Unit 3 Lab: Icy Hot

Lab Write-up – Evaluation & Conclusion

Divide your heating curve into three regions; label each region:

(A) a low temperature plateau
(B) a region of temperature change
(C) a high temperature plateau

The following questions should be answered on the back of your graph from the lab.

1. Did the system in this lab involve a chemical change? Explain. Did the system absorb or release energy? Explain.

2. For each region on your graph,
   a. describe how the energy supplied by the burner was stored by the system (E_{th} or E_{ph})
   b. state what phases were present
   c. draw a model at the particle level that shows how the water particles were behaving.

3. How would increasing the rate of heating by using two burners affect the shape of the curve?
Icy-Hot Sample Data
Chemistry – Unit 3
Energy and Kinetic Molecular Theory

In the 18\textsuperscript{th} and 19\textsuperscript{th} centuries scientists wrestled with identifying and describing the nature of the “stuff” that produced change. One concept that became popular for a while was that of “caloric” (what we now call heat).

“Caloric was originally conceived of as a quantity that would flow from a hotter object to a cooler one that would warm up as a result. It answered the need for a way for the cause of warming to get from here to there. Not only did caloric serve as a cause for warming, it was also considered to be the cause for changes of phase. Caloric enabled particles of a substance to move farther apart until the attraction of the particles for each other became too weak to hold them together. Although Lavoisier did not think that caloric necessarily was an actual substance, in its storage and transfer it was \textit{like} a substance.”.\textsuperscript{i}

When scientists recognized that the “stuff” involved when forces were applied to objects to lift them or change their speed was the same “stuff” that was involved when the temperature of objects changed, they worked to develop a single energy concept. “So when the energy concept was developed it was important to distinguish it from caloric. In snuffing out the caloric concept, the clear picture of energy storage and transfer that it fostered was unnecessarily lost, too.”\textsuperscript{ii}

Even though we recognize that energy is not a \textit{physical} substance, we choose to use the substance \textit{metaphor} to describe it.

We'll use three principles to guide us in the development of the energy concept.
1. Energy can be viewed as a substance-like quantity that can be stored in a physical system.
2. Energy can “flow” or be “transferred” from one system to another and so cause changes.
3. Energy maintains its identity after being transferred.

If you are unsure what we mean by the use of a substance metaphor, consider how we describe information. We say that it can be stored in books, on computer hard drives or floppy disks or CD-ROMs. Information can be transferred from place to place via cables or by wireless transmission techniques - in fact you just did this when you accessed this lesson via the Internet, transferred it to your computer and then (perhaps) printed it. But there is nothing substantial about the information itself; you can’t touch it or measure its mass on a balance. The third point is important to consider because many texts talk about energy \textit{transformations} as if somehow it is the \textit{energy} that is changing rather than the physical system that gains or loses it. Consider the information metaphor again: even though we move information from place to place or store it in different ways, nothing about the information itself has changed.
Energy Storage and Transfer

At this point, let us consider another metaphor to describe energy storage and transfer – that of money. We store money in accounts at the bank or credit union. We can have checking accounts, various savings accounts, certificates of deposit, etc. These accounts store money. There is nothing different about the money in checking and savings accounts. This money can be transferred back and forth in the bank without changing the nature of the money or the total quantity of money that resides in the collection of accounts that is attached to your name; let’s call this the system for convenience.

The same is true of energy. It is stored in objects and in the arrangement of objects in a physical system. We use different “accounts” to help us keep track of energy as its transfer causes change in the objects or in their arrangement. As with money, nothing about the energy itself has changed. Let’s consider the accounts we will use in this course.

1. Thermal energy, \( E_{\text{th}} \) – is the energy stored by moving particles. The quantity of thermal energy stored by a collection of particles is related to both their mass and velocity. You instinctively recognize this as you would rather catch barehanded baseballs thrown by your instructor than ones thrown by a major league pitcher. Similarly, you wouldn’t be hurt if you were pelted by ping-pong balls, but would suffer if you were showered with golf balls.

2. Phase energy, \( E_{\text{ph}} \) – is the energy stored in the system due to the arrangement of particles that exert attractions on one another. Attractions result in a decrease in the energy of a system of particles. As particles become more tightly bound, their \( E_{\text{ph}} \) is lowered. Solids possess the lowest phase energy; liquids possess more, since the particles in a liquid are freer to move than those in a solid; and a gas possesses the greatest amount of \( E_{\text{ph}} \) since the particles in a gas have completely broken free from one another. \( E_{\text{ph}} \) is the energy account involved when phase changes occur.

3. Chemical energy, \( E_{\text{ch}} \) – is the energy due to attractions of atoms within molecules. These attractions are described as chemical bonds because they are directed between specific atoms in the molecule.

There are also three ways that energy is transferred between system and surroundings. While most texts refer to them as nouns (work, heat and radiation) we prefer to describe the ways as gerunds to emphasize that they are processes rather than real things apart from energy. They are working (\( W \)), heating (\( Q \)) and radiating (\( R \)). It is very important to recognize that such energy transfers affect both the system and the surroundings. Energy doesn’t mysteriously appear or get lost.

1. Working (usually referred to as work by the physicists although it is not something different from energy) is the way in which energy is transferred between macroscopic (large enough to be seen) objects that exert forces on one
It is OK to calculate how much “work” one object does on another so long as you do not think that work is something an object stores.

2. Heating (referred to as heat by the chemists) is the way in which energy is transferred by the collisions of countless microscopic objects. Energy is always transferred from the “hotter” object (one in which the particles have greater $E_{th}$) to a colder one (one in which the particles have lower $E_{th}$). If all the particles have the same mass, then the “hotter” ones are moving faster than the “colder” ones. It’s OK to say that you heat an object – just not that the object stores heat.

3. Radiating is the process in which energy is transferred by the absorption or emission of photons (particles of light). A light bulb filament can be heated to the point that it glows; this is the emission of photons that carry energy away from the filament. You can be warmed by light from the sun as the photons transfer energy to you.

The relationship between energy storage and transfer is given by the 1st Law of Thermodynamics, $\Delta E = W + Q + R$. This is shown by the system schema below:

It shows that energy transferring into and out of the system affects the nature of the energy storage in the system. The 1st Law of Thermodynamics and the Law of Conservation of Energy state that the algebraic sum of these energy changes and transfers must add up to zero, accounting for all changes relative to the system.

**Kinetic Molecular Theory (KMT)**

This is one of the really important theories in chemistry. It accounts for the behavior of substances during all sorts of physical change. There are three key points:

1. Matter is made of tiny particles that are in constant random motion.
2. These particles exert long-range attractions and short-range repulsions on one another. Attractions bring about a reduction in the energy state ($E_{ph}$) of the system; repulsions bring about an increase in the energy.
3. A hotter sample is one whose particles are moving (on average) faster than the particles in a colder sample.

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ii G. Swackhamer, p 7
A Coherent Approach to Energy
Adapted from Presentation at the Summer 2003
AAPT Meeting
Larry Dukewich

Current State of Energy Concept
- Energy is regarded as an abstract quantity, “invented” for doing calculations
- Treatment of energy is inconsistent from discipline to discipline
- Students cannot use energy to adequately describe or explain everyday phenomena
- Students are taught that energy comes in different forms

The Problem with Transforming Energy
- Focus on “changing one form of energy into another” implies that there are different “kinds” of energy
- “Forms of energy” location implies that somehow energy is changing - diverting attention from the changes in matter that we can describe
  - James Clerk Maxwell argued against “forms of energy” treatment, calling it the “old theory”
  1. American Association for the Advancement of Science, Project 2061 Benchmarks Online

Substance Metaphor
- Substance metaphor focuses attention on energy storage and transfer
  - “Energy is stored in different systems and in different ways in those systems, and it is transferred by some mechanism or other from one system to another”.
- Consider information
  - “It would be nonsense to say that hard disk information is transformed into wire information and then into RAM information and then into CD information”
- Use of substance metaphor can integrate the way physics and chemistry approach energy
  2. 3 – G Swackhamer, “Understanding Energy Insights”

Problems with Energy in Chemistry
- Heat regarded as an entity, rather than a mechanism for energy transfer
- Different variables used interchangeably
  - Q - what you can calculate
  - E - what you’d really like to discuss
  - ΔH - what you can discuss
  - Only in college texts is treatment of 1st law of Thermodynamics more thorough

Problems with Energy in Chemistry
- Tenuous connection between kinetic energy and potential energy - typical examples are from realm of physics
- Students try to apply energy conservation to heating or cooling curves
  - Kinetic energy changes with temperature
  - Potential energy changes on plateaus
  - Therefore, energy is shuttling back and forth between kinetic and potential
Problems with Energy in Chemistry

- Role of energy in bonding is muddled
  - Rearranging atoms in molecules results in energy change
  - But is it kinetic, potential or both?
- Students conclude that somehow bonds store energy
  - ATP → ADP releases energy because "high-energy phosphate bond" is broken
  - View is inconsistent with bond dissociation energy
  - This naive conception is difficult to dispute
    - Cooper-Krynicki article (2009), The Trouble with Chemical Energy
    - http://www.rci.rutgers.edu/groupns/articles/PMC2304106/

Approach Consistent with That Used in Physics

- Do brief coherent treatment of 1st Law of Thermodynamics - Modeling Instruction in HS Physics

- Focus on ways to represent energy storage and transfer

EBC’s to Track Energy During Change

Use of Energy Bar Charts leads to conceptual understanding

- Introduced by Alan van Heuvelen years ago in physics
- Used successfully by Modeling Instruction in Physics to account for energy storage and transfer

Two Categories of Potential Energy

- In physics, it is useful to subdivide potential energy into gravitational, elastic and electrical categories
- In chemistry, it is useful to consider two categories
  - Phase - due to van der Waals type attractions between particles (non-directional & non-specific)
  - Chemical - due to bonds within molecules (covalent) or within crystal lattices (ionic). Bonds are directional and involve specific particles.

Distinguish between attractions and chemical bonds

- Both involve electrostatic interactions
- Specificity and directionality of these interactions differ sufficiently that it is useful to treat them separately
- These interactions are associated with different kinds of change
  - Attraction - physical changes
  - Bonds - chemical changes

Attractions and Energy

- Attraction lower the potential energy of a system of particles by drawing them closer together, whether due to
  - gravitational forces between macroscopic bodies
  - electrostatic forces between microscopic particles
- It always requires energy to separate bound particles
Examine Physical Change

- What happens during phase change?
  - The substance doesn’t change - only the arrangement of the constituent particles
  - We are considering the attractions between molecules, not the attractions between atoms within the molecules
  - Use separate account - \( E_{\text{ph}} \), the energy due to interactions between particles in a given phase

Attractions Lower Energy of a System of Particles

- The more tightly bound the particles, the lower the energy of a system
  - Particles in the solid state adopt the most orderly, lowest energy configuration
  - Energy is required to break down this orderly array (melt the solid)
  - Energy is released when particles in a liquid crystallize into an orderly array (freeze).

How is the Energy Stored?

What are you getting for your energy dollar?

- What is the added energy doing if the temperature of the system is not increasing?
- It must be overcoming attractions between the particles
- The particles are less tightly bound in liquid phase
- Phase energy stored is related to \( \Delta H \), and mass of system

During evaporation

- Particles in the liquid require energy input in order to overcome attractions and become widely separated in the gas phase.
- Unless energy is supplied to the system, energy for this change must come from another account, \( E_{\text{th}} \)
- Particles in remaining liquid become cooler (lower \( E_{\text{th}} \))

Examine Energy in Chemical Change

- Standard chemical potential energy diagram (left) shows only part of the picture

Re-scale the Potential Energy Graph

- As we do in physics, we can represent energy wells (-) as energy bars (+) by moving zero position,
By tracking energy storage and transfer during change, students

- Have better understanding of role of energy in physical and chemical change
- Are less likely to think that energy is somehow "gained" or "lost" during change
- Can move beyond rote statements of the Law of Conservation of Energy
Energy Bar Graphs

How to represent the role of energy in physical change

Constructing an Energy Bar Graph

Consider this example
A cup of hot coffee cools as it sits on the table.

1. Determine what is in the system

- Everything else makes up the surroundings

Consider this example

Decide whether $E_{ch}$ is involved

- In this case, you start with coffee and end with coffee; particles are not rearranged to form new substances
- So, ignore $E_{ch}$ for now.

Assign values to $E_{ph}$

- Due to interactions between particles, the energy stored due to the arrangement of particles is ranked:
  - solids < liquids < gases
- We choose to represent these phases by using:
  - Solids = 1 bar
  - Liquids = 2 bars
  - Gases = 4 bars

Assign values to $E_{ph}$

- Use two $E_{ph}$ bars before and after

Choose bars for $E_{th}$ depending on temperature

- Use 4 bars for hot coffee and 2 bars for room temp coffee

- Other values might also work; try to be consistent in your representations
Now show energy transfer

- Final situation has 2 less bars of $E$ than initial; 2 bars had to leave the system

Now, consider phase change

- A tray of ice cubes (-8 °C) is placed on the counter and becomes water at room temperature
- What do we know about the situation?
  - The system is the tray of ice cubes.
  - The solid water turns to liquid water - no change in $E_{ch}$
  - The $E_{ph}$ increases (solid $\rightarrow$ liquid)
  - The $E_{th}$ increases (temp rises)

Initial & Final States

- Choice of bars for $E_{th}$ arbitrary, but consistent.
  - We generally use 2 bars for room temp and one bar for cold liquid

Account for Energy

- Energy must flow into system via heating
Unit 3 - Worksheet 1

For each of the situations described below, use an energy bar chart to represent the ways that energy is stored in the system and flows into or out of the system. Below each diagram describe how the arrangement and motion of the particles change from the initial to the final state.

1. A cup of hot coffee cools as it sits on the table.

   ![Energy Bar Chart for A cup of hot coffee cooling](chart1)

   Initial: 
   - $E_{th}$
   - $E_{ph}$
   - $E_{ch}$

   Energy Flow: None

   Final: 
   - $E_{th}$
   - $E_{ph}$
   - $E_{ch}$

2. A can of cold soda warms as it is left on the counter.

   ![Energy Bar Chart for A can of cold soda warming](chart2)

   Initial: 
   - $E_{th}$
   - $E_{ph}$
   - $E_{ch}$

   Energy Flow: None

   Final: 
   - $E_{th}$
   - $E_{ph}$
   - $E_{ch}$

3. A tray of water (20 °C) is placed in the freezer and turns into ice cubes (- 8 °C)

   ![Energy Bar Chart for A tray of water freezing](chart3)

   Initial: 
   - $E_{th}$
   - $E_{ph}$
   - $E_{ch}$

   Energy Flow: None

   Final: 
   - $E_{th}$
   - $E_{ph}$
   - $E_{ch}$
4. Where does the energy that leaves the system in #3 go? How does this energy transfer affect the room temperature in the kitchen? Do you have any experience that supports your answer?

5. One of the ice cubes described in #3 is placed in a glass of room temperature (25 °C) soft drink. Do separate bar charts for the ice cube and the soft drink.

![Energy Flow Diagram](image)

Describe how the arrangement and the motion of the particles in each system change from the initial to the final state.

6. The graph below left shows the cooling curve for a substance as it freezes.

![Temperature vs. Time Graph](image)

a. On the graph at right sketch the cooling curve for a larger sample of the same substance.

b. Label which phase (or phases) of the substance is present in each of the three portions of the cooling curve.

c. Describe the arrangement and motion of the particles during each portion of the graph.
Unit 3 - Worksheet 2

For each of the situations described below, use an energy bar chart to represent the ways that energy is stored in the system and flows into or out of the system. Below each diagram describe how the arrangement and motion of the molecules change from the initial to the final state.

1. Some of the water you spilled on your shirt evaporates.

2. Water vapor in the room condenses on a cold surface

3. A pan of water (25°C) is heated to boiling and some of the water is boiled away. Do separate energy bar charts for each stage of the process.

Multiple representations are possible. An alt is to show a decrease in $E_{th}$ with no outside input of energy.

Part 2 of this EBC considers only the water that vaporizes. One option below is to split the $E_{ph}$ bar.
4. During boiling, bubbles appear in the liquid water. In the boxes below represent the arrangement of molecules inside the liquid water and inside a bubble.

![Molecules of water](image1.png)

What is inside the bubble? Why do you think so?

*Molecules of water, widely separated, make up the bubbles in boiling water.*

5. Suppose the burner under the pan of boiling water is turned to a higher setting. How will this affect the temperature of the water in the pan? Explain.

*The water continues to boil at 100°C. It will vaporize more rapidly if more heat is supplied to it.*

6. The graph below left represents the heating curve for a liquid heated from room temperature to a temperature above its boiling point.

![Heating curves](image2.png)

a. Sketch the heating curve for a larger sample of the same liquid.

b. Label which phase (or phases) of the substance is present in each of the three portions of the heating curve.

c. Describe the arrangement and motion of the molecules during each portion of the graph.
Unit 3 Worksheet 3 – Quantitative Energy Problems

Energy constants (H₂O)

- 334 J/g  Heat of fusion (melting or freezing) H_f
- 2260 J/g  Heat of vaporization (evaporating or condensing) H_v
- 2.1 J/g°C  Heat capacity (c) of solid water
- 4.18 J/g°C  Heat capacity (c) of liquid water

For each of the problems sketch a warming or cooling curve to help you decide which equation(s) to use to solve the problem. Keep a reasonable number of sig figs in your answers.

1. A cup of coffee (140 g) cools from 75°C down to comfortable room temperature 20°C. How much energy does it release to the surroundings?

2. Suppose during volleyball practice, you lost 2.0 lbs of water due to sweating. If all of this water evaporated, how much energy did the water absorb from your body? Express your answer in kJ. 2.2 lbs = 1.0 kg

3. Suppose that during the Icy Hot lab that 65 kJ of energy were transferred to 450 g of water at 20°C. What would have been the final temperature of the water?
4. The heat capacity of solid iron is 0.447 J/g°C. If the same quantity of energy as in #3 were transferred to a 450 g chunk of iron at 20°C, what would be the final temperature?

5. Suppose a bag full of ice (450 g) at 0.0 °C sits on the counter and begins to melt to liquid water. How much energy must be absorbed by the ice if 2/3 of it melted?

6. A serving of Cheez-Its releases 130 kcal (1 kcal = 4.18 kJ) when digested by your body. If this same amount of energy were transferred to 2.5 kg of water at 27°C, what would the final temperature be?

7. If this same quantity of energy were transferred to 2.5 kg of water at its boiling pt, what fraction of the water would be vaporized?
Unit 3 Worksheet 4 – Quantitative Energy Problems

Part 2

Energy constants (H₂O)
- 334 J/g: Heat of fusion (melting or freezing) \( H_f \)
- 2260 J/g: Heat of vaporization (evaporating or condensing) \( H_v \)
- 2.1 J/g°C: Heat capacity (c) of solid water
- 4.18 J/g°C: Heat capacity (c) of liquid water

For each of the problems sketch a warming or cooling curve to help you decide which equation(s) to use to solve the problem. Keep a reasonable number of sig figs in your answers.

1. How much energy must be absorbed by a 150 g sample of ice at 0.0 °C that melts and then warms to 25.0°C?

   \[
   Q = m \cdot c \cdot \Delta T \text{ (°C)}
   \]

   \[
   Q = m \cdot H_f \text{ or } m \cdot H_v
   \]

   \[
   Q_1 = 150 \text{ g} \cdot 334 \text{ J/g} \\
   Q_1 = 50,100 \text{ J}
   \]

   \[
   Q_2 = 150 \text{ g} \cdot 4.18 \text{ J/g°C} \cdot 25 \text{ °C} \\
   Q_2 = 15,700 \text{ J}
   \]

   \[
   Q_{\text{total}} = Q_1 + Q_2 = 50,100 \text{ J} + 15,700 \text{ J} = 65,800 \text{ J} \rightarrow 66,000 \text{ J} \rightarrow 66 \text{ kJ}
   \]

2. Suppose in the Icy Hot lab that the burner transfers 325 kJ of energy to 450 g of liquid water at 20.°C. What mass of the water would be boiled away?

   \[
   Q_1 = m \cdot c \cdot \Delta T \\
   Q_1 = 450 \text{ g} \cdot 4.18 \text{ J/g°C} \cdot 80 \text{ °C} \\
   Q_1 = 150 \text{ kJ}
   \]

   \[
   Q_2 = Q_1 - Q_2 \\
   Q_2 = 325 \text{ kJ} - 150 \text{ kJ} \\
   Q_2 = 175 \text{ kJ}
   \]

   \[
   Q_2 = m \cdot H_v \\
   m = \frac{Q_2}{H_v} = \frac{175,000 \text{ J}}{2260 \text{ J/g}} = 77.4 \text{ g} \rightarrow 77 \text{ g}
   \]

3. A 12oz can of soft drink (assume \( m = 340 \text{ g} \)) at 25°C is placed in a freezer where the temperature is –12 °C. How much energy must be removed from the soft drink for it to reach this temperature?

   \[
   Q_1 = m \cdot c \cdot \Delta T \\
   Q_1 = 340 \text{ g} \cdot 4.18 \text{ J/g°C} \cdot 25 \text{ °C} \\
   Q_1 = 35,5300 \text{ J or } 35.5 \text{ kJ}
   \]

   \[
   Q_2 = m \cdot c \cdot \Delta T \\
   Q_2 = 340 \text{ g} \cdot 2.1 \text{ J/g°C} \cdot 12 \text{ °C} \\
   Q_2 = 8568 \text{ J or } 8.6 \text{ kJ}
   \]

   \[
   Q_{\text{total}} = Q_1 + Q_2 + Q_3 \\
   = 35.5 \text{ kJ} + 113.6 \text{ kJ} + 8.6 \text{ kJ} \\
   = 158.6 \text{ kJ or } 160 \text{ kJ}
   \]

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4. 65.0 kilojoules of energy are added to 150 g of ice at 0.0°C. What is the final temperature of the water?


diagram

\[ Q_1 = m \cdot c \cdot \Delta T \]
\[ Q_1 = 150 \cdot 334 \div 1 \]
\[ Q_1 = 50.1 \]
\[ Q_2 = 65.0 - 50.1 = 14.9 \]
\[ Q_2 = 14.900 \]

5. 250 kJ of energy are removed from a 4.00 x 10^2 g sample of water at 60°C. Will the sample of water completely freeze? Explain.


diagram

\[ Q_1 = m \cdot c \cdot \Delta T \]
\[ Q_1 = 400 \cdot 4.18 \div 60 \]
\[ Q_1 = 100 \]
\[ Q_2 = 250 - 100 = 150 \]
\[ Q_2 = 150,000 \]

maximum mass:

\[ Q_2 = m \cdot H_f \]
\[ m = \frac{Q_2}{H_f} = \frac{150,000}{334} = 449 \]

Our mass is less than the maximum mass 250kJ could freeze so we could freeze even more than the 400g sample.

6. An ice cube tray full of ice (235g) at –7.0°C is allowed to warm up to room temperature (22°C). How much energy must be absorbed by the contents of the tray in order for this to happen?


diagram

\[ Q_1 = m \cdot c \cdot \Delta T \]
\[ Q_1 = 235 \cdot 2.10 \div 7 \]
\[ Q_1 = 3.5 \]
\[ Q_2 = 235 \cdot 4.18 \div 22 \]
\[ Q_2 = 78.5 \]

7. If this same quantity of energy were removed from 40.0 g of water vapor at 100°C, what would be the final temperature of the water?


diagram

\[ Q_1 = m \cdot H_v \]
\[ Q_1 = 40.0 \cdot 2260 \div 1 \]
\[ Q_1 = 90.4 \]
\[ Q_2 = 104 - 90.4 = 13.6 \]
\[ Q_2 = 13,600 \]

\[ T_{final} = 100°C - 81.3°C = 18.7°C \]
For each of the reactions below, write the balanced chemical equation, including the energy term on the correct side of the equation. Then represent the energy storage and transfer using the bar graphs. Below the bar graph diagram for 1 and 2, sketch a standard chemical potential energy curve for the reaction.

1. When you heated sodium hydrogen carbonate, you decomposed it into sodium carbonate, water vapor, and gaseous carbon dioxide.

2. When solid zinc was added to hydrochloric acid, the products were hydrogen gas and an aqueous solution of zinc chloride. You could feel the test tube get hotter.
3. Isopropyl alcohol (C₃H₇OH) burns in air to produce carbon dioxide and water vapor.

4. In chemical cold packs, solid ammonium chloride dissolves in water forming aqueous ammonium and chloride ions. As a result of this solvation reaction, the pack feels cold on your injured ankle.

5. In chemical hot packs, solid sodium acetate crystallizes from a supersaturated solution of sodium acetate. The pack feels warm to the touch for 30 minutes or longer.
9. Representing Chemical Potential Energy – ws 4

We revisit the use of energy bar charts to account for energy storage and transfer; this time, during chemical change. The PowerPoint presentation included in this unit should help you with the class discussion. In chemical change, there are exchanges between the chemical potential energy \((E_{\text{ch}})\) and the thermal energy \((E_{\text{th}})\) of the system as the atoms in the molecules are rearranged. The treatment of energy in high school chemistry texts usually does not give an explicit mechanism for energy changes during a reaction. The question students might ask is, "How does the energy transferred by heating know whether it should go into the thermal or the chemical energy account?" The answer is, "Energy transferred by heating always goes into (or comes from) the thermal account. The system "decides" whether the energy stays in the thermal account or is transferred to the phase or chemical energy accounts. What factors affect at what point these internal exchanges occur is something we'll address in a later unit. For now, the key concept is that changes in the phase or chemical energy of the system (due to phase change or chemical change) also involve changes in the thermal energy of the system.

Consider the decomposition of sodium hydrogen carbonate. This reaction can be represented by

\[
\text{energy} + 2\text{NaHCO}_3 \rightarrow \text{Na}_2\text{CO}_3 + \text{CO}_2 + \text{H}_2\text{O}. 
\]

Here, the product molecules store more \(E_{\text{ch}}\) than do the reactants; energy had to be supplied continuously in order for the reaction to occur. We can represent this process with an energy bar chart shown below.

This representation has essentially the same features as the standard representation found in texts (at right), though it has the advantage of showing the transfer of energy from surroundings to the system.

The problem with the standard representation is that it provides no mechanism to account for how the energy supplied to the system causes the rearrangement of the atoms to form the products. We suggest that the process is more clearly understood if thermal energy is re-connected to chemical potential energy. How does the rearrangement of atoms take place? It occurs through the collisions of particles. The energy required to move to a state of higher...
chemical potential energy must come from the thermal energy of the particles involved in the reaction. An increase in $E_{ch}$ must be accompanied by a decrease in $E_{th}$. However, slower, low-energy collisions are not effective in producing rearrangement of atoms, so we must increase their $E_{th}$ by heating the system. This process can be represented in a 2-step energy bar chart shown below.

The collisions of hotter, high-energy gas molecules in the Bunsen burner flame with the walls of the test tube transfer energy to the NaHCO$_3$ inside, increasing the $E_{th}$ of the reactant. The vibration of the ions in the crystal lattice becomes sufficiently energetic to produce the rearrangement of atoms that result in the formation of the products. The $E_{th}$ of the system decreases for each NaHCO$_3$ unit that decomposes, so energy must be continually supplied to keep the $E_{th}$ of the reactant sufficiently high to allow the reaction to proceed. Of course, the energy transfers occur so rapidly that we do not observe cooling and re-heating; however, at the atomic level, this must be occurring. Otherwise, once the NaHCO$_3$ reached a sufficiently high temperature, the entire sample would decompose at once. Suggest to the students that the process represented by the 2-step bar chart occurs repeatedly until you stop supplying energy or all the NaHCO$_3$ has decomposed.

Now consider an exothermic reaction: the combustion of methane. The balanced chemical equation, including the energy term is: $\text{CH}_4 + 2 \text{O}_2 \rightarrow \text{CO}_2 + 2 \text{H}_2\text{O} + \text{energy}$. The arrangement of the atoms in the products stores less chemical potential energy ($E_{ch}$) than does the arrangement of atoms in the reactants. Students may find this counter-intuitive at first. If so, ask them which variable in the equation $y = x + 3$ is larger. They should see that the molecules on the product side have lower $E_{ch}$ than the molecules on the reactant side, since excess energy is available. If the $E_{ch}$ of the system decreases, the energy must be transferred to another storage mechanism in the system of particles – the motion of the particles. Therefore, the $E_{th}$ of the system must increase. As a result, the temperature of the system becomes hotter than that of the surroundings. If interaction with surrounding molecules can take place, energy will flow to the surroundings (by heating, $Q$). We call such a reaction exothermic. This can be represented in the 2-step energy bar chart shown below.
The final state here represents the system after it has reached thermal equilibrium with its surroundings. We are ignoring, for now, the energy required to initiate a reaction. This is a sticking point for many as they attempt to understand the role of energy in chemical reactions. Many students erroneously conclude that since some energy is required to initiate the reaction, the overall process is endothermic. Draw from examples using gravitational potential energy and kinetic energy to help them past this obstacle. Consider a boulder precariously perched at the top of a cliff (earth-boulder system has high gravitational energy, $E_g$). Once dislodged, the boulder falls to the earth, and the system trades $E_g$ for kinetic energy, $E_k$; the speed of the boulder increases as the boulder approaches the earth. The resulting increase in $E_k$ is substantially greater than the energy required to nudge the boulder over the edge. Inform the students that we will do a more thorough treatment of “activation energy” later in the course.

Recall from our discussion in unit 3, that when the discussion centers on phase changes, the changes in the arrangement occur between molecules. While most call this potential energy as well, we promote the use of $E_{ph}$ (phase energy) to help students distinguish this category of potential energy from chemical potential energy. For the purpose of keeping the treatment from getting overly complicated, we will ignore change in $E_{ph}$ at this stage.

Now, consider the case of the chemical cold-pack used to treat sports injuries. The reaction between the ammonium chloride and water lowers the $E_{th}$ (and temperature) of the ions and those water molecules involved in hydration. The system cools, so energy from the surroundings flows into the system. Of course, paying attention to the temperature change sparks some interesting discussion items (cold does not flow from the bag to an athlete’s sprained ankle) and helps to resolve confusion about a reaction being endothermic while the system gets colder. Students hearing an instructor say that the system absorbs energy from the surroundings while feeling the bag getting colder frequently ask, "How can the system get colder if it's absorbing energy from the surroundings?" The answer, of course, is that the system is transferring energy from $E_{th}$ to $E_{ch}$ to produce an arrangement of particles that stores more energy. This is happening faster than energy can be transferred from the $E_{th}$ of the surrounding molecules to the system molecules. Consider the energy bar diagram below.
As a result of the hydration process, the system cools down; *this* is why energy flows into the system from the surroundings. The energy flow (heating) occurs as the system and surroundings re-establish thermal equilibrium (notice the $E_{th}$ returns to its original level in the final graph).

Of course, these exchanges and transfers are simultaneous, but we think it's easier for students to sort things out if they pretend that they occur in separate steps. This treatment accounts for what students can experience and provides a *reason* for the flow of energy between system and surroundings. It also nicely sets up the role of temperature in reaction kinetics later in the course. It is important to emphasize that the energy term in a balanced chemical equation refers only to the chemical potential energy; the thermal energy depends on the temperature of the system.

The bar graph diagram has been extended so as to be able to consider transfers *between accounts* and transfers *between system and surroundings* in separate steps. You will need to link this more robust representational tool to the standard chemical potential energy graph found in most texts so that students can see the parallel structure. Whiteboard discussion should help the students tie energy to the changes that occur in the system and surroundings.
Law
Patent attorneys must have a background in a technical field like physics. Physics majors also earn the highest Law School Admission Test (LSAT) scores and med school admission rates than almost any other major—including biology and pre-med!

“ My physics training helped me stand out when I was applying for my current job.”
—Alison Binkowski, Health Policy Analyst, Government Accountability Office

Engineering
Any type of engineer needs physics coursework. In fact, physics majors often get jobs as engineers.

Medicine and Health
Medical physics offers high-paying and rewarding jobs. Students planning to go to medical school will also need at least a year of physics, and physics majors get higher Medical College Admission Test (MCAT) scores and med school admission rates than almost any other major—including biology and pre-med!

Business
Physics provides an excellent background for starting a company, especially in high-tech fields.

Finance
The mathematical and problem-solving abilities provided by a physics education are highly valued by investment banks and other financial institutions.

Education
Teaching at the high school or college level are excellent careers. High school physics teachers are in high demand around the country.

Writing
Many who study physics go on to write articles and books for general or technical audiences. Aspiring science fiction writers will need a background in physics.

Technical Careers
Forensic scientists, electricians, auto mechanics, machinists, physical therapists, and sound engineers all need knowledge of physics.

For More Information and Statistics
Information on physics careers
www.CareersInPhysics.org

Reasons to study physics
www.aps.org/programs/education/whystudy.cfm

Slide show with physics career information
www.aps.org/careers/insight

Careers that Involve Physics:

This brochure is produced by the American Physical Society, the American Association of Physics Teachers, and the Society of Physics Students.

Revised 3/18/2011
**MYTH NO. 1**

Physics will lower students’ GPAs and hurt their chances of getting into college.

**FACT:** Colleges want to see that students have taken a challenging curriculum, and a B in physics is often better than an A in a less challenging course.

“College admission is never just about the GPA. A transcript with physics is better than one without it.”
– Vikki Otero, Senior Assistant Director, University of Colorado Admissions Office

**MYTH NO. 2**

Students won’t miss out on future opportunities or experiences if they don’t take physics.

**FACT:** Physics answers questions about the world that no other field can. In addition, not taking physics closes doors to a huge number of potential careers.

**MYTH NO. 3**

Only the most mathematically advanced students can handle physics.

**FACT:** Physics can be taught at a variety of levels for students with different mathematical backgrounds.

**All students should have the chance to spark their curiosity with physics.**

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**MYTH NO. 4**

Physics is for boys.

**FACT:** Over 600,000 girls take high school physics each year, nearly half of the nation’s enrollment.

**MYTH NO. 5**

Students don’t need to take physics in high school because they can just take it in college.

**FACT:** Research shows that students who have taken high school physics do better in college physics courses, which are required for a large number of degree paths.

**MYTH NO. 6**

Physics knowledge has little relevance to the world we live in or to most jobs.

**FACT:** Physics is fundamental to every other science and to most major technological innovations of the past century. Moreover, physics teaches critical thinking and problem-solving skills that are useful no matter what a student goes on to do.

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**MYTH NO. 7**

The only careers you can have with a physics degree are to be a professor or teach high school.

**FACT:** Physics opens doors to a wide variety of excellent careers. Physics majors have high employment rates and are among the best paid of all college graduates.

**Typical Salary Offers by Campus Recruiters**

<table>
<thead>
<tr>
<th>Bachelor’s Field</th>
<th>Starting Salary in Thousands</th>
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<tbody>
<tr>
<td>Computer Science</td>
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<tr>
<td>Electrical Engineering</td>
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<td>Physics</td>
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<td>Chemistry</td>
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<tr>
<td>Biology / Lifescience</td>
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Typical salaries are the middle 50%, i.e. between the 25th and 75th percentiles.
Sources: American Institute of Physics; National Association of Colleges and Employers