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| Enthalpy of Hydrogen Peroxide Decomposition |
| C2.1a, C2.1b, C3.2b & C3.3c |
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Enthalpy of Hydrogen Peroxide Decomposition

**Bond Strength & Molecular Stability**

**Background:**

Hydrogen peroxide is a natural byproduct of cellular metabolism that is probably more familiar as a laundry and hair bleach, and as disinfectant. Interestingly, the same properties that make hydrogen peroxide such a good disinfectant (it is a strong oxidizer), also make it toxic to the cell in which it is produced. In another instance of biological systems being very conservative with their resources, by “taking lemons and making lemonade,” the cell uses the enzyme catalase to decompose hydrogen peroxide into water, oxygen and energy, by the following reaction:



The release of energy in this reaction indicates that it is exothermic, and that an energy transformation is taking place. Because energy leaves the system it can be inferred that the products have a stabler configuration than the reactants. Standard heats of formation can be used to determine whether the reaction is exothermic or endothermic. ***Standard Heat of Formation*** is the amount of energy absorbed by or evolved from a system to form one mole of product from its elemental substances, at 25˚C and one atmosphere. Also known as standard enthalpy of formation, these values are obtained from tables. Using such information, and a balanced chemical equation, the heat of reaction can be determined, as in the following example.

Sodium hydroxide is a compound put to a wide variety of uses, from drain cleaner to all sorts of industrial purposes. You may have observed its formation when your teacher placed a small piece of it in water and the following reaction occurred: Na(s) + H2O(*l*) ➝ NaOH(aq) + ½H2(g). What is the heat of reaction for this chemical equation? Start with a simple statement: products minus reactants, the rule of thermodynamics. Following this rule means take a table of standard heats of formation, and using the balanced chemical equation subtract the sum of the heat of formation for each of the reactants times its coefficient in the balanced chemical equation from the sum of the heat of formation for each of the products times its coefficient from the balanced chemical equation. Using the standard heats of formation from [http://en.wikipedia.org/wiki/Standard\_enthalpy\_change\_of\_formation\_(data\_table)](http://en.wikipedia.org/wiki/Standard_enthalpy_change_of_formation_%28data_table%29)<http://en.wikipedia.org/wiki/Standard_enthalpy_change_of_formation> , and Hess’s law the calculation proceeds as follows:



Because the sign of this het of reaction is negative heat energy is leaving the system as the reaction occurs, so the reaction is exothermic. You probably already guessed that this reaction is exothermic if you have observed it, because enough heat is released to ignite the hydrogen gas, producing a flame. The reaction can be written in its entirety as follows:



Note that the sign of the enthalpy of reaction is positive because it is listed as one of the products.



An ***enthalpy diagram*** is an illustration of the changes in energy state of the reaction as it occurs. Enthalpy diagrams are useful in determining exactly what is happening in terms of energy during a chemical reaction. The reaction for the synthesis of nitric acid is:



The enthalpy diagram for this process is to the right:

I 

n

c

r

e 109.8kJ

a

s -206.6kJ

i **NO2(g)+¼O2(g)+½H2O(*l*)**

n

g

 **HNO3(aq)**

H

 Progress of Reaction

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Another way of evaluating the energy changes in a chemical reaction is in terms of bond energies. ***Bond energy*** is the energy that is required to break a mole of bonds of a given type, producing neutral atoms as the result. These values are listed in a table in your book. If all the bond energies in the bonds of the products of a reaction are added up and all the bond energies in the bonds of the reactants are subtracted from this the enthalpy of reaction should be the result. In other words, if all the energy required to break all the chemical bonds in the reactants is subtracted from all the energy released in the formation of the chemical bonds of the products, the difference will be the enthalpy of reaction.

**Purpose:**

In this laboratory the student will be able to:

* Qualitatively determine whether the decomposition of hydrogen peroxide is endothermic or exothermic.
* Calculate the heat of reaction for the decomposition of hydrogen peroxide.
* Draw an energy diagram for this reaction.
* Use Lewis strictures and the energy diagram to explain this heat of reaction.

**Hypothesis:** (a testable prediction.)

Write the balanced chemical equation for the decomposition of hydrogen peroxide into water and oxygen, and predict whether it is an endothermic or exothermic process.

**Materials:**

Safety goggles, laboratory apron, 8mL test tube with 5mL of 3% hydrogen peroxide, pea sized piece of liver chopped to increase surface area, stirring rod and test tube rack.

**Procedure:**

Notes:

* Hydrogen peroxide, a strong oxidizer, can seriously injure eyes and causes skin irritation at the concentration used. Ware safety goggles and a laboratory apron at all times. Should any hydrogen peroxide get in the eyes flush immediately with water from an eye wash for fifteen minutes. Rinse skin that comes in contact with this solution with fresh water.
* One of the products of this reaction is oxygen which is a flame accelerant. Do not allow open flames or flammable materials near this reaction.
* The liver you will be using is not cooked. Wash hands thoroughly with soap and water when the lab is complete.
1. Use the back of your hand to observe the temperature of the system, the test tube and solution, before the reaction begins.
2. Place the liver in the solution and mix gently using the stirring rod for thirty seconds. Place in the test tube rack and allow to react for ten minutes. Observe the temperature of the system using the back of your hand during this period.
3. Record your observations in the data section below.
4. Clean all supplies. Throw the liver in a waste basket. Place the test tube upside down and the stirring rod in the test tube rack to dry. Then wash your hands thoroughly.

**Data:**

Did the system warm or cool as the reaction progressed?

**Analysis:**

1. Was the reaction exothermic or endothermic?
	1. Explain your answer.

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1. Using the standard enthalpy of formation table in your text, calculate the heat of reaction from the balanced chemical equation in your hypothesis.
	1. Is this value in agreement with your observation?
		1. Explain why or why not.
2. Draw and label an energy diagram for this reaction.
	1. Using this diagram describe what happens to the energy in the chemical bonds of hydrogen peroxide as it decomposes.
3. Draw the Lewis structure for each of the reactants and products in this reaction.
	1. Based on these structures, use a table of bond energies and the balanced chemical equation to explain why this reaction is exothermic or endothermic, based on the number and type of bonds before and after the reaction.
4. Is hydrogen peroxide good or bad for the cell?
	1. Are the products of this reaction good or bad for the cell?

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Teacher Companion Notes to Enthalpy of Hydrogen Peroxide Decomposition

**Safety Notice:**

It is assumed that the instructors presenting this material are trained in appropriate safety procedures in the chemistry laboratory, and that the students under their tutelage have been completely informed of the specific precautions to be undertaken for this laboratory and the general behaviors appropriate to the chemistry laboratory. It is further assumed that instructors have familiarized themselves with the Material Safety Data Sheets (MSDS) for all the chemicals present in this laboratory, observe all the precautions that the MSDS indicates and have a copy of the MSDS on hand during the investigation. Additionally, it is assumed that all appropriate safety gear necessary to an adequately equipped chemistry laboratory is present in the room in which the laboratory is taking place, the instructor and students are familiar with its proper use, and that this equipment is in excellent functioning order.

It is the instructor’s sole responsibility to insure the safety of the students and staff in the chemistry laboratory, and the individuals in the surrounding areas. It further is the instructor’s sole responsibility to be fully informed of the regulations pertainment to their locale and to follow those regulations completely. This applies to the proper use and disposal of chemicals in the laboratory, equipment in the laboratory, and training of the instructor and students as to procedures in the laboratory.

An excellent resource for MSDSs is Flinn Scientific: <http://www.flinnsci.com/search_MSDS.asp> .

The class room teacher takes sole responsibility for the safe conduction of this laboratory.

**High School Content Expectations:**

**C2.1a:** Explain the changes in potential energy (due to electrostatic interactions) as a chemical bond forms and use this to explain why bond breaking always requires energy.

**C2.1b:** Describe energy changes associated with chemical reactions in terms of bonds broken and formed (including intermolecular forces).

**C3.2b:**Describe the relative strength of single, double and triple covalent bonds (between nitrogen atoms).

**C3.3c:** Explain why it is necessary for a molecule to absorb energy in order to break a chemical bond.

For an excellent explanation of the reaction mechanism for catalase catalyzed decomposition of hydrogen peroxide see: <http://en.wikipedia.org/wiki/Catalase>

As the reaction proceeds it will warm, indicating that heat is leaving the system, and the reaction is exothermic. This indicates that more energy is released in the formation of the bonds in products than is required to break the bonds of the reactants. Therefore, the products are stabler than the reactants.

The calculation for the enthalpy of reaction is:



 Enthalpy of formation Enthalpy of formation Enthalpy of formation

 for Water for Oxygen for Hydrogen Peroxide

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The enthalpy diagram is:

A simplified diagram for the students could be:

I H2(g) + O2(g) ΔH0 = -98.3kJ

n

c

r 187.6kJ

e

a -285.9kJ

s

I H2O0(*l*)

n

g

 H2O(*l*) + ½O2(g)

H

 Progress of Reaction

I

n

c

r

e ΔH0 = -98.3kJ

a

s

i H2O2(*l*)

n

g -98.3kJ

 H2O(*l*) + ½O2(g)

H

 Progress of Reaction

Note that the simplified enthalpy diagram makes it difficult for the students to explain why energy has to be put into the system to break the bonds of the reactants, so the first diagram is much preferred.

The Lewis dot structures indicate the formation of an oxygen, oxygen double bond in the oxygen molecule and the breaking of a oxygen, oxygen single bond in hydrogen peroxide. The oxygen, oxygen double bond is more than twice as strong as the single bond in the peroxide which explains the release of energy when this double bond forms. The difference in the bond energies for this reaction is -101kJ, in very close agreement with the

-98.3kJ for heat of reaction. There is the further dynamic of other atoms around the oxygen bond in the peroxide that explains the difference based on bond dissociation energies verses heat of reaction. The other bonds of the reaction are quite similar . . . This is a worthy post laboratory discussion topic.

Suggested additional resources: calculators, tables of enthalpy of formation and bond dissociation energies.

**Contact Information:**

Please contact the author if it is found that the safety precautions are incomplete or inaccurate, factual information is inaccurate, or there are any modifications/augmentations that could improve this laboratory. KingChemistry@comcast.net

**Please Provide Feedback:**

If this material was useful in improving student understanding of the content, please let me know. If this material could use revision to improve student learning, again, please let me know. KingChemistry@comcast.net .

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