**Particle interaction with matter**

Understanding particle nature in matter is essential in neutron detection. One must be mindful of materials utilized in particle detectors and how they affect its performance. Knowing which interactions take place makes it possible to choose proper material for neutron converters (to maximize yield) and sensitive volumes (to optimize effectiveness), as well as surrounding electronics and other components (to minimize interference), of the detector. All types of particles, heavy, light and neutral, are present in neutron detection, though some are more interesting than others, specifically neutrons and signal generating particles.

Particles of interest in a gadolinium-based semiconductor neutron detector are neutrons, electrons and gammas (i.e. photons). Neutrons are absorbed in gadolinium and produce electrons and gammas. The reaction products generate a signal by transferring energy to the detectors sensitive volume, thus acting as neutron indicators.

The following sections will look at neutron, electron and gamma interactions with matter, to provide a ground understanding of the physics inside the neutron detector in question.

…

Particles traversing matter lose energy and/or are scattered from their original path. Particles characteristic determine which types of interaction take place and thus also its propagating nature. For instance, particles with electric charge behave quite differently from those without (i.e. neutrons). Charged particles experience intervening Coulomb forces and slow down or stop. On the other hand, neutral particles are indifferent to such forces and because of this, travel rather large distances in comparison.

It is therefore necessary to distinguish particles of different nature. The two major groups of particles are charged and neutral.

**CHARGED PARTICLES**

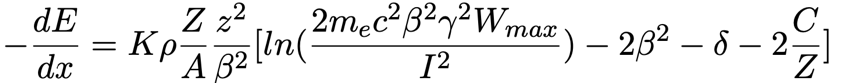
Particles with electrical charge are subject to electromagnetic forces. Matter is made up of atoms, which composite atomic electrons and nuclei. Atomic constituents are each surrounded by an electric field and in the path of a traversing particle, causes deacceleration and divergence from its original trajectory. Energy loss mechanisms of a charged particle are:

Again, one must distinguish based on particle properties, this time, namely mass.

The mass of a "heavy" particle is one atomic unit or greater. This includes protons, alpha and other ions. That leaves electrons and positrons as "light" particles, with an atomic mass is ... Less than protons. Heavy particles (e.g. ions) are less effected by a nuclei electric field than light particles (e.g. electrons). Elastic scattering of the nuclei effect both heavy and light, however, the impact is greater for the latter.

**Heavy charged particles and Bethe-Bloch**

Though there are several types of interactions, heavy charged particles mainly lose energy due to inelastic collisions with outer-shell electrons. The Bethe-Bloch formula describes their average energy loss per unit length:



Noteworthy symbols in the formula are B (representative of incident particle speed) and z (charge of incident particle). Remaining parameters are listen in table ??

B = v/c and thus, according to Bethe-Bloch, mean energy loss dE/dx is inversely proportional to v^2, the particle speed squared. As particles slow down their speed decreases and energy deposition increases, until fully at rest. The other dependency, z, shows how particles of heavier charge ionize material more effectively. (rewrite)

Electrons

Other interactions

A screenshot of a cell phone

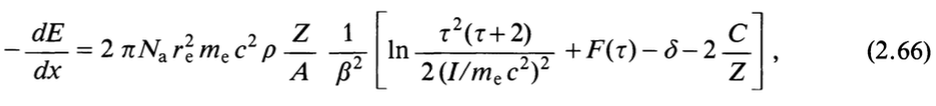
Description automatically generated

**8/29/20,**

**Electron**

Light particles lose energy via other interactions in addition to elastic scattering. The total energy loss is a combination of radiational and collisional loss.

**Collisional loss** can be described by modifying Bethe-Bloch. Light particles are small in mass, as per definition, and are prone to scattering. Like heavy particles, workings of collision also apply for light particles. However, when considering electrons, Bethe-Bloch’s assumptions of large incident particle mass and non-deviating trajectory are no longer valid and must be corrected for. Moreover, in case of an incident electron, collisions occur with identical particles, atomic electrons, and the formula must account for their indistinguishability. This changes a couple of terms in Bethe-Bloch, notably maximum allowed energy transfer $W\_max = \frac{T\_e}{2}$ for electrons of kinetic energy $T\_e$. Considering electron properties, the modified formula becomes



The particles kinetic energy is represented by t, in units of mc^2 and, for electrons,

A close up of a logo

Description automatically generated

**Meaning of the equations?! (check out Glenn Knoll)**

Light particles also lose energy by radiation. Electrons passing a nucleus experience an attractive coulomb force, exerted by the nucleus positive electric field. In a curved like manner, the electrons deviate from their straight-line path and accelerate. Accelerating charged particles emit electromagnetic waves known as breaking radiation, or bremsstrahlung. Bremsstrahlung comes at a cost of diminishing particle kinetic energy. In other words, scattered electrons lose energy and slow down.

*An electron can lose up to 100% of its energy in only one or two photons. Because of this, same energy electrons vary greatly in energy loss and path length.*

**COME BACK TO LATER:** Energy loss by collision varies logarithmically with energy while probability of radiation loss increases nearly linearly with energy; small for few MeV and in most material dominates above a few tens of MeV.

Collision loss varies logarithmically and radiation loss linearly with energy. Effects of radiation loss is small for a few MeV and becomes the dominating factor above a few tens of MeV.

**Electron Range**

Features of electron range in matter greatly attribute to the effects of elastic scattering. In only a few single collisions, electrons may lose substantial amounts of energy. Similarly, major parts of the electron energy can be transferred to just a few photons during bremsstrahlung radiation. Both cases contribute to range straggling, varying path lengths for particles of same initial energy. The effect is illustrated in figure ??. (greater effect for higher energy eletrons?)

**Backscattering effects**

Electron-nuclei scatter events ending in a large angle deflection of the electron are highly probable, due to the electrons inherently small mass. The scattering probability is, in fact, so large that many scattering electrons are backscattered; flipped 180 degrees, heading back the way they came from. Low energy electrons in high-Z materials are most susceptible to the effect. Also dependent on incident angle, backscattering is more probable for electrons approaching at oblique angles than for electrons traveling parallel with the surface normal.