



Fission

Nuclear fission is the division of the nuclei of heavy atoms into pairs of nuclei that each have roughly half the mass of the original nucleus. Fission differs from other nuclear reactions in that the changes in atomic mass are much greater than those caused by the capture or expulsion of small particles, such as electrons, neutrons, or alpha particles (helium nuclei). Nuclear fission is accompanied by the release of energy that can be used to generate electricity or to provide the explosive power of atomic weapons.

Discovery of fission

The fission of uranium was first observed in the 1930s, when the German scientist Otto Hahn was attempting to produce transuranic elements by bombarding uranium with neutrons. Hahn detected barium-141 in the products of his tests but hesitated until 1939 to publish his unexpected finding. When he did, the Austrian physicist Lise Meitner realized that barium was being formed by uranium nuclei splitting in two.

Working with her nephew Otto Frisch, Meitner performed a series of experiments that revealed the amount of energy released by the fission of uranium. They also discovered that each fission releases at least two neutrons, which they realized could sustain chain reactions by causing other fissions, themselves releasing neutrons.

The principal applications of the energy released by fission—nuclear weapons and nuclear power—were developed in the 1940s and 1950s. Two atomic weapons devastated the Japanese cities of Hiroshima and Nagasaki in August, 1945, and the first full-scale nuclear power station opened at Calder Hall, Britain, in 1956.

Energy from mass conversion

With the exception of hydrogen nuclei, which are protons, all atomic nuclei are agglomerations of nucleons—protons and neutrons—held together by the strong nuclear force. As a consequence of that force, all nuclei have less energy than their nucleons would have in isolation. The energy difference is called the nuclear binding energy.

As part of his Special Theory of Relativity of 1905, the German-born physicist Albert Einstein formulated an equation connecting energy (E) and mass (m): $E = mc^2$, where c is the speed of light. This equation holds true for nuclei, which have less mass than their component nucleons. According to Einstein's equation, the binding energy is the mass difference multiplied by the square of the speed of light. It is always negative.

Fission reactions release energy because their products have a greater binding energy per nucleon than the original fissile nuclei. The products therefore have less mass than the nuclei that give rise to them, and the energy released by the reaction is equal to the reduction in mass through the course of the fission reaction.

Fission energy is released in various forms, including the electromagnetic energy of gamma rays and the kinetic energies of fast-moving neutrons. Since the release of energy is accompanied by a reduction in mass, fission is an example of energy production by mass conversion.

Chain reactions

A crucial feature of the fission process is the release of neutrons that can initiate other fissions and sustain a chain reaction. If one neutron from each fission triggers exactly one fission, then the rate of fission is stable, as is the rate at which energy is released. This is the type of chain reaction that releases heat in a controlled manner for use in the generation of electricity.

If conditions are created such that more than one fission is triggered by the neutrons from a single fission, then the chain reaction can soon get out of hand. The increased rate of fission produces more and more neutrons, which in turn boost the rate of fission. This type of chain reaction, which releases vast amounts of energy in a short time, is the basis of nuclear explosions.

If neutrons are somehow prevented from causing fissions, the chain reaction stops and the nuclear reactors will shut down. The spontaneous radioactivity of the reactor contents continues to generate some heat, however.

Criticality

Two factors determine whether a chain reaction can proceed in a given collection of fissile material: the frequency of collisions between neutrons and fissile nuclei and the probability that each collision will cause a fission. If the combination of these factors is favorable, then a chain reaction proceeds and the assembly is said to be critical.

The rate of collisions between neutrons and fissile nuclei depends largely on the amount of fissile material present and the physical form in which it is assembled. The minimum amount of a given fissile material that can sustain a chain reaction is called its critical mass. The atomic bomb that was dropped on Hiroshima consisted of a conical wedge of uranium that was driven by high explosive into a matching hole in a sphere of uranium. Combined, the two masses exceeded the critical mass, and an explosion ensued.

The amount of nuclear fuel necessary for a chain reaction to occur can be reduced by increasing the concentration of fissile material in the fuel. Natural uranium is more than 99 percent nonfissile U-238, with just over 0.7 percent fissile U-235. This is increased to around 3 percent U-235 for use in most nuclear reactors or to more than 90 percent for use in nuclear warheads.

FACT FILE

- *In June 1972, technicians of the French nuclear power industry found that a batch of uranium ore from Oklo, Gabon, contained 0.621–0.717 percent of the 235 isotope rather than the 0.720 percent that would have been expected. Further samples showed U-235 contents as low as 0.292 percent—less than half the expected value. These results indicated that some of the fissile isotope had been consumed by a chain reaction. The hypothesis was supported by the relative percentages of neodymium isotopes in the region, which are similar to those produced by fission reactors. It is estimated that the Oklo natural reactor was critical some 1.45 billion years ago, when around 3 percent of uranium was U-235 and there was sufficient water in the ground to moderate the chain reaction.*
- *The energy released by the fission of 1 lb. (454 g) of uranium-235 is 3.7×10^{13}*

Moderators and control rods

The amount of material necessary to sustain a chain reaction can be reduced by improving the chances of a neutron causing a fission. Slow neutrons have better chances of interacting with nuclei than fast neutrons, which pass straight through nuclei without causing fission.

Most nuclear reactors use moderators to sustain controlled chain reactions by slowing neutrons released by fission. In pressurized-water reactors, for example, purified water is the moderator as well as being the fluid that carries heat from the reactor. This design has the safety advantage that an accidental loss of cooling water would stop the chain reaction by removing its moderator. The pace of a chain reaction can be slowed or stopped by inserting control rods into a reactor core. These rods are made of boron or cadmium, which are strong neutron absorbers.

Fissile isotopes

The only natural fissile isotope is uranium-235. Its fission produces uneven pairs of nuclei with around 95 and 137 nucleons, respectively—strontium-94 and xenon-140 are a typical pair. Many of the initial products decay rapidly to other elements with the release of more energy.

The other isotope used in some fission reactors is plutonium-239. This material is produced by bombarding uranium-238 with neutrons in fast-breeder fission reactors.

See also: [ATOMIC STRUCTURE](#); [BINDING ENERGY](#); [ENERGY RESOURCES](#); [FUSION](#); [NUCLEAR FUEL CYCLE](#); [NUCLEAR REACTOR](#).

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