# The Origin of Energy



## Exothermic Chemical Reactions

Heat is produced in the chemical reaction in which hydrogen and oxygen are combined into water; i.e. the combustion of hydrogen. Such chemical reactions in which heat is produced are called exothermic reactions. The chemical equation for this reaction for one mol of hydrogen is written,

$H_2$+1/2 $O_2$=$H_2O$+286 kJ (1)

That means, when one mol of hydrogen burns in oxygen (or air), 286 kJ of heat is produced.
Another example is,

C+$O_2$=$CO_2$+394 kJ (2)

where one mol of carbon is combusted into carbon dioxide under the production of 394 kJ of heat.

The heat productions of the above chemical equations, (1) and (2), represents one mol of hydrogen and carbon, respectively. In order to compare these chemical reactions with nuclear reactions, it is convenient to recalculate the heat production for one molecule or one atom. For this, let us divide the heat production by the Avogadro constant

$N_A=6.02\times10^{23}mol^{-1}$

The results are

$H_2$+1/2 $O_2$=$H_2O$+3.0 eV (3)

C+$O_2$=$CO_2$+4.1 eV (4)

Equation (3) means that the process in which one hydrogen molecule (two hydrogen atoms) and one half oxygen molecule combine into one water molecule generates 3.0 eV energy in the form of heat (i.e. 1.5 eV per hydrogen atom). And Eq. (4) says that, when a carbon atom combines with an oxygen molecule and become a carbon dioxide molecule, 4.1 eV energy is released.
The use eV is because it is the most common unit of energy used in the atomic and nuclear world. It is the work done on an electron that is accelerated through a potential difference of one volt. Its value is

1 eV = 1.6 x $10^{-19}$ J

Moreover, the units of energy, keV and MeV, are often used in the nuclear world; the former is 1,000 times eV and the latter 1,000,000 times eV.
When it comes to arbitrary carbohydrate based fuels, the energy production will be of the order of 4 eV x #(carbon atoms) +1.5eV x #(hydrogen atoms) per molecule combusted in oxygen.

## Exothermic Nuclear Reactions

Nuclei show various types of reactions: For example, one nuclide splits into two or more fragments. This type of reaction is called nuclear fission. Contrarily, two nuclides sometimes combine with each other to form a new nuclide. This type of reaction is called nuclear fusion. There are many other types of reaction processes; they are generally simply called nuclear reactions and contain everything from gamma emission to alpha decays.
Among these various types of nuclear reactions, there are some types of exothermic reactions which are sometimes called "exoergic" reactions in nuclear physics.
The nucleus of deuterium atom is called deuteron which consists of a proton and a neutron. It is represented by a symbol "d". The nuclear reaction in which two deuterons bind with each other is an example of nuclear fusion. This exoergic reaction is written has 3 forms,

d+d->$^{3}_{2}$He+n+3.27 MeV (5)
d+d->$^{3}_{1}$T+p+4.03 MeV
d+d->$^{4}_{2}$He+24 MeV

If a neutron is absorbed in the uranium-235 nucleus ($^{235}_{92}$U), it would split into two fragments of almost equal masses and produce some number of neutrons and energy Q. One of the equations for the processes is

$^{235}_{92}$U+n->$^{137}_{56}$Ba + $^{97}_{36}$Kr + 2n + Q (6)

This is an example of nuclear fission.
The amount of energy released in this process is about 200 MeV which will be explained in more detail in next section.

## The Origin of the Nuclear Energy

Let us take up the d-d fusion reaction shown by the above Eq. (5) as an example. Since the experimental value of the binding energy of deuteron is 2.2246 MeV, the sum of the binding energies of the two deuterons before the reaction (on the left-hand side of Eq.(5)) is 4.449 MeV. On the other hand, the experimental value of the binding energy of ($^{3}_{2}$He) is 7.719 MeV. Therefore, the total binding energy after the reaction (on the right-hand side of Eq. (5)) is 3.27 MeV (= 7.719 – 4.449) larger than the binding energy before the reaction (on the left-hand side of Eq. (5)). Thereby the total mass decreases after the reaction and the mass defect corresponding to the above increase of the binding energy occurs. This mass defect is released as heat (or energy) in this exothermic (or exoergic) process.
Looking at the fission of uranium-235 ($^{235}_{92}$U) shown by Eq. (6), the binding energy per nucleon in nuclei around A = 240 is about 7.5 MeV. On the other hand, that in nuclei around A = 120 is about 8.5 MeV. Accordingly, if a uranium nucleus splits into two fragments with almost equal masses, the binding energy per nucleon would increase by about 1 MeV and the total mass of the fission fragments would decrease by the corresponding amount. This loss of mass (or mass defect) is converted into the heat (or energy) product Q. Since an energy of about 1 MeV per nucleon is released, the total energy Q would be more than 200 MeV.
According to the above discussions, it becomes clear that the origin of nuclear energy is the change of nuclear masses, and it is based on the principle of Einstein's Mass-Energy Equivalence.
If the total binding energy after the reaction is larger than before, the total sum of the masses of the reaction products becomes smaller than that before the reaction. This decrease in mass is converted into an energy, so that the process would be an exothermic (exoergic) reaction.

## The Origin of the Heat in Exothermic Chemical Reaction, Law of Energy Conservation

If hydrogen and carbon burn in oxygen gas, heat or energy is produced but what is the origin of this heat or energy?
The principle of the heat production in a chemical reaction is just the same as that in the nuclear reaction.
The hydrogen molecule is a bound system of two hydrogen atoms. The mass of a hydrogen molecule is slightly smaller than the sum of the masses of two hydrogen atoms. Converting this difference (= mass defect) into an energy with Einstein's Mass-Energy Equivalence, we have the binding energy of the hydrogen molecule.
In the process of combustion of hydrogen represented by Eq. (3), the total mass after the reaction is slightly smaller than before, and this decrease in mass is transformed into heat in the exothermic reaction.
Strictly speaking, conservation of mass does not hold in a chemical reaction, though, both in chemical and nuclear reactions, the energy of the total system with converting mass into energy is conserved before and after the reaction.

## Huge Amount of Nuclear Energy

Comparing Eq. (3) with (5), and Eq. (4) with (6), we can easily understand that the nuclear reactions yield a huge amount of energy in comparison with ordinary combustion processes.
As explained above, the energy produced from an exothermic chemical reaction like combustion of hydrogen or carbon is about 3 or 4 eV per molecule and atom, respectively. In contrast, d-d fusion reaction shown by Eq. (5) releases at least 3.27 MeV of energy. It is about one million times as large as the ordinary combustion.
In the fission of uranium-235 shown by Eq. (6), more energy than 200 MeV is released. It is about 100 million times as large as an ordinary chemical reaction.
Thus, the nuclear energy released in nuclear fission and fusion is several million times as large as an ordinary chemical reaction like a combustion process.