



Nuclear Energy

Energy released by changes in the atom

HIGHLIGHTS

- The nucleus of an atom is made of protons and neutrons.
- Some atoms are unstable and radioactive.
- In nuclear fission, the nuclei of large atoms split into smaller ones and release energy.
- In nuclear fusion, light atomic nuclei combine to form heavier nuclei. This process also releases energy.

Nuclear energy, also called atomic energy, is created by changes inside atoms of radioactive materials. People use this energy in nuclear power stations and nuclear weapons, as well as in medicine and scientific research and for helping keep food fresh.

Atoms form the building blocks of all matter. An atom is the smallest particle of an element that can exist alone. However, atoms are made up of even smaller particles, called protons, neutrons, and electrons. Each proton carries a positive electric charge, while each electron carries a negative electric charge. Neutrons do not have an electric charge. Atoms of different elements contain different numbers of protons, neutrons, and electrons. Protons and neutrons are held together by incredibly strong forces to form the nucleus—the central core of the atom. Electrons orbit the nucleus of an atom.

Radioactivity

Most atoms of an element have a fixed number of protons and neutrons in their nuclei, but some have more or fewer neutrons than usual. The different forms of an element's atoms are called its isotopes. For example, the most common form of carbon is the isotope carbon-12, which has six protons and six neutrons. The isotope carbon-13 has seven neutrons, and carbon-14 has eight. Many isotopes are unstable. They move to a more stable state in one of three ways. They may release two protons and two neutrons bound together—this is called alpha decay. In beta decay either an electron or a positron (a positively charged electron) is lost, while in gamma decay a high-energy electromagnetic wave is released. These processes are collectively known as radioactivity, and the isotopes are called radioisotopes. French scientist Henri Becquerel (1852–1908) discovered radioactivity in 1896. He found that minerals containing uranium gave out a form of invisible radiation that clouded a photographic plate. New Zealand physicist Ernest Rutherford (1871–1937) was the first to identify the types of radiation coming from decaying atoms. He introduced the terms *alpha*, *beta*, and *gamma radiation*.

Rutherford also found that heavy elements are transformed into lighter elements during radioactive decay.

Ionizing radiation

Normally, an atom has no overall electric charge. The negative charges of its electrons balance the positive charges of its protons. However, if an atom loses one or more electrons, it becomes positively charged and is called a positive ion. If it gains one or more electrons, it becomes negatively charged and is called a negative ion. Together, alpha, beta, and gamma radiation are known as ionizing radiation. When they pass through a material, they strip electrons away from its atoms. This changes them into positive ions. This ionizing action makes nuclear radiation dangerous to people and other living creatures. It harms the chemical structure of living cells, causing damage such as burns and cancers.

Uses of radiation

Medicine was the first field to make widespread use of radiation sources. Hospitals use gamma radiation from radioisotopes to produce images of soft tissue such as heart muscle. This process is similar to using X rays to produce images of bones. Radioisotopes are also used to track the path of materials through the body and to kill cancer cells.

Radioactive sources have found many uses in science. In 1907 U.S. chemist Bertram Boltwood (1870–1927) used the rate of decay of uranium to calculate the age of Earth. Archeologists use similar processes to estimate the age of ancient objects. Radiocarbon dating measures the proportions of radioactive carbon-14 and nonradioactive carbon-12 in once-living things to calculate how old they are.

Industrial uses of radiation include exposing plastics and rubbers to gamma radiation to harden them. Exposing fresh foods such as fruit, meat, and seafood to ionizing radiation kills the microbes that cause food to spoil. This makes the food stay fresh for longer.

Mass and energy

The amount of matter an object contains is called its mass. Mass is measured in grams or kilograms (kg), with 1 kg weighing about 2.2 pounds. During radioactive decay, an atom loses mass in the form of radiation, but the mass of all the radiation plus the mass of the atom left behind is less than the mass of the original atom. The missing mass of the atom is converted into energy during radioactive decay. The conversion of mass into energy also occurs during nuclear fission. In nuclear fission, the nucleus of a heavy atom splits into two lighter nuclei. The combined mass of the two lighter nuclei is less than the mass of the original heavy nucleus.

Mass is also converted into energy in nuclear fusion. This happens when the nuclei of two light atoms join together to form the nucleus of a heavier atom. The mass of the heavier nucleus is less than the combined mass of the two light nuclei. In both fission and fusion, the missing

mass is converted into energy. This energy is released in a slow, controlled fashion in nuclear power stations. However, it is released in a violent explosion in nuclear weapons.

Nuclear power

In a nuclear power station, fission takes place in a large structure called a reactor. The reactor is surrounded by lead and concrete shielding to prevent harmful radiation from escaping into the environment. The most common type of nuclear reactor is the thermal reactor, which uses a heavy metal called uranium for fuel. The uranium is mostly the isotope uranium-238 (U-238), but it also contains around 2 to 4 percent of a radioactive isotope called uranium-235 (U-235).

LOOK CLOSER

The Chernobyl disaster

Since the 1950s, there have been a number of nuclear power plant accidents involving the release of radioactive materials. The worst was at the Chernobyl nuclear power station in modern-day Ukraine on April 26, 1986. The accident happened during an experiment. The engineers wanted to see how the reactor systems would cope if the electricity supply to the coolant pumps failed. After shutting down four of the eight coolant pumps, the engineers found they could not operate the control rods to shut the reactor down. The heat in the core rose rapidly, boiling water in the core and causing a steam explosion. Then, there was a build-up of heat and pressure, which caused the containment vessel to rupture. This destroyed the reactor and the reactor building roof. Radioactive materials blown into the air were carried across northern Europe to Britain and Scandinavia. Estimates suggest that the amount of radiation released was enough to cause 30,000 potentially fatal cancers.

When atoms of U-235 undergo nuclear fission they split into lighter atoms and give off neutrons. A U-235 atom that splits gives off two or three neutrons. If these neutrons collide with nuclei of other U-235 atoms, they make them split. When the conditions are right, this process will continue until most of the U-235 atoms have been used up. This is called a chain reaction.

A chain reaction produces an enormous amount of energy in the form of heat and radiation. In an atomic bomb, the chain reaction happens in a fraction of a second and produces a massive explosion. However, a nuclear reactor controls and slows the chain reaction. It then uses the heat from the reaction to boil water and produce steam, which drives turbogenerators that produce electricity. Nuclear submarines use reactors to generate electricity, which powers electric motors that drive the submarines.

The heart of a nuclear reactor is called the core. Uranium fuel is contained in metal tubes called fuel rods, which are inserted into the core. In the core, a material called a moderator helps keep the chain reaction going. It does this by slowing down the fast-moving neutrons coming from the reaction. Slow neutrons are more likely than fast ones to collide with U-235 nuclei and make them split. Materials used as moderators include water and graphite (a form of carbon).

As well as fuel rods and a moderator, a reactor core has sets of control rods. These are made of materials, such as boron, that absorb neutrons. Inserting control rods into the reactor slows the chain reaction to reduce the amount of heat it produces. Withdrawing rods allows the reaction to speed up and produce more heat.

A coolant such as water or carbon dioxide gas removes heat from the core. The coolant then passes into a device called a heat exchanger. The heat exchanger takes heat from the coolant and uses it to boil water. This produces the steam that drives the turbogenerators.

Nuclear power can be very dangerous. Fission reactors produce large amounts of harmful radioactive material. Some radioactive substances remain dangerously radioactive for thousands or even millions of years. If they escape into the environment, they can be lethal.

Nuclear fusion

Nuclear fusion is the power source that lights the Sun and the other stars. Inside the Sun, enormous pressures and temperatures force hydrogen nuclei together to form helium nuclei. This fusion process releases energy that streams from the Sun as light and heat.

On Earth, nuclear fusion forms the basis of the hydrogen bomb. Inside the hydrogen bomb, energy released by a small atomic (fission) bomb compresses and heats a form of hydrogen called deuterium (doo-TIR-ee-uhm). Pressure and heat trigger a fusion reaction that converts the deuterium into helium and releases a vast amount of energy in a fraction of a second.

Scientists are working on ways to produce controlled nuclear fusion as a source of energy. They are experimenting with laser beams and powerful electric currents in an attempt to trigger and control fusion reactions. If they succeed, fusion could one day provide an almost pollution-free source of power.

PEOPLE

Lise Meitner

One of the first people to trigger an artificial fission reaction was Austrian-born scientist Lise Meitner (1878–1968). It happened in 1938, when she was working with German scientists Otto Hahn (1879–1968) and Otto Frisch (1904–1979) at the Kaiser Wilhelm Institute for Chemistry in Berlin, Germany. They were bombarding uranium with neutrons and thought the neutrons would be transformed into protons and electrons. However, the uranium atoms split into two equal chunks, producing several new radioactive isotopes of barium.

See also: [ENERGY RESOURCES](#); [NUCLEAR WEAPONS](#).

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