Nuclear battery based on beta decay of isotopes of radioactive elements

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Abstract. This article is dedicated to the creation of the nuclear battery as a portable source of electric power, capable of producing energy for a long period, and the prospects of using them as energy storage devices for consumer goods. This article will consider existing analogues and ways of improving them.

1. Introduction

Modern society consumes a lot of electricity, and that inevitably leads to the problem of finding and using inexhaustible and promising resources. Power supply circuitry gives life to the advancements of technological progress and does so indistinctly while the electric current flows. Needless to say, that the discourse will not be about «perpetual motion machine», but about long service energy sources. Modern batteries are capable of supplying power to the electrical devices connected to them for a limited time periods while the electrochemical reaction is taking place in those batteries. Many researchers think that in order to develop a new generation of batteries, we need to turn to previously unused materials and chemical processes.

In 1913, Henry Moseley demonstrated his device – a spherical glass globe with silver lining the interior with radium isotope subjected to beta decay in the center. This device can be considered the first atomic battery capable of producing energy for a long period of time. Service life of a battery working on principles of nuclear decays depends on half-life period because of its connection with electron release time with electrons being absorbed by the shell with the result that an electric potential difference is created. Device of Henry Moseley was not perfect, and gave very low currents; thereby this device did not even become naturalized in laboratory circles.

In 1953, Paul Rappaport suggested to use semiconductors for electron absorption that increased absorption efficiency which in turn increased current characteristics.

Production of such batteries was unnecessarily expensive and their capabilities in the 20th century were extremely small compared to lithium-ion batteries that had just appeared.

Now in 21st century the question about the need for an energy source that can work for decades is raised again. Scientists from different countries are developing an atomic battery, structure of which was suggested by Paul Rappaport. The work of a nuclear battery is based on the physical principles of the internal photoemission and beta decay.
2. Nuclear battery structure

2.1. Photoelectric effect
Photoelectric effect was discovered in 19th century and was described by different scientists from Alexandre Edmond Becquerel to Albert Einstein. Main characteristic of such phenomenon consists in the conductivity of a semiconductor connected to the grid and illuminated with natural light. In the 19th century another property was noted, called the internal photoemission - the release of electricity during the irradiation of the p-n junction connected to the electric load. This property of semiconductor p-n junction is used in modern solar batteries. In the 19th century it was also discovered that the internal photoemission is also observed when the flow of photons (natural light) is replaced with the flow of electrons. This property is used in the schematic proposed by Paul Rapport.

2.2. p-n junction
The device called p-n junction can be separated in two parts – p-type semiconductor, and n-type semiconductor [1]. Generally, an n-type semiconductor is a semiconductor where the charge carriers are electrons, i.e., it has electronic conductivity. A semiconductor of p-type is a semiconductor where the charge carriers are holes, i.e., it has hole conductivity. To achieve different kinds of semiconductor conductivities donor-acceptor admixtures are used (see figure 1). For example, consider silicon (Si). In order for the electron to become the main carrier of current, it is required to add arsenic to the silicon structure (As). In the structure of 4-valent silicon, one of the atoms is replaced by an atom of 5-valent arsenic, resulting in one extra electron that does not participate in chemical bonds. Such a substance will be called n-silicon.

![Figure 1. Donor admixture.](image1)

2.3. Solar cell
Solar batteries work on the basis of internal photoemission – an electromotive force (EMF) appears when a p-n junction is irradiated with natural light. A connected p-n junction is called a solar cell. Specifically, the solar cell is the basis of the nuclear battery, it absorbs electrons released during beta decay of a radioactive substance.

![Figure 2. Schematic of the solar cell.](image2)
2.4. Beta decay

One of the types of nuclear decays is called beta decay [2], during which the spontaneous transformation of one of the neutrons of the nucleus into a proton, or a proton into a neutron occurs. Generally, during beta decay, an electron and a positron (a positively charged electron) fly out and so the β+ and β- decays are distinguished.

During β+ decay, a positron flies out of the nucleus of an atom, a proton turns into a neutron, and a neutrino is released (see figure 3).

\[
A^Z_X \rightarrow A^{Z-1}_X + e^+ + \nu
\]

**Figure 3.** Schematic of the β+ decay.

Neutrino (ν) is an electrically neutral particle with spin $\frac{1}{2}$. It has a large path length in various substances and a colossal penetrating ability, which allows it to penetrate even lead and concrete media easily.

During β- decay (see figure 4), an electron flies out of the atomic nucleus, the neutron turns into a proton, and the antineutrino is released. Beta decay takes place with a relative excess of neutrons in the nucleus.

\[
A^Z_X \rightarrow A^{Z+1}_X + e^- + \bar{\nu}
\]

**Figure 4.** Schematic of the β- decay.

Antineutrino ($\bar{\nu}$) is the antiparticle for the neutrino (see). In neutrinos, the spin is equal to $\frac{1}{2}$ and its projection on the direction of the impulse can take the values $\pm \frac{1}{2}$. The double value of this projection is the helicity $\lambda$. Neutrino $\lambda = -1$ i.e. the spin is directed against the pulse, and in antineutrino $\lambda = +1$ i.e. spin is co-directed with impulse.

**Figure 5.** Neutrino and antineutrino.

As described above, a solar cell absorbs the flow of electrons, so a nuclear battery needs β- decay specifically. The β- decay energies range from 0.02 MeV to about 20 MeV.

2.5. Battery structure.

Atomic battery (see figure 6) is comprised of a protective hermetic case, positive side, negative side, solar cell, radioactive material, positive and negative terminals [3].
3. Analogues
Currently, in 2019, there are several analogues, some of them can be bought on the Internet. All analogues are different. They differ in the type of material used and the output characteristics. For example, let us compare two batteries. The first battery is made by a group of scientists from Lomonosov Moscow State University, Russia. The second battery is made by a group of scientists from the United States. As the radioactive element, the first group used Nickel-63, the second group used the isotope of Hydrogen-3 – Tritium.

These two batteries have different characteristics. This is due to the power of ionizing radiation of each, with the technical features of the device. The prospect of using these batteries in consumer goods is determined by the main operational parameters. The average values of the parameters of these batteries are shown in table 1.

| Characteristic     | Tritium       | Nickel        |
|--------------------|---------------|---------------|
| Power              | 75 nW         | 60 μW         |
| Cost               | 1,000…3,000 USD | 500,000…3,000,000 USD |
| Voltage            | 0.75 V        | 3 V           |
| Battery life       | 12 years      | 100 years     |
| Size               | 4x1.5x2 mm    | 2x2x0.001 mm  |

As can be seen from the table, the characteristics of the nickel battery surpass those of the tritium battery. Of course, these values are not comparable in power with modern alkaline and lithium batteries, but still these batteries will find their niche - medicine, oil and gas industry, outer space, etc. However, using this energy source in consumer goods (mobile phones, computers, other everyday gadgets) in the foreseeable future is not worthwhile. The main problem in the way of launching nuclear batteries into mass production is high cost. At this moment, 1 gram of radioactive Nickel-63 costs around 4,000 USD. Nickel-63 isotope does not occur in nature, it is obtained by irradiating Nickel-62 inside a nuclear reactor. This process can take years, hence the high cost of this device.

Currently there is a lot of research being done on nuclear batteries - experimenting with combinations of several solar cells, sorting out various radioactive substances, based on accessibility and price, coming up with new and modernizing old solar cells, and much more.
4. Disposal
One of the problems associated with the production of nuclear batteries is the problem of disposal without harm to the environment. At the moment there is no solution to the problem of complete disposal of nuclear waste in the world. Hazardous materials still have the ability to damage the environment. The optimal methods of disposing nuclear batteries are vitrification and cementation.

5. Areas of use
The scope of potential applications of such power sources in the 21st century is very extensive. First of all, these are “technologies of the future”. Due to their compact size and uninterrupted service life, such batteries are suitable for various types of sensors in automated control and monitoring systems, including monitoring of oil and gas pipelines during their entire life cycle in hard-to-reach regions. The nuclear batteries can also be used in spacecrafts for deep space exploration.

Nuclear batteries can also have a wide range of applications in medicine and prosthetics. In modern medicine, a procedure is being developed - the implantation of electronic devices in the human body. In this field the longest battery life of the device is important as nowhere else. For example, cochlear implants (medical devices, snails implanted into the tympanic cavity to compensate for hearing loss), artificial cardiac pacemaker, bionic limb prostheses, various chips and electrodes implanted into the nervous and muscular tissue and more. Not all patients can withstand hardships of repeated surgery, in order to replace the power source in a medical device.

Therefore, the examples above clearly show the need for power sources that would work without additional maintenance for many decades. Based on this, we can state with confidence that atomic batteries have broad prospects and potential advantages.

6. Conclusion
Nuclear batteries are far from perfect. They are costly, hard to manufacture. They are not very likely to be used in consumer electronic goods. However, these devices have their niche as long-term energy storage devices for hard-to-reach applications; the future is definitely secured for them.

References
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