Oakland Schools Chemistry Resource Unit

Thermodynamics & Kinetics

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Thermodynamics and Kinetics

Content Statements:

C2.1x Chemical Potential Energy:

Potential energy is stored whenever work must be done to change the distance between two objects. The attraction between the two objects may be gravitational, electrostatic, magnetic, or strong force. Chemical potential energy is the result of the electrostatic attractions between the atoms.

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.

Great link showing formation of NaCl and the release of energy as the crystal lattice forms.
http://cwx.prenhall.com/petrucci/medialib/media_portfolio/05.html

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

Great animation for the dissolving of sodium chloride. The ion dipole intermolecular force.

http://programs.northlandcollege.edu/biology/Biology1111/animations/dissolve.ht

INSRUCTIONAL BACKGROUND INFORMATION

As a bond forms: Attraction and repulsion between electrons and nuclei of two atoms always exists. If attraction outweighs repulsion, a bond forms at a potential energy minimum. If repulsion outweighs attraction, no bond forms. The potential energy change in bond formation is the difference between zero for the isolated atoms and the point of minimum potential energy. This amount of energy (distance between the zero level and the bottom of the valley) is released as the bond is formed. The same amount of energy must be added to separate the atoms.

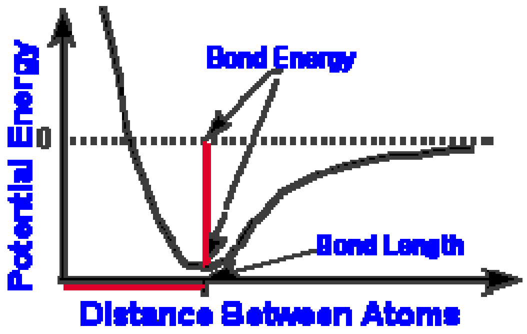


Figure 1-Potential Energy of a Chemical Bond

Electrostatic charges are responsible for the formation of ionic bonds in a crystal lattice. The bond energy is derived from the formula $E=q1q2/d^2$. The energy is related to the size of the charges and the distance between the ions involved.

Energetics of Ionic Bond Formation

The formation of ionic compounds (like the addition of sodium metal and chlorine gas to form NaCl) are usually ***extremely exothermic***.

The loss of an electron from an element:

- Always ***endothermic*** (takes energy to strip the e' from the atom)
- $Na(g) \rightarrow Na^+(g) + 1e^-$ ☐H = 496 kJ/mol

The gain of an electron by a nonmetal:

- Generally ***exothermic*** (energy released)
- $Cl(g) + 1e^- \rightarrow Cl^-(g)$ ☐H = -349 kJ/mol

The formation of NaCl from Na and Cl would thus ***requires the input of 147 kJ/mol***. However, it appears to be a highly exothermic reaction.

Ions - Ionic compounds are stable due to the ***attraction between unlike charges***:

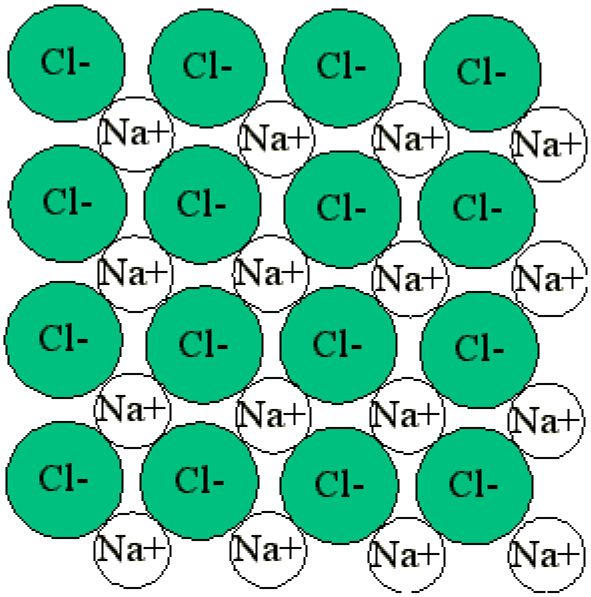
- The ions are drawn together
- Energy is released
- Ions form solid ***lattice***

Lattice energy - ***the energy required to separate completely a mole of a solid ionic compound into its gaseous***

It is a measure of just how much stabilization results from the arranging of oppositely charged ions in an ionic solid.

To completely break up a salt crystal:

Slice through a NaCl crystal



Potential Energy and Chemical Bonds

name Angela
status student
grade 9-12
location N/A

Question - How does potential energy change when a chemical bond is formed? when a chemical bond is broken?
How does the potential energy of two atoms in a chemically bonded condition compare to their energy when separated?

Angela,

This is a difficult question to answer exactly since (1) potential energy is not something that is directly measured - it can only be deduced from the heats produced or absorbed in a transformation, and (2) the heat produced or absorbed (enthalpy) in a chemical transformation vary from substance to substance.

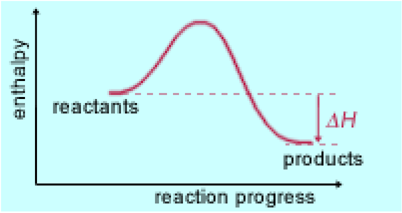
In general, we expect that when chemical bonds are formed, energy is released - imagine the individual atoms as having energy and have to be slowed down in order that chemical bonds can form. Alternatively, and more accurately, when two atoms spontaneously form a chemical bond it must mean that the entropy of this system has increased, since two separate atoms have more disorganization (entropy) then one complete molecule, then in order for the process to be spontaneous (entropy increases), there must be some heat released.

The problem now is relating heat to potential energy. I would rather you relate this to internal energy rather than potential energy (which is not quite directly applicable to chemical systems). If we think of internal energy, we know, by definition, that internal energy is a function of the heat and work that goes in and out of the system. Since most chemical transformations do not involve work, then internal energy is mostly a function of the heat that enters or leaves the system.

Thus, when a chemical bond is formed spontaneously, heat leaves the system; the internal energy of the system goes down. You may then think of internal energy as a kind of potential energy and say that because the system is less energetic (since heat left the system) that it must now have a lower potential energy.

Greg (Roberto) Gregorius

Energy changes in a reaction: The heat of reaction is the quantity of heat released or absorbed during a chemical reaction. It is the difference between the stored heat energy (or heat content) of the reactants and products. For example, in an exothermic reaction, the heat evolved is the difference between the higher heat content of the reactants and the lower heat content of the products.



Bond breaking is an endothermic (energy absorbing) process and bond breaking is and exothermic (energy releasing) process.
Think of bond breaking like pulling two magnets apart. The magnets have stored (potential) energy.

Content Statement C2.2x Molecular Entropy: As temperature increases, the average kinetic energy and entropy of the molecules in a sample increases.

C2.2e: Compare the entropy of solids, liquids, and gases.

C2.2f: Compare the average kinetic energy of the molecules in a metal object and a wood object at room temperature.

INSTRUCTIONAL BACKGROUND INFORMATION

Entropy increases (becomes more positive) as you go from solid to liquid to gas. The randomness or disorder increases from one phase to another.

The randomness or disorder increases as the phase changes. There are more degrees of freedom and thus an increase in entropy.

http://www.uwsp.edu/cnr/wcee/keep/Mod1/Whatis/experiments.htm
(Go to the entropy chapter- Wonderful animation of the changes in molecular entropy as the phase of a substance changes)

http://www.saskschools.ca/curr_content/chem30_05/1_energy/teacher/energy_lab_index.htm#spontaneous_endothermic

Temperature is a measure of the average kinetic energy of the particles. As the temperature increases, the average kinetic energy increases.

The average kinetic energy of the molecules in a metal object and a wood object are the same at room temperature.

Content StatementC3.3x - BOND ENERGY: **Chemical bonds possess potential (vibrational and rotational) energy.**

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

INSTRUCTIONAL BACKGROUND INFORMATION

There is a potential energy change when two atoms come together to form a bond. All the repulsive and attractive forces are balanced. At this point, the same amount of energy must be added (absorbed) to break the bond and create neutral molecules

Teacher Demonstration: Bond Energies

Purpose: Students observe two reactions in which bonds are formed and compare ionic and covalent bond energies.
Materials: 10-15 cm piece of clean magnesium ribbon, a small piece of charcoal, tongs, Bunsen burner, filters for viewing.
Safety: Goggles and lab apron
Procedure: Using tongs, hold the piece of magnesium in a Bunsen burner. *Do not look directly at flame. Observe through filters.* Discuss with students the large amount of heat and light given off in the formation of MgO. Write the balanced equation on the board for magnesium plus oxygen yields magnesium oxide plus energy. Using tongs place a small piece of charcoal in the Bunsen burner flame and try to ignite it. Write the balanced chemical equation for carbon plus oxygen yields carbon dioxide and energy.
Expected Outcome: Students note that much less energy is given off in forming CO2 than in forming MgO Ask, **What kind of bond is MgO?(Ionic)**

What kind of bonds are in CO2? (Covalent)
Ionic bond energies are, in general, greater that covalent bond energies due to the energy stored in the crystal lattice.

Content Statement
C5.4 PHASE DIAGRAMS: Changes of state require a transfer of energy. Water has unusually high energy changes associated with its changes of state.

C5.4A: Compare the energy required to raise the temperature of one gram of aluminum and one gram of water the same number of degrees.

INSTRUCIONAL BACKGROUND INFORMATION

Why does water have such a high specific heat capacity? Hydrogen bonds cause water to have a greater specific heat (thermal inertia) than many other substances. When heat is applied to water, much of the heat is consumed in breaking hydrogen bonds. Broken hydrogen bonds are a form of potential energy. Much of the heat added to water is therefore stored as potential energy. Consequently, less heat is available to increase the kinetic energy of the water molecules. Since temperature is a measure of the kinetic energy, we find that as water is heated, its temperature rises slowly. By the same token, when water is cooled, its temperature drops slowly-as the kinetic energy decreases, molecules slow down and more hydrogen bonds are able to reform. This releases heat that helps to maintain the temperature.

Water and its structure. http://www.chem1.com?acad/sci/aboutwater.html

http://www.northland.cc.mn.us/biology/Biology1111/animations/hydrogenbonds.html

C3.2x Enthalpy: *Chemical reactions involve breaking bonds in reactants (endothermic) and forming new bonds in the products (exothermic). The enthalpy change for a chemical reaction will depend on the relative strengths of the bonds in the reactants and products.*

C3.2a: Describe the energy changes in photosynthesis and in the combustion of sugar in terms of bond breaking and bond making.

INSTRUCTIONAL BACKGROUND INFORMATION

Use the bond enthalpy values for the reactants and products to prove that photosynthesis is an energy absorbing process and combustion of sugar is an

energy releasing process. Overall reaction enthalpy equals the total product bond enthalpies minus the total reactant bond enthalpies.
Great link of an animation of bond breaking and bond forming showing energy absorbed and released.
http://wps.prenhall.com/wps/media/objects/4974/5093961/emedia/ch09/AACXJRD0.html

DEMO: Flash Paper

Ignite a piece of nitrocellulose paper. It will disappear in a flash. The overall reaction is: $4N_6H_7N_5O_{16} + 19\ O_2 \text{ ----------}\rightarrow 24\ CO_2 + 20\ NO_2 + 14\ H_2O$
A spark of activation energy starts this rapid burning reaction. We know the burning of flash paper is exothermic because the amount of energy released as product bonds form is greater than the amount absorbed as reactant bonds break. The reactions results in a dispersal of energy which means an increase in entropy. Energy is released in the form of light and fast moving molecules. The air where the flash paper once was is appreciably warmer.

Safety: Flash paper is extremely flammable and should be stored in a container such as a coffee can. It should not be agitated. It can be purchased at most novelty stores or online. Hold the paper away from you as you ignite it and drop it immediately after lighting it.

Terms and Concepts

Potential Energy	Heating curve for water	Heat Capacity
Electrostatic attraction	Hydrogen Bonds	Lattice Energy
Bond Energy	Specific heat	
Entropy	Enthalpy Diagram	
Endothermic	Ion Dipole interaction	
Exothermic	Solubility	
Bond Enthalpy	Calorimeter	

Thermodynamics and Kinetics

Activity # 1

**- How is potential energy stored in a chemical bond?
Does breaking the bond require energy?**

Objective: C2.1x C3.3x

Materials: Large Rubber Bands

Safety Concerns: none

Procedure / Description:

Potential Energy

Rubber Band Experiment [picture]

A simple way to demonstrate elastic energy is to stretch a rubber band and not let go, the stretch demonstrates potential energy. Let go of the rubber aiming it toward a wall and it is converted to kinetic energy.

The rubber band can also illustrate energy conversion. Place the band against your upper lip to measure its temperature. Stretch and release the band repeatedly. Test the temperature again. It should feel warmer. Why does it feel warmer and where do you think the heat energy came from

(Might want to look up the chemical structure of the polymer rubber)

Sources:

http://www.uwsp.edu/cnr/wcee/keep/Mod1/Whatis/experiments.htm

Thermodynamics and Kinetics

Activity #2 Vinegar and Baking Soda Rocket

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

Safety Concerns: The film canisters will pop off their tops. Make sure the students have adequate space and eye protection.

Procedures: This activity can be done as a demo or by students as an activity. Film canisters may be used instead of a flask

Rocket Experiment

Materials: Plastic flask, cork, 1/2 cup water, 1/2 cup vinegar, spoonful of baking soda, paper coffee filter
Note: *Only attempt this activity where this is overhead space and room to move away.*

Pour a 1/2 cup of water and a 1/2 cup of vinegar into the flask. Put a spoonful of baking soda into a coffee filter, roll and twist it closed. Put the coffee filter in the flask, cork it and move away...fast! Both the baking soda and vinegar contain molecules (which have potential energy in their bonds). When mixed together the bonds break and the molecules rearrange themselves to produce a gas releasing energy. The continued production of gas in a closed container increases the pressure (potential energy) in the container. This experiment demonstrates chemical energy converted to mechanical energy or movement.

Design a film canister to look like a rocket (add fins, nose cones, etc.). Put a little baking soda and vinegar in the rocket and quickly close the lid and invert. Lift off! (NOTE: You'll need to use the type of canister where the lid fits inside the canister rather than the cap style

Source: Same Website as activity #2.

Thermodynamics and Kinetics

Activity # 3

Question: Which substance has a higher specific heat? (Racing Temperatures)

This could be done as a student take home activity.

Objective: C5.4A - Compare the energy required to raise the temperature of one gram of aluminum and one gram of water the same number of degrees.

This example does not involve water, but it could be modified to add a test of the specific heat of water.

Materials: Uncooked rice, table salt, 1-cup measuring cup, aluminum foil, baking sheet, two identical ceramic coffee mugs, thermometer.

Procedure:

1.) Tear off two pieces of foil, each about half the size of the baking sheet. Place them side-by-side on the baking sheet.
2.) Measure out one sup of rice and pour onto one of the foil sheets. Measure out one cup of salt and pour onto the other foil sheet.
3.) Heat the rice and salt for 10 minutes in an oven preheated to 250C, and then pour the rice into one of the coffee mugs and the salt into the other.
4.) Use a thermometer to note which comes out of the oven at the higher temperature and which cools down faster. If you don't have a thermometer, leave the heated rice and salt on the aluminum foil and judge their cooling rates by *cautious* touch.

Which has the higher specific heat?

Sources: Conceptual Chemistry, John Suchocki

Thermodynamics and Kinetics

Activity #4 Measuring Bond Energy of an Ionic Compound

Objectives: C3.3x Bond Energy

Procedure/Materials/Safety:

Measuring the Bond Energy of an Ionic Compound

- Lesson
- Standards

Overview

Many students are familiar with cold packs—plastic bags that when manipulated to break an internal compartment exhibit a sudden drop in temperature, making them useful as first aid for sports injuries. One of the chemical compounds used in this type of product is ammonium chloride. In this lesson, students study the endothermic dissociation of ammonium chloride in water and, by taking careful measurements of its heat of solution with a calorimeter, determine its bond energy in kJ/mole.

Objectives

- Be able to calibrate a calorimeter
- Understand how calorimeters are used to measure energy transfers in endothermic reactions
- Understand what is bond energy
- Understand the concept of dissociation
- Understand the difference between endothermic and exothermic reaction
- Apply the law of conservation of energy to endothermic reactions
- Learn how scientists measure bond energy, and how they minimize sources of error between their measurements and standard reference measurements

Grade Level: 9-12

Suggested Time

- Four 45-minute class periods or two 1.5-hour lab periods

- TIP: The lab activity may be adapted to be a classroom demonstration, or the calorimeters can be calibrated ahead of time, allowing more time for the dissociation experiment.

Multimedia Resources

- Ionic Bonding Flash Interactive
- Dissolving Salts in Water Flash Interactive

Materials

Lesson Preparation

- Preparing the Calorimeters PDF Document
- 8-oz plastic thermos jar (one for each lab group)
- Electric drill with 1/2 in (12 mm) bit
- One-holed rubber stoppers (to fit hole made by drill)
- Disposable stir rods

Part II

- Calibrating the Calorimeters PDF Document
- Determining a Calorimeter's Heat Capacity PDF Document
- Cold pack, such as those used in sports first-aid kits
- Celsius thermometers, capable of 0.1°C measurements in the range of 5°C-105°C
- Laboratory scale (accurate to 0.1 g)
- Stopwatches/timers
- 100 g aluminum cylinder
- Laboratory tongs
- Laboratory heater
- Several 1 L Pyrex beakers (fill two with tap water, and leave out for several hours to equilibrate with room temperature)
- 250 mL graduated cylinders
- Safety goggles

Part III

- Measuring the Heat of Disassociation of NH4Cl Activity PDF Document
- Ammonium chloride—NH_4Cl (53.4 g per student). Common name: sal ammoniac. Safety information: harmful if swallowed or inhaled. Eye irritant. Do not allow dust to enter air, and use safety goggles. For more safety information about ammonium chloride, please check out the Ammonium Chloride International Chemical Safety Card from the National Institute for Occupational Safety and Health.
- Water at 8°C above room temperature, 0.2 L per lab group

Before the Lesson

- Arrange computer access so students can work in pairs or small groups.
- Familiarize yourself with the media resources and make copies of the following documents for students: Calibrating the Calorimeters PDF Document, Determining a Calorimeter's Heat Capacity PDF Document, and Measuring the Heat of Disassociation of NH4Cl Activity PDF Document.
- Prepare the calorimeters for each small group of students. Refer to the Preparing the Calorimeters PDF Document.

The Lesson

Part I: Thinking About Chemical Reactions

1. Begin by eliciting students' prior understanding about chemical bonds. Write the following questions on the board and ask students to answer them in their science notebooks:

   a. What is a force? Name as many different kinds of forces as you can.
   b. What is the relationship between force and energy?
   c. Give an example of how forces might be active on the microscopic scale of atoms.
   d. What are some ways forces might change how matter behaves at the
   e. atomic scale?

2. Have students work through the Dissolving Salts in Water Flash Interactive in pairs or small groups. Ask students to discuss the questions on the board as they work through the activity. When they have finished, ask them if they would like to revise their examples of how forces might be active on the microscopic scale. In what ways might the arrangement of atoms in an ionic compound reflect these forces?

3. Bring the class back together and review the terms "endothermic reaction" and "exothermic reaction." Ask students how they think they could determine if a reaction they are observing and measuring is endothermic or exothermic. What do they think they would need to know to be able to make this determination? Lead the class to the understanding that changes in temperature will help them determine if a reaction is endothermic (it absorbs energy and thus a temperature drop occurs) or exothermic (it releases energy in the form of heat and thus a temperature increase occurs).

4. Show students the first-aid instant cold pack and ask them to describe it. What is it for? How is it used? Record their answers on the board then choose a volunteer to demonstrate how the cold pack works. After the student activates the cold pack, pass it around the room so that everyone can feel the change in temperature. Then ask students to jot down in their notebooks whether they think an exothermic or endothermic reaction is occurring, and their initial ideas about the role energy plays in the cold pack becoming cold. When they are finished, have them compare their ideas in their small groups, and then discuss the following questions:

a. Why do you think the pack became cold when the internal compartment inside the bag was broken? How is this different from other reactions (i.e., instant heat packs) that raise the temperature of the reactants and their surroundings?
b. What do you think is happening at the molecular level? How would you apply the law of conservation of energy to the situation with the cold pack? (According to the law of conservation of energy, the total energy at the end of the experiment is equal to the energy at the beginning of the experiment.)
c. Predict what you think you'd find if you could measure the total energy in the bag before and after the bag was activated.

5. When they are finished, ask representatives of each group to share their ideas with the class. Some students will say that there was a chemical reaction, and that bonds were made and/or broken, and that these contributed to the energy equation. Explain that in the case of the cold pack, they observed the large-scale result of the breaking of billions of chemical bonds of a compound called ammonium chloride (NH_4Cl) as it dissociates into ammonium and chloride ions when it dissolves in water.

At this point, make sure students understand the connection between the breaking of the bonds and the temperature change. Remind them that if the temperature went down, then heat energy was required, and therefore the chemical reaction required energy, which it took from its environment. Since the environment is quite large, and heat can be transferred from it in many ways, measuring the temperatures of the cold pack before and after activation would allow them to determine heat of dissociation. But how could they accurately measure how much energy is required to break these bonds? Have students throw out some initial ideas before you introduce the calorimeter.

Part II: Calibrating a Calorimeter

6. Tell students that they will be measuring the heat absorbed or released in a chemical reaction using a calorimeter, a device that includes an insulated container, a solution that provides energy or absorbs energy in a reaction, and a thermometer to monitor the temperature. By knowing the mass of the calorimeter and the specific heat of the calorimeter (the solution and container combined)—all of which are constant values—you can determine the heat capacity of the calorimeter. (A bigger calorimeter will have a bigger heat capacity.) And knowing the heat capacity of the calorimeter will allow you to measure the change in temperature during a chemical reaction inside the calorimeter. This temperature change helps determine the amount of energy used to break chemical bonds in an endothermic reaction or the amount of energy released in an exothermic reaction.

Explain that the first step will be to calibrate the calorimeters. Ask students why they think they need to calibrate the calorimeters.

After students share some ideas, explain that there is always some loss of heat to or from the calorimeter itself during any reaction. Calibrating the calorimeter accounts for this heat loss so that the reactions that take place inside the calorimeter can still be measured with a level of accuracy. For example, if a certain amount of hot water were added to a known amount of cool water in a calorimeter, the water temperature inside the calorimeter would increase, but less than expected because of heat loss from the calorimeter. Students can calculate the specific heat ($C_{calorimeter}$) of their calorimeters and use that factor to make more accurate measurements.

7. Have students go to the lab to calibrate their calorimeters. The procedure they will use involves adding a known quantity of hot aluminum to a fixed amount of water in the calorimeter and then measuring the temperature change. Since the specific heat of the aluminum (0.9 J/g-°C at 300°K) and other metals is available from tables, students can calculate the missing energy when a hot cylinder of that metal is added to their calorimeters. Provide students with the necessary supplies and the Calibrating the Calorimeters PDF Document.

[Note: It is important that the calorimeters are calibrated before students do the activities in Part III, otherwise the experiment will not return consistent results. If time is limited, you can calibrate the calorimeters ahead of time or do it as a teacher-led demonstration.]

8. When students are finished recording their temperature measurements, have them use the Determining a Calorimeter's Heat Capacity PDF Document to determine the heat capacity of the calorimeter. Note that a typical heat capacity of the type of calorimeter illustrated in the Preparing the Calorimeters PDF Document was determined to be 54 ± 7 J/°C. If all the calorimeters are made with the same materials, their heat capacities should be similar. It may be useful to take a class average of the values obtained, and use that figure in future calculations for consistency and ease of discussion.

Part III: Using the Calorimeter to Measure Heat of Dissociation

9. Tell students that they will now use their calibrated calorimeters to accurately measure the heat of dissociation (bonding energy) of 53.4 g (one mole) of the salt ammonium chloride. Ask students what is special about 53.4 g of that compound. Make the connection to the atomic weight of the compound by looking up the weights on the periodic table. Then provide students with all necessary supplies at their lab tables and distribute the Measuring the Heat of Disassociation of NH4Cl Activity PDF Document.

10. After students have completed the activity, bring the class back together. Remind students that according to the law of conservation of energy, the total energy of the system before and after the reaction will be the same (leaving out relatively small factors like thermal conduction of the calorimeter and the difference between the C (temperature) of the salt solution and that of the water). Write the following equation on the board:

- Total energy before = Total energy after
- Total bond energy (in 53.4g NH_4Cl)
  - $= q_{sol} + q_{cal}$
  - = (200 g x 1 cal/g-°C x (ΔT)) + (54 J/g-°C x (ΔT))
  - = ΔT x (200 J/g-°C + 54 J/g-°C)

Help students understand that this means that when the ammonium chloride salt dissolves, the ammonium ion (+) becomes dissociated from the chloride ion (-). Because of the microscopic arrangement of the molecules, this requires energy.

11. Break students up into their small groups, and ask them to predict what the curve of temperature over time would look like for the salt ammonium chloride.

Then have students view the Dissolving Salts in Water Flash Interactive. Have them choose NH_4Cl, and observe the curve of temperature over time after the salt is introduced. Encourage them to try different combinations of the amount of the salt and the water. How do these affect the curve?

Part IV: Sharing Results

12. Have the groups chart their data in a visible way (with a histogram, for example) to see if there is a pattern. Students should record their data on the board or on a piece of chart paper where the whole class can see it. There will most likely be some variation among the results. Use the class data to determine a class average. [Note: While there may be some disparities, the result should be near the experimentally determined standard of 14,780 J.]

13. Remind students that they dissolved one mole of the compound, so that by dividing the total energy required in the reaction by Avogadro's number (the number of molecules in one mole of a substance); they will determine the individual bond energy of each molecule. Ask students to summarize how energy transfer in exothermic and endothermic reactions is related to breaking or creating chemical bonds in these reactions. What claims can they make about the energy released by using different quantities of the compound in the experiment? What about using the same quantity of a different compound, such as table salt? Would they predict that the post-reaction temperature would be the same, higher, or lower? If lower, would it be the same drop as with the ammonium chloride? Conclude by having students return to their computers and check these other compounds using the Dissolving Salts in Water Flash Interactive.

Check for Understanding

Have students discuss the following questions or record their answers in their notebooks:

1. Write the chemical formula for the dissociation of ammonium chloride and then write the energy reaction underneath.
2. How might you use the calorimeter to determine the exothermic heat of reaction of combustion? What would be the difference in the measurement of ΔT?
3. What could you do to improve the accuracy and reliability of your experiment?
4. Describe how the calorimeter offers an example of the law of conservation of energy.

Teachers' Domain is proud to be a Pathways portal to the National Science Digital Library.

Multimedia Resources Used in this Lesson:

Dissolving Salts in Water
Flash Interactive

Ionic Bonding
Flash Interactive

Save this lesson plan as a Folder

National Science Foundation

Thermodynamics and Kinetics

Activity # 4

Calculating Bond Enthalpy

Objective: C3.3x - Bond Energy

Chemical bonds possess potential energy.

C3.2x - Enthalpy

Chemical reactions involve breaking bonds in reactants (endothermic) and forming new bonds in the products (exothermic). The enthalpy change for a chemical reaction will depend on the relative strengths of the bonds in the reactants and products.

Description: Worksheet on calculating bond enthalpy

Materials: small amount of vinegar and baking soda, container for experiment

Simply pour a small amount of vinegar onto baking soda causing a chemical change.

Chapter 4 Class Work Partner ______________________________

COUNTING BONDS AND CALORIES:
A Molecular View of Reaction Energy

This is not a quiz, but rather a class exercise. The papers will be collected and graded. You may talk to your classmates and you may refer to your textbook, but you must write your answers to each question in your own words. (Don't just copy things right out of the textbook).

1. Look at the table of "bond energies" on page 99*.

a. Which are the two strongest bonds on this table?

b. Which are the two weakest bonds on this table?

c. The complete combustion of hydrocarbons (compounds of carbon and hydrogen, such as methane and octane) in air produces carbon dioxide and water. Show that the bond energies in this table would generally lead you to expect that such reactions would be exothermic. (Hint: what the energies of the bonds in hydrocarbons and in oxygen, compared to those of the bonds in water and carbon dioxide?)

d. Figure 4.10 (page 104) shows that the energy released by burning (the "heat of combustion") of carbon to carbon dioxide is greater than that of carbon to carbon monoxide. How can this be, when table 4.2 says that the CO TRIPLE bond energy is greater (1072 KJoules/mole) that the CO DOUBLE bond energy (799 KJoules/mole)?

2. a. Here is a partial table of bond energies, showing how to compute
the heat of reaction for the synthesis of water

2H2 + O2 --> 2H2O

which can we viewed as

H-H + O=O --> H-O-H
H-H H-O-H

to show the bonds more clearly.

Bond	Bond energy (KJ/mole)	Number of bonds broken	Energy required	Number of bonds formed	Energy released
H-H	432	2	864		
H-C	411				
C-C	346				
H-O	459			4	1836
C-O	359				
C=O	799	1	494		
O=O	494				
N#N	942				
C-N	305				
N-O	201				
O-O	142				
		Total (KJ/mole)	1358		1836

Since the energy released by forming bonds is greater than the energy required to break bonds, the reaction is predicted to be EXOTHERMIC (energy producing). The "heat of reaction" is conventionally calculated as:

Heat of Reaction = Energy required - Energy released

so that the heat of reaction turns out to negative for an exothermic reaction. In this case the Heat of Reaction = 1358 - 1836 = _______

b. Using the table below as a worksheet, compute the heat of combustion (KJoules/mole) of ethyl alcohol (C_2H_5OH), whose structure is shown on page 100. How does this compare to the heat of combustion of propane, also given on page 100?

Bond	Bond energy (KJ/mole)	Number of bonds broken	Energy required	Number of bonds formed	Energy released
H-H	432				
H-C	411				
C-C	346				
H-O	459				
C-O	359				
C=O	799				
O=O	494				
N#N	942				
C-N	305				
N-O	201				
O-O	142				
		Total (KJ/mole)	-----------		------------

c. Do you think it is likely that someone could invent an engine that would burn nitrogen (N2) as a fuel? Explain on the basis on bond energies in the above table?

3. a. The reaction for the combustion of glucose (a type of sugar) is given on page 102. The structural formula for glucose is given on page 335 (upper left corner of the blue box). Use this information and the table below as a worksheet to compute the heat of combustion of glucose in KJoules/mole and compare to the measured value given on page 102.

Bond	Bond energy (KJ/mole)	Number of bonds broken	Energy required	Number of bonds formed	Energy released
H-H	432				
H-C	411				
C-C	346				
H-O	459				
C-O	359				
C=O	799				
O=O	494				
N#N	942				
C-N	305				
N-O	201				
O-O	142				
	Total (KJ/mole)				

b. Convert the heat of combustion of glucose into KJoules per gram. You will need to compute the molecular weight (grams/mole) of glucose; the atomic weights are: H =1 gram/mole; C = 12 gram/mole; O - 16 gram/mole.

c. Chemically, wood consists of organic compounds which are long chains of simple sugar units like glucose. Therefore wood is expected to contain many of the same chemical bonds as glucose. The "heat content" of wood, in KJoules per gram, is given in Table 4.3. How does this compare to your calculated heat of combustion of glucose in KJoules per gram?

Bibliography

* American Chemical Society, "Chemistry in Context: Applying Chemistry to Society", Wm. C. Brown Publishers, 1994.

Thermodynamics and Kinetics

Activity #5 Fire Starter

Objectives: C3.2x

Procedure / Description: (See scanned in document on next page)

Students will learn that bond breaking is exothermic and bond breaking is endothermic. The topic is explored using enthalpy diagrams, teacher demos, and a discussion of the rates of reaction.

Source: Living By Chemistry, General Chemistry, Angelica M. Stacy

Investigation III – Energy for Change

LESSON 2 – Fire Starter

In this lesson, students learn that bond making is exothermic while bond breaking is endothermic. Both events happen in every chemical reaction. The first step of any chemical reaction is the breaking of "old" bonds. This step requires an input of energy called the activation energy. If other circumstances are the same, reactions with high energies of activation are less likely to occur than those with low energies of activation. Once a reaction has been initiated, "new" bonds form with release of energy.

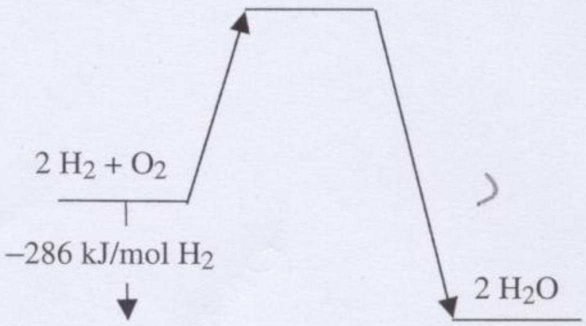
Exploring the Topic (10 min)

1. Introduce the ChemCatalyst.

Write the ChemCatalyst exercise on the board for students to complete individually.

In the previous lesson we showed you an energy diagram for the combustion of hydrogen. In actuality, that diagram was simplified. This new energy diagram is more accurate.

- What is different about this diagram? Explain what you think is going on, and why you think the diagram has the shape it has.



2. Discuss the ChemCatalyst exercise.

Use the discussion to get a sense of students' initial ideas.

Discussion goals:

Use the students' written responses to stimulate a discussion about this new energy diagram.

Sample questions:

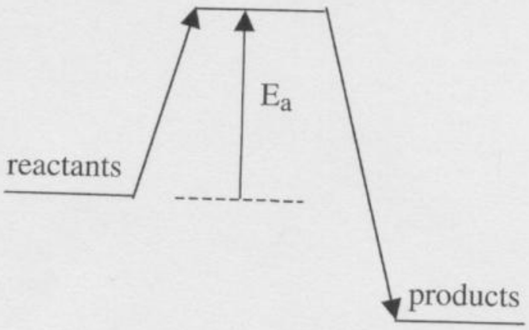
Why do you think there is a hill in this energy diagram? What do you think it represents?

What do you think the energy diagram for the reverse reaction would look like?

Is this reaction exothermic or endothermic? Explain.

3. Briefly introduce energy of activation.

Draw the diagram below on the board. Show students that energy diagrams can also be represented as smooth curves (not shown).



Points to cover:
The hill on the energy diagram represents the energy that it takes to get a reaction started. This energy is called the **energy of activation** or the **activation energy.**

Energy of activation: The energy that is required to get a reaction started.

4. Complete the "Writing with Fire" demonstration.

Demonstration – Writing with Fire

The day before class, prepare the invisible ink sign as directed on the Before Class page. It is suggested that you write the word "Fire" on the paper, but any word will do, as long as the letters are continuous. On the day of the demonstration, show the students the blank paper. Tape it to the board where all can see it. Tell the students you are going to write with fire. Light a match. Make sure it is burning well before blowing it out. Then touch the beginning of your word with the glowing tip of the match. The word will ignite and a glowing front will travel along the path of the dried potassium nitrate solution, leaving behind a black trail of ash. The paper around the word will not burn.

Discussion goals:

Allow students to speculate about what is going on in the "Writing with Fire" demonstration.

Sample questions:

What evidence do you have that combustion took place in the demonstration?
Was the reaction exothermic or endothermic? How do you know?
What usually happens when paper burns?
How was the reaction started?
Why do you think only some of the paper burned?
Why do you think the reaction proceeded without a flame?

Give students a little time to give their observations and discuss what they think might be going on. Tell them that you will get back to discussing the demonstration on the worksheet.

5. Explain the purpose of today's activity.

If you wish you can write the main question on the board.

Points to cover:

Tell students they will be gathering information to explain the demonstration and consider the role of the energy of activation on a reaction. The focus is to answer the question: "What does the activation energy tell us about a reaction?"

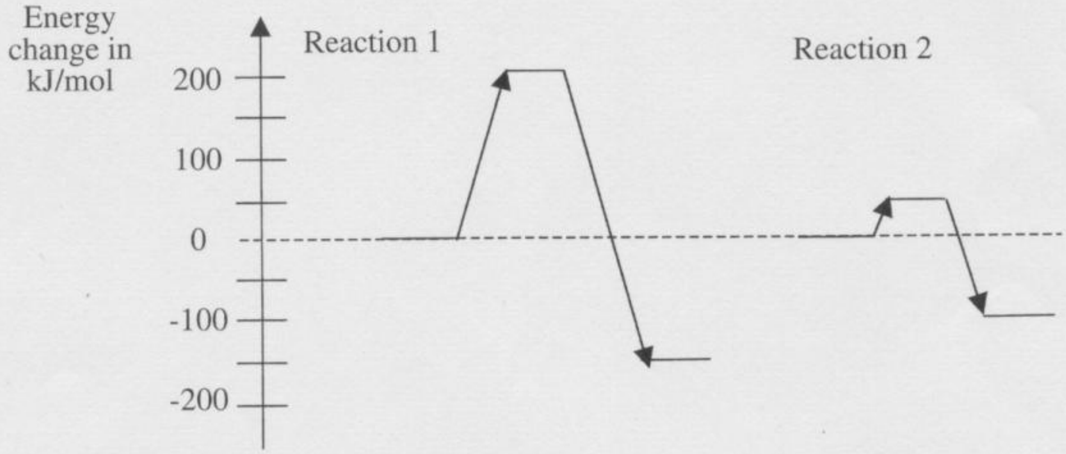
Activity – Fire Starter (10–5 min)

6. Introduce the activity. (Worksheet)

Pass out worksheets. Ask students to work individually.

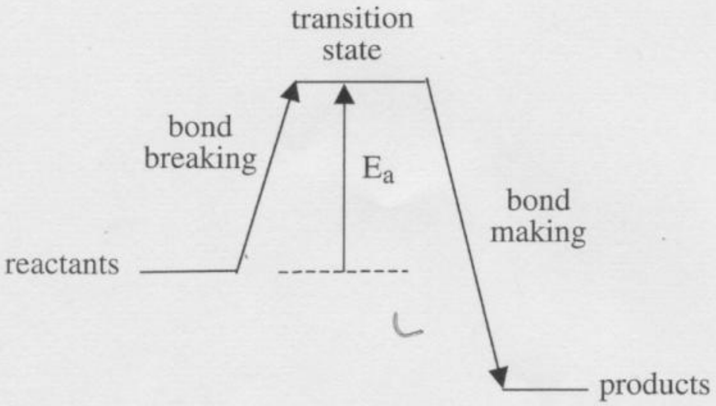
Answer the following questions.

1. The diagrams below show the changes in energy for two different reactions.



   a. What is the energy of activation for Reaction 1? (200 kJ/mol)
   b. What is the energy of activation for Reaction 2? (50 kJ/mol)
   c. Which reaction requires more energy to get it started? (Reaction 1)
   d. What is the heat of reaction for Reaction 1? (–150 kJ/mol)
   e. What is the heat of reaction for Reaction 2? (–100 kJ/mol)
   a. Which reaction releases more heat? (Reaction 1)

2. The diagram below shows one way to think about a chemical reaction. You can think of the top of the hill as the **transition state,** an intermediate step in the reaction. Some bonds of the reactants are broken to reach the transition state. Then, atoms come together to form the bonds in the products.



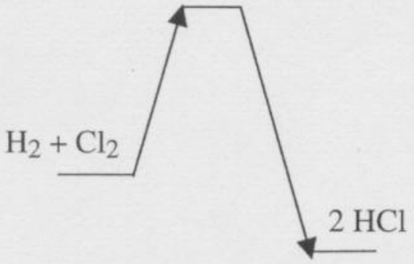
a. Bond breaking requires energy. How is bond breaking related to the energy of activation? Explain your thinking. (You need to break bonds to get a reaction started.)

b. Use the law of conservation of energy to explain why bond making releases energy. (If you need energy to break a bond, the same amount of energy will be released when the same bond forms.)

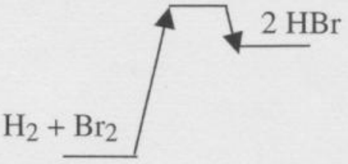
c. The energy diagram shown represents a combustion reaction. Why is a spark required to get the reaction started? (to supply the energy of activation to break bonds)

d. Heat must be supplied to reverse the reaction because the reverse reaction is endothermic. Do you also need more heat to get the reverse reaction started? Explain. (Yes – more energy is required to break the bonds of the product to get to the transition state.)

3. The two energy diagrams below show the formation of HCl and HBr.



Reaction 1:
$H_2 + Cl_2 \rightarrow 2\,HCl$



Reaction 2:
$H_2 + Br_2 \rightarrow 2\,HBr$

a. Is Reaction 1 exothermic or endothermic? (exothermic)

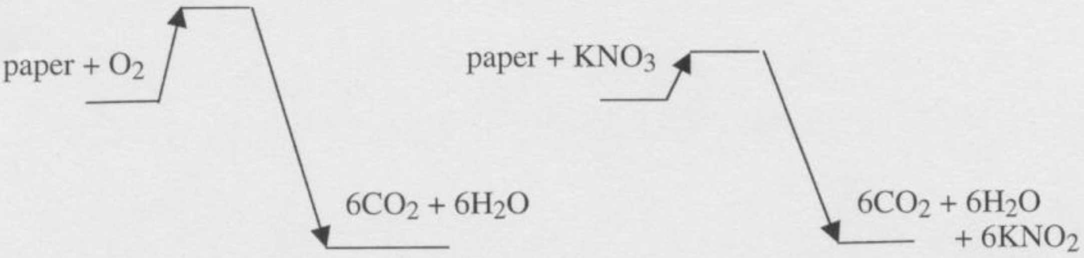
b. Is Reaction 2 exothermic or endothermic? (endothermic)

c. Which bonds need to be broken to get the reaction started? (H-H, Cl-Cl, and Br-Br)

d. Which bonds need to be formed? (H-Cl and H-Br)

e. For which reaction is the energy required for bond breaking greater than the energy released for bond making? (Reaction 2)

4. In the "Writing with Fire" demonstration, the writing was done with the reaction between potassium nitrate (KNO_3) and paper. Use the diagrams below to explain why the paper ignited with KNO_3. (The energy of activation is lower for the reaction with KNO_3, so it gets started with a match that has been blown out. Without KNO_3, a lit match is needed to start the reaction between paper and oxygen.)



Making sense:
Explain the energy of activation and the heat of reaction in terms of bond breaking and bond making.

If you finish early...
Sketch an energy diagram for the combustion of hydrogen, including the energy of activation. Explain why a spark is needed to ignite a mixture of hydrogen and oxygen.

Making Sense Discussion (15 min)

Major goals: The main goal of this discussion is to make sure students are proficient at interpreting energy diagrams and activation energies. They should be able to examine diagrams and relate them to the heat of reaction and the heat required to get the reaction started. Help students to recognize that the energy of activation has to do with the energy required to break bonds. The heat of reaction is the difference between the energy required to break bonds and the energy released in making bonds.

7. Discuss energy of activation.

You may wish to ask students to draw graphs on the board showing different types of reactions that you describe.

Discussion goals:
Discuss why energy is needed to start an exothermic reaction.

Sample questions:

How can you determine the energy of activation from an energy diagram?

Why is a spark needed to start a combustion reaction?

Why did the paper in the "Writing with Fire" demonstration react with potassium nitrate but not with oxygen?

What do you need to do to get the paper to react with oxygen in the air? (Can you use a match that has been blown out?)

Is the energy of activation for the reverse reaction of combustion larger or smaller? Explain.

Points to cover:

It takes energy to get a fire started. This is easy to see if you have ever tried to start a fire by rubbing two sticks together. Most of the time when we light a fire we do not have to work so hard. We simply pull out a lighter or a match and the match does the work for us to start the barbecue or the presto log.

Most chemical reactions (not just combustion reactions) require some sort of energy input to get them started. This is called the **activation energy.** The match that lights a fire is responsible for delivering the activation energy that gets the chemical reaction of combustion going. Most chemical reactions have some sort of activation energy. In other words, most reactions begin with a push of some sort.

The activation energy shows up on an energy diagram as a small barrier that must be overcome before a reaction goes forward. This "speed bump" or barrier is simply the energy needed to start the reaction. You can see that when the speed bump on an energy diagram is small, the activation energy is low, and that reaction is easier to get started.

8. Discuss bond breaking and bond making.

Have two bar magnets on hand to use in demonstrating bond breaking and bond making between two atoms. The magnets can be labeled with atoms if you wish, such as O and O.

Discussion goals:

Assist students in relating energy changes to what is happening on a particulate level during a reaction.

Sample questions:

Does bond breaking require or release energy? Explain.

Does bond making require or release energy? Explain.

Just because a reaction is endothermic, does that mean there is only bond breaking occurring during that reaction? Explain.

Just because a reaction is exothermic, does that mean there is only bond making occurring during that reaction? Explain.

How is the heat of reaction related to bond breaking and bond making?

Thermodynamics and Kinetics

Activity # 6 - Exploding Hydrogen Bubbles In Your Hand

Objectives: C5.4 Water has unusually high energy changes associated with its changes of state. It has high heat capacity and high specific heat.

Materials: Bubble solutions (Dawn dish detergent, glycerin, and water)

Hydrogen generator: Erlenmeyer flask, one-hole stopper with glass bend and hose attached

Glass pan to hold the bubble solution

Mossy Zinc

3M hydrochloric acid

Small tea light candle

Safety:

Hydrochloric acid is toxic by ingestion or inhalation and is severely corrosive to skin and eyes.

Hydrogen gas is very flammable and yields explosive mixture with air.

Wetting your hand is absolutely critical to prevent burning your hand.

Do not ignite bubbles near the hydrogen generator.

Wear goggles

Procedures/Description:

1. Prepare a bubble solution by mixing 100 mL of Dawn dishwashing liquid with 50 mL of glycerin.
2. Pour the bubble solution into a plastic container of sufficient size that you can easily scoop handful of bubbles form the top of the soap solution.
3. Place a small amount of zinc in the bottom of the Erlenmeyer flask. Add about 75 mL of 3M hydrochloric acid. Quickly insert the one hole stopper with glass bend and attached hose.

4. Wait a short time for air to clear the system, the then immerse the unattached end of the hose in the bubble solution.
5. Light candle at a considerable distance from the hydrogen generator and the bubble solution.
6. Perform the following steps quickly:
    a.) Wet your hand thoroughly with tap water
    b.) Scoop a handful of bubbles from the bubble solution.
    c.) Holding your hand sideways, bring the bubbles in your hand alongside the candle flame.

The hydrogen bubbles will explode, yet your hand will not be burned because it was wet with water which can absorb a great amount of energy before changing phase.

I usually do this activity in my fume hood. I allow my students to form a line, wet their hand one by one and try it themselves. The reaction is great.

Discussion

The zinc reacts with the hydrochloric acid to produce hydrogen gas:

$Zn + 2 HCl \text{-----}\rightarrow H_2 + ZnCl_2$

The hydrogen gas reacts with the oxygen in the air to produce water vapor.

$2H_2 + O_2 \text{---------}\rightarrow 2H_2O$

The explosion produced by the reaction of hydrogen indicates that this is an exothermic reaction. Heat generated by this reaction is absorbed by the water on your hand, and also by the water in your body tissues. Since water requires a significant amount of heat to change temperature (the specific heat of water is 4.184 Joules/g°C), the temperature of your hand does not change sufficiently to produce a burn.

You might mention that fire walkers depend on the high specific heat of water, as they dip their feet in water and or damp grass before walking on hot coals.

Sources: Demonstration performed originally by Michael Bannon of St. James, New York.