Journal of Physics: Theories and Applications E-ISSN: 2549-7324 / P-ISSN: 2549-7316
J. Phys.: Theor. Appl. Vol. 7 No. 2 (2023) 168-176 doi: 10.20961/jphystheor-appl.v7i2.78406

Experiments in nuclear physics using inexpensive instruments

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Received 30 August 2023, Revised 21 September 2023, Published 30 September 2023

Abstract: The scarcity of experimental activities is one of the challenges of teaching current physics. This study resolves these issues and suggests three nuclear physics experiments using a low-cost ion chamber, whose construction is explained: the measurement of ^{222}Rn progeny collected from the indoor air; the measurement of the range of alpha particles emitted by the ^{232}Th progeny, present in lantern mantles and in thoriated welding rods, as well as by the air filter containing ^{222}Rn progeny; and the measurement of 220Rn half-life collected from In this study, the experimental methods and anticipated findings are presented, showing that the experiments could help nuclear physics curricula. These procedures may provide broad access to either academic laboratories in high schools or colleges and the equipment may be used to create novel nuclear physics teaching strategies.

Keywords: experimental, low-cost, nuclear physics, progeny.

1. Introduction

Both elementary school and high school physics curricula include nuclear physics, but most educational institutions globally lack the cutting-edge tools necessary to teach experimental nuclear physics (Costa & Muleri, 2014). One of the largest challenges to involving students in hands-on activities (Herlina et al., 2022), whether at a high school or university (Nurhasnah et al., 2022), is instrumentation (Zainuddin et al., 2022). Many software programs and interactive applets are accessible online (Suba et al., 2022), and instructional materials frequently recommend analogies and computational simulation-based exercises (Bhowmik, 2011). Modern physics experiments are limited to computational simulations (Ghufron & Prayogi, 2023), which over time have been produced and exploited for their instructional value as well as to save costs and alleviate logistical challenges associated with the experimental activity (Silviana & Prayogi, 2023).

There are several drawbacks to ionizing radiation-based nuclear physics experiments (Boucher et al., 2018). Despite the existence of suggestions (Junaeti et al., 2022), high schools seldom find them since they are difficult to execute (Putra, 2022). Every nuclear physics experiment uses a radiation detector and an ionizing radiation source (Artiani et al., 2019). When using radioactive sources for instruction (Sriyani et al., 2021), they should typically be sealed (Hamdani et al., 2022), or if not (Ramadhan et al., 2023), they should have a short half-life and/or activities that don't require radiation protection because the sources should be handled by the students (Syafutri et al., 2020). In the case of detectors, they need to be sensitive enough to measure the sources being investigated (Rattyananda et al., 2022). In several circumstances, this indicates the requirement for a suitable shield to reduce background radiation (Prayogi & Marzuki, 2022).

This study's goal is to present nuclear physics experiments using readily available equipment. A low-cost gas ionization detector (ion chamber) was built, and ^{222}Rn progeny gathered from the air, gas light mantles, and thoriated welding rods were utilized as radionuclide sources. According to CLEAPSS, none of these sources engage in actions that exceed the exemption thresholds for acquiring, maintaining, and disposing of. To prevent dust or other minute particles from separating from the mantle, it is crucial to notice that the mantles should be cloth and unused (e.g., not brittle). However, this specific ion chamber has some drawbacks.

2. Experimental Method

The schematic diagram of the amplifier circuit in the room where the voltmeter doubles as an ammeter is shown in Figure 1. Two images showing the detector's construction are shown in the same figure. The same ion chamber was used for all experiments that produced the results in this research. This detector demonstrated its sensitivity to sources of low-intensity alpha particles but did not demonstrate any responsibility for sources of low-intensity beta and gamma radiation.

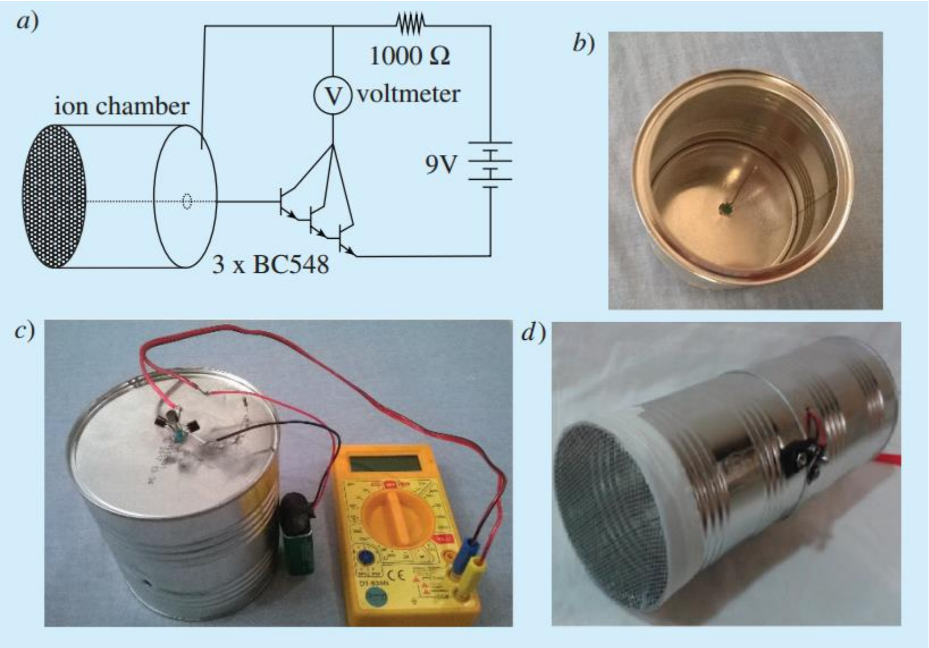

Figure 1. The schematic diagram of the amplifier circuit-enabled chamber where the voltmeter doubles as an ammeter.

Figure 1(a) shows the schematic for an ion chamber along with its amplifier circuit. Figure 1(b) shows the interior of the chamber with the central electrode (a straightened paper clip) isolated from the metal can with a plastic necklace bead. Figure 1(c) shows details of the transistor configuration and resistor on the metal that can connect to the battery and the multimeter. Figure 1(d) shows the chamber with a metal sieve window that is ready for use. Another metal container can be used to accomplish the electrostatic shielding that is required to isolate the amplifier circuit.

The purpose of this experiment is to confirm the existence of airborne alpha particle emitters. A gauze was placed in the vacuum cleaner's inlet tube to collect ^{222}Rn offspring that were present in aerosols (Prayogi & Zainuddin, 2023). In a room that had been closed for roughly 12 hours prior, the collection is carried out for 5 to 10 minutes. The ion chamber was next placed in front of the gauze bandage.

3. Results and Discussion

The gauze bandage is placed in front of the chamber after the collection, which causes a change in the voltage value displayed in the multimeter. In one instance, following stabilization, the voltage value displayed by the multimeter linked to the ion chamber was 1.10V. The voltage increased to 1.25V when the ventilated gauze was placed in front of the chamber, and when it is withdrawn, the voltage decreases to 1.10V. One might draw the conclusion that the gauze bandage turned into a weak radioactive source and that the chamber is sensitive to ionizations caused by the emission of alpha particles from the ^{222}Rn progeny that has been gathered (Frane & Bitterman, 2022). To conduct the method in various interior locations, the same circumstances may be used (Bahrum et al., 2020). The variance in voltage in each case reveals the variations in the ambient air's concentration of ^{222}Rn progeny activity in the various rooms (Prayogi, 2022). For another illustration, the same process was carried out in the basement of one of the authors' homes while altering the detector's voltage from 1.25V to 3.15V.

The range of α particles experiment made use of the ionization chamber and three various radiation sources. Three thoriated welding rods, thorium-containing gas light mantles, and 222Rn offspring were gathered by filtering the inside air of a chamber that had been closed for 12 hours. The source is placed a short distance (approximately 15 cm) in front of the detector's window, and the distance is then estimated using the voltage the detector is reporting (Abrevaya & Thomas, 2018). The range of alpha particles that the source emits in the air would be the distance at which the detector starts to react to the source if the detector is sufficiently sensitive (Susila et al., 2019). It is feasible to pinpoint the radionuclide that is emitting the particles because the range may indicate the energy of the alpha particles.

The energy of a charged particle in an absorber can be calculated from its range. An alpha particle is a heavily charged particle with a rather narrow range in a gas, liquid, or solid (Passon et al., 2018). The primary way the particle loses energy is through exciting and ionizing the atoms in its passage. The energy loss happens in several, minute chunks (Wisnubroto, 2010). Due to the alpha particle's high momentum, the slowing mechanisms do not significantly alter its orientation. It eventually runs out of kinetic energy and comes to rest (Nicholls et al., 2017). The range is the distance traveled, and it is determined by the alpha particle's energy, the material's atom density (Prayogi et al., 2021), the average atomic number, and the average ionization potential of the material's constituent atoms. The behavior of the alpha particle range in air is shown in Figure 2.

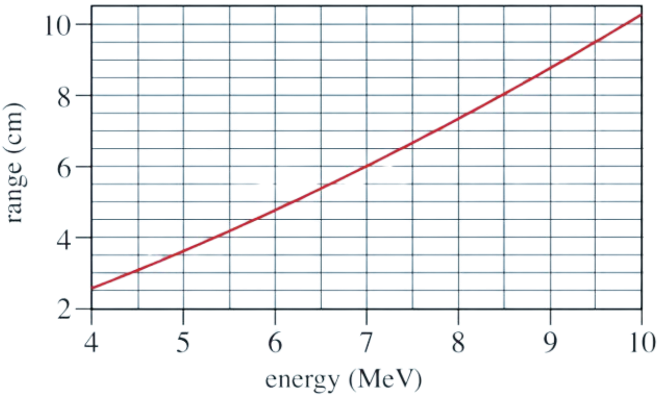

Figure 2. The alpha particle range in the air as a function of particle energy ($R = 0.325E^{1.5}$)

Range employing thoriated welding rods and a gas light mantle. Figure 3 shows the findings of the voltage fluctuation in the ion chamber detector as a function of the separation between the light mantle and the detector window. In this instance, the steady voltage was 1.36V. The voltage, which is 1.43V at 8.5 cm, starts to slowly increase. This indicates that at this distance, the mantle's highest energetic alpha particles begin to ionize the chamber's air. Figure 2 shows that an energy of approximately 8.75 MeV is associated to a distance of 8.5 cm.

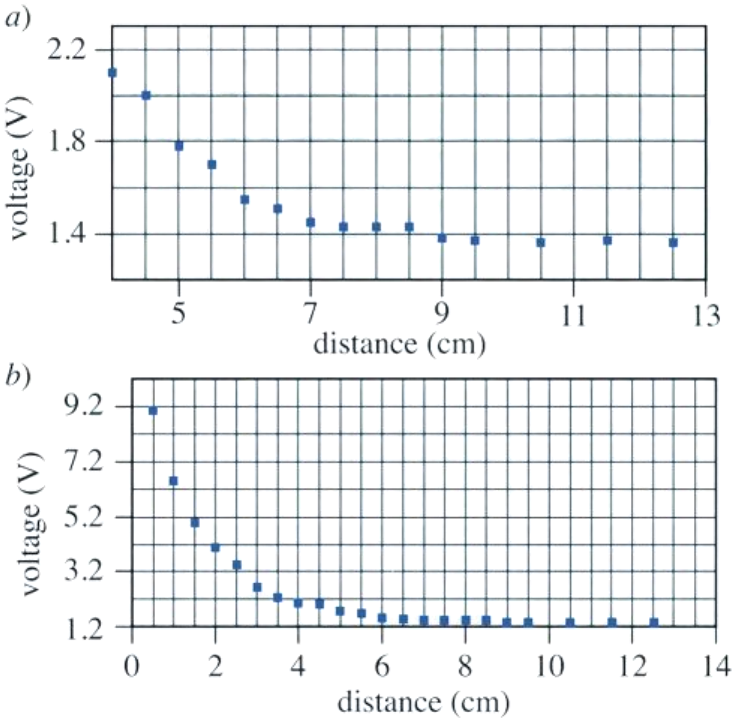

Figure 3. The range of alpha particles produced by the ionization chamber and light mantles. (a) Pay attention to distances more than 4 cm. (b) The full range of separations.

The alpha particle observed is from ^{212}Po and has an energy of 8.8 MeV, according to the alpha particles produced by the ^{232}Th decay series. A thoriated welding rod (TIG) can be used to create a graph with this comparable feature, as shows in Figure 4. In fact, we had to utilize three rods at once to collect data in order to generate the graph due to the chamber's lack of sensitivity.

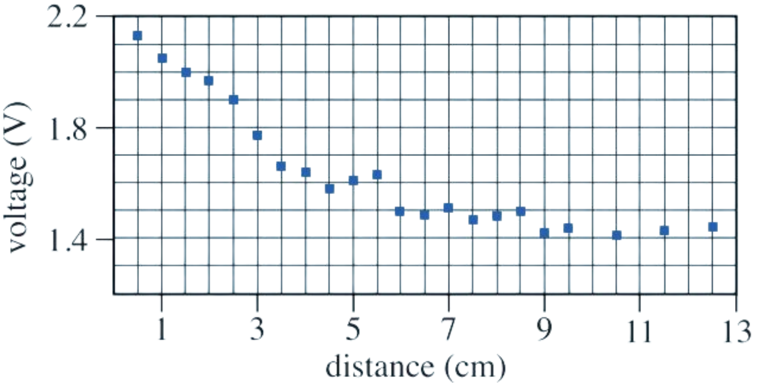

Figure 4. The range of alpha particles produced by the ionization chamber and three thoriated welding rods (TIG).

Using a ventilated gauze bandage, range. We are interested in locating the 6.1 MeV and 7.8 MeV, respectively, ^{218}Po and/or ^{214}Po alpha particles in the gauze bandage employed as the filter in experiment 3.1. Figure 5 shows the voltage change as the gauze approaches the detector. One can see how the experimental data separates from the base voltage value at 7 cm, proving the presence of ^{214}Po. The fact that the voltage significantly changes despite the minimal gauze activity shows that the chamber is sensitive enough to pick up the ^{214}Po alpha particles.

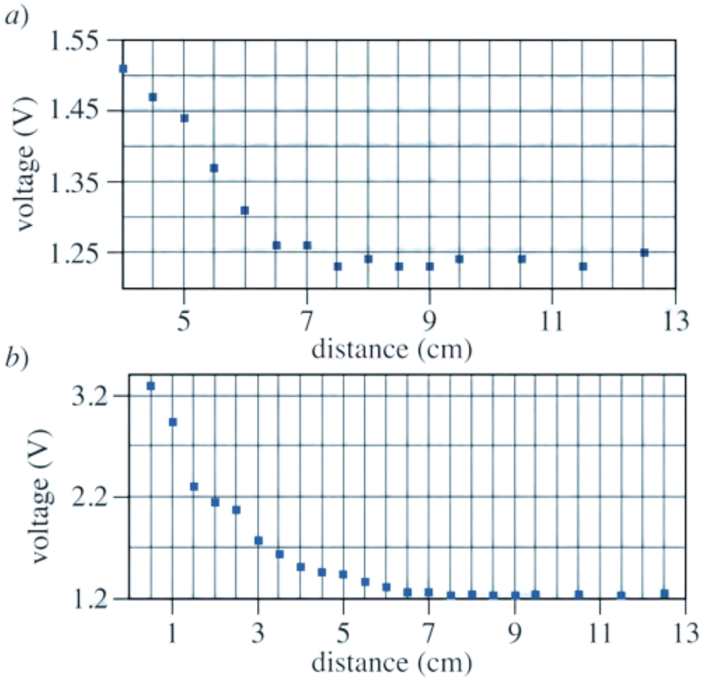

Figure 5. The range of alpha particles that might be produced using an approximation of the ion chamber made of vented gauze. (a) Pay attention to distances more than 4 cm. (b) The full range of separations.

The results of this experiment reveal that inexpensive instruments can be used effectively to teach nuclear physics concepts in education. This has positive implications in teaching nuclear physics to students who have limited access to expensive instruments. Inexpensive instruments such as the Geiger-Muller detector have been proven to be able to understand the basic principles of nuclear physics clearly and easily (Prayogi et al., 2023). In addition, this experiment also underscores the importance of measuring background radiation in nuclear physics experiments. This allows students to understand the role of natural radiation in the context of nuclear decay.

In addition, observations of background radiation variations between locations highlight geographic differences in natural radiation exposure. The use of inexpensive instruments in these experiments also sparked further discussions about resource efficiency and radiation risk management. The limitations of the instruments used remind us of the importance of safety in the use of radioactive materials in nuclear physics experiments. This encourages critical thinking and careful planning in the use of radiation sources in education.

4. Conclusion

In conclusion, this investigation underscores that while the distribution function (frequency versus Geiger Muller measurement) for the decay of a radioactive source is well described by Poisson statistics, this is not the case when an absorber is present. In this case, because of the build-up factor, the distribution function assumes a distorted width structure to a higher value than it produces and makes applying simple Poissonian statistics an approximation. This results in (i) larger errors in the Geiger Muller measurements, (ii) larger errors in the linear attenuation coefficients, and (iii) a systematic decrease in the average value of the attenuation coefficients. This experimental device, although impractical, can be used to investigate radioactive rays very effectively. As build-up factors depend on the nature, construction, and strength of the radioactive source, absorbent material, thickness, and geometry as well as the presence of shielding relative spacing between various parts of the arrangement and other factors. The results of this experiment make a positive contribution to the development of more inclusive and sustainable nuclear physics teaching methods. In addition, background radiation measurements deepen understanding of natural radiation exposure and radiation risk in educational contexts. The implications of this experiment show that a more cost-effective approach could allow more people to understand and appreciate fundamental nuclear physics concepts.

Acknowledgments

The authors thank Pertamina University and Syiah Kuala University for the support and facilities that have been provided

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