EXCESS NEGATIVE CHARGE OF AN ELECTRON-PHOTON SHOWER AND ITS COHERENT RADIO EMISSION

G. A. ASKAR'YAN

P. N. Lebedev Physics Institute, Academy of Sciences, U.S.S.R.

Submitted to JETP editor March 24, 1961

J. Exptl. Theoret. Phys. (U.S.S.R.) **41**, 616-618 (August, 1961)

We investigate the excess of electrons in an electron-photon shower. This excess is caused by annihilation of the positrons in flight and by the Compton and δ-electrons in the cascade. It is shown that at the maximum of the shower the excess may comprise ten percent of the total number of shower particles. The Cerenkov radiation from this excess charge in a dense medium is estimated. It is indicated that this radio emission from showers produced by high-energy accelerator particles or cosmic rays in blocks of dense matter can be recorded and used. The possibility of recording radio waves from penetrating particle showers in the moon's ground, by apparatus dropped on the lunar surface, and in underground layers on the Earth in which radio waves can propagate, is also noted.

1. EXCESS NEGATIVE CHARGE OF ELECTRON-PHOTON SHOWER

THREE processes contribute to the formation of an excess of electrons in a cascade, namely annihilation of the positrons in flight and dragging of the Compton and δ-electrons into the shower cascade. Let us estimate this excess charge.

We write the equation for the average number of electrons n_- and of positrons n_+ with energies of interest to us in the form

$$\dot{n}_- = \Phi(t) - n_-/\tau_- + \dot{n}_{\delta,\,C}, \quad \dot{n}_+ = \Phi(t) - n_+/\tau_+,$$

where $\Phi(t, n_\pm, n_\gamma)$ is a function of the electron and positron pair production by γ rays and shower particles, $\dot{n}_{\delta,\,C}$ is the number of Compton and δ-electrons with energies of interest to us produced per unit time by the quanta and shower particles, $\tau_\pm$ is the lifetime of the charged particles prior to energy loss to production of the γ quanta. We put $1/\tau_+ = 1/\tau_- + 1/\tau_a$, where τ_a is the lifetime of the positron prior to annihilation.

Subtracting the equation for n_+ from the equation for n_- we obtain for the excess particles $\nu = n_- - n_+$ the equation

$$\dot{\nu} + \nu/\tau_- = n_+/\tau_a + \dot{n}_{\delta,\,C} | \approx n_+/\tau_a.$$

The value of ν can be estimated by putting $n_+/\tau_a \approx Ae^{t/T_+}$, where T_+ is the characteristic build-up time of the number of annihilating positrons. For this case we obtain

$$\nu \approx Ce^{-t/\tau_-} + \frac{Ae^{t/T_+}}{1/T_+ + 1/\tau_-} \approx \frac{n_+}{\tau_a(1/T_+ + 1/\tau_-)} \qquad t \gg \tau_-.$$

It is easy to see that $T_+ \sim \tau_-$, and therefore $\nu \sim n_+\tau/\tau_a$. Inasmuch as $\tau \approx l_{rad}/c$ and $\tau_a \approx 1/N_e\sigma_a c$, where the annihilation cross section is

$$\sigma_a \approx \pi r_0^2 (mc^2/E_+) \ln(2E_+/mc^2),$$

and the radiational length

$$l_{rad} = 137/4ZN_e r_0^2 \ln(183/Z^{1/3}),$$

we obtain

$$\frac{\tau}{\tau_a} \approx \frac{137}{4Z}\left(\frac{mc^2}{E_+}\right)\frac{\ln(2E/mc)}{\ln(183/Z^{1/3})} \approx \frac{B}{ZE_+}.$$

This ratio is independent of the density of the medium, and depends only on its atomic number Z and on the particle energy. For example, when $Z \approx 10$, with a mean particle energy at the maximum of shower development $E \approx 10^8$ ev, we obtain $\tau/\tau_a \sim 0.1$, i.e., the number of moving electrons in the shower can exceed the number of positrons by some ten percent.

2. COHERENT RADIO EMISSION FROM THE SHOWER

The presence of a moving uncompensated charge in a shower may increase by many orders of magnitude a flash of Cerenkov, bremsstrahlung, or transition radiation in the radio range. Various possibilities of recording cosmic showers by radio emission bursts have been discussed numerous times (see, for example,[1]). Coherent amplification of the radio emission from the excess charge increases the chances of registering the showers by radio. Indeed, in the range of wavelengths greater than the dimensions of the cluster, the intensity of radiation is proportional to ν^2. This value is the greater the more particles in the shower, so that radio registration of powerful electron-photon showers becomes preferable.

The density of the medium determines the dimensions of the localized region of shower particles and the range of wavelengths in which the radiation is coherent. A flash of coherent radiation is produced when there are created in the shower a large number of particles of such energy that the positron annihilation becomes noticeable, but the range of the positrons is still not too small. In air, the shower dimensions and the wavelengths radiated are of the order of hundreds of meters. In dense media, the coherent radio emission is in the $\sim 1 - 100$ cm wavelength range. Interest attaches to registering the flash of radio emission from a shower created in a block of dense matter by a high-energy particle (from outer space or from an accelerator), since it is possible to estimate from the intensity of the flash the number of particles in the shower and the energy of the primary particle. The radiation power is greatly dependent on the energy E_0 of the primary particle:

$$\Delta J_\omega \approx (e^2\nu^2/c)\,\omega\Delta\omega \approx 3\,(10^{-16}E_0)^2 \cdot \text{mw for}$$

$$\Delta\omega \sim 0.1\omega \sim 2\cdot 10^9\,(\lambda \sim 10\text{ cm}):$$

For example, when $E_0 \approx 10^{18}$ ev, the radiation power is $\Delta J_\omega \approx 30$ w. It is obviously expedient to use media in which the shower has minimum dimensions, since this permits the use of higher frequencies, where the Cerenkov radiation is more intense.

We note that other mechanisms for the separation of charges in the shower are possible. For example, V. I. Gol'danskii indicated (private communication) that the polarization of a shower by the earth's magnetic field can give rise to coherent radio emission. To him is also due the idea of using the transition radiation to register such a shower as it arrives to the earth's surface.

Increased efficiency of registration of cosmic particles and showers of superhigh energies may yield valuable information on rare processes involving gigantic energies and occurring in outer space. We consider below a possible method of remote registration of penetrating particles by using flashes of radio emission produced underground, either on earth or on the moon.

3. REGISTRATION OF PENETRATING PARTICLES AND SHOWERS UNDERGROUND ON EARTH AND ON THE MOON

The presence of extensive underground zones in which radio waves can propagate was noted recently.[2] It was established that the surface layer of the earth screens the internal zone completely against external electromagnetic interference. The small attenuation of the radio waves (particularly in substances such as rock salt, marble, granite, etc.), the dielectric constant of the rocks, and the absence of radio interference at great depths offer hope of effective registration of cosmic particles of high penetrating ability, for example muons, by means of the Cerenkov radiation of the radio waves emitted when the particles penetrate deeply underground or when a shower is produced there by these particles.

Let us estimate the effective signal produced by the shower: the radiated power due to the motion of the excess shower charge is $\Delta J_\omega \sim (e^2\nu^2/c)\,\omega\Delta\omega \sim 30\,\mu$w when $\nu \sim 10^7$ and $\Delta\omega \sim 0.1\omega \sim 2\times 10^8$ $(\lambda - 1)$ meters. Estimates of the absorption path l, for not too short wavelengths, $l \approx \sqrt{\epsilon}c/2\pi\sigma$ (see[3]), based on values of the conductivity σ of pure rocks such as salt, marble, or granite (see, for example,[4]), show that the absorption paths are greater than the distance R of interest to us, which is on the order of a kilometer to the point of reception. The field intensity of a signal equivalent to the radiated power is $\mathscr{E} \approx (e\nu/cR)\sqrt{\omega\Delta\omega} \sim 30\,\mu$v/m, which is many times greater than the level of internal noise of an ordinary receiver ($\mathscr{E}_{\text{noise}} \approx 0.1\,\mu$v/m — see, for example,[3] p. 88).

It must be noted that the dimensions of rocks in which interactions can be registered are commensurate with the radiation length for a muon in a dense medium (on the order of several kilometers), thus permitting more efficient registration of the muons by means of the electron-photon showers that they produce. The absence of external radio interference allows amplifiers with low internal noise to be used and to register flashes of radio emission from groups of mesons of a shower produced in the atmosphere, or from individual mesons.

We note that the generation of radio waves by cosmic particles and by showers should be more intense in the ground of the moon, which has no magnetic field or atmosphere, and which permits all cosmic rays of any energy to reach its surface; the absorption of radio waves in the ground of the moon should in this case be small even near the surface. This facilitates the registration of flashes of radio emission of showers in the ground by means of suitable apparatus dropped on the moon.

In general, the importance of ground-wave radio communication on the moon will apparently be great, owing to the lack of a Heavyside layer and to the large curvature of the moon's surface, which makes it impossible otherwise to communicate by radio between two remote objects on the moon's surface.

[1] J. Jelley, Cerenkov Radiation and Its Applications, Pergamon, 1958, Chapter II, Section 5.

[2] Radio-Electronics, **31**, No. 10, 6 (1960).

[3] Al'pert, Ginzburg, and Feĭnberg, Rasprostranenie radiovoln (Propagation of Radio Waves), Gostekhizdat, (1953).

[4] Sb. fizicheskikh konstant (Collection of Physical Constants), ONTI, 1937, p. 202.

Translated by J. G. Adashko
109