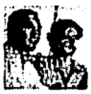
Ending Misconceptions About the Energy of Chemical Bonds



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The Key Misunderstanding

Students are often confused about issues relating to chemical bond energy, thinking that **chemical bonds store energy that is used to make them.**

This response can be seen when bond formation or breaking is discussed and when bond energies or reaction energies are being calculated using Hess's law or reaction energy equations based on summation of heats of formation of products and reactants. This results in incorrect signs being applied in calculations and the loss of points in both essay and computational questions on the AP Chemistry Examination. In the future, more conceptual and applied questions on the AP Examination may require students to have a more complete understanding of chemical bond energy.

Why does the misconception exist? This appears to be related to earlier instruction, perhaps in biology classes, where molecules, such as carbohydrates, are described as a "source of energy," and ATP (adenosine triphosphate) "has strong bonds that store needed energy." While this is not strictly incorrect, it gives rise to misleading concepts. The complete picture is insufficiently emphasized and overlooked by many students.

What is the correct picture? Stable chemical bonds release energy as they form, and bond formation thermodynamically happens spontaneously. However, formation reactions often do require energy of activation to rearrange bonds and get reactions over activation barriers (which usually involves **breaking** bonds first before forming new ones). Stable bond formation is always exoergic.

Why do chemical bonds appear to "store" energy? They certainly "contain" energy, but energy must be added to get any energy out. Where can the energy for breaking bonds come from -- **only when stronger** bonds are formed instead? This is the true driving energy for biochemistry, where cellular respiration provides energy by **forming** the strong oxygen bonds in carbon dioxide and water, **breaking** the weaker bonds in carbohydrates and sugars. In photosynthesis, energy from the sun is used to break the CO_2 and H_2O bonds (overall), and the fairly strong O_2 bond is formed as well. The larger the difference between the bond energies of the formed products (CO_2 and H_2O) and the reactants, the more energy is available. So, in fact, more energy is "available" when the **weakest** bonds are broken in favor of the stronger bonds being formed. ATP provides energy when it transfers phosphate moieties to **more strongly** bonded glucose or fructose phosphates.

Instructional Recommendations

Standard textbooks will contain adequate explanations of the correct picture. Rarely do they emphasize the need to address the confusion of students who have accepted an incorrect view.

Back-and-forth dialogue between the student and teacher (almost more than demonstrations, which can easily be misconstrued) is essential. As in other content areas, the answer is to start at a microscopic level and build to a result, using a fully logical approach. A suggestion is to lead a discussion somewhat as follows:

1. We exist! (Setting aside the view of a minority of philosophers who claim we only think we exist.) We are made of atoms. Conclusion: some force called a chemical bond must successfully hold atoms together.
2. It takes energy to pull us (and therefore chemical bonds) apart. Burns or sports injuries testify that this can happen. However, normally we just "stay together."
3. The obvious force/energy holding atoms together is electrical attraction between opposite charges. A balloon sticking to the wall is just one example of attractive electrical force.
4. Once we have the atomic model with both positive and negative charges in a single atom, we can see that when two atoms are brought together, something must pull them together. Taking H_2 as the simplest model, since it is a known stable gas, the only explanation is that the positive nucleus on one atom attracts not only its own electron but also the electron (to a lesser extent) on the other atom. And vice versa for the other nucleus. Eureka -- this is what holds the world together.

5. Furthermore, since this attraction is demonstrably holding things together, energy must be released by bringing one H atom up to the other from an infinite distance.
6. But, the critic says, if all this is so "attractive," why doesn't it collapse into a black hole? Ah-ha! Fortuitously there are repulsive forces at work that also become larger as the pieces (electrons or protons) get closer together. (Even modern quantum theory with electron waves has to accept this.) So...
7. An equilibrium finally exists where attraction and repulsion balance at a certain distance called the **bond length.** The full picture has the bond in oscillation about the equilibrium point, resulting in observable quantized absorption of electromagnetic radiation.
8. But we haven't yet addressed the issue of hydrogen storing energy. Isn't it currently being promoted as a fuel for cars? And a new "hydrogen economy" is a political as well as scientific issue. Is it that hydrogen stores especially large amounts of energy in its bonds? Not really! The energy that makes hydrogen an attractive fuel comes from formation of water molecules from the reaction of hydrogen with oxygen to form water. This is 242 kJ/mol and is the source of the "hydrogen fuel energy." Carbon-containing fuels release more energy -- 393 kJ/mol of CO_2 formed -- the reason why fossil fuels have been the preferred energy source.

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See also...

- Ending Misconceptions About Inter- and Intramolecular Forces
- Misconceptions and Issues in Quantum Theory
- AP Chemistry Course Home Page
- Teachers' Resources