

Equilibrium Lesson Plan and Handout for Chemistry I

High Tech High

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Equilibrium Lesson Plan and Handout for Chemistry I

Duration: 1 Hour

Goals:

1. To help prepare students for Reaction Direction and Rate portions of General Chemistry section of California Standardized Testing and Reporting (STAR) Test.
2. To help students obtain subject-specific mastery of Content Standards as provided by California Dept. of Education
3. Students will apply these principles to understanding how chemical reactions progress in future courses.

Objectives

1. Instruction will be provided to students to understand vocabulary necessary to understand principles of Thermodynamics, Reaction Rates, and Equilibrium.
2. From the in-class handout, students will be able to understand Activation Energies and make predictions whether the product will be stable or unstable.
3. Students will read about Hess's Law.
4. Students will learn how reactions can absorb heat and still be spontaneous using First-Aid cold packs as an example.
5. Students will be introduced to the relationship between reaction rates and energy transfer.
6. Students will be asked to apply the Law of Mass Action to calculate reaction rate constants.
7. Students will discuss the role of catalysts in altering reaction rates and thermodynamics.
8. Students will read and discuss LeChatelier's Principle

State Standards:

Reaction Rates

8. Chemical reaction rates depend on factors that influence the frequency of collision of reactant molecules. As a basis for understanding this concept:
 - a. *Students know* the rate of reaction is the decrease in concentration of reactants or the increase in concentration of products with time.
 - b. *Students know* how reaction rates depend on such factors as concentration, temperature, and pressure.
 - c. *Students know* the role a catalyst plays in increasing the reaction rate.
 - d. * *Students know* the definition and role of activation energy in a chemical reaction.

Chemical Equilibrium

9. Chemical equilibrium is a dynamic process at the molecular level. As a basis for understanding this concept:
 - a. *Students know* how to use Le Chatelier's principle to predict the effect of changes in concentration, temperature, and pressure.
 - b. *Students know* equilibrium is established when forward and reverse reaction rates are equal.
 - c. * *Students know* how to write and calculate an equilibrium constant expression for a reaction.

Prerequisites:

1. Students must have completed most of General Chemistry and understand how to balance chemical equations and understand the basic structure of atoms and molecules.
2. Students must have completed Algebra I to grasp the chemical rate equations
3. Students must have completed a General Science course that provided them with a basic understanding of basic Laws of Physics.

Instruction/Class Activities:

1. Students may ask questions about terms they should know: classes of chemical reaction; Gibbs Free Energy; Enthalpy; Entropy; Kinetics; Exothermic/ Endothermic; Spontaneous reaction.
2. Students will explore why certain reactions are favored and others are not. Students will demonstrate how to predict when a reaction is reversible (can proceed in either direction).
3. In a demonstration, students will learn how reactions that absorb energy (endothermic) can also be spontaneous.
4. Students will list common reactions that are reversible (sugar metabolism and biosynthesis) and apparently irreversible (conversion of graphite to diamond).
5. Students will learn how Hess's Law applies to nutrition, and why food Caloric value measurements are representative of how much energy they provide to people.
6. Students will learn how two opposite reactions can be in equilibrium.
7. In their journals, students will reflect on how "dueling reactions" are best understood and why they are important in Biological Systems.

Assessment:

1. Students will apply what they learned in the STAR test
2. Students will EMAIL me their calculations of the relative amounts of acetic acid, ethanol, and ethyl acetate assuming one starts with 1mol/L of acetic acid and ethanol and the $K_{eq} = 4.0$.
3. Students will email me explanations of why combustion is a special type of oxidation and predict if burning of wood could be made reversible.

.References: At end of handout

Dr. Jay's Handout on
Chemical Reaction Direction
And Equilibrium
April 27, 2007

Part I. Background

A **chemical reaction** can be defined as "a process where one or more substances are changed due to rearrangement of atoms."

Atoms are rearranged when their bonds are broken and reformed. Reactions can be:

- A. Rearrangements (Isomerization)
- B. Additions (Synthesis)
- C. Decomposition
- D. Substitution $2\text{Na} + 2\text{HCl} \rightarrow 2\text{NaCl} + \text{H}_2$
- E. Combustion (Oxidation)

Collision Theory states that chemical reactions occur when reactants collide and form an *activated complex* with a higher Internal energy. At impact, old bonds are broken and new ones form. Often collisions have to occur in the proper orientation. After a productive collision, Energy is either *absorbed* or *released into the system*.

To understand how this leads to prediction of the direction of the reaction, we must also review some *Thermodynamic* terms:

Gibbs Free Energy (G) is the energy from the molecules capable of doing useful work (like breaking bonds)

Enthalpy (H) is the total energy in the system

Entropy (S) or Temperature x Entropy Energy in the system that cannot be harvested to do useful work. For gases, it involves molecular movement (rotation, vibration, *etc.*).

They are all related in the formula $\Delta G = \Delta H - T\Delta S$ where Δ means "change"

Why are these terms important? You need thermodynamics to understand the steps in a reaction and you need collision theory to understand the *kinetics* or rate that a reaction proceeds. This will be particularly important when we discuss Equilibrium

Part II Reactions

Reactions proceed by the following steps:

Initial State where the reactants are unchanged

Activated Complex where sufficient energy is transferred to molecules to allow for breaking of old bonds and forming new ones

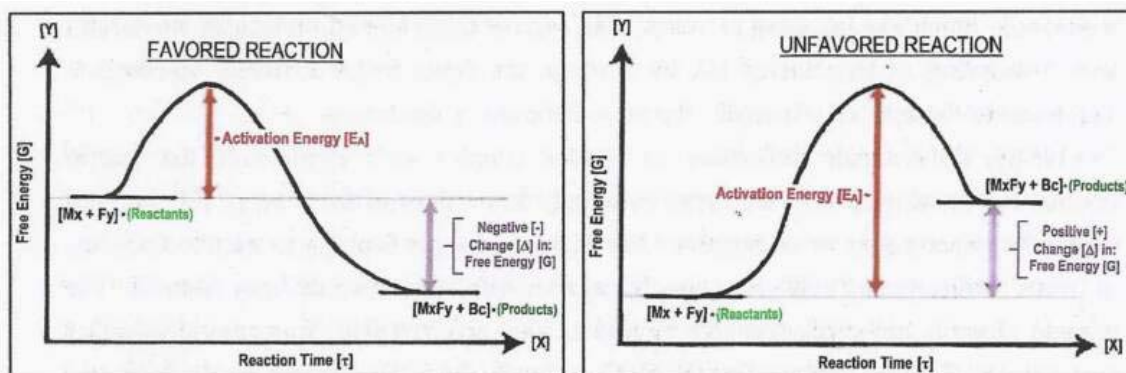
Final State new molecules after reaction has occurred.

Other terms

Exothermic - when the $\Delta H < 0$

Endothermic - when the $\Delta H > 0$

Spontaneous - When the Energy of Activation = Free Energy of the Reactants



From www.humanthermodynamics.com/HT-Glossary.html

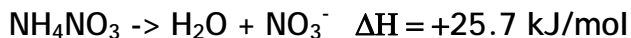
It is important to note that in the right hand example, the products have more free energy than the reactants. The energy necessary to reverse the reaction is LESS than it was to create it. It is **highly likely that this reaction is reversible, and will be applicable to Equilibrium calculations.**

Typically, a reaction is virtually irreversible when the Free Energy of the products is much lower than that of the reactants. However, an incorrect assumption from this data is that only Exothermic Reactions can proceed spontaneously!

The Enthalpy, not the Free Energy, Predicts the Direction of the Reaction.

It is the TOTAL energy in the system that controls whether a reaction is energetically favorable. If the Free Energy was sufficient, only Exothermic reactions could be favorable.

Take, for example, a First-Aid Cold Pack. It is a bag within a bag of water. Breaking the internal bag releases solid Ammonium nitrate into the water.



Ionization proceeds when the reaction is *Endothermic* due to the contribution of the increase in *Entropy* from the salt disrupting the structure of the water.

Hess's Law - The change in Enthalpy during a reaction is the same no matter if the reaction occurs in one step or many.

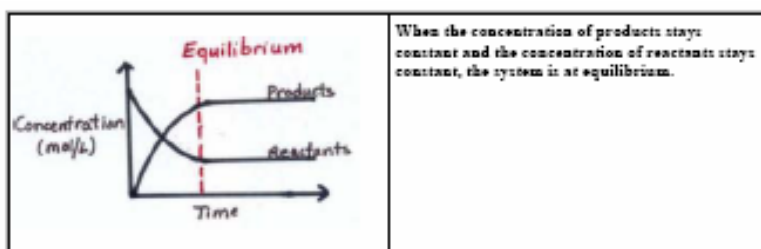
Part III Equilibrium

Most reactions are reversible. Thermodynamics predicts what is energetically feasible. **Kinetics** predicts how rapidly a reaction will proceed. Ionization of HCl in water is rapid, but converting graphite to a diamond is not. It is useful to view these processes starting with the Law of Mass Action, which states "the rate of a reaction in either direction is proportional to its *active masses*". In another words, the forward rate of a specific reaction is the product of a rate constant (K_f) and the product of the concentrations.

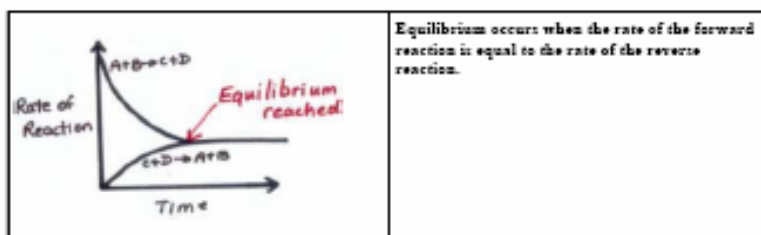
In the reaction $aA + bB \rightarrow cC$, the conversion rate to C equals $K_f \times [A]^a [B]^b$

If the reverse reaction also happens, then there are "dueling reactions" and you have to define a reverse rate constant k_r and multiply it by $[C]^c$ to determine the rate of the reverse reaction (production of A and B).

What does the relative change in reactants and products look like in an equilibrium reaction? First, you can rule out both extremes, where the forward or reverse reaction dwarves the other. These calculations are only useful where the forward and reverse reactions occur at similar rates.



At equilibrium, the rates of the forward and reverse reactions will be equal.



From <http://hsc.csu.edu.au/chemistry/options/industrial/2761/Ch952.htm>

In a closed system, at equilibrium, the two reactions will proceed at the same rate.

The relative heights and times vary greatly, but it is central to understand that at the macroscopic level, concentrations do not change. Changes only occur for individual molecules.

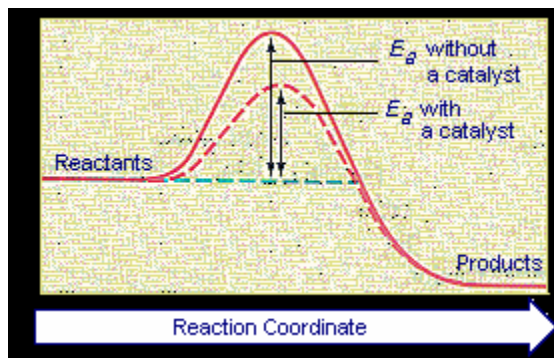
For the reaction above, $A + B \rightarrow C + D$, the equilibrium constant is simply the ratio of the two competing reactions:

$$K_{Eq} = \frac{[C][D]}{[A][B]}$$

If K_{Eq} is large ($>10^3$) the reaction is said to run almost to completion.

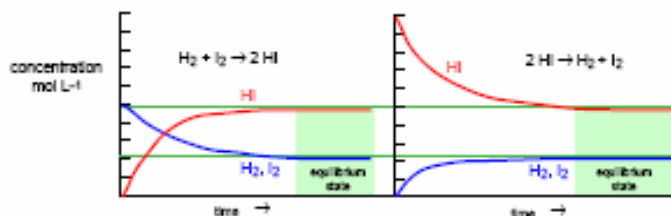
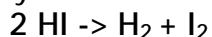
Ionization of acids is a type of equilibrium. The rate constant for acetic acid is approx. 10^5 and for boric acid it is 10^{16} . Clearly rate of ionization has little to do with other properties of acids.

In the reaction $H_2 + O_2 = 2H_2O$, the reaction is highly favored *thermodynamically* but is inhibited *kinetically*. Add a catalyst like Platinum, and stand back! That is because catalysts can lower the Energy of Activation (remember that?)

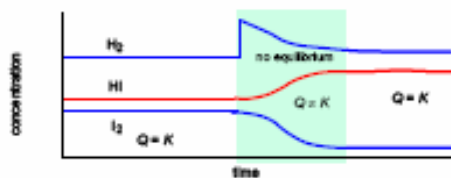


From www.humanthermodynamics.com/HT-Glossary.html

LeChatelier's Principle: If a system in equilibrium is subjected to a change (concentration of reactant, heat, pressure) there will be a shift in the net reaction to reduce the effect. If you look at the reaction:



And then you disturb the equilibrium by adding more Hydrogen...



Then the equilibrium restores itself and there is more Hydrogen present, but not as much as was added. The change introduced was counteracted by the equilibrium shift.

From chem1.com/acad/webtext/chemeq/Eq-02.html or .pdf version at:
<http://www.chem1.com/acad/pdf/chemeq.pdf>.

References

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