152

TESTING OF MODELS OF VVH PARTICLE SOURCES AND PROPAGATION

G. E. Blanford Jr.,* M. W. Friedlander, M. Hoppe, J. Klarmann,
R. M. Walker and J. P. Wefel**

Laboratory for Space Physics, Washington University
St. Louis, Missouri 63130

For comparisons between theoretical and observed
charge spectra of the VVH particles to be meaningful,
at least two conditions must be met. First, charge
resolution must be adequate to separate important
groups of nuclei, and there should be no signifi-
cant systematic errors in the charge scale developed.
Interactions of VVH particles that we have observed
give us confidence in the charge scales. Second,
there must be adequate rejection of slower particles
of smaller Z, which have been observed in several
flights. Within these conditions, it has been
shown that observed features of the charge spectrum
are not accidents of the analysis but reflect real
variations in the relative abundances that must be
explained by any successful model.

1. Introduction. The extension of cosmic ray observations
to nuclei much heavier than the well-established Fe-peak has
raised again the problems of the accuracy of individual particle
identification and the calibration of the charge scale. Recent
measurements, made during the analysis of data accumulated in
large-area systems during balloon flights, give us confidence
regarding the charge scale while drawing our attention to a
hitherto unsuspected source of spurious VVH particles. We
describe in this paper the data available to the end of May;
updated results will be reported at the meeting and the final
data published later.

2. Calibration of the Charge Scale. The methods of measurement
and the calibration procedures for the plastic detectors have
been described in detail by Blanford et al, (1973). Because
relativistic Fe nuclei do not register in even the most sensitive
plastic (Daicel cellulose nitrate), the calibration for fast
very heavy particles rests on tracks of slow particles, either
low energy primary cosmic rays or heavy ions from the HILAC.
For emulsions, on the other hand, the prominent Fe-peak is
available, but even though the energy loss mechanisms are con-
sidered well understood, the identification of the heaviest VVH
particles involves ionizations over ten times larger than that
of the comparison Fe-nuclei. In our most recent set of plastics

---

TESTING OF MODELS OF VVH PARTICLE SOURCES AND PROPAGATION

G. E. Blanford Jr.,* M. W. Friedlander, M. Hoppe, J. Klarmann,
R. M. Walker and J. P. Wefel**

Laboratory for Space Physics, Washington University
St. Louis, Missouri 63130

and emulsions, exposed in a balloon flight from Palestine,
Texas, we have observed two VVH particle interactions in which
the interlocking identifications of the primary and secondary
particles provides an independent test of the charge measure-
ments. In these events, the primary particles were found in
routine scanning of detector layers high in the stack. Sub-
sequent attempts at tracing these events through to lower layers
revealed, in each case, a bundle of closely spaced and almost
parallel tracks. The data are summarised in Table I. Emulsion
charge estimates for the heavy particles are derived from photo-
densitometer measurements (Fowler et al, 1970; Blanford et al,
1973); for the plastics, etching was carried out under carefully
controlled conditions in the Lexan, cellulose triacetate (Bayer
TN-CTA) and cellulose acetate butyrate (Bayer BN-CAB) (Blanford
et al, 1973).

The lighter secondary particles were identified solely
through their tracks in the emulsion, using the conventional
procedures. In all the events, exhaustive scanning was carried
out to locate the secondary particle tracks and especially
those due to singly charged particles. Despite this care,
it is possible that a very few secondaries might have been
missed, but it is considered unlikely that any spurious second-
aries have been wrongly included, for all tracks finally accepted
had to satisfy the geometrical reconstruction.

TABLE I
HEAVY PARTICLE INTERACTIONS

Event	Track	Detector	Charge Estimate	Kinetic Energy (GeV/Nucleon)
#1	Primary	A and B emulsions	78	20
		Mean of 4 independent Lexan sheets	75	
	Secondaries	emulsion		
		#1	18	
		#2	15	
		#3	15	
		10 He-nuclei	20	
		2 Li-nuclei	6	
		1 Proton	1	
		Total	75	
#2	Primary	A and B emulsions (no plastics)	78	5
	Secondaries	#1: emulsion	53	
		TN-CTA	50	
		BN-CAB	52	
		Mean	52	
		1 Li-nucleus	3	
		5 He-nuclei	10	
		7 protons	7	
		Total	72	
#3	Primary	emulsion	22	
	Secondaries	emulsion		
		1 Be-nucleus	4	
		2 Li-nucleus	6	
		3 He-nuclei	6	
		7 protons	7	
		Total	23	

From the orientation of the tracks of the secondaries, it was possible to deduce the locations of the actual interactions (none of which actually occurred in an emulsion). The angular divergence of the secondary tracks also permits an energy estimate to be made for each event, and these energies are listed in Table I. These energy values allow us to make better charge estimates than is the case for large samples of random VVH tracks where individual particle energies are not known other than as defined by the geomagnetic cutoff.

Event #3 has been included, for it shows (in the same set of emulsions) the consistency that can be achieved in charge identifying interactions and because its primary was so similar to some of the secondaries in the other events.

From the consistency displayed by these events, it would appear that the charge scales based on our independent calibrations have no serious systematic errors, up to Z = 78. Extrapolation to yet higher charges would seem to be reasonable and certainly secure enough for us to separate with confidence Pb_{82} and Bi_{83} from the long-lived r-process nuclei that we have grouped generally together under the designation $Z \geq 86$ (see preceding paper). For very much higher charges, it would seem prudent to extrapolate with caution, for we have observed saturation effects in some of the plastics (Blanford et al, 1973).

3.   Rejection of Low Energy Particles. The responses of both the plastics and emulsions to ionizing particles are governed by the rates of loss of energy, and can be very generally represented by relations of the form

$$\left(Z^2/\beta^2\right)\left[A + B \ln\left(\beta^2/1-\beta^2\right) - \beta^2\right].$$

It had been assumed that identification would be easier for particles recorded during balloon flights in regions where the geomagnetic cutoff rigidity was high, for example above 4.5 GV. However, as already reported (Blanford et al, 1972), at a Texas flight location we detected heavily ionizing particles whose kinetic energies were well below the geomagnetic cutoff. We have continued this analysis in another set of plastics and emulsions, also flown over Texas. In this system, a total of close to 2 gm/cm² of absorber was distributed between the topmost and lowest detecting layers, and we have found that there were more slow particles and at higher kinetic energies than had been previously recognised.

In the earlier work, we had noted a decrease in the number of particles with kinetic energies above ≈150 MeV/nucleon, but with the increased absorber thickness we have now found particles up to 270 MeV/nucleon. Table II shows the spectrum of apparent charges of the particles of this group (i.e., the charges attributed on the basis of the ionization in the top detector layer, assuming that the particles had been fast) and the true charge

spectrum (i.e., the charges as deduced from the changes in ionizqtion observed in successive layers). These 26 particles must be compared to a total of 108 events recorded at altitude; of these, 25 were identified as being due to fast particles with Z > 40. The "slow" particle contamination is therefore comparable to the VVH particle flux, and, as can be seen from Table II, can be serious if unrecognised.

Table II
Distribution of Charges

Charge Group	8-10	11-20	21-30	31-35	36-40	41-45
Apparent Charges	-	-	4	11	8	3
True Charges	5	6	15	-	-	-

In order for an Fe Nucleus to ionize as heavily as a fast nucleus of $Z \sim 50$, it must be so slow that its range will be less than 1 gm/cm^2; correspondingly, detector stacks of at least this thickness can provide a clean sample of particles with $Z \gtrsim 50$, but the problem of contamination becomes more severe as one approaches $Z = 30$ when greater absorber thicknesses (or a velocity indicator such as Cerenkov counter) are needed.

4. The Charge Spectrum Observed for VVH Particles. In the preceding paper, the accuracy of the charge determinations was given as $Z = {}^{+3}_{-6}\%$ these limits are largely set by the uncertainty in the particles' kinetic energies. With the arrival zenith angle known, there is still uncertainty in the azimuthal angle and, as a result, in the geomagnetic cutoff. Even for particles that are too fast to exhibit detectable energy losses in the 1 or 2 gm/cm^2 of absorber, there is a residual uncertainty in velocity and thus an uncertainty in the assigned charge. Caution must therefore be exercised in not overinterpreting the data, and we prefer to present our results in charge groups that are 5 charge units wide. With the slow particles rejected, and with the interactions giving support to the charge scale, we may consider that the general features of the charge spectrum--such as the high or low abundance of different charge groups--can be considered significant. More detailed features such as prominent peaks of individual nuclides, must await improved techniques, better velocity information (in the case of fast particles) and larger numbers of events.

References

BLANFORD, G. E. Jr., M. W. Friedlander, J. Klarmann, S. S.
    Pomeroy, R. M. Walker and J. P. Wefel, J. Geophys. Res.
    1972, $\underline{77}$, 6037.

BLANFORD, G. E. Jr., M. W. Friedlander, J. Klarmann, S. S.
    Pomeroy, R. M. Walker, J. P. Wefel, P. H. Fowler, J. M.
    Kidd, E. J. Kobetich and R. T. Moses and R. T. Thorne,
    1973, Phys. Rev. (in course of publication).

FOWLER, P. H., V. M. Clapham, V. G. Cowan, J. M. Kidd and
    R. T. Moses (1970), Proc. Roy. Soc. Lond $\underline{A318}$, 1.