Implementation of Gamma-Ray Simulation for Educational Purposes with An Innovative Web Approach

[Marco Citossi]

Abstract—Simulations are a significant educational tool as they help the students to understand complex concepts and get to learn them in an interactive manner. Therefore, this research aims at implementing and studying gamma-ray simulation for educational purposes, with the help of an innovative web approach. The behavior of the 1 MeV gamma-rays using the Monte Carlo algorithm is studied as well. The study includes the use of a combination of three different frameworks i.e. Jupyter, AppMode and MyBinder for the development of a program to be used by the students for visualizing the simulation while learning concepts, related to the physics subject. Mostly in covid-19 epidemic students can use this approach to carry out experiments that are not possible to be conducted under normal conditions.

Keywords—gamma spectroscopy, educational, python, physics simulation

I. Introduction

In nuclear spectroscopy, spectra are a combination of radioactive sources that are created due to background signals. It is important to note that gamma rays, coming from different sources contribute to the creation of spectra. Therefore, it is essential to have a picture of the spectrum that is expected from a gamma-ray source, beforehand starting an experiment. With the help of the image, a resultant spectrum can be analyzed to detect a possible deterioration of the detection system. For the purpose of education, simulation programs are used because the usage of real radioactive sources is undesirable [1]

Educational simulations are essential tools as they help students in effectively learning different topics, especially related to physics [2]. This is due to the plethora of difficulties encountered by students, specifically when they have to visualize different scenarios to understand the basic principles of physics. With the simulation tools in place, students can imagine, interact, and develop the context of different topics, related to the subject – physics. The physics education technology simulations can help the students in understanding the concepts of physics because they are highly effective teaching tools. The tool aids in introducing new topics to the students, while facilitating them in building concepts.

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This aspect eventually leads the students to reinforce the learned ideas and concepts. Moreover, simulation tools also help in reviewing and reflecting the concepts uniquely; hence, bridging the gap between class-based activities and laboratory work.

This paper aims at using the Monte Carlo algorithm to stimulate gamma rays with an energy level of 1MeV, traveling through the media. In addition, the paper also evaluates gamma-ray spectroscopy by adopting a computational and educational approach. For this purpose, the combination of various tools such as python, Jupyter, MyBinder, and AppMode have been used to make necessary modifications to the algorithm. These tools provide a user-friendly interface that can be easily understood by entry-level users.

II. Description of the simulation methods

In radioactive decay, radionuclides lose their energy in the form of radiation. There are three types of radioactive decay, i.e., alpha, beta, and gamma decay which emit more than one photon or particles during the decaying process. For accurate and dependable outcomes, individual particles call for distinct styles of detectors. For instance, an alpha particle can be barred by a sheet of paper, while plastic can be used for blocking a beta particle. Thus, it is exceptionally futile to measure the radioactive particles at a reasonable distance. Fortunately, gamma rays are emitted by a considerable number of radionuclides. Unlike beta or alpha particles, gamma rays possess an extraordinary amount of energy that boosts their penetrative ability. Gamma-rays have a tremendous amount of energy, but have no mass; hence, making it detectable at a safe distance.

Gamma rays that are emitted from the same radioisotope possess the same energy that makes them monoenergetic. However, in a scenario where a radioisotope emits different gamma rays, it represents two or more particular energies. Thus, with this knowledge, a person can accurately tell the presence of radioactive elements adjacent to them by measuring the energy of the nearby gamma rays. For this purpose, NaI detectors are usually applied in gamma spectroscopy due to their ability to measure gamma rays along with their corresponding energy configuration and required conviction. NaI detectors are regarded as the ideal, cost-effective, practical radiation detectors. They are easily available and specialists – working in the radiation field – ought to easily comprehend their usage. However, the process of radiation detection is quite complex and it needs sufficient knowledge of ambiguity in gamma-ray interactions and the

detection systems to yield meaningful data. Ambiguity in gamma-ray spectroscopy is referred to as energy resolution, which is an essential measure for spectroscopic systems. Thus, there is a need for having a dependable method to easily assess the effects of multiple interactions and for performing numerical simulations.

Monte Carlo simulation works best in modeling multiple interactions while performing numerical simulations. Even though other methods of simulation are available to simulate the interaction of the gamma-ray beam with a medium, unlike Monte Carlo, they are complex and require a deeper knowledge of the process [3]. Monte Carlo simulation is a simple tool to simulate the interaction of the gamma-rays of 1MeV with a medium. Notably, 1 MeV can be equated to the energy of gamma rays, emitted from a radioactive source [4]

Depending on the given range of energy, the chance of gamma-rays for coherent scattering, Rayleigh scattering, or the elastic scattering, is minimal. The energy range is beneath the threshold value, which is required for its conversion to an electron-positron pair, i.e., 1.02 MeV; thus, showing incoherent scattering in which, photon's energy is transferred to electron, which is ejected due to its excited state. In the simulation, incoherent scattering is approximated with the Compton effect [5].

Incoherent scattering and the photoelectric effect have a unique characteristic property where the energy transfers to the electrons within the atom [2]. As a result, the atom undergoes through a process known as absorption, where its ground state changes to an excited state. Afterwards, de-excitation of the electrons within an atom is achieved by emitting x-rays or Auger electrons. It is important to note that, these electrons have a short free path as compared to gamma rays.

III.   Physics of the model

The travel of a photon through a medium is limited by a certain distance and is regulated by its interaction with an atom. The probabilities of the photoelectric effect or Compton effect, in this case, are proportional to the cross-section of the respective case [5].

In the case of photoelectric absorption, the complete energy transfer takes place from the photon to the medium at the point of interaction.

IV.   Algorithm and code

The code works by using two geometries that can be taken from the user interface. The geometries comprise a layer with infinite parallel faces and a cylinder. The medium is assumed to be made up of an atom, a molecule, or a compound.

For more details of the Monte Carlo code see [4]. The process involves the selection of particular parameters and process selection, which is either Compton or Photoelectric effect [6].

The algorithm was implemented through a combination of python, Jupyter, MyBinder, and AppMode, which is discussed in the later section.

V.   Jupyter Implementation of the Code

Instructors often recommend Jupyter notebook to entry-level students who are unaware of its functionalities. Instructing entry-level students to use Jupyter notebook is trivial, as they may end up changing the code that would result in different outputs because of syntax or logical errors. In order to alleviate this problem, the current study incorporates Ipywidgets. With the help of Ipywidgets, students can use GUI inside the notebook. This is a perfect way for learners to expose themselves to various functions of the Jupyter notebook.

Nonetheless, the Ipywidgets have their shortcomings too. The user has to run all the cells as an initial step and is required to have access to the code. To get rid of these two problems, the AppMode - which is an extension that turns notebooks into web applications - is adopted. According to the factory setting of the extension, the user can still access the code [7].

The Jupyter notebook uses the AppMode plugin, developed by the Swiss NCCR MARVEL, that runs the notebook while hiding all inputs cells and showing only the outputs. When combined with interactive widgets, this plugin provides a very intuitive and interactive graphical user interface (GUI) that makes it very easy for users to try out the functionalities, without having the need to know python or other programming languages. In addition, interested students and developers can still have full access to the source code (just with a click on the "Edit App" button) to understand and modify it.

Furthermore, the removal process under AppMode is quite simple. If the user wants an interactive hosting where other users can execute simple notebook operations, MyBinder comes into play. MyBinder is a server, allocated within a GitHub repository, that allows the creation of a temporary server that executes all Jupyter notebooks. It contains the content or code that one seeks to run or reproduce by creating an executable environment. In the current case, the code is a Jupyter notebook that illustrates an idea. The configuration files are used to build the environment, which is needed to run the code. To prepare a repository for Binder, the user needs to ensure that the repository is in a public online location, in this case, GitHub. The repository does not require any personal passwords or sensitive information [7]. Consequently, the combination needed for the execution of the notebook, as a web app, is free of charge. This aspect validates the adoption

and integration of combination for teaching purposes, in a more innovative way.

Jupyter notebook supports the mixing of executable code, visualization, and equation among other texts ranging from different disciplines. Precisely, it helps the students to bring together the codes, data, and prose bearing a computational background. It is available free of cost and is regarded as an excellent learning platform. It helps the students and instructors to understand each other through better problem identification while establishing a link to resources through visualization.

Incorporating Jupyter notebook allows the instructors to enhance student's understanding regarding various concepts especially in physics. Its benefits are twofold, as it enhances a student's understanding of different relevant concepts while increasing their participation during the derivation of meaningful data. Notably, the notebook allows students to increase their engagement in a subject, while actively participating in the related activities. The way in which Jupyter notebook implements the simulation is helpful, educative, and innovative. It allows users to interactively engage with the variables, at each step, to generate results [8]. Additionally, it aids the user in understanding the code as well as the entire process of simulation.

VI. Examples and discussion

The code was run with the following specifications. The depicted values were considered as inputs for a Medium of NaL and gamma-ray of 1MeV. The user was then asked to input all the parameters and corresponding values.

The appmode implementation of the code can be loaded from computer, tablet or mobile devices as a standalone webapp.

In the first example, plane geometry shows the corresponding results of the 500-photon beam. A closer look at the plot provides valuable information, related to visualization of the spatial distribution of the energy present in the plane. In the second plane geometry, the gamma rays undergo several Compton collisions before their absorption. Additionally, it can be seen that backscattering is the effect brought by several accidents with high scattering angles.
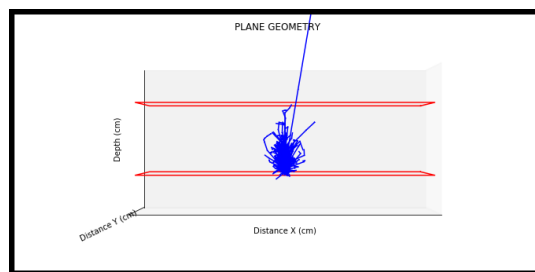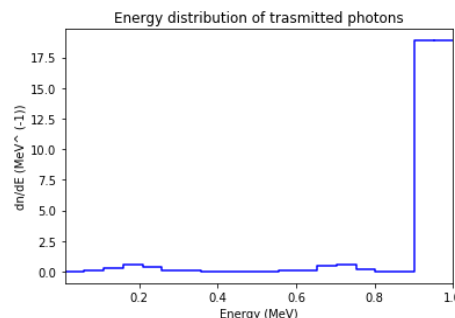

Figure 1.   Graph of plane geometry

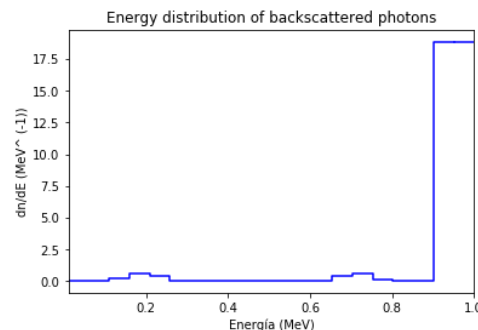Figure 2.   Energy distribbution of transmitted photons

Figure 3.   Energy distribution of backscattered photons

In the first example, the absorption coefficient generated by the simulation method is higher than the backscattering coefficient and transmission coefficient, respectively. The histogram under the energy distribution of transmitted photons shows three different photon peaks. The initial peak was achieved at around 0.2 MeV, while the second and third peaks were achieved at 0.7 MeV and 0.9 MeV, respectively. The second histogram under the energy distribution of backscattered photons shows a similar trend, as witnessed in the previous histogram.

It is essential to comprehend how gamma rays interact with matter, even at a small measurable scale. It is important to note that gamma-rays possess no mass; therefore, it is effortless to measure them at the instant they interact with other charged particles. The photoelectric effect, Compton scattering, and pair production allow the gamma rays to

interact with orbital electrons, surrounding the nuclei atoms in the detector [5]. The data recorded by the detector solely depends on the type of interaction that the gamma-rays undergoes. The electronic elements in the detector process the signal, after which it is sent to a computer for analysis. The data recorded consists of tabulated high energy photons as well as energy recorded by the detector from the photons [5]. Such data produces a spectrum, which is a pulse height histogram that is easier to comprehend. In most cases, the number of photons undergoing the interaction is plotted against the energy that is produced by the incident gamma rays. These results further highlight the importance of this technology in learning, as it is practically impossible to count the number of photons in a class setting.

VII. **Conclusion**

The examples discussed in the paper highlight the advantages of using simulations in teaching physics to the students. As highlighted, the combination of Jupyter, AppMode, and MyBinder offers a simple way of developing and executing the notebook as a web page that is free of cost. This combination is easy to implement in classroom settings, especially when the equipment to experiment with gamma-ray spectroscopy is either unavailable or impractical. Furthermore, such combinations can be used in addressing other experiments that are impossible in a school setting [9]. For example, the combination can simulate the transportation of gamma rays within a medium.

Notably, the simulations code allows more natural change of variables that can be used in addressing students' difficulties, which is otherwise impossible using the real apparatus in a laboratory. The Compton effect and photoelectric effect are invisible phenomena and the usage of the simulations is ideal in explaining their working principles. Additionally, students can also use this combination comfortably at home. This helps in extending the laboratory experiments away from their natural settings; hence, enhancing student's understating regarding significant concepts [9]. With the basic knowledge of programming, the algorithm is simple enough to understand and is easy to integrate into a computer program. Through this simulation, the students can quickly become familiar with the gamma-ray spectroscopy in the matter [10]. Additionally, it can help in testing the dependency of energy and material properties [11][12]. The examples given in this paper provide a better way of understanding the effectiveness of the method.

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