The Cosmic Ray Energy Spectrum and Chemical Composition at the Knee Region

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ABSTRACT

It has been shown that there is the break in energy spectrum of cosmic rays above 10^{15} eV/particle by the air shower measurements. The direct observation by our new emulsion chambers with the extensive use of screen type x ray films extended the energy region to more than 10^{14} eV/particle and we can infer the chemical composition as well as the energy spectrum in the knee region. Our indication is that heavier elements would not dominant and the break would look more milder than air shower measurements, though the the direct observation is required.

1.INTRODUCTION

The steepening of the energy spectrum can be due to the exhaust of acceleration mechanisms or the rigidity dependent confinement mechanisms. Thus its existence is crucial for cosmic ray physics. Actually air shower experiments have been reporting the knee of energy spectrum above 10^{15} eV [1], but because of its indirect measurement, the chemical composition is not definitely determined yet at this energy region.

We have been studying heavy cosmic ray primaries, using the new type of emulsion chambers with screen type x ray films [2], and extended the energy regions explored up to 10^{14} eV/particle for iron nuclei. Before that, we studied the energy spectra of protons and helium nuclei by the conventional emulsion chambers [3]. Combining these results with other measurements, we can make up all particle spectrum which reaches more than 10^{14} eV/particle and can extrapolate the chemical composition and all particle energy spectrum to the knee region. In this report, how the all particle energy spectrum is made up from energy spectra for each elements is explained. The comparison of this spectrum with other experiment is made and discussions are given.

2.ALL PARTICLE SPECTRUM

2.1 Proton and Helium spectra

Proton and helium consist of substantial parts of all energy spectrum. In addition to our previous measurement [3], we use other measurements referred to 4),5),6). The agreement among these are not very good, thus we do not use the simple least square fit but make the band which contain the all measurements more or less as shown in Fig. 1. Here note that we do not use the Proton satellite data [7] for protons and helium nuclei.

2.2 Heavier Element spectrum

For the heavier elements, we also use other measurements[8] with ours [2] as shown in Fig. 2 and 3. In our chambers, the energy spectra for Si, S and Fe are measured. For the details to get the absolute intensities for each element, see ref.2). The line for each element is drawn going through the all measured points and dashed part is the natural extrapolation of the solid part with measurements.

2.3 All particle spectrum

Summing up the each spectrum discussed above, we make the all particle spectrum as shown in Fig. 4, where for JACEE[5], × for Proton satellite[7], +, for air shower data [1] . The dotted region reflect the uncertainty of the energy spectrum of protons and helium nuclei. The uncertainty of heavier components is not so significant as that of proton and helium. The energy fraction of each element vs primary energy per particle is shown in Fig. 5.

In Fig. 4, the agreement of all particle spectrum below 5×10^{13} eV/particle with the Proton satellite data is remarkable but above 10^{14} eV/particle other measurements are well outside of our band. Our extrapolation to the knee region is hard to reconcile with the previous measurements.

The iron spectrum which become more dominant as shown in Fig. 5, would not increase any more from our measurements in Fig.4. Thus the iron itself is hard to explain the enhancement reported by the previous direct measurements and air shower experiments. If there is any break, then it could be softer than it looks now.

In Fig.6, the average mass number of cosmic primary nucleus is shown[9]. This is mainly determined by proton, helium and iron nucleus, which we measured. Again our measurement of the solid line with dotted area is lower than the result of JACEE.

3.DISCUSSIONS

Although our observation has not reached to the knee region yet, we can naturally extrapolate the energy spectrum and can see the chemical composition. As shown in Fig.4, the air shower data are somewhat higher than our extrapolation and the break can be more milder than measured so far. And there is no indication of the increase of heavier components. Specially it is worth noting that JACEE data indicate the enhancement of sub iron group because their iron data agrees reasonably well with ours.

Of course, anything can happen in unobserved region, but if we take the moderate position we could say the above. This results increased the importance to measure the knee region directly in order to answer the question raised by the knee. We are planning this observation which is discussed elsewhere[10].

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Figure Captions
Fig.1 Fluxes of proton and helium components as a function of energy per particle
Fig.2 Fluxes of carbon ~ magnesium
Fig.3 Fluxes of silicon ~ iron
Fig.4 All particle spectrum
Fig.5 Fraction of cosmic ray elements relative to the total flux
Fig.6 Average value of mass number as a function of particle energy

Fig.1

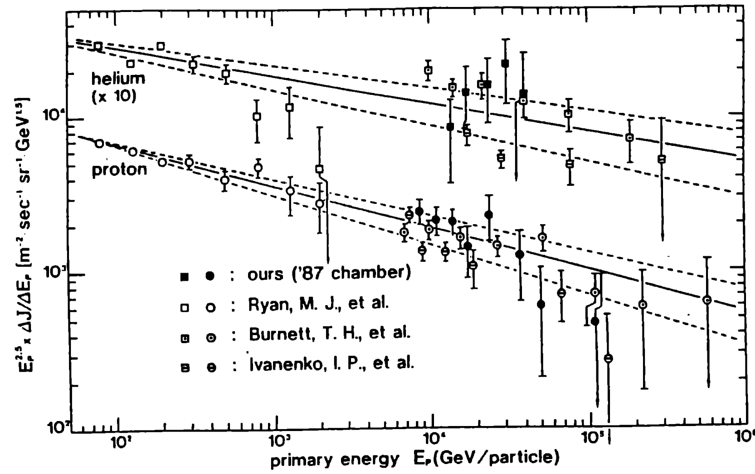

Fig.2

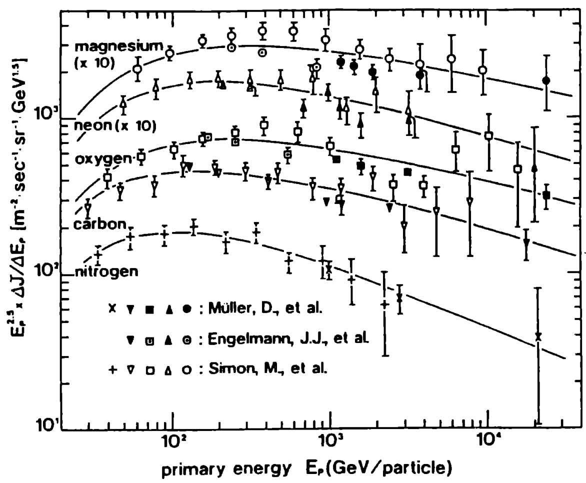

Fig.3

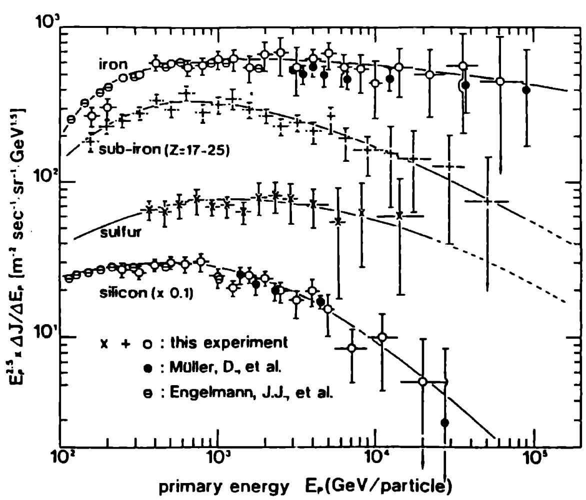

Fig.4

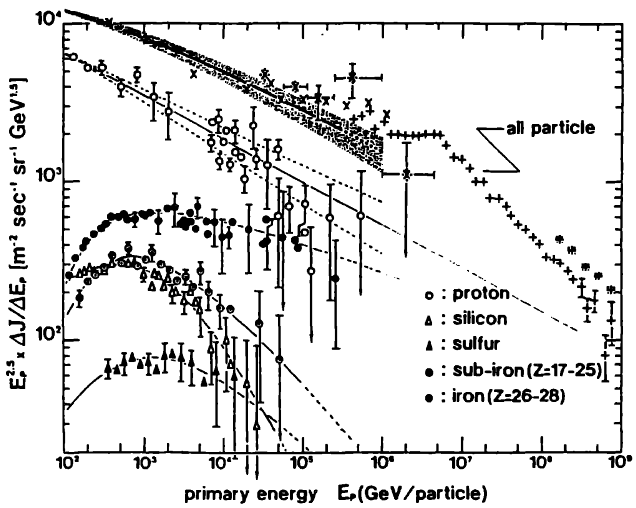

Fig.5

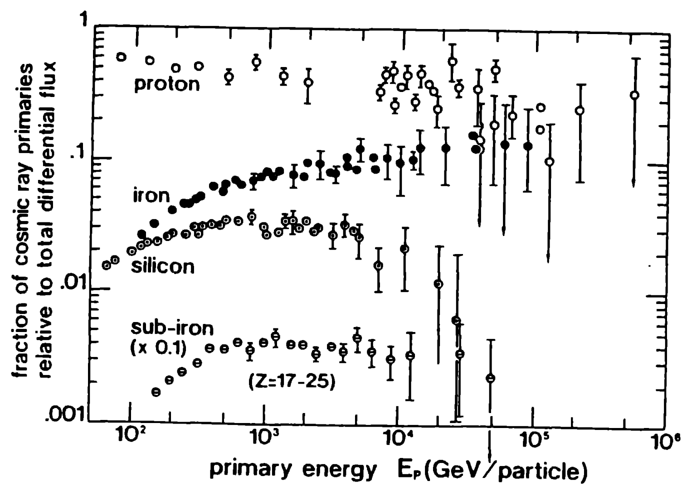

Fig.6