CHAPTER V

COMPARATIVE STUDY OF DETECTION FEATURES OF THE THREE PLASTICS AND THE POSSIBILITY OF QUALITATIVE AND QUANTITATIVE ALPHA RADIOPHOTY WITH THEM

5.1 Introduction

In this chapter we present the results of the optical density measurements for $\alpha$-particles in the case of the three plastic detectors namely cellulose nitrate, cellulose acetate and polycarbonate, and compare their detection features. For a proper comparison of similar curves in the case of the different plastics we have plotted the optical density ($D$) as a function of removed layer ($h = r_b t$) from the single surface of the detector and not the etching time ($t$). As the bulk etch rate ($r_b$) is different for different plastics, a proper comparison is not possible under the other case. These curves have been found to be very reproducible under standard irradiation and etching conditions. In sequence we will refer to these curves as $D (h)$ curves.

Our investigations on the $D (h)$ curves have yielded new information for quantitative alpha radiography and in addition provided a simple method for studying the registration features of plastic track detectors. (167)
As for a planning of an alpha radiographic experiment the knowledge of the requirements for track appearance and track etching kinetics is essential we will first develop a simple track growing process based on our observations in plastics before discussing our results on optical density measurements.

5.2 Track Growing Process in Plastics During Stching

As the plastic containing the damage trails is etched in an appropriate solution, the tracks first appear on the etched surface only when the end of the etchable part lies on the detector surface. In 2π-geometry clear conical α-tracks are seen. The direction of entrance of the particles can also be guessed (see Fig.36). In the case of normal incidence circular tracks due to the horizontal section of the conical tracks are seen on the etched surface (see Fig.2 (j), 33 and 37). Our continuous observations of normally entering α-particle tracks revealed that as the etching is continued the track size enlarges and a single track remains black till it has been etched to the end of the particle trajectory after which it starts paling. When the track density is large, prolonged etching results into mutual touching of the enlarged tracks yet their remains a clear-cut boundary between them (see Fig.37).
Fig. 36. Optical micrograph of $\alpha$-particle tracks in Cellit-T plastic irradiated in $2\pi$ geometry with a degrader foil on the alpha-source. Conical tracks can be clearly seen.

Fig. 37. Optical micrograph of the over etched tracks of normally entering 3 MeV $\alpha$-particles in Makrofol-E plastic. Note the clear-cut boundary between the enlarged touching tracks.

To develop the track growing process let us refer to Fig. 38 in which $AB$ represents the original surface of the detector and $CD$ and $EF$ represent the etched surfaces.
after etching times $t$ and $(t+dt)$ respectively. At time $t$, the point $O$ reaches $G$ so that $OG = r_T^t t$ and at time $(t+dt)$ $O$ reaches $H$ so that $OH = r_T^t (t+dt)$. At time $t$ the radius of the etch pit on the etched surface $CD$ is $JK = R$ and at time $(t+dt)$ the radius of the etch pit on the etched surface $DF$ is $MN = (R + dR)$. To find the rate of increase of radius of the etch pit with etching time, consider the similar triangles $JKG$ and $MNH$, whence

$$\frac{R + dR}{R} = \frac{(r_T^t - r_B)(t + dt)}{(r_T^t - r_B)t}$$

which gives the rate of increase of radius of the etch pit as

$$\frac{dR}{dt} = \frac{R}{t} \quad \text{(V-1)}$$

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**Fig. 38.** Initial track growing process in plastics for a particle entering normally into the detector. The etch rate $r_B$ and $r_T$ have been assumed to be constant during the whole process of etching.
To find $\frac{R}{t}$, consider similar triangles OPG and JKG, whence

$$\frac{r_B t}{r_T t} = \frac{R}{\sqrt{R^2 + (r_T - r_B)^2}}$$

which on solving gives

$$\frac{R}{t} = r_B \sqrt{\frac{r_T - r_B}{r_T + r_B}} \quad \ldots \ldots \quad (V-2)$$

From (V-1) and (V-2) we get the rate of increase of radius of the etch pit in the beginning as

$$\frac{dR}{dt} = r_B \sqrt{\frac{r_T - r_B}{r_T + r_B}} \quad \ldots \ldots \quad (V-3)$$

It is clear that if the track etch rate $r_T$ and the bulk etch rate $r_B$ are assumed to be constant under the given etching condition, the radius of the etch pit will grow linearly with time till the whole length of the particle trajectory is etched out. It should be noted that Eq. (V-3) can be used to calculate the track etch rate $r_T$ by knowing $r_B$ from direct measurement and finding the slope $dR/dt$ of the measured curve showing the variation of radius of the etch pits with time for normally entering particles in the beginning. We have found that $r_T$ varies exponentially towards the end of the $\alpha$-particle trajectory in all the three
To find $R/t$, consider similar triangles OPQ and JKG, whence

$$\frac{r_B t}{r_T t} = \frac{R}{\left[R^2 + (r_T - r_B)^2 t^2\right]^{1/2}}$$

which on solving gives

$$\frac{R}{t} = r_B \sqrt{\frac{r_T - r_B}{r_T + r_B}} \quad \ldots \ldots \quad (V-2)$$

From (V-1) and (V-2) we get the rate of increase of radius of the etch pit in the beginning as

$$\frac{dR}{dt} = r_B \sqrt{\frac{r_T - r_B}{r_T + r_B}} \quad \ldots \ldots \quad (V-3)$$

It is clear that if the track etch rate $r_T$ and the bulk etch rate $r_B$ are assumed to be constant under the given etching condition, the radius of the etch pit will grow linearly with time till the whole length of the particle trajectory is etched out. It should be noted that Eq. (V-3) can be used to calculate the track etch rate $r_T$ by knowing $r_B$ from direct measurement and finding the slope $dR/dt$ of the measured curve showing the variation of radius of the etch pits with time for normally entering particles in the beginning. (We have found that $r_T$ varies exponentially towards the end of the $\alpha$-particle trajectory in all the three
plastics used by us. The implications of this variation of track etch rate will be discussed in Appendix I).

If \( l \) be the maximum etchable range of the particle trajectory then at time

\[ t_0 = \frac{1}{r_T} \quad \ldots \ldots \quad (V-4) \]

the etch pit radius on the etched surface of the detector will be

\[ R_0 = \frac{(dR/dt)t_0}{r_T} = \frac{1 \cdot r_B}{r_T} \sqrt{\frac{(r_T - r_B)}{(r_T + r_B)}} \quad \ldots \ldots \quad (V-5) \]

Or

\[ R_0 = \frac{r_B}{r_T} \sqrt{\frac{1 - r_B/r_T}{1 + r_B/r_T}} \quad \ldots \ldots \quad (V-6) \]

(It is obvious from the above equations that the rate of increase of radius of the etch pit on the etched surface of the detector is a function of preferential track etch ratio \((r_T/r_B)\) which in turn has been found to depend upon the etching solutions, its contents, concentration, temperatures, and the type of plastic material).

After the time \( t_0 \), the track etches all round only with the bulk etch rate \( r_B \) normal to the free surface as shown in Fig.39, but the etch pit continues to have conical surface with a little spherical bottom till the time when all the
conical surface is etched out and there remains only the spherical surface as shown by the surface HVIJ in Fig. 39.

Fig. 39. Track growing process in the plastic after a time $t_0$ when maximum etchable length $l$ has been etched out.

During the interval while there remains a cylindrical surface, the rate of growth of diameter with time on the etched surface
of the detector is still given by Eq. (V-3). If this
time counted after \( t_o \) be \( t'_1 \) (so that the actual etching
time from the beginning is \( t_1 = t_o + t'_1 \)), the radius of
the etch pit at this instant will be

\[
R_1 = \frac{dr}{dt} (t_o + t'_1) = r_B \sqrt{\frac{r_T - r_B}{r_T + r_B} x (t_o + t'_1)} \quad \ldots \ldots (V-7)
\]

To find the value of \( t'_1 \), consider similar triangles
\( OQG \) and \( GV'O \), whence

\[
\frac{R_1}{r_B t'_1} = \frac{\sqrt{r_T t_o^2 - r_B t'_1^2}}{r_T t_o}
\]

Or

\[
\frac{R_1}{r_B t'_1} = \sqrt{\frac{r_T^2 - r_B^2}{r_T^2}}
\]

Putting the value of \( R_1/r_B \) in the above equation
from (V-7) we get

\[
\frac{(t_o + t'_1)}{t'_1} \sqrt{\frac{r_T - r_B}{r_T + r_B}} = \sqrt{\frac{(r_T + r_B) (r_T - r_B)}{r_T}}
\]

which on solving gives

\[
t'_1 = \frac{r_T}{r_B} t_o \quad \ldots \ldots \quad \ldots \ldots \quad (V-8)
\]

The actual etching time at this instant is given by

\[
t_1 = t_o + t'_1 = t_o + \frac{r_T}{r_B} t_o = (1 + \frac{r_T}{r_B}) t_o
\]

Or

\[
t_1 = (1 + \frac{r_T}{r_B}) \frac{1}{r_T} \quad \ldots \ldots \quad \ldots \ldots \quad (V-9)
\]
i.e., upto the time given by (V-9) the rate of increase of radius of the etch pit on the etched surface of the detector will be given by Eq. (V-3) and so the curves showing the variation of etch pit diameter with etching time should be linear in the beginning for this time interval (see that a part of every measured curve in Fig. 40 is linear in the beginning).

![Graph showing track diameter growing curves](image)

**Fig. 40.** Track diameter growing curves for fission fragments (H in Hostaphan plastic etched in 20% NaOH solution at 50°C; M and G in Muscovite mica and glass respectively etched in 40% HF at 22°C) and for 1 MeV α-particles (C in cellulose nitrate plastic etched in 20% NaOH at 50°C).

After this time the track grows only spherically.

Let the position after a time \( t' \) measured after \( t_0 (t' > t_1) \)
be shown by NWTU in Fig. 39. The radius of the etch pit on the etched surface of the detector at this instant will be given by

\[ R = \sqrt{r_B^2 \cdot t'^2 - \left[ r_B^* t' - (r_T - r_B) t_0 \right]^2} \]

\[ = \sqrt{(r_T - r_B) t_0 \left[ 2 r_B^* t' - (r_T - r_B) t_0 \right]} \]

but \( t_0 = 1/r_T \) and \( t' = t - t_0 = t - 1/r_T \), where \( t \) is the actual etching time from the beginning to this instant.

\[ \therefore \quad R = \sqrt{(r_T - r_B) \cdot \frac{1}{r_T} \left[ 2 r_B^* (t - \frac{1}{r_T}) - (r_T - r_B) \frac{1}{r_T} \right]} \]

which on rearranging gives

\[ R = \sqrt{(1 - \frac{r_B}{r_T}) \cdot \frac{1}{r_T} \left[ 2 r_B^* t - \left(1 + \frac{r_B}{r_T}\right) \frac{1}{r_T} \right]} \quad \ldots \quad (V-10) \]

Thus, after the etching time \( t_1 \) given by (V-9) the radius of the etch pit on the etched surface of the detector will be given by Eq. (V-10) which shows that the radius growing curve should become parabolic in nature (this tendency is clearly seen in our measured curves shown in Fig. 40).

In the case where \( \frac{r_T}{r_B} \gg 1 \) (for example for \( \alpha \)-tracks in cellulose nitrate etched in 20% NaOH at 55°C), the radius of the etch pits on the etched surface will be given by the
approximate formula

\[ R = r_B t \quad \text{for } t < t_1 \quad \ldots \quad (V-11) \]

and

\[ R = \sqrt{2 r_B t - t^2} \quad \text{for } t > t_1 \quad \ldots \quad (V-12) \]

where \( t_1 = \frac{1}{r_B} \) from Eq. (V-9) \( \ldots \quad (V-13) \)

In the case of oblique incidence at an angle \( \theta \) with the surface a similar track growing process may be assumed. In this case the depth below the etched surface at time \( t_0 \) will be given by \( \frac{1}{r_T} \cdot (r_T \cdot \sin \theta - r_B) \) instead of \( \frac{1}{r_T} \cdot (r_T - r_B) \) and the horizontal section of the track will become elliptical instead of circular. The minor axis of the elliptic etch pit will be given by

\[ D_{\text{min}} = 2 r_B \sqrt{\frac{(r_T \cdot \sin \theta - r_B)}{(r_T \cdot \sin \theta + r_B)}} \times t \quad \ldots \ldots \quad (V-14) \]

upto a time

\[ t_1 = \frac{1}{r_T} \cdot \frac{(r_T \cdot \sin \theta + r_B)}{r_B} \quad \ldots \ldots \quad (V-15) \]

and for \( t > t_1 \) it will be given by

\[ D_{\text{min}} = 2 \sqrt{(r_1 \cdot \sin \theta - r_B) \cdot \frac{1}{r_T} \left[ 2 r_B t - (r_T \cdot \sin \theta + r_B) \cdot \frac{1}{r_T} \right]} \ldots (V-16) \]
CELLULOSE NITRATE
$r_b = 4.50 \mu m/h$

CELLULOSE ACETATE (Cellit-T)
$r_b = 4.25 \mu m/h$

POLYCARBONATE (Makrofol-E)
$r_b = 11.7 \mu m/h$

Optical Density (D = log $b/\bar{b}$)

Removed Layer From Single Surface
5.3 Results and Discussions of the Optical density Measurements

The measured optical density in plastics irradiated with high flux of \( \alpha \)-particles depends, as in nuclear emulsions, on the entering angle, integrated flux of the particles as well as on the etching conditions and the type of the detectors. These parameters play important role in the development of the number, shape and size of the etch pits (see our derivations in Appendix I) and thus determine the amount of light scattered by them.

The correlation between the optical density \( (D) \) and the removed layer \( (h = r_B \cdot t) \) from a single surface of the plastic detector irradiated in \( 2\pi \) -geometry by \( \alpha \)-particles from a thin source has been investigated. The results of our measurements are shown in Fig.41. The number \( (N) \) of

![Fig.41](image)

(See opposite page) Optical density \( (D) \) versus removed layer from single surface \( (r_B \cdot t) \) curves for cellulose nitrate, cellulose acetate and polycarbonate plastics irradiated in air by \( \alpha \)-particles from \( ^{241} \text{Am} \) source. For irradiation an aluminium foil \( (3.8 \text{ mg/cm}^2) \) was placed in between the detectors and the source in perfect contact with them. This reduced the energy of 5.5 MeV \( \alpha \)-particles to 2.9 MeV. The numbers on the curves represent the relative number of \( \alpha \)-particle emitted from the source towards the plastic with a unit of \( 5.07 \times 10^5 \) alpha/cm\(^2\) - St itching conditions are given in Chap.III.
α-particles emitted from unit area of the source towards the detector surface in arbitrary unit has been used as parameter in this figure. The actual integrated flux of α-particles can be calculated from the formula $\phi = 5.07 \times 10^5 \times N_{\text{alpha}} \text{ cm}^2$.

Fig. 42 shows the optical density of plastic detectors irradiated in $2\pi$-geometry as a function of integrated flux of α-particles with etching time in minutes as parameter for the etching conditions mentioned in Chap. III. These curves will henceforth be referred to as the D(\phi) curves.

Fig. 42. (See opposite page) Optical (D) versus integrated α-flux (\phi) curves for cellulose nitrate, cellulose acetate and polycarbonate plastics with etching time in minutes as parameters, irradiation and etching conditions being the same as for Fig. 41.

The D (h) curves for the three plastics irradiated in air by 3 MeV α-particles entering the detectors at right angles are shown in Fig. 43. The numbers on the curves represent the relative track density in arbitrary
CELLULOSE NITRATE

CELLULOSE ACETATE (Cellul-T)

POLYCARBONATE (Makrofol-E)

REMOVED LAYER FROM SINGLE SURFACE
units. The real track density in tracks per cm$^2$ can be calculated by multiplying the number with a factor $2.5 \times 10^5$.

Fig. 43. (See opposite page) Optical density (D) versus removed layer from the single surface ($E_0, t$) curves for cellulose nitrate, cellulose acetate and poly-carbonate plastics irradiated in air with 3 MeV $\alpha$-particles entering the detectors at right angles. The numbers on the curves represent the relative track density on the surface of the detectors with a unit of $2.5 \times 10^5$ tracks/cm$^2$. The etching conditions are given in Chap. III.

The effect of particle energy on the D(h) curves for the three plastics has also been investigated by irradiating the plastics under similar geometrical conditions with $\alpha$-particles of different energies. For this purpose the three plastics were first stored for one hour in vacuum and then irradiated for 24 hours in similar perpendicular geometry in vacuum by $\alpha$-particles of different energies as obtained by using different thicknesses of aluminium foils. The distance of the $^{241}$Am

* Our experience showed that one hour storage in a vacuum of $\sim 10^{-2}$ torr was enough to remove practically most of the free oxygen present in the detector material.
source (used for such irradiation) from the detectors was 2.4 cm in every case. The track density could, thus, be maintained as constant \((7.0 \times 10^6 \text{ tracks/cm}^2)\). Fig. 44 shows the results of such measurements.

Fig. 44. (See opposite page) Optical density \((D)\) versus removed layer from the single surface \((r.r.t)\) curves for cellulose nitrate, cellulose acetate and polycarbonate plastics irradiated in vacuum for one day by \(\alpha\)-particles of energies 4.9, 4.2, 3.5, 2.7 and 1.75 MeV entering normally into the detectors. The track density was the same in all the cases \((7.0 \times 10^6 \text{ tracks/cm}^2)\). The numbers on the curves represent the thickness of the aluminium foils in mg/cm\(^2\) used to get the above mentioned energies. Etching conditions are given in Chap. III.

The striking features of the \(D(h)\) and \(D(\phi)\) curves shown in Fig. 41-44 are summarized below.

1) There exists a correlation between certain features of these curves and the sensitivities of the plastic detectors. From Fig. 41 and 43 it can be seen that the maximum value in the \(D(h)\) curves becomes constantly lower and the place of this maximum shifts towards the higher value of the removed layer if one uses the plastics of lower sensitivities in the order \(\text{CN} \rightarrow \text{CA} \rightarrow \text{PC}\).
The value and the place of the maximum and the slope of the $D(h)$ curves depend upon the track density. This dependence is strongest in the case of the most sensitive plastic (cellulose nitrate) and weakest in the case of the least sensitive plastic (polycarbonate).

The position of the $D(h)$ curves along the $'h'$ axis for a given track density depends upon the particle energy (Fig. 44). In the case of photoemulsions the optical density for a given track density increases with particle energy but in the case of plastic track detectors, due to their threshold features, this kind of dependence is valid only for particles having energy less than the critical energy for track registration (see the $D(h)$ curves in Fig. 44 for cellulose nitrate for which $E_c \approx 3$ MeV). At higher energies than the critical one there is only a shift in the position of the $D(h)$ curves (see for example the case of cellulose acetate in Fig. 44). In the case of polycarbonate however, an especially different effect is observed which may be attributed to the vacuum-effect (see Sec. 5.4).

The relationship between the optical density and the track density is quite linear for shorter etching time (see Fig. 42). For a wider range of $\alpha$-exposure ($\Sigma$)
one can use the formula \( D = D_{\text{max}} (1-e^{-k\phi}) \), where \( D_{\text{max}} \) is the maximum value of the optical density, \( k \) is a constant for a given material depending upon the etching time.

A few aspects of the above observations will now be discussed in sequence.

Let us first consider the registration efficiencies of these detectors. The track registration in these detectors is limited by a critical angle \( \theta_C = \arcsin\left(\frac{r_B}{r_m}\right) \). Under the etching conditions mentioned in Chap. III the ratio \( r_m/r_B \) for \( \alpha \)-particle tracks was determined from measurements based on Eq. (V-3). In the case of cellulose nitrate, cellulose acetate and polycarbonate respectively, values equal to 11.5, 8.5 and 5.5 were obtained. Thus in the above mentioned conditions the calculated values of registration efficiencies of these detectors for \( \alpha \)-particles will be 91.3, 88.3 and 71.8% respectively as calculated by using Eq. (II-4).

On actually counting the track in plastics irradiated in 2\( \pi \)-geometry by monoenergetic \( \alpha \)-particles one gets smaller values of registration efficiency than calculated by Eq. (II-4). One of the causes of this is the fact that the tracks of particles having same energy but entering the detector at different angles do not appear on the etched
surface of the detector simultaneously because the first etchable points of the latent tracks are at different depths from the detector surface (see Appendix I). The difference between the first and last track appearing times can be calculated by the formula (A-1.5) as given in Appendix I. Another reason of getting less registration efficiency in actual track counting is that the particles entering the detector at angles only slightly greater than $\theta_c$ give short etch pits (Cf. Eq. (A-1.10) given in Appendix I) which are very pale and make it very difficult to be distinguished from the background.

Because of the strong track paling, the pits due to the particles entering the detector at angles slightly greater than $\theta_c$ do not play major role in causing the optical density in plastic detectors. This tendency is reverse of what it is in the case of photoemulsions in which the maximum optical density is caused by the particles which enter the plates at oblique angles and the optical density in their case is proportional to the cosine of entering angles. (165)

An alpha-ray pattern in plastics contains informations not only about the track density but also about the energy distribution of the particles. In photoemulsions the particles of different energies produce the optical density
simultaneously. In the case of plastic detectors, however, the alpha-ray patterns belonging to $\alpha$-particles of different energies appear on the etched surface of the detector at different etching times. This is illustrated in Fig. 45 which shows the optical micrograph of a part of alpha-ray pattern in cellulose acetate plastic irradiated in perpendicular geometry by a monoenergetic homogeneous $\alpha$-source using a thin aluminium foil in contact with the detector and facing the source.

Fig. 45. Optical micrograph of a part of alpha-ray pattern in cellulose acetate plastic irradiated in perpendicular geometry by a monoenergetic homogeneous $\alpha$-source.
In this photograph a part with larger tracks than in the surroundings can be seen, indicating an inhomogeneity in the thickness of the aluminium foil. Because of the larger thickness of the foil in this part, the tracks appeared earlier and by the time the tracks passing through the homogeneous part appeared, the older tracks became much larger. From this it appears that by choosing a suitable plastic detector one can get information about the $\alpha$-activity belonging to particles of different energy in the same alpha-ray pattern. This is not possible with photoemulsions.

In polycarbonate detectors it is found that the nature of the $D(h)$ curves remains practically the same in the case of perpendicular and $2\pi$-irradiation geometries. This can easily be seen by comparing the measured curves for polycarbonate in Fig.41 and the curve marked with number 4 in Fig.44. In these two figures the maximum $\alpha$-energies were nearly the same (2.9 and 2.7 MeV respectively) but in the first case the irradiation was made in $2\pi$-geometry and in the second case in perpendicular geometry. As can be seen, the shapes and the half widths of the $D(h)$ curves in these two limited geometries are nearly the same. This indicates that by using this plastic and suitable etching
times it is possible to select even in contact $\alpha$-radiograms the parts produced by $\alpha$-particles belonging to different energies emitted by the $\alpha$-active sample.

The curves shown in Fig. 44 convey very important information about the energy resolution obtainable from the three kinds of plastic detectors for alpha particles. It is clearly seen that the least sensitive plastic (polycarbonate) will give greatest energy resolution and the most sensitive plastic (cellulose nitrate) will give least energy resolution. The resolution for the cellulose acetate plastic has an intermediate value but is near to that of polycarbonate.

5.4 Effect of Absence of Air (Vacuum-Effect) on the Detection Features of the Plastics

It may be expected that the features of the unetched damaged region may change due to environmental conditions such as presence of different gases, irradiation by ultra violet light etc. To show such effect of environmental conditions on the track registration features of plastic track detectors, a good parameter connected with the track development has to be chosen. We found that investigation of the variation of optical density in a
detector irradiated with high track density provided a quick and reliable method for this purpose. By using this method investigations were made to study the change in the registration features of cellulose nitrate, cellulose acetate and polycarbonate plastic detectors when they were irradiated in vacuum instead of air. This effect will henceforth be referred to as 'vacuum-effect'.

For α-particle tracks the vacuum-effect has so far been investigated only by Becker (166) in the case of cellulose derivatives. He irradiated the detectors in direct contact with a thick ²³⁸U source and investigated the change in relative sensitivities by counting the observable number of track etch pits per unit area. The reproducibility of this method is given to be only about ± 10%. In the case of cellulose nitrate he could not find any vacuum-effect.

For fission fragment tracks a change in the registration features due to the presence or absence of oxygen during irradiation was evidenced by Monnin (152) in polycarbonate, cellulose acetate and polyethylene glycolerephthalate. He could also not observe any vacuum-effect in the case of cellulose nitrate. His method was to observe
the difference in the appearance time of fission fragment tracks registered in the detectors in vacuum and air respectively.

Below we summarize our observations for the change in the registration sensitivities of the three plastic detectors irradiated in vacuum and in air respectively, as observed by the optical density curves which have been found to be very reproducible under standard irradiation and etching conditions. Such measurements were made for detectors irradiated both in $2\pi$ as well as in perpendicular geometries. The knowledge of the first case is important in making $\alpha$-radiograms when we perform irradiation in vacuum for getting sharp alpha-ray patterns. The latter case is interesting when the detectors are irradiated in vacuum chamber of an accelerator viz., in the study of nuclear reaction (see Chap. VI) and investigations of channelling effect in crystals using plastic track detectors.

In one of our experiments cellulose nitrate, cellulose acetate and polycarbonate detectors were stored for two days in vacuum of about $5 \times 10^{-2}$ torr so as to remove any chemically unbound oxygen present in the plastics. These detectors were then irradiated in $2\pi$-geometry by $\alpha$-particles obtained from a very thin homogeneous $\alpha$-source.
CELLULOSE NITRATE

- Stored and irradiated in air
- Stored and irradiated in vacuum

CELLULOSE ACETATE (Cellit-T)

POLYCARBONATE (Makrofol-E)

REMOVED LAYER FROM SINGLE SURFACE

OPTICAL DENSITY $(D = \log_\text{base} B/t)$
(\textsuperscript{241}Am with a 3.8 mg/cm\textsuperscript{2} Al-degrader which reduced the maximum alpha energy from 5.5 MeV to 2.9 MeV). Similar detectors were also irradiated in air for the same time and in the same geometrical conditions as in vacuum. On measuring the \( D(t) \) curves for the two cases systematic differences have been found (see Fig.46). A shift in the position and a decrease in the value of maximum in the \( D(t) \) curves is found for the case of plastics stored and irradiated in vacuum when compared to that for those stored and irradiated in air in all the three plastics. A measurable vacuum-effect can be seen even in the case of cellulose nitrate.

Fig.46. (See opposite page). Showing the effect of absence of air during irradiation on the optical density \( (D_\lambda) \), versus removed layer from single surface \( (r_{37}.t) \) curves for cellulose nitrate, cellulose acetate and polycarbonate irradiated in 2\( \pi \)-geometry by \( \alpha \)-particles from \textsuperscript{241}Am source using a 3.8 mg/cm\textsuperscript{2} aluminium degrader foil. Irradiation and etching conditions were the same as for Fig.42.

The explanation of this observation may be that the etch rates along the particle trajectories and/or the registration thresholds of the detectors irradiated in oxygen-free environment are smaller than those in the case
of detectors irradiated in air. It should be noted that no change was found in the bulk etch rate of a given plastic placed in air and in vacuum of about $5 \times 10^{-2}$ torr when etched under similar conditions. The amount of vacuum effect is found to be maximum in the case of the least sensitive plastic (polycarbonate) and minimum in the case of most sensitive plastic (cellulose nitrate). The effect is found to be more pronounced when polycarbonate plastic is irradiated with $\alpha$-particles normally (see Fig. 47).

Fig. 47. Showing the vacuum-effect on the optical density curve for polycarbonate plastic irradiated normally with 3 MeV $\alpha$-particles. The track density was kept constant in the two cases.
The reversibility of the vacuum-effect on the optical density curves was also investigated. For this purpose the three plastics were kept in vacuum of $5 \times 10^{-2}$ torr for two days and then irradiated in $2\pi$-geometry by $\alpha$-particles in vacuum for one hour. Such irradiated plastics were then stored in air for various times (0 hour, 1 hour, 5 hours, 1 day, 5 days and 8 days) between irradiation and etching. Practically no change in the measured $D(h)$ curves for these cases have been found within experimental errors thus indicating the irreversibility of vacuum-effect for $\alpha$-particles—a result which is not the same which Monnin\(^{(152)}\) had found for fission fragments. This shows that in the case of $\alpha$-particles the effect of oxygen on the track formation takes place only in the course of irradiation.

5.5 Conclusions

It is clear that due to their reproducible character under controlled irradiation and etching conditions the optical density curves can be used to study the relative detection features of various kinds of plastic track detectors and also any change in their sensitivity due to environmental conditions like presence or absence of various gases;\(^{(180)}\) irradiation by ultra violet light, high doses of X-rays or
\(\gamma\)-rays etc. Because of the linear character of the track optical density versus density curves for smaller etching times, they may be used for counting of \(\alpha\)-particle tracks in the large track density region \((10^5 - 3 \times 10^7)\) tracks/cm\(^2\) where the visual counting becomes practically impossible. This naturally suggests the possibility of quantitative alpha radiography with plastic track detectors.\(^{(167)}\)

From our experience in alpha radiography using plastic track detectors we conclude that the plastics can easily replace photoemulsions for alpha radiographic purposes\(^{(165)}\) such as for studying the activity of rocks and solutions, for determining the spatial orientation of radioactive ions in crystals, for the study of activity of crystal faces, for auto-radiography of alloys, for studying diffusion processes in metals, for studying creeping of radioactive sources, for studying diffusion of radioactive materials in porous media, and also in biological applications viz., for localization of lead, bismuth, polonium, astatine, radioactive emanations, radium, thorium, plutonium and other transuranic elements. For qualitative work cellulose nitrate plastic is most suitable as it is most sensitive and possesses minimum energy resolution. For quantitative and energy selective alpha radiography cellulose acetate or polycarbonate plastics should be used.
Our findings of a large vacuum-effect in the case of polycarbonate plastic detectors has a great practical implication as this kind of plastic (Lexan polycarbonate) is currently being standardized and used for the identification of cosmic ray particles. The calibration curves for such identifications are obtained by irradiating the plastic detectors in the vacuum chambers of heavy ion accelerators with different kind of heavy ions of various energies. Any change in the etching features of the plastics due to vacuum-effect is liable to cause great error in the particle identification.