

Carbon-14 Diamond Batteries: New Nuclear Technology in Energy Storage

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ABSTRACT

The novel technology of carbon-14 diamond batteries is an advanced solution for the effective use of nuclear waste and its transformation into a sustainable and long-term source of energy production. The battery is safely enclosed in a synthetic diamond and uses the decay of a radioactive isotope to produce energy. These batteries, which have a long lifespan and have the potential for widespread application in scientific, medical and space fields. This article examines in detail the principles of operation, structure, advantages, challenges and potential applications of this technology.

Keywords: Carbon-14, Diamond batteries, Nuclear energy, Radioactive decay, Beta decay.

Received: May 20, 2025;

Accepted: May 23, 2025;

Published: May 31, 2025

Introduction

An Introduction to Nuclear Physics

Atoms are the smallest units of matter, made up of elementary particles including electrons, protons, and neutrons. The structure of an atom consists of a nucleus at the center, which contains positively charged protons and uncharged neutrons (together called nucleons). Negatively charged electrons move in orbits around the nucleus (Figure 1).

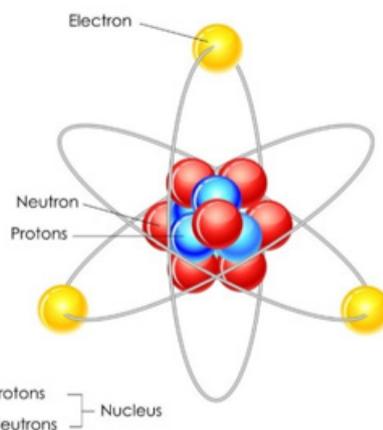


Figure 1: Atomic structure

The atomic number (Z) refers to the number of protons in the nucleus of an atom and is

a characteristic that distinguishes different elements from each other. In a neutral atom, the number of electrons around the nucleus is equal to the number of protons in it. The number of neutrons in the nucleus is known as the neutron number (N). The sum of the protons and neutrons in the nucleus is also defined as the mass number (A), which represents the total mass of the atomic nucleus. Isotopes are forms of a chemical element that have the same number of protons in the nucleus (atomic number) but a different number of neutrons in the nucleus (neutron number). Because of this, isotopes have similar chemical properties but may have different physical properties, such as mass and nuclear stability.

The nucleus of an atom is very small compared to the size of the entire atom, but more than 99.9% of the mass of the atom is concentrated in this part. Although the protons in the nucleus are positively charged and there is a strong electrostatic repulsive force between them, the nucleus does not disintegrate. This indicates the presence of a strong force within the nucleus that holds its components together. This force, known as the "strong nuclear force", is short-range and only effective at distances smaller than the dimensions of the

Citation: Rahele Zadfathollah, Bahman Zohur, and Seyed Kamal Mousavi Balgehshiri (2025) Carbon-14 Diamond Batteries: New Nuclear Technology in Energy Storage. J All Phy Res Appli 1: 1-4.

nucleus. One of the important features of this force is its independence from electric charge; so that the same attractive force is applied between protons, neutrons, or a combination of them (such as protons and neutrons). This property means that from the point of view of the nuclear force, there is no difference between protons and neutrons, which is why they are generally called "nucleons" [1].

Radioactive Decay

Some elements have isotopes that do not have a stable atomic nucleus and are called unstable isotopes. Unstable isotopes differ from stable isotopes in the number of neutrons and protons and, unlike them, undergo nuclear decay. The neutron-to-proton ratio or nuclear ratio expresses the ratio of the number of neutrons in the atomic nucleus to the number of protons. This ratio generally increases with increasing atomic number. A higher neutron-to-proton ratio indicates instability and radioactivity of the nucleus, so that in the early elements of the periodic table, where this ratio is approximately 1, stability is greater than in the elements at the end of the periodic table. Unstable nuclei decay under a process called radioactivity. In this process, the unstable atomic nucleus is converted into new nuclei by releasing energy, which leads to the emission of radioactive radiation. Radioactive decay is divided into three main types: alpha decay, which involves the release of alpha particles; beta decay, which is accompanied by the emission of an electron or positron; and gamma decay, which occurs as the emission of high-energy electromagnetic radiation.

Types of Radioactive Decay

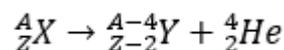
Alpha Decay

Alpha decay is a nuclear process in which an unstable nucleus (the parent nucleus) is converted into a more stable nucleus (the daughter nucleus) by emitting an alpha particle (α). The alpha particle consists of two protons and two neutrons and is structurally similar to the nucleus of a helium atom, except that the alpha particle has 2 positive charges while helium is neutral. This process is part of the natural mechanisms of radioactivity that help reduce the energy and make the nucleus more stable.



Figure 2: Alpha decay, Uranium-235

In alpha decay, the atomic number of the daughter nucleus is 2 less than the atomic number of the parent nucleus, and the mass number of the daughter nucleus is 4 less than the mass number of the parent nucleus.

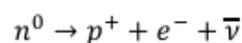


The alpha decay of uranium-235 reduces its mass to 231. The daughter isotope of uranium-235 is thorium-231. The half-life of uranium-235 is 700 million years.

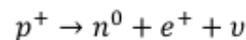
Beta Decay (β)

Beta decay is a type of radioactive process in which an unstable nucleus emits a beta particle (electron or positron) and becomes more stable. This process includes two main types:

Negative Beta Decay (β^-): In this case, a neutron in the nucleus is converted into a proton. As a result, an electron (negative beta particle) and an antineutrino are released. This change increases the atomic number of the element, because the number of protons in the nucleus increases



Positive Beta Decay (β^+): In this type, a proton in the nucleus is converted into a neutron and a positron (positive beta particle) is released along with a neutrino. This process reduces the atomic number of the element, because the number of protons in the nucleus decreases:



Beta decay is a fundamental mechanism in nuclear phenomena that, in addition to the emission of particles, plays an important role in changing the nuclear nature and transforming elements. This phenomenon has wide applications in the study of radioactivity and nuclear processes.

Carbon-14 undergoes beta decay, transforming into nitrogen-14 by emitting a beta particle (electron) and an antineutrino. Similarly, when carbon-10 undergoes beta decay, it releases a positron and a neutrino while one of its neutrons converts into a proton. As a result, the final product is boron-10 (B^{10}), making it the most likely resulting nuclide.

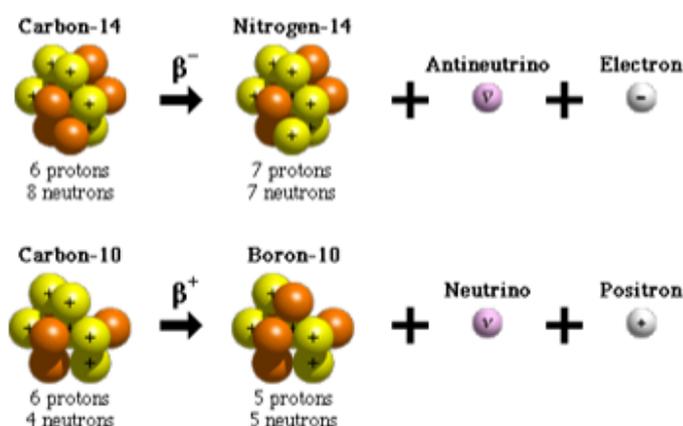


Figure 2: Beta decay

Gamma Decay (γ)

After alpha or beta decay, most nuclei transition to an excited state. This excited state is converted to the ground state by emitting high-energy photons, called gamma rays. In the process of gamma decay, the mass number (A) and atomic number (Z) of the nucleus remain unchanged. The excited nucleus, indicated by the symbol $*$, gives off its excess energy by emitting gamma rays and returns to the ground state, without any change in the composition of the nucleus.

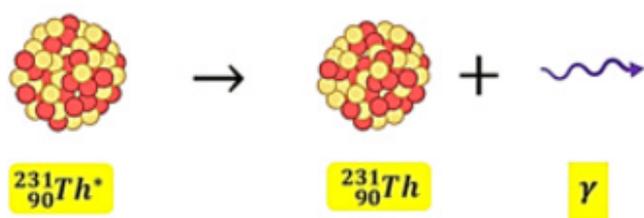
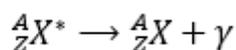


Figure 3: Gama decay, Uranium-235

Introduction to Semiconductors: A semiconductor is a type of material whose electrical behavior is between that of a conductor (such as a metal) and an insulator (such as glass). In simple terms, a semiconductor neither completely allows nor completely blocks the flow of electricity. The most famous semiconductor is silicon, which is used in most electronic devices such as cell phones and computers.

How do Semiconductors Generate Electric Current through Radiation?

When light or energetic particles (such as beta particles) strike a semiconductor material, the energy from this radiation is absorbed by the material. The absorbed energy causes electrons that were not moving in the semiconductor material to be released. These electrons move to a layer called the conduction band and begin to move. When the electrons are released, they begin to move in the semiconductor material. This movement of electrons is the electric current that we use.

Carbon-14 Diamond Nuclear Battery

One of the main challenges of nuclear energy technology is the production of radioactive waste during the fission process, which can remain radioactive for thousands of years. However, rather than treating these materials as an environmental threat, their nuclear decay could be harnessed as a sustainable, long-term source of energy. The advanced technology of carbon-14 diamond nuclear batteries offers an opportunity to reduce the challenges of managing nuclear waste and make more efficient use of it. The new technology uses nuclear waste to generate electricity. A team of physicists and chemists from the University of Bristol in UK have created a diamond that produces a small electric current when placed in a radioactive field. With the ability to store energy for thousands of years, these batteries are an efficient solution for powering small and specialized devices, especially in applications such as pacemakers and space probes that require low-voltage and limited-access power sources.

In addition, this new technology plays a key role in advancing sustainable technologies and improving the efficiency of energy systems by reducing the challenges associated with nuclear waste management [3].

Unlike most electricity generation technologies, which use mechanical energy to move a magnet through a coil (Faraday's law) to generate electricity, synthetic diamonds can generate current simply by being placed in the vicinity of a radioactive source. In this advanced technology, the entire energy generation process is carried out directly, without the use of moving parts. This feature eliminates the production of greenhouse gases.



Carbon-14 nuclear batteries work by converting radiant energy into electrical energy. The basis of these batteries is the presence of a radioisotope source and a semiconductor diode. The starting material of this type of battery is carbon-14. This naturally occurring radioactive isotope is mainly formed in the Earth's atmosphere and is a sustainable source of energy due to its half-life of about 5730 years. It is also found naturally in graphite used in nuclear reactors. This isotope is produced in nuclear power plants through nuclear reactions and is specifically formed in graphite blocks that act as neutron moderators. In this process, thermal neutrons react with the nitrogen in the graphite to produce the isotope carbon-14. This mechanism is important as part of the role of graphite in controlling and slowing down neutrons in nuclear reactors. When decaying, it produces beta particles (highly energetic electrons). This decay process is the primary source of energy for a battery. Beta particles are high-energy electrons that are released from the isotope carbon-14 during radioactive decay. These electrons have high kinetic energy that can be used to generate an electric current. The beta particles collide with layers of synthetic diamond (chosen for their stability and electrical conductivity). The diamond acts as a semiconductor, converting the kinetic energy of these particles into an electric current. When the beta particles hit the diamond, their kinetic energy is absorbed into the diamond's crystal structure. This energy creates free electrons in the diamond's semiconductor structure, which produce an electric current. This process is similar to how solar cells work; in a solar cell, sunlight releases electrons in the semiconductor material, and these electrons generate an electric current. In nuclear batteries, beta particles do the same thing instead of sunlight.

The synthetic diamond used in these batteries has the following properties:

1. It is stable and can absorb the energy of beta particles without being affected by radiation.

2. It is electrically conductive, as it acts as a semiconductor in some conditions and has the ability to convert the kinetic energy of electrons into an electric current.
3. It provides radiation safety, as its layers act as a shield and prevent radiation leakage.

Due to the use of synthetic diamond, these batteries are durable and resistant to harsh conditions. Also, the energy conversion process is very stable and efficient, which makes these batteries ideal for long-term applications such as aerospace, medical and industrial equipment.

It was chosen as the raw material in diamond batteries because the short-range radiation emitted by this radioactive isotope is quickly absorbed by solid materials. This property can be dangerous if it comes into direct contact with bare skin or is swallowed. However, encapsulating it in a layer of synthetic diamond, the hardest material known to man, allows for complete radiation leakage. Despite their lower power compared to conventional battery technologies, carbon-14 diamond batteries have the potential to revolutionize the way devices are powered over long periods of time. The technology uses the isotope to enable sustainable energy production with an extraordinary lifespan. It is estimated that a 1-gram battery can produce 15 joules of energy per day, less than the energy produced by a typical standard battery, which stores about 700 joules of energy per gram. However, conventional batteries are designed to discharge energy quickly, so they are completely discharged in just 24 hours. In contrast, diamond batteries, with a long half-life of about 5,730 years, reach 50 percent of their original capacity in a time frame comparable to the lifespan of human civilization. This unique feature enables the widespread use of this technology in devices with long-term energy needs, significantly reducing the challenges of sustainable energy supply.

Conclusion

Carbon-14 diamond batteries are an innovative type of nuclear-powered battery that can last for thousands of years. Scientists from the UK have successfully developed these batteries, leveraging the radioactive decay of carbon-14 to generate electricity. Carbon-14 emits short-range radiation, which is safely encased within a diamond structure to prevent harmful exposure. The battery functions similarly to solar panels, but instead of converting light into electricity, it captures fast-moving electrons from radioactive decay. Since carbon-14 has a half-life of 5,700 years, the battery retains half of its power even after thousands of years, making it an ultra-long-lasting energy source [4].

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