Chemistry—Unit 3
Energy and Heating/Cooling

Energy is a substance-like quantity that is always involved whenever a system undergoes change (hotter-colder, faster-slower, higher-lower).

A key to understanding energy is to recognize that energy is always and everywhere only energy. Energy is stored in a system in several different "accounts" and can be transferred between system and surroundings in different ways, but it *does not come in different forms*. When there is a change in the way the system stores energy or if energy is transferred between system and surroundings, something about the *system* changes, but the energy remains the same.

One difficulty we have in understanding energy is that our everyday use of words can sometimes muddy the waters. For example, use of the word "heat" can leave the impression that it is somehow different from energy. It would be better if we viewed "heat" as one of the ways that energy is transferred from one object to another. While it is helpful to say that we "heat" an object (as a shortcut for "transfer energy to"), it is not useful to say that an object stores "heat". It's fine to describe an object that stores a lot of thermal energy as "hot", but saying that it stores a lot of "heat" confuses energy with a way that it is moved from one object to another.

Heating a system increases its thermal energy (E_{th}) through the collisions of more energetic particles with particles of lower energy; as a result, the particles in the system move more rapidly than before. Use of the –ing ending helps us view "heating" as a *process* of energy transfer through collisions of particles rather than as something different from energy. The *quantity of energy* transferred in this way is often referred to as "heat" (assigned the variable name Q), but it is important to remember that it is simply energy. Conversely, a system cools when its particles transfer thermal energy (through collisions) to particles in the surroundings. This process lowers the amount of thermal energy (E_{th}) stored by the system.

Temperature is a useful tool because it allows us to assign a numerical value that helps us describe the thermal energy of a system (or surroundings). It is important to recognize that temperature and energy are not the same. *Changes* in temperature (ΔT) help us to determine the amount of thermal energy gained or lost by a system, as we shall discuss at a later time.

We're now ready to discuss the role of energy during phase change. We'll first examine what happens when a solid melts. As energy is transferred into the system, the thermal energy (and motion) of the particles increases. At some temperature, the particles are vibrating to and fro so rapidly that they can no longer maintain the orderly arrangement of a solid. They break free of the attractions and begin to move around more freely – they become "liquid". We use another account to describe the way the system stores energy when the particles exist as a liquid rather than as a solid; we call this phase energy, E_{ph}. Particles in the liquid phase store more phase energy than do particles in the solid phase.

As you recall from the experiment, during the melting of the solid, the temperature remained more or less constant, despite the fact that energy was being continually transferred to the system. To explain this, consider the fact that energy is required to

overcome the attractions that bind the particles in an orderly array. Apparently, at the melting point, energy entering the system can no longer be stored in the motion of particles *in the solid phase* - the particles are moving too rapidly to remain as solid. Instead, the particles trade thermal energy for phase energy as they break free from their neighbors and are able to move around more freely.
This decrease in thermal energy is temporary, however, as energy is still being supplied via collisions to the particles in the system.

A closer examination of the plateau region of the heating curve would reveal tiny zigzags in the temperature, like the teeth of a hacksaw blade. Energy enters the thermal account (raising the temperature) and then is immediately transferred to the phase account (lowering the temperature) as the particles break free from their mutual attractions. This internal energy transfer keeps the temperature more or less constant during the phase change. This process of energy shuttling between accounts continues until the solid is completely melted.

It may be helpful to consider an analogy for this process. Let's substitute money for energy and substitute a checking account for the thermal energy account and a savings account for the phase energy account. Let's also say that the checking account is set up to have a maximum balance of $1000. So long as the checking balance is lower than this amount, money can be deposited into this account. Once the balance reaches $1000, however, any money entering the checking account is quickly transferred to the savings account. If $50 is deposited into the checking account, the balance becomes too high so the excess is transferred to savings. This transfer increases the amount in the savings account by $50 and the checking account balance returns to $1000.

Once all the particles in the system are in the liquid phase, energy transfers to the system are once again stored in the thermal account and the temperature increases. This process continues until the temperature reaches the boiling point. At this temperature, the particles are moving too rapidly to remain in the liquid phase. Thermal energy is again exchanged for phase energy as the particles break free from one another and enter the gas phase.

Now, let's examine a situation where energy is transferred *out* of a system during a phase change. An example of such a situation is the condensation of water vapor. In order for a collection of gaseous water particles to condense (become bound to one another in the liquid phase) they must transfer phase energy to the thermal account. The particles of liquid water are now hotter than they once were. When these higher temperature particles in the liquid phase come into contact with lower temperature particles in the surroundings, a transfer of thermal energy from system to surroundings via heating occurs. The system cools and the immediate surroundings get warmer.

The bottom line is that any time energy enters or leaves a system via heating (collisions of particles), the motion of the particles changes first. This means that energy entering or leaving a system does so via the thermal energy account. When the temperature of a single phase changes, the only account that changes is the thermal energy. During a phase change, the thermal account experiences small but temporary changes as it serves as the conduit for energy moving from the phase account to the surroundings (during freezing or condensing) or from the surroundings to the phase account (during melting or vaporization).