POTASSIUM SALT BASED *β*-RADIATION SOURCES IN EXPERIMENTAL TRAINING IN EXPERIMENTAL LABORATORIES ON NUCLEAR PHYSICS

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Abstract

There is a great interest in finding a safer alternative to a traditional choice of artificially produced radionuclides for students' training in experimental laboratories on nuclear physics. The synthetic elements have an advantage of a small size and the range of radioactive properties appropriate for the teaching lab settings, however, they are often expensive, have limited lifetime and often present a radioactive hazard, hence requiring special, often very strict, radiologic protection protocols. In this article we find and prove that it is possible to use naturally occurring radioisotope ${}_{19}K^{40}$ as a source of *β*- radiation for the purpose of student's training in experimental laboratory settings. The isotope ${}_{19}K^{40}$ can be found in common and safe potassium salts KCl and K_2SO_4

The main approach to this problem is experimental studies of *β*-radiation absorption in matter which allowed us to confirm that results obtained from experiments with the radioactive sources based on both synthetic isotope ${}^{90}_{38}Sr$ and naturally occurring in salt K_2SO_4 isotope ${}^{40}_{19}K$ are in qualitative agreement.

In this paper we compare experimental results on *β*-radiation penetration with isotopes ${}^{90}_{38}Sr$ and ${}^{40}_{19}K$ as sources in the same experimental set-up using the same solid samples (polyethylene, aluminum and brass). We find that the experimental results qualitatively do not depend on the type of the source used: the absorption curves have the same exponential behavior, the same dependence of electron absorption coefficient on the sample density is observed. The materials of the article can be useful for engineering and technical personnel, as well as for lecturers and instructors of Physics departments of higher education institutions involved in setting up educational laboratory tasks on nuclear physics, and for companies specializing in the production of laboratory equipment.

Keywords: Radioactive sources of *β*-radiation, potassium isotope ${}^{40}_{19}K$, *β*-radiation absorption, teaching laboratory settings, nuclear physics.

1.INTRODUCTION

When training future specialists in the field of nuclear physics, as well as students studying nuclear physics within the course of general physics in Russian universities, the typical sources of β-radiation are artificial radioactive isotopes (Antonova et al, 1965). Such isotopes are produced by specialized enterprises for educational laboratory research with isotope ${}^{90}_{38}Sr$ being a typical representative. Among the advantages of artificially produced sources are compactness and radioactivity that is necessary and sufficient for training purposes. The radiant picture of using these isotopes in the educational process is seriously compromised by their price, limited lifetime, difficulties related to working with any radioactive materials such as acquiring, protection against radiation protocols, as well as the special conditions for storage and subsequent disposal of radioactive hazard materials.

The isotope ${}^{40}_{19}K$ is naturally radioactive, and any available potassium salt can be chosen as a source of β-radiation, for example, potassium chloride KCl or potassium sulfate K_2SO_4. Such a radioactive source does not pose danger to humans. The specific activity of chemically pure potassium chloride due to the decay of the isotope ${}_{19}K^{40}$ is 3.87 10^{-7} Ci/kg.

Using potassium salts as a source of radioactive radiation in laboratory practice settings raises a number of difficulties. The main difficulty is due to the low density of the radiation flux from such a source. Because of this, radioactive sources of potassium salts must be made in sizes of tens or even hundreds of square centimeters. On the other hand, artificial isotopes have a high intensity of radiation and are made in the form of thin layers with linear dimensions of several millimeters. Within the scope of educational laboratory facilities such size sources can be considered as point sources of radiation. The potassium salt based sources made in this size would be unsuitable for the educational purposes because of weak radioactivity of potassium isotope. That is why the potassium radiation is traditionally used to only calibrate the equipment but not as a radioactive source to study, for example, the interaction of radiation with matter.

However, at present there are examples of using the radioactive sources based on the isotope ${}^{40}_{19}K$ for setting up educational laboratory practice (Babenko and Aliev, 1991; Balabina and Fetisov, 1997). With sources based on potassium salts, the standard teaching tasks to determine the percentage of potassium in a mixture of potassium and sodium salts are solved (Glushakov and Podvalny, 1981)

We have been using the naturally occurring radioactive isotope ${}^{40}_{19}K$ as a source of β-radiation in educational laboratory facilities for over twenty years (Belyanin, 2009) when training students studying the general physics course. To date, we have carried out experimental studies and based on them, 15 educational research labs have been developed, in which potassium salts are used as a source of β-radiation.

Electrons arising from the β-radioactivity of chemical isotopes have a continuous energy spectrum with a maximum energy of $E_{\max}$. The absorption curves for β-radiation with a continuous energy spectrum have an approximately exponential course (Zhukovskii, 1975). Qualitatively, the initial part of the curve can be explained by the fact that in the beam of β-particles there are electrons of all possible energies, including very small ones, while slow electrons are very strongly absorbed. The end of the absorption curve asymptotically approaches the background level. This is explained by the continually decreasing number of fast electrons in the β spectrum and the relatively weak absorption of electrons with maximum energy.

2.MATERIALS AND METHODS

To prove the possibility of using potassium salts as a source of β-radiation, we conducted a special comparative experiment on the absorption of β-radiation from two radioactive sources in identical solid samples in the same experimental setup, in the same measuring chamber, with the same mutual position of the radioactive source, radiation absorber and radiation counters and under the same radiation background conditions.

The measurements were performed on the “Arion” instrument (Belyanin, 2004). Radioactive sources were the salt of K_2SO_4 and the isotope ${}^{90}_{38}Sr$. The energy spectrum of the β-radiation of the isotope ${}^{40}_{19}K$ is continuous with maximum electron energy of about 1.3 MeV, most of the electrons in this spectrum have an energy of about 0.5 MeV. The β-radiation spectrum of the isotope ${}^{90}_{38}Sr$ is also continuous; the maximum electron energy emitted by strontium is 2.26 MeV, which is approximately twice the limiting energy of the electrons emitted by the potassium isotope.

The setup scheme used in the experiment is traditional for such measurements: a radiation beam from a radioactive source passes through an absorber and is recorded by a Geiger-Muller counter. To reduce the background radiation, a lead box was used. The electronic part of the setup consisted of an interface with an ATmega640 / v microcontroller (Belyanin et al., 2010) connected to the USB port of a personal computer.

The radioactive source from the K_2SO_4 salt had an area (15x4) cm^2, a thickness of 6 mm, and was thick for β radiation while the standard source was practically point-like as its radioactive surface diameter did not exceed 5 mm.

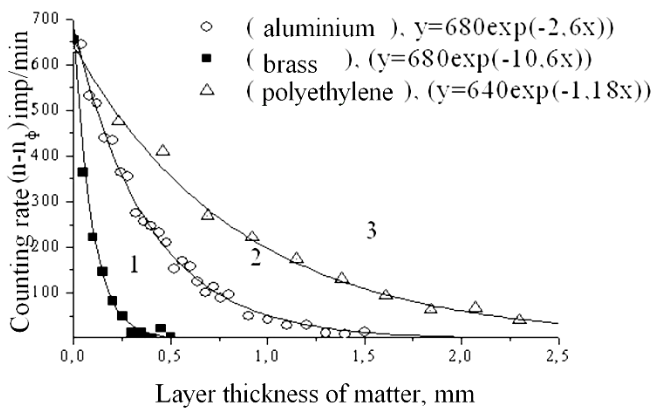
The distance from the radioactive sources to the counters recording the radiation was not more than 2 cm. The radiation absorbers in the form of thin plates of solid material were placed between the source and the counters. The thickness of the radiation absorber was increased by adding additional plates.

3.RESULTS

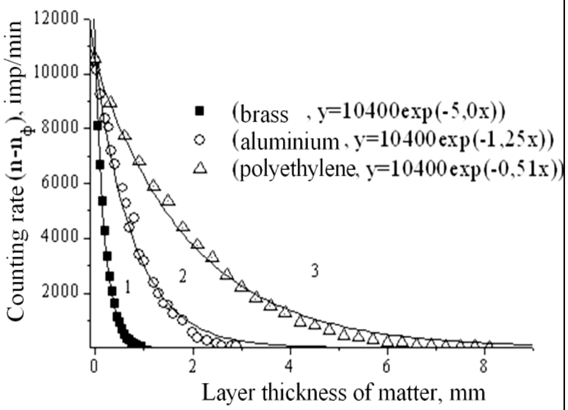
The results of the experiment on the β-radiation absorption from both sources (K_2SO_4 and $^{90}_{38}Sr$) in brass, aluminum and polyethylene are shown in Figures 1 and 2 in the form of exponential dependences of the counting rate (minus the background) on the thickness of the absorbing substance layer. Through the experimental points, a solid line is fitted with the help of the Origin program, the equation for which is shown on the corresponding figure inset.

Figures 3 and 4 characterize the same experiments in a semilogarithmic scale. We would like to underline that the straight lines in Figures 3 and 4 confirm the exponential nature of the dependences obtained.

Figures 1-4 illustrate qualitatively identical results of absorption of β-radiation from two compared sources (K_2SO_4 , $^{90}_{38}Sr$) and allow us to draw a conclusion about identical exponential character of decrease in intensity of β-radiation passing through solid matter and the same dependence of the electron absorption coefficient on the density of the sample.



1. Dependence of the counting rate of the β radiation receiver on the thickness of the absorbing substance layer, K_2SO_4 source



2. Dependence of the counting rate of the β radiation receiver on the thickness of the absorbing substance layer, $^{90}_{38}Sr$ source

The linear absorption coefficient of *β*-radiation (the coefficient of x in the exponential equation in the inset) increases with the density of a sample. As we go from polyethylene to brass, the absorption coefficient increases approximately by a factor of 10, remarkably, for both sources of radiation.

4.DISCUSSION

Comparison of the graphs plotted from the results of the experiments with both different radioactive sources and presented in Figures 1, 2, 3, 4, indicates a qualitative agreement of the results on β-radiation absorption from the two compared radioactive sources

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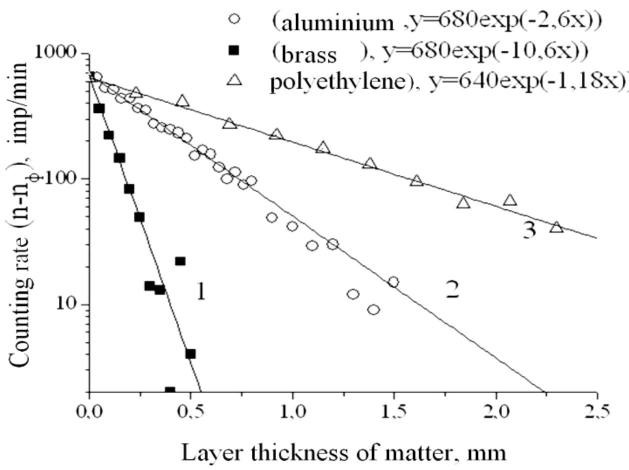
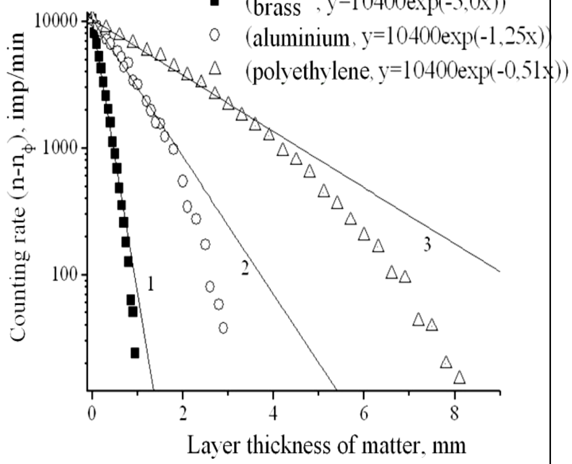


3. Dependence of counting rate (semilogarithmic scale) on the thickness of the radiation absorber, K_2SO_4 source



4. Dependence of counting rate (semilogarithmic scale) on the thickness of the radiation absorber, ${}^{90}_{38}Sr$ source

The quantitative difference between the results on penetration of *β*-radiation from the two sources passing through the solid materials used in the experiment is following:

- The maximum counting rate from *β*-radiation of the K_2SO_4 salt is approximately 15 times smaller
- For the K_2SO_4 source, a noticeable spread of the experimental points is observed, indicating a greater measurement error in the experiments performed with potassium salts,
- *β*-radiation absorption coefficient of ${}^{90}_{38}Sr$ is approximately twice less, which agrees with the idea that there is dependence of mean free path of free-electrons in matter on their energy (Kabardin, 1965),
- The maximum possible path of free electrons in matter correlate in the same way,
- The tail of the curves represented on a semilogarithmic scale is "swamped down" down for ${}^{90}_{38}Sr$ while there is no such effect in explicit form for the curves with ${}^{40}_{19}K$ as a source,
- The *β*-radiation absorption coefficients for ${}^{90}_{38}Sr$ at the "tail" of the curves are close to the *β*-radiation absorption coefficient for the K_2SO_4 salt.

5.CONCLUSION

The results of comparative experiment on *β*-radiation penetration with isotopes ${}^{90}_{38}Sr$ and ${}^{40}_{19}K$ as sources in the same experimental set-up using the same solid samples (polyethylene, aluminum and brass) have shown that the experimental results do not qualitatively depend on the type of radioactive source used: the absorption curves have the same exponential behavior, the same dependence of electron absorption coefficient on the sample density is observed.

Consequently, on the basis of the results of the conducted experiments, we consider it possible to conclude that today there are no fundamental objections to the scientific, experimental or methodological plan for using potassium salts as a radioactive source in laboratory practice when studying the passage of *β*-radiation through a solid matter. The features of potassium salts as a source of *β*-radiation are explainable, predictable and related mainly to their low radioactivity and the effect of self-absorption phenomenon on the properties of *β*-radiation, which can be easily compensated for, if necessary, by the design features of the experimental setups and the experimental protocols.

The materials of the article can be useful for engineering and technical personnel, as well as for lecturers and instructors of Physics departments of higher education institutions involved in setting up educational laboratory tasks on nuclear physics, and for companies specializing in the production of laboratory equipment.

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