

Mise à niveau Astroparticules

Exercices

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1. A cosmic-ray proton enters the Earth's atmosphere and collides with a proton at rest. a) What's the minimum energy of the cosmic-ray proton to have the reaction

$$p + p \rightarrow p + n + \pi^+$$

with the production of a charged pion π^+ ? b) What is the energy of the pion for an observer on Earth in this case? c) What is the mean distance that the pion travels before decaying? The pion decays producing a muon and a neutrino:

$$\pi^+ \rightarrow \mu^+ + \nu_\mu.$$

What is the maximum energy of the muon for an observer on Earth (the mass of the neutrino is negligible)?

2. An electron of energy 1 TeV interacts with a radio photon of frequency 1 GHz that propagates in the opposite direction at an angle 30° with respect to the electron trajectory.

$$e^- + \gamma_1 \rightarrow e^- + \gamma_2$$

a) What is the maximum energy of the photon after the interaction? b) The photon γ_2 reaches the atmosphere of the Earth where it interacts with a nitrogen nucleus at rest, producing an electron/positron pair:

$$\gamma_2 + N \rightarrow e^+ + e^- + N$$

What is the maximum energy of the electron and positron if all particles propagate in the photon arrival direction? c) And the nitrogen momentum? d) Could the photon produce an electron/positron pair without the presence of the nucleus?

Data:

- light speed $c = 3 \times 10^8$ m/s;
- Planck constant $h = 4.14 \times 10^{-15}$ eV s;
- proton mass $m_p = 0.94$ GeV/c²;
- neutron mass $m_n = 0.94$ GeV/c²;
- charged pion mass $m_\pi = 140$ MeV/c²;
- muon mass $m_\mu = 106$ MeV/c²;
- electron mass $m_e = 0.5$ MeV/c²;
- nitrogen mass $m_N = 13$ GeV/c²;
- mean lifetime of the pion $\tau_\pi = 2.6 \times 10^{-8}$ s.