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Problem 25 Fluorescence light

Electrons (and positrons) in air showers excite the nitrogen molecules in the atmosphere to emit fluorescence light. The light is mainly emitted in the wavelength interval from 300 to 400 nm. The maximum of the emission is at 337 nm. Each electron (or positron) stimulates the emission of about 4 photons per meter of its trajectory.

Calculate the energy radiated in fluorescence light at the shower maximum for an air shower, induced by a primary proton with an energy of 10^{20} eV.

Use the number of electrons at shower maximum according to a Heitler model. Assume the electrons propagate for one radiation length X_0. To calculate the energy of the photons, use the maximum emission only, i.e. the 337 nm line.

Which fraction of the primary energy is radiated as fluorescence light.

Problem 26 Fluorescence detector

With imaging fluorescence telescopes the amount of fluorescence light in air showers can be measured as function of depth in the atmosphere. The total amount of light collected is proportional to the shower energy.

Use a Heitler model and derive the relation (1), which describes the number of photons per square meter registered in a detector at distance r.

Using the number of electrons at shower maximum the number of photons registered per square meter in a detector at a distance r to the maximum of a shower with energy E_0 can be estimated as

$$\nu_\gamma = \frac{N_e X_0 N_\gamma}{4\pi r^2} \approx 790\,\frac{\gamma}{\mathrm{m}^2}\,A^{-0.046}\left(\frac{E_0}{\mathrm{EeV}}\right)^{1.046}\frac{1}{\left(r/10\ \mathrm{km}\right)^2}, \tag{1}$$

where $N_\gamma \approx 4\ \gamma/\mathrm{m}$ is the fluorescence yield of electrons in air and $X_0 = 36.7\ \mathrm{g/cm}^2$ (or 304 m at normal pressure) the radiation length. Absorption and scattering in the atmosphere have been neglected in this simple estimate, thus, the equation gives an upper limit for the registered photons.

Estimate the number of fluorescence photons measured in a telescope with a collecting area of 12 m^2 at a distance of 20 km to the shower maximum for a shower induced by a proton with an energy of 10^{20} eV.

see reverse side!

Problem 27 GZK Cutoff

High-energy cosmic rays (protons) interact with the photons of the 3 K microwave background if the protons exceed a minimum energy E_{GZK}. High-energy pions are produced via the interactions

$$p + \gamma_{3K} \rightarrow \Delta^+ \rightarrow p + \pi^0$$

or

$$p + \gamma_{3K} \rightarrow \Delta^+ \rightarrow n + \pi^+.$$

These interactions take place if the energy of the 3 K photons exceeds $m_\Delta\ c^2 = 1232$ MeV in the rest frame system of the protons.

Calculate the threshold energy E_{GZK}.

The energy of the photons is given as $\epsilon_\gamma \approx 2.5$ meV.

This effect has been recognized 1965 by the physicists Greisen, Zatsepin and Kuz'min. Hence, the name GZK effect.

The density of the 3 K photons is $n_\gamma = 411$ photons/cm^3, the cross section for the above mentioned interactions is $\sigma_{p\gamma} = 300\ \mu$b (1 b=$10^{-24}$cm^2).

Calculate the mean free path of the protons and use the unit [Mpc].

Problem 28 Neutrons in high-energy cosmic rays

In the literature it is argued that neutrons emitted from the center of our Galaxy could yield to an anisotropy in the arrival direction of cosmic rays at Earth at ultra high energies. Neutrons are not deflected in the (galactic) magnetic fields and, therefore, would keep the direction information about their source.

At which energies would such an effect be dominant?

Deliver answers to box "astroparticle physics" in front of secretariat Sterrenkunde HG 03.720 before 27.05.2010.
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Lecture web site: http://particle.astro.kun.nl/goto.html?astropart0910