PHYSICS 221A FALL 2023 – HOMEWORK 3

Due in class Tuesday, December 5, 2023

In addition to thinking about radiation and detectors, this problem set will give you a little practice with a few basic concepts in probability and statistics, and basic Monte Carlo generation technique.

Background: W. R. Leo, Chapters 2,6,10; Particle Data Group resources, sections on radiation and detectors, and probability and statistics.

Note that for Problems 1-3, I am trying to give you some practice in quickly estimating answers using information in resources such as the Particle Data Group book rather than have you derive precise answers from derived formulae. Please do not take too long on any of these first three problems! Just provide rough estimates.

Problem 1 [10 pts]
For a charged pion entering a block of iron, at roughly what energy will the pion lose on average 10% of its incident energy before suffering an inelastic nuclear collision? Please just provide a rough estimate based on a simple algebraic calculation.

Problem 2 [10 pts]
An extensive cosmic ray shower strikes the earth, which we assume to be uniform quartz (SiO_2) rock of density $3g/cm^3$. The shower has a core of 1000 GeV muons, and a broad distribution of electrons of energies between 10 GeV and 100 GeV.

a) Assuming that the muons ionize 'minimally' until they stop, how deeply do the muons penetrate?

b) At this depth, what fraction of its original energy remains in the electron component of the shower?

Problem 3 [10 pts]
What thickness of aluminum attenuates a 3 MeV beam of gamma rays by 90%? You may find it easiest to search through the PDG's 'Passage of Radiation through Matter' to find a plot that provides the relevant information on the attenuation of gamma rays by matter.

Problem 4: the famous $\sqrt{12}$ factor! [10 pts]
Calculate the RMS resolution for an MWPC with a wire spacing of 2mm, assuming that each passing particle produces a signal in one and only one wire of the chamber. This is a very important result. (Hint: if all you see is a single channel saying it was hit, what can you say about the probability distribution of the location of the particle in the MWPC, given that single piece of empirical evidence?) If there is a region between the wires for which a passing particle generates a signal on both of the two adjacent wires, does the resolution improve or worsen?

Problem 5 [10 pts]
In an experiment, a 100 μm thick silicon sensor is exposed to a flux of 50 keV X-rays. What fraction of these X-rays interact in the sensor? You might the information available at

https://physics.nist.gov/PhysRefData/XrayMassCoef/tab3.html
to be helpful in this calculation.

Problem 6 [20 pts]
For a 50 keV X-ray interacting within a silicon sensor, the probability that the interaction will be a Compton scatter is 42.6%, with the remainder interacting via photoelectric absorption. Making use of a Monte Carlo computer program, make a histogram of the energy deposition distribution for the experiment of the previous problem. You may assume that the X-rays pass through the 100 μm thick sensor one at a time, and that the Compton-scattered X-rays exit the detector without interacting. You will need to make use of the Klein-Nishina differential cross section to develop your Monte Carlo, which is readily found on Wikipedia (google 'Klein Nishina Wikipedia' and it should pop right up).

Here are a few hints. First, recal that

$$d\Omega = -d(\cos\theta)d\phi$$

so $d\Omega$ is flat (evenly distributed) in $\cos\theta$. Next, in order to use the acceptance/rejection method, one has to normalize the distribution they want to simulate. What is the maximum value of the Klein-Nishina cross section over all θ? Finally, don't forget that we're interested in the energy distribution for this problem, not the angular distribution. How do you make that transformation? (Hint to the hint: don't overthink this by, say, trying to calculate a Jacobian. It's not that complicated!).