a. $N_{2\,(g)}$ + $3H_{2\,(g)}$ $\leftrightharpoons$ $2NH_{3(g)}$ + 92 KJ

Initial Stress	Gradual Change Over Time				
	$[N_2]$	$[H_2]$	$[NH_3]$	Shifts	Creates More
$[N_2]$ is Increased					
$[H_2]$ is increased					
$[NH_3]$ is increased					
Temp is increased					
$[N_2]$ is Decreased					
$[H_2]$ is Decreased					
$[NH_3]$ is decreased					
Temp is Decreased					
A catalyst is added					
He(g) is added.					

b. $N_2O_4\,_{(g)}$ ⇋ $2NO_{2(g)}$ $\Delta H = + 92$ KJ

INITIAL STRESS	**GRADUAL CHANGE OVER TIME**			
	[N_2O_4]	**[NO_2]**	**Shifts**	**Creates More**
[N_2O_4] is increased				
[NO_2] is increased				
Temp is increased				
[N_2O_4] is decreased				
[H_2] is decreased				
[NO_2] is decreased				
Temp is decreased				

c) $4HCl\,_{(g)}$ + $O_2\,_{(g)}$ ⇋ $2H_2O_{(g)}$ + $2Cl_2\,_{(g)}$ + 98 KJ

Initial Stress	**GRADUAL CHANGE OVER TIME**				
	[O_2]	**[H_2O]**	**[HCl]**	**Shifts**	**Creates More**
[HCl] is increased					
[H_2O] is increased					
[O_2] is increased					
Temp is increased					
[H_2O] is decreased					
[HCl] is decreased					
[O_2] is decreased					
Temp is decreased					
A catalyst is added					

2. State the direction in which each of the following equilibrium systems would be shifted upon the application of the following stress listed beside the equation.

a.	$2\ SO_{2\ (g)} + O_{2\ (g)} \leftrightarrow 2\ SO_{3\ (g)}$ + energy	decrease temperature
b.	$C_{\ (s)} + CO_{2\ (g)}$ + energy $\leftrightarrow 2\ CO_{\ (g)}$	increase temperature
c.	$N_2O_{4\ (g)} \leftrightarrow 2\ NO_{2\ (g)}$	increase total pressure
d.	$CO_{\ (g)} + H_2O_{\ (g)} \leftrightarrow CO_{2\ (g)} + H_{2\ (g)}$	decrease total pressure
e.	$2\ NOBr_{\ (g)} \leftrightarrow 2\ NO_{\ (g)} + Br_{2\ (g)}$	decrease total pressure
f.	$3\ Fe_{\ (s)} + 4\ H_2O_{\ (g)} \leftrightarrow Fe_3O_{4\ (s)} + 4\ H_{2\ (g)}$	add $Fe_{(s)}$
g.	$2SO_{2\ (g)} + O_{2\ (g)} \leftrightarrow 2\ SO_{3\ (g)}$	add catalyst
h.	$CaCO_{3\ (s)} \leftrightarrow CaO_{\ (s)} + CO_{2\ (g)}$	remove $CO_{2\ (g)}$
i.	$N_{2\ (g)} + 3\ H_{2\ (g)}\ 2\ NH_{3\ (g)}$	increase [$H_{eg)}$]

3. Consider the following equilibrium system:

$$3\quad H_{2\ (g)} + N_{2\ (g)} \leftrightarrow 2\ NH_{3\ (g)} + \text{Heat.}$$

State what effect each of the following will have on this system:

a. More N_2 is added to the system

b. Some NH_3 is removed from the system

c. The temperature is increased

d. The volume of the vessel is increased

e. A catalyst was added

f. An inert gas was added .

4. Consider the following equilibrium system

$$H_{2\,(g)} + I_{2\,(g)} \leftrightarrow 2\ HI_{(g)}$$

State what effect each of the following will have on this system in terms of shifting.

a. The volume of the vessel is increased

b. The pressure is increased

c. A catalyst is added

5. Consider the following equilibrium system:

$$3\ Fe_{(s)} + 4\ H_2O_{(g)} \leftrightarrow Fe_3O_{4\,(s)} + 4\ H_{2\,(g)}$$

State what effect each of the following will have on this system in terms of shifting.

a) The volume of the vessel is decreased

b) The pressure is decreased

c) More Fe is added to the system

d) Some Fe_3O_4 is removed from the system

e) A catalyst is added to the system

6. Consider the following equilibrium:

$$2NO_{(g)} + Br_{2\,(g)} + energy \leftrightarrow 2NOBr_{(g)}$$

State what affect each of the following will have on this system in terms of shifting.

a) The volume of the vessel is increased

b) The pressure is decreased

c) More Br_2 is added to the system

d) Some NO is removed from the system

e) A catalyst is added to the system

Consider the following equilibrium:

$$2CO_{(g)} + O_{2\,(g)} \leftrightarrow 2CO_{2\,(g)} + energy$$

A) Some CO was added to the system and a new equilibrium was established.

7. Compare to the original system, the rates of the forward and reverse reactions of the new equilibrium.
    a. Forward Rate has

    b. Reverse Rate has

8. Compared to the original concentrations, after the shift, have the new concentrations increased or decreased?
    a. [CO]

    b. [O_2]

    c. [CO_2]

9. Did the equilibrium shift favour the formation of reactants or products?

B) The volume of the container was decreased and a new equilibrium was established.

10. Compared to the original concentrations, after the shift, have the new concentrations increased or decreased?
    a. [CO]

    b. [O_2]

    c. [CO_2]

11. Did the equilibrium shift favour the formation of reactants or products?

ACTIVITY #6 –LAB: SHIFT HAPPENS!

Background:

Le Chatelier's Principle states that when a chemical system at equilibrium is disturbed by the application of a stress (i.e. a change in a system property), the system adjusts in such a way that minimizes and counteracts the stress, and a new equilibrium state is attained. In this activity, predictions made using Le Chatelier's Principle will be tested for a specific chemical equilibrium system, as shown below:

$$\underset{\text{(blue)}}{CoCl_4^{2-}(aq)} + 6\ H_2O(l) \leftrightarrow \underset{\text{(pink)}}{Co(H_2O)_6^{2+}(aq)} + 4\ Cl^-(aq) + \text{heat}$$

Problem:

1. What effect does changing the temperature have on the state of a chemical equilibrium system?
2. What effect does changing the concentration of chemicals have on the state of a chemical equilibrium system?

Predictions:

Complete predictions for each of the applied stresses. In your explanation, speak in terms of rates of reaction forward and backwards and effective collisions.

1. According to Le Chatelier's Principle if the **system is cooled**, then the colour will become _____________________. This signifies that the equilibrium has shifted _________________to re-establish equilibrium. This shift will happen because ____
____
____
____.

2. According to Le Chatelier's Principle if the **system is heated**, then the colour will become _____________________. This signifies that the equilibrium has shifted _________________to re-establish equilibrium. This shift will happen because ____
____
____
____.

3. According to Le Chatelier's Principle if **sodium chloride is added**, then the colour will become ____________________. This signifies that the equilibrium has shifted ________________to re-establish equilibrium. This shift will happen because ____
____
____
____.

4. According to Le Chatelier's Principle if **silver nitrate is added**, then the colour will become ____________________. This signifies that the equilibrium has shifted ________________to re-establish equilibrium. This shift will happen because ____
____
____
____.

Procedure:

1. Fill one of your 250 mL beakers ½ full with tap water and place it on your hot plate. Turn the hot plate to high. Congratulations! You've just made a hot water bath. You will need this later.
2. Fill your second 250 mL beaker ½ full with tap water. Take it to the buffet table and place a handful of ice into it. Boom…ice bath!
3. Take your 150 mL beaker from your bench to the buffet table. Pour about 100 mL of CoCl2.6H2O(aq) into it and return to your bench.
4. Fill each of your 5 test tubes about ½ full of the solution. Set one of the test tubes aside as your control group.
5. Place your first test tube into the hot water bath and allow it to sit for a few minutes. Make observations. Do not allow the test tube to reach a boil!
6. Place your second test tube into the ice bath and allow it to sit for a few minutes. Make observations.
7. Come to the buffet table and obtain two cupcake wrappers, one containing sodium chloride crystals and the other containing silver nitrate crystals. Take them back to your bench. Don't get them mixed up!
8. Pour the sodium chloride crystals into your third test tube. Agitate gently to allow dissolving. Make observations.
9. Pour the silver nitrate crystals into your fourth test tube. Agitate gently to allow dissolving. Make observations.
10. Dispose of all chemicals in the waste beaker provided.

Observations:

Stress Applied	**Colour Change Observed**	**Prediction Confirmed?**
Cooled		
Heated		
Sodium Chloride Added		
Silver Nitrate Added		

Conclusions:

Did your observations match your predictions? If not, correct your original prediction with a modified version based on what you observed.

ACTIVITY #7 – SOLVING EQUILIBRIUM PROBLEMS PART 2

1. In a 1.00 L flask, 0.150 mol of SO_3(g) and NO(g) are sealed at STP and allowed to reach equilibrium according to the reaction below. The equilibrium constant (*K*) for this reaction at this temperature and pressure is 0.50

$$SO_3 + NO \leftrightarrow NO_2 + SO_2$$

   a. Determine the equilibrium concentrations of each species using an ICE table.

   b. Does this reaction favour the reactants or the products? Why?

2. Gaseous phosphorus pentachloride is heated, it decomposes into phosphorus trichloride and chlorine gas. The *K* value for this reaction at this specific temperature is 1.00×10^{-5}. 2.00 mol/L of PCl_5 are placed in a flask and allowed to reach equilibrium according to the reaction below.

$$PCl_{5(g)} \leftrightarrow PCl_{3(g)} + Cl_{2(g)}$$

   a. Can you apply the "100 Rule" in this case and ignore "-x" in your ICE table? Justify you answer.

   b. Determine the equilibrium concentrations of each substance using an ICE table.

3. A 1.000 L flask is filled with 1.000 mol of H_2 and I_2 at 448°C. The value of the equilibrium constant at this temperature is 2.5. What are the equilibrium concentrations for each of the species?

$$H_2(g) + I_2(g) \leftrightarrow 2HI(g)$$

   a. Can you apply the "100 Rule" in this case and ignore "-x" in your ICE table? Justify you answer.

   b. Determine the equilibrium concentrations of each substance using an ICE table.

4. Suppose that hydrogen fluoride gas, HF(g) is synthesized by combining 3.000 mol of hydrogen gas, $H_2(g)$, with 6.000 mol fluorine gas, $F_2(g)$, in a 3.000 L sealed flask. Assume that the equilibrium constant for this reaction at this temperature is 1.15×10^2.

$$H_2(g) + F_2(g) \leftrightarrow 2\,HF(g) \qquad \Delta H = -50.0\text{ kJ}$$

   a. What are the concentrations of each gas at equilibrium?

   b. Does this reaction favour the reactants or the products? Why?

   c. What stresses could you apply to this reaction to increase the [HF(g)] produced?

ACTIVITY #8 – THE REACTION QUOTIENT (Q)

1. Consider the following reaction:

   $2SO_2(g) + O_2(g) \leftrightarrow 2SO_3(g)$ K = 3900

   a) Write the equilibrium expression for this reaction.

   b) Write the reaction quotient (Q) expression for this reaction.

   c) A student starts this reaction with 0.150 M SO_2, 0.150 M O_2, and 2.00 M SO_3. Predict the direction this reaction must shift to reach equilibrium. Show a calculation to justify your answer.

2. Consider the following reaction:

   $2HI(g) \leftrightarrow H_2(g) + I_2(g)$ K = 0.25

   A reaction vessel initially contains 0.500 M H_2, 0.500 M I_2, and 0.750 M HI.

   a) Predict the direction the reaction must shift to reach equilibrium. Show a calculation to justify your answer.

   b) From what you concluded in a), create an ICE table and calculate the equilibrium concentrations of each chemical species.

3. Use the following chemical equation to answer the following questions:

$$N_2O_4(g) \leftrightarrow 2NO_2(g) \quad + \text{energy} \qquad K = 6.01 \times 10^{-6} \text{ @ } 500^{o}C$$

a) Circle the correct stress that would maximize the production of nitrogen dioxide, NO_2, in this reaction.

[$N_2O_4(g)$]	Increase	Decrease
[$NO_2(g)$]	Increase	Decrease
Temperature	Increase	Decrease
Volume of vessel	Increase	Decrease

b) If this reaction were started with 1.00×10^{-3} M of each substance, which direction would the reaction have to shift to reach equilibrium? Show a calculation to justify your answer.

c) Calculate the [NO_2] at equilibrium.

4. Carbon monoxide gas, $CO(g)$, reacts with steam, $H_2O(g)$, to produce carbon dioxide gas, $CO_2(g)$, and hydrogen, $H_2(g)$. At 700K, this reaction has a K value of 5.10. Calculate the equilibrium concentrations if 1.250 mol of each substance were initially placed in a 500.0 mL sealed flask and allowed to react.

ACTIVITY #9 – SOLUBILITY EQUILIBRIUM CALCULATIONS

1. Write the equilibrium expression for the following solubility equilibrium:

$$MgCO_3(s) \leftrightarrow Mg^{2+}(aq) + CO_3^{2-}(aq)$$

2. Write the equilibrium expression for the solubility equilibrium of iron(II) hydroxide, $Fe(OH)_2(s)$.

3. Which of the following salts has the greater solubility, mercury(I) chloride or copper(I) chloride? How did you determine this?

4. In a saturated solution of calcium phosphate, $Ca_3(PO_4)_2(aq)$, at 25°C, the concentrations of the calcium ions and the phosphate ions are 4.53×10^{-7} mol/L and 3.02×10^{-7} mol/L respectively. Calculate the Ksp of calcium phosphate

5. Silver bromide has a solubility of 6.1×10^{-2} mol/L at 95°C. Calculate the Ksp of silver bromide at this temperature.

6. 0.00243 g of $Fe_2(CO_3)_3$ is required to saturate 100.0 mL of solution. What is the Ksp value of iron(III) carbonate at this temperature?

7. Calculate the molar solubility (the molarity of the saturated solution) of silver iodide, AgI(s), at 25ºC. The Ksp of silver iodide at this temperature is 8.5×10^{-17}.

8. The Ksp of zinc hydroxide, $Zn(OH)_2$(s), is 7.7×10^{-17} at 25ºC. What is the molar solubility of zinc hydroxide at this temperature?

9. Calculate the molar solubility of $Fe(OH)_3$ at 25ºC. Calculate the mass required to prepare 2.0 L of saturated iron(III) hydroxide solution.

10. The solubility of magnesium fluoride, MgF_2(s), is 1.72×10^{-3} g/100 mL at 25ºC. What is the Ksp value for magnesium fluoride at this temperature?

ACTIVITY #10 – LAB: SOLUBILITY PRODUCT CONSTANT (Ksp) FOR SILVER ACETATE

In a saturated solution, the ions in solution are in equilibrium with the solid. The rate at which ions are leaving the solid crystal is equal to the rate at which they are returning to the crystal. According to solubility rules, acetate salts are generally quite soluble. An exception to that is silver acetate which has only a moderate solubility in water. The purpose of this experiment is to determine the value of its solubility product constant, Ksp.

Procedure:

(Day 1)

1. Use a graduated cylinder to carefully measure 100.0 mL of a saturated silver acetate solution and record this in your observations. Pour the solution into a clean, dry 250 mL beaker.
2. Obtain about 30 cm of 16-gauge copper wire. Clean the surface of the wire with some steel wool and wind the wire into a loose coil around a test tube.
3. Find the mass of the copper coil to the nearest 0.01 g and record this mass in your observations. Place it into the beaker containing the saturated solution of silver acetate. Allow the system to stand overnight so all the silver ions will have an opportunity to react.

(Day 2)

4. Shake the silver crystals free from the copper wire into the beaker. Wash any adhering crystals into the beaker with a stream of distilled water from a water bottle. Finally, wash the wire in a stream of water from the tap. When the wire is dry, find its mass and record this in your observations.
5. Decant the solution off the silver crystals into another beaker and rinse them with distilled water.
6. Obtain a piece of filter paper and record its mass. Record this value in your observations.
7. Filter your silver crystals. Set your filter paper aside to dry overnight.

(Day 3)

8. Measure the mass of your filter paper and record this in your observations.

Observations:

Volume of Saturated Silver Acetate solution (mL)	
Mass of Copper Wire BEFORE Reaction (g)	
Mass of Filter Paper (g)	
Mass of Filter Paper + Silver Crystals (g)	
Mass of Copper Wire AFTER Reaction (g)	

Analysis:

1. Write the balanced chemical equation and the net ionic equation for the reaction that occurred between the saturated solution of silver acetate and the copper wire.

2. Calculate the mass of silver metal collected.

3. Calculate the moles of silver metal collected.

4. Use stoichiometry to calculate the moles of Ag+ present in the saturated solution.

5. Determine the molarity of the Ag+ in the saturated solution.

6. Write the dissociation equation for silver acetate dissolution. Create an ICE table and fill it in.

7. Write the Ksp expression for silver acetate and calculate Ksp based on the silver collected.

ACTIVITY #12 – LAB: THE COMMON ION EFFECT ON SOLUBILITY

In the last activity, you used empirical evidence gathered in the lab to determine the solubility product constant (Ksp) of lead(II) chloride. Today, you are going to investigate the effect that adding a "common ion" (increasing the concentration of an ion already present in the saturated solution) has on the solubility of the solution.

Procedure and Observations:

	A	B	Result of mixing A + B	Explanation (according to Le Chatelier's principle)
1	5 ml $PbCl_2$	2.5 ml saturated NaCl		
2	5 ml $PbCl_2$	2.5 ml saturated $NaC_2H_3O_2$		
3	5 ml $PbCl_2$	A few crystals of $Pb(C_2H_3O_2)_2$		

Analysis:

1. Calculate the solubility of lead(II) chloride.

2. Calculate the solubility of lead(II) chloride upon the addition of 0.20M sodium chloride to the solution.

3. What happens to the solubility of an ionic compound with the addition of a common ion?

4. Use your knowledge of equilibrium and Le Chatelier to explain your answer to the previous question.

ACTIVITY #13 – UNIT TEST REVIEW

1. Write the equilibrium expressions for each of the following:

   a) 2 Bread + 1 Cheese + 4 Ham ↔ 1 Sandwich

   b) $F_{2(g)}$ + $I_{2(g)}$ ↔ $2FI_{(g)}$

   c) $N_{2(g)} + 3H_{2(g)} \leftrightarrow 2NH_{3(g)}$

   d) HCl(aq) + NaOH(aq) ↔ NaCl(aq) + H_2O(l)

   e) NaCl(s) ↔ Na^+(aq) + Cl^-(aq)

   f) $Ca_3(PO_4)_2$(s) ↔ $3Ca^{2+}$(aq) + $2PO_4^{3-}$(aq)

2. Write the K expression in terms of concentration. Given the **equilibrium concentrations**, calculate the value of K. From the K value state whether each equilibrium is product-favored, reactant-favored, or fairly even ([products] ≈ [reactants]).

   a) N_2(g) + 3 H_2(g) ⇆ 2 NH_3(g)

   At equilibrium: [N_2] = 0.750 M
   [H_2] = 1.25 M
   [NH_3]= 0.025 M

   b) HF(aq) ⇆ H^+(aq) + F^-(aq)

   At equilibrium: [HF] = 0.250 M
   [H^+] = 1.50 M
   [F^-]= 1.25 M

3. A closed system initially containing 1.5 mol/L H_2 and 2.0 mol/L I_2 at 448°C are allowed to reach equilibrium. Equilibrium is reached after 10 minutes and analysis shows the concentration of HI at this time to be 1.87 mol/L. Calculate the K for this reaction and sketch a concentration-time graph of the reaction for the first 20 minutes of the reaction.

4. During WWI, the Germans used a chemical process known as the Haber process that combined nitrogen and hydrogen from the air to create ammonia, which they used for explosives. Since then, this process has become the main method of creating fertilizer for agriculture. If 100 kg of nitrogen gas and 20 kg of hydrogen gas are added to a 300 L vat at SATP state and there is 50 kg of nitrogen left in the vat at equilibrium:

    a. What mass of ammonia could be produced at equilibrium? (Hint…think stoichiometry)

    b. What is the K for this reaction?

    c. What changes could be made to the system to help increase the quantity of ammonia?

5. Use your knowledge of Le Chatelier's Principle to complete the following chart:

$2NO_2(g) \rightarrow 1N_2O_4(g)$ $\Delta H = -85kJ/mol$			
Stress	Equilibrium Shift – Left or Right?	[Products] Increase or Decrease?	[Reactants] Increase or Decrease?
Add $NO_2(g)$			
Remove $N_2O_4(g)$			
Increase Temperature			
Decrease Volume			

6. At 800°C, the K value of the reaction below is 0.279

$$CO_2(g) + H_2(g) \rightleftarrows CO(g) + H_2O(g).$$

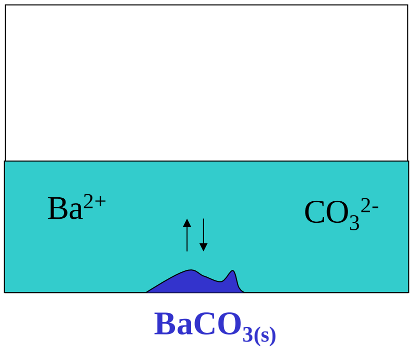
If 2.00 moles $CO_{(g)}$ and 2.00 moles $H_2O_{(g)}$ are initially placed in a 500 ml container and allowed to reach equilibrium, calculate all equilibrium concentrations.

7. Initially, 0.750 mol of <u>each</u> chemical substance are placed in a 2.0 L flask at 100°C and allowed to reach equilibrium:

$$N_2(g) + I_2(g) \leftrightarrow 2NI(g) \qquad K = 145$$

a) Calculate the reaction quotient (Q) for this situation. Will this reaction shift to reach equilibrium? If so, which direction will it shift? Provide evidence for your choice.

b) Determine the equilibrium concentrations of each of the substances.



8. The solubility of $BaCO_3$ is 5.1×10^{-5} mol/L @ 25^0 C. Calculate the solubility product equilibrium constant (Ksp). Is this salt more or less soluble than lead(II) iodide? How did you determine this?

9. Magnesium hydroxide, also known as Milk of Magnesia, is commonly used as a remedy for heartburn. It has a low solubility in water at 25^{o}C. Use the Ksp value for magnesium hydroxide to calculate the solubility of this solution in both mol/L and g/L.

10. Below is some information about the solubility of calcium hydroxide. Use it to complete the chart.

$$Ca(OH)_2(s) \leftrightarrow Ca^{2+}(aq) + 2OH^{-}(aq) \qquad \Delta H = +135 kJ/mol$$

Stress	Equilibrium Shift – Left or Right?	Products Increase or Decrease?	Solubility Increase or Decrease?
Add $Ca(NO_3)_2$			
Add NaOH			
Add HCl			
Increase Temperature			
Decrease Temperature			

11. Calculate the solubility of magnesium hydroxide at 25^{o}C when it is dissolved in a solution of 0.500 M NaOH. Compare this answer with your answer to Q#9. What do you notice? Make a general statement regarding the solubility of substances in common ion solutions.

SOLUBILITY PRODUCT CONSTANTS AT 25°C

Name	Formula	K_{sp}
Barium carbonate	$BaCO_3$	2.6×10^{-9}
Barium chromate	$BaCrO_4$	1.2×10^{-10}
Barium sulphate	$BaSO_4$	1.1×10^{-10}
Calcium carbonate	$CaCO_3$	5.0×10^{-9}
Calcium oxalate	CaC_2O_4	2.3×10^{-9}
Calcium sulphate	$CaSO_4$	7.1×10^{-5}
Copper(I) iodide	CuI	1.3×10^{-12}
Copper(II) iodate	$Cu(IO_3)_2$	6.9×10^{-8}
Copper(II) sulphide	CuS	6.0×10^{-37}
Iron(II) hydroxide	$Fe(OH)_2$	4.9×10^{-17}
Iron(II) sulphide	FeS	6.0×10^{-19}
Iron(III) hydroxide	$Fe(OH)_3$	2.6×10^{-39}
Lead(II) bromide	$PbBr_2$	6.6×10^{-6}
Lead(II) chloride	$PbCl_2$	1.2×10^{-5}
Lead(II) iodate	$Pb(IO_3)_2$	3.7×10^{-13}
Lead(II) iodide	PbI_2	8.5×10^{-9}
Lead(II) sulphate	$PbSO_4$	1.8×10^{-8}
Magnesium carbonate	$MgCO_3$	6.8×10^{-6}
Magnesium hydroxide	$Mg(OH)_2$	5.6×10^{-12}
Silver bromate	$AgBrO_3$	5.3×10^{-5}
Silver bromide	$AgBr$	5.4×10^{-13}
Silver carbonate	Ag_2CO_3	8.5×10^{-12}
Silver chloride	$AgCl$	1.8×10^{-10}
Silver chromate	Ag_2CrO_4	1.1×10^{-12}
Silver iodate	$AgIO_3$	3.2×10^{-8}
Silver iodide	AgI	8.5×10^{-17}
Strontium carbonate	$SrCO_3$	5.6×10^{-10}
Strontium fluoride	SrF_2	4.3×10^{-9}
Strontium sulphate	$SrSO_4$	3.4×10^{-7}
Zinc sulphide	ZnS	2.0×10^{-25}

Solubility of Common Compounds in Water

The term soluble here means > 0.1 mol/L at 25°C.

Negative Ions (Anions)	Positive Ions (Cations)	Solubility of Compounds
All	Alkali ions: Li^+, Na^+, K^+, Rb^+, Cs^+, Fr^+	Soluble
All	Hydrogen ion: H^+	Soluble
All	Ammonium ion: NH_4^+	Soluble
Nitrate, NO_3^-	All	Soluble
Chloride, Cl^- or Bromide, Br^- or Iodide, I^-	All others	Soluble
	Ag^+, Pb^{2+}, Cu^+	Low Solubility
Sulphate, SO_4^{2-}	All others	Soluble
	Ag^+, Ca^{2+}, Sr^{2+}, Ba^{2+}, Pb^{2+}	Low Solubility
Sulphide, S^{2-}	Alkali ions, H^+, NH_4^+, Be^{2+}, Mg^{2+}, Ca^{2+}, Sr^{2+}, Ba^{2+}	Soluble
	All others	Low Solubility
Hydroxide, OH^-	Alkali ions, H^+, NH_4^+, Sr^{2+}	Soluble
	All others	Low Solubility
Phosphate, PO_4^{3-} or Carbonate, CO_3^{2-} or Sulphite, SO_3^{2-}	Alkali ions, H^+, NH_4^+	Soluble
	All others	Low Solubility

Periodic Chart of Ions

Table of Polyatomic Ions

acetate	CH_3COO^-	dichromate	$Cr_2O_7^{2-}$	dihydrogen phosphate	$H_2PO_4^-$
ammonium	NH_4^+	cyanide	CN^-	silicate	SiO_3^{2-}
benzoate	$C_6H_5COO^-$	hydroxide	OH^-	sulphate	SO_4^{2-}
borate	BO_3^{3-}	iodate	IO_3^-	sulphite	SO_3^{2-}
carbonate	CO_3^{2-}	nitrate	NO_3^-	hydrogen sulphide	HS^-
hydrogen carbonate	HCO_3^-	nitrite	NO_2^-	hydrogen sulphate	HSO_4^-
chlorate	ClO_3^-	oxalate	$OOCCOO^{2-}$	hydrogen sulphite	HSO_3^-
hypochlorite	ClO^-	permanganate	MnO_4^-	thiocyanate	SCN^-
chromate	CrO_4^{2-}	phosphate	PO_4^{3-}	thiosulphate	$S_2O_3^{2-}$
		hydrogen phosphate	HPO_4^{2-}		

IA	IIA	IIIB	IVB	VB	VIB	VIIB	VIIIB	VIIIB	VIIIB	IB	IIB	IIIA	IVA	VA	VIA	VIIA	VIIIA
1 H^+ hydrogen																	2 He helium
3 Li^+ lithium	4 Be^{2+} Beryllium											5 B boron	6 C carbon	7 N^{3-} nitride	8 O^{2-} oxide	9 F^- fluoride	10 Ne neon
11 Na^+ sodium	12 Mg^{2+} magnesium											13 Al^{3+} aluminum	14 Si silicon	15 P^{3-} phosphide	16 S^{2-} sulfide	17 Cl^- chloride	18 Ar argon
19 K^+ potassium	20 Ca^{2+} calcium	21 Sc^{3+} scandium	22 Ti^{4+} titanium (IV) Ti^{3+} titanium (III)	23 V^{5+} vanadium (V) V^{4+} vanadium (IV)	24 Cr^{3+} chromium (III) Cr^{2+} chromium (II)	25 Mn^{2+} manganese (II) Mn^{4+} manganese (IV)	26 Fe^{3+} iron (III) Fe^{2+} iron (II)	27 Co^{2+} cobalt (II) Co^{3+} cobalt (III)	28 Ni^{2+} nickel (II) Ni^{3+} nickel (III)	29 Cu^{2+} copper (II) Cu^+ copper (I)	30 Zn^{2+} zinc	31 Ga^{3+} gallium	32 Ge^{4+} germanium	33 As^{3-} arsenide	34 Se^{2-} selenide	35 Br^- bromide	36 Kr krypton
37 Rb^+ rubidium	38 Sr^{2+} strontium	39 Y^{3+} yttrium	40 Zr^{4+} zirconium	41 Nb^{5+} niobium (V) Nb^{3+} niobium (III)	42 Mo^{6+} molybdenum	43 Tc^{7+} technetium	44 Ru^{3+} ruthenium (III) Ru^{4+} ruthenium (IV)	45 Rh^{3+} rhodium	46 Pd^{2+} paladium (II) Pd^{4+} paladium (IV)	47 Ag^+ silver	48 Cd^{2+} cadmium	49 In^{3+} indium	50 Sn^{4+} tin (IV) Sn^{2+} tin (II)	51 Sb^{3+} antimony (III) Sb^{5+} antimony (V)	52 Te^{2-} telluride	53 I^- iodide	54 Xe xenon
55 Cs^+ cesium	56 Ba^{2+} barium	57 La^{3+} lanthanum	72 Hf^{4+} hafnium	73 Ta^{5+} tantalum	74 W^{6+} tungsten	75 Re^{7+} rhenium	76 Os^{4+} osmium	77 Ir^{4+} iridium	78 Pt^{4+} platinum (IV) Pt^{2+} platinum (II)	79 Au^{3+} gold (III) Au^+ gold (I)	80 Hg^{2+} mercury (II) Hg^+ mercury (I)	81 Tl^+ thallium (I) Tl^{3+} thallium (III)	82 Pb^{2+} lead (II) Pb^{4+} lead (IV)	83 Bi^{3+} bismuth (III) Bi^{5+} bismuth (V)	84 Po^{2+} polonium (II) Po^{4+} polonium (IV)	85 At^- astatide	86 Rn radon
87 Fr^+ francium	88 Ra^{2+} radium	89 Ac^{3+} actinium															

KEY

atomic number → 26

symbol → Fe^{3+} ← ion charge

iron (III) ← stock name (IUPAC)

Fe^{2+}

iron (II)

58 Ce^{3+} cerium	59 Pr^{3+} praseodymium	60 Nd^{3+} neodymium	61 Pm^{3+} promethium	62 Sm^{3+} samarium (III) Sm^{2+} samium(II)	63 Eu^{3+} europium (III) Eu^{2+} europium(II)	64 Gd^{3+} gadolinium	65 Tb^{3+} terbium	66 Dy^{3+} dysprosium	67 Ho^{3+} holmium	68 Er^{3+} erbium	69 Tm^{3+} thulium	70 Yb^{3+} ytterbium (III) Yb^{2+} ytterbium (II)	71 Lu lutetium
90 Th^{4+} thorium	91 Pa^{5+} protactinium (V) Pa^{4+} protactinium(IV)	92 U^{6+} uranium (VI) U^{4+} uranium (IV)	93 Np^{5+} neptunium	94 Pu^{4+} plutonium (IV) Pu^{6+} plutonium (VI)	95 Am^{3+} americium (III) Am^{4+} americium (IV)	96 Cm^{3+} curium	97 Bk^{3+} berkelium (III) Bk^{4+} berkelium (IV)	98 Cf^{3+} californium	99 Es^{3+} einsteinium	100 Fm^{3+} fermium	101 Md^{2+} mendelevium(II) Md^{3+} mendelevium (III)	102 No^{2+} nobelium (II) No^{3+} nobelium (III)	103 Gd^{3+} lawrencium

PERIODIC TABLE OF THE ELEMENTS

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1 **H** Hydrogen 1.0																	2 **He** Helium 4.0
3 **Li** Lithium 6.9	4 **Be** Beryllium 9.0											5 **B** Boron 10.8	6 **C** Carbon 12.0	7 **N** Nitrogen 14.0	8 **O** Oxygen 16.0	9 **F** Fluorine 19.0	10 **Ne** Neon 20.2
11 **Na** Sodium 23.0	12 **Mg** Magnesium 24.3											13 **Al** Aluminum 27.0	14 **Si** Silicon 28.1	15 **P** Phosphorus 31.0	16 **S** Sulphur 32.1	17 **Cl** Chlorine 35.5	18 **Ar** Argon 39.9
19 **K** Potassium 39.1	20 **Ca** Calcium 40.1	21 **Sc** Scandium 45.0	22 **Ti** Titanium 47.9	23 **V** Vanadium 50.9	24 **Cr** Chromium 52.0	25 **Mn** Manganese 54.9	26 **Fe** Iron 55.8	27 **Co** Cobalt 58.9	28 **Ni** Nickel 58.7	29 **Cu** Copper 63.5	30 **Zn** Zinc 65.4	31 **Ga** Gallium 69.7	32 **Ge** Germanium 72.6	33 **As** Arsenic 74.9	34 **Se** Selenium 79.0	35 **Br** Bromine 79.9	36 **Kr** Krypton 83.8
37 **Rb** Rubidium 85.5	38 **Sr** Strontium 87.6	39 **Y** Yttrium 88.9	40 **Zr** Zirconium 91.2	41 **Nb** Niobium 92.9	42 **Mo** Molybdenum 95.9	43 **Tc** Technetium (98)	44 **Ru** Ruthenium 101.1	45 **Rh** Rhodium 102.9	46 **Pd** Palladium 106.4	47 **Ag** Silver 107.9	48 **Cd** Cadmium 112.4	49 **In** Indium 114.8	50 **Sn** Tin 118.7	51 **Sb** Antimony 121.8	52 **Te** Tellurium 127.6	53 **I** Iodine 126.9	54 **Xe** Xenon 131.3
55 **Cs** Cesium 132.9	56 **Ba** Barium 137.3	57 **La** Lanthanum 138.9	72 **Hf** Hafnium 178.5	73 **Ta** Tantalum 180.9	74 **W** Tungsten 183.8	75 **Re** Rhenium 186.2	76 **Os** Osmium 190.2	77 **Ir** Iridium 192.2	78 **Pt** Platinum 195.1	79 **Au** Gold 197.0	80 **Hg** Mercury 200.6	81 **Tl** Thallium 204.4	82 **Pb** Lead 207.2	83 **Bi** Bismuth 209.0	84 **Po** Polonium (209)	85 **At** Astatine (210)	86 **Rn** Radon (222)
87 **Fr** Francium (223)	88 **Ra** Radium (226)	89 **Ac** Actinium (227)	104 **Rf** Rutherfordium (261)	105 **Db** Dubnium (262)	106 **Sg** Seaborgium (263)	107 **Bh** Bohrium (262)	108 **Hs** Hassium (265)	109 **Mt** Meitnerium (266)									

14	Atomic Number
Si	Symbol
Silicon	Name
28.1	Atomic Mass

58 **Ce** Cerium 140.1	59 **Pr** Praseodymium 140.9	60 **Nd** Neodymium 144.2	61 **Pm** Promethium (145)	62 **Sm** Samarium 150.4	63 **Eu** Europium 152.0	64 **Gd** Gadolinium 157.3	65 **Tb** Terbium 158.9	66 **Dy** Dysprosium 162.5	67 **Ho** Holmium 164.9	68 **Er** Erbium 167.3	69 **Tm** Thulium 168.9	70 **Yb** Ytterbium 173.0	71 **Lu** Lutetium 175.0
90 **Th** Thorium 232.0	91 **Pa** Protactinium 231.0	92 **U** Uranium 238.0	93 **Np** Neptunium (237)	94 **Pu** Plutonium (244)	95 **Am** Americium (243)	96 **Cm** Curium (247)	97 **Bk** Berkelium (247)	98 **Cf** Californium (251)	99 **Es** Einsteinium (252)	100 **Fm** Fermium (257)	101 **Md** Mendelevium (258)	102 **No** Nobelium (259)	103 **Lr** Lawrencium (262)

Based on mass of C^{12} at 12.00.

Values in parentheses are the masses of the most stable or best known isotopes for elements which do not occur naturally.