Calculations of Track Growth's and Profile's Plots in Cellulose Nitrate LR-115 Detector for Alpha Particles

Naseem Salim A'bdel

Department of Physics
College of Science , Mosul University

الملخص

يهدف البحث إلى دراسة نمو الآثار تجريباً ونظرياً في كاشــف نتــرات الـــسيليلوز LR-115 ذو سمك 12μm , إذ شععت قطع الكاشف بجسيمات الفا المنبعثة مــن مــصدر الامريشيوم ^{241}Am بزاوية سقوط 90° ضمن مدى الطاقة (1-5MeV) , لقد أجريت عمليــة القشط الكيميائي لقطع الكواشف المشععة باستخدام المحلول الكيميائي NaOH بتركيــز 10% ودرجة حرارة 60±1°C , كذلك استخدم برنــامج كمبيــوتر(TRACK_TEST) لحــساب متغيرات الأثر كعمق الآثار ولرسم المنظر الجانبي للأثر(شكل الأثر) وقطر الأثر المتكــون . لقد أظهرت النتائج أن أعلى امتصاص للطاقة القاصفة بجسيمات الفا يحــصل عنــد 2MeV تقريبـــاً , كـــذلك لـــوحظ إن قمـــة الأثـــر عنـــد طاقـــات جــسيمات الفــا (1 , 2MeV) تكون ذات شكل كروي ويدعى بالشكل المدور أو الشكل الكامل القشط , بينما تكون قمة الأثر عند الطاقات (3 , 4 , 5MeV) ذي شكل حاد . كما وجد أن عمــق الآثــار المحسوبة نظرياً باستخدام برنامج الكمبيوتر اكبر من تلك المقاسة تجريبياً وان نسبة الاختلاف بينهما وصلت حوالي 38% عند الطاقة 3MeV .

ABSTRACT

The aim of this research is study of tracks growth experimentally and theoretically in cellulose nitrate LR-115 detector .The detector of 12μm thickness is irradiated normally by alpha particles with incident energies from 1 to 5MeV and incident angle 90°,by using ^{241}Am source , The etching of the detector Pieces was implemented by using chemical etchant NaOH with concentration 10% and temperature (60±1°C) ,A

computer program (TRACK_TEST) also used for calculating track parameters as tracks depth and plotting track-wall profiles and contours of the track opening . The results showed that a maximum energy lost is occurred when the energy of the α-particles is about 2MeV, The tracks' tip for incident alpha energies 1 and 2MeV appeared in a spherical phase which is called rounded or over etched phase ,while a sharp phase for energies 3,4 and 5MeV was investigated . It was found that the track's depth which is calculated by computer program greater than that measured experimentally and that the percentage difference between two can be about 38% for 3MeV .

1. Introduction

A heavy charged particle leads to intensive ionization when it passes through dielectric materials. 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 solution), the chemical reaction would be more intensive in the latent track. Through the etching, the latent track becomes visible as a particle "track" which may be seen under an ordinary optical microscope. The effect itself has been known for long time, which is called the "track effect" [1] ,This is the operational principle for solid-state nuclear track detectors (SSNTDs). The technique has been extensively investigated in the literature, and has been widely applied in many fields of science and technology.

The most important point in the application of SSNTD,s is the accurate measurement of track's growth parameters .So, starting from the early studies on particle tracks and the geometry of track development has attracted much attention and over the years, many models have been developed to calculate track parameters and to plot track openings and wall profiles . All models described in the mentioned references were based on two parameters, namely, the bulk etch rate V_B and the track etch rate V_T[2]. Recently, the tracks were considered as three-dimensional objects [3] which enabled calculations of the track parameters including the lengths of the major and minor axes of track openings and plotting of their profiles . For actual applications, the studied models require computer programs to simulate the track growth and to calculate track parameters (major axis and minor axis of track's depth, etc.), as well as plots of track shape (track profiles and track contours). Although the track growth models have been developed for more than 30 years, comparisons between the values calculated from the track growth models with

experimental values of track parameters for various incident angles and energies of the ions have been scarce .For example, Droschel et al., (2003)[4] compared the calculated and experimentally measured profiles of tracks from alpha particles in the CR-39 detector by using model of Fromm et.al.(1988)[5],comparisons were made for incident energy 5.9MeV,Good agreement between the experimental and calculated profiles was found in all examined cases . Also from previous studies about track's growth which were presented by Nikezic and Yu.(2002)[6], it was studied the three-dimensional and analytical theory for track growth in the LR-115 detector by using a computer program for calculating track parameters and for plotting track-wall profiles and contours of the track opening in detector material irradiated by alpha particles energies from 1 to 4 MeV and incident angles between $20°$ and $90°$.

In the present work, calculations of track parameters (track diameter,Etching rates and track depth) are presented experimentally during the aggressive chemical etching of alpha irradiated LR-115 detector pieces. Moreover the computer program is used to calculate track parameters and plots of contours of track openings and wall profiles in the detector .The study also indicates the comparison between the experimental track's depth with the values which are calculated by using computer program (TRACK_TEST) .

2. Geometry of track development and basic terms

Development (Growth) of tracks in materials during etching has attracted much attention for a long time, [2,7]. Formation of a track as a result of the incidence of an ion is due to the simultaneous acting of the etching solution with two etching rates, a variable rate along the path of the incident particle which calls the track etch rate V_T and a constant rate in all other regions which denotes as the bulk etch rate V_B [8] .

2.1. Geometry of track development for constant V_T ;

During etching, the track development passes through three phases ; the beginning of etching, the aggressive solution progresses toward the end point E of the particle trajectory. The track end is sharp and the track is fully conical. However, at the time t_0, the etchant reaches the end point E of the particle path ,and the detector surface at that time is denoted as surface 1(in Fig. 1). The etching after that moment progresses in all directions with the same rate V_B, and the corresponding track becomes an "over-etched" one. A sphere is now formed around the point E, and the shape of the track has changed to one with a cone joined with a sphere (surfaces 2 and 3 in Fig. 1). With prolonged etching, the spherical part is enlarged and the conical part is relatively smaller and smaller. Finally, if

the etching lasts sufficiently long, the whole track will become spherical (surface 4 in Fig. 1).The contrast of a spherical track is lost and the track might be seen with difficulties or might even become invisible [9].
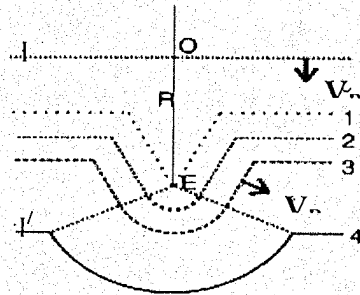

Fig. (1); Three phases in the track development. I is the initial(original) detector surface, O and E are the entrance and end points of the particle path, R is the particle range in the detector material, (1) Conical track; (2 and 3) the track wall is partially conical and partially spherical;(4) the track is fully spherical [9].

2.2. Geometry of track development for variable V_T ;

In the previous section, the track growth for a constant V_T developed by Somogyi and Szalay, (1973) [10] has been presented. However, V_T is not constant in most of the realistic cases. The same authors developed equations to describe track growth for the case of a variable V_T. The difference in comparison to the constant V_T case is that the track wall cannot be described as a regular cone, and the track is now a semi-conical surface shown in Fig. 2 (right panel, case 2). The cross-section between the post-etching detector surface and the track is now more complex than a simple ellipse. It can be close to an ellipse, but it might also be very different from an ellipse, such as some egg-like curve, etc .depending on the removed layer, range and V_T[9] .
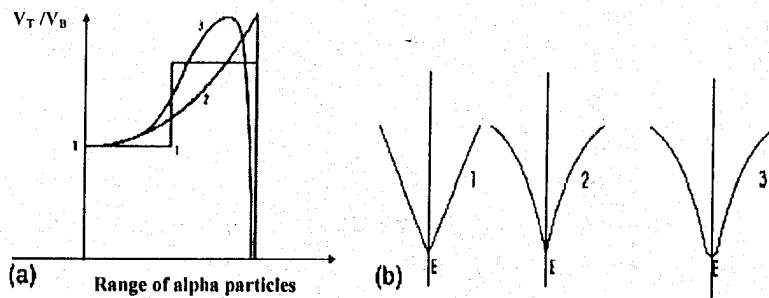

Fig. (2) ; (a) Variation of the V_T function along the particle path: (1) V_T = constant; (2) V_T is variable with maximum at the end of the particle path;

(3) V_T is variable with the maximum before the end of particle path (this is the realistic situation).(b) Track profiles for the cases (1), (2) and (3), respectively [9].

The track opening also passes through different phases, which were analyzed in details too by Somogyi and Szalay,1973 [10]. The track opening is circular when the incident angle is normal incidence . For oblique incidence, the track opening is elliptical, elliptical + circular or circular depending on the etching condition, incident energy and incident angle (for a constant V_T), or semi-elliptical or an even more complex "egg-like" geometrical figure (for a varying V_T)[3].

3. Program description

Several models have been presented in the track development, one of which is the model of Nikezic and Yu, (2003) [11], which is used in the present program. This computer program (TRACK_TEST) was written in the standard Fortran 90 language .The program integrates routines for calculations of the coordinates of the track profile and the contour of the tack opening and for graphical presentation of these . It is mainly intended for calculations for alpha-particle tracks in CR-39 and LR-115 detectors

The program enables calculations for two kinds of the most frequently used detectors, namely, the LR 115 and CR-39 detectors. The user can choose the detector by typing "C" for CR-39 or "L" for LR- 115. Besides the detector type, the input includes the alpha-particle energy (it should be below 10 MeV), the incident angle(it should be between 0° and 90°), time of etching in hours ,bulk etch rate(V_B) in micrometers/h , type of the V function with new constants and determination of the alpha-particle range R in the detector by using the computer program on the Stopping and Range of Ions in Matter ,which is developed by Ziegler ,(2001) [12] .The outputs of the program are the major and minor axes of the track opening, as well as the track depth ,the program also plots on the computer screen the following: the initial detector surface, the detector surface after etching, the profile of the track, the contour of the track opening and the trajectory of the particle .

4. Experimental Procedure

A cellulose nitrate LR 115 detector has been used in the present study The LR-115were purchased from DOSIRAD, France(LR115 ,Type1, non-strippable, as a 12μm of an active layer of red cellulose nitrate is based on a 100μm clear polyester base substrate .The chemical composition of cellulose nitrate LR-115 is $C_6H_8O_9N_2$ [8] and it have

Accordingly, it was found that the alpha particles within high energies ($E_\alpha \geq 3MeV$) which have lengthy range were penetrated the detector .

The maximum energy lose by α-particles is found at 2MeV for etched detectors .Accordingly , the tracks which formed in LR-115 on both sides of maximum energy loss in a given figure (3) are found to have a nearly similar identification with similar diameter and size .This result agrees with that found by Yip, et al.,(2006) [8] who reported the maximum α-energy absorption by LR-115 detector at this value .
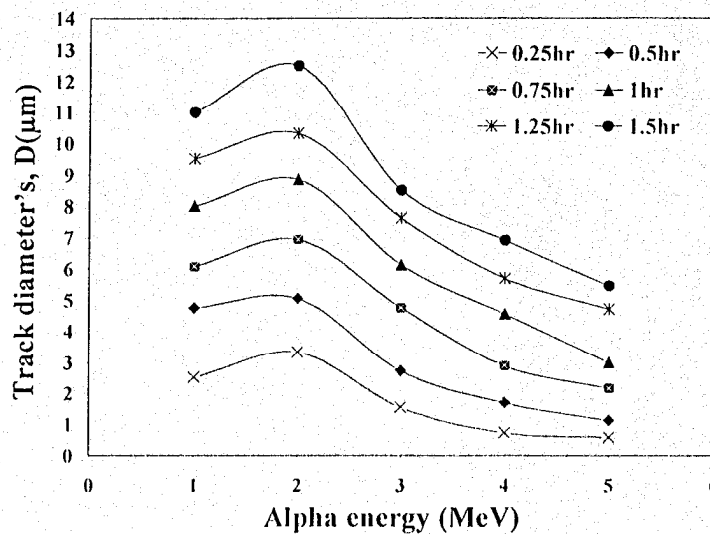

Fig.(3)Track diameters as a function of α-Energy for different

etching times in LR-115 detector.

Table (1); Calculated range of alpha particles in LR-115 detector for different alpha energies.

Alpha Energy E_α(MeV)	Alpha Particle Range R (μm)
1	4.71
2	9.10
3	14.73
4	21.60
5	29.51

Tabl   ite V_D ,the track etch rate V_T and etching ratio V which are calculated experimentally for irradiating energies 1, 2, 3, 4 and 5MeV of α-particles in cellulose nitrate LR-115 detector .The table shows that there is an

inversion point in V_T values that refers to maximum value of V_T at a certain energy of α-irradiating which is about 2MeV.This result is compatible with Nikezic and Yu.,(2004) [9].

It is convenient to mention here that the bulk etch rate V_B for used cellulose nitrate LR-115 detector was noticed to equal to be 4.5μm/hr under used conditions of etching .This value agrees with that investigated Ho,et.al.,(2002)[14]for LR-115 detector .

Table (2); Calculated etching rates for LR-115 detector for different alpha energies.

Alpha Energy $E_α$(MeV)	Track Growing Rate V_D (μm/hr)	Track Etch Rate V_T (μm/hr)	Etching Ratio (V)
1	6.02	11.787	2.619
2	6.88	17.154	3.812
3	5.95	11.487	2.552
4	4.40	7.335	1.630
5	2.98	5.608	1.246

5.2. Plots of track openings and wall profiles

As mentioned before, the computer program was required determination
V function . So, it is consider as a function of residual range ($\dot{R}$), this denote the ratio $V(\dot{R}) = V_T(\dot{R}) / V_B$, So, experiential data were used altogether to obtain a V function(7), which took the functional form of the Durrani–Green's function[16], but with new constants as $a_1=102.09$; $a_2=0.440$; $a_3=4.85$; $a_4=0.102$; $a_5=0.803$. The variations of the track etch rate value V_T with the residual range $\dot{R}$ of alpha particles in the detector material ,which are shown in fig. (4).

$$V = 1 + (a_1 \exp^{-a_2 R} + a_3 \exp^{-a_4 R})*(1 - \exp^{-a_5 R}) \dots\dots\dots\dots(7)$$

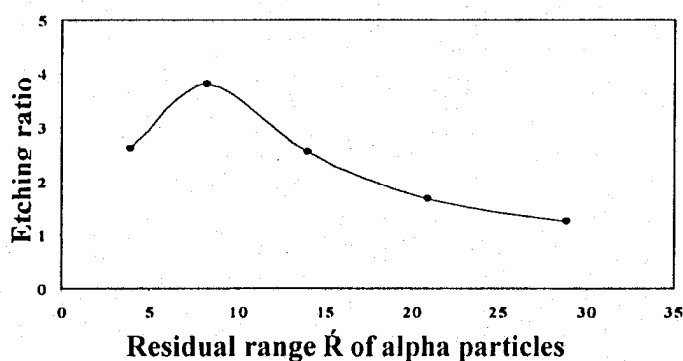Residual range $\dot{R}$ of alpha particles

Figure (5), shows contour plots of track openings and wall profiles ,they are processed by the computer to generate an output graph showing the profile of the scanned surface corresponding to our present work conditions for LR-115 detector .The energies of alpha particles are 1, 2, 3, 4 and 5MeV , etching time is 30min ,the incident angle is 90° and the bulk etch rate values V_B which found experimentally is equal to 4.5μm/hr.

It is shown from this figure that the upper horizontal lines represent the detector surface before etching (Initial detector surface),and the detector surface after etching (post etching surface).The lower horizontal line represents the bottom of the active layer, which is adhered to the supporting plastic. The track depth is also shown in the mentioned figure, which represents the track depth of the detector LR-115 after etching .

Figure 5 (a ,b, c) shows the results for the track profile (or vertical cross section of the track) and contours of tracks openings for incident alpha energies
5 ,4 and 3MeV . It can be observed that the tracks' tip is sharp (which explains the term " sharp phase") ,The sharp phase on track development can be obtained as if the etching solution does not reach the full particle range in the detector , in contrast, the track wall is regular conical for 5 and 4MeV ,due to that the track etch rate (V_T) is nearly constant , while, it has semi-conical shape for 3MeV , due to that V_T is variable with maximum at the end of the alpha particle path.

The track profiles for incident alpha energies 2 and 1MeV are shown in figure 5 (d , f). It can be observed that the tracks tip are rounded phases as a part of spherical shapes. Furthermore, rounded phase of track development is occurred, when the etching solution passes over the range of the alpha particle in the detector material , a spherical structure is formed around the ending point and the track has a rounded tip. This is called the rounded or over-etched phase of track development .While , track wall can be described as a not regular cone, due to that the track etch rate V_T here is considered to be variable with the maximum before the end of particle path . This result is compatible with that estimated by [17] who predicted about a formation of the spherical or sharp part of the track's tip for alpha energies from 1 to 5 MeV by using LR-115 detector.
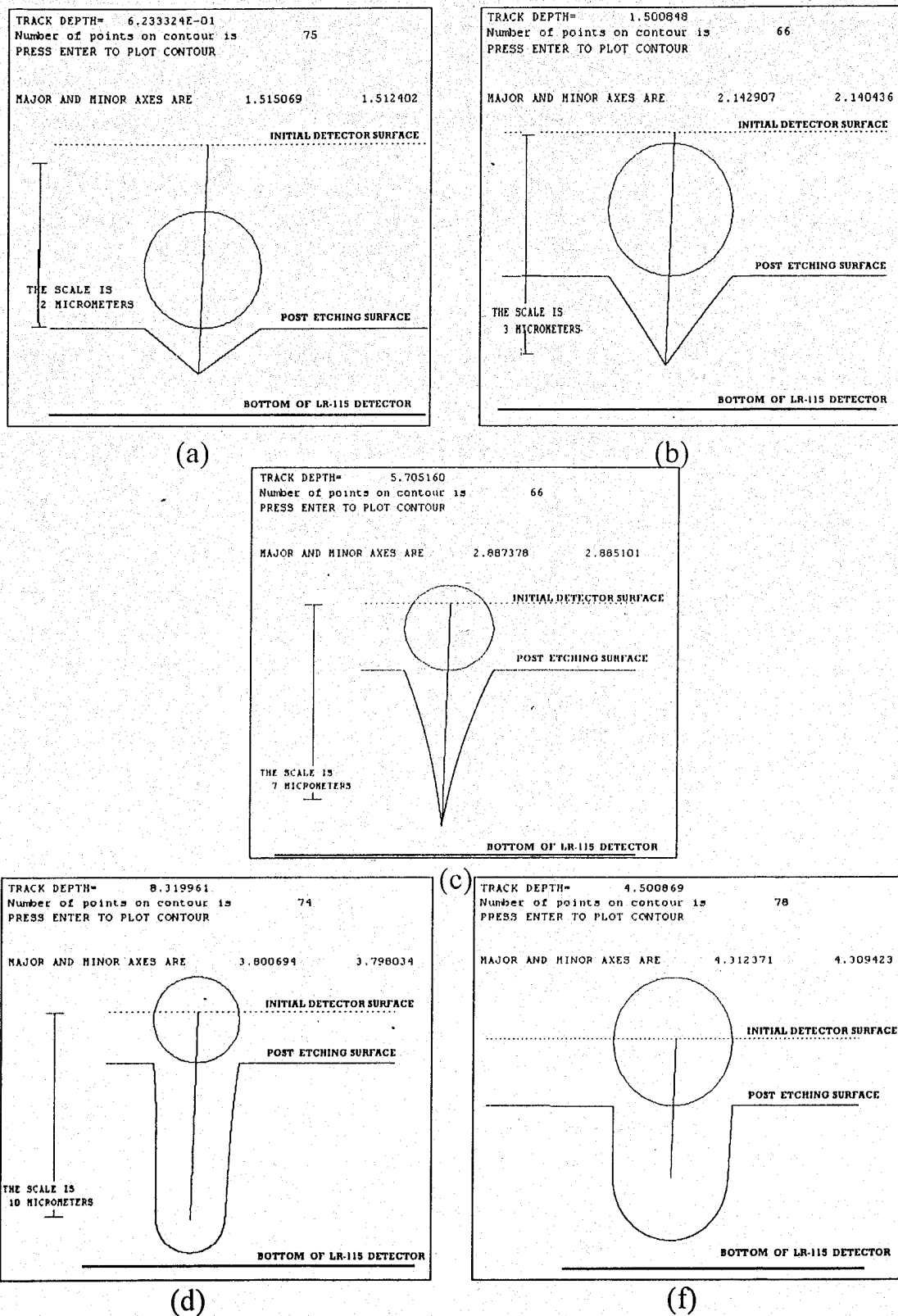
(a)

(b)

(c)

(d)

(f)

Fig. (5);Calculated track shape (the track profile and track-opening contour) for incident energy: (a) 5MeV, (b) 4MeV, (c) 3MeV, (d) 2MeV and (f) 1MeV in the LR-115 and etched for 30 min

5.3. Track depth

Table(3) summarizes the comparative tracks depth which are measured experimentally and calculated theoretically from the computer program for 1, 2, 3, 4 and 5MeV of alpha-particles in LR-115 for an etching time of 30 min

It can be observed that the track's depth increases with the incident energy and reach maximum value at 2MeV , afterwards, it decreases with increasing the incident energies above 2MeV both methods (measured experimentally and calculated theoretically by using the computer program).This means that the maximum value of tracks depth was obtained at energy 2MeV using both methods ,which due to the very fast etching along the particle track in the low energy region (Bragg peak), and that the maximum energy lose by α-particles is found to be at 2MeV for LR-115 detector , this leads to a maximum's diameter and size of track and then ,which is leading to the maximum depth at this energy.

The results also show in table (3) that there are percentage different of tracks depth between experimental measured and theoretically calculated by using computer program . So, it can be observed that the theoretically data of tracks depth greater than that of experimental data for all used energies of alpha particles. As well as , It can be seen that the percentage differences (Δ%) of the track depth between the two (measured experimentally and calculated theoretically) are more pronounced for low alpha energies region .So, it is found that the maximum discrepancy of the track depth is about 38% for incident alpha energy of 3 MeV ,_this due to that the track etch rate V_T is varying for low α-energies within the range $(E_\alpha \leq 3MeV)$ and it is nearly constant for $(5MeV \geq E_\alpha > 3MeV)$ at same etching time . It is important to know that the bulk etch rate value V_B is considered to be constant at α-energies within the range $(5MeV \geq E_\alpha \geq 1MeV)$ .This leads to that the track depth is depended on energy of the incident particles. These results are compatible with that found by Nikezic, et. al., (2002)[17]who observed that a maximum value of tracks' depth for LR-115 were occurred when incident α-energy is about 2MeV at etching times (15-30)minutes .

Table(3);Calculated tracks' depth for LR-115 using experimental proceeding (under the columns 'Experimental data')and the simulated track's depth by using computer program(under the columns 'Calculated data')and the column 'Δ%' gives the percentage
difference between the two , for different alpha energies at etching time 30min .

Alpha Energy (MeV)	Track Depth (μm)		
	Etching time ;30min		
	Experimental data	Calculated data	Δ%
1	3.643	4.509	19.2
2	6.327	8.319	23.9
3	3.493	5.705	38.7
4	1.417	1.500	05.5
5	0.554	0.623	11.0

6. Conclusion

- It is found that the maximum energy lose by α-particles in cellulose nitrate
  LR-115 detector occurs at about 2MeV.
- It was seemed that the computer program (TRACK_TEST) is useful for investigation of track parameters and profile.
- The track tip is in sharp phase for alpha energies 5 ,4 and 3MeV and the track wall is conical except for 3MeV it is semi-conical .
- It is found for alpha energies 2 and 1MeV the track tip is rounded as a part of spherical shape which is called rounded or over-etched phase of track development .
- The maximum depth of the etched track is occur at about 2MeV of alpha energy for both cases (measured experimentally and calculated by using the computer program) under used conditions .
- It is found that the track's depth which is calculated by computer program greater than that measured experimentally and that the maximum discrepancy of the track depth between two is about 38% for 3MeV.
- The accuracy of the theoretical calculations presented in this study depend on the accuracy of the function V .

Reference

1. Fleisher ,R.L., Price, P.B. and Walker, R.M., Nuclear Track in Solids. Principles And Applications, University of California Press, Berkley(1975).
2. Nikezic, D. , Kostic, D., Yip, C.W.Y. and Yu, K.N. ,Radiation Measurements, 41 , pp. 253–256(2006).
3. Nikezic, D. and Yu ,K.N., Radiation Measurements, 37, pp. 39–45(2003).
4. Dorschel, B., Hermsdorf ,D. and Starke, S., Radiat. Meas., 37 ,: pp. 583(2003).
5. Fromm, M., Awad,E. M. and Ditlov, V. , Nuclear Instruments Methods, B226, pp. 565-574(2004).
6. Nikezic, D. and Yu, K. N., Nuclear Instruments and Methods in Physics Research, B196, pp. 105–112 (2002).
7. Nikezic, D. and Yu ,K.N., Radiation Measurements, 37, pp. 595–601(2003b).
8. Yip ,C.W.Y., Nikezic, D. , Ho, J.P.Y. and Yu, K.N., Materials Chemistry and Physics, 95, pp. 307–312 (2006) .
9. Nikezic , D and Yu ,K.N , Reports; A Review Journal ,Materials Science and Engineering R 46 , pp. 51–123(2004).
10. Somogyi, G. and Szalay, A. S., Nuclear Instruments and Methods, 109,pp. 211(1973).
11. Nikezic, D. and Yu, K.N., Computer Physics Communications, 174, pp.160–165 (2006).
12. Ziegler, J. F., (http://www.srim.org/)(2001).
13. Mahesh , K. and Mustafa , S. M. , Nuclear Radiation Detectors and Experiments , Mosul Univ. Press , Iraq (1976)
14. Ho, J.P.Y., Yip, C.W.Y., Koo ,V.S.Y., Nikezic, D. and Yu, K.N. ,Radiation Measurements 35, pp. 571 – 573 (2002).
15. Durrani, S.A. and Bull, R. K. , "Solid State Nuclear Track Detection", Pregman press , Oxford, (1987).
16. Durrani, S. A. and Green, P.F. , Nuclear Tracks, 8 , pp. 21(1984).
17. Nikezic, D., Ho, J.P.Y., Yip ,C.W.Y., Koo ,V.S.Y. and Yu, K.N., Nuclear Instruments and Methods B 197, pp. 293–300 (2002).