17.6: Nuclear Fission

The process of splitting of the nucleus into less massive daughters is called *fission*. We know that some elements will fission spontaneously. We've learned that isotopes are created when the same number of protons are paired with different numbers of neutrons. In general, isotopes become less stable as the number of neutrons increase. Enrico Fermi started bombarding elements with neutrons in the early 1930s. He assumed this process would lead to less stable nuclei and increased activity, but had difficulty in identifying the daughter products. The idea that scientists could increase the chances of a fission event revolutionized physics and ushered in new science and applications.

Fermi's experiments were reproduced by several other physicists from that era, including Lise Meitner, Otto Hahn and Fritz Strassman. They used uranium as the target and they were able to verify that the neutron bombardment caused the uranium nucleus to split into less massive daughters. Each of the daughters had a larger BEN than the parent and were more stable as a result. When a neutron is added to a uranium nucleus there are multiple possible outcomes, some of which are shown here:

$$ {}^{1}_{0}\mathrm{n} + {}^{235}_{92}\mathrm{U} \rightarrow {}^{141}_{56}\mathrm{Ba} + {}^{92}_{36}\mathrm{Kr} + 3\,{}^{1}_{0}\mathrm{n} + Q $$

$$ {}^{1}_{0}\mathrm{n} + {}^{235}_{92}\mathrm{U} \rightarrow {}^{140}_{54}\mathrm{Xe} + {}^{94}_{38}\mathrm{Sr} + 2\,{}^{1}_{0}\mathrm{n} + Q $$

$$ {}^{1}_{0}\mathrm{n} + {}^{235}_{92}\mathrm{U} \rightarrow {}^{132}_{50}\mathrm{Sn} + {}^{101}_{42}\mathrm{Mo} + 3\,{}^{1}_{0}\mathrm{n} + Q $$

We label the energy associated with a fission event as Q. If Q is positive, the fission will release energy into the environment. The energy is in the form of the kinetic energy of the daughters and we know that collisions can transfer kinetic energy between objects. We can calculate the value of Q by examining the mass deficit.

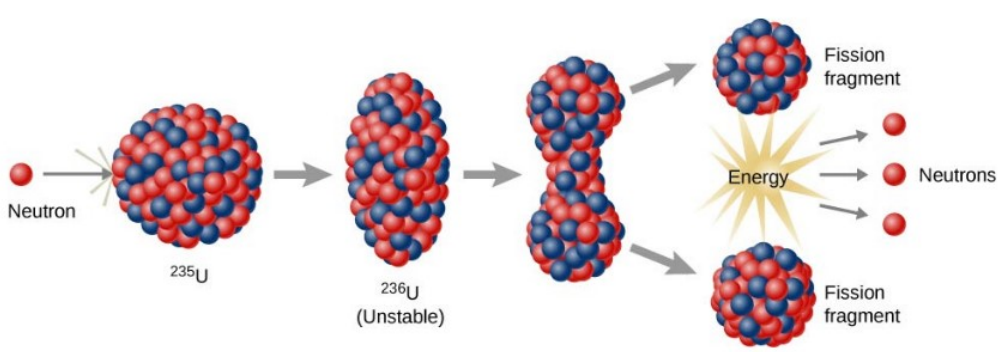
Example 17.6.1

Calculate Q, the total energy released in the following reaction: ${}^{1}_{0}\mathrm{n} + {}^{235}_{92}\mathrm{U} \rightarrow {}^{140}_{54}\mathrm{Xe} + {}^{94}_{38}\mathrm{Sr} + 2\,{}^{1}_{0}\mathrm{n} + Q$. Answer in units of MeV. You will need to look up the masses of products and reactants to three decimal places.

Solution

The Q value is calculated by $Q = \Delta mc^2 = ((1.008u + 235.043u) - (140.883u + 91.926u + 3 \times 1.008u))\ c^2 = 0.218u$ $(931.502 \frac{\mathrm{MeV}}{\mathrm{u}})$ = 203.07 MeV

Neils Bohr and John Wheeler used a *liquid drop model* to explain this process. In the water drop model, a nucleus can absorb a nucleon in much the same way that two drops of water can combine to form a larger drop. We saw hints of this behavior when we examined the model for the nuclear radius. Just as smaller drops can combine to form a larger one, a large drop can break into smaller droplets if it is disturbed. A neutron fired into the nucleus can cause it to vibrate. If the vibration is violent enough the nucleus will divide into smaller nuclei and emits two or three neutrons.



Liquid drop model of fission taken from OpenStax *University Physics vol. 3* and is licensed under CC-BY

This process is the basis for how a nuclear power plant and a nuclear weapon works. When the first nucleus fissions and emits multiple neutrons, each of those neutrons can cause a fission event in another nearby uranium atom. One fission becomes three, and three become nine and then twenty seven and so on. This cascade of fission events release large amounts of energy into the environment. If that energy release is controlled, then the heat can be used to boil water and turn a steam turbine to produce electricity. If the energy release is uncontrolled then this becomes a nuclear weapon.

As with most energy production processes, whether they involve burning fossil fuels or splitting atoms, the combustion byproducts are hazardous. Coal, oil and gas-burning power plants contribute to ground, air, and water pollution and all the ills associated with that pollution. Fission reactors produce radioactive waste, composed of elements that continue to decay and radiate energy into the environment. Radioactive waste has the potential to damage the environment and pose a risk to human health. One of the great challenges facing humanity is the disposal of the waste produced by combustion processes of all sorts.