PLASTIC SCINTILLATORS IN COINCIDENCE FOR THE STUDY OF MULTI-PARTICLE PRODUCTION OF SEA LEVEL COSMIC RAYS IN DENSE MEDIUM

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1. Introduction. Cosmic-ray particles at sea level penetrate a thick layer of dense medium without appreciable interaction. These penetrating particles are identified with muons(1). The only appreciable interaction of muons are by knock-on processes(2). A muon may have single, double or any number of knock-on with atoms of the material so that one, two, three or more particles will come out from the medium in which the knock-on processes occur. The probability of multi-particle production is expected to decrease with the increase of multiplicity.

The present report presents measurements of the single, double, and triple particles generated in a dense medium (Fe and Al) by the sea level cosmic rays at 22.42 N. Lat. and 114.20 E. Long. (Hong Kong) using a detector composed of two plastic scintillators connected in coincidence.

2. Experimental. The detector consists of two units, each of which comprises a plastic scintillator, 1 m^2 x 5 cm, and an RCA-8055 ($\emptyset$ = 12.7 cm) photomultiplier tube installed in a light-tight iron case as shown in Fig. 1. A block diagram of the counting system is also shown in Fig. 1. The whole system is installed in a room where the room temperature is kept within 20 ± 1^{o}C.

By adjusting the high voltages and the amplifier-gains, differential pulse height spectra for each of the detector systems, as shown by curve (A) in Fig. 2, were brought to nearly matching. Then, setting the high voltages and the amplifier-gains at the optimum values and the SCA discriminator of the upper detector fully open, coincidence measurements of the signals from the upper and the lower detectors were made by varying the SCA discriminator level of the lower detector with the channel width 0.1 V. A suitable resolving time of the coincidence unit was chosen to be 0.5 μs so that the accidental coincidence counts were always negligibly small (i.e. less than 0.01 cpm against a counting rate of about 1000 cpm in each of the two detectors.

Keeping the two detector surfaces 11.7 cm apart and having the dense medium, Fe or Al slabs, of varying thicknesses placed between the detectors, the coincidence pulse height spectra were measured for each of the varying conditions (Fig. 2; curves (B)).

With Fe-absorber, the peak positions for triple-particle spectra are clearly appearing in the multi-particle spectra, e.g. at discriminator level 2.48 in Fig. 3(B). The corresponding peak area, however, can hardly be determinable due to poor counting statistics. Existence of triple-particle is further confirmed by the nearly equidistances of the triple-particle peak position from that of the double-particle (ΔL = 0.76) and the double-particle peak position from that of the single-particle (ΔL = 0.72). (Fig. 2(B) and 3(B))

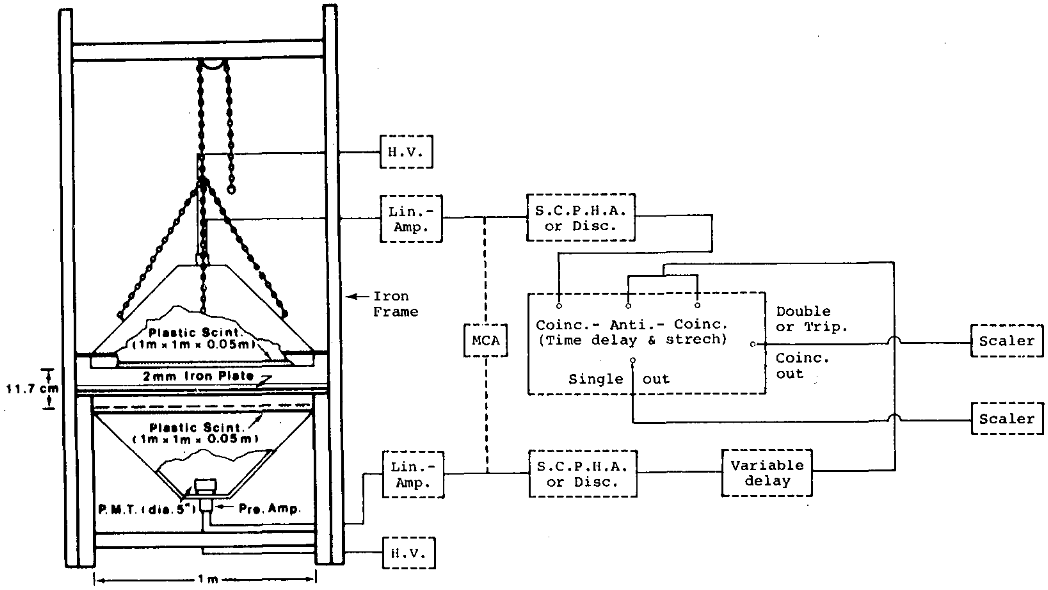

Fig. 1 The detector and the counting system.

The same procedures as above were applied in the measurements using Al-absorber of thicknesses 1.28 - 5.29 cm. None of the four absorption curves obtained gave good linearity to be able to obtain the absorption coefficient. Inspection by superpositions of the spectra for the four different absorber thicknesses with the single-particle spectrum reveals the poor absorption power of Al-absorber - little evidence of absorption or with irregularities, if any, in the multi-particle free portion and also in the portion where multi-particle contribute. This is thought to be due to very poor absorptivity and thus poor productivity for multi-particle of Al-absorber in the present experimental conditions.

3. Data analysis and Results. Each of the five pulse height spectra resulting from coincidence measurements, Fig. 2(B), is expected to be a result of superpositions of the multi-particle pulse height spectra over the single-particle spectrum.

To obtain the multi-particle spectra, the single particle spectrum (This spectrum too is superposed with multi-particle spectra due to the 0.4 cm thick Fe medium making up the surfaces of the detector housings) which has been corrected for absorption in the absorber is used for subtraction from the experimental spectrum which is placed with an absorber. An exponential form of absorption is adopted with reference to the nature of absorption of charged particles in passing through matter. In the lower pulse heights region, i.e. where the discriminator levels are smaller than that for the peak point of the spectrum, effect of multi-particle is absent. In this region, we have $\ln(I_0(L)/I(L)) = \mu(L - L_0)$ (where $I_0(L)$ and $I(L)$ are the coincidence counting rates of the single-particle, with pulse height L, before and after passing through the absorber, and μ is a linear absorption coefficient of the absorber for the sea level cosmic-ray particles. L_0 is a threshold discriminator level which is a constant of the system). From the plots of $\ln(I_0(L)/I(L))$ versus $(L - L_0)$ for the various absorber thicknesses, e.g. Fig. 3(A), the slopes μs are obtained with an average value 0.15 ± 0.06. Once μ is known, the multi-particle spectra can be determined from $I(L) - I_0 \exp(-\mu(L-L_0)) = I_2(L) + I_3(L) + \ldots$ (where $I_2(L)$, $I_3(L)$ ..., are the double-triple-, and the successive higher order multi-particle spectrum, respectively.)

Defining the peak area (K) as a product of the peak value and the FWHM of the peak, we obtain an average value of (K_d/K_s) as 0.07 ± 0.01 for Fe-absorber (where the subscripts d and s denote for double-particle and single-particle, respectively) which is identical to say that the probability of double-particle production in Fe-absorber of thicknesses ranging 0.65 - 4.97 cm is 0.07 ± 0.01.

To the single-particle spectrum, a Gaussian curve is fit to the single-particle portion. The difference between the experimental curve and this hypothetical curve is considered as due to the multi-particle spectra. A remarkable double-particle peak with a value 0.07 for K_d/K_s is also obtained.

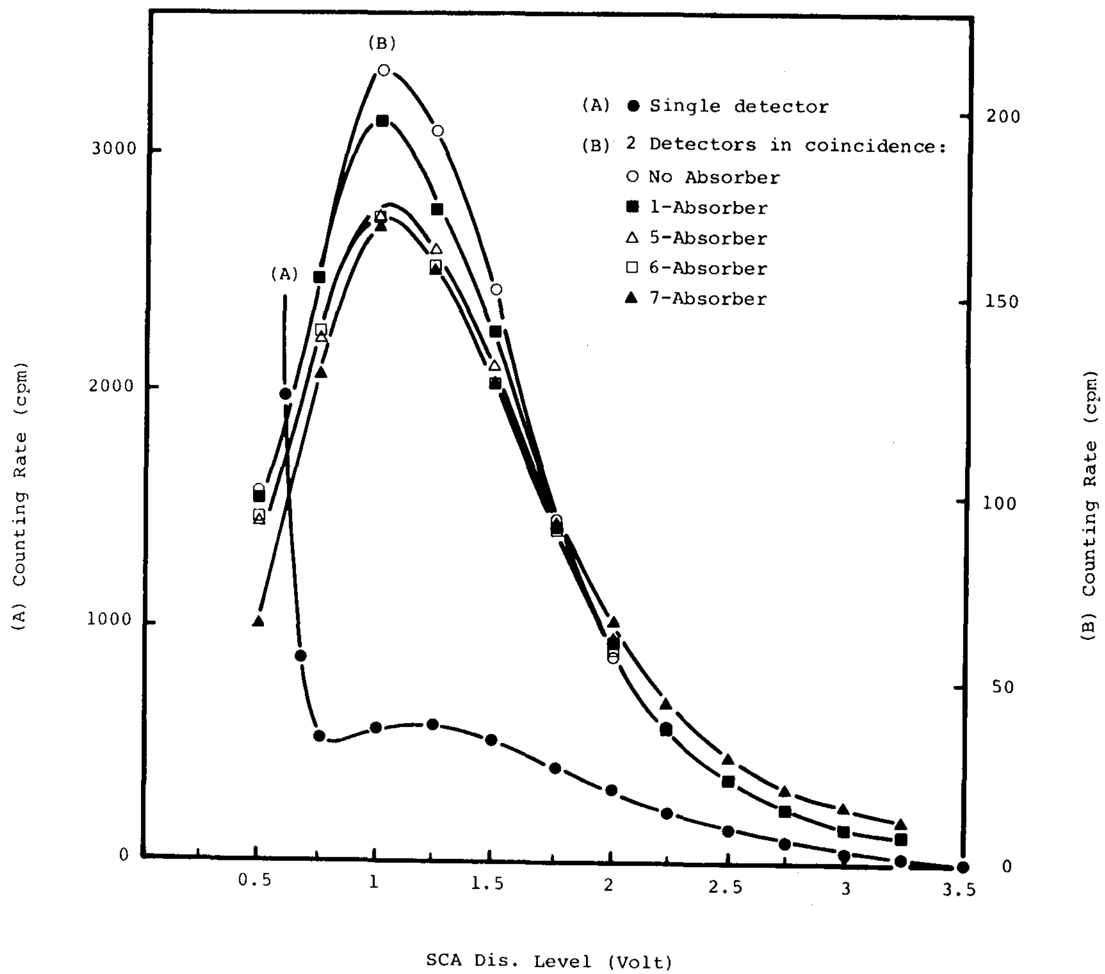

Fig. 2 Pulse height spectra: (A) taken with single detector (B) taken with upper and lower detector in coincidence (Dis. levels: upper fully open; lower varied from 0.5 to 3.25 with channel width 0.1 V).

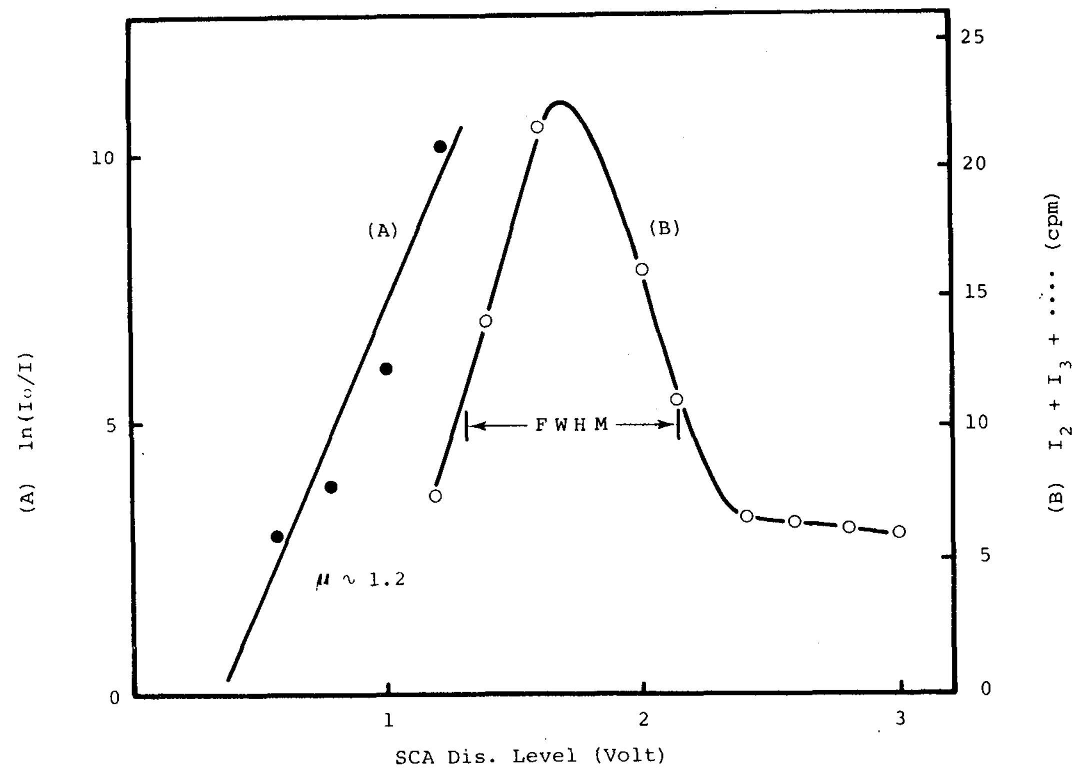

Fig. 3 (A) Absorption curve for single-particle in Fe.
(B) Double-particle peak and triple-particle component seen at Dis. level 2.3 - 3.0.

4. Discussion. The average value 0.07 ± 0.01 for the probability of double-particle production per muon (i.e. one knock-on process) in Fe-absorber of thicknesses 0.4 to 4.97 cm, which is negligibly small as compared to the range of sea level muons in Fe-absorber (e.g. 71 cm of Fe for muon with momentum 1000 MeV/c(3)) seems reasonable from the following comparisons with theoretical information: Taking the value 0.07 per g cm^{-2} to be the probability of double-particle production (one knock-on process) in Fe medium the agreement with the theoretical calculation of 0.14 per g cm^{-2} in Fe medium(4) for muons with the average momentum of sea level muons, 3500 MeV/c(5), is rather good. Present result for the average value of energy transfer per knock-on is estimated to be about 29 MeV with the rate of energy loss in Fe medium by 3500 MeV/c muons taken as 2 MeV per g cm^{-2}(3). While, the calculated maximum transferable energy per knock-on is 545 MeV.

References

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