Ph.D. Quals Question

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The Geiger Counter

The students enter the examiner's office to find the device pictured below sitting on the table in front of them – clicking irregularly and with a small red light flashing as it does so. The screen typically reads 0.008 mR/hr or less. They are asked what they think it is and what it is doing.

Front Back

At this early stage it is not particularly critical for them to know what it is, but they can at least notice that it says "radiation alert" on both its back and front. At this stage, if they are in doubt, the examiner points out that it is a *Geiger counter* and enquires about what radiation it is detecting. The student really should show some awareness about the radiation that is being detected, since it consists of electrical charges and high-frequency radiation photons: alpha, beta, or gamma (and x-ray) radiation, i.e., helium nuclei, electrons, and gamma (and x-ray) photons. When this has been straightened out, the examiner goes on to point out that the key sensor in the counter is a Geiger-Müller tube and that although the technology dates back to the early 1920's it is still the most widely used technology for radiation detectors. However, it has one severe weakness: the counter cannot distinguish between the different forms of radiation. Positive particles, negative particles, and high-energy photons all produce the same output from the counter. It cannot distinguish between them.

While this discussion is going on the examiner will have placed the counter on a piece of innocuous-appearing rock, which increases the clicking to a level about five times the previous background level, or more (> 0.030 mR/hr). The rock contains granite, which is naturally radioactive, but at a level that is considered harmless.

The examiner then proceeds to ask his **key exam question**: With the information that has been given about the counter, how does the student, a potential electrical engineer, think the counter works? In several cases the photoelectric effect was mentioned, but his was easily dismissed as an explanation since it involves photons hitting a surface, but the Geiger counter also responds to energetic charged particles. In the following, for simplicity, we will lump these photons together with the energetic charged particles and call them all "particles." The thinking process should have proceeded very roughly as follows:

(1) Since the response of the Geiger counter is independent of the form of the radiation, i.e., whether it is photons or particles, much less whether the particles are positively or negatively charged, about the only thing relevant seems to be the energy of the particles/photons. Given that the sensor is a tube, it should be concluded that the particles' energy leads to them ionizing some gas particles (of an assumed low pressure inert gas) in the tube through collisions.

(2) Since the Geiger counter responds to single particles, of various energies but which in macroscopic terms are not very substantial, it seems necessary for some amplification of the ionization to take place for it to be detected. At this stage it would be natural for the student to enquire if there was a voltage applied to the tube (yes; some hundreds of volts DC) or this information was given as a hint. Making the assumption (correct) that a high (positive) voltage was applied to an electrode inside the tube and that its metal walls were grounded, the electric field inside the tube would accelerate the original ionization electrons, producing even more ionization, thus creating an "avalanche" of electrons. Some students were aware of *avalanche photodiodes*, solid state devices that amplify an initial small burst of ionization on similar principles. These avalanches would be detected as a measureable pulse of current passing between the tube's electrode and its metal walls.

(3) The ions produced as part of the ionization in the gas would also be accelerated by the electric field, in the opposite direction to the electrons of course, but being much heavier they will not produce much additional ionization. Instead, they will tend to remain in the region around the electrode, creating a positive space charge that will help prevent the electrons reaching all the way to the electrode. Thus the ions act to quench the generation of avalanches.

Note: the circular patch in the back of the counter is a thin mica window that allows low energy particles to penetrate into the Geiger-Müller tube. It is protected from being punctured by a thin metal mesh.