Teaching about the Gamma Camera and Ultrasound Imaging

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Introduction

Loyola University Maryland and Rockhurst University received an NSF Transforming Undergraduate Education in Science, Technology, Engineering, and Mathematics (TUES) grant award in 2012 for collaborative work on the Physics of Medicine (POM).

Project design

We are developing algebra-based teaching modules aimed at students who have had 0.5-1 year of introductory physics. The modules include:
- Fiber optics and light delivery (available upon request)
- Gamma camera
- Ultrasound imaging
- Pressure in the human body
  - Lungs and alveoli (available upon request)
  - Cardiovascular system

Overall teaching approach

- Underlying science. We aim to teach the physics and basic instrumentation principles through lecture, reading, hands-on activities, and homework problems.
- Classroom setting. Our modules are designed to be run in standard rooms with tables, blackboards, and projection equipment.
- Active learning. Medically relevant content modules. Active learning engages the students’ interest more strongly than pure lecture.
- Hands-on activities. These augment the presentation in textbooks and make the students observe real phenomena and interpret the results.
- Flexible set of teaching materials to fit different course needs.
- Broad audience of science students. Courses at Loyola and Rockhurst have been targeted at undergraduates studying physics, chemistry, biology, computer science, engineering, physical therapy, etc.

Teaching about the gamma camera

In many instructional settings, having students work with a real gamma camera is not feasible, but we wish that they can learn the basic principles of how it can detect gamma ray photons to form an image. We have developed two types of hands-on, optical apparatus to teach the main principles. The hands-on work is supplemented with lecture, reading materials, and homework to relate the optical apparatus to nuclear physics principles and instrumentation.

Reading about the gamma camera. Options:
- Kane, Introduction to physics in modern medicine
- Ch. 6 Images from radioactivity (Sec. 6.4 Gamma camera imaging)
- Cherry, Physics in Nuclear Medicine
- Ch. 13 The gamma camera: Basic principles
- Ch. 14 Sec. C Design and performance characteristics of parallel-hole collimators
- Our materials

Overall apparatus

From http://www.cyberphysics.co.uk/topic/s/radioact/flash/humanact.htm

Anger logic and centroid algorithm

- Since the results of the Anger and centroid calculations appear to be the same, we teach the centroid algorithm because it is used more widely.
- The positions of the “PMTs” are given to the students.
- Intensities of the signals for all PMTs are measured or given to the students.
- Using Excel, students calculate the position of the “gamma emitter.”
- A comparison is made with the known position of the gamma emitter.
- Methods to correct the values can be discussed.

Gamma camera collimator

To understand the collimator, we have designed an optical apparatus using an array of LEDs to represent sources of gamma radiation within an organ (Fig. 1). The LEDs produce diverging rays similar to the isotropic emission of gamma ray photons by radioisotopes. An array of tubes acts as the collimator, and is placed a distance \( L \) away from the LEDs. The geometry of the tubes and their position can be varied to understand the effects upon the image.

Using lenses, the results can be projected onto a large screen for a class to see (Fig. 2), or can be imaged onto a small screen placed within 1 m of the LEDs. The latter is suitable for small group work.

Complex collimators can be constructed with a 3-d printer. Fig. 5 is an example of a close-packed hexagonal array with parallel holes. This collimator is useful for understanding the point spread function, its dependence on \( L \), and resolution (Fig. 6).

Students draw ray tracings (Fig. 3) to understand the effects of \( L \), the diameter of the holes, the septum thickness, and the length of the tubes. Students can derive the width of the region that a particular collimator hole can “see” to understand resolution, i.e. the ability to distinguish two gamma emitters (Fig. 4).

Detection system: scintillation crystal, light guide, PMTs

Once the gamma ray photons have passed through the collimator, there are several stages to understanding how the position of the photon can be determined.

- Scintillation crystal
  Before working with a 2-dim apparatus (Fig. 7), each group of students works with a 1-dim apparatus (Fig. 8). The NaI crystal fluoresces when a gamma photon enters the material. In our apparatus, a green diode laser mimics the gamma photons exiting from one collimator hole. The light hits a plastic sheet that fluoresces orange.

- Light guide and optical grease
  Using calculations and ray tracings, the students understand the effects of total internal reflection and the lightness of the light guide and optical grease (Fig. 8).

- Photomultiplier tubes
  Acrylic rods (2” diameter, wrapped in foil) mimic the PMTs in the sense that an intensity signal is detected at the output (top) of each rod. The photodetector is a silicon photodiode. Reading materials and lecture supplement the presentation to teach the students how real PMTs operate.

Echoes on the oscilloscope

We would like our students to become more proficient with using an oscilloscope. Measurements and calculations can be made of:
- Echoes from the front and back surfaces of an object.
- Speed of sound in materials.
- Acoustic impedance.
- Reflection and absorption.

B-scan

By placing the sample on a linear translation stage, students can understand how a B-scan can be constructed from a series of A-scans. The B-scan of an L-shaped object (Fig. 9) is a good introduction. More complex objects can be constructed from pins. As shown in Fig. 10, the sample consists of an array of pins which form a void ("cyst") in the middle. The pins and soundhead sit in water, but the void can be filled with a sugar gel whose speed \( v \) of sound is greater than that of water. In Fig. 11, each white spot represents a pin. The pins to the right of the void appear to be displaced to the left due to the increased \( v \).

Teaching about ultrasound imaging

Because ultrasound diagnostics are so prevalent, we want students to gain an understanding of the basic principles for the formation of an ultrasound image. This includes the physics, instrumentation, artifacts, reconstruction software, and medical applications.

- Reading about ultrasound
  - Kane, Introduction to physics in modern medicine (Ch. 4 Seeing with sound)
  - Book chapter in a standard introductory physics textbook.
  - Lab handouts. “Ultrasound imaging physics” by Kane; our materials.

- Apparatus
  Small groups of students can work on an ultrasound apparatus (Fig. 9), or a B-scan imaging apparatus can be used. To project onto a screen, we use a Tek MDO3000 series scope.

Students observe pulse and ultrasound production, ringing, and time-gain compensation.

Axial and lateral resolution

Observing echoes from a single pin (0.5 mm diameter) is a good method for understanding axial and lateral resolution (Fig. 12a).

- Axial resolution: By observing the echoes on the oscilloscope, students can understand the significance of the spatial pulse length for determining resolution.
- Lateral resolution: The beam diameter determines the lateral resolution.

We would appreciate advice on:
- Improving our teaching materials.
- Checking technical accuracy.
- Ultrasound image reconstruction algorithms

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