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# A New Method to Determine the Maximum Value of the Track Length of Alpha Particle in CR-39 Detector

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## Abstract

**The aim of this paper is to determine the maximum values of the track length ($L_{max}$) of alpha particles in Nuclear Track Detector (type CR-39) using a new method by taking the relation between the etching time and the diameter square of alpha particle with different energies at constant bulk etch rate VB (1.45 μm/hr) by using TRACK_TEST program from Brun *et al.* function and Yu *et al.* function. Using the new equation, the maximum values of the track lengths of alpha particles measured in CR-39 detector have been found to be in a good agreement with the values measured by using Brun *et al.* function and Yu *et al.* function in TRACK_TEST program.**

## Keywords

## 1. Introduction

A heavy charged particle leads to intensive ionization when it passes through matter. Along the path of the particle, a zone called the latent track is created, which is enriched with free chemical radicals and other chemical species. If a piece of material containing the latent track is exposed to some chemically aggressive solution (such as aqueous NaOH or KOH solution), the chemical reaction would be more intensive in the latent track. Such a solution is called the etchant. Through the etching, the latent track becomes visible as a particle "track" which may be seen under an optical microscope. The effect itself has been known for a long time, which is called the "track effect" [1]. The technique has been extensively investigated in the literature, and has been widely applied in many fields of science and technology [2]. The main use of CR-39 plastic detector is in the field of health physics, such as detection of proton, helium and heavy charged particle, radon monitoring and

neutron dosimetry [3].

Characteristics of solid state nuclear track detectors were studied by many authors. It is well known that, track size, bulk etch rate and track etch rate are affected by exposing detectors to several types of radiations such as, X-ray, G-rays, UV and alpha particles. The two main changes noticed in polymers are:

1) chain cross-linking resulting in an increase of molecular weight because of a large number of free radicals produced in polymer;

2) chain scission resulting in a decrease of molecular weight and substantially changing in polymer material properties. In addition to these changes, small molecules such as $Co$, $Co_2$ and $H_2$ may be produced resulting from bond scission [4].

There is no complete theory so far which completely describes the physics of track formation. In spite of the fact that such theory is not so essential as far as SSNTD practical uses are concerned, the problem is still an open one. Thus, the problem of the track development geometry has been the subject of many studies in recent years. Emphases have been paid on two aspects of three dimensional track developments upon etching. The first is an experimental one. This involves the use of atomic force microscopes [5]-[7] and confocal microscopy techniques [8]-[11] to obtain a direct view of the track profiles in three dimensions. The second type of studies is mainly concerned with geometrical equations related to track shapes upon different etching times [2] [12]-[14]. Both normal and oblique incidences have been treated. A user computer program that can calculate track profiles under different conditions has been presented by Nikezic and Yu [1]. A new empirical equation describing the development of charged particles radiation track against etching time and the longitudinal depth of track is presented [15].

We can determine the maximum value of the track's length corresponding to the energy of alpha particles, while the conical shape of the etch pit turns to a hemispherical shape. This occurs, when the total particle range is etched. Further prolongation of the etching time does not result in further growing of the track length, because the etching now takes place with the bulk etch rate in all directions [16].

GyAlmasi *et al.* proposed an equation to find the range of alpha particles theoretically by using over-etched track profile technique [17]:

$$R = \frac{S}{16 * V_B} - \frac{I}{S} V_B \tag{1}$$

We proposed a new equation to determine the maximum values of the track lengths ($L_{max}$) of alpha particles in CR-39 detector depending on Equation (1), but after multiplying it with a specific parameter to get the value of the track length at energy of each alpha particle.

## 2. Experiment

We got the maximum values of the track lengths and the values of the diameters of alpha particles in CR-39 detector at different duration times of etching process from Nikezic and Yu *et al.* function and from Brun *et al.* function by using TRACK_TEST program for the same energies of alpha particles (2.5, 3.0, 3.6 and 4.0) MeV and with the same bulk etch rate (1.45 µm/hr) for the two functions.

## 3. Results and Discussion

The values of diameter square ($D^2$) have been plotted versus etching time (t) for the data that we obtained from Brun *et al.* function [18], and from Nikezic and Yu *et al.* function [19] by using TRACK_TEST program [1] for CR-39 detector for the two functions with different energies of alpha particles as shown in (**Figures 1-4**). We showed from the figures the non-linear relationships between the etching time and the diameter squares of the of alpha particles and by taking the fitting of the straight line of the curve we measured the slope of the linear part and the intercept with the x-axis, and then we could calculate the $L_{max}$ of alpha particle in the CR-39 detector by using the Equation (1) but after multiplying it with 2.56.

$$L_{max} = 2.56 \left[ \frac{S}{16 * V_B} - \frac{I}{S} * V_B \right] \tag{2}$$

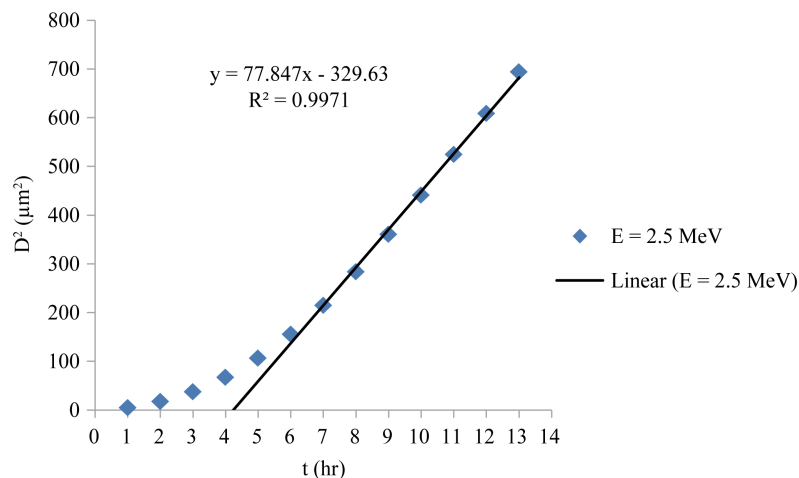where S is the slope of straight line of $D^2$ and t relation and I is the intercept of straight line with x-axis.

**Figure 1.** Diameter square (D$^2$) as a function of etching time (t) for alpha energy Eα = 2.5 MeV by using Brun *et al.* function.
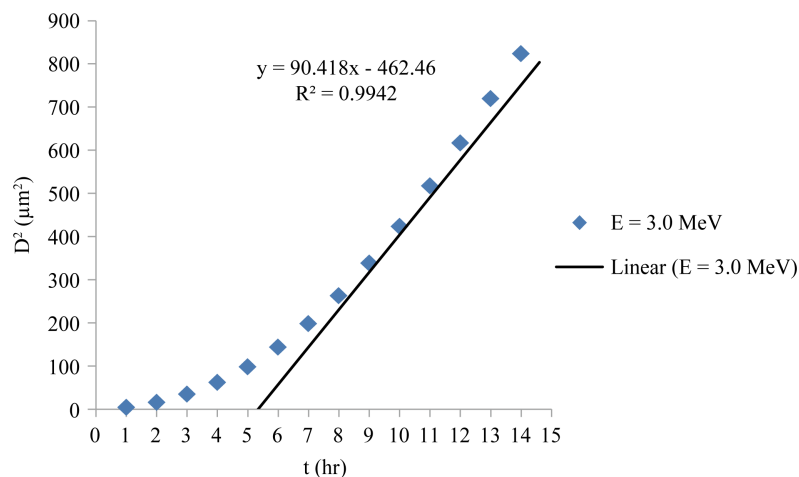


**Figure 2.** Diameter square (D$^2$) as a function of etching time (t) for alpha energy Eα = 3.0 MeV by using Brun *et al.* function.
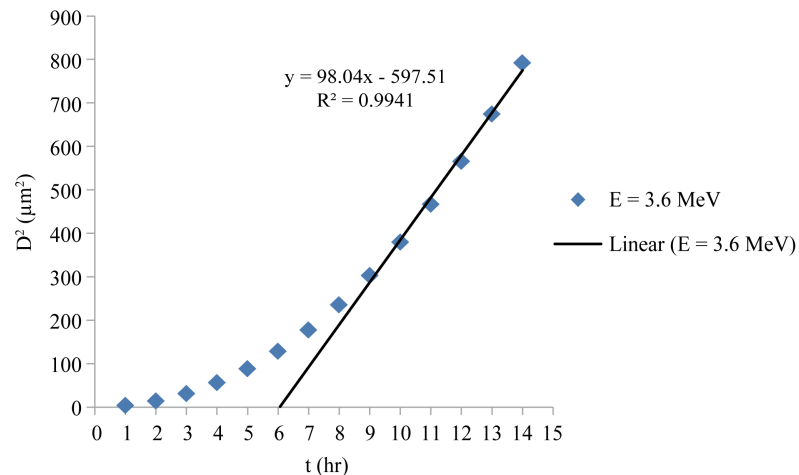


**Figure 3.** Diameter square (D$^2$) as a function of etching time (t) for alpha energy Eα = 3.6 MeV by using Brun *et al.* function.
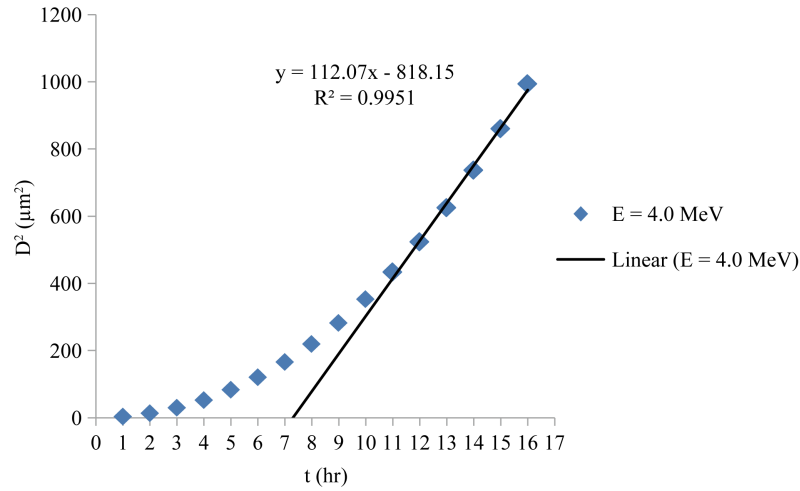
**Figure 4.** Diameter square ($D^2$) as a function of etching time (t) for alpha energy $E\alpha$ = 4.0 MeV by using Brun *et al.* function.

While $V_B$ is constant and equal to 1.45 µm/hr [20], and it is determined from the change in the mass of the detector $\Delta m$ and the density of the detector material [21] [22] and it is based on Equation (3):

$$V_B = \frac{\Delta m}{2A\rho t} \tag{3}$$

where $\Delta m$ is mass difference, A is the etched surface area, $\rho$ is the density of the detector and t is the etching time.

We found the parameter 2.56. By comparing the results of $L_{max}$ that we obtained directly from Brun *et al.* function by using TRACK_TEST program with the results that we obtained by using Equation (1), we observed that Equation (1) will give me correct results for the maximum values of the track length alpha particles if we multiplied it with 2.56. and we found this parameter by dividing the value of $L_{max}$ from Brun *et al.* function over the theoretical value of $L_{max}$ from Equation (1) for the same used energy, and after multiplying the theoretical values that we obtained by using Equation (1) by the factor 2.56 (Equation (2)), we got values very close to the maximum values of the track lengths that we obtained directly from Brun *et al.* function [18] by using TRACK_TEST program [1].

Let us now take the same kind of $L_{max}$ measurements directly from Yu *et al.* function [19] in TRACK_TEST program [1], and then compare the results of $L_{max}$ theoretically that we obtained by using Equation (2) from the data between the etching time and the diameter square (t & $D^2$) that we obtained from Yu *et al.* function [19] in TRACK_TEST program [1]. We found that Equation (2) gave good results of $L_{max}$ comparing it with the values of $L_{max}$ that have obtained directly by using Yu *et al.* function in TRACK_TEST program. **Figures 5-7** and **Figure 8** show the relation between etching time and the diameter square.

**Table 1** shows the comparison between the values of $L_{max}$ for alpha particles in CR-39 at different energies from Brun *et al.* function [18] by using TRACK_TEST program [1], and the theoretical method by using Equation (2). It is clear that there is a good agreement between the values of $L_{max}$ that have been calculated theoretically by using Equation (2) and the values of $L_{max}$ from Brun *et al.* function by using TRACK_TEST program.

**Table 2** shows the comparison between the values of $L_{max}$ for alpha particles in CR-39 at different energies from Yu *et al.* function [19] by using TRACK_TEST program [1], and the theoretical method by using Equation (2). It is clear that there is a good agreement between the values of $L_{max}$ that have been calculated theoretically by using Equation (2) and the values of $L_{max}$ from Yu *et al.* function by using TRACK_TEST program.

## 4. Conclusion

The maximum values of the track lengths in CR-39 detector for different energies of alpha particles (2.5, 3.0, 3.6 and 4.0 MeV) have been calculated from a simple relation between the etching time and the diameter square of alpha particles from track diameter measurements. From the obtained results we found that Equation (2) will
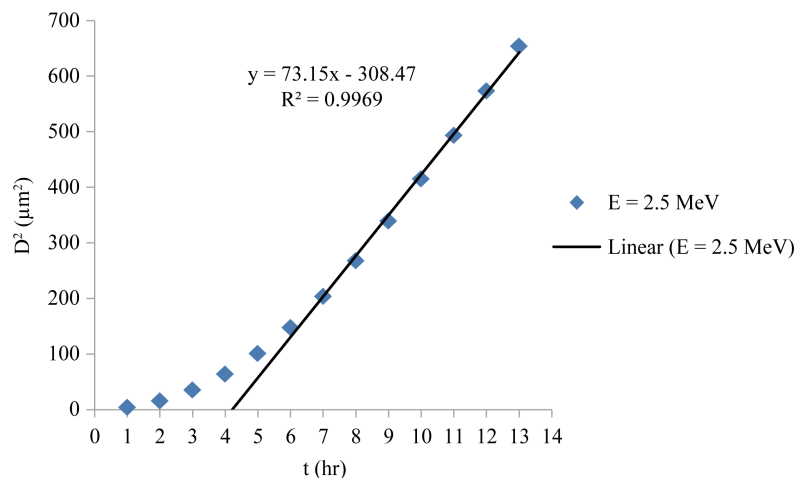
**Figure 5.** Diameter square (D$^2$) as a function of etching time (t) for alpha energy E$\alpha$ = 2.5 MeV by using Yu *et al.* function.
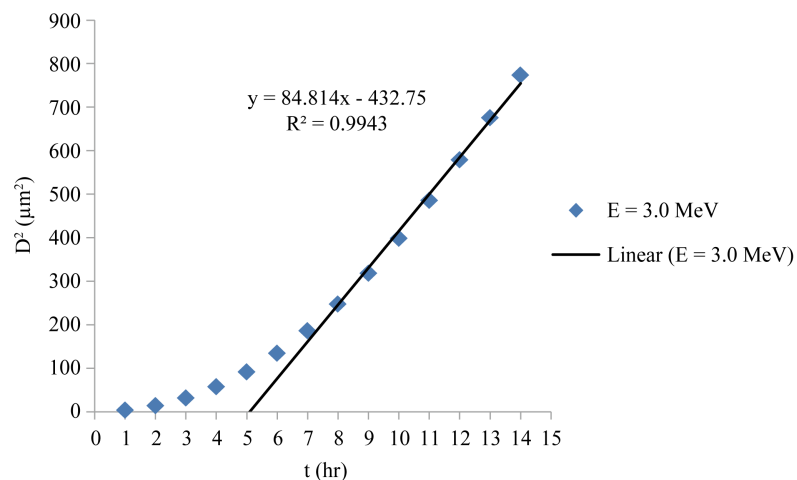


**Figure 6.** Diameter square (D$^2$) as a function of etching time (t) for alpha energy E$\alpha$ = 3.0 MeV by using Yu *et al.* function.
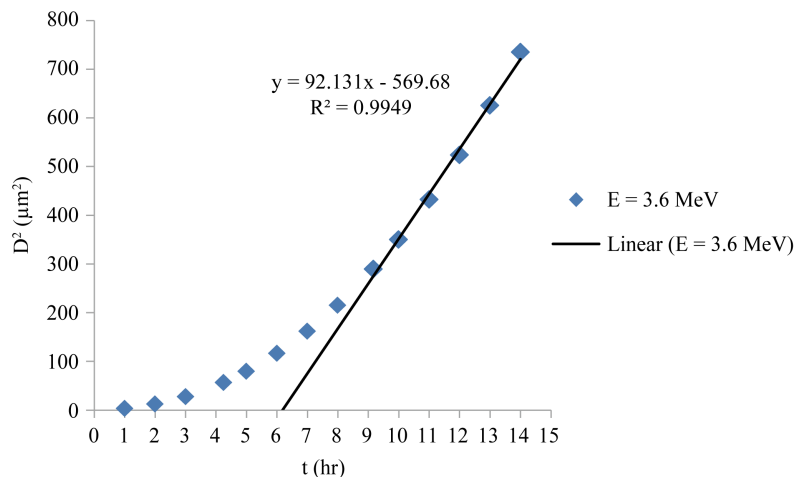


**Figure 7.** Diameter square (D$^2$) as a function of etching time (t) for alpha energy E$\alpha$ = 3.6 MeV by using Yu *et al.* function.
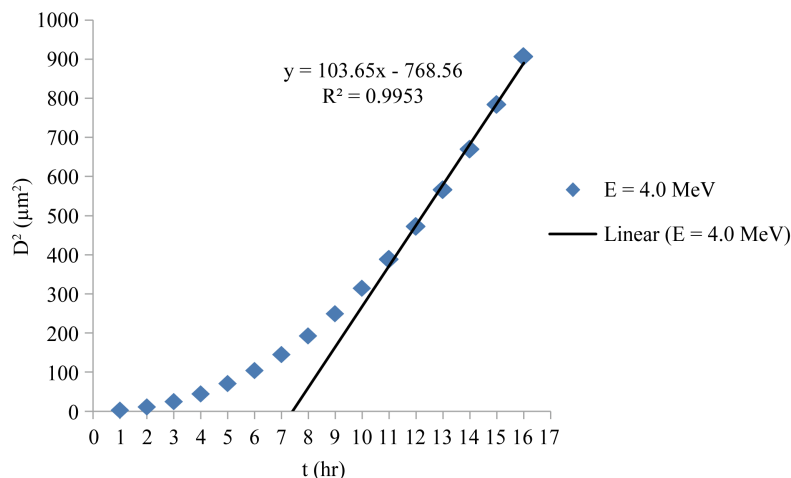
**Figure 8.** Diameter square ($D^2$) as a function of etching time (t) for alpha energy E$\alpha$ = 4.0 MeV by using Yu *et al.* function.

**Table 1.** Comparison between the maximum values of track lengths in CR-39 detector for different values of $\alpha$-particle energy theoretically and from Brun *et al.* functions.

| E (MeV) | The maximum value of the track length (µm/hr) | |
|---|---|---|
| | Theoretically | Brun *et al.* function |
| 2.5 | 8.37 | 7.45 |
| 3.0 | 9.76 | 9.25 |
| 3.6 | 10.6 | 11.52 |
| 4.0 | 12.14 | 13.09 |

**Table 2.** Comparison between the maximum values of track length in CR-39 detector for different values of $\alpha$-particle energy theoretically and from Yu *et al.* function.

| E (MeV) | The maximum value of the track length (µm/hr) | |
|---|---|---|
| | Theoretically | Yu *et al.* function |
| 2.5 | 7.9 | 7.1 |
| 3.0 | 9.13 | 8.8 |
| 3.6 | 9.91 | 10.9 |
| 4.0 | 11.17 | 12.28 |

give good results for the maximum values of the track lengths ($L_{max}$) of alpha particle with any energy in CR-39 detector.

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