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ABSTRACT

The evidence for a change of the chemical composition of the primary cosmic ray flux at high energies is reviewed. An interpretation using the fluctuation origin of cosmic radiation is given. It is found that there may also be an increase in the total inelastic interaction cross-section at high energies.

Recently a number of experiments have been performed that indicate the changing nature of the chemical composition of the primary cosmic ray flux at very high energies. They include (1) the existance of multicore extensive air showers (EAS); (2) the Russian measurements with satellites; and (3) the measurement at Mt. Chacaltaya of the residual proton flux.

All of these experiments are inconclusive at the present time. However, the question of the chemical composition in the high energy range of the primary radiation is one of the main questions in present cosmic ray origin. It has long been felt that as one goes to higher energies, the composition should gradually change form one dominated by protons to one in which the heavy component (H, $Z \geq 10$) is the most predominant. We will consider briefly each of the results and then make a plausible extension of the fluctuation origin of cosmic radiation to interpret the observations.

(1) Multicore EAS

Many groups have reported the existance of multicore EAS at high energies.(1) These are events in which the electron distributions in the plane of the shower front show separate peaks. Normally there are two cores but it is not unusual for several cores to be present. Most of these experiments find rather high values of transverse momenta that are associated with collisions of energy greater than approximately 10^{14} eV. A possible explanation is that we are observing the breakup of heavy nuclei in the incident cosmic radiation. That it is mainly a high energy phenomenon might be due to a dominance of heavy particles in the primary flux. This is far from being clear cut. McCusker(1) points out that Monte Carlo calculations indicate these events are not due to very heavy primary particles and normal transverse momenta. The problem here is what we should take for normal transverse momenta at these high energies.

(2) The Russian Satellite Data

Two satellites were flown containing ionization calorimeters to determine the energy of the incident particles(2). The total flux of cosmic ray particles was measured. The proton component was also reported to have been measured. This component becomes steeper in slope above 10^{12} eV. The Russian group also points out that to explain their measurements at mountain altitudes of the residual proton flux, i.e., those protons which reach the mountain altitude without inelastic interactions in the atmosphere, a steepening of the primary proton is likely. There is, however, the possibility that the cross-section of the proton interaction with air nuclei at high energies ($> 10^{12}$ eV) begins to increase. Because of the difficulty in matching this spectra with the spectra observed by EAS studies and other methods, we will not use this spectra in our analysis below. However, we note that this is a clue to the change in composition of the primary flux.

(3) Mt. Chacaltaya Residual Proton Flux

The Japanese-Bolivian(3) group at Mt. Chacaltaya has begun a study of the residual proton flux using the 60 m^2 scintillation detector. The proton spectrum should be a direct reflection of the primary flux if there is not a sudden change of the nuclear interaction mean free path in the energy range observed. After 40 days running time, the preliminary results show that the proton spectrum has a slope of about 2.45 in the range of $\sim 10^{13}$ to 10^{14} eV.(3) These results are not final but will probably remain approximately the same.

It is interesting to note that Neito(4) has suggested that most of the above data can be explained by the existence of a strangeness-zero, neutral, vector boson (W) with a mass of about 30 GeV and strong coupling to muons. But, in like manner, the analysis of this paper will also attempt to explain this information form a different viewpoint. Regardless of which, if either, proves to be true, the proposed possibilities are of fundamental importance.

When one considers the origin of cosmic radiation, one usually assumes a sudden injection of particles in time, momentum and space. One then requires appropriate boundary conditions for the various regions through which particles pass. We will take the case of a source that gives all particles the required injection energy, but the particles' acceleration is within a turbulent region surrounding the source. The spectrum is explained by a continuous deceleration in which statistical fluctuations dominate(5). This conclusion is imposed by the observed spectra. The agreement with the measured spectra is good. The form of the primary cosmic ray flux is found to be

$$J(>p) = \frac{\phi}{(\gamma-1)} \left(\frac{P_o}{P}\right)^{\gamma-1} \tag{1}$$

where ϕ is approximately a constant, p is the momentum of the particle and

$$\gamma - 1 = \frac{k(k-1)}{8} \ln (P/P_o) + \frac{1-k}{2} \tag{2}$$

Here k is a constant of order unity that couples the average momentum change to the average fluctuations in the momentum. Note that $k < 0$ and $P > P_o$. In an analysis of source requirements(6) we have found that P_o is approximately the momentum of a particle at minimum ionization. Thus we would expect $P_o(Z) = P_o$ (proton) Z^2.

If one uses the relative content of nuclei with a given total nucleus energy at 10^{10} eV(7) to normalize the amount of p,α,L,M and H groups of nuclei, and take $k = -0.37 \pm 0.01$, P_o (proton) = 3 GeV/c, we obtain the results shown in Fig. I. We have not considered the effects of particle propagation and fragmentation in detail but have, as a first approximation, taken the measured low energy composition. In a later paper this will be considered in a more elaborate fashion. Note that we are restricted in our choice of P_o to values approximately equal to 3 GeV/c. Thus k becomes the only way we can vary the slopes. The slope of the proton component is about 2 in the energy range 10^{13} to 10^{14}. This cannot be increased without destroying the fit to the total flux. This seems to imply that perhaps there is also an increase in the inelastic interation cross-section with air nuclei at these energies.

To the extent that one believes the fluctuation origin of cosmic radiation(6)(7), the change in the chemical composition of the primary flux at high energies can be explained in a natural way. There is also, then, some hint that the total inelastic cross-sections may be increasing with energy. Both of these questions will be more fully understood when the measurements of the primary flux by high flying balloon observatories are made.

It is a pleasure to thank Drs. M. LaPointe, Y. Toyoda and G. Mejia for the information from the Mt. Chacaltaya work.

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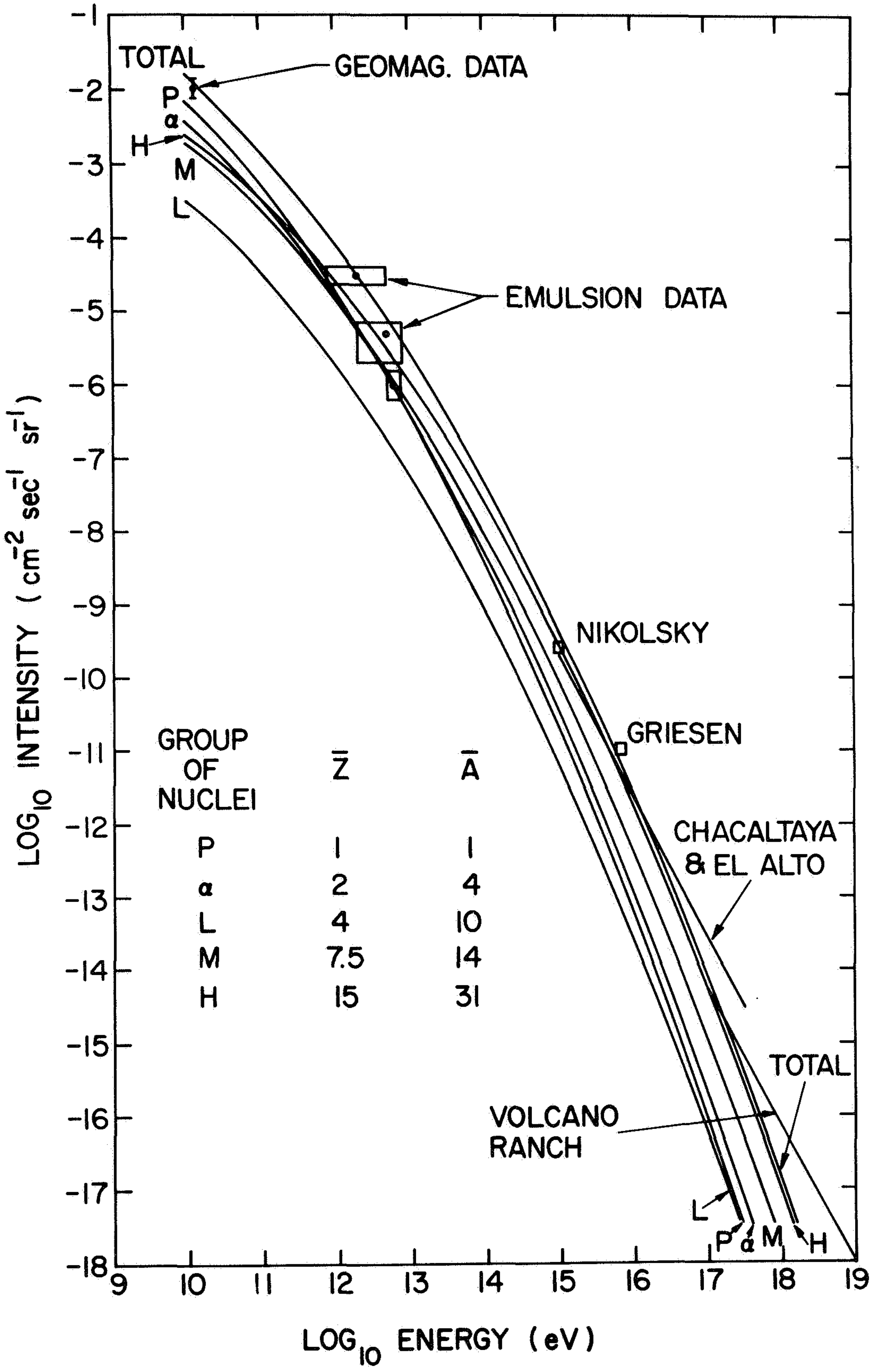
FIGURE CAPTION

Fig. I The Integral Primary Cosmic Ray Flux. The experimental points are adapted from Ref. 6.



GROUP OF NUCLEI	$\bar{Z}$	$\bar{A}$
P	1	1
α	2	4
L	4	10
M	7.5	14
H	15	31

Fig. I