ENERGY SPECTRUM OF VH-NUCLEI OBSERVED WITH EMULSION CHAMBER

T. Matsubayashi, M. Noma*, T. Saito**, Y. Sato+ and H. Sugimoto**

Department of Physics, Showa Yakka College, Tokyo, Japan.

*Department of Physics, Yamagata University, Yamagata, Japan.

**Cosmic Ray Laboratory, University of Tokyo, Tanashi, Tokyo, Japan.

+Science and Engineering Research Laboratory, Waseda University, Tokyo, Japan.

The observed energy spectrum of VH-nuclei and one possible explanation of this result are shown. Measurements were performed with balloon-borne emulsion chambers, which were flown from Sanriku Balloon Center in Japan to study of cosmic ray particles at energies above 1 TeV/nucleon. In this paper, the preliminary results of VH-nuclei at several tens of Gev/nucleon are reported.

1. Introduction. Recent observations of the energy spectra and composition of cosmic ray nuclei at high energies lead to interesting results that the abundance of galactic secondary nuclei decrease with energies as compared to the abundance of mostly primordial nuclei (Juluiusson et al,. 1972; Smith et al., 1973; Oremes et al., 1973). Ramaty et al. (Ramaty et al., 1973) have in addition reported that the difference between the spectra of iron and the other primordial nuclei is significantly larger than that between the spectra of the primary and secondary nuclei. They came to the conclusions that the enhancement of iron at high energies is due to effects occurring at the source and that iron is produced by a different mechanism other than the rest of the primordial nuclei which have the same spectrum as having a common origin.

In this paper, we report the energy spectrum of VH-nuclei ($Z \geq 20$) obtained with balloon-borne emulsion chambers (BEC), which were flown from Sanriku Balloon Center for about 14 hours on May 1973 (BEC-I) and for about 10 hours on June 1974 (BEC-II) at an altitude of 10 g/cm^2.

2. Experimental.

Instrument. Schematic diagrams of the emulsion chambers are shown in Fig. 1. The emulsion chamber is composed of three parts, upper chamber (I), middle chamber (II) and lower chamber (III). Upper chamber of BEC-I consists of 130 sheets of 200 μm emulsion coated on 1.5 mm acrylics plate, Em(2), which are set vertically at intervals of 1.5 mm. These 130 sheets of emulsion plate are got between two horizontal 400 μm emulsion plate. That of BEC-II is 5 sheets of 200 μm emulsion plates. This chamber is used to measure the charges of incident particles. Middle chamber of BEC-I consists of 90 sheets of 50 μm double-coated emulsion on 0.8 mm acrylics plate, Em(1).

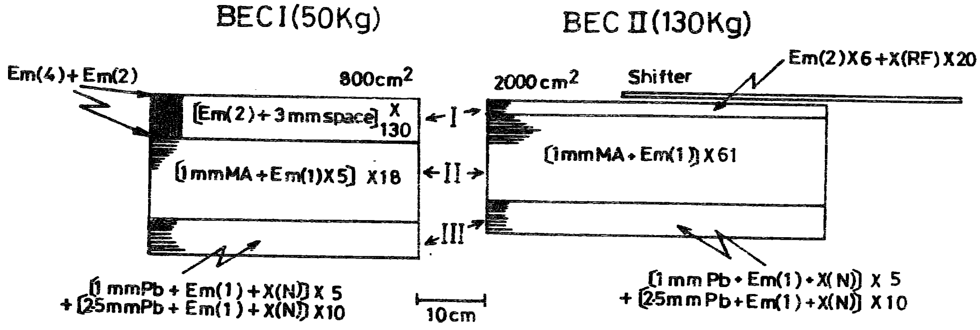

Fig. 1. Schematic cross section of the chamber.

That of BEC-II consists of 61 alternating sets of Em(1) and 1.0 mm acrylics plate. This chamber is used as target materials and for the angular measurements of shower particles, namely created particles and fragmented particles. Lower chamber consists of 5 alternating sets of 1.0 mm lead plate, N type X-ray film, X(N), and Em(1), and of 10 alternating sets of 2.5 mm lead plate, X(N) and Em(1). This chamber is used to detect high energy γ-rays originated mainly from π° and estimate the energies of these γ-rays.

Event taking Two methods in event taking are adopted. One is area scanning of 400 μm emulsion at the top of the chamber to detect cosmic ray particles above 10 GV, i.e. vertical threshold rigidity near Japan. Fig. 2 shows zenith angle distribution of about 500 nuclei with $z \geq 20$, which were scanned by X40 microscope. These nuclei were traced until they interacted in the middle chamber or left the chamber. The scanning efficiency, $e_i(Z,\theta) = N_{ij}(Z,\theta)/N_j(Z,\theta)$, was estimated from independent scanning of 200 cm² by different scanner, where $N_{ij}(Z,\theta)$ is the number of events with charge z and zenith angle θ detected by both i-th and j-th scanner and $N_j(Z,\theta)$ is the number of events detected by j-th scanner. The scanning efficiency was found to be almost 100% for nuclei of $Z \geq 24$ at all the zenith angle, and 94% for nuclei of $Z > 20$ and $\cos\theta \leq 0.91$.

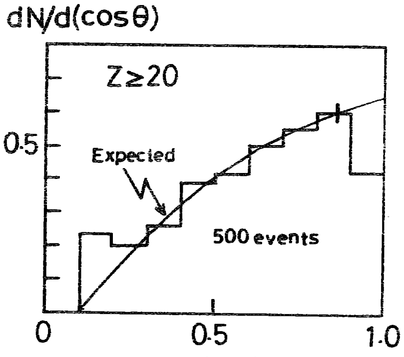

Fig. 2. Zenith angle distrubution

The other is the method of eye scanning for high energy γ-rays detected in the x-ray film of the lower chamber. In this method, we can select the cosmic ray particles with energies greater than about TeV/nucleon. It was estimated from the energy spectrum of single γ-rays observed in the lower chamber that 100%

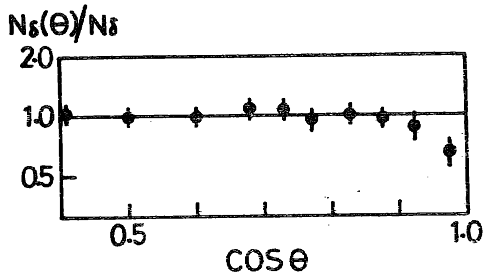

Fig.3. $N_\delta(\theta)/N_\delta$ - distribution

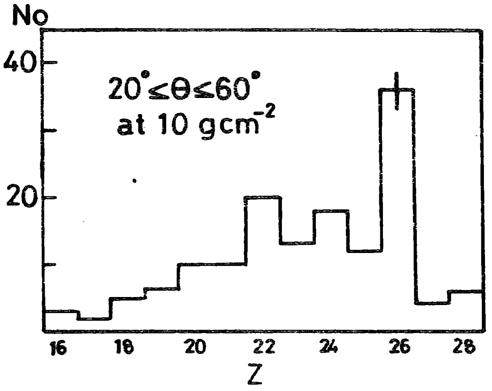

Fig.4. Charge distribution of VH-nuclei

Charge determination. The charges of heavy nuclei were measured within the error of about 1.0 units of charge for iron group nuclei, by counting δ-rays with length larger than 3.0 mm. in order to know the effect of an angle of track with respect to emulsion plane in the δ-ray measurement, the δ-ray counting was performed for the tracks of the same heavy nuclei in both the horizontal and vertical emulsion plate in the upper chamber. The $N_\delta(\theta)/N_\delta$ values are shown in Fig. 3, where $N_\delta(\theta)$ is the number of δ-rays per 100 μm for the tracks with an zenith angle θ smaller than 68° and N_δ is the number of δ-rays per 100 μm for the track of the same nuclei with an angle smaller than 22° with respect to the emulsion plane, namely the track with projected length longer than 500 μm. For the present investigation, we accepted the events with $\mathrm{Cos}\theta \leq 0.9$, which were free from biases in the scanning (Fig. 2) and the charge measurement (Fig. 3). Fig. 4 shows the charge distribution of VH-nuclei. Since our observation was done at an altitude of $\sim$10 g/cm^2, it contains atmospheric secondary nuclei.

Energy Estimation. The energies of heavy nuclei were mainly estimated by using the angular distribution of helium nuclei emitted from incident nucleus, the so-called opening angle method, which was first proposed by Peters et al. (Peters et al., 1952) on the basis of evaporation theory as:

$$P_0 = K(\bar{E}^*_\alpha) \times \langle\theta_\alpha^2\rangle^{\frac{1}{2}},$$

where P_0 is the momentum per nucleon in GeV of incident particles, $\langle\theta_\alpha^2\rangle^{\frac{1}{2}}$, the root-mean-square angle of helium nuclei with respect to the incident direction and $\bar{E}^*_\alpha$ is the mean kinetic energy of helium nuclei in the rest system of incident nucleus. The cases that the shower contains only a few helium nuclei and that the heavy nuclei break up into just only two helium nuclei were already discussed (Saito, 1971).

The mean energy, $\bar{E}^*_\alpha$, increases with the charge of incident nuclei. Several authors reported that $\bar{E}^*_\alpha$ is considerably larger than that expected from the evaporation theory (Fowler et al., 1957; Cester et al., 1958; Garelli et al., 1958;Kullberg and Otterlund, 1973). Garelli et al. found to be $\bar{E}^*_\alpha$ = 10 MeV in carbon and oxygen and 23 MeV in silver and bromine. Küllberg and Otterlund showed that more than 28% of the helium nuclei can be expected to be produced in other process different from conventional evaporation theory. However, if we use the experimental values of mean energy $\bar{E}^*_\alpha$ corresponding to the charges of the incident nucleus, instead of what could be expected by evaporation theory, the opening angle method is still usefull for estimating the energy of the incident nucleus. Kullberg et al. reported that helium nuclei are frequently emitted with transverse momentum much larger than that given by the Caussian distribution which is found by Heckmann et al. (Heckman, 1973). According to Heckmann, the momentum distribution for projectile fragments follows the Gaussian function, $N(P)\sim\exp[P^2/2\sigma^2]$, and the σ depends on masses of both the projectile A_P and fragment nuclei A_F as $\sigma\sim\sqrt{A_P(A_P-A_F)/A_P}$. When the mean energy of helium nuclei $\bar{E}^*_\alpha$ depends on the type of interaction, the energy values based on the opening angle method will give large fluctuation. The details for energy estimate will give elsewhere.

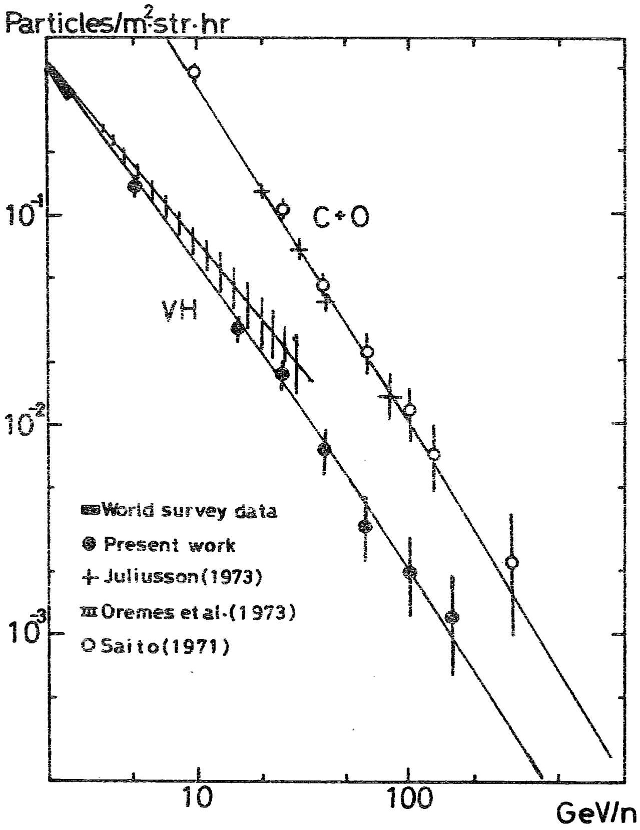

Fig. 5. Integral Energy Spectrum

3. Preliminary Result and Discussion. The energy spectrum of VH-nuclei observed from BEC-I is shown in Fig. 5, together with the data of C + O nuclei observed by one of authors using similar method of energy and charge measurements in a large emulsion stack (Saito, 1971). The energy spectrum of VH-nuclei is somewhat flatter than that for the C + O nuclei, although not as flat as reported by Oremes et al. [Oremes et al., 1973].

The expected energy spectra of C + O and VH-nuclei are shown by the solid curves in Fig. 5. The iron nuclei are highly destroyed during their propagation. If the energy dependent abundance of galactic secondary nuclei is interpreted as that the mean path length of cosmic ray particles decreases with energies, this propagation effect is more effective at lower energies and disappears at higher energies. The propagation effects were calculated assuming that the cosmic ray path length keeps the exponential distribution derived at GeV energy regions and the energy dependence of the path length comes mainly from escape efficiency from the confinement region and that the iron has the spectral index of ~ 1.7 at the source. The energy dependent escape length used in the calculation is derived from the observed energy dependence of the secondary to primary ratio which was fitted in a form of a single power law, $E^{-0.3}$ (Juliusson et al., 1973). The fragmentation probabilities in hydrogen were calculated by a simple semiempirical formula proposed by Shapiro and Silberberg (Shapiro and Silberberg, 1970).

In the present analysis, there is no strong evidence that iron is produced by a different source mechanism. The flatness of the spectrum of VH-nuclei seems to be explained by the propagation effect within the limit of experimental errors of data available at present. The analysis is in progress. The data from BEC-II will resolve this discrepancy.

The authors wish to thank to Professor J. Nishimura and all the staffs of Sanriku Balloon Center for the successful balloon flight.

References.

Cester, R., Debenedetti, A., Garelli, C.M., Quassiati, B., Tallone, L. and Vigone, M., 1958, Nuovo Cimento, 7, 371.

Fowler, P.H., Hilier, R.R., Waddington. C.J., 1957, Phil. Mag., 2, 293.

Garelli,C.M., Quassiati, B. and Vigone, M., 1958, Nuovo Cimento, 8, 731.

Heckmann, H.H., 1973, Proc. Fifth Intern. Conf. on High Energy Physics and Nuclear Structure, Uppsala, Sweden.

Juliusson, E., 1973, Proc. Intern. Conf. on Cosmic Rays. Denver, 1, 178.

Peters, B., 1952, Progress in Cosmic Ray Physics, Vol.I, 193

Kullberg, R. and Otterlund, I., 1973, Z. Physik, 259, 245.

Oremes, J.F., and Balasubrahmanyan, V.K., 1973, Proc. Intern. Conf. on Cosmic Rays., Denver, 1, 153.

Ramaty, R., Balasubrahmanyan, V.K. and Oremes, J.F., 1973, Science, 180, 731.

Saito, T., 1971, J. Phys. Soc. Japan, 30, 1535.

Shapiro, M.M. and Silberberg, R., 1970, Ann, Rev. Nucl. Sci., 20, 323.

Smith, L.H., Bufflington, A., Smoot, G.F. and Alvarez, L.W., 1973, Ap. J., 180, 987.