Astroparticle physics, Excercises 1, 06.10.2009

1. What is the minimum kinetic energy of a cosmic-ray muon to survive to the sea level from a production altitude of 20 km? Assume no interacton in the atmosphere.
   Average lifetime of the muon is $\tau_\mu = 2.197$ μs and its rest mass is $\mathrm{m}_\mu = 105.66$ MeV$/c^2$.

   What is the average energy-loss of these muons in the atmosphere?

2. The mean free path λ is related to the nuclear cross section σ_N by
   $$\lambda = \frac{1}{\mathrm{N_A}\sigma_\mathrm{N}},$$
   where $\mathrm{N_A}$ is the Avogadro number, i.e., the number of nucleons per gram and σ_N is the cross section per nucleon.

   The number of particles, N, penetrating a target thickness x unaffected by interactions is
   $$N = N_0 e^{-x/\lambda},$$
   where N_0 is the initial number of particles.

   Assume target thickness of 100 mg/cm^2, 10^8 beam particles and cross section of 1 b.

   How many collisions happen? Use thin-target approximation and series expansion to create simple expression (without the exponent). $\mathrm{N_A} = 6.0 \times 10^{23}$ 1/g.

3. The range of a particle in matter is defined as
   $$R = \int_E^0 \frac{dE}{dE/dx}.$$
   Work out the range of a muon under the assumption of simplified and parametrised energy loss formula (i.e., a and b energy independent)
   $$-\frac{dE}{dx} = a + b \cdot E.$$
   What is the range of a muon of energy $E = 100$ GeV in rock? Asssume $a = 1.8$ MeV$\cdot$cm$^2\cdot$g^{-1} and $b = 4.4 \times 10^{-6}$ cm$^2\cdot$g^{-1}.

   Using typical rock density of $\rho = 2.5$ g/cm^3, what is the range in metres?

4. In principle, neutrons would be excellent candidates for primary cosmic rays. What would be their advantages? But why neutrons have not been observed as primary cosmic rays? Make a small estimative calculation. Hint: Look at the properties of neutrons.