Chemistry – Unit 3
Energy and Kinetic Molecular Theory

In the 18th and 19th 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 *like* a substance.".[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."[ii]

Even though we recognize that energy is not a *physical* substance, we choose to use the substance *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 *transformations* as if somehow it is the *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_{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_{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_{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_{ph} since the particles in a gas have completely broken free from one another. E_{ph} is the energy account involved when phase changes occur.

3. Chemical energy, E_{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.

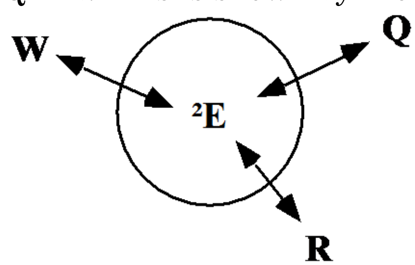
1. Working (usually referred to as work by the physicists although it is not something different from energy) is the way in which energy is transferred between macroscopic (large enough to be seen) objects that exert forces on one

another. 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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[i] G. Swackhamer, *Cognitive Resources for Understanding Energy*, 2003, p 6
[ii] G. Swackhamer, p 7