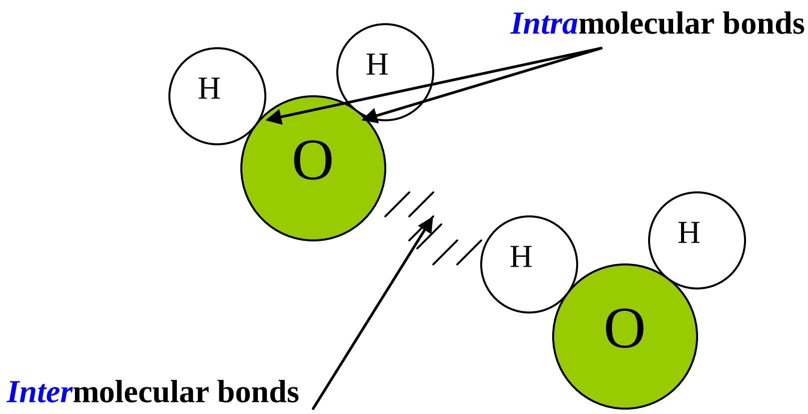
Endothermic Versus Exothermic Reactions

To understand the difference between these two types of reactions, we need to explore a couple of other concepts.

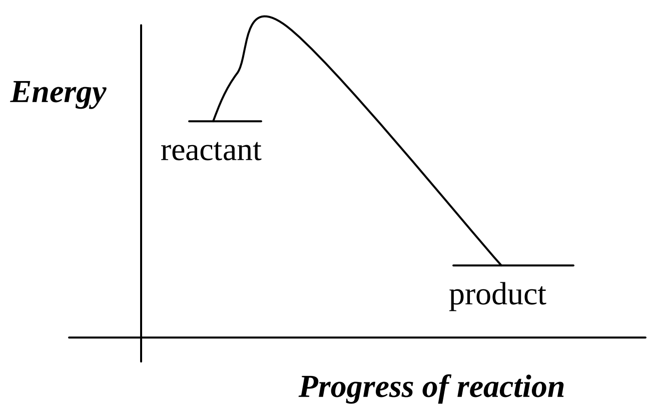
In addition to kinetic energy (vibrational, rotational and translational motion), molecules also have potential energy. Potential energy is energy due to position and composition. It is stored in molecular bonds that exist within molecules (intramolecular) and also between different molecules (intermolecular). In water for example, there is energy stored in the bonds between oxygen and the two hydrogen atoms in each molecule, and also between the oxygen atom of one molecule and one of the hydrogen atoms of another molecule.



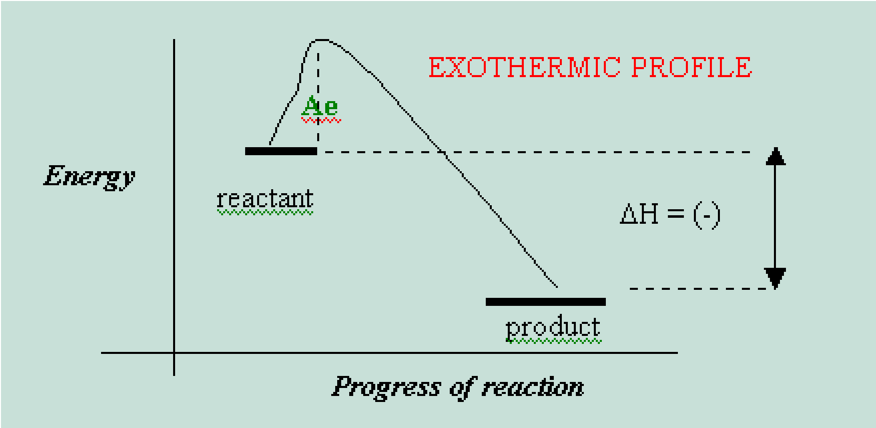
The sum of all kinetic and potential energies of a substance is known as **enthalpy** (H). If in a reaction molecule A becomes molecules B and C, and if molecule A has more energy that both B and C combined, then the excess energy will be released into the environment. The environment becomes hotter; we have an exothermic reaction:

A	→	B + C + energy
Reactant		products

On a graph exothermic reactions are represented as follows:



If we examine the graph more closely, we will notice that exothermic reactions have a *negative change in enthalpy*. A change in enthalpy, ΔH, is defined as the enthalpy of products – heat of reactants:



$\Delta H = H_p - H_r$

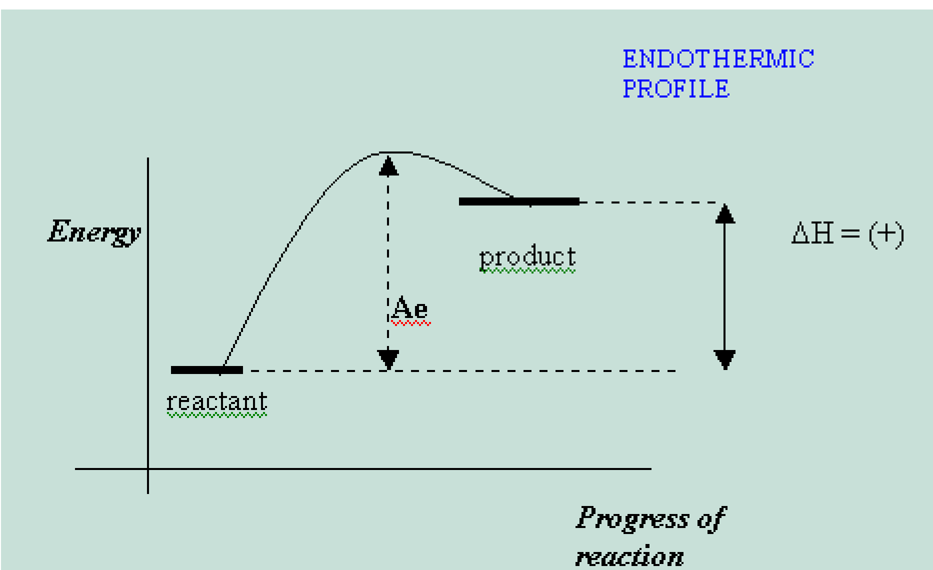
What is that little hill labeled, Ae? Ae = activation energy. This is the energy that reactants must absorb in order to form products, even if the products will not need the energy to store within their bonds. So Ae = $H_{maximum} - H_{reactants}$

Examples of exothermic reactions:

- Digestion of food releases energy
- All combustion reactions (fires)
  $C + O_2 \rightarrow CO_2$ + energy
- Adding an alkali metal to water
  $2\ Na + 2\ H_2O \rightarrow 2\ NaOH + H_2$ + energy
- Condensation of water
- Explosion of bombs

Endothermic Reactions

If substance **A** must take energy away from the environment in order to form product D, then the reaction is said to be endothermic, and the victimized environment will feel *colder* after the reaction.
$\Delta H = (+)$ for endothermic reactions and their profile looks like the following:



Examples of endothermic reactions:

- Melting of ice absorbs energy
- Dissolving ammonium nitrate in water(the essence of commercial cold packs)

  $NH_4\,NO_{3(s)}$ + energy$\rightarrow NH_4\,NO_{3(aq)}$

- $N_2 + O_2$ + energy$\rightarrow NO$

Endothermic vs Exothermic Reactions

All chemical reactions involve bond breaking and bond making.

Bond breaking is endothermic (energy is absorbed from surroundings)

Bond making is exothermic (energy is released into surroundings)

Imagine stretching a rubber band until it breaks. You must do work to stretch the band because the tension in the band opposes your efforts. You lose energy; the band gains it. Something similar happens when bonds break in a chemical reaction. The energy required to break the bonds is absorbed from the surroundings.

Energy is absorbed or released when the heat capacities of the products and reactants differ. Usually this is small. *The heat capacity of an object is best thought of with a penny – a penny has a certain amount of heat capacity due to its size and nature and specific heat best thought of as copper metal which has a specific heat capacity due to its chemical nature. How much energy it takes to change the temperature of a penny by 1 ^{o}C (heat capacity) is different that the amount of energy needed to raise a gram of Cu up 1 ^{o}C (specific heat capacity).*

Neutralization reactions (acid + base = salt + water) are usually exothermic but when you add baking soda to vinegar, or HCl it is slightly endothermic. The neutralization reaction actually does release heat:

Energy absorbed by products leaving $+HC_2H_3O_2 + NaHCO_3 \rightarrow CO_2 + NaC_2H_3O_2\,(aq) + H_2O$ *+ Energy released due to bond formation*

Bond breaking is endothermic (energy is absorbed from surroundings) Bond making is exothermic (energy is released into surroundings)

$CO_2 + NaC_2H_3O_2\,(aq) + H_2O$ all formed new bonds hence exothermic but the energetic release of CO_2 and the evaporation of some H_2O causes a net loss of average kinetic energy from the remaining liquid. Thus although the reaction should be exothermic due to the chemical change and bond formation, it is slightly endothermic due to the loss of KE caused by the physical state change of the water to vapor and the energetic evolution of the carbon dioxide and vapor from the solution. When the High KE particles leave it lowers the average KE of the liquid (Weidkamp)

This is because there is net bond formation. The products collectively have lower energy than the reactants. But evaporation of the liquid occurs as the carbon dioxide escapes from solution. Evaporation absorbs heat, cooling the liquid. (The expansion of the carbon dioxide gas bubbles as they are released also helps to cool the surroundings by Joule-Thomson cooling). The net result is an endothermic reaction.

Mixing a strong acid with water is exothermic. Breaking a chemical bond requires energy (remember that stretching a spring until it breaks requires energy). Forming a chemical bond will release energy. So in a reaction that releases heat (exothermic) there must be net bond formation. Lets looks at HCl dissolved in water:

$HCl \rightarrow H^{+}\,(aq) + Cl^{1-}\,(aq)$

You would think at first this would be a heat absorbing (endothermic) process, because it looks like the bond between H and Cl is broken. But there is another reaction hiding here. The hydrogen ion reacts with water to form a complex of the form: $H_3O\bullet(H_2O)^+_n$ where n is a number between 1 and 9. It is much easier just to write $H^+(aq)$. Because the hydrogen ion is so tiny, a large amount of charge is concentrated in a very small area, and the polar water molecules are strongly attracted to it. This "hydration" of the hydrogen ion involves the formation of a covalent bond to one of the waters and a large number of strong hydrogen bonds, so it's a strongly exothermic process. This causes the mixing of a strong acid with water to be strongly exothermic overall.

What would happen if you add table salt to ice?

The intramolecular ionic bonds between Na and Cl and the intermolecular bonds between water molecules would break (Endothermic) as the water forms new bonds solvating the sodium and choride ions (Exothermic). The ice melts when the released exothermic energy is absorbed breaking the bonds between water molecules and the ions.

What would happen if you add table salt to distilled or pure water? The ionic bonds of between Na and Cl would break (Endothermic) and water would form bonds with the ions as they become solvated, (Exothermic). The colder temperature of the salt water indicates this net energy change is Endothermic.

Exothermic processes (Energy released)	**Endothermic processes (Energy Absorbed)**
making ice cubes	melting ice cubes
formation of snow in clouds	conversion of frost to water vapor
condensation of rain from water vapor	evaporation of water
a candle flame	forming a cation from an atom in the gas phase
mixing sodium sulfite and bleach	baking bread
rusting iron	cooking an egg
burning sugar	producing sugar by photosynthesis
forming ion pairs	separating ion pairs
combining atoms to make a gas molecule	splitting a gas molecule apart
mixing strong acids and water	mixing water and ammonium nitrate
nuclear fission	melting solid salts