Experiment 9

Mass of the Electron

9.1 Objective

To determine the rest mass of the electron, m_e, via γ-ray interactions (mainly Compton scattering and photoeffect) in a NaI scintillation detector. Based on the enclosed article by Mudhole and Umakantha, you will perform this experiment as outlined there.

9.2 Theory

You must become familiar with γ-ray interactions in matter, the Sodium Iodide (NaI) detector including the Photomultiplier Tube (PMT), and the Multichannel Analyzer (MCA). See the enclosed handout (mainly from ref.1). Our MCA is actually a PC with an internal MCA card (called PCA3). It digitizes pulses in the range (0-10)V and with risetimes from (0.5-30)μs.

9.3 Procedure

Warning! Check the polarity of the high voltage for the PMT, and do not exceed the maximum HV, which should be indicated on the NaI detector. If in doubt, ask before turning on the HV!

The PMT output needs to be connected to the MCA via a preamp/amplifier module. Check the signals at various places with an oscilloscope. For instance, the raw anode output of the PMT should be a negative pulse (why?). The preamp/amp module will then integrate, amplify, and shape this pulse into a positive (or bipolar with positive leading part) pulse with significantly longer rise time than the raw anode pulse. This amplification and shaping is required for the pulse to become 'digestible' to the MCA.

Also observe the PMT output as you change the HV (gain of the PMT increases with increasing HV - make sure you understand why).

Record the spectra from several γ-sources to familiarize yourself with the physics and the hardware. If the backscatter peak is weak try to enhance it by positioning some material appropriately. Use the photopeaks for calibration, i.e., channel number versus energy deposited. This relationship should be highly linear. Do a linear least squares fit. Good sources for the calibration are ^{22}Na, ^{137}Cs, and ^{60}Co, resulting in a total of 5 photopeaks. Please make sure your lab report contains copies of all your spectra. The most useful sources, based on their longevity, are (with their half-life and most abundant E_γ):
^{137}Cs ($\tau_{1/2}$= 30.2 years; 0.662 MeV)
^{60}Co ($\tau_{1/2}$= 5.3 years; 1.17 MeV, 1.33 MeV)
^{22}Na ($\tau_{1/2}$= 2.6 years; 0.511 MeV, 1.275 MeV)
^{133}Ba ($\tau_{1/2}$= 10.5 years; 0.356 MeV)
Note that in case of ^{22}Na and ^{60}Co you might also see the sum peak at higher energies. Look for it and make sure you understand what is happening there. If you take data long enough with your detector close to a wall (no Pb bricks as shielding and no sources around!) you will likely see a peak at 1.46 Mev from ^{40}K in concrete, a well-known background line in concrete buildings. Identify this peak in a background spectrum.

Also determine the resolution (FWHM) in % using your ^{137}Cs photopeak. Typical numbers for NaI detectors are 5%-10%. Another useful exercise is to take data for a certain amount of time with a weak source, then remove the source, and take data for the same amount of time with the MCA in subtract mode, i.e. performing a background subtraction.

Using your calibration determine the Compton edge and the backscatter peak (both in keV) for as many sources as possible. Then calculate m_e incl. error(in keV). It is important to collect as many data points for m_e as possible, at least four each from the Compton edge and from the backscatter peak. If, for example, you can't use the Compton edge from a particular source, try to still use the backscatter peak. An example for this is ^{60}Co - why can't you use the Compton edge in this case? For sources with two γ lines accumulate enough statistics so that you can use the sum peak and its Compton edge. In addition, take a long-enough background spectrum so that you can use the ^{40}K line, mentioned above.

Do your results from the Compton edges indicate whether the half-height point is really the best measure of the Compton edge?

Is there any systematic difference in your results between the accuracy obtained for m_e using the Compton edges vs. using the backscatter peaks? If yes, can you think of a reason why?

Why do the backscatter events show up in a *peak*, i.e. why are they not distributed over a much wider energy range?

9.4 References

[1] Melissinos and Napolitano, Chapter 8.
[2] Appendix: "Determination of the rest-mass energy of the electron...", Am J. Phys Vol 45 No 11, Nov. 1977.
[3] Appendix : Interaction of Electrons and Photons with Matter
[5] G.F. Knoll, Radiation Detection and Measurement, 2nd ed., 1989, Wiley.
[6] W.R. Leo, Techniques for Nuclear and Particle Physics Experiments, 2nd ed., 1994, Springer.