AN EXPERIMENT FOR MEASURING THE CHEMICAL COMPOSITION OF PRIMARIES IN THE AIR SHOWER REGION

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Jain, Lohrmann and Teucher$^{1)}$ have recently investigated with emulsions the primary spectra up to an energy

$E = 4 \times 10^{12}$ eV for heavy nuclei and up to
$E = 6 \times 10^{12}$ eV for α-particles.

At these energies the primary composition is still substantially the same as at lower energy. Less systematic investigations by many different groups extend into the air shower region, up to 10^{14} eV and show approximately the fraction of α-particles and heavy nuclei which is expected if the composition remains essentially unchanged. The chemical composition of the primary cosmic radiation is therefore a property which is independant of energy up into the region where air showers are produced.

As is shown elsewhere$^{2)}$, a formula which represents the chemical composition correctly by groups of elements as a function of energy per nucleon $\mathcal{E}$ and of total energy, E, is the following:

$$n(\mathcal{E}, A)\,d\mathcal{E}\,dA = \frac{F_o\ d\mathcal{E}\,dA}{A^{\sigma+1}\,\mathcal{E}^{\gamma+1}} \quad \text{and}$$

$$n(E, A)\,dE\,dA = \frac{F_o\ dE\,dA}{A^{\sigma-\gamma+1}\,E^{\gamma+1}} \quad \text{particles}/\text{m}^2,\ \text{sec, ster,}$$

where $F_o = 1{,}7 \times 10^4$,
$\sigma = 2.0$ and γ lies between 1.45 and 1.65.
(All energies are expressed in GeV).

This formula predicts that the incident primaries which carry a given energy, E, are distributed among various charge groups as follows:

	H	He, Li, Be, B.	C, N, O, F.	$Z \geq 10$	$\langle A \rangle_E$
$\gamma = 1.45$	53.4 %	21.2 %	6.2 %	19.2 %	8.0
$\gamma = 1.65$	38.5 %	19.5 %	7.0 %	35.0 %	13.6

It may be possible to determine the charge composition of the primary radiation even beyond the emulsion region i.e. between 10^{15} and 10^{16} eV, although not as directly as can be done by observations with emulsions. For this purpose an experiment has been built up which is based on the following assumptions:

a) At very high energy each nucleon belonging to the primary particle acts as an independant unit.

b) In each of the approximately 16 collisions which nucleons suffer in traversing the atmosphere, they lose a comparatively small fraction (ca.25-30%) of their energy to secondary particles and emerge, still carrying between 70 % and 75 % of the incident energy.

The arrival of a complex nucleus of atomic weight, A, and energy per nucleon, $\mathcal{E}_o$, implies then the arrival of A nucleons at sea level, each carrying an energy of order $\mathcal{E} \simeq \frac{\mathcal{E}_o}{100}$, confined to a very small target area. Their energy should exceed the energy of secondary nucleons and of π- mesons which are produced on the way, by a very large factor. They also should be much more collimated than secondary particles of the shower.

The size of the target area can be estimated. If K is the fraction of energy retained by a nucleon after each meson producing collision, P_t the transverse momentum transferred by the primary in each collision and λ the interaction mean free path, then the angular deflection suffered in a collision at the atmospheric depth, x, is given by:

$$\vartheta(x) = \frac{P_t}{\mathcal{E}_0 e^{-x(1-K)/\lambda}}$$

Existing evidence, obtained at somewhat lower energies, indicated that both K and λ, as well as that fraction of the transverse momentum which goes into the π-meson component are reasonably independant of the energy $\mathcal{E}_0$. Thus the divergence of nucleons due to meson production at height h should be of order:

$$s(x) = h(x)\vartheta = \frac{P_t}{\mathcal{E}_0} h_0 e^{x(1-K)/\lambda} \log(x/x_0),$$

where $h_0 \simeq 8$ km is the characteristic height for a decrease of atmospheric pressure by a factor 1/e.

If one uses K = 0.7, $\lambda = 65$ g/cm², one finds that s has a broad maximum at $x \simeq 4.2\lambda = 275$ g/cm². For $P_t = 1$ Gev/c, $s_{max} = \frac{4.6 h_0}{\mathcal{E}_0}$ or 30 cm if $\mathcal{E}_0 = 10^{14}$ eV and 3 cm if $\mathcal{E}_0 = 10^{15}$ eV.

The cumulative effect of ca. 16 meson-producing collisions at different altitudes should increase the spread to about 1 meter for $\mathcal{E}_0 = 10^{14}$ and 0.1 meter for $\mathcal{E}_0 = 10^{15}$.

One is therefore led to the phenomenon which Grigorov[3], Nikolskij[4] and others have called structural cores, i.e. the presence in an airshower core of several nuclear active particles with practically identical energies much higher than that of other nuclear active particles near the showercore.

Since the detector used by Grigorov et. al. was rather small (0.6 m²), just comparable to the predicted target area for primary nucleons with $\mathcal{E}_0 \simeq 10^{15}$ ev, it is expected that the fraction of cases in which multiple cores are observed, should increase as the target area contracts and the number of primary nucleons increases; it should therefore increase with energy and size of the air shower.

If one wants to measure the atomic number of the primary of an air shower and if this line of reasoning is correct, then it will be necessary to observe all high energy nucleons within about one meter from the shower axis. This demands larger detectors for NAP's than have been employed until now. The specifications for such a detector are that it should detect high energy nucleons efficiently in the presence of more than 1000 electrons in an area of several square meters and make it possible to measure their energy accurately.

The most important component of the apparatus used in this experiment is a set of two large area spark counters in coincidence. Each consists of 1/8 "brass welding rods, 1/8" apart and placed 1/8" above a polished stainless steel plate. A clearing field is maintained between the rods and the base plates. High voltage is applied whenever a dense electron core produces a large light pulse in the liquid Czerenkov counters at the bottom of the assembly.

Counting efficiency for single charged relativistic particles can be varied from 0.2 to 90% by changing the voltage supplied to the sparkcounter. When operating at an efficiency of 5% for cosmic ray μ-mesons, polonium α-Particles are counted with 100% efficiency.

For such counters placed in coincidence above one another and operated at an efficiency of 1% for minimum ionizing particles, are insensitive to the passage of several thousand electrons, but respond with very high efficiency to the passage of narrow jets of electrons, produced by local penetrating showers. By placing the trays below a cloud-chamber as well as a lead converter and a horizontal G-5 emulsion, one can see that the two sparks give the direction of the electron jets correctly and respond to jets with as few as 5 parallel minimum tracks in a field of view of the microscope (100 μ diameter)

The apparatus operates as follows: High energy nucleons incident on the water tank interact and give rise to high energy π_0-mesons, which decay into γ-rays, but do not initiate electron-photon cascades until they reach the 5 cm Pb plate below the water tank. Narrow electron-jets emerge from the lead plate and traverse a nuclear emulsion before being detected by coincident sparks in the two spark counters. The sparks are photographed and used to identify the particular piece of emulsion in which the jet is to be found.

Since all γ-rays have to traverse the same amount of lead and since the angle of incidence is known from the spark photographs, and the direction of the tracks in the emulsion, the number of electrons is a measure of the energy given to the π_0-component and therefore a measure of the energy of the nucleons which interacted in the water tank. The entire arrangement is triggered by large pulses in the liquid Czerenkov counters below the assembly.

The full scale apparatus has begun to operate only recently. By demanding a certain minimum size for the pulse in the Czerenkov counters the counting rate is adjusted to about 2 counts per day. At present it is only possible to state that a large fraction of all shower cores contain several high energy nucleons of comparable energy.

Neutron piles and unshielded counter trays at various distances from the apparatus serve to measure at the same time other properties of the air showers.

References

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