Physics

DEPENDENCE OF SENSITIVITY OF DIFFERENT PLASTIC TRACK DETECTORS ON ETCHING TEMPERATURE

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SUMMARY: Exposures of Cellulose nitrate (Russian) CN (R) and Makrofol-E polycarbonate plastic track detectors to different ions have been obtained from the cyclotron at JINR, Dubna (USSR). In this study ^{12}C, ^{16}O, ^{20}Ne, ^{40}Ar, ^{50}Ti-ions different energies are used as energetic heavy ions for track formation in the detectors. The chemical etching is carried out in stirred (6.00 ± 0.05) N NaOH solution. The dependence of bulk etch rate, V_b and track etch rate, V_t on etching temperature, T is exponential and can be expressed by Arrhenius correlation. The dependence of activation energy for track etching, E_t on mass A of the bombarding ion is studied. The experimental results show that for CN(R) both V_t and reduced etch rate, $V=V_t / V_b$ along the trajectory of the particle depend on etching temperature. For Makrofol-E, V_t depends on etching temperature but V is independent of etching temperature. It is observed that the tracks of heavy ions etch faster. Using theoretical equations and with the help of computer the energy-loss, dE/dx US V_t curves λ are drawn for different etching temperatures. The dependence of "Sensitivity" [(V-I) VS Z] of the detectors on etching temperature is also shown. It is evident from these figures that the sensitivity of CN(R) depends strongly on etching temperature while that of Makrofol E is independent of etching temperature.

Key Words: Solid state nuclear track detector; bulk and track etch rate; activation energy; energy-loss; response curve; sensitivity.

INTRODUCTION

Dielectric detectors, in which nuclear particle tracks are made visible by a preferential chemical etching, are uniquely useful for certain studies in nuclear physics, geophysics and astrophysics (7, 12). The curve of the track etching rate as a function of the energy deposited along the trajectory of the particle is known as "response curve". For particle identification with solid state Nuclear Track Detectors (SSNTDS), it is necessary to have the response curves of differentions. The etch rate ratio, $V=V_t / V_b$, as a function Z of the ions indicates the "Sensitivity" of SSNTDS (5,8). The aim of the present study is to draw the response curves of CN(R) and Makrofol-E detectors using different ions. The dependence of response curves on etching temperature is shown. The temperature dependence of Sensitivity is also shown. The bulk etch rate and track etch rate are measured for different temperatures. The experimental results show that both V_t and V alon the trajectory of the particle depend on etching temperature for CN(R) detector while for Makrofol-E V_t depends on etching temperature but V is independent of etching temperature.

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Table 1: Ions and their energies used in the present study.

Detector	Ion	Energy	Angle of exposure (w.r.t) detector surface)	
Cellulose	16	8.75 MeV/N		30°
Nitrate (Russian)	8°			
$C_6H_8O_9N_2$	20	10.00 MeV/N	30°	
	10^{Ne}			
p = 1.45 g/cm^3	40	7.5 MeV/N	30°	
	18	4.9 MeV/N	30°	
Makrofol-E	12	5.5 MeV/N	30°	
polycarbonate	6°			
$_{12}H_{14}O_3$	16	5.5 MeV/N	30°	
	8°			
p = 1.20 g/cm^3	20	5.5 MeV/N	30°	
	10^{Ne}			
	40	7.5 MeV/N	30°	
	18^{Ar}			

EXPERIMENTAL PROCEDURE

Detector samples exposed to different ions from Cyclotron have been obtained from Cyclotron have been obtained from JINR, Dubna (USSR). The exposure conditions are given in Table 1. The etching is carried out in stirred (6.000 ± 0.05) N NaOH solution at a constant temperature in a thermostatic bath. The temperature at which etching takes place is maintained constant to ± 0.5°C. The measurements are taken with an "Olympus" microscope with a 40x objective and 15x eyepiece. The least count of the eyepiece micrometer is LC= 0.215 μm at a magnification of 900x. In figures the accuracy of the measurements is better than the size of the symbols, unless the error bases are specially shown.

RESULTS AND DISCUSSIONS

Determination of Bulk Etch Rate, V_b.

The bulk etch rate, V_b of Cellulose nitratie (R) has been determined by the following two methods:

(I) Thickness measurement method

(II) Track-diameter method.

In case of Makrofol-E polycarbonate the following methods have been used to determine the bulk etch rate, V_b.

(I) Gravimetric method

(II) Track-diameter method

These methods are discussed elsewhere (4-6). The bulk etch rate, V_b of CN(R) is determined at 30°, 40°, 50°, 60° and 70°C for 6N NaOH solution while that of Makrofol-E polycarbonate is determined at 50°, 60°, 70°, 80° and 90°C. Both methods give the same results within the limits of uncertainty. This shows the isotropic etching character of CN(R) and Makrofol-E polycarbonate detectors. The plot of 1n V_b vs 1/T is a straight line which indicates the exponential dependence of V_b on etching temperature, T (in absolute scale). This dependence can be expressed by a relation of the form (Somogyi 1980),

$$V_b = A \exp(-E_b / kT)$$

Where A is a constant, is the Boltzmann's constant and E_b is the activation energy for bulk etching. From the slope of the straight line, the value of E_b is calculated to be E_b = (1.06 ± 0.1) eV for CN(R) and E_b = (0.70 ± 0.08) eV for Makrofol-E polycarbonate detector. These values are in good agreement with those reported in literature (Enge *et al.* 1974; Dwivedi and Mukherji, 1979).

Effect of Temperature on Track Etch Rate, V_t.

When detector samples exposed to accelerated ions are etched in NaOH solution we observe the appearance of conical tracks. The projected lengths are measured. The detailed procedure is discussed elsewhere (5,6). The true track length, L (the length from the original surface to the terminal end of the track) is determined by the relation (2,5,6).

$$L = \frac{1p}{\cos\theta} + \frac{V_b t}{\sin\theta} - V_b (t - t_c) \quad .....(1)$$

where 1p = the projected length

θ = angle of incidence

$V_b t / \sin\theta$ = the surface etching correction

$V_b(t-t_c)$ = the over-etching correction

t_c = the time required to etch the track upto the point where they stop (etched until the track ends become round).

The track etch rate, V_t is calculated by the relation (1,2,5,6),

$$V_t = \Delta L / \Delta t \quad ....(2)$$

where ΔL is the track length increase in etching time Δt. Samples of CN(R) exposed to $^{20}_{50}$Ti-ions are etched in 6N NaOH solution. At least 50 tracks are measured for each set of observation. The plot of the variation of 1_p and L with etching time is shown in Figure 1. Similar curves are also drawn for $^{40}_{18}$Ar, $^{20}_{10}$Ne and $^{16}_{8}$O-ions (but they are not shown). Using equation (2), the values of V_t at different points on the track are obtained from Figure 1. Figure 2 shows the variation of V_t with residual range of different ions for etching in 6N NaOH at 60°C. Clearly V_t increases with penetration depth. Following the same procedure, V_t is calculated for different ions in Makrofol-E. Figure 3 shows the variation of V_t with residual range of different ions in Marofol-E for 70°C.

Similarly the plots of V_t vs. residual range of different ions in CN(R) are drawn for etching temperatures of 30°, 40°, 50° and 70°C. The same plots for different ions in Makrofol-E are also drawn for temperatures of 50°, 60°, 80° and 90°C. These plots which are similar in nature to those shown in Figures 2 and 3 are not presented here. In etching tracks of light and heavy particles, it is immediately observed that tracks of heavy particles etch faster (Figures 2 and 3).

The track etch rate V_t corresponding to a particular range (50 μm in this case) is obtained from these curves

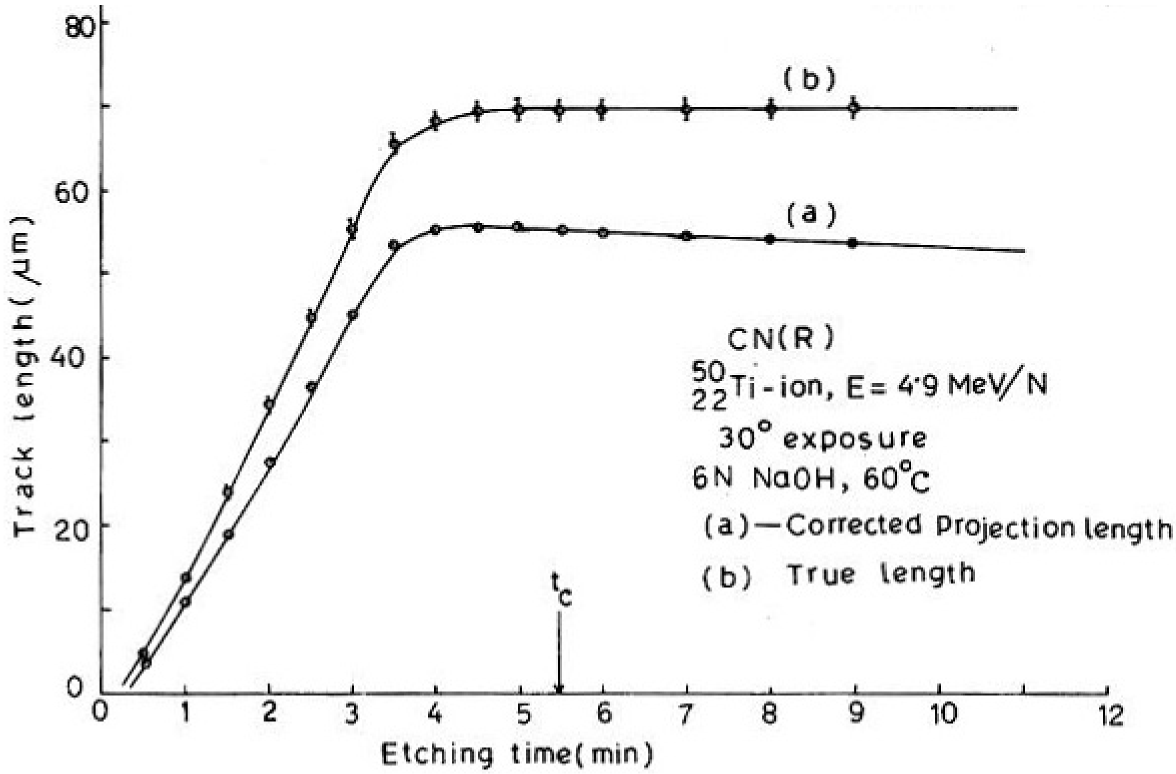

Figure 1: Variation of (a) corrected projection length, 1_p and (b) true track length, L of $^{50}_{22}$ Ti-ions in CN(R) with etching time.

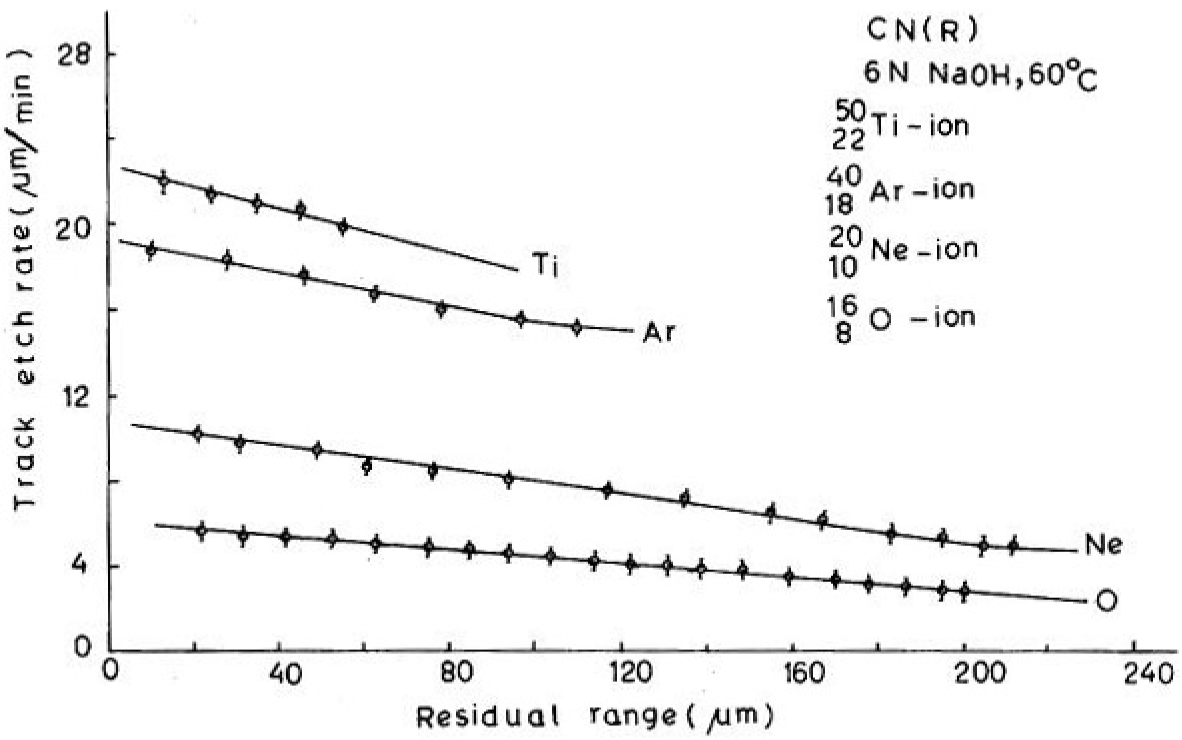

Figure 2: Variation of track etch rate, V_t residual range of different ions in CN(R) for 60°C.

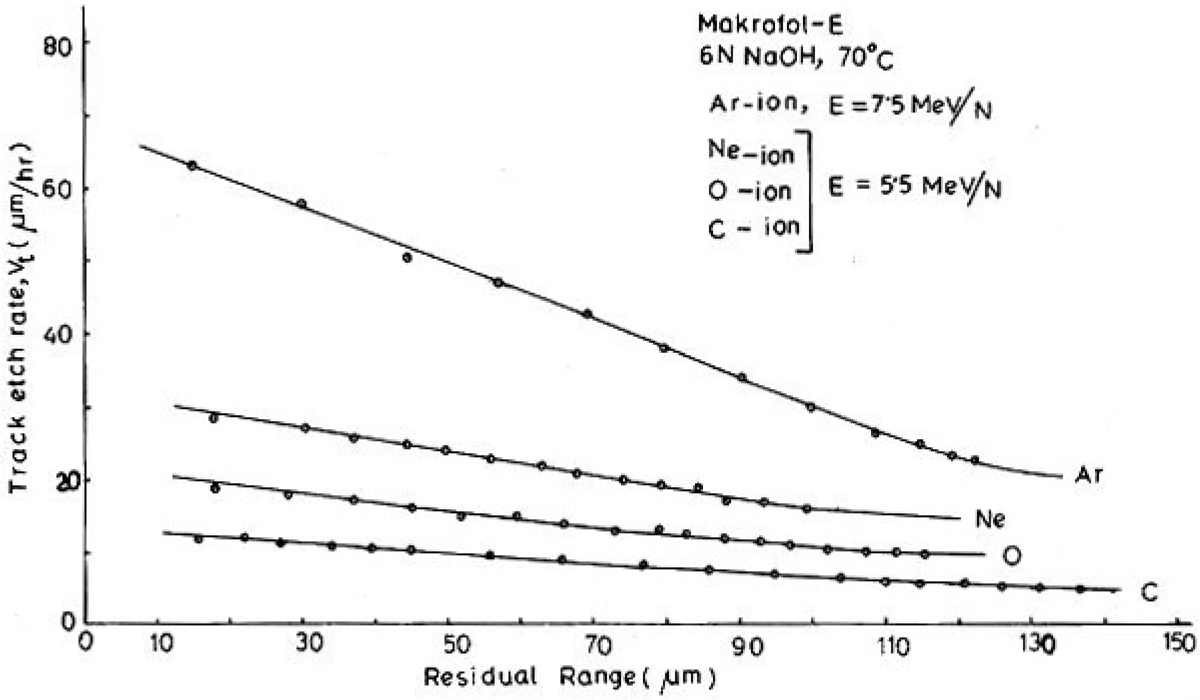

Figure 3: Variation of track etch rate, V_t with residual range of different ions in Makrofol-E detector for 70°C.

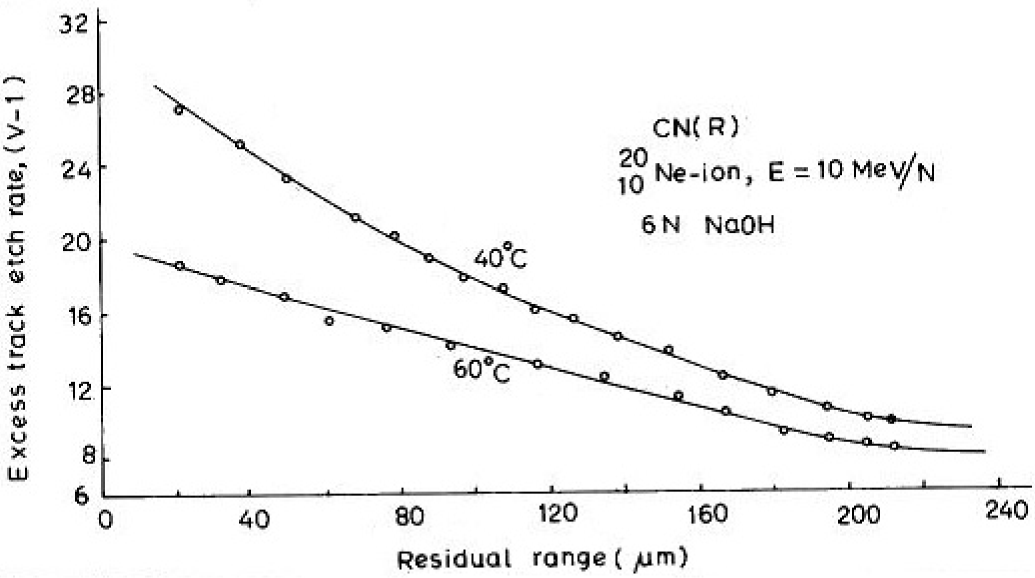

Figure 4: Variation of excess track etch rate, (V-1) with residual range of $^{20}_{10}$ Ne-ion tracks in CN(R) for two different etching temperatures.

for different temperatures. The plot of In V_t against 1/T is again a straight line which shows the exponential dependence of V_t on 1/T. This can be expressed by a relation of the form (Hilderbrand and Benton 1980):

$$V_t = B \exp(-E_t / kT)$$

Where B is a constant, E_t is the activation energy for track etching, k is the Boltzmann's constant and T is the etching temperature in absolute scale. The values of E_t for different ions are calculated from the slopes of the straight lines obtained by plotting In V_t vs 1/T for CN(R) and Makrofol-E. These values are presented in Table 2. It is observed that the value of E_t does not change significantly with mass A of the bombarding ion in a particular detector but is different for different plasma.

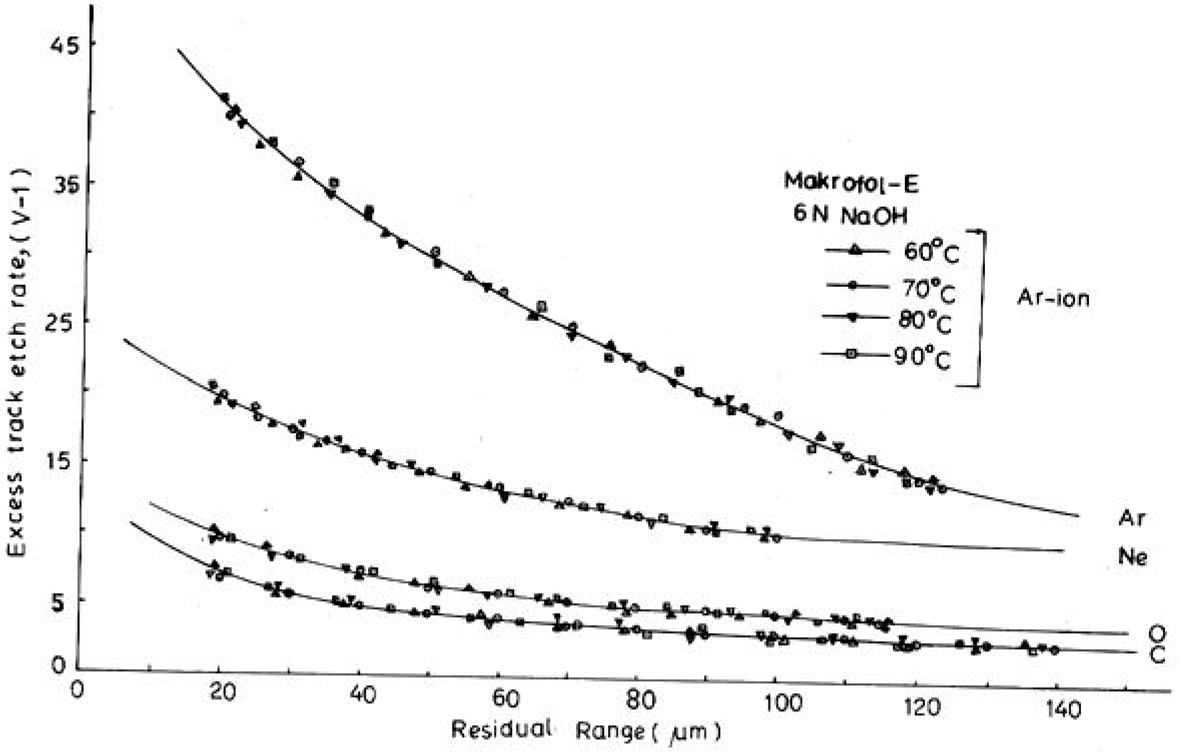

Figure 5: Variation of excess track etch rate, (V-1) with residual range of different ions in Makrofol-E for different etching temperatures.

In Figure 5, V vs residual range curves are shown for different ions in Makrofol-E for different etching temperatures. It is noted that all the points belong to the same curve within the accuracy of the measurements. The solid curve is the best fit to the experimental points. It is concluded from Figures 3 and 5 that V_t along the particle trajectory depends on the etching temperature but $V=V_t / V_b$ is independent of the etching temperature for Makrofol-E detector.

Table 2: Activation Energy for track etching of different ions in plastic detectors.

			Activation energy, E_t (eV) for		
Detector	C	O:	Ne:	Ar:	Ti
CN(R)	-	0.85±0.08	0.83±0.08	0.81±0.08	0.80±0.08
Makrofol-E	0.68±0.07	0.66±0.07	0.65±0.07	0.64±0.07	-

The "Response Curve"

To calculate the energy-loss, dE / dx of the ion in the detector we have used the range and stopping power equations of Mukherji and Nayak (1979). Using these equations a computer pogramme is made and with the help of computer the energy-loss, dE/dx of different ions in CN(R) and Makrofol-E is computed. Using the values obtained from the computer output, the plots of energy-loss, (dE/dx) vs residual range have been drawn for different ions in CN(R) and Makrofol-E (not shown). The variation of V_t with residual range is shown in Figures 2 and 3. Combining these figures, 'response curves' [(dE/dx) vs V_t)] of CN(R) and Makrofol-E are shown in Figures 6 and 7 for different etching temperatures. In figures 6 and 7 for different etching temperatures. In Figures 8 and 9, the reduced etch rates, $V = V_t / V_b$) are plotted against (dE/dx) of different ions in CN(R) and Makrofol-E respectively. Thus for CN(R) both V_t and $V = V_t / V_b$ depends on dE/dx as well as on etching temperature. For Makrofol-E, V_t depends on dE/dx as well as on etching temperature but $V = V_t / V_b$ depends only on (dE/dx) and not on etching temperature.

Dependence of Sensitivity on Etching Temperature.

The teoretical plots of dE/dx vs residual range for different ions are known. From these curves the residual ranges of different ions corresponding to a particular

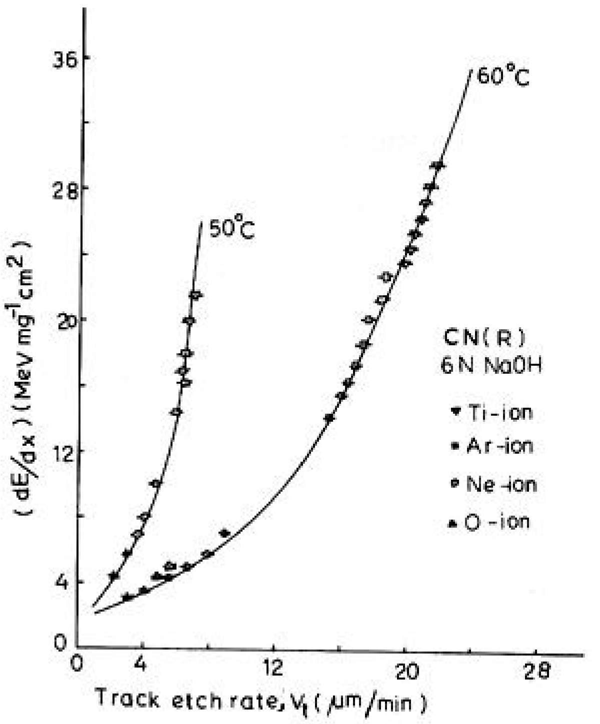

Figure 6: Dependence of track etch rate, V_t on the energy-loss, dE/dx of different ions in CN(R) for different etching temperatures.

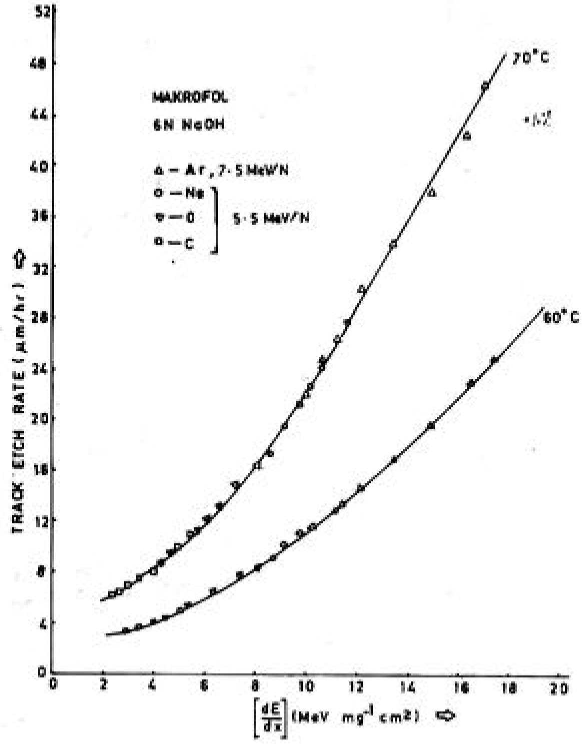

Figure 7: Dependence of V_t on the energy-loss, dE/dx of different ions in Makrofol-E for 60° and 70°C.

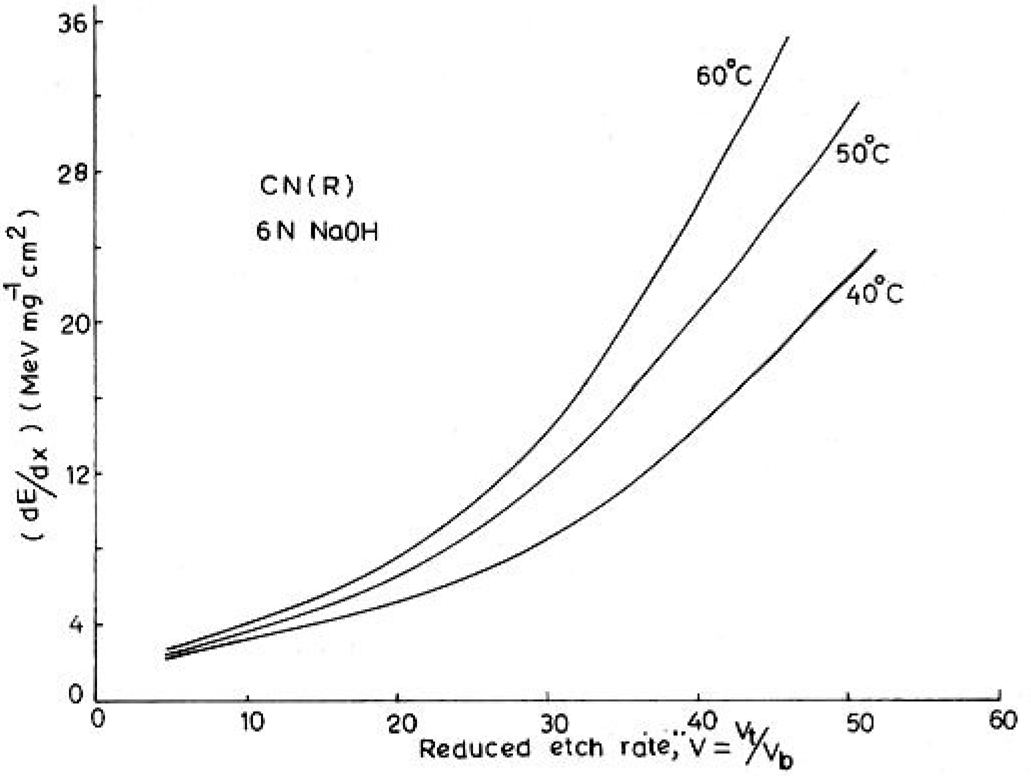

Figure 8: Dependence of reduced track etch rate, V= V_t /V_b on the energy-loss, dE/dx of different ions in CN(R) for different etching temperatures of etching.

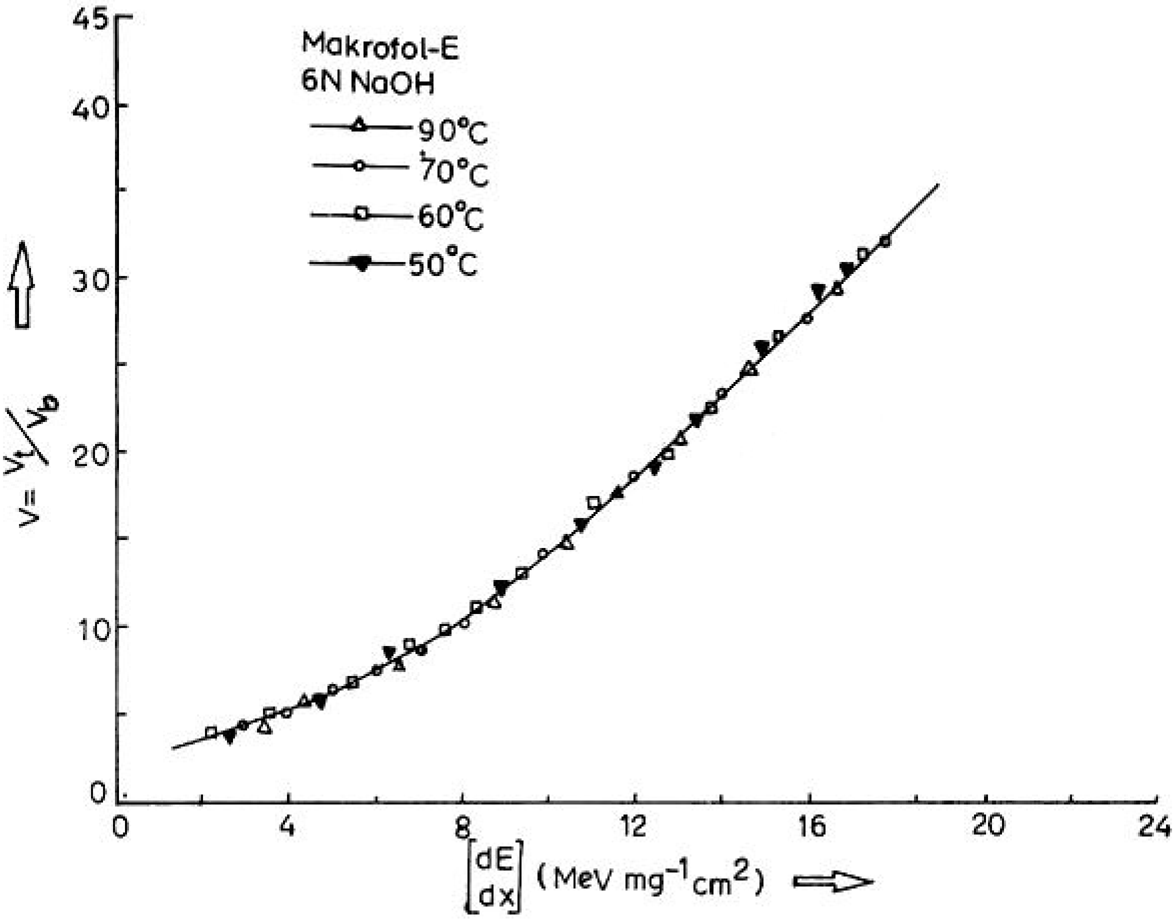

Figure 9: Dependence of reduced etch rate, V on the energy-loss, dE/dx of different ions in Makrofol-E for different etching temperatures.

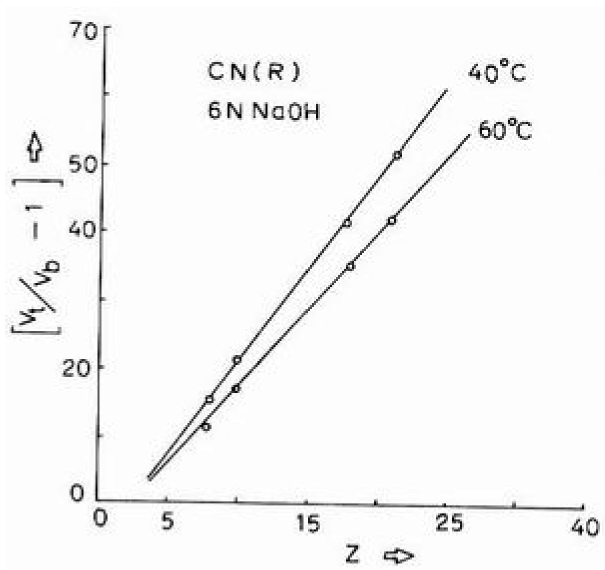

Figure 10: Dependence of sensitivity of CN(R) plastic detector on etching temperature.

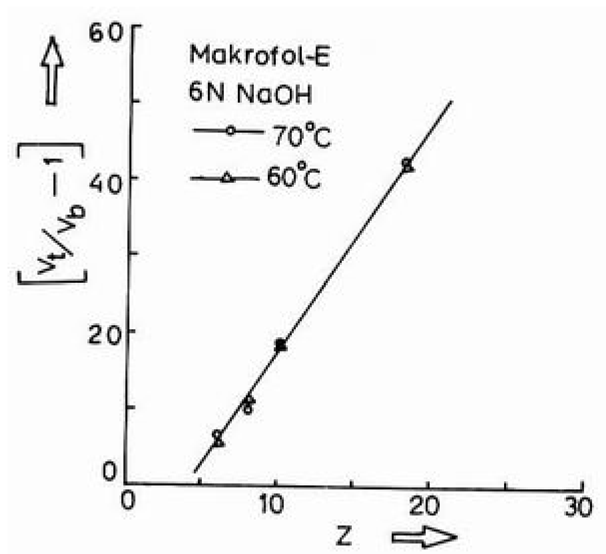

Figure 11: Dependence of sensitivity of Makrofol-E plastic detector on etching temperature.

dE/dx are determined. The track etch tics, being the characteristic of the detector material. Again it is noted that $E_b = E_t$ for Makrofol-E but $E_t < E_b$ for CN(R) detector.

In Figure 4 data of excess track etch aret ratio, (V - 1) are plotted vs the residual range of $^{20}_{10}$Ne-in in CNR(R) for 40° and 60°C. It is observed from Figures 2 and 4 that both V_t and V along the trajectory of the particle depend on the etching temperature. The same conclusion is valid for the other ions in CN(R) detector.

Rate, V_t corresponding to these residual ranges are obtained from Figures 2 and 3 for different ions. The relationship between (V_t / V_b-1) and Z thus determined is shown in Figure 10 for CN(R) at two different etching temperatures. The same curve for Makrofol-E is shown in Figure 11. It is clear from these figures that the sensitivity of CN(R) depends strongly upon the etch bath temperature while that for Makrofol-E is independent of etch bath temperatures.

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