Particle Detectors, Second Edition

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1 Interactions of Particles and Radiation with Matter

Problem 1.1
The range of a 100 keV electron in water is about 200 µm. Estimate its stopping time.

Solution:

Problem 1.2
The energy loss of TeV muons in rock can be parametrised by

$$-\frac{\mathrm{d}E}{\mathrm{d}x} = a + bE$$

where a stands for a parametrisation of the ionisation loss and the b term includes bremsstrahlung, direct electron-pair production and nuclear interactions $\left(a \approx 2\mathrm{MeV}/(\mathrm{g/cm^2}), b = 4.4 \times 10^{-6} (\mathrm{g/cm^2})^{-1}\right)$. Estimate the range of a 1 TeV muon in rock.

Solution:

Problem 1.3
Monoenergetic electrons of 500keV are stopped in a silicon counter. Work out the energy resolution of the semiconductor detector if a Fano factor of 0.1 at 77 K is assumed.

Solution:

Problem 1.4
For non-relativistic particles of charge z the Bethe-Bloch formula can be approximated by

$$-\frac{\mathrm{d}E_{\mathrm{kin}}}{\mathrm{d}x} = a\frac{z^2}{E_{\mathrm{kin}}} \ln\left(bE_{\mathrm{kin}}\right),$$

where a and b are material-dependent constants (different from those in Problem 1.2). Work out the energy-range relation if $\ln\left(bE_{\mathrm{kin}}\right)$ can be approximated by $\left(bE_{\mathrm{kin}}\right)^{1/4}$.

Solution:

Problem 1.5
In *Compton telescopes* for astronomy or medical imaging one frequently needs the relation between the scattering angle of the electron and that of the photon/ Work out this relation from momentum conservation in the scattering process.

Solution:

Problem 1.6
The ionisation trail of charged particles in a gaseous detector is mostly produced by low-energy electrons. Occasionally, a larger amount of energy can be transferred to electrons (δ rays, knock-on electrons). Derive the maximum energy that a 100 GeV muon can transfer to a free electron at rest in a μe collision.

Solution:

Problem 1.7
The production of δ rays can be described by the Bethe-Bloch formula. To good approximation the probability for δ-ray production is given by

$$\phi(E)\,\mathrm{d}E = K\frac{1}{\beta^2}\frac{Z}{A}\cdot\frac{x}{E^2}\,\mathrm{d}E,$$

where

$$\begin{aligned} K &= 0.154\mathrm{MeV}/(\mathrm{g/cm^2}), \\ Z, A &= \text{atomic number and mass of the target}, \\ x &= \text{absorber thickness in g/cm}^2, \end{aligned}$$

Work out the probability that a 10 GeV muon produces a δ ray of more than $E_0 = 10$ MeV in an 1 cm argon layer (gas at standard room temperature and pressure).

Solution:

Problem 1.8
Relativistic particles suffer an approximately constant ionisation energy loss of about 2 MeV/(g/cm^2). Work out the depth-intensity relation of cosmic-ray muons in rock and estimate the intensity variation if a cavity of height $\Delta h = 1$ m at a depth of 100 m were in the muon beam.

Solution:
