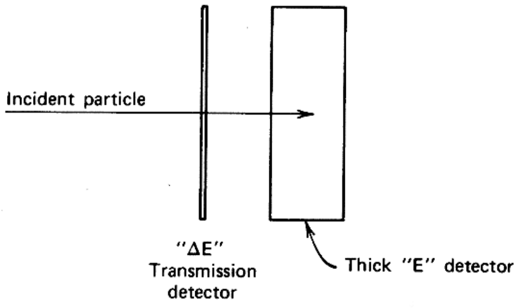
Nuclear instrumentation, partim radiation detectors: exercise 1

A ΔE-E detector system consists of a thin ΔE transmission detector and a thick E detector and allows to identify charged particles (see chapter 11). On both detectors an energy threshold is set: a detector only generates an output signal when the energy deposited by a particle in the detector exceeds the threshold value. **Particles are only observed in the ΔE-E detector system when they generate a signal in both detectors, i.e. the detectors are used in “coincidence mode”.**



(a)

In the system considered here, the ΔE transmission detector consists of silicon and the E detector is made of germanium. The energy threshold on the Ge E detector is 5,2 MeV. **Deuterons** need to have an energy of at least 13,3 MeV to be detected in de ΔE-E detector system. **Protons** with an energy above 60 MeV are not detected in the system. The Ge E detector has a thickness of 11 mm.

Task:
Write a computer program that allows to calculate the energy loss of protons, deuterons and tritons with a given kinetic energy in a layer of Si or Ge of a given thickness, using the Bethe-Bloch formula for heavy charged particles (formula 2.2b in the document h2_enloss_en.pdf):

$$S_m = \frac{S}{\rho} = S_{m,0}\frac{Z_X}{A_X}\left(\frac{Z_a}{\beta}\right)^2\left[\ln\frac{2m_e c^2\beta^2}{\langle I\rangle} - \ln\left(1-\frac{v^2}{c^2}\right) - \frac{v^2}{c^2}\right] \qquad (2.2b)$$

where the stopping power is obtained in $MeV.cm^2.g^{-1}$ if for $S_{m,0}$ the numerical value 0,307 is used and for A_X the numerical value is used when A_X is expressed in $g.mol^{-1}$.

Use your program to
(a) Determine the thickness of the ΔE detector (with an accuracy of 1 micrometer)
(b) Make a plot showing the proton, deuteron and triton energy loss in the ΔE detector as a function of particle energy in steps of 0,1 MeV or smaller, between 0 and 60 MeV
(c) Explain on the basis of this plot why a ΔE-E detector system can discriminate between the different particles
(d) What is the energy of protons that are stopped in the **ΔE detector**?
(e) Determine the energy threshold on de **ΔE-detector** of the system
(f) Determine the low energy threshold for the detection of protons in the **ΔE-E system**
(g) Determine the low energy threshold for the detection of tritons in the **ΔE-E system**
(h) What is the energy of protons that are stopped in the **complete ΔE-E system**?
(i) What energy do such protons deposit in the ΔE detector and are they still detected **in the ΔE-E system**?
(j) What step size did you use for your calculations (see below)? How did you determine it?

Data:

Ionisation potentials:	Si: 173 eV	Ge: 350 eV	
Densities:	Si: 2,32 g/cm^3	Ge: 5,3 g/cm^3	
Atomic mass:	Si: 28,0855	Ge: 72,59	
Z:	Si: 14	Ge: 32	
Rest energies:	m_ec^2=0,511 MeV		m_pc^2= 938,2723 MeV

For this exercise one is asked to write a program that calculates the energy loss of several particles in Si or Ge. For a given calculation, the variables the program should ask for are: choice of material (Si or Ge), choice of particle type (p, d or t), thickness of the material layer, kinetic energy of the incoming particle. The output of the program is simply the energy loss of the particle in the material layer. Once the program is written, one can answer the questions by using the code in a kind of "trial and error" way to estimate the required values (whereby one can converge very fast to a correct answer). For easy use of the program, it can be handy to include a loop such that after a given calculation a new value of the particle energy can be given to start a new calculation, without the need of providing all variables again (this is certainly the case to make the plot). Also a version of the program for which the layer thickness can be given with fixed other parameters can be very handy for the given problem.

To calculate the energy loss one uses the Bethe-Bloch equation (preferably formula 2.2b in the additional notes h2_enloss_en.pdf to chapter 2) and an extension of the method explained in section 1.E of Chapter 2. The method works as follows: one calculates the stopping power for a given particle having a starting kinetic energy T_1. The particle crosses now a thin layer, whereby its energy loss is given by $S(T_1).dx$. After crossing this thin layer, the particle has a new energy $T_2=T_1-S(T_1).dx$. One can now calculate the stopping power for the particle having the new energy, and let the particle pass again a thin layer with the same thickness as before. The energy loss in the second layer can be calculated in the same way as in the first layer, but now using the updated stopping power. Continuing the calculation in this way (i.e. $T_{i+1}=T_i-S(T_i).dx$), one can compute the total energy loss of the particle crossing the complete layer. It is simply the difference between the incoming energy and the energy with which the particle leaves the material.

A very important parameter for this approach is of course the thickness of the thin layers or the step size being used in the calculation. If this thickness is taken too large, the calculation will not be accurate enough. If the thickness is too small, the calculation will take a long time and one will encounter numerical problems. So, it is advisable to anticipate that the step size can be easily adapted in the program such that its effect on the calculation can be verified.

Another remark: if the material layer is thick enough, the particle can be stopped in the layer. As such, one has to anticipate this in the program. In case the particle energy $T_{i+1}=T_i-S(T_i).dx$ becomes zero or negative, the calculation has to stop and the energy loss in the layer is then simply the incoming particle energy. In case the particle energy becomes very low (below 100 keV for protons) the expression for S can give rise to non-realistically small or even negative values for the stopping power. When this happens, one can also stop the calculation and consider the particle to be stopped in the material. Whether S will become very small or negative or not at the end of the calculation for particles being stopped depends on the step size being used in the calculation.