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Alpha Activity of ^{190}Pt Isotope Measured with CR-39 Track Detector*

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Abstract – A new method to measure alpha activity of long-lived radioisotopes is reported. The method consists basically in using CR-39 track detectors in close contact with thick samples of the radioelement to be investigated. Accordingly, a long-term exposure experiment (up to two years) has been performed in the Gran-Sasso Underground Laboratory (INFN-LNGS, Italy), in which metallic sheets of natural platinum have been used to measure alpha activity of ^{190}Pt isotope. The half-life of ^{190}Pt has been obtained as $(3.2\pm\ 0.1)\times\ 10^{11}$ yr, in good agreement with two recent theoretical half-life predictions.

*Dedicated to Prof. Dr. H.G. de Carvalho, by the occasion of his 80th anniversary.

1. INTRODUCTION

THE NATURALLY OCCURRING ^{190}Pt isotope (0.013% of atoms in ^{nat}Pt) is known to disintegrate by alpha-particle emission (Hoffmann, 1921). Previous measurements of its alpha activity using the nuclear-track emulsion technique (Porschen and Riezler, 1954) and ionization chambers (Petrzhak and Yakunin, 1961; Macfarlane and Kohman, 1961; Graeffe and Nurmia, 1961; Graeffe, 1963; Al-Bataina and Jänecke, 1987) have indicated half-life-values in the range $(4-10)\times10^{11}$yr. Differences among the various experimental half-life determinations may be related to difficulties experienced when measuring half-lives as long as $\sim10^{12}$yr, such as in the case of ^{190}Pt isotope, which decays by emitting an alpha particle of average kinetic energy of 3.18 MeV (Graeffe, 1963).

In the present paper, we report on a new method to measure alpha activity of long-lived radioisotopes, which method consists basically in using plates of CR-39 track detector in close contact with thick samples of the radioelement to be investigated. Accordingly, an experiment to re-determine the alpha decay half-life of ^{190}Pt isotope has been performed for the first time under the following conditions: i) use of high-purity, thick metallic sheets of natural platinum, thus with the maximum amount of ^{190}Pt isotope ($\sim$ 0.34 μg/cm^2) available; ii) use of CR-39 polymer as the most efficient track detector to alpha particles of energy $E \leq 3.18$ MeV; iii) long-term exposures (up to two years) arranged in the Gran-Sasso Underground Laboratory (INFN-LNGS, Italy), therefore providing great amounts of exposure (up to 6.2 mg.h.cm^{-2} of ^{190}Pt) for alpha-particle-track counting, and, at the same time, protecting detectors against background due to cosmic-ray-induced events. Background from actinide contaminants has been measured by an appropriate method of filtering of the alpha particles from ^{190}Pt isotope in supplementary exposure experiments. Finally, the detection efficiency has been evaluated for the present, particular configuration of the contact of a thick sample of natural platinum with the CR-39 track recorder.

2. EXPERIMENTAL

2.1. *Exposures*

High-purity, 25-μm thick, natural platinum sheets were closely contacted with 750-μm thick CR-39 plates (TASTRAK Solid State Nuclear Track Detector, supplied by Track Analysis Systems Limited, Bristol, UK). Twelve platinum sheets and CR-39 plates of 2.1 cm $\times$ 2.1 cm were arranged in a stack, pressed by a clamp, and stored in Hall C at the Gran-Sasso Underground Laboratory. For background control, three additional CR-39 plates were stored under the same conditions. The samples were divided into three groups, which were analysed after 5.4 (Group I), 18.7 (Group II), and 24.5 (Group III) months of exposure, respectively, from the beginning of the experiment.

2.2 *Etching procedure*

At the end of each exposure, the CR-39 plates were processed by immersion in a 6.25-N NaOH solution at 60^0C with gentle stirring, throughly rinsed in distilled water, and dried. The thickness of detector layer removal during etching was found to be $h_I = (1.4\pm0.2)$ μm for the plates of Group I, and $h_{II} = (4.2\pm0.2)$ μm for those of Groups II and III. The present etching conditions were selected based on the current etching methods for registration of charged particles of low ionization rate by the polymeric CR-39 track detector (Somogyi and Hunyadi, 1980; Benton *et al.*, 1980; Green *et al.*, 1982; Martins *et al.*, 1992). The h-values have been evaluated from direct measurements of maximum track-diameter for alpha particles of normal incidence, combined with both the track-diameter response curve of CR-39 (Somogyi and Hunyadi, 1980) and the standard model for etch pit evolution in isotropic solid detectors (Somogyi and Szalay, 1973) (see 3.1).

2.3 *Track analysis*

The etched CR-39 plates were scanned by using Leitz Ortholux microscopes fitted out with objective 25X for track counting, and 45X for measurement of etch pit opening. Calibrated eye-pieces mounted in oculars of 10X magnification allowed us to determine the scanning area and track-diameter. Scanning on both top and bottom surfaces of each detector allowed for evaluation of detector intrinsic background. Determination of track population, i.e., number of tracks per unit area, was done in all cases by counting those tracks having track-diameter larger than a certain minimal etch pit opening, D_m, capable of being observed with given optics (Tavares, 1993). In the present measurement, the value $D_m = (1.9\pm0.1)\mu$m has been fixed for alpha-particle track identification.

2.4 *Background from actinide contaminants*

When measuring the alpha activity of ^{190}Pt isotope, attention has to be given to the possible presence of actinide contaminants at both the platinum sample and detector surfaces. It is estimated that a concentration as low as $\sim$0.5 ppm of natural uranium or $\sim$3ppm of natural thorium eventually present as impurities on the material surfaces would indeed produce an alpha activity which is roughly equal to that of natural platinum. A direct evaluation of the alpha-particle background due to surface actinide impurities has been obtained in supplementary exposure experiments in which a 15-μm thick makrofol filter was inserted between the platinum foil and the CR-39 plate detector. Such a filter assures complete absorption for the alpha particles emitted by ^{190}Pt isotope ($E \leq$3.18 MeV), allowing at the same time the detection of those emitted by the actinide contaminants (U, Th, and their decay products, for which $E \geq 4.25$ MeV). For alpha particles of energy $E \geq 4.25$ MeV the residual kinetic energy after passing through the 15-μm makrofol filter is such that these alpha particles can still produce etchable tracks. Additional exposures of CR-39, with and without the same filter, to alpha particles from a very thin ^{nat}U-film ($\sim$2dps/cm^2) in 2π-geometry enabled us to obtain the appropriate

correction for detection efficiency. In all cases the same etching procedure and scanning methodology were used as for the plate detectors in the main exposures. Accordingly, the background level due to actinide impurities was found within the range of 200–800 alpha-tracks/cm^2.yr, whereas the alpha-signal coming uniquely from ^{190}Pt isotope was about 700–2200 alpha-tracks/cm^2.yr, this latter value being therefore nearly three times greater than the background level. The equivalent alpha emission rate from the surface actinide contaminants in the platinum samples is estimated as ∼0.8–3.4 counts/cm^2.d. This result is comparable with the level of actinide impurities which has been found in other common materials, such as aluminum (∼7.4), tin (∼3.4), brass (∼1.2), stainless steel (∼0.7), and copper (∼1.9–5.0 counts/cm^2.d) (Bearden, 1933), and in aluminum (∼6.4), brass (∼3.1), and stainless steel (∼0.28–0.77 counts/cm^2.d) (Al-Bataina and Jänecke, 1987b).

3. DETERMINATION OF THE HALF-LIFE

The configuration of the contact of thick metallic platinum foils with CR-39 plate detectors, although very simple, is the novelty introduced by the present method to measure alpha activity of ^{190}Pt isotope. In such arrangement, alpha particles are recorded as trails of damage formed along the alpha-particle path in the polymeric material, and, after etching, these latent images become visible at the level of ordinary optical microscopy as etched alpha tracks. The fraction of latent tracks revealed by etching defines the etching efficiency, ε_e, which depends essentially upon the rates of chemical attack along the latent track (track etching velocity, v_T) and the undamaged detector material (bulk etching velocity, v_B). In addition, identification of etched alpha tracks depends strongly upon the magnification of the optical system used for observation of tracks, in the sense that not all the etched alpha tracks are actually observed. This introduces an additional efficiency factor, ε_i, related to visualization (identification) of the etched alpha tracks. The total, combined efficiency (detection efficiency, ε) is clearly given by $\varepsilon_e\varepsilon_i$. Besides, although alpha particles (or, alternatively, alpha disintegration events) are produced in the whole volume of the sample material, only a fraction of such events is visualized as alpha tracks in the detector surface. As alpha particles move towards the detector surface from point-origins inside the sample, their kinetic energy is degraded along their trajectories. Thus, there is an additional effect to be considered in measuring the alpha activity, namely, the alpha particle self-absorption effect in the thick sample material.

Since we are dealing with alpha particles of low rate of ionization in CR-39 ($V = v_T/v_B > 1$), the geometrical aspect of the alpha tracks is cone-shaped, the etch pit opening being circular or elliptical, depending upon the normal or oblique incidence. Etch pits will be identified as alpha tracks if their measured diameter (or minor axis) is greater than a certain minimal etch pit opening, D_m, defined by the optics used for observation of tracks (see 2.3). In summary, to obtain the alpha-decay half-life of ^{190}Pt isotope, the various effects mentioned above have to be considered. The relationship between the number of alpha disintegration events which occur in the thick platinum sample and the number of alpha tracks observed in the detector surface will depend upon i) the response

curve track-diameter, D, *versus* incident alpha-particle energy, E; ii) the energy-loss-rate (essentially due to ionization) of alpha particles in both platinum and CR-39; iii) the residual range of 3.18-MeV alpha particles in both the sample (a_0) and detector (r_0) materials; iv) the residual range of threshold-energy alpha particle in the platinum sample (a_{th}); v) the thickness of detector layer removal during etching, h; and vi) the minimal etch pit opening capable of being observed under given optics, D_m, which in turn will define the alpha-particle threshold energy.

Figure 1-a shows schematically the arrangement of the present experiment, where the various quantities needed for half-life determination have been defined. The number of alpha particles of energy $E_0 = 3.18$ MeV emitted per unit area and per unit time in a sample layer $\mathrm{d}x$, and within the solid angle $\mathrm{d}\Omega{=}2\pi\cos\phi\mathrm{d}\phi$, is given by

$$\frac{\mathrm{d}^2N}{\mathrm{d}\Omega\mathrm{d}x} = \frac{1}{4\pi} \times \frac{\ell\mathrm{n}2}{T_{1/2}} \times N_n, \tag{1}$$

where N_n denotes the number of ^{190}Pt nuclei per unit volume of the sample, and $T_{1/2}$ is the half-life. For each x-value in the interval $0 \leq x \leq x_{_M}$ alpha tracks will be observed only for alpha particles of incident angle $\phi_{_0} \leq \phi \leq \pi/2$. Therefore, the total number of alpha tracks observed per unit area of the detector surface and per unit time is calculated from (1) as

$$N_{ob} = \frac{1}{2} \times \frac{\ell\mathrm{n}2}{T_{1/2}} \times N_n \int_0^{x_{_M}} (1\text{-}\sin\phi_{_0})\mathrm{d}x. \tag{2}$$

On the other hand, for each x-value in the range $0 \leq x \leq x_{_M}$ the number of alpha particles which intercept the sample-detector interface is obtained from those particles of incident angle $\varphi_{_0} \leq \phi \leq \pi/2$. Thus, the total number of alpha particles intercepting a unit area of the detector surface per unit time is calculated from (1) as

$$N_{in} = \frac{a_0}{4} \times \frac{\ell\mathrm{n}2}{T_{1/2}} \times N_n. \tag{3}$$

The quantity $a_0/4$ represents the effective platinum sample thickness. The total detection efficiency is defined by the ratio $\varepsilon = N_{ob}/N_{in}$, and from (2) and (3) it is calculated by

$$\varepsilon = \frac{2}{a_0} \int_0^{x_{_M}} (1\text{-}\sin\phi_0)\mathrm{d}x. \tag{4}$$

The actual number of alpha tracks observed per unit area and per unit time of exposure due uniquely to alpha particles emitted by ^{190}Pt (i.e., after background subtraction) is therefore related to half-life by

$$N = N_{in}\varepsilon = \frac{a_0}{4} \times \frac{\ell\mathrm{n}2}{T_{1/2}} \times N_n\varepsilon, \tag{5}$$

and the number of alpha disintegration events which have occurred during the exposure time τ per unit area of the sample is given by

$$\mathcal{N} = \frac{N\tau}{\varepsilon} = \frac{a_0}{4} \times \frac{\ell\mathrm{n}2}{T_{1/2}} \times N_n\tau. \tag{6}$$

The quantity N_n is found to be $8.61\times10^{18}\mathrm{cm}^{-3}$. A range-energy curve for alpha particles in metallic platinum has been constructed by interpolating the range data for various materials taken from the tables by Northcliffe and Schilling (1970), from which curve the value a_0 =5.1μm has been evaluated. Finally, by expressing $\mathcal{N}$ in units of $10^3\mathrm{cm}^{-2}$, τ in yr, and $T_{1/2}$ in units of 10^{11}yr, the statistical analysis on the linear regression $\mathcal{N} = k\tau$, where the slope is given by k =7.6/$T_{1/2}$, will give the $T_{1/2}$-value.

3.1 *Response curves of CR-39 to low-energy alpha particles*

The currently accepted model for etchable track formation in polymeric materials assumes the restricted energy-loss-rate (*REL*) as the quantity responsible for the preferential dissolution of the detector material along the charged particle trajectory, so as to give visible etched tracks under ordinary optical microscopy (Benton, 1967; Benton, 1970). The quantity *REL* has been shown to be very adequate in describing the geometrical aspect of the etched tracks through the semiempirical response curve $v_T/v_B = V = \mathrm{f}\,(REL)$. Besides, the standard, widely used model for etch-pit evolution in isotropic solid detector materials under the constant V assumption (Somogyi and Szalay, 1973) expresses D (normal incidence particles) as a function of h, V, and etchable residual range, $R_e(E)$, for a charged particle of energy E (in the case of low-energy protons and alphas in CR-39 $R_e(E)$ is much the same as the full residual range, $R(E)$). Adopting the REL_{1keV} data for alphas and protons in CR-39 as calculated by Almási and Somogyi (1981), and using the D-values measured by Somogyi and Hunyadi (1980) for low-energy incident alphas and protons in CR-39 at different h-values, a response function of the form

$$V = 1 + \alpha(REL - REL_c)^{\beta} \tag{7}$$

has been obtained, with parameter-values α=2.5, β=1.2, and REL_c=0.10 MeV.cm^2.mg^{-1}. Firstly, this response function is used in combination with the expressions for track-diameter following the model for etch-pit evolution, i.e.,

$$D = 2h\sqrt{\frac{V-1}{V+1}}, \qquad h \le R(1{+}1/V) \tag{8}$$

$$D = 2\sqrt{R(1-1/V)[2h - R(1{+}1/V)]}, \qquad h \ge R(1{+}1/V), \tag{9}$$

to evaluate the actual h-values from the maximum track-diameter, D_M (normal incidence), measured under the conditions of the present experiment. For D_M=$(2.4 \pm 0.3)\mu$m (plates of Group I) this gives h_I =$(1.4\pm 0.2)\mu$m, whereas for D_M =$(7.4\pm0.4)\mu$m (plates of Groups II and III) it results h_{II} =$(4.2\pm0.2)\mu$m. Next, these actual h-values are used together with equations (7-9) to construct the D *vs* E response curves to alpha particles in CR-39. Such curves are shown in Fig. 2 (full lines), where the track-diameter threshold for track visualization, D_m, is indicated by the dashed line. The curves depicted in Fig. 2 represent the semiempirical response curves of CR-39 to alpha particles of energy $E \le 3.18$ MeV at each h, as obtained under the conditions of the present experiment.

3.2 *Alpha-particle threshold energy and the $x_{_M}$ value*

Inspection of Fig. 2 reveals that for h_I =1.4μm, i.e., for the amount of etching applied to plates of Group I, the CR-39 is able to detect alpha particles of energy greater than a threshold-value $E_{th} \simeq$ 90 keV, and for h_{II} =4.2μm (plates of Groups II and III) alpha particles are detected from a threshold as low as $E_{th} \simeq$ 14 keV. These results are used to evaluate, in each case, the maximum thickness of the platinum layer, $x_{_M}$, which does contribute to visible alpha tracks. This quantity is given by (Fig. 1-b)

$$x_{_M} = a_o - a_{th} \quad , \quad a_{th} = R'(E_{th}), \tag{10}$$

with R' standing for alpha particle residual range in metallic platinum. Again, the range-energy curve, $R'(E)$, constructed from the range tables by Northcliffe and Schilling (1970) is here used to obtain a_0 =5.10μm, R'(90 keV)=0.48μm, and R'(14 keV)=0.14μm. Therefore, $x_{_M}$ =4.6μm for plates of Group I, and $x_{_M}$ =5.0μm for those of Groups II and III. The $x_{_M}$-values are essential to perform integration in (4).

3.3 *Total detection efficiency*

In order to evaluate the total detection efficiency, ε, it is necessary to know the relationship between $\sin\phi_{_0}$ and x to be inserted into equation (4). Since alpha particles of oblique incidence must be considered here, the general expressions for etch-pit minor axis and/or diameter have been used following the model for track evolution at constant V (Somogyi and Szalay, 1973). Thus, according to Fig. 1-a, we can write

$$\sin\phi_{_0} = \begin{cases} \dfrac{1}{V} \times \dfrac{1+r^2}{1-r^2} \ , \ \text{if} \quad h \le h_\ell \\ \dfrac{h}{R(E)} \left[1 - \sqrt{(1 - \dfrac{R(E)}{hV})^2 - r^2} \right] \ , \ \text{if} \quad h \ge h_\ell, \end{cases} \tag{11}$$

where

$$r = \frac{D_m}{2h} \qquad \text{and} \qquad h_\ell = \frac{1}{V} \times \frac{2R(E)}{1-r^2}. \tag{12}$$

Also, from Fig. 1-a we have

$$x = a\sin\phi_{_0}, \tag{13}$$

where the quantity $a = R'(E_0) - R'(E) = a_o - R'(E)$ represents the path-length travelled by the alpha particle inside the platinum sample from the point-origin where the particle kinetic energy is E_0 =3.18 MeV down to the point at the original detector surface where the energy equals to E. The $\sin\phi_{_0}$ dependence upon x at each h is then found from equations (11-13) by numerical calculation, where the incident particle energy is allowed to vary in the interval $E_{th} \le E \le E_{_0}$. In these calculations we have adopted for $R(E)$

the range-energy data for alpha particles in CR-39 as reported by Almási and Somogyi (1981). The function $\sin\phi_0$ *vs* x thus obtained is plotted in Fig. 3 for both h-values.

Finally, the detection efficiency is calculated by numerical integration in equation (4). This gives ε_I =60% (h_I =1.4μm), and ε_{II} =90% (h_{II} = 4.2.μm). It is worthwhile to mention that if very thin ($<$ 0.2-μm thick) platinum samples were used instead of thick metallic foils like the ones in the present experiment the detection efficiency would be given by the usual, simple formula $\varepsilon = 1-\sin\phi_0$. In this case, $\varepsilon_I \simeq 22\%$ at h_I =1.4 μm, or $\varepsilon_{II} \simeq 68\%$ at h_{II} = 4.2μm. Since the number of alpha tracks is proportional to effective thickness times total detection efficiency (cf. equation (5)), the use of thick samples provides measurement with a gain in track population by at least a factor of $\sim$17 (h_I =1.4 μm), or a factor of $\sim$8 (h_{II} =4.2μm), as compared with the case for thin samples.

3.4 *The half-life-value for* ^{190}Pt

Table 1 summarizes the main data obtained by the procedures described in the preceding sections. The statistical analysis on the linear regression $\mathcal{N}$ *vs* τ indicates that the density of alpha disintegration events of $(4.91\pm 0.15)\times 10^3$cm^{-2} corresponding to the longest exposure of 2.04 yr represents the more reliable result. From these data the value $T_{1/2}$ =$(3.2\pm0.1)\times 10^{11}$yr has been obtained for the half-life of ^{190}Pt isotope.

4. DISCUSSION AND CONCLUSION

Table 2 lists the available literature data concerning the experimental $T_{1/2}$-determinations for ^{190}Pt isotope, as well as the two most recent theoretical $T_{1/2}$-predictions. As can be seen in this table, the result of the present measurement shows agreement, within the uncertainties, with the one measured by Petrzhak and Yakunin (1961), although it is seen to be lower than the other measurements by an average factor of $\sim$2. Just a $\sim$40% difference is verified when comparing the present $T_{1/2}$-value with the one obtained by Graeffe (1963). It should be noted, however, that the present experimental method and conditions have provided the greatest amount of exposure up to date (6.2 mg.h/cm^2 of ^{190}Pt) for alpha-particle-track counting, thus leading to the best statistics as well ($\sim$ 3% uncertainty). The analysis of the variation of the density of alpha events with exposure time ($\mathcal{N} = k\tau$) has assured an unbiased result for the half-life of ^{190}Pt isotope. Besides, a special care against the background due to actinide contaminants has been taken.

The techniques employed for precise determination of very low alpha activities must be characterized not only by a high detection efficiency (or, in other words, a high performance in detecting alpha events), but also by the ability in discriminating between alpha-emission events ascribed to the radioisotope under investigation and background events produced either by contaminants or environmental radioactivity. We remark that the present experiment has been carefully planned in order to meet the requirements above.

Table 2 shows, in addition, that the present experimental half-life-value, $(3.2\pm0.1)\times 10^{11}$yr, compares rather well with two recent half-life predictions. The first one, 3.8×10^{11}yr, comes from a systematic study of half-lives of favoured alpha transitions covering around 500 alpha emitters (Buck *et al.*, 1993), and it is based on a simple cluster model with four free parameters to be fitted to the body of alpha decay half-life data. In this study, excellent agreement has been found with the available data. The second one, $(2.6\pm1.0)\times10^{11}$yr, results from a simple, Gamow's-like model which includes the quadrupole deformation of the product nucleus, yielding a formula without any adjustable parameter to calculate the half-life of favoured alpha transitions of even-even parent nuclei (Tavares, 1996). This model also predicts the possible existence of anisotropic alpha emission of even-even alpha emitters.

In summary, the agreement found between the present experimental determination and the most recent theoretical predictions points towards a half-life-value of 3.2×10^{11}yr for ^{190}Pt isotope. This value corresponds to a half-life of 2.5×10^{15}yr for natural platinum, which is equivalent to an activity of $\sim$100 alpha disintegrations per hour and per gram of natural platinum, i.e., an activity $\sim$1 million times less than that for natural uranium.

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Table 1: Data regarding the determination of the half-life of ^{190}Pt isotope

Group of CR-39 plates	Exposure time, τ (yr)	Detector layer removal by etching, $h(\mu m)$	Detection efficiency, $\varepsilon(\%)$	Total number of alpha tracks recorded^{+}, $N_T(10^3 cm^{-2})$	Background tracks from actinide impurities^{+}, $N_I(10^3 cm^{-2})$	Number of alpha--particle events, $\mathcal{N} = (N_T - N_I)/\varepsilon$
I	0.45	1.4±0.2	60	0.39±0.02	0.090±0.020	0.50±0.05
II	1.56	4.2±0.2	90	6.09±0.08	1.23±0.09	5.40±0.13
III	2.04	4.2±0.2	90	6.03±0.07	1.61±0.12	4.91±0.15

$^{+}$Intrinsic background of detectors has been subtracted; errors indicated are statistical ones.

CBPF-NF-076/96

Table 2. Half-life measurements and predictions for ^{190}Pt isotope

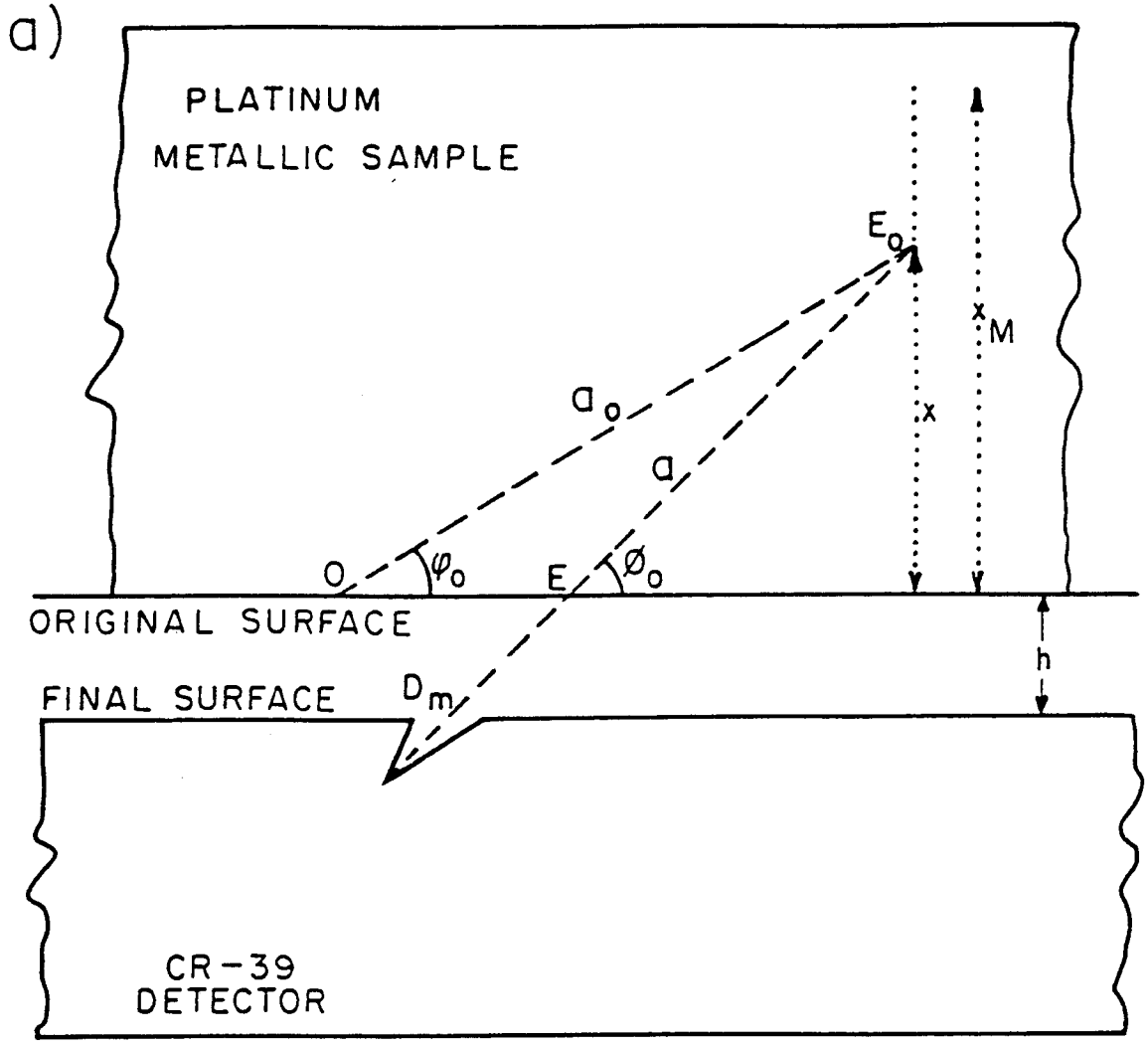
Author	Year	Method	Amount of ^{190}Pt-exposure (μg.h.cm^{-2})	Half-life (10^{11}yr)
Hoffmann	1921	Ioniz. chamber	$\sim$15	$\sim$5
Porschen and Riezler	1954	Nuclear-track emulsion	$\sim$15$-$45	10
Petrzhak and Yakunin	1961	Ioniz. chamber	$\sim$1.8	4.7$\pm$1.7
Macfarlane and Kohman	1961	Ioniz. chamber	$\sim$2.2$-$7.0	6.9$\pm$0.5
Graeffe and Nurmia	1961	Ioniz. chamber	$\sim$17	6.8
Graeffe	1963	Ioniz. chamber	240	5.4$\pm$0.6
Al-Bataina and Jänecke	1987	Ioniz. chamber	$\sim$1.6$-$3.9	6.65$\pm$0.28
Tavares and Terranova	this work	CR-39 track detector	$\sim(1.4-6.2)\times10^3$	3.2$\pm$0.1
Buck *et al.*	1993	Cluster model (4 parameters)	—	3.8
Tavares	1996	Gamow's-like model with deformation (no parameter)	—	2.6$\pm$1.0

FIGURE CAPTIONS

FIG. 1. Schematic representation of a thick metallic foil of natural platinum in contact with a CR-39 track detector to measure alpha activity of ^{190}Pt isotope. The dashed lines represent alpha-particle trajectories from a point-origin inside the sample, where the initial kinetic energy is E_0 =3.18 MeV; h is the thickness of detector material removed by etching. In (a) the limiting dip angle ϕ_0 does correspond to the threshold etch pit opening D_m, and φ_0 does correspond to particle full residual range $a_0 = R'(E_0)$ in the sample. (b) Shows the maximum thickness of the platinum layer, x_M, which contributes to visible alpha tracks (normal incidence); E_{th} is the alpha particle threshold energy.

FIG. 2. Semiempirical response curve, D *vs* E, of CR-39 to alpha particles of normal incidence. The curves have been obtained as described in the text; the dashed line indicates the threshold track-diameter D_m =1.9μm; points near the curves represent the maximum track-diameter, D_M, measured at each h.

FIG. 3. sinϕ_0 plotted against x. The quantities ϕ_0 and x are defined in Fig.1-a. The curves have been obtained by numerical calculation as explained in the text.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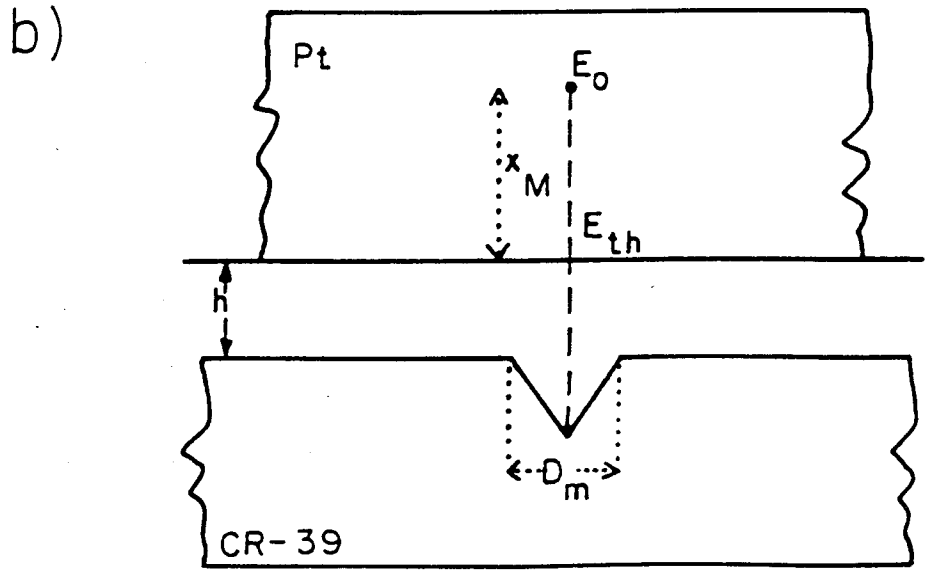
b)
Pt
E_o
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Fig. 1

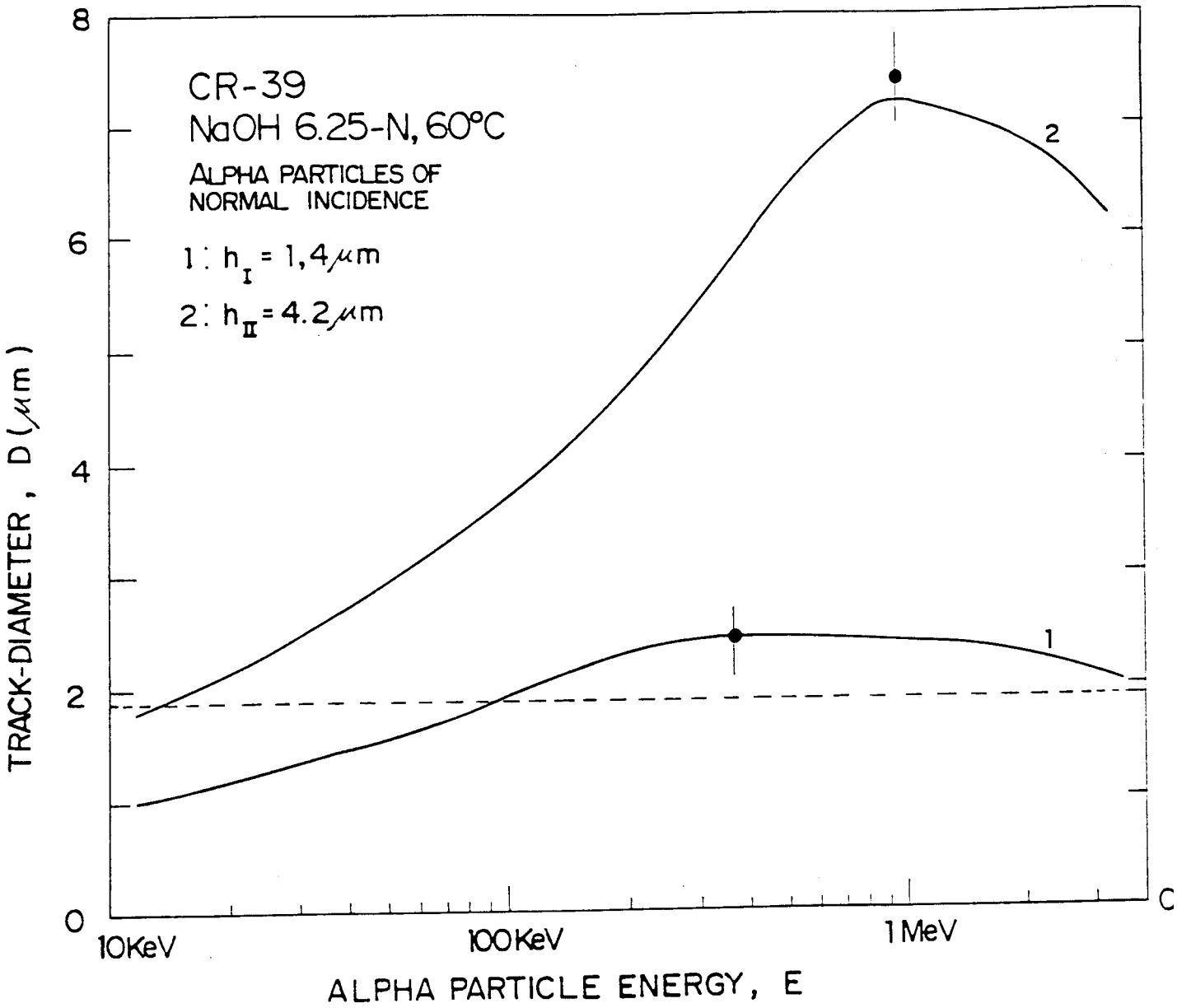
CR-39
NaOH 6.25-N, 60°C
ALPHA PARTICLES OF
NORMAL INCIDENCE
1: h_I = 1,4 μm
2: h_II = 4.2 μm
TRACK-DIAMETER, D (μm)
ALPHA PARTICLE ENERGY, E
10KeV
100KeV
1MeV
0
2
4
6
8
1
2

Fig. 2

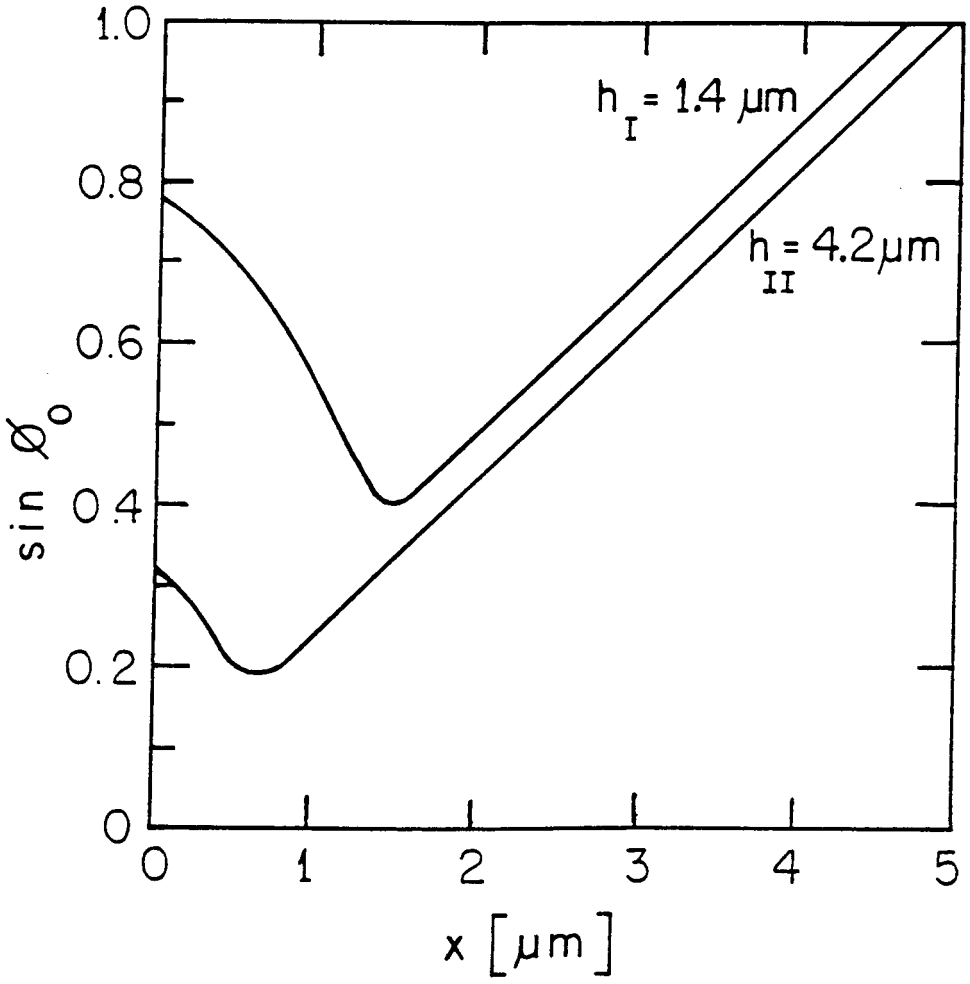

Fig. 3

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