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SHORT COMMUNICATION

RANGE STUDY OF HEAVY IONS IN PLASTIC TRACK DETECTORS

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Abstract—The maximum etchable ranges of heavy ions such as ^{238}U (16.53 MeV/u), ^{208}Pb (13.6 MeV/u), ^{197}Au (11.4 MeV/u), ^{132}Xe (14.5 MeV/u, 13.02 MeV/u and 5.6 MeV/u) and ^{93}Nb (18.0 MeV/u) in CR-39 and ^{238}U (16.53 MeV/u, 15.0 MeV/u and 5.6 MeV/u), ^{197}Au (13.42 MeV/u) and ^{132}Xe (14.5 MeV/u and 5.6 MeV/u) in Lexan have been determined experimentally. The ranges of these heavy ions in these detectors have also been computed theoretically using the Mukherjee and Nayak stopping power equations. A reasonably good agreement has been observed between the experimental and theoretically computed values. Finally, a theoretical study of the relation R (range) $= aE^b$ (energy) has been made using the Mukherjee and Nayak stopping power equations for different heavy ions in CR-39 and Lexan polycarbonate.

INTRODUCTION

During the last few years the scope of solid state nuclear track detectors (SSNTDs) has been widened to a large extent for studying heavy ion interactions with matter. Track detectors have been improved and characterized in various laboratories for better detection sensitivity, and charge and energy resolutions. Heavy ion research involving track detectors in several fields like nuclear reactions (Brandt *et al.*, 1967), lifetimes of heavy unstable nuclear particles (Fleischer and Price, 1964), ternary fission (Fleischer *et al.*, 1966), particle identification (Price *et al.*, 1967), cosmology (Price *et al.*, 1968) and health physics (Benton *et al.*, 1972) is well developed. It is important to note that these studies require reliable and accurate data on range and energy in any desired material.

In the present work, we have used CR-39 and Lexan polycarbonate as detector material. The irradiated samples were etched in 6.25 N NaOH solution under optimum conditions for varying lengths of time and the value of total etchable range has been determined. The range of these heavy ions in these detectors has been computed theoretically using the computer program of Dwivedi (1988) based on the stopping power equations of Mukherjee and Nayak (1979). A theoretical study has also been made about the relation $R = aE^b$ (R is the range and E is the energy of the ion) for different heavy ions in CR-39 and Lexan polycarbonate.

EXPERIMENTAL DETAILS

Irradiation

The samples of CR-39 (composition $C_{12}H_{18}O_7$, molecular weight 274 amu, density 1.32 g/cm^3) have been irradiated by heavy ions such as ^{238}U (16.53 MeV/u), ^{208}Pb (13.6 MeV/u), ^{197}Au (11.4 MeV/u), ^{132}Xe (14.5 MeV/u, 13.02 MeV/u and 5.6 MeV/u) and ^{93}Nb (18.0 MeV/u) available from the UNILAC accelerator at GSI, Darmstadt, Germany. Similarly, the samples of Lexan (composition $C_{16}H_{14}O_3$, molecular weight 254 amu, density 1.23 g/cm^3) have been irradiated by heavy ions such as ^{238}U (16.53 MeV/u, 15.0 MeV/u and 5.9 MeV/u), ^{197}Au (13.42 MeV/u) and ^{132}Xe (14.5 MeV/u and 5.6 MeV/u) by the same source. All the irradiations were performed at an angle of 45° with respect to the surface of the detector with well collimated beams of different heavy ions having the same fluence of 10^4 ions/cm^2.

Chemical etching and other measurements

After irradiation, the samples of CR-39 and Lexan were cut into small pieces and etched in 6.25 N NaOH solution at a constant temperature of 60°C with a control accuracy of ±1°C. The etched samples were washed under running tap water for about 10 min. After washing, the samples were dried in the folds of tissue paper. For determining the total etchable range, the samples were etched for a sufficiently long

Table 1. Comparison between experimental and theoretical values of range for different heavy ions in CR-39 detector

Incident ion	Energy (MeV/u)	Experimental range (μm)	Theoretical range (μm)
^{238}U	16.53	207.92	209.22
^{208}Pb	13.60	166.00	171.23
^{197}Au	11.40	142.68	144.00
^{132}Xe	14.50	191.45	195.00
^{132}Xe	13.02	169.29	173.00
^{132}Xe	5.60	72.00	75.00
^{93}Nb	18.00	263.00	265.00

time until the tip of the tracks became round. The washed and etched samples were scanned using a binocular Carl Zeiss microscope with a magnification of 1000×. After measuring the projected track length, the total etchable range was determined by applying the corrections due to angle of incidence, bulk etching and over-etching (Dwivedi and Mukherjee, 1979). Finally, a comparison was made between experimental and theoretical values of the ranges.

RESULTS AND DISCUSSION

A comparison between experimental and theoretically computed values of ranges for different heavy ions in CR-39 and Lexan are shown in Tables 1 and 2, respectively. It is evident from the tables that the experimental values of range are slightly lower than the corresponding theoretical values. This is so because each detector material fails to record the last few microns of length of the track where the energy loss rate, (dE/dx), of the ion becomes less than the critical energy loss rate, $(dE/dx)_c$, for that detector (Cartwright *et al.*, 1978). Thus, it is clear that the values of range computed theoretically using the Mukherjee and Nayak stopping power equations are in good agreement with the corresponding experimental values.

In order to make a theoretical study of the relation $R = aE^b$ (to study the variation of range with energy for the same ion) in CR-39, the value of ln R has been plotted against ln E for different heavy ions having energy in the range of 0.525 to 20.025 MeV/u. The value of R in CR-39 has been computed theoretically from the Mukherjee and Nayak stopping power equations for different heavy ions in the aforementioned energy range. The value of exponent b (of energy) has been calculated by taking the slope of the plot ln R vs ln E for different heavy ions. One such plot for the ^{132}Xe ion having energy in the range 0.525 to 20.025 MeV/u has been shown in Fig. 1(a). It is concluded from such studies that the value of b (exponent of energy) increases with the increase in atomic number (Z) of the incident ion. Such a variation of b with Z has been shown in Fig. 2(a).

Table 2. Comparison between experimental and theoretical values of range for different heavy ions in Lexan polycarbonate detector

Incident ion	Energy (MeV/u)	Experimental range (μm)	Theoretical range (μm)
^{238}U	16.53	226.82	227.00
^{238}U	15.00	202.85	205.00
^{238}U	5.90	91.72	92.00
^{197}Au	13.42	181.43	183.29
^{132}Xe	5.60	83.10	87.00
^{132}Xe	14.50	205.94	209.00

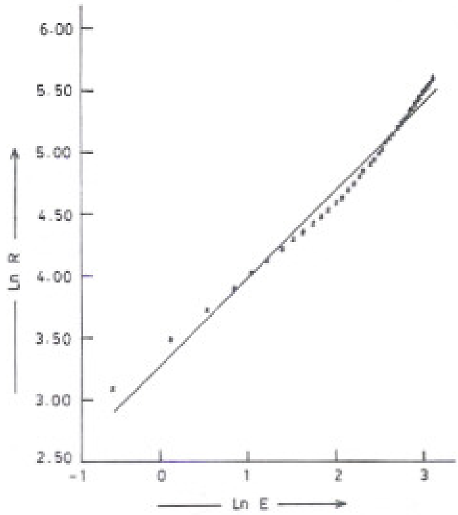

Fig. 1a. Variation of ln R (range) with ln E (energy) for ^{154}Xe in CR-39.

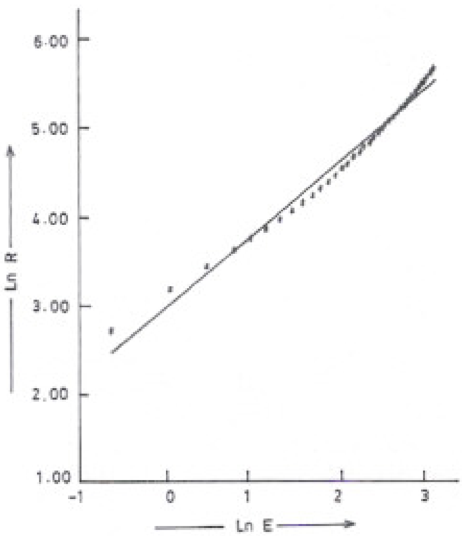

Fig. 1b. Variation of ln R (range) with ln E (energy) for ^{238}U ion in Lexan polycarbonate.

A similar study has been performed for Lexan by choosing the relation $R = cE^d$. For example the relation between ln R and ln E for ^{238}U is shown in Fig. 1(b). The variation of exponent d of energy with atomic number Z of the incident ion in Lexan is shown in Fig. 2(b). It is concluded from these studies that the range varies strongly with energy for light ions in comparison to the heavy ions. Such a study

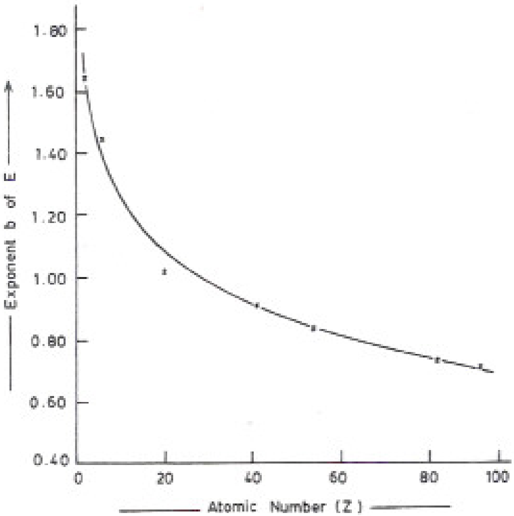

Fig. 2a. Variation of the exponent of energy with atomic number Z of the incident ion in CR-39.

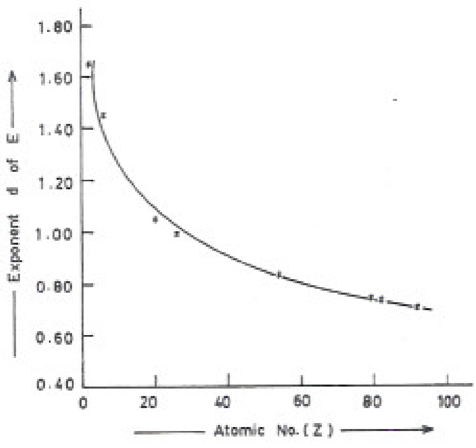

Fig. 2b. Variation of the exponent of energy with atomic number Z of the incident ion in Lexan polycarbonate.

is much more helpful in the identification of particles from cosmic rays using these SSNTDs.

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