Pramāṇa, Vol. 10, No. 2, February 1978, pp. 131-141, © Printed in India.

A new interpretation of an event attributed to a magnetic monopole

N DURGAPRASAD and M V S RAO
Tata Institute of Fundamental Research, Bombay 400 005

MS received 13 May 1977; revised 14 November 1977

Abstract. An alternate and a new interpretation is given for the event attributed to a magnetic monopole by Price and coworkers found in an emulsion plastic sandwich stack flown from Sioux City, Iowa, USA on 18 September 1973. The electron pick-up and stripping cross-sections of nuclei of $Z \sim 70-80$ and $v \sim 0{\cdot}6-0{\cdot}7\,c$ in Lexan polycarbonate are calculated using the formulae given by Nikolaev. It is shown that the corresponding mean free paths are of the order of thickness ($\sim 250\mu$) of Lexan plastic sheets used by them. In such a case a *snapshot* of these processes is believed to have been observed in plastic sheets. Monte-Carlo simulations of the event have been made for three values of charges at the top of the main Lexan stack, namely $Z=83$, 78 and 70 respectively. The event is thus interpreted as a cosmic ray nucleus of $Z=70-83$ and $v=0{\cdot}6-0{\cdot}7\,c$ losing and capturing electrons (mainly the latter) as it passes through the stack. The probability of the occurrence of such an event is estimated by several methods.

Keywords. Monopole; ultraheavy cosmic ray nuclei; electron capture; electron stripping; effective charge.

1. Introduction

In a balloon flight made from Sioux Falls, USA, for ultraheavy cosmic rays, Price *et al* (1975a) have reported the observation of a peculiar event and ascribed it due to the passage of a magnetic monopole. They had flown a sandwich stack consisting of Cerenkov film, nuclear emulsion and Lexan sheets. From the data obtained from Cerenkov film it was concluded, the particle had a velocity less than $0{\cdot}7\,c$ and charge $Z \gtrsim 70$, whereas from the analysis of the event in nuclear emulsion, they concluded that the particle had a velocity $v=0{\cdot}5c^{+0{\cdot}1c}_{-0{\cdot}05c}$ and $Z=80$. However, the analysis of the event in Lexan detector showed that it was due to a nearly constantly ionizing particle. Hence, they concluded that it ionized like a particle with velocity $v=0{\cdot}9\,c$ and charge $Z=125-137$. The only consistent explanation they could offer was that it was due to a magnetic monopole. From the time of the postulate of the magnetic monopole by Dirac (1931), several attempts have been made to look for it but with little success. Hence the present event evoked lot of interest amongst various scientists. Alvarez (1975), Friedlander (1975) and Fowler (1975) carefully reanalysed this event and tried to explain it as due to the fragmentation of a cosmic ray nucleus. They, however, concluded in their analysis that the estimates of charge and velocity made from the nuclear emulsion are probably wrong as it was an event with large dip angle and only one emulsion of small thickness was used. Discarding the emulsion data and taking the Cerenkov film and Lexan stack data only, Alvarez (1975) explained the event as due to a cosmic ray platinum nucleus undergoing

Table 1. Interpretation given by Fleischer and Walker (1975)

Charge of the nucleus at entry into Lexan stack	Velocity of nucleus at entry into the Lexan stack	Number of fragmentations required for getting best fits	Probability of the occurrence of event
83	0·70	2	$1{\cdot}7 \times 10^{-2}$
77	0·65	3	$3{\cdot}1 \times 10^{-4}$
70	0·60	8	6×10^{-13}

fragmentation first into an osmium nucleus and later into a tantulum nucleus. Fowler (1975) and Friedlander (1975) independently gave a similar explanation. Fleischer and Walker (1975) summarized these observations and gave the probabilities of occurrence of such an event as shown in table 1.

Price *et al* (1975b) in a subsequent paper argued that there is no reason to assume that the emulsion measurements are in error. If one takes the velocity of the particle as $0{\cdot}6c$ as measured in the emulsion, the probability of occurrence of eight fragmentations is 6×10^{-13} which indicates the monopole interpretation as the most likely one.

We have in this paper reanalysed the event in a novel framework not considered so far and calculated the cross-sections for the orbital electron capture and stripping at these energies and charge values. These processes become significant at velocities near $v\lesssim Zc/137$ and hence could be important for this event. We show that the corresponding mean free paths are of the order of the thickness of the plastic sheets. In such a case we show that the new interpretation of this event as due to a cosmic ray nucleus picking up and losing electrons is the most probable one.

2. Cross-sections

As mentioned earlier, when a particle of near relativistic velocity loses energy in a medium and approaches a velocity $v\lesssim Zc/137$ and hence for $Z=70$–80, at $\beta=v/c\lesssim 0{\cdot}6$, the capture and pick-up processes become important. To calculate the stripping and pick-up cross sections of heavy nuclei we use the formulae given by Nikolaev (1965). These cross-sections are found to be accurate up to 10–20% experimentally for ions up to krypton ($Z=36$) at high energies and for fission fragments of high charge at low energies. In the absence of experimental data at high energies and high charge values, we assume that the relations hold good for nuclei in the charge range $Z=70$–80 also.

2.1. *Pick up cross-sections*

2.1.1. *Non-radiative capture cross-sections:* Oppenheimer (1928) and Brinkman and Kramers (1930) have given the pick-up cross-sections for protons. The formula, usually applied to protons of low energies, is known as the OBK formula. These capture cross-sections for fast particles have been discussed by Bohr and Lindhard (1954). Nikolaev (1965) has reviewed and extensively discussed the relevant formulae to be used for heavy nuclei and fast particles. In figure 1, we show the capture cross-sections σ_c as a function of β for the values 1, 10 and 70 of primary charge. We have compared in figure 1 the following formulae given as equations in Nikolaev (1965): (1) OBK formula eq. (4.1) (1965) and denoted as OBK in our figure; (2) Bohr and Lindhard formulae—eq. (4.9) and denoted as BL. (3) Nikolaev formula for high charges—eq. (4.11) and denoted as NH. (4) Nikolaev formula for low charges —eq. (4.12) and denoted as NL. We have used formula (4) for calculating the pick-up cross-sections for reasons mentioned below:

It can be seen from figure 1 that for protons, formulae (1) and (4) both give nearly the same cross-sections within a factor of 2 to 5, while the other formulae give much higher cross-sections. But they all show the same trend, i.e. the decrease of cross-sections with increasing value of β.

For heavy nuclei like $Z=70$, OBK formula shows a peculiar trend. The cross-section rises with increasing β, reaches a maximum around 0·4c and then falls with increasing β. The other formula, on the other hand, shows decreasing cross-sections with increasing β.

But which of these formulae is applicable for nuclei of very high charges? Nikolaev (1965, p. 282) comments that for uranium fission fragments formulae (2) and (3) agree

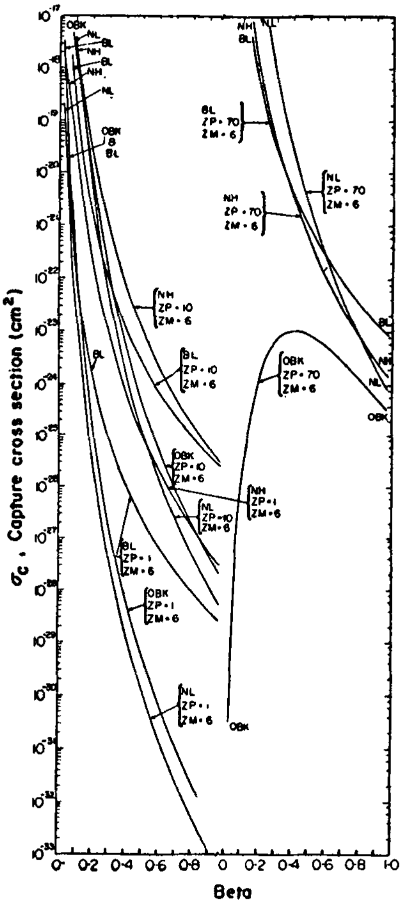

Figure 1. Capture cross-sections σ_c as a function of β in carbon medium for primary nuclei of charges $Z_P=1$, 10 and 70 given by different formulae referred to in the text.

within a factor of 1·6 and that formula (3) gives values closer to experimental values. The OBK formula gives cross-sections in orders of magnitude lower than the rest. Apparently, one should use Nikolaev formula (3) for high charges. But after a careful consideration, we feel that in the present case, where Z/β is of the order of 110–120, formula (4) is better applicable. The difference between formulae (3) and (4) is not appreciable in this range. It may be noted that for $\beta=0{\cdot}7$, formulae (2), (3) and (4) for $Z=70$, give values of capture mean free paths in Lexan as 0·21, 0·47, and 0·30 g/cm^2 respectively. They all agree within a factor of a 2 but disagree with the value obtained using OBK formula.

We calculate the pick-up cross-section σ_c, according to the formula (eq. 4.12 of Nikolaev 1965) for ions of atomic number Z

$$\sigma_c=\sigma_{Z,\,Z-1}=\pi a_0^2\, Z^5\, Z_{\rm med}\, (Z^*_{\rm med})^5 \left(\frac{2v_0}{v}\right)^{12} \left[1+4\, Z^{*2}_{\rm med}\, \frac{v_0^2}{v^2}\right]^{-4} \qquad (1)$$

where a_0 is the Bohr radius$=0{\cdot}53\times10^{-8}$ cms, v_0 is the corresponding electron velocity, $Z_{\rm med}$ is the atomic number of the medium and $Z^*_{\rm med}$ is the effective charge of the medium. At a velocity $v=5\times10^8$ cm/sec, the value of $Z^*_{\rm med}$ is given by $Z^*_{\rm med}=Z^{2/3}_{\rm med}$. With increasing velocity, the value increases and at $v=0{\cdot}6c$ to $0{\cdot}7c$, $Z^*_{\rm med}$ can be taken as equal to $Z_{\rm med}$ (Teplova *et al* 1958).

Raisbeck and Yiou (1971) have measured the electron capture cross sections of 40, 155 and 600 MeV protons in thin foils of Mylar, Al, Ni and Ta. These cross-sections (column 4) are given in table 2, together with the calculated σ_c (column 5) according to eq. (1). The cross-sections calculated according to OBK formula (column 3) are also

Table 2. Experimental and theoretical capture cross-sections

Target	Energy (MeV)	σ_c (OBK) cm^2/atom	σ_c (Expt) cm^2/atom	σ_c (NL) cm^2/atom
Mylar	40	$9{\cdot}7\times10^{-27}$	$2{\cdot}4\times10^{-27}$	$2{\cdot}2\times10^{-27}$
	155	$9{\cdot}6\times10^{-30}$	$3{\cdot}4\times10^{-30}$	$2{\cdot}5\times10^{-30}$
	600	$5{\cdot}4\times10^{-32}$	$6{\cdot}1\times10^{-32}$	$1{\cdot}4\times10^{-32}$
Al	40	$1{\cdot}2\times10^{-25}$	$3{\cdot}0\times10^{-26}$	$3{\cdot}4\times10^{-26}$
	155	$1{\cdot}7\times10^{-28}$	$2{\cdot}2\times10^{-29}$	$7{\cdot}1\times10^{-29}$
	600	$1{\cdot}1\times10^{-30}$	$1{\cdot}6\times10^{-31}$	$5{\cdot}2\times10^{-31}$
Ni	40	$2{\cdot}0\times10^{-25}$	$1{\cdot}4\times10^{-25}$	$1{\cdot}7\times10^{-25}$
	155	$2{\cdot}4\times10^{-27}$	$2{\cdot}3\times10^{-28}$	$1{\cdot}7\times10^{-27}$
	600	$3{\cdot}2\times10^{-29}$	$6{\cdot}3\times10^{-31}$	$2{\cdot}5\times10^{-29}$
Ta	40	$4{\cdot}4\times10^{-26}$	$5{\cdot}4\times10^{-25}$	$8{\cdot}9\times10^{-26}$
	155	$8{\cdot}6\times10^{-28}$	$1{\cdot}4\times10^{-27}$	$4{\cdot}7\times10^{-27}$
	600	$1{\cdot}7\times10^{-28}$	$3{\cdot}8\times10^{-30}$	$3{\cdot}3\times10^{-28}$
N_2	37·5	$1{\cdot}4\times10^{-26}$	$2{\cdot}7\times10^{-27}$	$3{\cdot}2\times10^{-27}$
Ar	37·5	$2{\cdot}8\times10^{-25}$	$8{\cdot}7\times10^{-26}$	

There is good agreement between σ_c(NL) and σ_c(Expt.) for N_2, Ar, Mylar and Al targets (light targets like Lexan) for all energies.

given in this table. It can be seen from the table that eq. (1) predicts σ_c values close to those of experiments for N_2, Ar_2, Mylar and Al targets (light targets like Lexan) for all energies including the one at 600 MeV. The agreement is better than with OBK formula.

2.1.2. *Radiative capture cross-sections:* The radiative capture cross-sections become important at high energies. Radiative capture can be considered as the reverse process of photoelectric absorption and should dominate at high energies. But at present, there are no experimental data to show at what energies it dominates. For this reason, we are not considering this cross-section for further discussion. If the radiative capture process dominates the nonradiative capture, it will only increase the capture cross-sections and will thus strengthen our argument that more electrons will be caputred.

2.2. *Stripping cross-sections*

The stripping cross-section, σ_s, is calculated according to the formula (eq. 3.11) of Nikolaev (1965), for ions of atomic number Z,

$$\sigma_s=\sigma_{z-1,\,z}=4\pi a_0^2\left(\frac{v_0}{Zv}\right)^2 [Z_{\text{med}}^2 (1+0{\cdot}55 \ln A)+Z_{\text{med}} (1+0{\cdot}55 \ln B)] \quad (2)$$

Here A is equal to the lesser of the quantities $1{\cdot}6V/ZV_0$ and $Z/(2Z^*_{\text{med}})$ and B is equal to the lesser of the quantities $1{\cdot}6V/Z\ V_0(1+1{\cdot}6\,I_{\text{med}}/Z^2\,\mu V_0^2)$ and Z/Z^*_{med}. Also I_{med} is the binding energy of an electron in the atom of the medium and μ is the rest mass of the electron.

From these cross-sections, the mean free paths in g/cm² are calculated using the formula, $\lambda=\sum_i[1/(n_i\,\sigma_i)]$ and taking into account Lexan molecular formula of $C_{16}H_{14}O_3$. The values of number, n, per gm for C, H and O atoms used are $3{\cdot}8\times10^{22}$, $3{\cdot}3\times10^{22}$ and $0{\cdot}7\times10^{22}$ respectively. The density, ρ, of Lexan is $1{\cdot}2$ g/cm³.

Price *et al* (1975a) have noted that the capture and pick-up processes are important at these energies for such high charged nuclei and took the effective charge, Z_{eff}, of the particle into consideration, where Z_{eff} is given by the formula,

$$Z_{\text{eff}}=Z\,[1-\exp(-130\,\beta/Z^{2/3})]$$

As we show later, we calculated the stripping and capture mean free paths and it is found, for example, that for $Z=83$ and $\beta=0{\cdot}678$, $\lambda_s=0.059$ g/cm² and $\lambda_c=0{\cdot}076$ g/cm² respectively. Thus they are of the order of two to three thicknesses of the sheets used. We argue that in such a case, contrary to the normal assumption, the charges do not attain an equilibrium value in these thicknesses. Instead, what one is observing here is a *snapshot* of the two processes taking place as they occur. Thus the formula (3) quoted above is not valid here. It will be applicable only when a large number of both types of collisions occur within the thickness used.

3. Analysis of the event

3.1. *Approximate probability calculations*

Price *et al* (1975a, b) have given a plot of the track etch rate (cone length per etching time) vs depth of the stack. The cone length or etch rate is proportional to $(Z_{\text{eff}}/\beta)^n$ where n is taken in the present analysis as 4·0 and Z_{eff} and β are the effective charge and velocity of the particle at the point. The experimental data given by Price *et al* consist of 56 points. The etch rate at the first point is 2·91 μ/hr. Three sets of the charge (Z_1) and velocity (β_1) at this starting point are assumed as follows for further analysis: (1) 83 and 0·678, (ii) 78 and 0·637 (iii) 70 and 0·571. Then we calculate the value of (Z_2/β_2) at the second point, from the etch rate. From β_1 and the matter traversed and the range-energy relations, we calculate β_2 at the second point. Then from (Z_2/β_2) and β_2, we obtain Z_2. Proceeding in a similar way, we have calculated the 55 values of Z_n and β_n for the three cases of incident Z_1 and β_1. The values Z_n as a function of matter traversed are shown in figures 2a, b, c for the three cases.

The second case of Z_1 and β_1 selected by us is similar to that selected by Alvarez (1975) and Fowler (1975) assuming the emulsion measurements to be not reliable. The third case of Z_1 and β_1 assumes that the velocity given by emulsion is correct. The relevant mean free paths at the top and the bottom of the stack for the three cases are given in table 3.

It is seen that in most cases the mean free paths, in general, are of the order of thickness of the sheets (~0.03 g/cm²). It is also seen that the value of $\triangle Z$ (decrease of charge from the top to the bottom of the stack) are 9, 11 and 16 for the three cases considered.

It can be seen from figure 2 that the values of Z_n fluctuate around a mean value

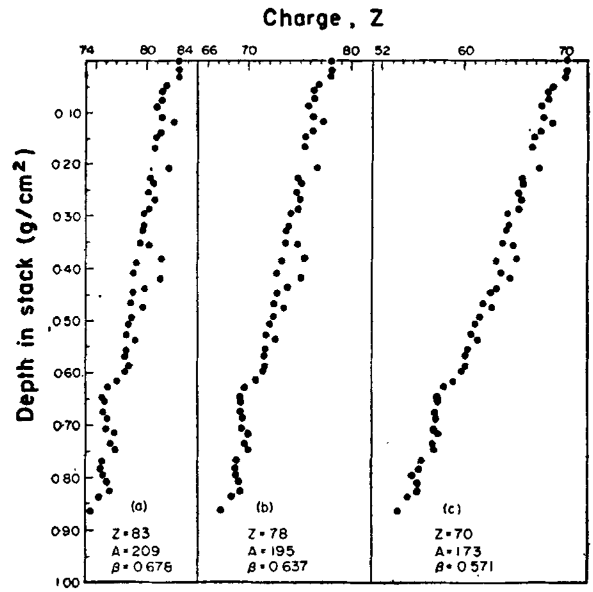

Figure 2. Charge Z, calculated for each of the experimental points of Price *et al* plotted as a function of depth in the Lexan stack for the three different nuclei incident at the top of the stack.

Table 3. Relevant mean free paths

A. *At the top of the stack*

Case	Z	β_1	λ_s(g/cm²)	λ_c(g/cm²)
1	83	0·678	0·059	0·076
2	78	0·637	0·046	0·053
3	70	0·571	0·031	0·024

B. *At the bottom of the stack*

Case	Z_{56}	β_{56}	λ_s	λ_c
1	74	0·607	0·037	0·038
2	67	0·552	0·025	0·020
3	54	0·439	0·011	0·0039

Table 4. Probability estimates using average mean free paths

Case	$\bar{Z}$	$\bar{\beta}$	λ_s(g/cm²)	λ_c(g/cm²)	ΔZ	Probability
1	79	0·642	0·048	0·054	9	$1{\cdot}1 \times 10^{-2}$
2	73	0·596	0·035	0·033	11	$2{\cdot}3 \times 10^{-2}$
3	62	0·509	0·019	0·011	16	$1{\cdot}7 \times 10^{-2}$

indicating that both capture and stripping processes are important up to about half the Lexan stack thickness ($\sim$0·4 g/cm²) and later the capture process becomes dominant. This point can also be seen from the mean free paths given in table 3.

To calculate the probability of occurrence of such an event, we first calculated the mean values of λ_s and λ_c from an average value of $\bar{Z}$ and $\bar{\beta}$ obtained for the whole stack. From these mean free paths, we then calculated the probability of the particle emerging out of the stack (of depth x g/cm²) losing $\triangle Z$ charge values (9, 11 and 16 for the three cases considered) in n collisions. This probability is given by the expression,

$$P = \sum_n \frac{[\exp(-x/\lambda_s)](x/\lambda_s)^n}{n!} \times \frac{[\exp(-x/\lambda_c)](x/\lambda_c)^{n+\Delta Z}}{(n+\triangle Z)!} \tag{4}$$

where λ_s and λ_c are stripping and capture mean free paths.

In the present calculation, we have used $n=1$ to 125. The probabilities thus obtained are shown in the last column of table 4 for the three cases.

It is thus seen that the probabilities, for the three cases of velocities considered, namely, $\beta_1=0{\cdot}68$, $\beta_2=0{\cdot}64$ and $\beta_3=0{\cdot}57$, are 0·011, 0·023 and 0·017 respectively. From a survey of the total number of cosmic ray events of $Z=70$–83, Fleischer and Walker (1975) give the number of events for $\beta_1=0{\cdot}7$, $\beta_2=0{\cdot}65$ and $\beta_3=0{\cdot}60$, as 14·4, 12·6 and 7·6 respectively. It is thus seen that the observation of the so-called monopole event in any one of these cases is not quite improbable. We now proceed with the estimates of the probabilities based on Monte-Carlo calculations.

3.2. *Monte-Carlo simulations*

To see how these two processes of stripping and capture of electrons are taking place in the Lexan stack, we simulated the events by Monte-Carlo technique, which is described below. We start from the top of the main Lexan stack and assume that the nucleus at the point of entering the stack is completely stripped of electrons. At the point of entry, that is at the first point, we assume that the nucleus has a charge Z_1 and velocity β_1 and atomic weight A_1. The value of etch rate (V_t), at this point was 2·91 μ/hr. We then allow the nucleus to pass through the Lexan stack (0·86 g/cm^2 of matter) and allow it to capture and lose electrons as it traverses through matter. The mean free paths λ_s and λ_c used for this purpose are those calculated as mentioned in section 2. The depths X_s and X_c in the stack at which the next stripping and capture process takes place, starting from the first point are determined from the random numbers generated by the random number routine in the DEC-10 computer on which these calculations have been done. If X_s is smaller than X_c, the stripping process is supposed to have taken place and the value of Z_2 is taken to be equal to $Z_1 + 1$. If X_c is smaller than X_s, the capture process is supposed to have taken place and the value of Z_2 is taken to be $Z_1 - 1$. The value of β_2 was obtained from the energy loss the particles suffered in traversing this distance. Using the new value of Z and β, the corresponding mean free paths λ_s and λ_c are again calculated and the next point and type of interaction were determined. For the sake of simplicity, the variation of β between two successive interactions is neglected for calculating the mean free paths. The calculations were repeated till the particle escaped the stack of total thickness of 0·86 g/cm^2. As the calculation proceeded, the values of Z and β

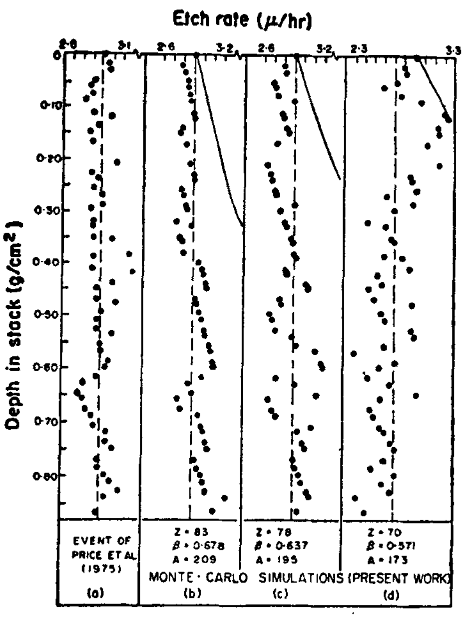

Figure 3. Monte-Carlo simulations of etch rate vs depth, (b), (c) and (d), in Lexan stack for three different nuclei undergoing stripping and capture processes. The dashed lines are the 'constant etch' rate lines explained in the text. The solid curves are obtained considering ionization loss only. At left (a) is shown the event of Price *et al.*

corresponding to those depths at which Price *et al* made their measurements were also obtained. The corresponding values of the etch rates, V_t were then obtained assuming the relation $V_t \propto (Z/\beta)^4$. Thus the values of Z_n, β_n and $(V_t)_n$ for various depths were obtained. Monte-Carlo simulations were made for 1000 such events for three sets of values of Z_1 and β_1 mentioned earlier and given below: (i) $Z_1=83$; $\beta_1=0{,}678$, (ii) $Z_2=78$; $\beta_2=0{\cdot}637$ and (iii) $Z_3=70$; $\beta_3=0{\cdot}571$. The plots of $(V_t)_n$ vs x_n obtained for three cases and for the most favourable events are shown in figure 3 together with the Price *et al* points. It can be seen from the figures that it is possible to simulate the monopole event by normal processes of capture and stripping of electrons.

To estimate the fit between the Monte-Carlo simulated curve and the experimental points of Price *et al* we obtained the values of $V_{MP}^2=\Sigma_1^{56}[(V_t)_M-(V_t)_P]^2$ where $(V_t)_M$ and $(V_t)_P$ represent the etch rates obtained at the same depth by Monte-Carlo technique and Price *et al*'s experimental points respectively. It was found for case, (i) out of 1000 events, 29 events have V_{MP}^2 values between 1 and 2 and 100 events between 2 and 3 and 108 events between 3 and 4. Similarly for case (ii), out of 1000 events, 8 events have V_{MP}^2 values between 1 and 2 and 34 events between 2 and 3 and 85 events between 3 and 4. For case (iii), out of 1000 events, 4 events have V_{MP}^2 values between 5 and 6. (Here it should be noted that the starting value of $(V_t)_P$ was about $2{\cdot}9\mu/\text{hr}$). The value of the χ^2 could then be obtained from the relation $\chi_{MP}^2 = V_{MP}^2 / (56\times\sigma^2)$ where σ is the standard deviation.

For each of three cases, the Monte-Carlo event with the least χ^2 value for a fit to constant etch rate is chosen and shown in figure 3 along with the event of Price *et al* (figure 3a). Also shown in the figure are the curves expected in each case in the absence of capture and stripping processes. The dashed lines in the figure are the ' constant etch rate ' lines, the etch rate having a value equal to the average of all the points. It can be seen that the Monte-Carlo events resemble the event of Price *et al* very closely in the sense that they are scattered about the straight line in both directions. The rest of the events have a much wider scatter. Indeed events similar to our Monte-Carlo events should have been recorded if a particle with the proper Z and β values was incident on a stack similar to that of Price *et al* and are likely to be identified as due to a monopole. We may point out that the case with $Z=70$ and $\beta=0{\cdot}571$ meets the requirement $\beta\sim0{\cdot}6$ as imposed by the measurements on emulsion and Cerenkov films.

The probability that one of the Monte-Carlo events reproduces exactly the event of Price *et al* is of course very low, since this would imply asking for a certain number of interactions of each type at certain predetermined points. Here we take the view that it is enough to find a mechanism by which particles which are known to exist, can give rise to an event closely resembling that of Price *et al* with a reasonable probability.

In section 3.1 we have estimated approximately the probability of the event having Z_{56} values taking the average mean free paths for the whole stack. Here we estimate the same probability using the Monte-Carlo calculations. First we have calculated the probabilities of obtaining various values of Z_n in the Monte-Carlo simulations. Using the three values of Z_{56} obtained in section 3.1, namely 74, 67, and 54 respectively for the three cases, the respective probabilities were calculated and these charge values were obtained in 70, 127 and 40 cases out of 1000 simulated cases. Thus, we can say that these probabilities are 0·07, 0·13 and 0·04 respectively for the three cases.

We also wish to point out that besides the 56 points, indicating 56 measurements, made in the main Lexan stack, Price *et al* (1975*a*) gave two more points for the top Lexan stack. In the case of these points, which were not considered so far by the previous workers, the fit will be poor if we assume them as due to a monopole. The probability for the fragmentation hypothesis will also decrease. As shown by us in figure 3, using the Monte-Carlo simulations, the two points are attributed as due to a cosmic ray nucleus undergoing stripping process between the first and the second point. The capture process then is assumed to take place near the top of the main Lexan stack. In such a case, however, the Z_1, the value of the charge of the nucleus at the top of the main Lexan stack may not correspond to a completely stripped nucleus. Since the purpose of the present work is to point out that strippping and capture processes are important at this energy range, we have not attempted any further detailed calculation.

We also wish to point out here that for large values of Z and at velocities less than $0{\cdot}7c$ in plastic detectors of about 200μ thickness, the equilibrium charges have no meaning. The most probable values of Z_{56} in the three cases obtained were 74, 67 and 54 respectively and were less than the equilibrium charge values. This point should be borne in mind while analysing the low energy ultra heavy nuclei in plastics.

We would like to emphasize here that this comment applies only to cosmic ray particles having velocities less than $\sim 0{\cdot}7$c and does not apply to those having energy $>1{\cdot}5$ GeV/n observed by Fowler *et al* (1970) and Price *et al* (see Israel *et al* 1975 for references). This point becomes evident if one calculates σ_c and σ_s values using the formulae given by Nikolaev (1965).

4. Summary and conclusions

We have considered for the first time the processes of electron capture and stripping at high velocities for high charges and calculated the probability of occurrence of the monopole-like events. We have also considered the three cases of charge values, namely $Z=83$, 78 and 70 at the top of the main stack and the probabilities for 'monopole-like' events were found to be 0·011, 0·023 and 0·017 respectively. We also found that the Price *et al* event could as well be simulated, using the Monte-Carlo method, assuming the stripping and capture of electrons to be the dominant processes, with probabilities of 0·07, 0·13 and 0·04 for the three cases respectively. We thus interpret the monopole event observed by Price *et al* as a cosmic ray nucleus of $Z=$ 70–83 and $\beta=0{\cdot}6$–$0{\cdot}7$ passing through Lexan stack undergoing stripping and capture processes. These processes were not considered before by earlier workers. It is also pointed out that the analysis of the low energy ultraheavy nuclei made from balloon flights at high latitudes and from satellites and using plastic detectors have to be carefully made taking into consideration the facts mentioned here.

Acknowledgements

We thank Dr B V Sreekantan for his interest and the encouragement given to us during the course of the work. We thank Drs S Biswas, S Sarkar, T N Rengarajan and V S Venkatavaradan for various discussions we had with them.

References

Alvarez L W 1975 *Proc. Stanford Int. Symp. on Lepton and Photon Interactions at High Energies* (Stanford Univ.) p. 967

Brinkman H C and Kramers H A 1930 *Proc. Acad. Sci. Amsterdam* **33** 973

Bohr N and Lindhard J 1954 *Dan. Mat. Fys. Medd.* **28** 7

Dirac P A M 1931 *Proc. R. Soc. (London)* **A133** 60

Dirac P A M 1948 *Phys. Rev.* **74** 817

Fleischer R L and Walker R M 1975 *Phys. Rev. Lett.* **35** 1412

Fowler P H, Clapham V M, Cowan V G, Kidd J M and Moses R T 1970 *Proc. R. Soc. (London)* **A318** 1

Fowler P H 1975 *Proc.* 14 *Int. Cosmic Ray Conf.* (Munich) **12** 4049

Friedlander M W 1975 *Phys. Rev. Lett.* **35** 1167

Israel M H, Price P B and Waddington C J 1975 *Phys. Today* **28** 23

Nikolaev U S 1965 *Sov. Phys. Usp.* **8** 269

Oppenheimer J R 1928 *Phys. Rev.* **51** 349

Price P B, Shirk E K, Osborne W Z and Pinsky L S 1975a *Phys. Rev. Lett.* **35** 487

Price P B, Shirk E K, Osborne W Z and Pinsky L S 1975b *Proc.* 14 *Int. Cosmic Ray Conf.* (Munich) **12** 4041

Raisbeck G and Yiou F 1971 *Phys. Rev.* **A4** 1848

Teplova Ia A, Nikolaev U S, Dmitriev I S and Fateeva L N 1958 *Sov. Phys. JETP* **7** 387