Pramana – J. Phys., Vol. 37, No. 5, November 1991, pp. 431–436. © Printed in India.

Response of triafol-TN plastic track detectors to ^{238}U-ions

R K JAIN, S K BOSE and K K DWIVEDI*

Department of Physics, Banaras Hindu University, Varanasi 221 005, India

*Chemistry Department, North Eastern Hill University, Shillong 793 001, India

MS received 25 February 1991; revised 13 August 1991

Abstract. Triafol-TN plastic detector foils have been irradiated with ^{238}U ions of energy 16·34 MeV/u and the tracks produced have been observed using the chemical etching technique. The bulk etch rate and track etch rate are determined under successive chemical etching. In our case, the validity of Arrhenius's law is confirmed by the fact that the same value of E_a obtained for these different concentrations, within experimental errors. The results show a linear correlation between the measured track etch rate along the track and the corresponding total energy loss rate and a threshold value of $\sim 5{\cdot}0\,\mathrm{MeV/(mg/cm^2)}$ for track registration was obtained. The maximum etched track length of ^{238}U-ion in triafol-TN has been compared with the theoretically computed range.

Keywords. Triafol-TN; chemical etching; activation energy; track length; response curve.

PACS No. 61·80

1. Introduction

The research activities in the field of "Trackology" have been going on since the last 32 years and interestingly more research groups are coming up to take up many diverse areas of research in this field. It is due to wide applications of already known solid state nuclear track detectors (SSNTDs), the development of newer detector materials was seen and also due to the availability of energetic heavy ion beams, a greater awareness has been aroused in recent years amongst the scientists (Book of Abstract 1990 and Fleischer *et al* 1975). The production of track by energetic ions in SSNTDs and subsequent revealing of these tracks by chemical etching has been widely used for detection and identification of ions (Fleischer *et al* 1965a; Price and Fleischer 1971; Dwivedi and Mukherji 1979a, 1979b). Triafol-TN (Manufactured by Bayer, AG, West Germany) ($C_3H_4O_2, D = 1{\cdot}153\,\mathrm{g/cm^3}$) has been generally found to be suitable for detection of the light and heavy ions. Knowledge of bulk etch rate (V_B) at different temperatures for any SSNTD is of considerable importance for obtaining the true track length of heavy ion in that detector medium, and the activation energy of bulk etching. The value of activation energies is very useful from the practical point of view since this would allow the value of V_B to be calculated at any desired etching temperature. Further the track etch rate (V_T) is the best observable quantity which provides us with a measure of damage intensity. Theoretically the two basic stopping power equations of Bethe (1930) and Bohr (1948) show a dependence of total energy loss rate ($\mathrm{d}E/\mathrm{d}x$) of a moving ion in any medium on its penetration depth. Hence an attempt to correlate V_T and ($\mathrm{d}E/\mathrm{d}x$) for any ion in any media not only provides us with an understanding of track forming mechanism but also a calibration curve to identify the unknown track forming particles. Hence the curve of the etching rate as a function of the energy deposited along the trajectory of the particle is often called a calibration curve or response curve.

The aim of the present study is to show the validity of Arrhenius's law for bulk etch rate at different concentrations. To obtain the response curves of triafol-TN plastic detector using ^{238}U ions, critical stopping power of triafol-TN for track etching and maximum etchable track length as a function of ^{238}U-ion energies were measured up to 16·34 MeV/u. The maximum etched track length is compared with the theoretical range.

2. Experimental

Several rectangular pieces (1 cm × 1 cm) were carefully cut from a thin foil of triafol-TN SSNTD (cellulose triacetate). The thickness of a foil was measured using an optical microscope (magnification 900 ×) and a Heidenhain depth measuring device (Saxena 1987) and was found to be 21·7 ± 0·5 μm. Stacks of triafol-TN foils were prepared by gently pressing 13 foils together and were mounted on slide glass baking for irradiation. All irradiations were done at the heavy-ion accelerator, UNILAC, at GSI, Darmstadt (Germany). A well collimated beam of ^{238}U-ions with initial energy 16·34 MeV/u, was used to expose the stack of triafol-TN plastics at an incident angle of 45° with respect to the surface of the detector. An optimum dose of 10^4 ion/cm^2 was used.

After irradiation the foils of triafol-TN were removed from the stack and numbered. The foils were than etched in 6·0 N NaOH at 60°C for 60 min in successive time intervals of 10 min each to develop narrow conical tracks. Out of thirteen foils of triafol-TN stack, the tracks were observed only in the first eight foils. The etching of the eight foil was continued till the track tip assumed a round shape. Unexposed triafol-TN foils were also etched in 2N, 4N and 6N NaOH at 40°, 50°, 60° and 70°C for different time intervals to determine V_B. After every etching interval the foils were thoroughly washed in distilled water and dried under vacuum. Plastic thickness and track lengths were measured using the method of Jain *et al* (1988). From the measured data the activation energies at different concentrations were determined. The 'true' (corrected) track lengths are obtained from the equation given by Dwivedi and Mukherji (1979a, b).

3. Results and discussion

The bulk etch rates at different temperatures and different concentrations have been determined for triafol-TN plastic (shown in table 1) using the formula

$$V_B = \Delta x / 2\Delta t \qquad (1)$$

where Δx is the thickness of the plastic dissolved from both sides in etching time Δt. An optical microscope was used for all these measurements with a magnification of 600 ×. The thickness of the dissolved plastic was measured by viewing it through an optical microscope while the plastic was held up in a piece of rubber in such a way that its edge was visible through the microscope. This method of measuring the total change in the thickness of the plastic, i.e. Δx, is more accurate than trying to measure

Table 1. Bulk etch rates (μm/h) of triafol-TN plastic at different temperatures and concentrations.

Temperature (°C)	Normality of NaOH		
	2N	4N	6N
40	0·049	0·212	0·498
50	0·135	0·522	1·380
60	0·309	1·316	3·018
70	0·705	3·004	6·996

the same by focussing the upper and lower surfaces of the plastic. The values of ln V_B have been plotted against the reciprocal of etching temperature (in °K) at different concentrations of NaOH (not shown) and the slope of straightlines gives the activation energy E_a defined by Arrhenius's law:

$$V_B = A\exp(-E_a/kT) \tag{2}$$

we find that

$$\text{for NaOH(2N)}: E_a = 0{\cdot}82\,\text{eV}$$
$$A = 8{\cdot}603 \times 10^{11}\,\mu\text{m/h}$$
$$\text{for NaOH(4N)}: E_a = 0{\cdot}82\,\text{eV}$$
$$A = 3{\cdot}13 \times 10^{12}\,\mu\text{m/h}$$
$$\text{for NaOH(6N)}: E_a = 0{\cdot}81\,\text{eV}$$
$$A = 6{\cdot}40 \times 10^{12}\,\mu\text{m/h}$$

where A is constant and k is Boltzmann's constant. In our case, the validity of Arrhenius's law is confirmed by the fact that almost the same value is obtained for E_a for three different concentrations.

The values of V_T at different points along the track have been measured after every successive etching time interval. The tracks were measured only in the first eight foils. Table 2 lists the values of V_T at various depths of penetration x of the ^{238}U ion in triafol-TN and the corresponding values of the energies and energy loss rates calculated from the computer code DEDXT (Dwivedi 1988) based on the stopping power equations of Mukherji and Nayak (1979). The plot of V_T and (dE/dx) as a function of thickness is shown in figure 1. A fairly good correlation has been observed. Figure 2 represents a linear dependence of energy loss rate dE/dx on the observed track etch rate V_T and can be expressed by the following equation

$$V_T = 0{\cdot}266(\mathrm{d}E/\mathrm{d}x) - 0{\cdot}666 \tag{3}$$

where V_T is expressed in μm/h and dE/dx in MeV mg^{-1} cm^{2}.

It has been observed from figure 2 that the value of $(\mathrm{d}E/\mathrm{d}x)_c$ (critical energy loss rate) for triafol-TN is nearly 5·0 MeV(mg/cm^2) corresponding to the point at which V_T equals V_B. The value of $(\mathrm{d}E/\mathrm{d}x)_c$ is comparable to the theoretical value $(\mathrm{d}E/\mathrm{d}x)_c = [25{\cdot}5(D-1)]/D$ given by Dwivedi and Mukherji (1979), where $(\mathrm{d}E/\mathrm{d}x)_c$ is in MeV/(mg/cm^2) and D is the density in g/cm^3. Calculated value of $(\mathrm{d}E/\mathrm{d}x)_c$ is found

Table 2. Values of V_T at various depth of penetration (thickness) x along with the corresponding values of energies and theoretical dE/dx at 50°C.

E (MeV/u)	Thickness (μm)	V_T (μm/h)	dE/dx MeV/(mg/cm^2)
15·50	12	37·2	138·0
15·02	20	36·0	140·0
13·53	40	39·3	146·1
12·52	56	39·0	150·3
9·52	98	42·5	157·9
6·02	141	48·2	184·3
4·03	163	47·1	178·7
3·52	169	46·0	172·0
2·52	182	37·6	143·3
2·02	189	34·3	131·8
1·50	198	29·8	117·0
1·03	207	26·0	98·0
0·52	219	22·0	73·9

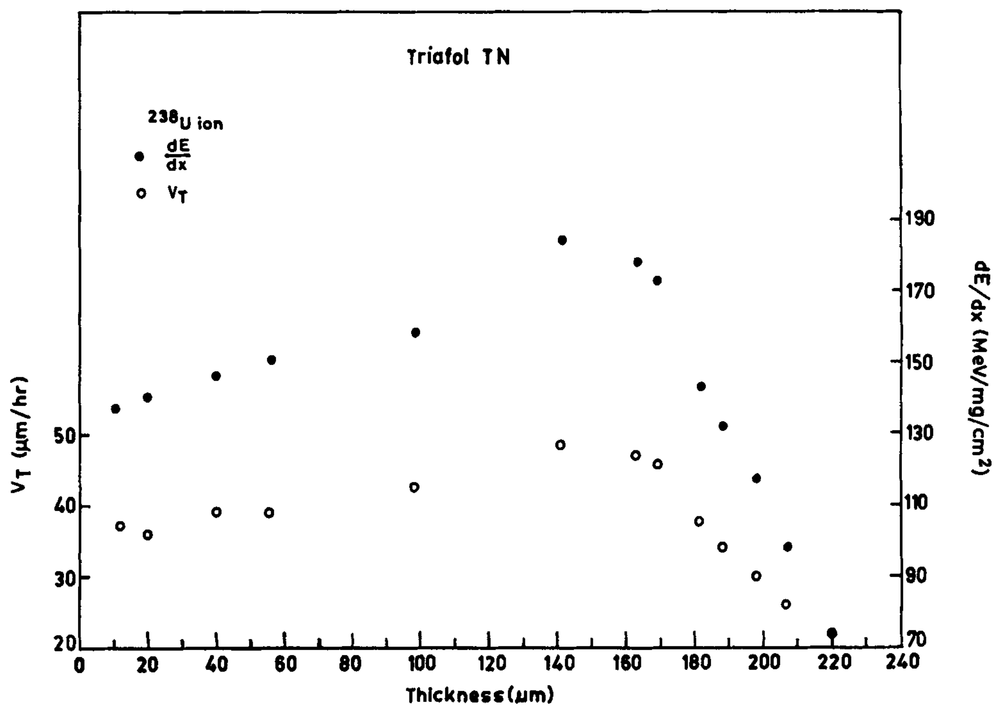

Figure 1. A plot showing measured V_T (in μm/h) and calculated dE/dx (in MeV mg^{-1} cm^2) for ^{238}U-ions in triafol-TN as a function of penetration depth.

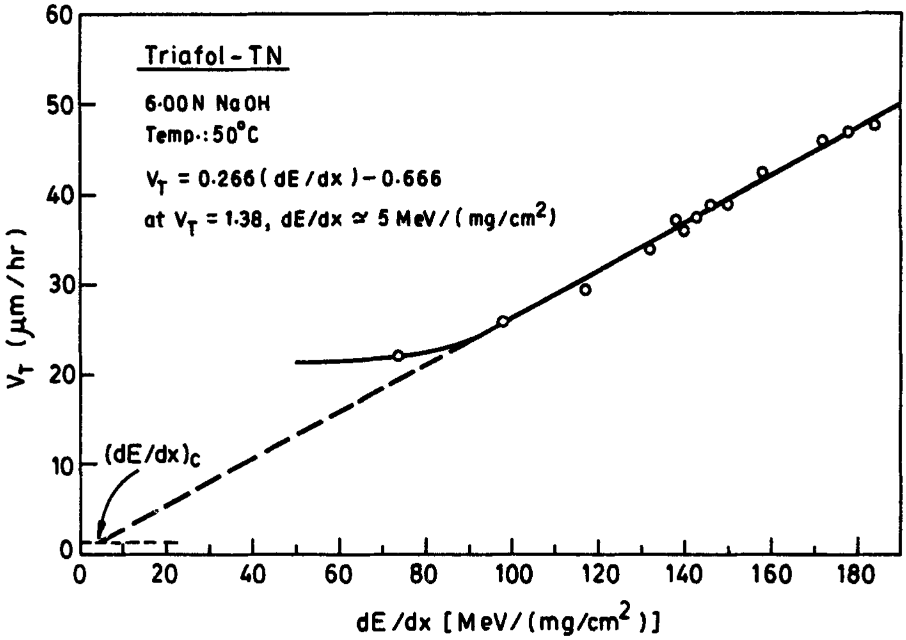

Figure 2. A plot showing calibration curve between V_T and dE/dx for ^{238}U-ions in triafol-TN. Tracks are etched in 6N NaOH at 50°C.

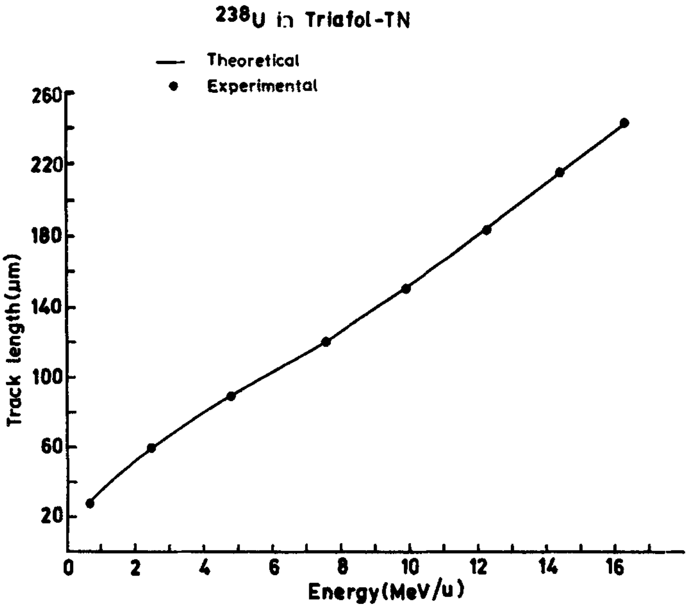

Figure 3. Measured track lengths of ^{238}U ions in triafol-TN are plotted along with calculated values from computer code DEDXT.

to be 3·38 MeV/(mg/cm^2). The present value of $(\mathrm{d}E/\mathrm{d}x)_c = 5$ MeV/(mg/cm^2) agrees with that reported in the literature (Debeauvais *et al* 1967; Fleischer *et al* 1965a, b; Ghosh *et al* 1988). The difference is considered negligible. The studies were carried out this time for another region of dE/dx values i.e. in the range 7 to 184 MeV/(mg/cm^2)

Table 3. Range and maximum etchable track lengths of ^{238}U in triafol-TN plastic detector.

Ion energy E(MeV/u)	Maximum etchable track length L(μm)	Theoretical range (μm)
16·34	242 ± 2	243·0
14·30	214 ± 2	214·0
12·20	182 ± 2	183·5
9·95	149 ± 3	152·5
7·50	120 ± 3	119·0
4·82	88 ± 3	89·0
2·41	58 ± 4	59·0
0·62	26 ± 4	28·5

while the earlier paper (Ghosh *et al* 1988) covered the range 8 to 23 MeV/(mg/cm^2). Hence it is possible to examine the data in the light of Z/β values of the detectors i.e. 40 and 60–65 for cellulose acetate and lexan respectively as such values are now considered as more basic. The plots of measured track length and theoretical range vs. ion energy are shown in figure 3. The experimentally measured range of 16·34 MeV/u ^{238}U-ion in triafol-TN was found to be 241 ± 3 μm corresponding to the value of $(dE/dx)_c$ equal to 5·0 MeV/(mg/cm^2). It was found that nearly 1 μm of the ^{238}U damage trail (range) remained unetched in triafol-TN. As this deficit range is within the experimental errors, we can find a meaningful comparison between measured track lengths and the theoretical ranges. The theoretical calculations for ^{238}U ions using the computer code DEDXT shows a reasonable agreement with our experimental results as shown in table 3.

Acknowledgements

The authors are thankful to Dr R Spohr, Dr J Vetter and other staff of UNILAC, Darmstadt for providing irradiation facilities.

References

"Book of Abstract", *15th Int. Conf. on particle tracks in solids*, Marburg (F R Germany), Sept. 3–7, 1990
Bethe H A 1930 *Ann. Phys.* Leipzig **5** 325
Bohr N 1948 *Mat. Fys. Medd. K. Dan. Vidensk. Selsk.* **18** No. 8
Dwivedi K K and Mukherji S 1979a *Nucl. Instrum. Methods* **159** 433
Dwivedi K K and Mukherji S 1979b *Nucl. Instrum. Methods* **161** 317
Dwivedi K K 1988 *Nucl. Tracks Radiat. Meas.* **15** 345
Debeauvais M, Stein R, Ralarosy J and Cuer P 1967 *Nucl. Phys.* **A90** 186
Fleischer R L, Price P B and Walker R M 1965a *Ann. Rev. Nucl. Sci.* **15** 1
Fleischer R L, Price P B and Walker R M 1965b *J. Appl. Phys.* **36** 3645
Fleischer R L, Price P B and Walker R M 1975 *Nuclear tracks in solids, principles and application* (California: University Press)
Ghosh S, Saxena A and Dwivedi K K 1988 *Pramana – J. Phys.* **31** 197
Jain R K, Singh A K, Mukherji S, Rama Rao J and Bose S K 1988 *J. Phys.* **D21** 768
Mukherji S and Nayak A K 1979 *Nucl. Instrum. Methods* **159** 421
Price P B and Fleischer R L 1971 *Annu. Rev. Nucl. Sci.* **21** 295
Saxena A 1987 *Measurement of heavy ion ranges in elemental and complex media using SSNTDs*. Ph.D. Thesis, NEHU, Shillong (unpublished) p. 29