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NOTE

RadSim: a program to simulate individual particle interactions for educational purposes

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Abstract

A program was developed, *RadSim*, which can be used to simulate certain individual interactions of photons, electrons, positrons and alpha particles with a single atom for educational purposes. The program can be run in two modes: *manual* and *simulated*. In the *manual* mode, an individual particle undergoing a specified interaction with a target atom can be simulated, which essentially comes down to a graphical evaluation of kinematic equations. In the *simulated* mode, a preset number of identical particles are allowed to undergo a specified interaction type with a target atom. The exit channel of the interaction is sampled from probability distributions using Monte Carlo methods. The incoming and outgoing particles are visualized and the frequency distribution of the kinematic variables of the exit channel is displayed graphically. It has to be emphasized that *RadSim* was mainly developed for educational purposes.

1. Introduction

In the field of medical physics, a thorough understanding of radiation interactions is required. This is mostly a prerequisite for medical physicists working in the fields of radiotherapy physics, diagnostic imaging physics and health physics, but also, to a lesser extent, for the radiotherapy oncologist and therapist. Radiation interaction physics involves a wide variety of particles (photons, electrons, positrons, neutrons, protons, alpha particles, etc) which can each undergo several interaction types, followed by the production of several secondary particles as an outcome. It is not surprising that it takes most students many years to master this complex material, and many remain confused. A deep understanding of radiation interactions can aid radiotherapy physics teaching and practice at several levels.

(i) A good knowledge of radiation interactions with human tissues is essential for accurate delivery of radiation dose to tumours, while optimally sparing healthy tissue.

(ii) A clear understanding of radiation interactions in radiation sources leads to a better comprehension of the radiation characteristics of the many different radiation sources available in radiotherapy. This is equally important for both external and internal radiation patient treatments.
(iii) Knowledge of the behaviour of photons in x-ray imaging devices leads to improved understanding of the formation and assessment of medical images. It is important to understand, e.g., the blurring of image details by scattered photons.

Therefore, teaching radiation interactions plays a pivotal role in medical physics. Indeed, novel radiotherapy physics techniques—essential for the radiotherapy patient's benefit—cannot be established when the basics of the field have not been mastered thoroughly. Current teaching of radiation interactions in medical physics is done in a textbook-based fashion. This is essential to teach the basic physics and principles and to show the exact relationships between dynamic interaction variables. However, this method does not bring the subject to life, and it is not always sufficient to aid the student in clearly distinguishing the different interactions and their relative importance. Self-study outside the classroom adds very little to the classroom method. It should also be pointed out that real radiation experiments for demonstrations in the classroom are almost always impossible.

To complement textbook teaching of radiation interactions of particular interest in radiotherapy physics, a program that combines graphical and numerical teaching methods, *RadSim*, was developed. The program simulates interactions of individual particles with preset kinematic characteristics with a single atom. In what follows, a description of the capabilities of *RadSim* is given, and an example is shown.

2. *RadSim* program

RadSim was developed in the *RealBasic* software development environment (REAL Software Inc., TX). Versions of *RadSim* for Windows, Mac and Linux operating systems can be downloaded[1] at no cost. While there are many Monte Carlo simulation programs available such as EGSnrc (Kawrakow and Rogers 2001), MCNP5 (RSICC 2003) and GEANT4 (2003), to name just a few, these programs are aimed at researchers and do not offer an easy means of studying individual particle interactions for the medical physics student, nor do they have an intuitive, learning-friendly interface. Therefore, *RadSim* was developed to aid the learning of single particle interaction physics. The current version of *RadSim* can simulate the particle interactions listed in table 1 with single targets, which are atoms or electrons depending on the process modelled. The implementation of the physical processes is loosely based on the EGSnrc manual (Kawrakow and Rogers 2001), but since the program is intended for educational purposes only, not all processes have been modelled as rigorously as in the EGSnrc Monte Carlo code.

3. Example

An example serves to illustrate *RadSim*'s capabilities and operation. Figure 1 shows a screenshot of a simulation of pair production. A 4.1 MeV photon was made to interact with the nucleus of an atom with atomic number $Z = 40$. The animation (top-left panel) shows the exit channel: an electron and a positron being emitted from the interaction site, both propagating towards the right of the screen. Animations can be paused and the animation speed can be selected. Below the animation panel is the control panel where the kinematic

[1] www.medphys.mcgill.ca/radsim.

Table 1. Modelled interactions in *RadSim*.

Particle type	Interaction type	Target	Secondary particles	Remarks
Photon	Compton (incoherent) scatter	Free electron	Scattered photon, electron	Klein-Nishina theory (1929)
	Rayleigh (coherent) scatter	Atom	Scattered photon	Atomic form factors from Hubbell and Øverbø (1979)
	Photo-electric effect	Atom	Electron, characteristic photon	K-shell ionization, no Auger electrons Electron ejection direction sampled from Sauter distribution (1931)
	Pair production	Atom	Electron, positron	Leading term of the charged particle angular distribution used (Kawrakow and Rogers 2001). Triplet production not simulated
Electron	Inelastic scattering	Electron	Scattered electron, knock-on electron	Møller theory (1932)
	Elastic scattering	Atom	Scattered electron, bremsstrahlung photon	Screened Rutherford elastic scattering and bremsstrahlung kinematics as in Kawrakow and Rogers (2001)
Positron	Inelastic scattering	Electron	Scattered positron, knock-on electron	Bhabha theory (1936)
	Annihilation	Electron	Two photons	
α particle	Rutherford scattering	Atom	Scattered α particle	

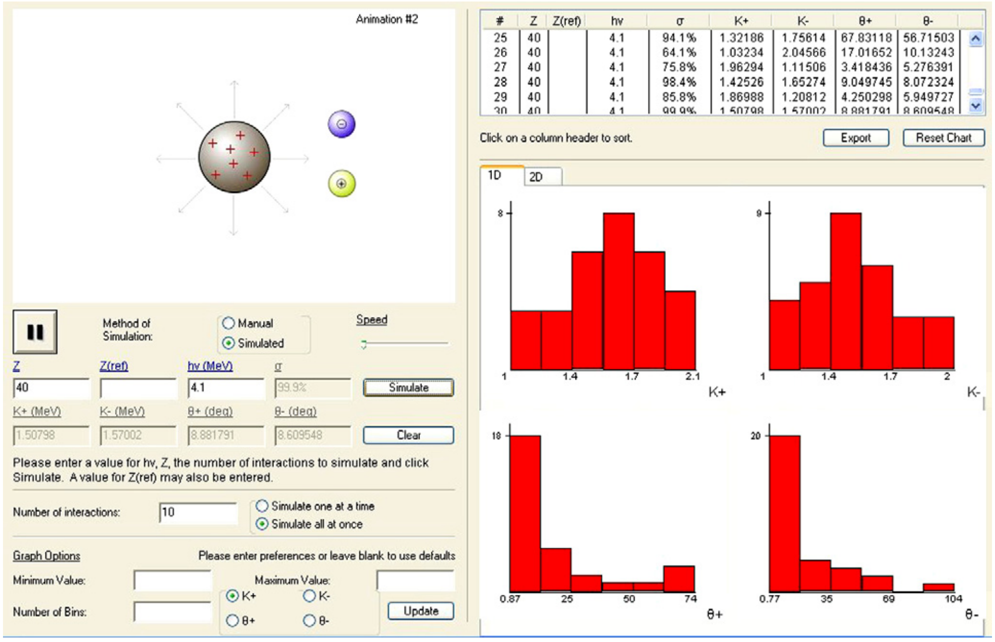

Figure 1. Screenshot of the simulation page for a pair production interaction.
(This figure is in colour only in the electronic version)

variables are initialized. These variables depend on the type of interaction simulated. The program can run in two different modes: *manual* and *simulated*. In the *manual* mode, a single particle is made to interact with a single target. The user sets a sufficient number of arbitrary kinematic variables for either the incoming or outgoing particles from which the remaining variables are calculated. In the animation screen, the same interaction is repeatedly shown. All kinematic variables for the single interaction are displayed in a table in the top-right panel. The simulation can be repeated for a different combination of kinematic variables and the results can be added to the table, which is sortable and can be exported as an ASCII file.

In the *simulated* mode, the user can only initialize the kinematic variables of the incoming particle (in our example, the photon) and the characteristics of the target (in this case, the atomic number Z). The user chooses a number of photons to be simulated. The kinematic variables of the exit channel (in our example, the electron and the positron) are determined from probability distributions using Monte Carlo techniques. This is reflected in the simulation panel where now a number of different outcomes are sequentially shown equal to the chosen number of photons. The bottom-right panel, which has no function in the *manual* mode, is used in the *simulated* mode to display statistics of the kinematic variables of the exit channel. This is done in the form of one- or two-dimensional histograms. The graphs can be customized and for the two-dimensional histograms the user can select which two variables are plotted against each other. The user can choose to simulate all photons at once, in which case the histograms appear for the number of photons chosen. Alternatively, the user can simulate the photons one at a time, in which case the histograms build progressively with time. When the simulation is finished, the user can decide to add more photons to improve statistics, if needed. The program can be set to show particle collisions run quickly (less than a second per simulation) or to very slow speeds (several seconds per photon simulation) for educational and demonstration purposes. When the option is selected to simulate all photons at once, the histograms are calculated at a much higher speed (hundreds of photons simulated per second) than the particle collisions shown on the screen.

4. Summary

A program, *RadSim*, was developed for the purpose of education in particle interaction physics, particularly as encountered in radiotherapy physics, diagnostic imaging physics and health physics. Several single target interactions of photons, electrons, positrons and alpha particles have been implemented. The *manual* and *simulated* modes allow simulation of either a single incoming particle with a single target, or a number of identical incoming particles with a single target in which case the outcome is determined from probability distributions. The program offers a user-friendly environment to explore the dependences of kinematic interaction variables. It is hoped that *RadSim* will be useful for teaching, demonstrating and studying particle interactions.

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