Exercise 1

1) What is the maximal kinetic energy that can be transferred to an atomic electron in the regime where $\beta\gamma$ reduces to β ?
2) Write the Bethe and Bloch formula in this regime when neglecting the atomic shell and the density corrections.
3) Show that charged and low-energy heavy particles of the same velocity could be separated by measuring they energy loss in a thin detector.
4) For particles moving with the same velocities, show that if the detector is thin enough the average energy loss of a particle of charge z (ΔE_z) is given by : $\Delta E_z = z^2 \Delta E_{proton}$
5) Write the relativistic equation that links β^2 , T and m .
6) Plot (draw) the curves $-\frac{dE}{dx}$ as a function of T for 100-200 MeV protons, deuterons, tritium nuclei and alphas in CH_x (specific mass = 1.03 g cm^{-3} and H/C ratio x = 1.1)
7) How could this plot be used to detect and identify heavy-charged particles ?

Exercise 2

An accelerator produces 100 MeV protons and deuterons .

1) Show that both particles satisfy the low-energy condition : $2\gamma\frac{m_e}{m_0} \ll 1$.
2) Compute β_p and β_d .
3) Compute the time of flight of both particles over a 10 m distance .
4) Compute the average specific energy loss (-dE/dx) in a plastic scintillator made of CH_x (specific mass = 1.03 g cm^{-3}) for both particles, where x=1.1 is the equivalent molecular H/C ratio. We will neglect the density and atomic shell corrections.
5) Compute the average energy loss ΔE in a 1-cm thick detector (D1) made of CH_x for both particles.
6) What should be the approximate thickness of a second detector (D2) located downstream of D1, if one wants to stop both protons and deuterons inside and measure their energies ?
7) If D1 is separated from D2 by 10 m what should be the signal time difference between D1 and D2 for protons and deuterons ?
8) Could you use that to separate protons from deuterons ?

Exercise 3

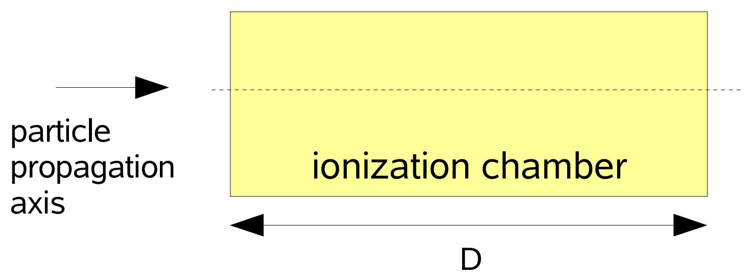
A particle accelerator produces proton or $^{12}_{6}C$ nucleus beams which are used to treat cancer patients. These particles are produced with a kinetic energy *K*=200 MeV/nucleon. The masses of these particles are : m_p = 938 MeV and m_C = 11178 MeV.

1) Compute the total kinetic energy K_P of protons and K_C of carbon nuclei.

2) Deduce from 1) the Lorentz factors γ_P , γ_C , β_P and β_C . (The *P* and *C* indexes refer to protons and carbon nuclei).

3) Could you explain why $\beta_P \simeq \beta_C$ and $\gamma_P \simeq \gamma_C$?

These particles are now detected in a ionization chamber filled with argon gas. We will consider that the particles entirely traverse the ionization chamber at (almost) a constant energy. The depth of the ionization chamber is D=1cm.



The atomic mass of argon is 39.948 g. The atomic number of argon is 18.

4) Compute the specific mass of argon gas knowing that the molar volume of gas is 24.79 l at Standard Temperature and Pressure conditions (operating conditions of the detector)

5) Which is the main physical process by which these particles will interact and deposit energy in these detectors ?

6) Do these particles satisfy the low energy condition $2\gamma \frac{m_e}{m_0} \ll 1$? where m_0 is the particle mass.

7) Compute the stopping powers of these protons and ^{12}C nuclei in MeV/(g/cm^{-2}) units in argon. For the ionization potential, use I = 215 eV. In this calculation, neglect the density and the atomic shell corrections.

8) Compute ΔE_P , the mean energy deposited by a proton when it crosses the ionization chamber.

9) Compute ΔE_C , the mean energy deposited by a carbon nuclei when it crosses the ionization

chamber.

10) How can ΔE_P and ΔE_C be used to measure the number of protons or carbon nuclei in the accelerator beam per unit of time ?

11) If all these particles stop in a volume wich is equivalent to 1 liter of water, how can we deduce from the previous question the absorbed dose rate of the patient ?

Exercise 4

What is the maximum kinetic energy of delta rays produced by 10 GeV/c K^- mesons in liquid hydrogen ? How many delta rays with kinetic energy greater than 100 MeV are produced in 2 cm ? The specific mass of liquid hydrogen is 0.071 g cm^{-3}.

Exercise 5

Plot the energy loss distribution of 100 GeV/c π^- mesons in a thin silicon layer of 500 μm.