Reaction Rates and Chemical Equilibrium

Learning Objectives

I. **Reaction Rates**
II. **Factors Affecting the Rate of Reaction**
III. **Chemical Equilibrium**
IV. **Equilibrium Constant**
V. **Magnitude of Equilibrium Constant**
VI. **Calculation Examples of the Equilibrium Constant**
VII. **Le Châtelier's Principle**

I. Reaction Rates

The rate of reaction is defined as the amount of the reactants consumed per time or as the amount of products produced per time:

2 A + 3B → 2 C + 5 D

Rate of Reaction = - 1/2 [∆ A] = - 1/3 [∆ B] = + 1/2 [∆ C] = + 1/5 [∆ D]

Where:

[∆ A] = final concentration of A – initial concentration of A

[∆ B] = final concentration of B – initial concentration of B

[∆ C] = final concentration of C – initial concentration of C

[∆ D] = final concentration of D – initial concentration of D

Example:

2 Mg(s) + O_2(g) → 2 MgO(s)

If 5.00 grams of magnesium are used for this reaction and the reaction had lasted 30.0 seconds. Calculate the rate of the reaction.

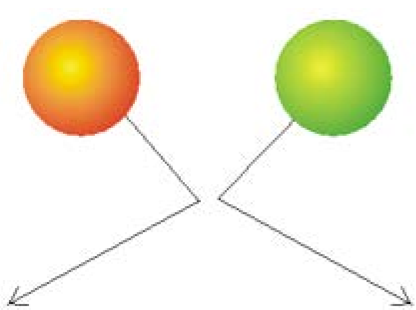
First let us calculate first number of moles of magnesium used for the reaction: [Hint: Mg atomic mass is used]

Number of magnesium moles = [5.00 g Mg x (1 mol Mg / 24.3 g Mg)] = 0.206 mol Mg

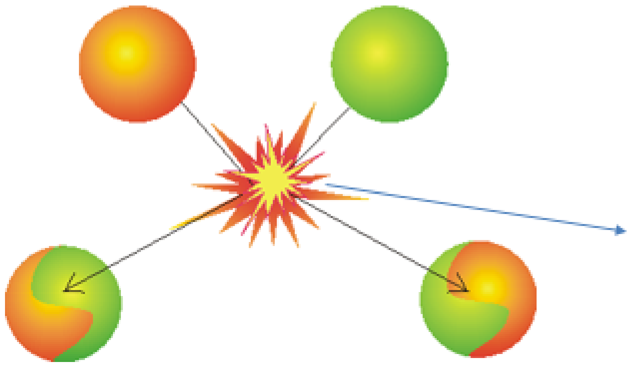
Rate of reaction = [0.206 mol Mg / 30.0 seconds] = 0.00687 mol /seconds

In order for a chemical reaction to progress certain conditions are needed:

a. Molecules must collide with each other
b. A proper orientation and alignment of the atoms within the molecules

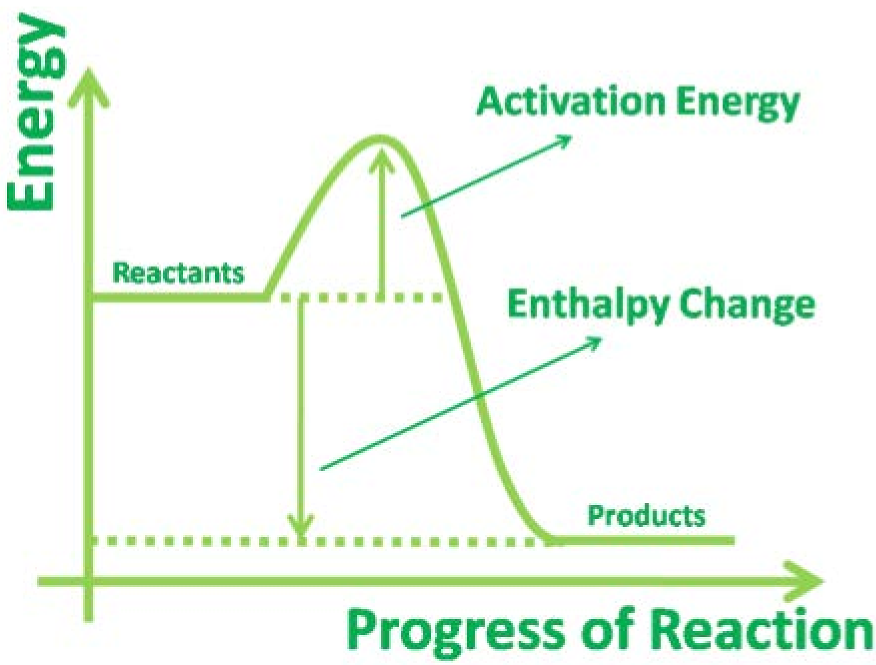


c. Activation energy is provided through the collision to help breaking the bonds among the atoms within the molecules. Activation energy is defined as amount of energy needed to break the atoms within the molecules.



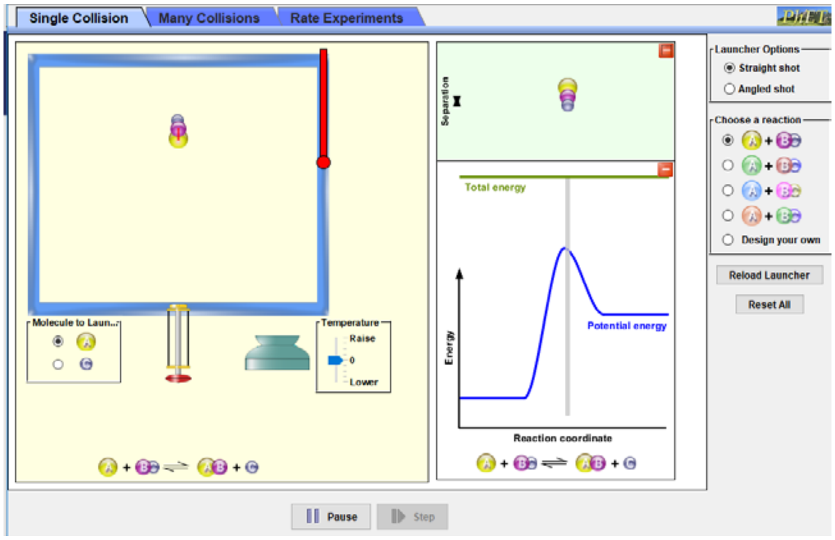
The above conditions are the bases for the collision theory.

The figure below illustrates the progress of the reaction versus the energies involved in the reaction.



The collision theory can be illustrated in the Phet Simulation below:

https://phet.colorado.edu/en/simulation/legacy/reactions-and-rates



The simulation discussed above leads to the fact that not all collisions result in a new substance and reactions are reversible. Reactions are the result of collisions and the products may collide and react to give reactant.

Questions:

Explain how the simulation model relates to test tube size experiments

What are the factors contributing to a successful reaction?

What would enable a reaction proceed or slow its progress with references to the reaction coordinate?

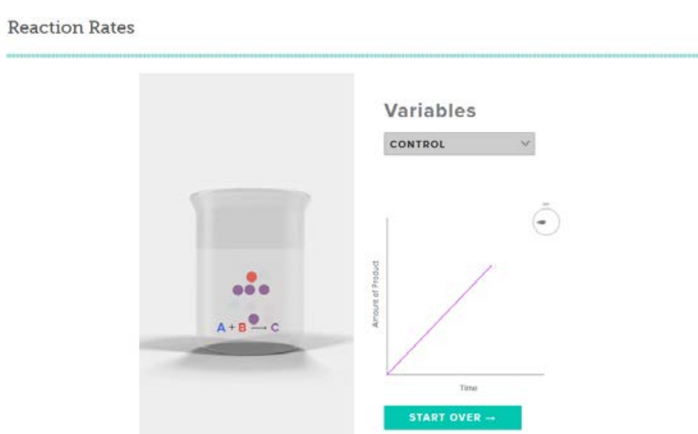
How does the reaction coordinate can show the potential energy changes with the separation of reactants and products?

Use the molecular model to explain why reactions have less than 100% yields.

Explain how can the effect of the heat of the chemical equilibrium?

The Chemistry Solution website illustrates the rate of the reaction and the collision among the reactants molecules to produce the products.

https://teachchemistry.org/periodical/issues/may-2018/reaction-rates

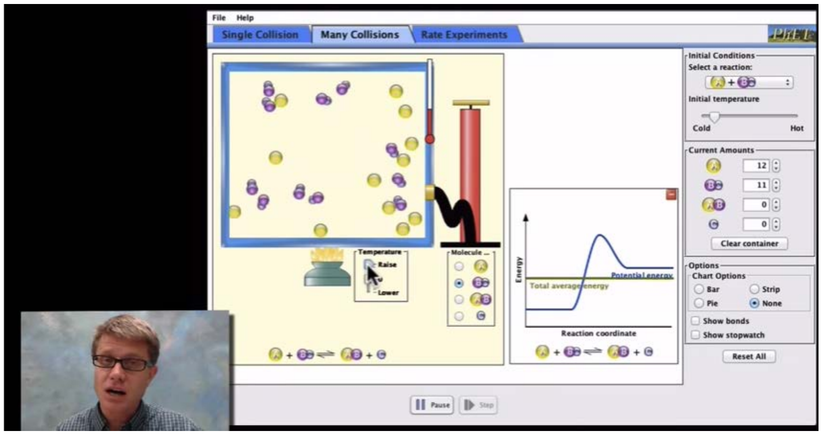


Explain the effects of the factors listed below on the rate of reaction using both the reaction simulation and the graph obtained from the corresponding simulation?

1. Concentration
2. Surface area
3. Temperature
4. Catalyst

A video of You Tube explains the rate of reaction concept in a very simple and systematic way:

https://www.youtube.com/watch?v=6mAqX31RRJU



The Rate of Reactions.mp4

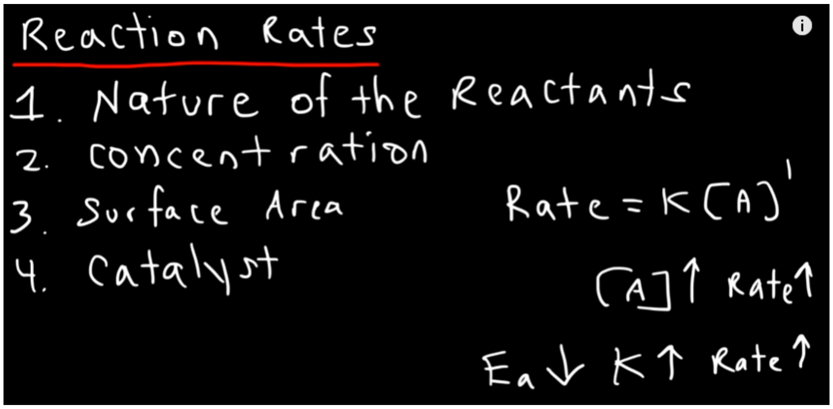
II. Factors Affecting the Rate of Reaction

The Solution Chapter did discuss the factors affecting the rate of solubility. Similar factors are affecting the rate of reaction which will be adopted here as well.

1. Temperature:
   The higher the temperature the higher the rate of the dissolution of the solute in the solvent
2. Surface area:
   The higher the surface area of the solute, the higher the rate of the dissolution of the solute in the solvent. An example of this can be seen in the solubility of fine powder sodium chloride in water compared with the solubility of the coarse sodium chloride (rocky sodium chloride) in water. The fine powder sodium chloride has larger surface area and hence higher rate of dissolution in water.
3. Solute concentration:
   The higher the concentration of the solute the higher the rate of dissolution in the solvent.
4. Catalyst: The use of catalyst increases the rate of reaction by decreasing the activation energy of the reaction. This is happening by re-routing the reactants through a rout with lower activation energy. The catalyst will be recovered, recycled and reused and it is not part of the products themselves.

The video below illustrates the factors that affect the rate of reaction:

https://www.youtube.com/watch?v=JpoOfrPKgmM

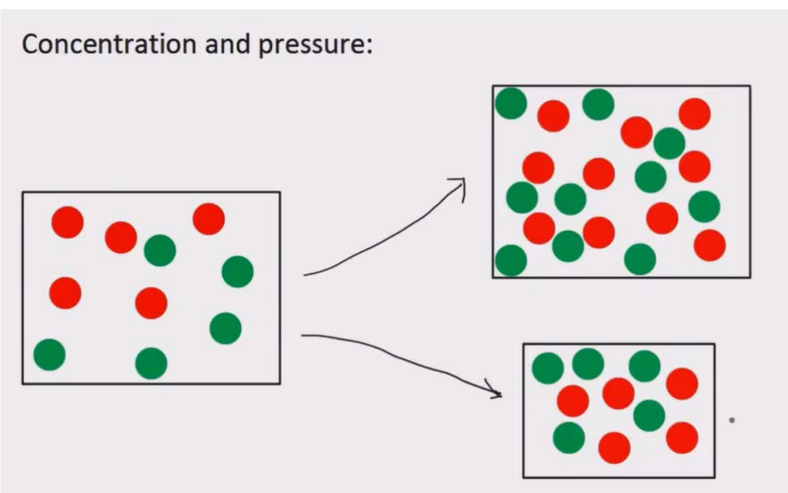


Factors Affecting the Rate of the Reaction.mp4

Another video illustrates the effect of these factors which are affecting the rate of the reaction:

Factors Affecting Rate of Reaction and Collision Theory.mp4

https://youtu.be/jd6U5nQcqKc



The Molecular Workbench simulation illustrates the effect of the concentration and the temperature on the rate of reaction.

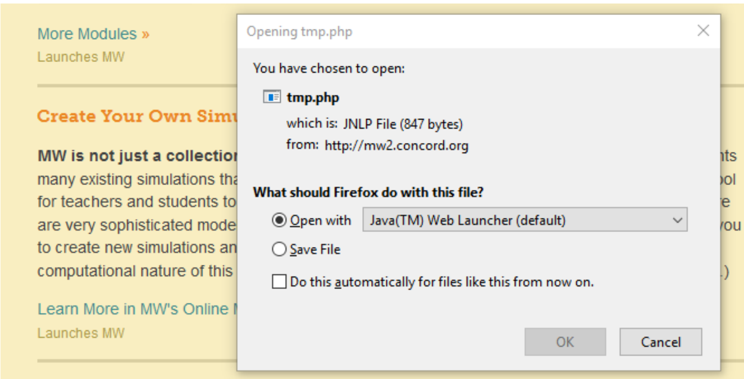
One can access the simulation in multiple steps:

First one has to access the Molecular Workbench general website:

http://mw.concord.org/modeler/index.html

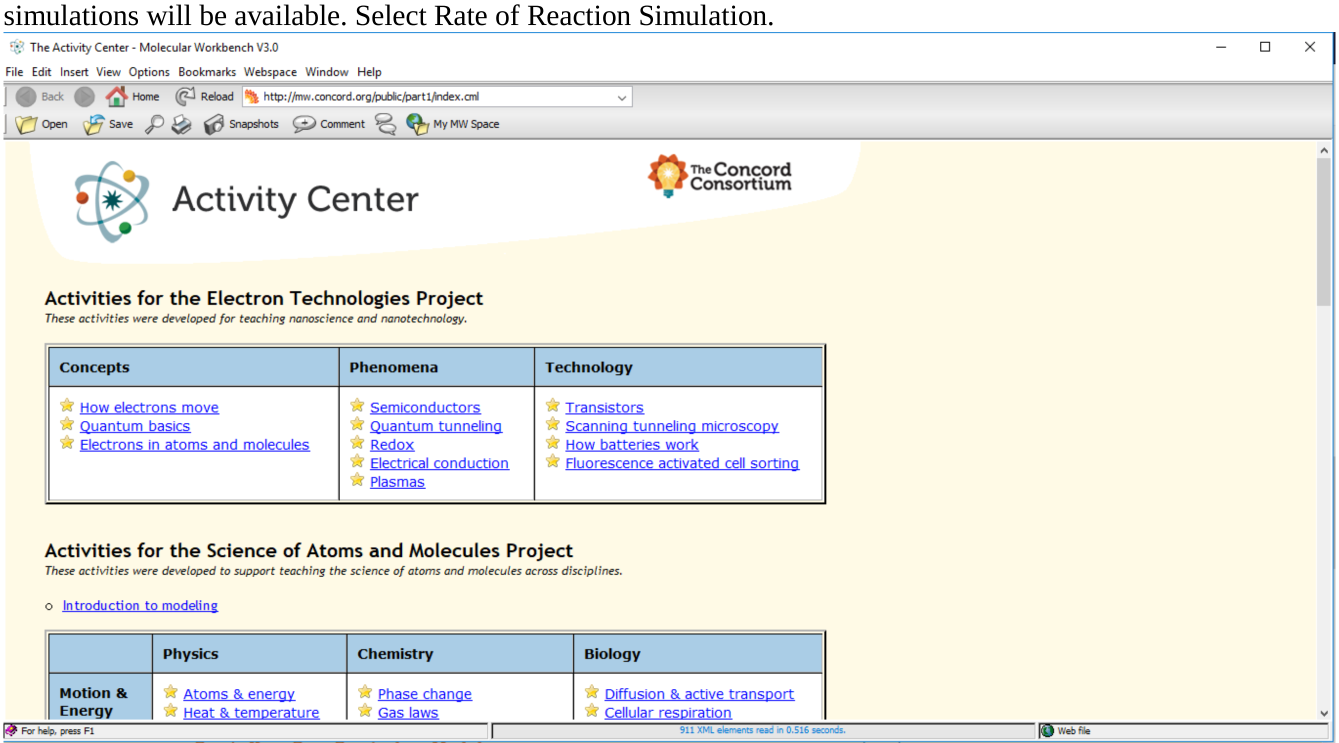
Second one has to look at the **Selected Curriculum Modules** and at the bottom of the section, one has to access more modules by accessing the link: **More Modules**

As soon as More Modules is selected a new Window with a dialog will appear:

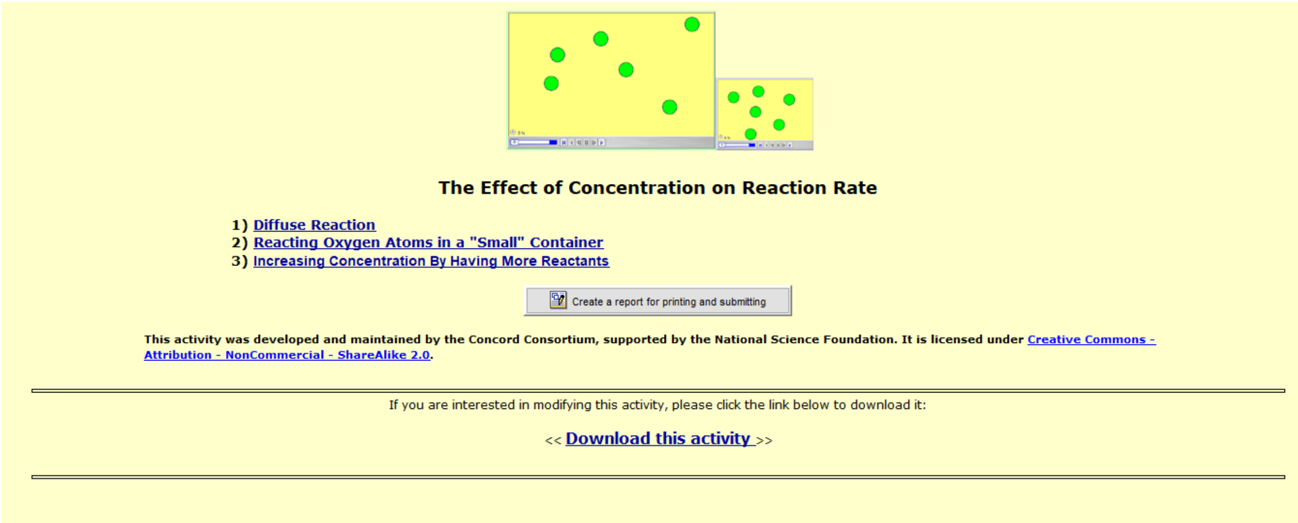


Then select the option: **Open with JAVA Web Launcher** and then click OK.

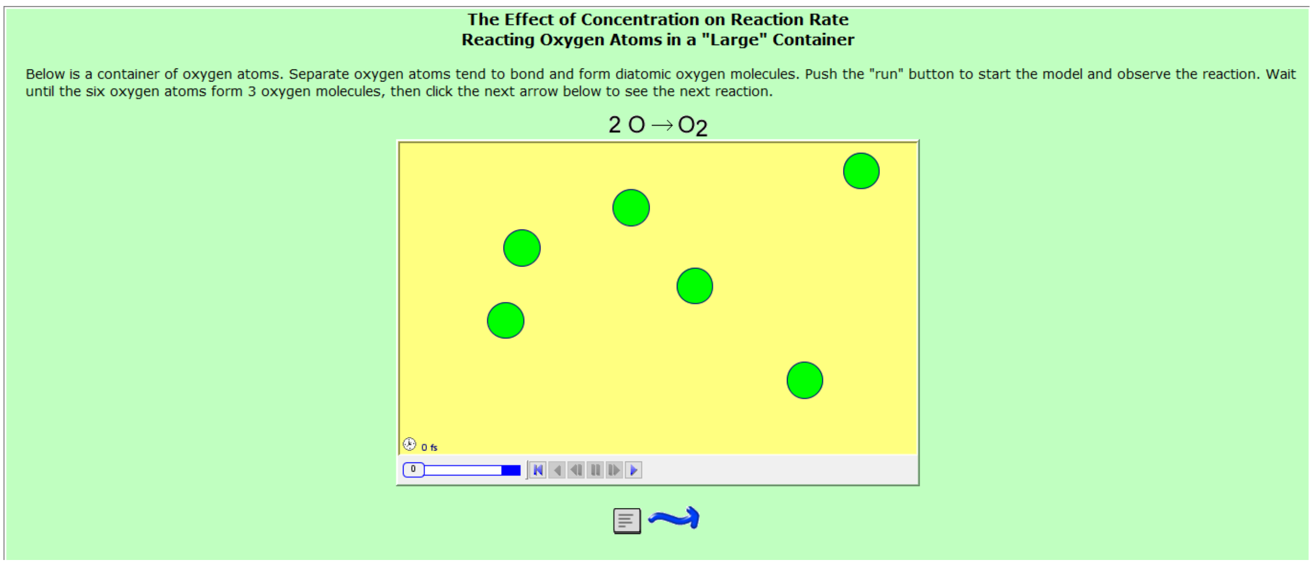
As soon as OK is selected the Activity Center - Molecular Workbench Version 3.0 will open up and several simulations will be available. Select Rate of Reaction Simulation.



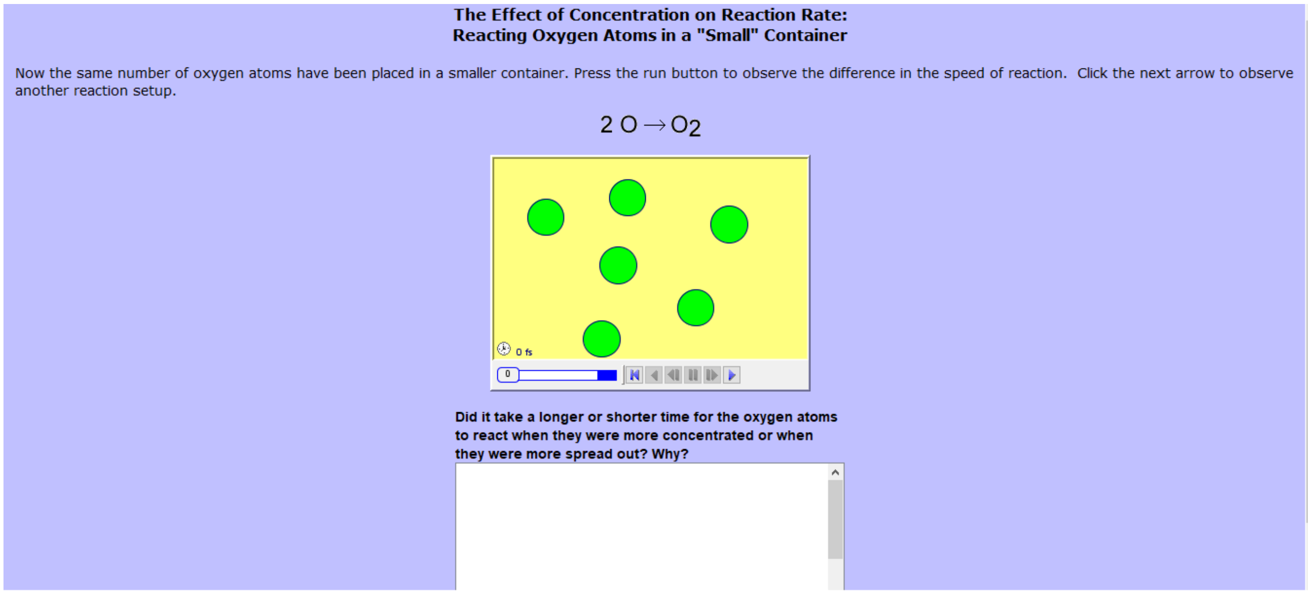
The simulation has many topics. The effect of **Concentration on the Rate of Reaction** is selected:



Click on the first step of the simulation:



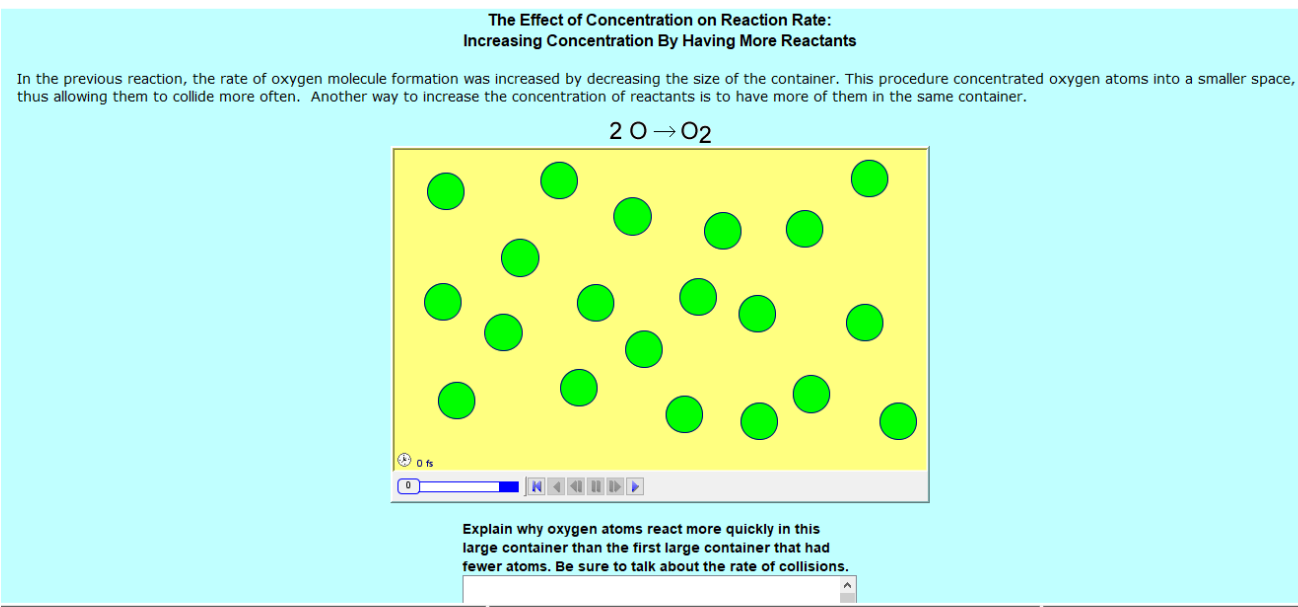
Make notes of the reaction of oxygen atoms to produce the oxygen molecules in the larger container and then click the Back Arrow and follow the same reaction in the smaller container. Make your notes as well.



Now you are ready to answer the question:

Did it take a longer or shorter time for the oxygen atoms to react when they were more concentrated or when they were more spread out? Why?

Now click on the last step of the simulation: Increasing concentration by having more reactants:

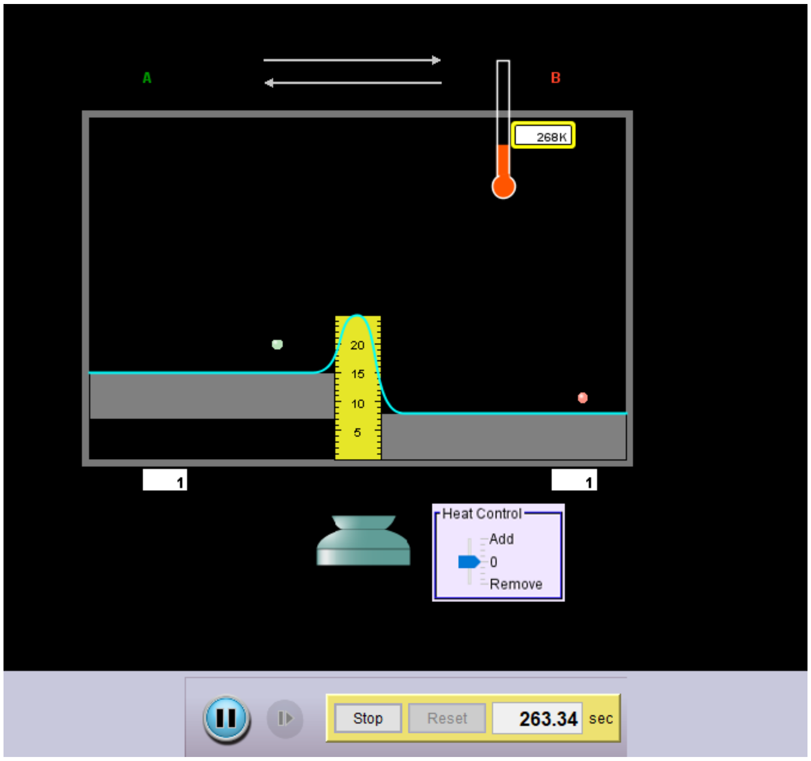


Now you are ready to answer the question of the third step of the simulation:

Explain why oxygen atoms react more quickly in this large container than the first large container that had fewer atoms. Be sure to talk about the rate of collisions.

A Phet simulation illustrates the Reverse Reactions and the factors affecting them:

https://phet.colorado.edu/en/simulation/legacy/reversible-reactions



Reversible Reactions Simulation

Learning Goals

1) Visualize a system at dynamic equilibrium state (DES)
2) Characterize the DES by finding the red : green ball ratio, K_{rg}.
3) Design an investigation to test the effect of changing temperature, number of balls and activation energy barrier has on the

Part 1: Play

Instructions:

1) Open the PhET "Reversible Reactions" simulation.

2) Play with the simulation. Click on EVERYTHING!

3) Answer the following questions:

1) Put some number of balls (>50) in one of the wells. In a table, record the number of green and red balls in each well as a function of time. (Suggested time length: 5 minutes, suggested intervals: 15-20 seconds) Paste the table into this document. (Google spreadsheet will work well for this.)

2) Paste in a graph of your data. Describe the shape of the graph and what it means in terms of the red and green balls. Consider the ratio of red balls to green balls. How does that change over time?

3) After some amount of time, this simulation reaches a dynamic equilibrium state (DES). That is, a situation in which components of a system are moving but no net change is observed. Describe how this simulation fits this model in terms of the amount of red and green balls.

Part 2: Investigate

Instructions: Investigate, using available tools in the simulation, the effect of a change in temperature, # of balls or activation energy on the K_{rg}. Your investigation must include the following factors (and fit onto the rest of this page):

- Experimental question (ie How does X affect Y?): (Check your question with Dr. White before beginning)
- Independent variable:
- Dependent Variable: The ratio of red : green balls. Let´s call it "K_{rg}". ;)
- Controlled Variables:
- Table
- Graph
- Conclusions (1 paragraph referring back to data)

Reversible Reactions Activity

1. **Setup -** Search "PhET Reversible Reactions" simulation. Open and run the simulation.

2. **Explore!** Click on everything to find the variables and observe how they affect the reaction. (Don't just try to max out the computer's memory chip.)

3. **Reaction Conditions**: Move the position of the reactants, transition state, and products wherever you wish and choose a temperature. **Be reasonable!!**

   Reactants ________________ Transition state ______________

   Products ______________ Temp _______________

4. **Design!** You will run three trials. Each one should have 100 total molecules*. Start with different amounts of A and B for each* trial. Place the starting amounts in the table at time 0. Record the amount of A and B in the chamber every 20 seconds for 5 minutes.

Trial 1			Trial 2			Trial 3		
Time	A	B	Time	A	B	Time	A	B
0 (initial)			0 (initial)			0 (initial)		
20			20			20		
40			40			40		
60			60			60		

80			80			80		
100			100			100		
120			120			120		
140			140			140		
160			160			160		
180			180			180		
200			200			200		
220			220			220		
240			240			240		
260			260			260		
280			280			280		
300			300			300		
Final A:B Ratio			Final A:B Ratio			Final A:B Ratio		

5. Which side of the reaction is favored (are there more reactants or products) for the experiment you set up? Why is that so?

6. Graph the concentration (number of molecules) of both molecules A and B vs time. You should have two separate curves (A and B).

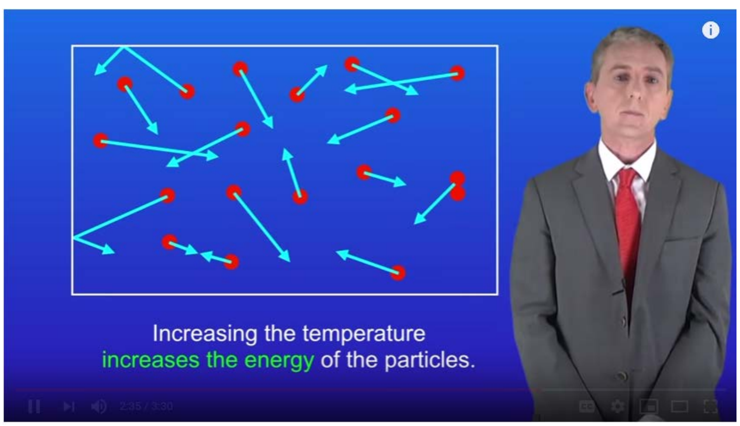
7. What is happening to the concentrations at the beginning of the experiment? How does that differ from what is happening at the end of the experiment? Mark a vertical line on the graph at the point where equilibrium is established.

8. All three trials started at different amounts. How did the final ratios of A to B compare?

9. Did the reaction ever stop?

You Tube Video shows the effect of the Temperature on the Rate of reaction:

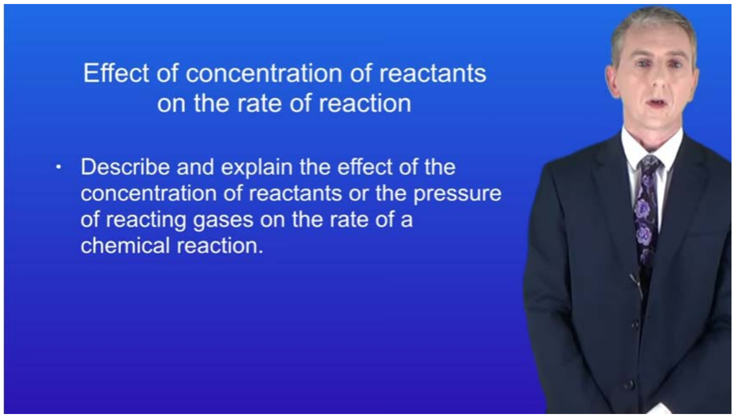
https://www.youtube.com/watch?v=G2TEfhwgq84



Effect of the Temperature on the Rate of Reaction.mp4

Also You Tube Video shows the effect of the Concentration on the Rate of reaction:

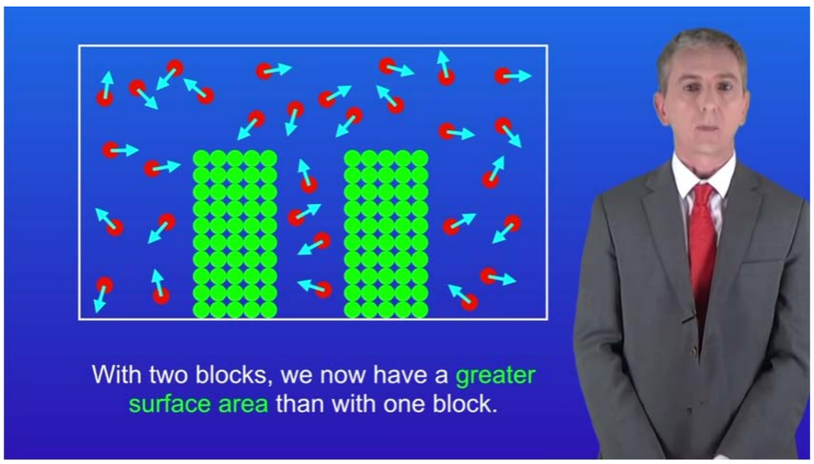
https://www.youtube.com/watch?v=u4Co4N-Jmbs



Effect of the Concentration on the Rate of Reaction.mp4

The Effect of the Surface Area of the Reactants on the Rate of Reaction is illustrated in the You Tube video below:

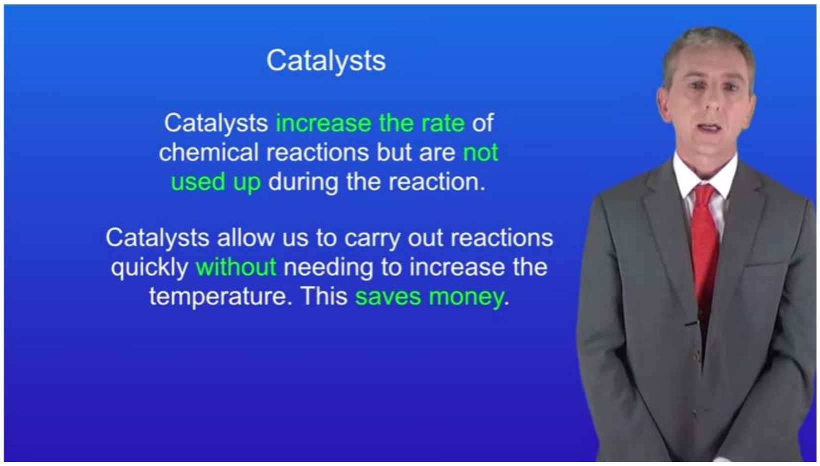
https://www.youtube.com/watch?v=WojotwxPD6I



Effect of the Surface Area of the Reactants on the Rate of Reaction.mp4

The Effect of the Catalyst on the Rate of Reaction is illustrated in the You Tube video below:

https://www.youtube.com/watch?v=hel8fQjxcO8



Effect of the Catalyst on the Rate of Reaction.mp4

III. Chemical Equilibrium

A Chemical Equilibrium is a chemical reaction by which the rate of forward reaction equals the rate of reverse reaction. As soon as the reactants react to produce the products, the products start reacting to re-produce the reactants back. This process goes back and forth. As a result of this the chemical equilibrium reaction ends up the reactants and products are present at the same time. This process is called to be reversible and designated by double arrows separating the reactants from the products.

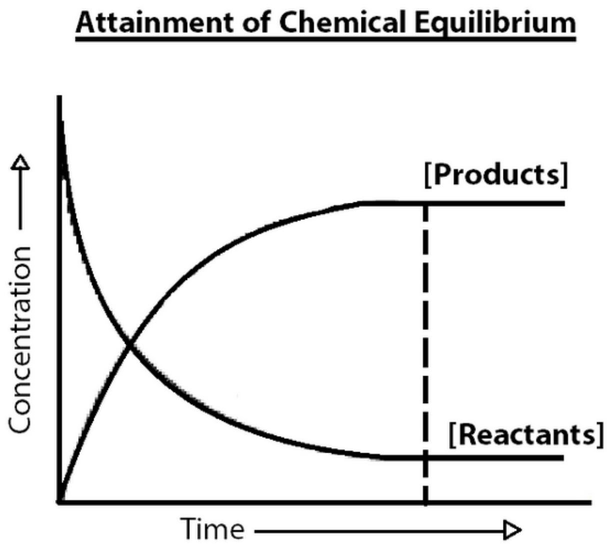
Example of a Chemical Equilibrium is given below:

N_2 (g) + 3 H_2 (g) ←→ 2 NH_3 (g) + Heat

N_2 (g) + 3 H_2 (g) are the reactants

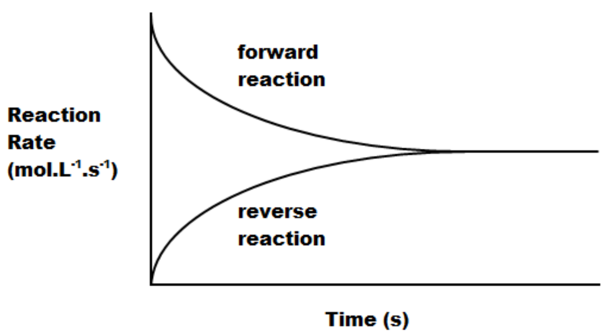
2 NH_3 (g) + Heat are the products

The graph below illustrates the progress of such chemical equilibrium:
https://www.toppr.com/bytes/everything-chemical-equilibrium/



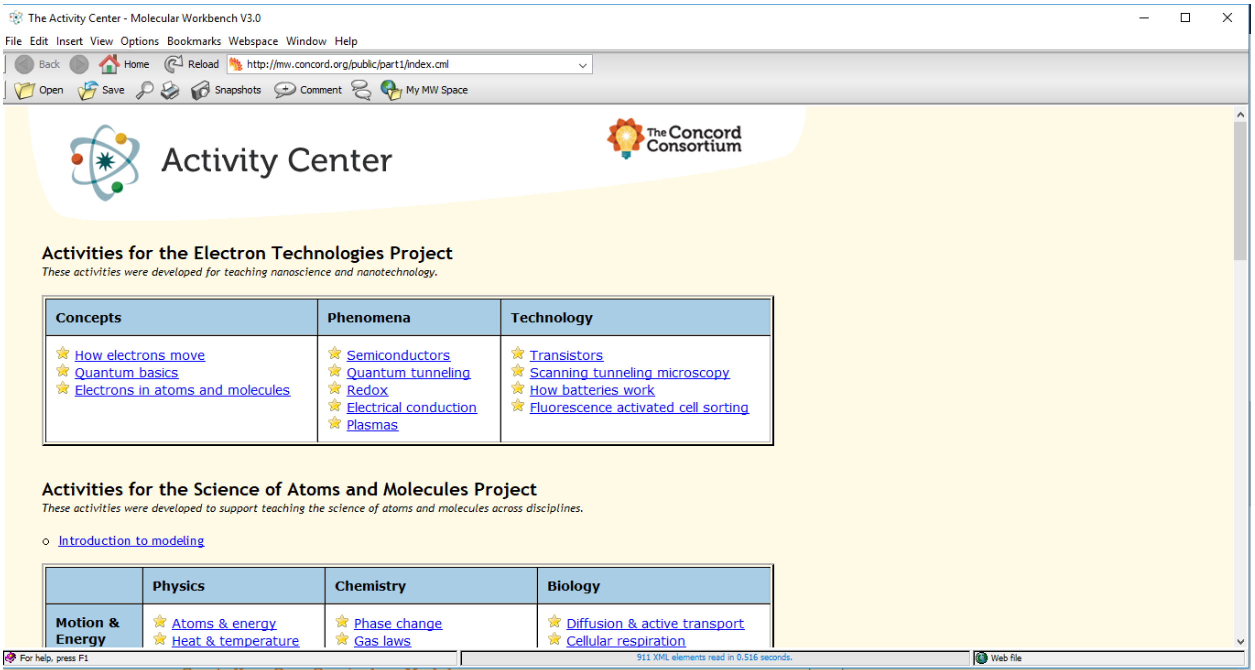
The concentration of the reactants decreases per time, while the concentration of products increases per time till both of reactants and the products concentrations are leveling off and the rate of the forward reaction equals the rate of the reverse reaction and the concentrations of reactants and products will exhibit no further change.

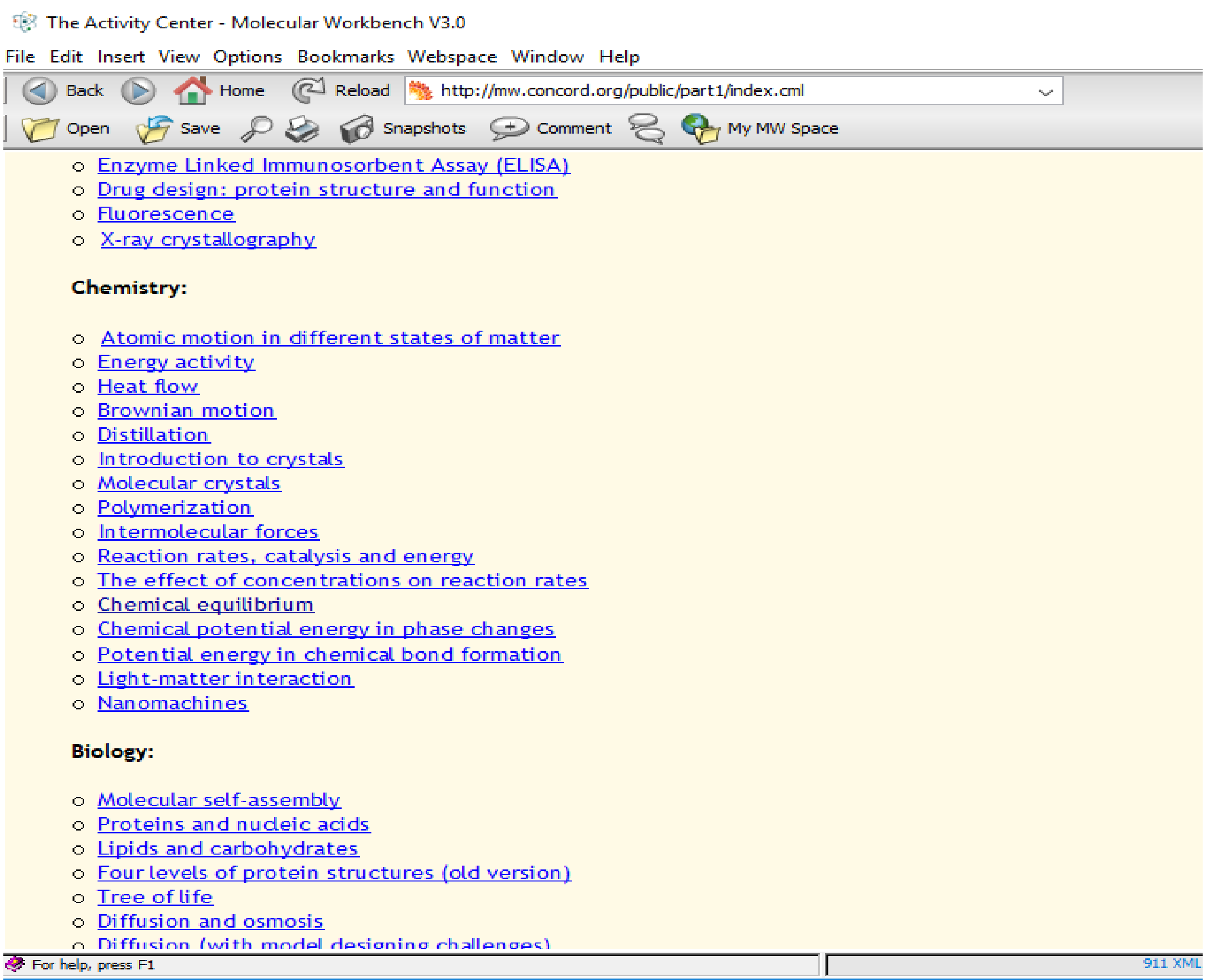
https://sites.google.com/site/chem4hsc/the-acidic-environment/chemical-equilibrium



A Molecular Workbench illustrates the concept of the Chemical Equilibrium.

One has to follow the same procedure mentioned to access the Activity Center of the Molecular Workbench and select the Chemical Equilibrium simulation.



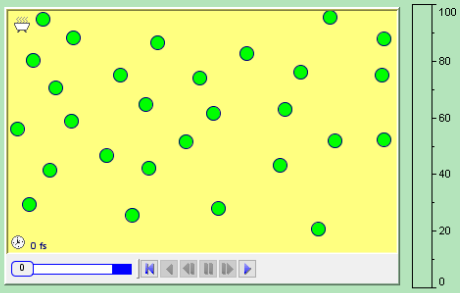


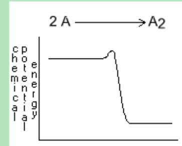
Start the simulation first step and answer the question(s):

Chemical Equilibrium and Le Chetalier's Principle
A "Normal" Reaction

Often when chemists write chemical reactions, they indicate what you start with by writing it down, and they then follow this with an arrow pointing to the right. Then they write what is formed. This notation implies that reactions do only that - start with one or more substances and form others. But is this always so? Run the reaction below to see how this works. The graph to the right will indicate what percentage of the reactants has turned into products. Are there any reverse reactions?

$2\,A \rightarrow A_2$





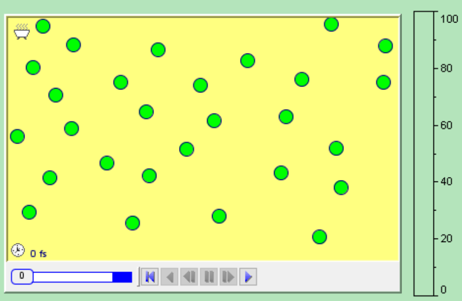
Take a look at the "chemical potential energy" graph. You should see that if you start with 2 A, it takes very little energy to bond together. However, if you start on the right side of the graph with A_2, then you have to climb up a steep energy hill in order to go back to being 2 A. What did you see happen when you ran the model, and why does this graph help to explain your observations?

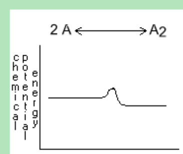
Continue to the second step and answer the question(s):

Chemical Equilibrium and Le Chetalier's Principle
An Equilibrium Reaction

Depending on the chemical potential energy curve, a reaction may go in the reverse direction almost as often as in the forward (left to right) direction. Run the reaction below to see what an equilibrium reaction looks like. Notice that we now write the chemical equation with a double arrow to show that this is an equilibrium reaction, not one that mostly goes in one direction.

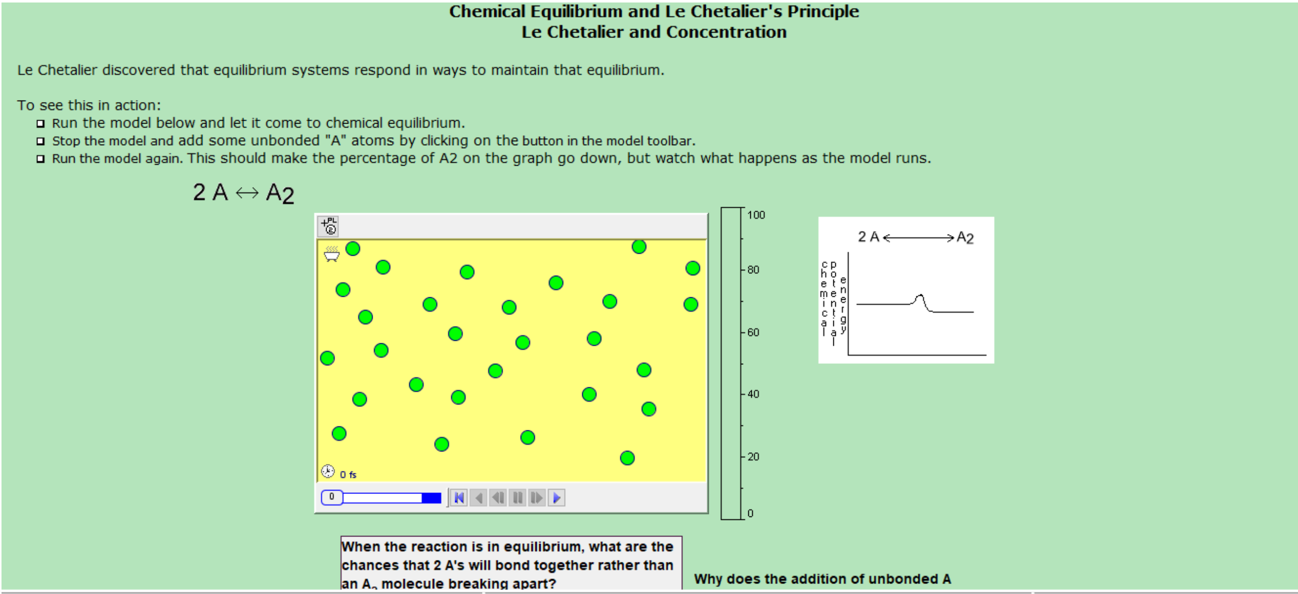
$2\,A \leftrightarrow A_2$



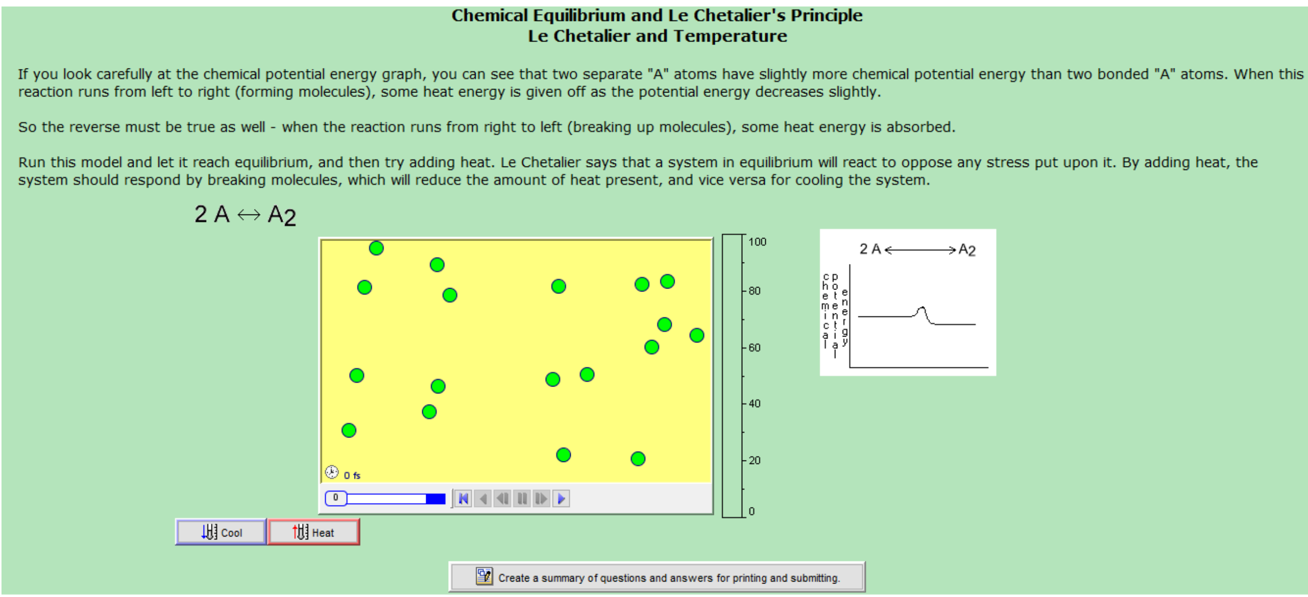


Now the "chemical potential energy" graph describing this reaction has changed. What did you see happen when you ran the model, and why does this graph help to explain your observations?

Continue to the third step of the simulation and answer the question(s):

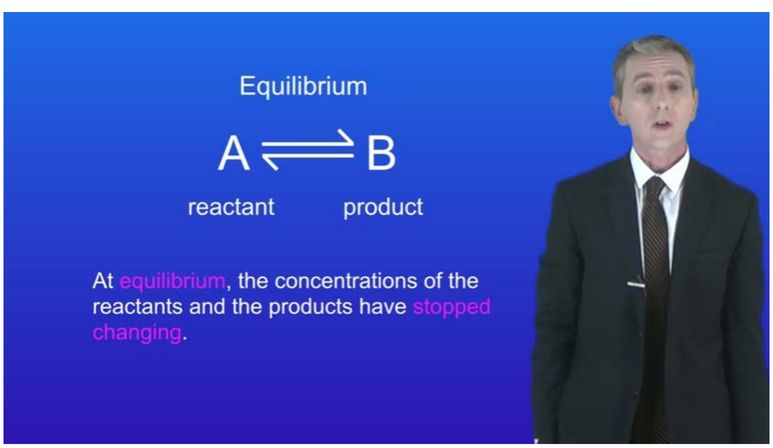


Finally, finish the last fourth step of the simulation and answer the question(s):



A You Tube video explains the Concept of the Chemical Equilibrium:

https://www.youtube.com/watch?v=L1QHCuFvkj4



Concept of the Chemical Equilibrium.mp4

IV. Equilibrium Constant

The Equilibrium Constant is defined as the ratio of the products (raised to their corresponding number of moles) to the reactants (raised to their corresponding number of moles).

An example of calculating the equilibrium constant is given below:

$2\ NO_2\ (g)\ \leftarrow\rightarrow\ N_2O_4\ (g)$

K_{eq} = Equilibrium Constant = $[\ N_2O_4\ (g)\ ]\ /\ [\ NO_2\ (g)\ ]^2$

Where $[\ N_2O_4\ (g)\ ]$ is the equilibrium concentration of N_2O_4 (g) and $[\ NO_2\ (g)\ ]$ is the equilibrium constant of $[\ NO_2\ (g)\ ]$.

$K_{eq} = K_c$ when the concentrations of reactants and products are used in mole/Liter
$K_{eq} = K_p$ when the pressures of the reactants and products are used in Pascal (unit of the pressure in SI system) or in atm (unit of pressure in the Metric system). In this case both the reactants and products should be gases.

If $[\ N_2O_4\ (g)\ ]$ and $[\ NO_2\ (g)\ ]$ are known, then the equilibrium constant K_{eq} can be calculated.

When setting up the formula of K_{eq} , one has to discard the liquids and the solids among the reactants and the products. Gaseous and aqueous reactants and products are the only ones considered for K_{eq} expression.

Example:

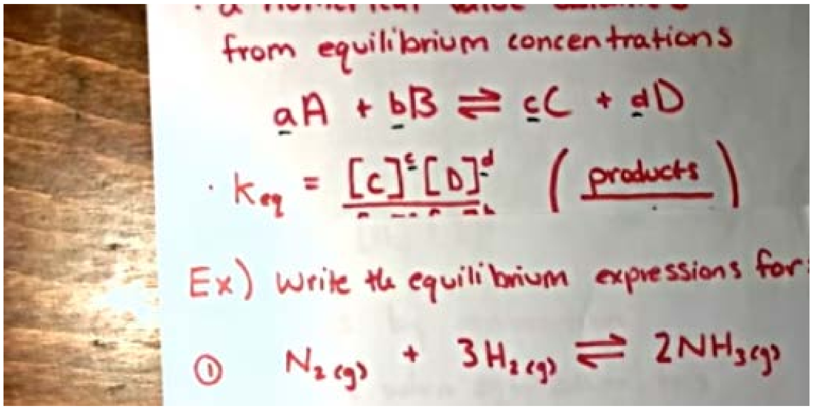
$PCl_5\ (s) + H_2O\ (g)\ \leftarrow\rightarrow\ 2HCl\ (g) + POCl_3\ (g)$

$K_{eq} = \{\ [\ HCl\ (g)\ ]^2\ [\ POCl_3\ (g)\ ]\ \}\ /\ \{\ [\ H_2O\ (g)\ ]\ \}$

PCl_5 (s) is solid and hence it is discarded from K_{eq} expression.

The video below illustrates the equilibrium constant calculations.

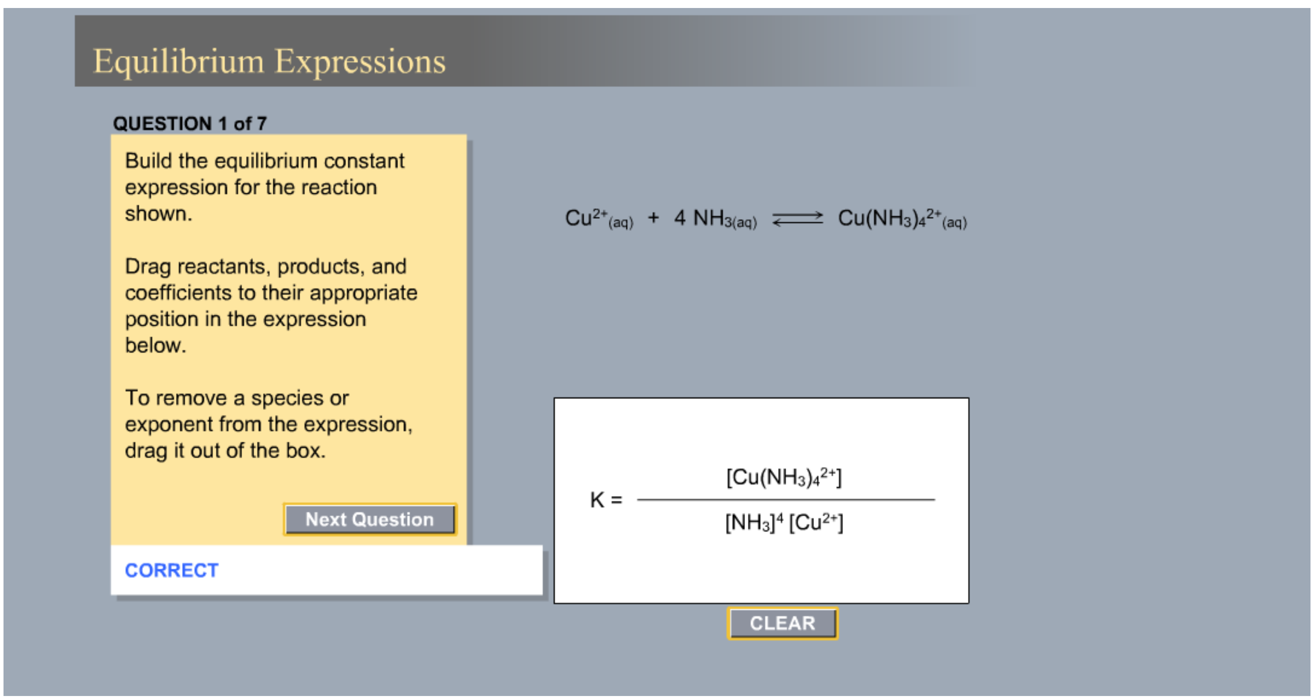
https://www.youtube.com/watch?v=QlaiTXIGDgg



The Equilibrium Constant and Expression with Examples.mp4

The State City of New York (SUNY) simulation illustrates how to set up the expression of K_{eq}.

http://employees.oneonta.edu/viningwj/sims/equilibrium_expressions_t.html



Finish all seven questions given in the simulation.

V. Magnitude of the Equilibrium Constant K_{eq}

The magnitude of the equilibrium constant K_{eq} can predict the direction of the chemical equilibrium. Three cases can be distinguished:

1. **K_{eq} >> 1**

   In this case, more products amount is present than the reactant and the reaction favors the products. The reaction is said to be complete.

2. **K_{eq} << 1**

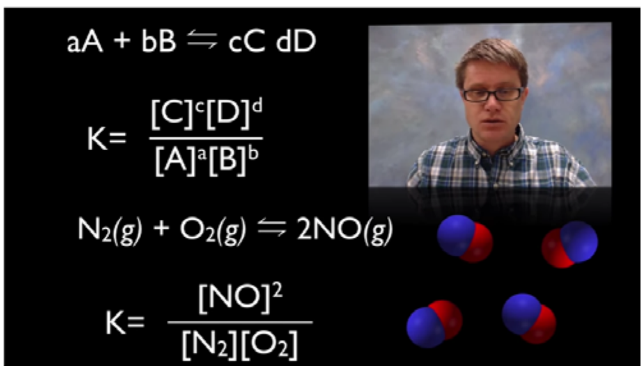
   In this case, more reactants amount is present than the products and the reaction favors the reactants. The reaction is barely progressed.

3. **K_{eq} is close to 1 (K_{eq} ~ 1)**

   In this case, the amount of products and the amount of reactants are close to each other and the reaction is said to be moderate.

A You Tube video illustrates the equilibrium constant calculation:

https://www.youtube.com/watch?v=xfGlEXWDRZE



The Equilibrium Constant.mp4

Selected Equilibrium Constants

http://www5.csudh.edu/oliver/chemdata/data-kc.htm

REACTION	K_c or K_p	T
ANTIMONY COMPOUNDS		
$SbC_5(g) \leftrightarrow SbC_3(g) + C_2(g)$	$K_p = 2.5 \times 10^{-2}$	248C
CARBON COMPOUNDS		
$CO(g) + 2H_2(g) \leftrightarrow CH_3OH(g)$	$K_c = 14.5(c)$	500 K
$CaCO_3(s) \leftrightarrow CaO(s) + CO_2(g)$	$K=1.9 \times 10^{-23}$	298 K
	$K=1.0$	1200 K
$C(s) + H_2O(g) \leftrightarrow CO(g) + H_2(g)$	$K=1.6 \times 10^{-21}$	298 K
	$K=10.0$	1100 K
$C(graphite) + CO_2(g) \leftrightarrow 2CO(g)$	$K_c = 0.64$	1200 K
$CO_2(g) + H_2(g) \leftrightarrow CO(g) + H_2O(g)$	$K_c = 1.4$	1200 K
$C(graphite) + 1/2\ O_2(g) \leftrightarrow CO(g)$	$K_c = 1 \times 10^3$	1200 K
$CO(g) + C_2(g) \leftrightarrow COC_2(g)$	$K_c = 1.2 \times 10^3$	668 K
$CO(g) + H_2O(g) \leftrightarrow CO_2(g) + H_2(g)$	$K_c = 23.2$	?
$2CH_4(g) \leftrightarrow C_2H_2(g) + 3H_2(g)$	$K_c = 0.154$	2000 K
$2COF_2(g) \leftrightarrow CO_2(g) + CF_4(g)$	$K_c = 2.00$	1000C
$COC_2(g) \leftrightarrow CO(g) + C_2(g)$	$K_p = 4.44 \times 10^{-2}$	395C
IODINE COMPOUNDS		
$H_2(g) + I_2(g) \leftrightarrow 2HI(g)$	$K_c = 50.2$	445C
$H_2(g) + I_2(g) \leftrightarrow 2HI(g)$	$K_p = 6.9 \times 10^1$	340C

$I_2(g)$ ← → $2I(g)$	$K_c = 1.1 \times 10^{-2}$	1200C
NITROGEN COMPOUNDS		

$N_2(g) + 1/2\ O_2(g) \leftarrow\rightarrow\ N_2O(g)$	$K_c = 2.4 \times 10^{-18}$	
$N_2(g) + O_2(g) \leftarrow\rightarrow\ 2NO(g)$	$K_c = 4.1 \times 10^{-31}$	
$N_2(g) + O_2(g) \leftarrow\rightarrow\ 2NO(g)$	$K_c = K_p = 1.7 \times 10^{-3}$	2300K
$N_2O(g) + 1/2\ O_2(g) \leftarrow\rightarrow\ 2\ NO(g)$	$K_c = 1.7 \times 10^{-13}$	
$2NO(g) + Br_2(g) \leftarrow\rightarrow\ 2NOBr(g)$	$K_c = 1.32 \times 10^{-2}$	1000 K
$N_2O_4(g) \leftarrow\rightarrow\ 2NO_2(g)$	$K_c = 4.61 \times 10^{-3}$	25C
$HCONH_2(g) \leftarrow\rightarrow\ NH_3(g) + CO(g)$	$K_c = 4.84$	400 K
$N_2(g) + 3H_2(g) \leftarrow\rightarrow\ 2NH_3(g)$	$K_c = 152$	500 K
$N_2(g) + 3H_2(g) \leftarrow\rightarrow\ 2NH_3(g)$	$K_p = 4.34 \times 10^{-3}$	300C
	$K_p = 1.45 \times 10^{-5}$	500C
	$K_p = 2.25 \times 10^{-6}$	600C
OXYGEN COMPOUNDS		
$2H_2(g) + O_2(g) \leftarrow\rightarrow\ 2H_2O(g)$	3.2×10^{81}	25C
PHOSPHORUS COMPOUNDS		
$PC_5(g) \leftarrow\rightarrow\ PC_3(g) + C_2(g)$	$K_c = 3.8 \times 10^{-2}$	250C
SULFUR COMPOUNDS		
$1/8\ S_8(s) + O_2(g) \leftarrow\rightarrow\ SO_2(g)$	$K = 4.2 \times 10^{52}$	25C
$2\ SO_2(g) + O_2(g) \leftarrow\rightarrow\ 2\ SO_3(g)$	$K_c = 280$	1000 K
$2\ H_2S(g) \leftarrow\rightarrow\ 2\ H_2(g) + S_2(g)$	$K_p = 0.012$	1065C
$2\ H_2(g) + O_2(g) \leftarrow\rightarrow\ 2\ H_2O()$	$K = 1.4 \times 10^{83}$	298 K
$NH_4HS(s) \leftarrow\rightarrow\ NH_3(g) + H_2S(g)$	$K_p = 0.108$	25C
$2H_2S(g) \leftarrow\rightarrow\ 2H_2(g) + S_2(g)$	$K_c = 1.0 \times 10^{-6}$	1000 K
$SO_2C_2(g) \leftarrow\rightarrow\ SO_2(g) + C_2(g)$	$K_p = 2.9 \times 10^{-2}$	303

VI. Calculation Examples of the Equilibrium Constant

Example 1:

Consider the following equilibrium reactions:

a) $2\ NO_{2\,(g)} \leftarrow\rightarrow N_2O_{4\,(g)}$ Keq = 2.2

b) $Cu^{2+}_{(aq)} + 2\ Ag_{(s)} \leftarrow\rightarrow Cu_{(s)} + 2Ag^{+}_{(aq)}$ Keq = 1×10^{-15}

c) $Pb^{2+}_{(aq)} + 2\ Cl^{-}_{(aq)} \leftarrow\rightarrow PbCl_{2(s)}$ Keq = 6.3×10^{4}

d) $SO_{2(g)} + O_{2\,(g)} \leftarrow\rightarrow SO_{3\,(g)}$ Keq = 110

Which equilibrium favors products to the greatest extent?
Which equilibrium favors reactants to the greatest extent?

Answer:

Higher K_{eq} value favors the products and lower K_{eq} value favors the reactants.

Choice C has the largest value of K_{eq} value and hence the equilibrium reaction of Choice C favors the product.

c) $Pb^{2+}_{(aq)} + 2\ Cl^{-}_{(aq)} \leftarrow\rightarrow PbCl_{2(s)}$ Keq = 6.3×10^{4}

Choice B has the lowest value of K_{eq} value and hence the equilibrium reaction of Choice B favors the reactants.

b) $Cu^{2+}_{(aq)} + 2\ Ag_{(s)} \leftarrow\rightarrow Cu_{(s)} + 2\ Ag^{+}_{(aq)}$ Keq = 1×10^{-15}

Example 2:

$SO_{3(g)} + H_2O_{(g)} \leftarrow\rightarrow H_2SO_{4(g)}$

At equilibrium $[SO_3]$ = 0.400M $[H_2O]$ = 0.480M $[H_2SO_4]$ = 0.600M

Calculate the value of the equilibrium constant.

Answer:

K_{eq} = $[\ H_2SO_{4(g)}\ ]\ /\ [\ SO_{3(g)}\ ] \times [\ H_2O_{(g)}\ ]$ = [0.600M] / [0.400M] x [0.480M } = 3.13

Example 3:

At equilibrium at 100ºC, a 2.0L flask contains:

0.075 mol of PCl_5 0.050 mol of H_2O 0.750 mol 0f HCl 0.500 mol of $POCl_3$

Calculate the Keq for the reaction:

PCl_5 (s) + H_2O (g) ←→ 2 HCl (g) + $POCl_3$ (g)

K_{eq} = { [HCl (g)]^2 [$POCl_3$ (g)] } / { [H_2O (g)] }

PCl_5 (s) is solid and hence it is discarded from K_{eq} expression.

K_{eq} = { [HCl (g)]^2 [$POCl_3$ (g)] } / { [H_2O (g)] } = {[0.750 mol/2.0 L]^2 x [0.500 mol/2.0L]}/{[0.050 Mol/ 2.0 L]} = 1.40625 = 1.4

Example 4:

Keq= 798 at 25°C for the reaction: **2 SO_2 (g) + O_2 (g) ←→ 2 SO_3 (g).**

In a particular mixture at equilibrium, [SO_2]= 4.20 M and [SO_3]=11.0M. Calculate the equilibrium [O_2] in this mixture at 25°C.

K_{eq} = 798 = {[**SO_3 (g)]^2} / {[SO_2 (g)]}^{2}x[O_2 (g)]} = {[11.0 M]}^{2} / {[4.20 M]^2 x [O_2]}**

Isolating [O_2]

[O_2] = {[11.0 M]}^{2} / {[4.20 M]^2 x [798] = 0.00860 M

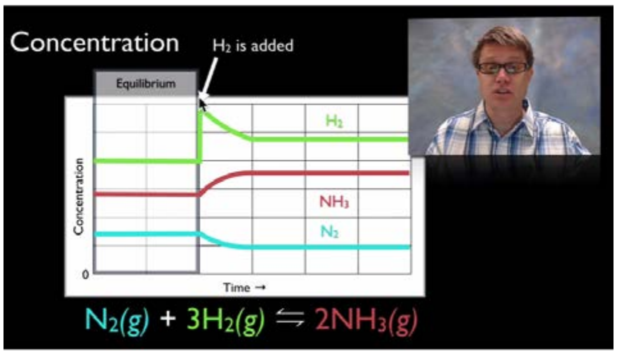
VII. Le Châtelier's Principle

The chemical equilibrium can be disturbed by an external condition which can affect the rate of the forward and the rate of reverse reaction equality and the chemical equilibrium is no longer held. In order to re-establish the chemical equilibrium, the chemical reaction has to shift to side of the reaction which has the least stress from adding this external condition.

This shifting to the least stressed side of the reaction and re-establishing the chemical equilibrium is known as **Le Châtelier's Principle.**

A video of You Tube illustrates the Le Châtelier's Principle as well as the effects of the shifting the chemical equilibrium by external conditions or stresses.

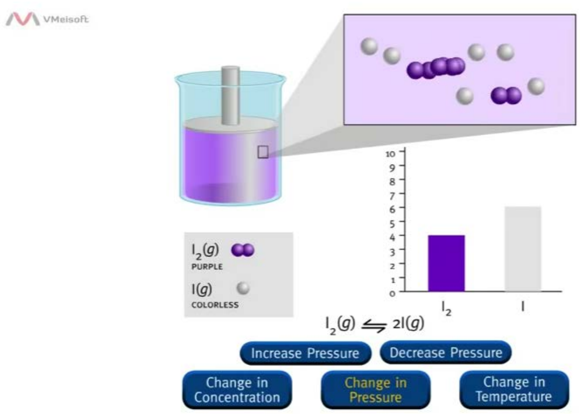
https://www.youtube.com/watch?v=PciV_Wuh9V8



Le Chateliers Principle.mp4

An animation made by the State University of New York illustrates the Le Châtelier's Principle:

https://www.youtube.com/watch?v=Kiidcw39Y0U



Le Chateliers Principle Animation.mp4

The external conditions can be a change in:

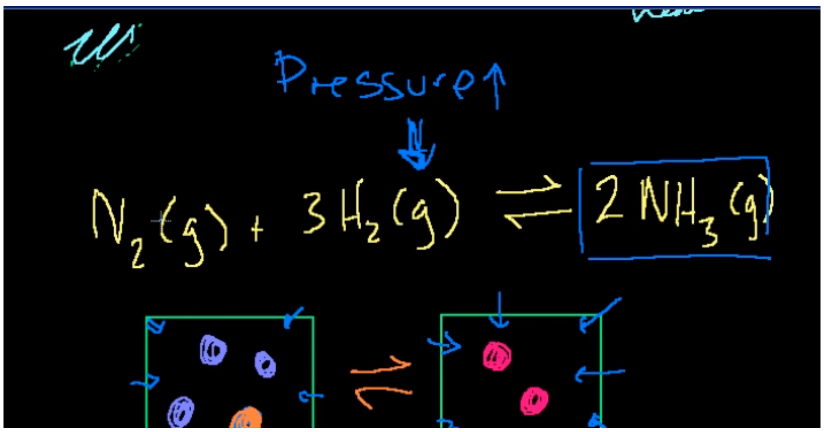
A. Changing the concentration of reactants or the products by adding or removing

B. **Changing the heat of the reaction by cooling or heating**
C. **Changing the volume of the reaction system**
D. **Changing the pressure of the reaction system**
E. **Effect of Catalysts on Chemical Equilibrium Reactions**

Now the external conditions can be closely discussed.

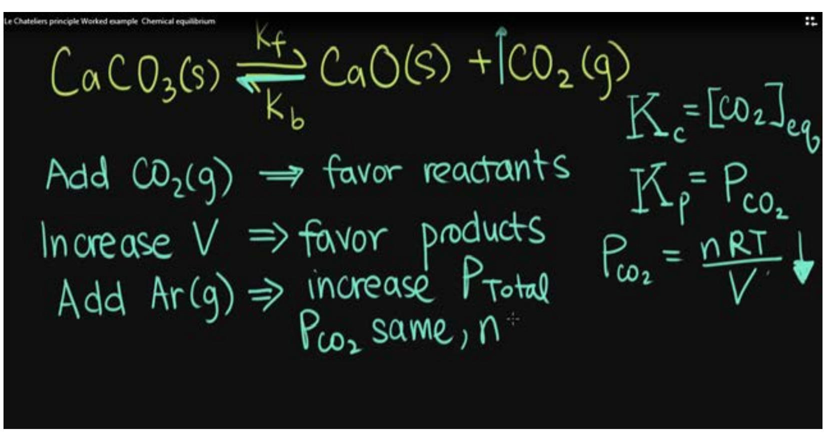
The videos from Khan Academy explain these factors in some details:

https://www.khanacademy.org/science/chemistry/chemical-equilibrium/factors-that-affect-chemical-equilibrium/v/le-chatelier-s-principle



Factors Affecting the Chemical Equilibrium.mp4

https://www.khanacademy.org/science/chemistry/chemical-equilibrium/factors-that-affect-chemical-equilibrium/v/le-chateliers-principle-worked-example-chemical-equilibrium-chemistry-khan-academy



Le Chateliers principle Worked example Chemical equilibrium.mp4

A. Changing the concentration of reactants or the products by adding or removing

Let us consider the chemical equilibrium below:

$NH_4HS(s)$ ←→ $NH_3(g)$ + $H_2S(g)$ K_p = 0.108 at 25ºC

K_p = 0.108 which means the equilibrium constant is considering only the gaseous phases. The K_p expression will be written as follows:

K_p = [$NH_3(g)$] x [$H_2S(g)$]

The solid NH_4HS is discarded from the equilibrium constant expression.

Now let us consider the cases of increasing and decreasing the products:

a. Increasing the concentration of $NH_3(g)$ or $H_2S(g)$ by adding them externally:

In case of increasing one of the products' concentration, the right side (the product side of the chemical reaction) will be more stressed. In order to re-establish the chemical equilibrium, the chemical equilibrium will shift to the side that is least stressed, namely; to the left side of the chemical reaction (to the reactant's side).

Evidence of this shift can be observed by the increase in the amount of the solid NH_4HS.

b. Decreasing the concentration of $NH_3(g)$ or $H_2S(g)$ by removing them from the chemical reaction:

In case of decreasing one of the products' concentration by removing them out of the chemical reaction, the right side (the product side of the chemical reaction) will be less stressed and the left side which is the reactant's side will be more stressed. In order to re-establish the chemical equilibrium, the chemical equilibrium will shift to the side that is least stressed, namely; to the right side of the chemical reaction (to the products' side).

Evidence of this shift can be observed by the decrease in the amount of the solid NH_4HS.

Let us look at another chemical equilibrium in which the reactant and the product have colors which makes it very easy to follow and observe:

$Co(H_2O)_6^{2+}(aq)$ + 4 $Cl^-(aq)$ + Heat ←→ **$CoCl_4^{2-}(aq)$** + 6 $H_2O(g)$

The $Co(H_2O)_6^{2+}$ complex is pink, and the $CoCl_4^{2-}$ complex is blue.

Let us consider the cases related to the concentrations of the reactants and the products:

a. Increasing the concentration of $Co(H_2O)_6^{2+}(aq)$ or $Cl^-(aq)$ by adding them externally:

Increasing the concentrations of the reactants will put stress on the side of the reactants' side and the chemical equilibrium will adjust itself by shifting to the side with the least stress, namely; to the right side of the chemical reaction (to the products' side).

Evidence of this shift can be observed by the color change from the pink color to the blue color.

b. Decreasing the concentration of $Co(H_2O)_6^{2+}$(aq) or Cl^-(aq) by removing them from the chemical reaction:

Decreasing the concentrations of the reactants will put stress on the side of the products' side and the chemical equilibrium will adjust itself by shifting to the side with the least stress, namely; to the left side of the chemical reaction (to the reactants' side).

Evidence of this shift can be observed by the color change from the blue color to the pink color.

c. Increasing the concentration of $CoCl_4^{2-}$(aq) or H_2O(g) by adding them externally:
Increasing the concentrations of the products will put stress on the side of the products' side and the chemical equilibrium will adjust itself by shifting to the side with the least stress, namely; to the left side of the chemical reaction (to the reactants' side).
Evidence of this shift can be observed by the color change from the blue color to the pink color.

d. Decreasing the concentration of $CoCl_4^{2-}$(aq) or H_2O(g) by removing them from the chemical reaction:

Decreasing the concentrations of the products will put stress on the side of the reactants' side and the chemical equilibrium will adjust itself by shifting to the side with the least stress, namely; to the right side of the chemical reaction (to the products' side).

Evidence of this shift can be observed by the color change from the pink color to the blue color.

B. Changing the heat of the reaction by cooling or heating

The **endothermic** reaction of the previous example will be considered:

$\mathbf{Co(H_2O)_6^{2+}(aq)}$ + 4 Cl^-(aq) + Heat ←→ $\mathbf{CoCl_4^{2-}(aq)}$ + 6 H_2O(g)

a. Increasing the heat by heating the chemical equilibrium system externally:

In an endothermic reaction, the heat is taken into the reaction system and it appears on the left side of chemical reaction. Thus increasing the heat will put more stress on the left side of the chemical equilibrium (reactants' side) and the chemical equilibrium will adjust itself by shifting to the least stressed side which is the right side (products side).

Evidence of this shift can be observed by the color change from the pink color to the blue color.

b. Decreasing the heat by cooling the chemical equilibrium system externally:

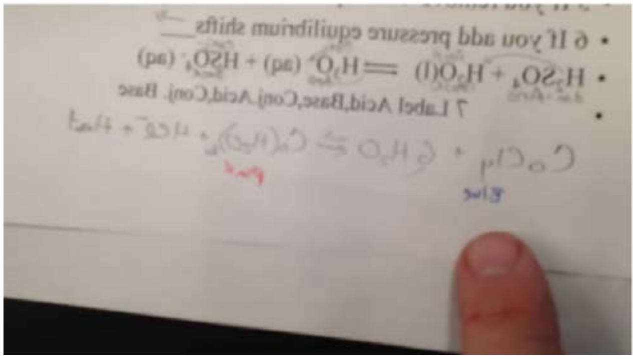
If the heat is decreased or removed by cooling the reaction system, then the products' side will be more stressed and the chemical equilibrium will adjust itself by shifting to the side that is least stressed. It will shift to the left to side of the reactants.

Evidence of this shift can be observed by the color change from the blue color to the pink color.

A video You tube shows the effect of the temperature on the chemical equilibrium:

$\mathbf{Co(H_2O)_6^{2+}(aq)}$ + 4 Cl^-(aq) + Heat ←→ $\mathbf{CoCl_4^{2-}(aq)}$ + 6 H_2O(g)

https://www.youtube.com/watch?v=uEVyEU7QNoQ



CoCl4 Chemical Equilibrium.mp4

C. Changing the volume of the reaction system

$Co(H_2O)_6^{2+}(aq)$ + 4 $Cl^-(aq)$ + Heat ← → **$CoCl_4^{2-}(aq)$** + 6 $H_2O(g)$

Increasing the volume of the reaction system of the chemical equilibrium will lead to a decrease in the pressure exercised on the system (Boyle's Law). In such case, the chemical equilibrium will adjust itself by re-establishing the chemical equilibrium and it will shift to side that has **the largest sum of the moles present**.

It is very important to note that, one should consider only gaseous and aqueous phases of the reactants and the products. Liquid and solid phases of the reactants and the products are considered and they are discarded form the equilibrium constant expression.

The sum of the number of moles of the reactants is 1 + 4 = 5 moles.
The sum of the number of moles of the products is 1 + 6 = 7 moles.

Increasing the volume of the chemical equilibrium system will cause the chemical equilibrium to shift to the side of the chemical equilibrium with the most number of moles. The shift will be to the products' side since it has **the large sum of number of moles.**

Decreasing the volume means increasing the pressure on the chemical equilibrium system. This will cause the chemical equilibrium to shift to the side with **least sum of number of moles present.** In this chemical equilibrium, decreasing the volume (increasing the pressure) will cause the chemical equilibrium to shift to the reactants' side (the least sum of number of moles).
Evidence of this shift can be observed by the color change from the blue color to the pink color.

D. Changing the pressure of the reaction system

The effect of changing the pressure of the reaction system is quite the opposite of changing the volume of the reaction system (Boyle's Law).

Increasing the pressure (decreasing the volume) will cause the chemical equilibrium system to shift to the side with the least sum of number of moles. In the reaction above, the shift will be to reactants' side to the left with the **least sum of number of moles** (to the left).

Decreasing the pressure (increasing the volume) will cause the chemical equilibrium system to shift to the side with the **largest sum of number of moles** to the products' side (to the right).

E. Effect of Catalysts on Chemical Equilibrium Reactions

Adding a catalyst to the chemical equilibrium reaction increases the rate of forward and reverse reactions at the time with the same magnitude.

The chemical equilibrium is reached much faster than without the catalyst. However, the chemical Equilibrium position does not change.

The rate of forward and reverse reactions at equilibrium are still equal but both rates are larger than the rates of forward and reverse without a catalyst.

End of Chapter Questions:

I. Reaction Rates

1. The rate of a reaction depends upon:

a) the concentration of the reactants.
b) the temperature of the reaction.
c) whether or not a catalyst is used.
d) the nature of the reactants.
e) all of the above are correct.

2. Which of the following statement(s) about a reaction mechanism is/are true?

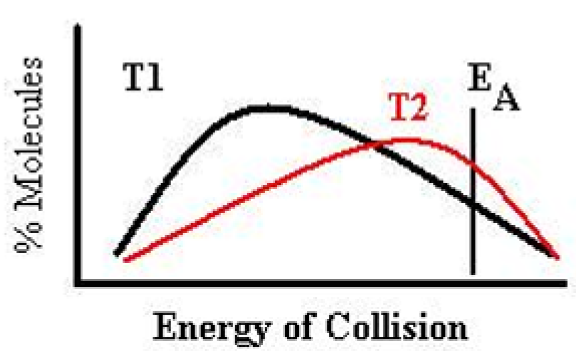
I. The mechanism is the series of steps needed to complete a reaction.

II. The rate of a reaction is only as fast as the slowest step in the mechanism.

III. You can usually deduce the reaction mechanism from its reactants and products.

a) I only
b) II only
c) III only
d) I and II only
e) I, II and III

3. Which is the highest temperature?



a) T1 = T2
b) T1 < T2
c) T1 > T2
d) it is impossible to tell.

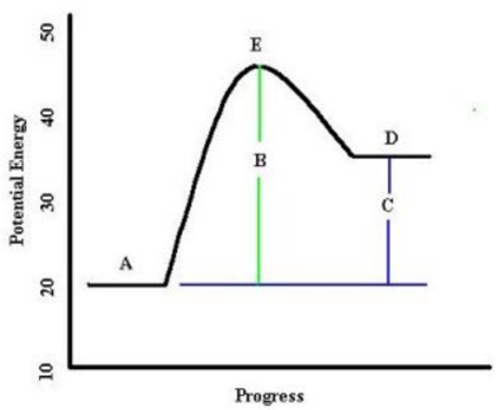
Use the above graph:

4. Which of the curves has the greatest number of collisions possessing the activation energy?
    a) T1 has the greatest number of collisions possessing the activation energy
    b) T2 has the greatest number of collisions possessing the activation energy
    c) both have an equal number of collisions possessing the activation energy.
    d) it is impossible to tell.

Use the above graph:

5. If a catalyst were used, how would the distributions change?
    a) both curves would shift to the right.
    b) both curves would shift to the left.
    c) the activation energy would shift to the right.
    d) the activation energy would shift to the left.
    e) nothing about the distributions would change.

Using the graph below for the questions 6 – 10:



6. Which letter shows the potential energy of the activated complex?

    A or B or C, D or E

7. What is the ΔH (Heat) of the reaction?
    a) + 35 KJ
    b) - 35 KJ
    c) + 25 KJ
    d) - 10 KJ
    e) None of the above

8. Which letter shows the activation energy?

    A or B or C, D or E

9. How would the graph change if the temperature were raised?
    a) A and D would have higher energies.
    b) C would be greater.

c) the activation energy would decrease.
d) more than one of the above are correct.
e) no change in the graph would occur.

10. How would the graph change if a catalyst were used?
    a) A and D would have higher energies.
    b) C would be greater.
    c) the activation energy would decrease.
    d) more than one of the above are correct.
    e) no change in the graph would occur.

11. The rate determining step for a complex reaction is the one which is
    a) fastest
    b) slowest
    c) last in the sequence
    d) first in the sequence

12. Which one of the following is **NOT** a key concept of the collision theory:
    a) particles must collide in order to react
    b) particles must move slowly when they collide, otherwise they simply “bounce off” one another
    c) particles must collide with the proper orientation
    d) particles must collide with sufficient energy to reach the activated complex in order to react

13. Which one of the following factors does ***not*** affect the rate of a chemical reaction:
    a) humidity
    b) temperature
    c) concentration
    d) nature of the reactants

14. Activation energy is the amount of energy required to
    a) break the bonds between the reacting molecules
    b) convert the reactants into the activated complex
    c) make the reacting particles collide
    d) form the bonds between the product molecules

15. The rate of a chemical reaction normally
    a) increases as temperature decreases.
    b) decreases when a catalyst is added.
    c) increases as reactant concentration increases.
    d) decreases as reactant concentration increases.

16. Crushing a solid into a powder will increase reaction rate because:
    a) the particles will collide with more energy
    b) the orientation of colliding particles will be improved
    c) the activation energy barrier will be lowered
    d) the powdered form has more surface area.

17. The series of steps that most reactions undergo, frominitial reactants to final products, is called the:
    a) catalytic conversion
    b) activation energy
    c) entropy of reaction
    d) reaction mechanism

18. Reaction rates generally increase with an increase in temperature. Four suggested reasons are:
    I. Molecules collide more frequently at higher temperatures.
    II. As the temperature of a reaction increases, the activation energy for the reaction decreases.
    III. The concentration of reactants will be greater at a higher temperature.
    IV. The fraction of high energy molecules is greater at higher temperatures.

    The correct statements are:

    a) II and IV only
    b) I, II and IV only
    c) I and IV only
    d) I, III, and IV only

19. A lump of ignited charcoal which is glowing in air burns more vigorously when lowered into a bottle of pure oxygen. This is due to an increase in
    a) surface area
    b) concentration
    c) temperature
    d) volume

20. What happens to a catalyst in a reaction?
    a) It remains unchanged.
    b) It is incorporated into the products.
    c) It is incorporated into the reactants.
    d) It evaporates.

21. It is generally believed that catalysts increase reaction rates by:
    a) removing the activation energy barrier
    b) providing an alternate activation energy barrier that is lower than the original barrier
    c) lowering the activation energy barrier
    d) giving the reacting particles more energy, thus there will be more successful collisions

22. Which one of the following statements concerning rates of reactions is **FALSE**?

    a) The higher the activation energy barrier, the faster the reaction.

    b) Increasing the concentration of a reactant may increase the rate of a reaction.

    c) Adding a catalyst speeds up the rate of reaction for both the forward and reverse reactions.

    d) Increasing the concentration increases the rate of a reaction, because it increases the number of collisions.

23. In general, an increase in temperature of 10^o C will have what effect on reaction rate:
    a) double the rate

b) half the rate
c) triple the rate
d) increase the rate but not by a specific amount

24. According to collision theory,
    a) all collisions result in some sort of chemical reaction
    b) molecular orientation alone determines the effectiveness of a collision
    c) the amount of energy of the particles determines whether a reaction occurs
    d) both molecular orientation and amount of energy must be right for a reaction to occur

II. Factors Affecting the Rate of Reaction

25. What effect does doubling the concentration of one of the reactants have on the rate of the reaction
    a) it increases the rate of reaction.
    b) It decreases the rate of reaction.
    c) It has no effect.
    d) The rate of reaction s halved.

26. Which of the following factors does not affect the rate of a chemical reaction?
    a) temperature of the reactants
    b) particle size
    c) nature of the reactants
    d) color of the reactants

27. A catalyst that slows down a chemical reaction is known as
    a) an inhibitor
    b) a converter
    c) an enzyme
    d) a heterogeneous catalyst

28. For the reaction between calcium carbonate solid and dilute hydrochloric acid
    $CaCO_3 + HCl \rightarrow CaCl_2 + H_2O + CO_2$
    which one of the following factors will speed up the reaction?
    a) lower the temperature of the hydrochloric acid.
    b) use a bigger conical flask.
    c) use more dilute acid.
    d) use smaller pieces of calcium carbonate ($CaCO_3$).
29. In a reaction between two gases, which one of the following factors will not affect the rate of reaction?
    a) the pressure of the gases
    b) the volume of the container that the gases react in
    c) The temperature of the gases
    d) the color of the gases

30. Which one of the following reactions will start with the highest rate?
    a) 5 g of limestone chips in 100 mL of 0.1 M HCl at 25ºC.
    b) 5 g of limestone powder in 100 mL of 0.1 M HCl at 25ºC.
    c) 5 g of limestone chips in 100 mL of 0.1 M HCl at 45ºC.
    d) 5 g of limestone powder in 100 mL of 0.1 M HCl at 45ºC.

31. Which one of the following chemical reactions takes place at the greatest rate?
    a) paint drying
    b) an egg boiling
    c) a match burning

d) cement setting

32. When **powdered** calcium carbonate is added to a solution of hydrochloric acid, it reacts completely within seconds. When the same mass of calcium carbonate **chips** are added to a similar amount of hydrochloric acid, the reaction takes several minutes to go to completion. Why?
    a) there are more impurities in the calcium carbonate chips.
    b) the powder has a greater surface area.
    c) an acid will react faster with a powder.
    d) the calcium carbonate chips are less soluble than the powder.

33. The rate of a chemical reaction may be defined as
    a) the change in concentration of any one of the products only
    b) the time it takes for the reaction to be completed
    c) the change in concentration of any one of the reactants or products
    d) the change in concentration of any one of the reactants only

34. A catalyst
    a) will be chemically unchanged at the end of a reaction.
    b) will always react with the reactants in a chemical reaction.
    c) will have a change in its mass at the end of a chemical reaction.
    d) must be in the same phase (state of matter) as the reactants.

35. Why does the rate of reaction increase when powdered calcium carbonate is used instead of marble chips?
    a) there is an increase of the particle size of the calcium carbonate
    b) there is an increase of the concentration of the calcium carbonate
    c) the powdered calcium carbonate acts as a catalyst
    d) there is an increase of the surface area of the calcium carbonate

36. Catalysts are used in industry because
    a) they remove the products from the reaction mixture as the products form.
    b) they increase the yield of the products.
    c) they lower the temperature at which the reaction can proceed.
    d) they increase the rate at which the products are formed.

37. Which one of the following statements is **TRUE** about catalysts?
    a) their appearance is unchanged at the end of the reaction
    b) they are metals
    c) they are chemically unchanged at the end of the reaction
    d) they are solids

38. If the temperature of a reaction is increased by 10^{o}C, the reaction rate will be
    a) doubled
    b) four times faster
    c) ten times faster
    d) halved

39. What is the general relationship between temperature and reaction rate:
    a) the higher the temperature, the higher the reaction rate
    b) the higher the temperature, the lower the reaction rate
    c) temperature and rate vary inversely
    d) there is no relationship between the two

40. What factor accounts for the fact that powdered sugar dissolves more quickly than granulated sugar under the same conditions?

a) temperature
b) concentration
c) nature of reactants
d) surface area

41. A substance that increases the rate of a reaction without itself being used up is called a(n)
    a) intermediate product
    b) catalyst
    c) inhibitor
    d) activated complex

III. Chemical Equilibrium and Equilibrium Constant

42. $\mathbf{SO_{3(g)} + H_2O_{(g)} \leftrightarrow H_2SO_{4(l)}}$

    At equilibrium $[SO_3] = 0.400M$ $[H_2O] = 0.480M$ $[H_2SO_4] = 0.600M$
    Calculate the value of the equilibrium constant.
    a) 3.13
    b) 2.15
    c) 5.87
    d) 4.03

43. At equilibrium at 100ºC, a 2.00 L flask contains:

    $\mathbf{PCl_5\,(s) + H_2O\,(g) \leftrightarrow 2HCl\,(g) + POCl_3\,(g)}$

    0.075 mol of PCl_5 0.050 mol of H_2O 0.750 mol 0f HCl 0.500 mol of $POCl_3$
    Calculate the K_{eq} for the reaction: [K_{eq} should not include any solids]
    a) 1.56
    b) 2.98
    c) 1.41
    d) 2.55

44. K_{eq} = 798 at 25ºC for the reaction:

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

    In a particular mixture at equilibrium, $[SO_2]$= 4.20 M and $[SO_3]$=11.0M. Calculate the equilibrium $[O_2]$ in this mixture at 25ºC
    a) 0.00750 M
    b) 0.00653 M
    c) 0.00963 M
    d) 0.00860 M

45. Consider the following equilibrium:

    $\mathbf{2SO_2\,(g) + O_2\,(g) \leftrightarrow 2SO_3\,(g)}$

    0.600 moles of SO_2 and 0.600 moles of O_2 are present in a 4.00 L flask at equilibrium at 100ºC. If the K_{eq} = 680. Calculate the SO_3 concentration at 100ºC
    a) 3.56 M

b) 2.30 M
c) 4.30 M
d) 1.54 M

46. Consider the following equilibrium:

$2\ NO_{2(g)}$ ←→ $N_2O_{4(g)}$

2.00 moles of NO_2 and 1.60 moles of N_2O_4 are present in a 4.00 L flask at equilibrium at 20ºC. Calculate the K_{eq} at 20ºC.

a) 1.60
b) 1.80
c) 1.90
d) 1.70

47. The following equilibrium is readily established:

$SO_2Cl_2\ (g)$ ←→ $SO_2\ (g)$ + $Cl_2\ (g)$

At equilibrium at 373 K, a 1.00-L reaction vessel contains 0.0106 mol of SO_2Cl_2 and 0.0287 mol each of SO_2 and Cl_2. What is K_{eq} for the reaction at 373 K?

a) 12.8
b) 2.72
c) 0.0781
d) 2.39

48. Dinitrogentetraoxide partially decomposes according to the following

equilibrium: **$N_2O_4\ (g)$ ¬ $2NO_2\ (g)$**

A 1.000-L flask is charged with 3.00 ¸ 10^{-2} mol of N_2O_4. At equilibrium, 2.36 ¸ 10^{-2} mol of N_2O_4 remains. K_{eq} for this reaction is:

a) 0.723
b) 1.92
c) 6.93×10^{-3}
d) 0.391
e) 0.212

49. Consider the following equilibrium:

a) $2NO_{2\ (g)}$ ←→ $N_2O_{4\ (g)}$ $K_{eq} = 2.2$
b) $Cu^{2+}_{(aq)}$ + $2Ag_{(s)}$ ←→ $Cu_{(s)}$ + $2Ag^{+}_{\ (aq)}$ $K_{eq} = 1 \times 10^{-15}$
c) $Pb^{2+}_{\ (aq)}$ + 2 $Cl^{-}_{\ (aq)}$ ←→ $PbCl_{2(s)}$ $K_{eq} = 6.3 \times 10^{4}$
d) $SO_{2(g)}$ + $O_{2\ (g)}$ ←→ $SO_{3\ (g)}$ $K_{eq} = 110$

Which equilibrium favors products to the greatest extent? a or b or c or d
Which equilibrium favors reactants to the greatest extent? a or b or c or d

50. At a certain temperature the K_{eq} for a reaction is 75.

$2O_{3(g)}$ ←→ $3O_{2(g)}$

Predict the direction in which the equilibrium will proceed, if any, when the following amounts are introduced to a 10 L vessel.

a) to the left of equilibrium
b) to the right of the equilibrium
c) no change
d) none of the above

51. If at equilibrium $[H_2]$ = 0.200M and $[I_2]$ = 0.200M and K_{eq}=55.6 at 250ºC, calculate the equilibrium concentration of HI.

H_2 (g) + I_2 (g) ←→ 2HI (g)

a) 1.49 M
b) 1.56 M
c) 1.89 M
d) 1.02 M

52. 1.60 moles CO, 1.60 moles H_2O, 4.00 moles CO_2, 4.00moles H_2 are found in a 8.00L container at 690ºC at equilibrium.

CO (g) + H_2O (g) ←→ CO_2 (g) + H_2 (g)

Calculate the value of the equilibrium constant.

a) 7.98
b) 8.54
c) 6.25
d) 9.34

53. The K_{eq} for the reaction below is 1.49 ¸ 108 at 100ºC:

CO (g) + Cl_2 (g) ←→ $COCl_2$ (g)

In an equilibrium mixture of the three gases, $P_{CO} = P_{Cl_2}$ = 8.60 x10^{-4} atm. The partial pressure of the product, phosgene ($COCl_2$):

a) 2.01x10^{14} atm
b) 1.72x10^{11} atm
c) 1.28x10^{5} atm
d) 4.96x10^{-15} atm
e) 1.10x10^{2} atm

54. Phosphorous trichloride and phosphorous pentachloride equilibrate in the presence of molecular chlorine according to the reaction:

PCl_3 (g) + Cl_2 (g) ←→ PCl_5 (g)

K_{eq} = 2.01 at 500 K. A 1.000-L reaction vessel is charged with 0.990 mol of PCl_5, 1.000 mole Cl_2 at equilibrium and at this temperature. The equilibrium partial pressure of PCl_3 is

a) 4.25 mol/L
b) 4.50 mol/L
c) 36.4 mol/L
d) 0.497 mol/L

55. Nitrosyl bromide decomposes according to the following equation.

2NOBr (g) ←→ 2NO(g) + Br2 (g)

A sample of NOBr 0.64 mol was placed in a 1.00-L flask containing 0.55 mol NO and 0.55 mol Br_2.At equilibrium. Calculate K_{eq}.

a) 0.350
b) 0.285
c) 0.332
d) 0.260
e) 0.254

56. In the equation $K = \frac{[W][X]}{[Y][Z]}$, what represents the concentrations of the products?

a. [Y] and [Z]

b. [W] and [X]

c. $\frac{[W][X]}{[Y][Z]}$

d. $K = \frac{[W][X]}{[Y][Z]}$

57. What is the chemical equilibrium expression for the equation

$2A_2B + 3CD \rightleftharpoons A_4D + C_3B_2$?

a. $\frac{6[A_2B][CD]}{[A_4D][C_3B_2]}$

b. $\frac{[A_4D][C_3B_2]}{6[A_2B][CD]}$

c. $\frac{[A_2B]^2[CD]^3}{[A_4D][C_3B_2]}$

d. $\frac{[A_4D][C_3B_2]}{[A_2B]^2[CD]^3}$

58. The equilibrium constant depends on changes in:
a) pressure
b) temperature
c) concentration
d) pressure, temperature and concentration

59. At equilibrium:
a) the forward reaction rate is lower than the reverse reaction rate
b) the forward reaction rate is higher than the reverse reaction rate
c) the forward reaction rate is equal to the reverse reaction rate
d) no reactions take place

60. How do coefficients from a chemical equilibrium appear when the chemical equilibrium expression is written?
a) as coefficients
b) as exponents

c) as subscripts
d) they do not appear

61. If the temperature of the equilibrium system

$CH_3OH(g)$ + 101 kJ ←→ $CO(g) + 2H_2(g)$ increases, K_{eq}:

a) increases
b) decreases
c) increases or decreases
d) does not change

62. A reaction in which products can react to re-form reactants is
a) at equilibrium
b) reversible
c) buffered
d) impossible

63. At equilibrium:
a) all reactions have ceased
b) only the forward reaction continues
c) only the reverse reaction continues.
d) both the forward and reverse reactions continue

64. A value of K_{eq} near 1 indicates that at equilibrium probably:
a) only products are present
b) only reactants are present
c) significant quantities of both products and reactants are present
d) the reactions occur at a moderate rate

65. If the pressure on the equilibrium system $2CO(g) + O_2(g)$ ←→ $2CO_2(g)$ is increased,
a) the quantity of $CO(g)$ increases
b) the quantity of $CO_2(g)$ decreases
c) the quantity of $CO_2(g)$ increases
d) the quantities in the system do not change

66. The value of K_{eq} for a system:
a) can be calculated from the molar masses of products and reactants
b) can be calculated from the heats of the forward and reverse reactions
c) can be calculated from the chemical properties of products and reactants
d) must be measured by experiment

67. At equilibrium, the total amount of the product(s)
a) is always equal to the total amount of the reactants
b) is always greater than the total amount of the reactants
c) is always less than the total amount of the reactants
d) may be equal to, greater than, or less than the total amount of the reactants

68. What is the equilibrium constant expression for the reaction

$3Fe(s) + 4H_2O(g)$ ←→ $Fe_3O_4(s) + 4H_2(g)$

a) $[Fe_3O_4][H_2]^4/[Fe]^3[H_2O]^4$
b) $[Fe]^3[H_2]^4/[H_2O]^3$
c) $[H_2]^4/[Fe_3O_4][H_2O]^4$
d) $[H_2]^4/[H_2O]^4$

69. The expression for K_{eq} for the reaction below is:

$4CuO\ (s) + CH_4\ (g) \leftrightarrow CO_2\ (g) + 4Cu\ (s) + 2H_2O\ (g)$

a) $[H_2O]^2[Cu]^4[CO_2] / [CuO]^4[CH_4]$
b) $[H_2O]^2[Cu]^4[CO_2] / [CH_4]$
c) $[H_2O]^2[CO_2] / [CuO]^4[CH_4]$
d) $[H_2O]^2[CO_2] / [CH_4]$

70. A reactant in which products can react to reform is:
a) buffered
b) reforming
c) reversible
d) cracking

71. A very high value of K_{eq} indicates that:
a) an equilibrium is reached slowly
b) products are favored
c) reactants are favored
d) an equilibrium has been reached

72. The value of K_{eq} for a system:
a) can be calculated form the molar masses of products and reactants
b) can be calculated from the enthalpies of the forward and the reverse reaction
c) can be calculated from the chemical properties of products and reactants
d) must be determined by experiment

73. A chemical reaction is in equilibrium when:
a) forward and reverse reactions have ceased
b) the equilibrium constant equals 1
c) forward and reverse reaction rates are equal
d) no reactants remain

74. Consider the following reaction:

$2\ C(s) + O_2(g) \leftrightarrow 2\ CO(g)$
a) $[O_2] /[CO]$
b) $[C][O_2] /[CO]^2$
c) $[CO]^2/[C][O_2]$
d) $[CO]^2/[O_2]$

75. In a bottle of unopened cola, the CO_2 gas dissolved in the liquid is in equilibrium with the CO_2 gas above the liquid. The dissolved gas reacts with water molecules in the cola to form carbonic acid, which is also dissolved into carbon dioxide and water. What a chemical equation(s) best describe this equilibrium system?
a) $CO_2(g) \leftrightarrow CO_2(l)$
b) $CO_2(g) \leftrightarrow CO_2(aq)$ and $CO_2(l) + H_2O(l) \leftrightarrow H_2CO_3(aq)$
c) $CO_2(g) \leftrightarrow CO_2(aq)$
d) $CO_2(g) \leftrightarrow CO_2(aq)$ and $CO_2(aq) + H_2O(l) \leftrightarrow H_2CO_3(aq)$

76. Chemical equilibrium is referred to as dynamic because at equilibrium, the
a) chemical constant changes
b) reactants and products keep reacting
c) rates of the forward and backward reactions change
d) concentrations of the reactants and products continue change

77. $N_2(g)$ + 3 $H_2(g)$ $\leftarrow\rightarrow$ 2 $NH_3(g)$

What is the equilibrium expression for the reaction?

a) $[NH_3]^2$ / $[N_2][H_2]$
b) $[N_2][H_2]^3$ / $[NH_3]^2$
c) $[NH_3]^2$ / $[N_2][H_2]$
d) $[NH_3]^2$ / $[N_2][H_2]^3$

78. For a reaction which goes to completion, the equilibrium constant K_{eq}:

a) = >> 1
b) = << 1
c) = 1
d) = 0

79. Which is statement is always type for a chemical reaction that has reached equilibrium:

a) the yield is less than 10%
b) the rate of reverse reaction is greater the forward reaction
c) the amount of the atoms of reactants equals the amount of atoms of products
d) both rate of forward and reverse reactions are equal

80. 2 $SO_3(g)$ + $O_2(g)$ $\leftarrow\rightarrow$ $SO_3(g)$ + Heat

The manufacture of SO_3 can be represented by the equation above. What will happen when a catalyst is added to the equilibrium mixture?

a) The rate of forward as well as the reverse reaction will decrease
b) the rate of forward as well as the reverse reaction will increase
c) The amount heat will increase
d) The yield of SO_3 will decrease

81. Which of the following is true for the chemical reaction at equilibrium?

a) only the forward reaction stops
b) only the reverse reaction stops
c) both the forward and reverse reactions stop
d) the rate constants for the forward and reverse reactions are equal
e) the rates of the forward and reverse reactions are equal

82. Which of the following is true regarding the concentration of products for a chemical reaction that is already at equilibrium, assuming no disruptions to the equilibrium?

a) the concentrations of the products will not change because there are more reactants
b) the concentrations of the products will not change because the limiting reagent is gone
c) the concentrations of the products will not change because the forward and reverse rate equal
d) the concentrations of the products will change continually because of reversibility

83. Which of the following conditions are equal for a chemical system at equilibrium?

a) the concentrations of reactants and products are equal
b) the rate constants for the forward and reverse reactions are equal
c) the time that a particular atom or molecule spends as a reactant and products are equal
d) the rate of forward and reverse reaction
e) all of the above are equal

84. A chemical equilibrium may be established by starting a reaction with:

a) reactants only
b) products only
c) any quantities
d) equal quantities of reactants and products
e) all of the above

85. An equilibrium that strongly favors the reactants:
   a) $K_{eq} >> 1$
   b) $K_{eq} << 1$
   c) $K_{eq} = 1$
   d) $K_{eq} = 0$
   e) none of the above

86. The equilibrium constant for the equilibrium below is $K_{eq} = 1.91 \times 10^{-10}$:
$HSCH_2CH_2OH(aq) \leftrightarrow H^+(aq) + SCH_2CH_2OH^-(aq)$

   Which of the following statements is true regarding this equilibrium?
   I. the reaction is product favored
   II. the reaction is reactant favored
   III. equilibrium lies far to the right
   IV. equilibrium lies far to the left
   a) I and III
   b) I and IV
   c) II and III
   d) II and IV
   e) none are true, as the concentration of reactants and products are comparable

87. The equilibrium constant for the equilibrium below is $K_{eq} = 45$:
$H_2(aq) + I_2(s) \leftrightarrow 2\ HI(g)$

   Which of the following statements is true regarding this equilibrium?
   V. the reaction is product favored
   VI. the reaction is reactant favored
   VII. equilibrium lies far to the right
   VIII. equilibrium lies far to the left
   a) I and III
   b) I and IV
   c) II and III
   d) II and IV
   e) none are true, as the concentration of reactants and products are comparable

88. If the equilibrium is established by initial 0.10 mol each of A and B to 1.0 L, then which of the following must be true once the mixture achieves equilibrium?
$A + 2B \leftrightarrow 2C \quad K_{eq} = 320$

   a) [A] = [B]
   b) [A] = [B] = [C]
   c) [A] > [B]
   d) [A] < [B]
   e) none of the above

89. The equilibrium constant K_{eq} of the reaction below is:
$Fe^{3+}(aq) + 6\ CN^-(aq) \leftrightarrow [Fe(CN)]^{3-}(aq)$

   a) $[Fe^{3+}][CN^-] / [[Fe(CN)]^{3-}]$
   b) $[Fe^{3+}] / [[Fe(CN)]^{3-}]$
   c) $[[Fe(CN)]^{3-}] / [Fe^{3+}][CN^-]$
   d) $[[Fe(CN)]^{3-}] / [CN^-]$
   e) none of the above

90. The equilibrium constant K_{eq} of the reaction below is:
$Zn^{2+}(aq) + 2\ NH_3(aq) \leftrightarrow [Zn(NH_3)_2]^{2+}$

a) $[Zn^{2+}][NH_3]^2$ / $[[Zn(NH_3)_2]^{2+}]$
b) $[Zn^{2+}]$ / $[[Zn(NH_3)_2]^{2+}]$
c) $[[Zn(NH_3)_2]^{2+}]$ / $[NH_3]^2$
d) $[[Zn(NH_3)_2]^{2+}]$ /$[Zn^{2+}][NH_3]^2$
e) none of the above

91. The equilibrium constant K_{eq} of the reaction below is:
$Ca(OH)_2$ (s) + 2 H^+ (aq) $\leftrightarrow$ 2 H_2O (l) + Ca^{2+}(aq)

a) $[H_2O][Ca^{2+}]$ / $[Ca(OH)_2][H^+]^2$
b) $[H_2O]$ / $[Ca(OH)_2]$
c) $[Ca(OH)_2][H^+]^2$ / $[H_2O][Ca^{2+}]$
d) $[Ca^{2+}]$ / $[H^+]^2$
e) None of the above

92. The equilibrium constant K_{eq} of the reaction below is:
$NH_4CO_2NH_2$(s) $\leftrightarrow$ 2 NH_3(g) + CO_2(g)

a) $[NH_3]^2[CO_2]$ / $[NH_4CO_2NH_2]$
b) $[NH_3]^2$ / $[NH_4CO_2NH_2]$
c) $[CO_2]$ / $[NH_4CO_2NH_2]$
d) $[NH_4CO_2NH_2]$ / $[NH_3]^2[CO_2]$
e) $[NH_3]^2[CO_2]$

93. The equilibrium constant K_{eq} of the reaction below is:
Ti(s) + 2 Cl_2(g) $\leftrightarrow$ $TiCl_4$(l)

a) $[TiCl_4]$ / $[Ti][Cl_2]^2$
b) 1 / $[Cl_2]^2$
c) 1/ [Ti]
d) $[TiCl_4(l)]$ / $[Cl_2]^2$
e) none of the above

94. The equilibrium reaction is given below:
A $\leftrightarrow$ B
The reverse equilibrium constant is equal to:
[Hint: $K_{forward}$ / $K_{reverse}$ = K_{eq}]

a) $K_{forward}$ / K_{eq}
b) K_{eq} / $K_{forward}$
c) 1/ $K_{forward}$
d) none of the above

95. Consider the following equilibrium system below. The K_{eq} is:
CO(g) + Fe_3O_4(s) $\leftrightarrow$ CO_2(g) + 3 FeO(s)

a) $[CO_2][FeO]^3$ / $[CO][Fe_3O_4]$
b) $[CO][Fe_3O_4]$ / $[CO_2][FeO]^3$
c) $[CO_2]$ / $[Fe_3O_4]$
d) $[FeO]^3$/ $[Fe_3O_4]$
e) $[CO_2]$ / [CO]

96. In which situation will K_{eq} not change:
a) when the reactants concentrations change
b) when the products concentration change
c) when temperature changes

d) when a catalyst is used

97. Aqueous and gases are included in the equilibrium constant because:
    a) of their molecular geometry
    b) their concentrations vary a great deal
    c) their concentrations are relatively constant
    d) they are covalent found always in nature

98. Liquids are not included in the equilibrium constant because:
    a) of their molecular geometry
    b) their concentrations vary a great deal
    c) their concentrations are relatively constant
    d) they are very often ionic in nature

99. The chemical equilibrium below implies:
    $Ca(OH)_2 + H_2SO_4 \leftrightarrow CaSO_4 + 2H_2O$

    a) if you start with 1 mol of $Ca(OH)_2$ and 1 mole H_2SO_4, then 1 mol of $CaSO_4$ and 1 mol of $2H_2O$ will be produced
    b) the reaction proceeds all the way to the products, then reverses going all the way to the reactants
    c) if $CaSO_4$ and $2H_2O$ are mixed then $Ca(OH)_2 + H_2SO_4$ will be formed
    d) at equilibrium, equal molar amounts of all four substances will exist
    e) none of the above

100. Which of the arrows represent the chemical equilibrium system:
    a) $\leftarrow$
    b) $\leftrightarrow$
    c) $\rightarrow$
    d) none of the above

IV. Le Châtelier's Principle

101. For the reaction below, which change would cause the equilibrium to shift to the right?
    $CH_4(g) + 2H_2S(g)_) \leftrightarrow CS_2(g) + 4H_2(g)$
    a) decrease the concentration of dihydrogen sulfide
    b) increase the pressure on the system.
    c) increase the temperature of the system.
    d) increase the temperature of the system.
    e) increase the temperature of the system.

102. What would happen to the position of the equilibrium when the following changes are made to the equilibrium system below?
    $2SO_3(g) \leftrightarrow 2SO_2(g) + O_2(g)$
    a) sulfur dioxide is added to the system
    b) sulfur trioxide is removed from the system
    c) oxygen is added to the system.
    d) none of the above

103. What would happen to the position of the equilibrium when the following changes are made to the reaction below?
    $2HgO(s) \leftrightarrow Hg(l) + O_2(g)$
    a) HgO is added to the system
    b) the pressure on the system increases
    c) none of the above

104. When the volume of the following mixture of gases is increased, what will be the effect on the equilibrium position?
$4HCl(g) + O_2(g)_) \leftrightarrow 2H_2O(g) + 2Cl_2(g)$
a) the shift of equilibrium will be to the reactants
b) the shift of equilibrium will be to the products
c) no change
d) none of the above

105. Predict the effect of decreasing the volume of the container for equilibrium.

$2H_2O(g) + N_2(g) \leftrightarrow 2H_2(g) + 2NO(g)$
a) the shift of equilibrium will be to the reactants
b) the shift of equilibrium will be to the products
c) no change
d) none of the above

106. Predict the effect of decreasing the volume of the container for equilibrium.

$SiO_2(s) + 4HF(g) \leftrightarrow SiF_4(g) + 2H_2O(g)$
a) the shift of equilibrium will be to the reactants
b) the shift of equilibrium will be to the products
c) no change
d) none of the above

107. Predict the effect of decreasing the volume of the container for equilibrium.

$CO(g) + H_2(g) \leftrightarrow C(s) + H_2O_((g)$
a) the shift of equilibrium will be to the reactants
b) the shift of equilibrium will be to the products
c) no change
d) none of the above

108. Predict the effect of decreasing the temperature of the container for equilibrium.

$H_2(g) + Cl_2(g) \leftrightarrow 2HCl(g) + heat$
a) the shift of equilibrium will be to the reactants
b) the shift of equilibrium will be to the products
c) no change
d) none of the above

109. Predict the effect of decreasing the temperature of the container for equilibrium.

$2NH_3(g) + heat \leftrightarrow N_2(g) + 3H_2(g)$
a) the shift of equilibrium will be to the reactants
b) the shift of equilibrium will be to the products
c) no change
d) none of the above

110. Predict the effect of decreasing the temperature of the container for equilibrium.

$CO(g) + H_2O(g) \leftrightarrow CO_2(g) + H_2(g) + heat$
a) the shift of equilibrium will be to the reactants
b) the shift of equilibrium will be to the products
c) no change
d) none of the above

111. Predict the effect of increasing the pressure of the container for equilibrium.

$2SO_2(g) + O_2(g) \leftarrow\rightarrow 2SO_3(g)$

a) the shift of equilibrium will be to the reactants
b) the shift of equilibrium will be to the products
c) no change
d) none of the above

112. Predict the effect of increasing SO_3 concentration in the equilibrium.

$2SO_2(g) + O_2(g) \leftarrow\rightarrow 2SO_3(g)$

a) the shift of equilibrium will be to the reactants
b) the shift of equilibrium will be to the products
c) no change
d) none of the above

113. Predict the effect of increasing CO concentration in the equilibrium.

$COCl_2(g) \leftarrow\rightarrow CO(g) + Cl_2(g)$

a) the shift of equilibrium will be to the reactants
b) the shift of equilibrium will be to the products
c) no change
d) none of the above

114. Predict the effect of increasing the pressure of the container for equilibrium.

$COCl_2(g) \leftarrow\rightarrow CO(g) + Cl_2(g)$

a) the shift of equilibrium will be to the reactants
b) the shift of equilibrium will be to the products
c) no change
d) none of the above

115. Predict the effect of increasing the pressure of the container for equilibrium.

$NH_4Cl(s) \leftarrow\rightarrow NH_4^+(aq) + Cl^-(aq)$

a) the shift of equilibrium will be to the reactants
b) the shift of equilibrium will be to the products
c) no change
d) none of the above

116. Predict the effect of increasing NH_4^+ concentration in the equilibrium

$NH_4Cl(s) \leftarrow\rightarrow NH_4^+(aq) + Cl^-(aq)$

a) the shift of equilibrium will be to the reactants
b) the shift of equilibrium will be to the products
c) no change
d) none of the above

117. Predict the effect of removing $NH_4Cl(s)$ from the equilibrium

$NH_4Cl(s) \leftarrow\rightarrow NH_4^+(aq) + Cl^-(aq)$

a) the shift of equilibrium will be to the reactants
b) the shift of equilibrium will be to the products
c) no change
d) none of the above

118. Predict the effect of adding both N_2 and O_2 to the equilibrium

$N_2(g) + O_2(g) \leftarrow\rightarrow 2NO(g)$

a) the shift of equilibrium will be to the reactants
b) the shift of equilibrium will be to the products
c) no change
d) none of the above

119. Predict the effect of adding catalyst to the equilibrium

$N_2(g) + O_2(g) \leftarrow\rightarrow 2NO(g)$

a) the shift of equilibrium will be to the reactants
b) the shift of equilibrium will be to the products
c) no change
d) none of the above

120. Predict the effect of increasing the pressure of the container for the equilibrium

$N_2(g) + O_2(g) \leftarrow\rightarrow 2NO(g)$

a) the shift of equilibrium will be to the reactants
b) the shift of equilibrium will be to the products
c) no change
d) none of the above

121. Predict the effect of adding CO_2 to the equilibrium

$2CO(g) + O_2(g) \leftarrow\rightarrow 2CO_2(g) + \text{Heat}$

a) the shift of equilibrium will be to the reactants
b) the shift of equilibrium will be to the products
c) no change
d) none of the above

122. Predict the effect of decreasing the volume container of the equilibrium

$2CO(g) + O_2(g) \leftarrow\rightarrow 2CO_2(g) + \text{Heat}$

a) the shift of equilibrium will be to the reactants
b) the shift of equilibrium will be to the products
c) no change
d) none of the above

123. Predict the effect of removing the heat from the equilibrium by cooling the equilibrium system.

$2CO(g) + O_2(g) \leftarrow\rightarrow 2CO_2(g) + \text{Heat}$

a) the shift of equilibrium will be to the reactants
b) the shift of equilibrium will be to the products
c) no change
d) none of the above

124. Predict the effect of adding the heat to the equilibrium.

$2CO(g) + O_2(g) \leftarrow\rightarrow 2CO_2(g) + \text{Heat}$

a) the shift of equilibrium will be to the reactants
b) the shift of equilibrium will be to the products
c) no change
d) none of the above

125. Predict the effect of adding O_2 to the equilibrium system

$2Mg(s) + O_2(g) \leftarrow\rightarrow 2MgO(s)$

a) the shift of equilibrium will be to the reactants
b) the shift of equilibrium will be to the products
c) no change
d) none of the above

126. Predict the effect of increasing the pressure of the container of the equilibrium

$2Mg(s) + O_2(g) \leftarrow\rightarrow 2MgO(s)$

a) the shift of equilibrium will be to the reactants
b) the shift of equilibrium will be to the products
c) no change
d) none of the above

127. Predict the effect of adding the catalyst to the equilibrium

$2Mg(s) + O_2(g) \leftarrow\rightarrow 2MgO(s)$

a) the shift of equilibrium will be to the reactants
b) the shift of equilibrium will be to the products
c) no change
d) none of the above

128. Predict the effect of increasing the volume of the container of the equilibrium

$2Mg(s) + O_2(g) \leftarrow\rightarrow 2MgO(s)$

a) the shift of equilibrium will be to the reactants
b) the shift of equilibrium will be to the products
c) no change
d) none of the above

129. Predict the effect of adding the $CaCO_3(s)$ to the equilibrium

$CaCO_3(s) \leftarrow\rightarrow CaO(s) + CO_2(g)$

a) the shift of equilibrium will be to the reactants
b) the shift of equilibrium will be to the products
c) no change
d) none of the above

130. Predict the effect of increasing the pressure of the container of the equilibrium

$CaCO_3(s) \leftarrow\rightarrow CaO(s) + CO_2(g)$

a) the shift of equilibrium will be to the reactants
b) the shift of equilibrium will be to the products
c) no change
d) none of the above

131. Predict the effect of increasing the volume of the container of the equilibrium

$CaCO_3(s) \leftarrow\rightarrow CaO(s) + CO_2(g)$

a) the shift of equilibrium will be to the reactants
b) the shift of equilibrium will be to the products
c) no change
d) none of the above

132. Predict the effect of adding CO_2 to the equilibrium

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

a) the shift of equilibrium will be to the reactants
b) the shift of equilibrium will be to the products
c) no change
d) none of the above

133. Predict the effect of increasing the volume of the container of the equilibrium

$2H_2(g) + O_2(g) \leftrightarrow 2H_2O(g) +$ Heat

a) the shift of equilibrium will be to the reactants
b) the shift of equilibrium will be to the products
c) no change
d) none of the above

134. Predict the effect of decreasing the pressure of the container of the equilibrium

$2H_2(g) + O_2(g) \leftrightarrow 2H_2O(g) +$ Heat

a) the shift of equilibrium will be to the reactants
b) the shift of equilibrium will be to the products
c) no change
d) none of the above

135. Predict the effect of adding the heat to the equilibrium system

$2H_2(g) + O_2(g) \leftrightarrow 2H_2O(g) +$ Heat

a) the shift of equilibrium will be to the reactants
b) the shift of equilibrium will be to the products
c) no change
d) none of the above

136. Predict the effect of removing the heat to the equilibrium system

$2H_2(g) + O_2(g) \leftrightarrow 2H_2O(g) +$ Heat

a) the shift of equilibrium will be to the reactants
b) the shift of equilibrium will be to the products
c) no change
d) none of the above

137. Predict the effect of adding $2H_2O$ the heat to the equilibrium system

$2H_2(g) + O_2(g) \leftrightarrow 2H_2O(g) +$ Heat

a) the shift of equilibrium will be to the reactants
b) the shift of equilibrium will be to the products
c) no change
d) none of the above

138. For the equilibrium system below, which of the following will increase the concentration of NO_2 gas?

$2NO(g) + O_2(g) \leftrightarrow 2NO(g) +$ Heat

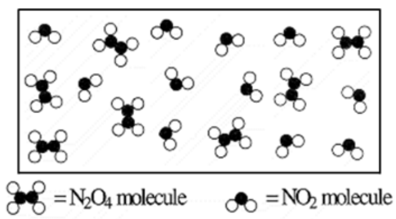
a) a decrease in the total pressure at constant temperature
b) a decrease in the concentration of O_2 at constant temperature
c) a decrease in the temperature at constant pressure
d) an increase in the volume of the reaction vessel at constant temperature

139. For the equilibrium system: $2H_2O(g)$ + Heat $\leftrightarrow$ 2 $H_2(g)$ + $O_2(g)$

Which of the following changes will decrease the equilibrium amount of H_2O?

a) adding more O_2
b) decreasing the volume of the container
c) adding a solid phase catalyst
d) increasing the temperature at constant pressure

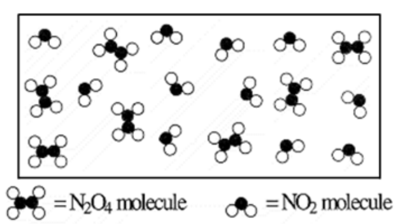
140. For the equilibrium system:
$N_2O_4(g) \leftrightarrow 2\ NO_2(g)$



Calculate the value for K_{eq} for the system as shown in the diagram to the right

a) 17.3
b) 4.45
c) 1.57
d) 0.636

141. For the equilibrium system:
$N_2O_4(g) \leftrightarrow 2\ NO_2(g)$



Predict (based on the value of K_{eq}) if the equilibrium will

e) favor the reactants
f) favor the product
g) no change
h) none of the above