POLYMER ELECTRET DOSIMETRY

by

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Department of **ELECTRICAL ENGINEERING**

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Date **22 Aug. 1974**
The work reported in this thesis investigates the possible use of thin film teflon electrets as X-ray dosimeters. Electrets were prepared by corona- and breakdown field-charging and found to exhibit a number of properties that would render them suitable for personnel dosimetry.

The stability of the residual electret charge as a function of environment was also studied and it was found that hot, humid or unshielded conditions led to rapid charge decay.
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I INTRODUCTION

An electret is a piece of material which is permanently electrically polarized and can be thought of as the electrostatic analogue of a permanent magnet i.e. it produces an electric field external to itself. The field arises from the distribution of charge within the electret and the charge can be introduced into the would-be electret in a variety of ways that have recently been reviewed by Wintle.\(^1\) We can distinguish between:

(i) dipolar electrets - formed in materials which have permanent dipole moments, the latter being forced (by a combination of heating and electric field application) to orient in one direction;

(ii) internal space charge electrets - formed, in a manner similar to (i) above, in materials in which free charges exist;

(iii) injected space charge electrets - formed by injecting charge into a material by application of an electric field approaching the breakdown strength.

(iv) deposited charge electrets - formed by bombarding the material with electric charge e.g. a corona discharge or an electron beam.

The most common type of electret formed by methods (i) and (ii) is the thermoelectret and the charge type can either be heteropolar or homopolar. In method (iii) the charge has the same sign as that of the adjacent electrode and is thus called homopolar. In method (iv) the electrets so formed are monopolar.

This thesis is concerned with application of electrets to radiation dosimetry, a topic which has come under recent investigation and seems to offer high promise as a cheap, sensitive method\(^2,3\) for
solid state dosimetry with an easy read-out procedure. In principle, any property of a solid material which can be related to the radiation dosage received can be utilized as a solid state dosimetric method and at present, only two types of solid state dosimeter \(^4\) have been extensively used. One type makes use of the fact that before and after ionizing radiation there can be a change of optical density of a visual color change and this change can be related to the dose received. However, fading (which can actually be positive or negative), due to thermal or ultra-violet bleaching, can take place and this is highly undesirable in a device in which stability under all conditions except the ionizing environment being monitored is required. The other type of solid state dosimeter is concerned with luminescence. In fact there are two types of luminescence relevant here namely, radio-photoluminescence and thermo-luminescence. The former process relies on the fact that after subjection to the ionizing irradiation, there would be a creation of color centres in the dosimetric material which would be luminescent under subsequent UV or X-ray excitation. The concentration of newly-created color centres is proportional to the dose received and, hence, the luminescence output can be employed as a measure of dose. However, the severe energy dependence, complex readout procedure and fading have limited the practical use of dosimeters of this type. If a thermo-luminescence solid, at a sufficiently low temperature, is exposed to ionizing radiation, many of the freed electrons (or holes) become trapped at lattice imperfections in the crystalline solid. They remain trapped for long periods of time when stored at the requisite low temperature. If the temperature is raised, the electrons (or holes) are released from the traps, subsequently returning to stable energy states
with emission of light. The total intensity of the emitted light can, in certain circumstances, correlate with the dose received. Fading varies from one material to another. Lithium fluoride shows little fading (less than 5% per year), is fairly sensitive (0.1 rad is detectable), and has been used as an X-ray dosimeter in spite of its complicated destructive readout procedure.

The property of interest here is the decay of stored charge in the electret under the influence of ionizing radiation. A correlation between destroyed charge and radiation dose has been noted in UV-irradiated ZnS electrets, X-ray-irradiated polymer electrets and X-ray-irradiated CaF$_2$ electrets. The use of polymer electrets seems particularly attractive in view of their low cost, long charge retention time and close relation of their X-ray and neutron absorption spectra to that of the human body. On account of these factors the use of polymer electrets as X-ray dosimeters was investigated in this present work. An exploratory investigation in this area by Fabel and Henisch indicated that mylar, polystyrene and teflon could be suitable starting materials and teflon was selected for this work because of its detailed characterization as an electret material. Fabel and Henisch prepared thermoelectrets but this charging method (cited as (i) earlier) may not be the most suited to dosimetric application on account of the partial recovery of stored charge during "dormant" periods between irradiations. The cause of this partial recovery is not known but it may possibly be related to the dipolar nature of the stored charge. In this study, therefore, alternative charging methods were investigated, namely: breakdown-field charging, giving homopolar electrets and corona-charging giving monopolar electrets.

With corona-charged electrets, the charges reside on the surface rather than in the bulk of the electret which is case in dipolar electrets and this
may possibly be related to the above-mentioned recovery process. The long charge stability of electrets formed by both of the proposed methods is well-established.6,10

Also investigated in this thesis was the effect of storage environment on the charge decay and from these measurements some conclusions about the physical mechanisms of charge decay can be drawn.

The next chapter of this thesis discusses charge trapping and stability in general and, in particular, deals with the effect of X-ray irradiation. In chapter III the experimental procedures and equipment used are described. Results are presented in Chapter IV and are discussed in Chapter V.
II ELECTRET. CHARGE STORAGE AND STABILITY

In this chapter information on the trapping and retention of charge is briefly reviewed with particular emphasis on homo- and mono- polar systems. The effect on the trapped charge of ionizing radiation is then discussed, with attention being given to X-ray irradiation of polymers.

2.1 TRAPPING MECHANISMS.

In corona-charged, polymer electrets three possible storage sites have been suggested and termed primary, secondary and tertiary levels of trapping. The primary level of trapping occurs at the particular individual atom bonds within the molecules. Trapping at the secondary level includes caging of the decelerated electrons between adjacent main C chains, due to the electron affinity of the neighbouring group (e.g. H, Cl, F). Trapping at a tertiary level accommodates trapping of the injected electrons in cavities (structural defects) within the crystalline or amorphous region, or at the crystalline-amorphous interfaces of the polymer. Impurities in polymers could also be directly responsible for the trapping. However, work by the Bell-Northern group on a series of corona-charged substituted polyolefins suggested the charge traps in the polymers do not arise from impurities but that the chemical changes caused by the corona itself may be important. In particular, corona discharges in air can give rise to double bond (\( \text{=C} \equiv \text{C} \)) and carbonyl group (\( \text{=C} \equiv \text{O} \)) formation, both of which may act as electron traps. Experiments using different ambients for corona support might prove useful in yielding more information on this possibility. Some experiments of this nature were carried out by Cross and Blake.
who investigated charging of a FEP teflon sample held between two elec-
trodes in ambients of both medium vacuum and SF$_6$ (highly electronegative) at atmospheric pressure. No differences in the level of retained charge were detected thus indicating that the most likely mechanism appears to be electron injection from the metal electrode aided by the applied electric field. The charging method referred to here might more properly be termed breakdown field-charging but was equated to corona-charging by Cross and Blake by the suggestion that the small, but finite, gaseous gap between the metal electrodes and the electret sample would allow a "corona" to form. However, because of the insensitivity of charging to the ambient the conclusion is that in breakdown field charging (as defined in this thesis) charge is injected directly from the contacting electrode and not via an intermediate gas discharge. However the final site of the trapped charge is not identified except that it is thought to be very close to the surface, e.g. within a depth equivalent to about 5% of film thickness.

The charging mechanism involved in the breakdown field charging method has not been investigated, although, as mentioned above, the work of Cross and Blake is probably relevant here. Charging is usually accomplished by applying a large voltage to a metal/polymer/glass dielectric/metal system and thus charges can be driven into the polymer from either the adjacent metal or the dielectric. By the polarity of the voltage recorded in an induction charge measurement method, it appears that homocharge electrets always result. The charge must be injected from the dielectric because as Sessler and West have shown, no voltage would result, using their measurement technique, for the case of homopolar charge injected from the metal.
2.2 **STABILITY OF ELECTRETS**

The stability of electrets is of major concern when possible applications are being considered. A series of negatively corona-charged electrets has been investigated by Creswell and co-workers for the stability of charges. Total halogen substitution improved electret stability whereas partial substitution, forming less symmetric polymers, caused large decreases in stability. So the most stable electrets were polytetrafluoroethylene (teflon) and linear polyethylene. It appears that the more electronegative halogen substituent (F in teflon) provides a more stable charge storage site for negatively charged electrets. However, even though teflon has been found to be the most stable material for retaining its charge, it still exhibits some charge decay. The charges accumulating on the insulator surface can diminish by travelling through any of three paths, viz: (1) the surrounding air; (2) the electret surface; and (3) the interior of the insulator.

Surface charges could be "lost" to the air either by dispersion into the air caused by the electret's own field or due to recombination with ions existing in the air. Ieda and his collaborators showed that if the capacitance between a probe (used to measure surface potential) and surface of the electret is independent of time, then the time derivative of potential would be inversely proportional to the capacitance and directly proportional to the decay of charge into the ambient. Since the capacitance is inversely proportional to the distance, the rate of change of potential would be larger on increasing the distance from the probe to the surface of the electret if dispersion was the main decay mode. However, Ieda et al's results show the opposite effect. Therefore, charge diminution by this mechanism is very probably negligibly small.
The other alternative is that charge compensation occurs at the surface and is due to ions in the atmosphere attracted to and adsorbed upon the electret surface. This mechanism is favoured by Anderson and co-workers\textsuperscript{13} who also mentioned that charge compensation can be proved by washing in ionic solutions containing a wetting agent, IGEPAL Co-630 (a non-ionic surfactant). This wash reduced the charge level to 6% of its initial level and on subsequent rinsing in distilled water the charge recovered to 89% of its initial value. Thus, charge compensation could be responsible for the decay of charges.

Decay across the surface is thought to be insignificant by Ieda et al\textsuperscript{12} who showed that the potential decay curves for different surface resistances and sample thicknesses were identical.

For internal charge decay there are 3 possibilities i.e. diffusion, ohmic conduction and drift through the electret's own field. Again, Ieda et al's\textsuperscript{12} finding that the potential decay curves are independent of specimen thickness suggests that diminishing of charges due to diffusion is insignificant. Ohmic conduction has been shown to be insignificant by van Turnhout\textsuperscript{14} in an experiment which consisted of vibrating an electrode (for measuring charge density) over the electret which was situated in a compartment in which the temperature could be raised uniformly (at a rate 1° C/min.). Van Turnhout found that in his 2nd run of heating, the charge remained remarkably constant, namely right up to the final temperature of the first heating run. If ohmic conduction had been the main decay mode then the charge-temperature curves would bend downward at the same temperature as in the first heating run. So ohmic conduction does not appear to be the main decay mode. In mono-charged electrets the free excess charges are
believed to drift in the electret's own internal field towards the image charges and this motion is space-charge-limited and therefore called SCL drift. Charges in trap sites are believed by Perlman and Unger\textsuperscript{15} to be untrapped by both a lowering of trap depth with molecular motion plus thermal excitation of the charge out of the trap, followed by drift in the bulk of the material with the possibility of retrapping as well. Wintle\textsuperscript{16,17} has tried to propose mathematical models which combine the equation of continuity and Poisson's equation under the condition that in the system under consideration, the total current density is zero. In his early model\textsuperscript{16} surface potential was related to the mobility of the carrier and to the time after charging. According to this model surface charge should initially fall linearly to half of its initial value and thereafter fall hyperbolically. This model could then explain the "cross-over effect" that had been noticed in various charge-time curves\textsuperscript{12,28}. However the observed trend of a higher initial field due to higher electret charge density giving a higher mobility cannot be explained with this model. Wintle tried to incorporate an explanation of this phenomenon in a later model\textsuperscript{17} in which a power-law dependence of mobility on electric field was proposed. However, the resulting decay curves, even though presenting a better fit to the initial decay data, still did not predict a cross-over effect.

In the above models the assumption that all charges reside uniformly on the surface of the electret and can be represented by a delta function at the very surface has been made. Although initial charges can reside on the surface\textsuperscript{9} the charge could also penetrate into the bulk\textsuperscript{18} depending on the charging conditions (e.g. applied voltage in breakdown field charging). For corona-charged electrets,
initial charges are believed to reside on the surface with little possibility of penetration into the bulk as well. Thus in these electrets there could either be an insufficient charge deposited to fill all the deep traps in the material or a much higher concentration of such traps could exist adjacent to the surface than the bulk. The observation of considerable lateral charge motion within a few minutes of deposition suggests that the first alternative is unlikely, although it cannot be ruled out entirely. The second alternative seems to be a more likely condition particularly as deep traps adjacent to the surface could arise from damage during the charging process or from prior oxidation and mechanical handling. Although none of the models completely fit the experimental results yet, the approach seems a reasonable way in which to attempt to characterize the decay mechanism. The only possible conclusions at present seem to be that the decay of charge in mono-charged electrets could either be due to surface compensation, SCL drift, or both.

2.3 CHARGE DECAY BY X-RAY IRRADIATION

In general the effect of ionizing radiation on insulators can result in four possibilities, namely (i) ionization-induced conduction, (ii) charge transfer (iii) air ionization (iv) space charge build-up. In ionization-induced conduction in insulator materials, the primary effect of a single ionizing particle traversing an insulating material is to create a "track" along which electrons could be ejected from their bound states, or moved to an orbit of higher energy (excitation). In the former case a positively charged atom or molecule (ion) and a free electron would be left and the positive ion may react with neighbouring electrons or ions. The
free electron may either return to its parent molecule to give a highly excited molecule, or it may be captured elsewhere, giving a negative ion. Nuclear reactions would not occur until energy levels reached millions of electron volts. Charge in the traps might be released by X-rays. The charges may be retrapped again or move along to neutralize the positive ions. Charge transfer in general is caused by incident radiation either because a secondary electron has received enough kinetic energy to move significantly in a preferential direction or because an electron was created close enough to the surface of a material to escape into the air. The basic processes in air ionization are identical to those in insulators, namely electron-ion production, thermalization and motion under the electric field and density gradient. Radiation-induced space charge can result from either direct injection or defect creation and subsequent charge trapping.

Considering the above four possibilities in relation to the observed charge decay on X-ray irradiating polymer electrets it appears that space-charge formation can be ruled out as X-ray photon absorption would lead to creation of equal amounts of positive and negative charge. Air ionization would appear to be insignificant as the size of air molecules is large and penetration into the teflon polymer is improbable, although some surface recombination may take place. Indeed, the presence on the surface of ions of polarity opposite to that of the initial charge on the surface could explain the recovery process noted in dipolar electret X-ray dosimeters. Ionization-induced conduction is believed to take place in teflon material and charge transfer could also occur as there are charges residing on the surface of the electret.
3.1 ELECTRET MATERIAL

As outlined in Chapter 1 the material chosen for this work was teflon, which is known to be a very stable electret. The teflon film used was 0.004 cm thick and was obtained, complete with an evaporated aluminum film backing, from Dielectrix Corp. This material was essentially charge-free. In order to handle the material without contaminating the surface, a double brass ring holder was designed (see figure 3.1). The holder consisted of two interlocking rings with the teflon film stretched like a drumskin across the inner ring (diameter 1\(\frac{1}{4}\) in.) and then clamped tightly between the rings. The uncoated side of the teflon film formed the top surface and was thus readily accessible for charging purposes. The bottom, metal-coated surface was in contact with the inner ring but insulated from the outer ring by the teflon film itself. A teflon rod could be screwed into the side of the outer ring to form a frying-pan-type structure very suitable for handling and transporting of the electret.

![Diagram](image)

Figure 3.1: electret ring holder
3.2 CHARGING EQUIPMENT

3.2.1 CORONA-CHARGING

The corona charging apparatus is shown in figure 3.2 and consisted of a knife edge electrode (razor blade) which could be moved vertically by a micrometer screw insulated from the electrode by a polymethylmethacrylate (PMMA) block. The razor blade corners were trimmed to prevent air breakdown at the edges. The would-be electret was positioned between the brass rings as described in section 3.1 and placed on a movable PMMA bed. By rotating an insulated handle the electret could be passed under the knife edge. Care had to be taken during charging to ensure that the razor blade would be far enough away from the rim of the outer ring so that the air would not breakdown. A piece of thin aluminum foil was placed on top of the PMMA bed and was connected to ground. A resistor of high resistance (>2 Mohms) was connected to the upper electrode in order to limit the current from the voltage source.

Corona-charging can proceed with either negative or positive applied voltages. Reiser, Lock and Knight have indicated that the rate of decay of positively and negatively corona-charged electrets is about the same for the same initial charge, but as the reproducibility of the positively corona-charged electrets was apparently poor, only negatively corona charged electrets were investigated in this study.

Electrets were produced with air gaps of 0.5 mm and 1 mm at different applied voltages (4, 5, 6 kV) and with up to three passes under the high voltage electrode, with each pass taking about 20 seconds. Figure 3.3 shows the resulting charge density as a function of voltage with air gaps of 1 mm and 0.5 mm. For both air gaps the charge densities
Figure 3.2: corona charging apparatus
Figure 3.3: the dependence of initial charge density on voltage for different passes.
(x-x-x) 1 pass. (Δ-Δ-Δ) 2 or 3 passes.
(———) air gap 0.5 mm
(— — —) air gap 1.0 mm
seemed to saturate after two passes at a value higher than that for one pass by about $4 \times 10^{-10}$ coul/cm$^2$ for the 1 mm gap and $2 \times 10^{-10}$ coul/cm$^2$ for the 0.5 mm gap. Each point on figure 3.3 is the average of two or more readings and the spread of results for any given condition was about ± 10%.

Perlman and his collaborators$^8$ charged polymer films (25μ thick) by a negative corona in air with 0.5 mm gap beneath a knife edge held at 4 to 6 kV. The net charge was measured immediately after charging with a biased vibrating electrode arrangement. A maximum charge density of $14 \times 10^{-8}$ coul/cm$^2$ was obtained which was more than twice as much as the maximum values ($\approx 5.6 \times 10^{-8}$ coul/cm$^2$) obtained in our experiment. This discrepancy might have been due the presence of the slight differences in the charging systems used, e.g. sharpness of high voltage electrode, suppression of corona from high voltage connectors, or could be the result of a difference in the charging time used (2 mins. in this work, unspecified in ref. 8). Another relevant fact may be that in Perlman et al's case charge was measured as the teflon electret was passed continuously from the corona apparatus using driven spools, while in our case the electret had to be manually moved from the charging set-up to the charge-measuring instrument. For X-ray dosimetry and charge stability investigations electrets of charge density $5.5 \times 10^{-8}$ coul/cm$^2$ were produced at a voltage of 6 kV with an air gap of 0.5 mm and employing 2 passes.

3.2.2 BREAKDOWN FIELD CHARGING

Sessler and West$^10$ were the first to investigate electret formation by the breakdown field charging method and the arrangement
described here is based on their description. A high field was applied to the teflon samples (clamped to the rings as shown in figure 3.1) by sandwiching between two electrodes. The arrangement is shown schematically in figure 3.4 with the actual apparatus being shown in figure 3.5.

Figure 3.4: (A) schematic cross section of setup for charging teflon foils through application of breakdown fields. (B) schematic representation of foil recovery after charging.

A voltage (several kV) was applied to the metallized side of the teflon, resting on the soda lime glass, for different periods of time (2-20 mins) at room temperature. The glass dielectric was required in order to obtain relatively high charge densities. The air gap voltage between the surface of the electret and the dielectric support has been shown to be less as the thickness of the dielectric support increases. Therefore surface charges should remain high for thicker dielectric supports on account of the smaller air gap voltage producing less charge leakage across the air gap.
Different thicknesses of soda lime glass plate were used to investigate the above argument. After charging, the upper electrode was disconnected and the handling rod was connected to the ring. If the metallized side of the teflon was connected to ground as suggested by Sessler and West, a charge density of only $1 \times 10^{-10}$ coul/cm$^2$ was detected. This presumably was the charge remaining after electret surface leakage, which could have been considerable in our case due to the geometry of the system. Thus in this work, the metallized side of the electret was not grounded during recovery.

As shown in figure 3.5, the apparatus consisted of a grounded stage, the height of which was adjustable by a screw shaft so that different thicknesses of dielectric plate could be accommodated. The teflon and support rings were pressed onto the glass plate during charging by two hooks fastened to the two pegs. After charging the stage could be released by the release handle and would come to rest on a rubber foam bed. The whole apparatus apart from the electrodes, was made of PMMA.

The charge densities resulting from different charging periods, voltages and insulator thicknesses are shown in figure 3.6. For soda lime glass of thickness 0.057 cm a voltage of 9 kV was needed to produce a charge density of $5 \times 10^{-8}$ coul/cm$^2$; while for thicknesses of 0.108 cm and 0.156 cm voltages of 1.8 kV and 1.77 kV respectively were required to produce the same charge density (duration of application of voltage was 10 mins.) This confirms that the thicker the dielectric plate the higher the charge density would be for a given charging voltage, although a saturation effect rapidly develops. The spread in results is about ±10% which is about the same as that reported by Sessler and
Figure 3.5: breakdown field charging apparatus
Figure 3.6: the dependence of charge density on voltage for different charging periods.

- (•••) 2 minutes.
- (o-o-o) 5 minutes.
- (Δ-Δ-Δ) 10 minutes.
- (x-x-x) 20 minutes.

- Thickness of soda lime glass = 0.057 cm
- Thickness of soda lime glass = 0.108 cm
- Thickness of soda lime glass = 0.156 cm

and is almost indifferent to time.
West\textsuperscript{10}. For a dielectric thickness of 0.156 cm, an application of 2 kV for 10 minutes yielded a charge density of $5.4 \times 10^{-8}$ coul/cm$^2$ in the present experiment. This magnitude was about 3 times as low than that obtained by Sessler and West\textsuperscript{10} under similar conditions. The difference is, again, most likely attributable to slight differences in the charging apparatus used. For X-ray dosimetry and investigation of stability of charge, electrets with a charge density of $5.5 \times 10^{-8}$ coul/cm$^2$ were produced by using a voltage of 2 kV for 10 minutes and employing a soda lime glass plate of thickness 0.108 cm.

3.3 Charge Measurement

3.3.1 Introduction

In this work it was necessary to make repeated measurements of the stored charge remaining in an electret after it had been subjected to various treatments. It was therefore necessary that a non-destructive measurement of charge density be used. There are three possible methods, two of which are based on the dissectible capacitor\textsuperscript{22,23}, while the other uses optical techniques\textsuperscript{24}. The latter method, even though it is capable of high resolution and fast response, was deemed not suitable for the present work in view of the necessity to maintain an optically flat electret surface. Of the former methods, one of them, the lifted electrode method, can be divided into two categories\textsuperscript{22,25} - the small potential probe used by Fabel and Henisch\textsuperscript{2} and the induction method\textsuperscript{22}. The potential probe method, which monitors the surface potential, is not desirable in this case as the surface potential could vary due to different distributions of the charge density within the dielectric and thus not give a unique reading for a given stored charge. So, the induction method and the vibrating capacitor method would appear to be the two possible candidates. Instruments utilising each of these methods
were constructed but the vibrating capacitor method proved easier to operate and yielded more reproducible data. Accordingly, the vibrating capacitor method was used in this work.

3.3.2 THEORY OF OPERATION OF VIBRATING ELECTRODE METHOD OF CHARGE MEASUREMENT

The vibrating capacitor method used in this work is based on the technique described by Reedyk and Perlman. Essentially it consisted of two metal electrodes sandwiching the electret, which had its metallized side resting on top of the lower electrode. The upper electrode, which was some distance from the electret, could be vibrated up and down. Because of the electric field produced by the electret, the vibration generated an A.C. signal which could then be measured with either an oscilloscope or voltmeter connected between the electrodes. If a bias of suitable polarity, depending on whether the net charge density of the electret was positive or negative, was then applied to the lower electrode, the A.C. signal could be nullified. The surface charge density is then related to the bias voltage. Figure 3.7 shows the schematic cross section of the vibrating capacitor.

Figure 3.7: schematic cross section of vibrating capacitor
To calculate the electric field in the air gap, apply the line integral law to the two-layer capacitor of figure 3.7
\[ d_1 E_1 + d_2 E_2 = V \]  
(1)

where \( d_1 \) and \( d_2 \) are the thicknesses of the electret and air gap respectively, \( E_1 \) and \( E_2 \) are the electric fields in the electret and the air gap respectively, and \( V \) is the potential difference between the electrodes. From Gauss's law we have
\[ D_1 - D_2 = \sigma_r \]  
(2)

where \( D_1 \) and \( D_2 \) are the electric displacements in the electret and the air gap respectively, and \( \sigma_r \) is the real charge on the surface of the electret. By definition
\[ D_1 = P_1 + \varepsilon_0 E_1 \]  
(3)

where \( P_1 \) is the polarization response of the electret to the applied field, and \( \varepsilon_0 \) is the permittivity of free space. The polarization response \( P_1(t) \) is resolved into two components
\[ P_1(t) = P_1(t) + P_s(t) \]  
(4)

where \( P_s(t) \) is the component that responds slowly to changes in the internal field \( E_1(t) \), and \( P_1(t) \) is the component that responds instantaneously to changes in the internal field and can be characterized by a dielectric constant \( K \), i.e.
\[ P_1(t) = \varepsilon_0 (K - 1) E_1(t) \]  
(5)

In the air gap, \( P_s(t) = 0 \), and thus combining eqs. (3), (4) and (5) we have
\[ D_2 = \varepsilon_0 E_2 \]  
(6)

and
\[ D_1 = K \varepsilon_0 E_1 + P_s \]  
(7)

Finally, combining eqs. (1), (2), (6) and (7), the field in the air gap is
where \( (\sigma_r - P_s) \) is the net surface charge density. If we now apply a bias \( V = V_B \) so that \( E_2 = 0 \), eq. (8) yields

\[
E_2 = \frac{K\gamma - (\sigma_r - P_s) d_1/\epsilon_0}{d_1 + Kd_2}
\]

(8)

Thus the net surface charge density of the sample is simply related to the D.C. bias that produces zero field in the air gap, and hence zero A.C. output signal when the upper electrode is vibrated. The value of the net surface charge is theoretically independent of the air gap \( d_2 \) and frequency of vibration. The polarity of the net surface charge is automatically given by the polarity of \( V_B \).

3.3.3 CONSTRUCTION

The vibrating capacitor utilised a 5 in. loudspeaker for providing the vibration instead of using the more conventional solenoid arrangement which is heavy, bulky and prone to generation of harmonics. Since the loudspeaker could drive only a relatively light weight, the upper electrode was made of a thin printed circuit board in which was etched a circle of diameter 2 in. and an outer ring, which when grounded served as a guard ring. The circular part of a thermal foamy cup 1 in. in length was glued inbetween the printed circuit board and the speaker. This allowed the upper electrode to be removed in order to facilitate transfer of the electret. The loudspeaker could be raised or lowered by means of a shaft threaded through a sturdy aluminum box (see figure 3.8). The lower electrode, which was a circular brass plate of diameter \( 2\frac{1}{2} \) in., was glued on top of a circular teflon disc. A small groove of i.d. 3/8 in. was cut on top
Figure 3.8: vibrating capacitor
of the lower electrode and inside the teflon disc there was a duct of diameter 3/8" connected to the groove so that a vacuum pump could be used to suck the electret tightly onto the top of the lower electrode to ensure good electrical contact. The circular teflon disc was supported by three replaceable legs which allowed for considerable length adjustment if so required i.e. in excess of that which could be met by adjustment of the upper electrode. All electrical connections used coaxial cables with the upper electrode line being specially made to reduce its weight. It was made from a thin insulated wire enclosed by a stranded light steel wire which was connected to ground.

3.3.4 OPERATION

For the driving source of the loudspeaker, a sinusoidal voltage from a Wavetek (model no.111) function generator was used. The A.C. output signal, obtained by vibrating the upper electrode, was monitored by an oscilloscope. A D.C. bias of negative polarity from a Harrison 6525A D.C. Power Supply with range 0-4000 V and 0-50 mA was then applied so that the resulting oscilloscope signal could be nulled i.e. reduced to less than one tenth of a volt.

Theoretically, from section 3.3.2, eq.9 shows that the measured surface charge density should be independent of the air gap length. To test this practically the system was designed to allow variation of the air gap separation. Reedyk and Perlman also made a harmonic analysis of the electrical mesh equivalent to the circuit
Figure 3.9: The dependence of charge density on frequency for 3 differently charged electrets at various air gaps $d_2$.

- (△-△-△) (●-●-●) (△-△-△) $d_2 = 0.37$ cm
- (●-●-●) (■-■-■) (●-●-●) $d_2 = 0.42$ cm
- (■-■-■) (□-□-□) (■-■-■) $d_2 = 0.47$ cm
shown in figure 3.7 and related the output voltage $V_o$ to the circuit parameters. $V_o$ should be independent of the frequency of vibration and this prediction was also investigated using the present apparatus.

Three different charge density levels in a series of electrets were obtained by breakdown field charging at voltages of 0.5, 1.0 and 2.0 kV for 2 mins. with a soda lime glass plate of thickness 0.108 cm. The workable frequency range was found to be from 50 Hz to 70 Hz. Frequencies lower than 50 Hz were not used because the lower limit of frequency response of the loudspeaker was 50 Hz. Frequencies higher than 70 Hz tended to cause non-sinusoidal signals presumably because of excessive vibration. Figure 3.9 shows the apparent change in charge density with change in frequency for air gap separations of 0.37, 0.42 and 0.47 cm. The measured charge density seems to be independent of frequency but does show a slight dependence on air gap separation. It seems that the closer the separation, the larger the apparent charge density. In spite of this discrepancy the method of charge measurement was still suited to our purposes of X-ray dose measurement, as it is the sensitivity and relative change in charge density that are important. As a result, all the charge density measurements were taken under a fixed separation of 0.42 cm and at a frequency of 60 Hz. Within the limits imposed by these conditions the overall accuracy was ±5%.

3.4 X-RAY APPARATUS AND MEASUREMENTS

3.4. X-RAY EQUIPMENT

The X-ray machine was from North American Philips Co. Inc, model no.42201-42202, and was capable of delivering 60 kV X-rays at target currents of up to 50 mA. A copper target was used in a tube which had four windows from which ejection of X-rays could be controlled.
by opening shutters; only one window was used in this work. The area over
which the X-rays would irradiate was detected by a fluorescent phosphor
detector and marked on a mount on which the electret to be irradiated
could be fixed. Every time during irradiation the electret was placed
at a fixed distance, 27 cm, away from the window. This distance was
chosen as a compromise between being close enough to get sufficient
intensity to reduce the charge of the electret and being far enough
away to get the required area-uniformity in the X-ray beam.

3.4.2 EXPOSURE MEASUREMENT

Exposure was measured by an ion-chamber X-ray dosimeter, model
no.37C made by Electronic Instruments Ltd. A 35 c.c. chamber placed
at the site (27 cm away from the source) at which the electrets received
irradiation was used to monitor the output of the X-ray machine. This
instrument is capable of measuring the exposure rates for various X-ray
over a period of time. The measured exposure rates for various X-ray
tube voltages and currents are shown in table 1. The figures quoted
refer to a sampling time of 10 seconds and are the average of two or
more readings.

<table>
<thead>
<tr>
<th>EXPOSURE RATE / $10^2$(R/min)</th>
<th>20</th>
<th>30</th>
<th>40</th>
</tr>
</thead>
<tbody>
<tr>
<td>VOLTAGE (kV)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CURRENT (mA)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>0.96</td>
<td>1.80</td>
<td>2.58</td>
</tr>
<tr>
<td>10</td>
<td>1.56</td>
<td>3.20</td>
<td>5.25</td>
</tr>
</tbody>
</table>

Table 1: the dependence of exposure rate on X-ray tube parameters
The results seem to be reasonable as the X-ray intensity $I$, which is proportional to the exposure rate measured here, can be described by the usual equation for a continuous spectrum:

$$I = Bi(V)^n$$

where $B$ is the proportionality constant, $V$ is the tube voltage, $n$ is a tube parameter and $i$ is the tube current. The accuracy of the result is dependent on the control of the timing of opening and shutting the window and on the accuracy of the X-ray dosimeter, which is stated by the manufacturer to be ±10%.

Electrets that had been charged by the breakdown field method at a voltage of 1 kV for 2 minutes using a soda-lime glass plate of thickness 0.108 cm were tested at different radiation levels and the complete annihilation of the electret's charge was found to occur, even for the lowest energies possible, in times of around 1 minute. This time is somewhat short for the initial experimental purpose of determining the electret's charge decay as a function of radiation exposure. Locating the electret significantly further away from the machine was not viable because of constraints imposed by the room boundaries. Thus in order to make the measurement possible aluminum filters, of different thicknesses according to the X-ray energies employed, were placed in front of the electret so that the complete reduction in charge density would require times of the order of several minutes. The exposure rate corresponding to irradiation through the various aluminum shields listed in table 2 were measured by the ion-chamber dosimeter and are recorded in table 3. It can be seen that the use of the filters enables similar exposure rates to be obtained for the range of tube voltages and currents used in this work.
Table 2: The thicknesses of Al filters used for different X-ray tube voltages and currents

<table>
<thead>
<tr>
<th>Voltage (kV)</th>
<th>20</th>
<th>30</th>
<th>40</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thickness (cm)</td>
<td>5</td>
<td>0.030</td>
<td>0.041</td>
</tr>
<tr>
<td>Current (mA)</td>
<td>10</td>
<td>0.036</td>
<td>0.077</td>
</tr>
</tbody>
</table>

Table 3: The dependence of exposure rate on X-ray tube parameters when using the different thicknesses of Al shielding referred to in Table 2

<table>
<thead>
<tr>
<th>Exposure Rate (R/min)</th>
<th>20</th>
<th>30</th>
<th>40</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage (kV)</td>
<td>5</td>
<td>4.10</td>
<td>5.2</td>
</tr>
<tr>
<td>Current (mA)</td>
<td>10</td>
<td>5.63</td>
<td>5.2</td>
</tr>
</tbody>
</table>
IV RESULTS.

4.1 CHARGE DECAY OF UNIRRADIATED ELECTRETS AS A FUNCTION OF STORAGE CONDITIONS

Stability of electrets is of great concern in the applications field, whether the electret be used as a microphone, dosimeter, electrostatic lens, air filter etc. In X-ray dosimetry if the charge of the electret is not stable enough, then one may confuse the "natural" decrease in charge with that due to the X-ray dose received. Tests were carried out with electrets left under different storage conditions to see which storage condition gave the most stable electret. Besides the usual parameters of temperature, light and humidity, the effect of shielding was also investigated.

Figure 4.1 shows the charge decay of corona-charged electrets stored under different conditions. All electrets were charged to a charge density of $5.4 \times 10^{-8}$ coul/cm$^2 \pm 10\%$ and the result quoted for any given condition is the mean taken from at least two (sometimes three or four) samples. The most stable electret was the one held at room temperature in an aluminum box ($1\frac{3}{4}'' \times 1\frac{3}{4}'' \times \frac{1}{2}''$) with aluminum thickness 0.42 mm. After 5 days there was almost 30% (spread of results between similarly-treated samples was $\pm 3\%$) decrease in charge density, a result which differs from that quoted by Anderson et al. $^{13}$, whose experiment showed almost no decrease in charge density after 5 days. The reason for this difference could simply be due to the low initial charge density ($2 \times 10^{-8}$ coul/cm$^2$) of the electrets used by Anderson et al. or it may be related to the relative "air-tightness" of the two enclosures. The electret stored in the laboratory atmosphere without shielding by the aluminum box showed a fast decay (39%) in the first 5 days but a much
slower decay for the next 25 days. After a total of 30 days a decrease of 55% (spread of results ±8%) was recorded. Anderson et al. 13 found a 45% decrease in charge density density in 30 days, and again this lower figure could be due to the lower initial charge density employed. A decrease of 37% (spread of results ±4%) in 30 days was recorded for the electret stored in the aluminum box at 36°C, and this was about the same decay rate as that for electrets stored in a 14" x 7" x 7" cardboard box instead. An electret stored in the aluminum box at 100% R.H. (relative humidity) shows a decrease of 45% over a period of 30 days.

Figure 4.2 shows the results for electrets charged by the breakdown field method when tested under the same storage conditions as used for the corona-charged electrets. All electrets were charged to 5.75×10⁻⁸ coul/cm² ±10%. Again the most stable electret was the one stored in the aluminum box at laboratory atmosphere. A decrease of only 8% (spread of result ±5%) was recorded after 5 days; after a total of 30 days the charge only decayed by 11% (spread of result ±5%) which was less than that of the best corona-charged samples. The decay observed by Sessler and West 10 was about 50% and this would be most likely due to the high initial charge density (about 5×10⁻⁷ coul/cm²) they used. Higher charge density electrets were not used here because of the insulation limitation imposed by the cable connectors of the D.C. bias voltage source used in the charge density measurement; also we wished to compare the decay with that of corona-charged electrets. Again the electret stored in the laboratory atmosphere without the aluminum box showed the fastest decay (36% in 30 days with spread of result ±8%). It seemed that the electret stored in the dark without benefit of the aluminum box decayed less than the electret stored in
Figure 4.1: charge decay for teflon electrets, corona-charged, stored under different conditions.

(Δ-Δ-Δ) stored in Al box at lab. atm. (○-○-○) open at lab. atm.
(●-●-●) stored in Al box at 36°C. (■-■-■) open in dark
(×-×-×) stored in Al box at 100% R.H.
Figure 4.2: charge decay for teflon electrets, charged with breakdown field under different conditions.

(Δ-Δ-Δ) stored in Al box at lab. atm. (o-o-o) open at lab. atm.
(○-○-○) stored in Al box at 36°C. (●-●-●) open in dark
(x-x-x) stored in Al box at 100% R.H.
the aluminum box at 36°C. The electret in the aluminum box at 100% R.H. decayed 33% (spread of result ±20%) in 30 days which was 12% less than that shown by the corona-charged electrets over the same period of time.

4.2 CHARGE DECAY OF IRRADIATED ELECTRETS

All electrets used in the X-ray irradiation studies were left in air for more than 5 days after charging in order to allow the initial rapid charge decay to occur and the electrets to "stabilize". Figure 4.3 shows the decrease in charge density versus the exposure received. For a given X-ray exposure, the decrease in charge density is slightly greater at the higher values of X-ray energy. Similar results were found for the breakdown field-charged electrets and are shown in figure 4.4 The exposure ranges used for the corona-charged and breakdown-charged electrets were 1-14 R and 1-17 R respectively.

Figure 4.5 shows the dosimetric response for electrets, corona-charged, when using different thicknesses of aluminum shielding. Because of the thicker aluminum shielding used for higher energy X-rays (see table 3), higher exposure of higher energy X-rays are needed for a given electret charge reduction. The possible exposure range depends, in fact, on the thickness of shielding used. The decay of charge density versus exposure curves shown in figure 4.6 are for the breakdown field-charged electrets. Doses about 400 R higher than used with the corona-charged electrets were possible due to the higher initial charge of the breakdown-field-charged electrets. The range of exposure was around 1-16x10² R and 1-20x10² R for the corona- and breakdown field-charged electrets respectively.

In order to test whether the X-ray-induced charge decay of the electrets was due to charge compensation, a test as mentioned by Anderson et al.¹³ (see sec.2.2) was carried out. An electret after X-ray irradiation had its
Figure 4.3: Dosimetric response for teflon electrets, corona-charged and irradiated without Al shielding.

- (Δ-Δ-Δ) 20 kV 5 mA
- (○-○-○) 20 kV 10 mA
- (□-□-□) 30 kV 5 mA
- (●-●-●) 30 kV 10 mA
- (△-△-△) 40 kV 5 mA
- (◆-◆-◆) 40 kV 10 mA

The graph shows the decrease in percent of charge density as a function of X-ray exposure (R).
Figure 4.4: dosimetric response for teflon electrets, breakdown field-charged and irradiated without Al shielding.

- (Δ-Δ-Δ) 20 kV 5 mA
- (○-○-○) 20 kV 10 mA
- (□-□-□) 30 kV 5 mA
- (●-●-●) 30 kV 10 mA
- (Δ-Δ-Δ) 40 kV 5 mA
- (■-■-■) 40 kV 10 mA
Figure 4.5: dosimetric response for corona-charged teflon electrets irradiated through Al shielding.

- ($\Delta-\Delta-\Delta$) 20 kV 5 mA
- (o-o-o) 20 kV 10 mA
- (o-o-o) 30 kV 5 mA
- (o-o-o) 30 kV 10 mA
- ($\Delta-\Delta-\Delta$) 40 kV 5 mA
- (o-o-o) 40 kV 10 mA
Figure 4.6: dosimetric response for breakdown field-charged teflon electrets irradiated through Al shielding.

- (Δ-Δ-Δ) 20 kV 5 mA (o-o-o) 20 kV 10 mA (o-o-o) 30 kV 5 mA
- (o-o-o) 30 kV 10 mA (Δ-Δ-Δ) 40 kV 5 mA (■-■-■) 40 kV 10 mA
charge density reduced to 10% of its initial value when washed by a non-ionic surfactant, monophenoxy-polyoxy-ethanol, (IGEPAL Co-630) diluted by tap water. After this washing procedure zero charge density was recorded. Then the electret was rinsed twice with distilled water. A charge density of $1.1 \times 10^{-8}$ coul/cm$^2$ was recorded i.e. 20% of the initial charge density might have been recovered. However, subjecting electrets, without X-ray irradiation possessing a charge density of $5.5 \times 10^{-8}$ coul/cm$^2$ to the same procedure, again yielded the same charge density of $1.1 \times 10^{-8}$ coul/cm$^2$. In fact teflon, possessing no charge, was tested with the same procedure as above and became charged to the same charge density of $1.1 \times 10^{-8}$ coul/cm$^2$. As a result the test performed by Anderson et al.$^{13}$ is inconclusive and the method used could in fact cause charging of the electret. Anderson et al.’s$^{13}$ quote of an 89% recovery probably is due to the fact that their samples had only a very low initial charge density ($\sim 2 \times 10^{-8}$ coul/cm$^2$). All tests and results were averages of 2 or more samples and the spread of results was ±25%.

4.3 RESIDUAL CHARGE VERSUS DOSE AS A FUNCTION OF STORAGE CONDITIONS:

In order to further see whether the teflon electret dosimeter might be of any practical value, a series of tests of residual charge retentivity versus exposure as a function of storage conditions was carried out. The procedure used was to irradiate the electret at a given X-ray energy for 1 minute, measure the residual charge, store the electret under a variety of conditions for 1 day, remeasure the residual charge and then repeat the sequence until nearly all the charge had been destroyed. Different electrets were irradiated at different X-ray energies. The results are summarized in figures 4.7 - 4.12. As was to be expected from the results reported in section 4.1 and by Anderson et al.$^{13}$, storage in high temperature ($36^\circ$C) and/or high humidity (100%) conditions
DECREASE IN CHARGE DENSITY

Figure 4.7: Dosimetric response for Geiger-Müller, corona-charged, and irradiated through Al shielding. After every day of irradiation, stored in Al box at lab. atm. for 1 day.

X-RAY EXPO/% (R)
Figure 4.8: dosimetric response for teflon electrets, charged with breakdown field and irradiated through Al shielding. After every irradiation electret store in Al box at lab. atm. for 1 day.

(Δ-Δ-Δ) 20 kV 5 mA (o-o-o) 20 kV 10 mA (□-□-□) 30 kV 5 mA
(●-●-●) 30 kV 10 mA (Δ-Δ-Δ) 40 kV 5 mA (■-■-■) 40 kV 10 mA
Figure 4.9: Dosimetric response for sцинotron electrons: corona-charged.
Figure 4.10: dosimetric response for teflon electrets, corona-charged, and irradiated through Al shielding. After every irradiation electret store in Al box at 100% R.H. at 23°C for 1 day.

- (Δ-Δ-Δ) 20 kV 5 mA
- (○-○-○) 20 kV 10 mA
- (△-△-△) 30 kV 5 mA
- (●-●-●) 30 kV 10 mA
- (●-●-●) 40 kV 5 mA
- (□-□-□) 40 kV 10 mA
Figure 4.11: dosimetric response for teflon electrets, charged with breakdown field, and irradiated through Al shielding. After every irradiation, electret store in Al box at 36°C for 1 day.

$(\Delta - \Delta - \Delta)$ 20 kV 5 mA $(\circ - \circ - \circ)$ 20 kV 10 mA $(\sigma - \sigma - \sigma)$ 30 kV 5 mA $(\Theta - \Theta - \Theta)$ 30 kV 10 mA $(\Delta - \Delta - \Delta)$ 40 kV 5 mA $(\sigma - \sigma - \sigma)$ 40 kV 10 mA
Figure 4.12: dosimetric response for teflon electrets, charged with breakdown field, and irradiated through Al shielding. After every irradiation electret store in Al box at 100% R.H. at 23°C for 1 day.

- (Δ-Δ-Δ) 20 kV 5 mA
- (o-o-o) 30 kV 10 mA
- (Δ-Δ-Δ) 40 kV 5 mA
- (o-o-o) 40 kV 10 mA
led to rapid charge decay. Storage in other environments produced charge
decays which were small in comparison. For all cases the charge decay
on storage decreased greatly as the magnitude of the residual charge
decreased.

All electrets after the final irradiation were left in their
respective environments for 6 days and no recovery were found, only
slight decays (less than 2%) were observed.
V DISCUSSION

The two methods of electret formation used in this work have proven easy to implement and have yielded electret samples of uniform charge density with magnitude up to $6 \times 10^{-8}$ coul/cm$^2$. Higher charge densities are undoubtedly possible but were not tried in this work owing to the modifications that would have been necessary to the bias circuit of the charge measuring instrument in order to measure the charge.

From the results of the charge decay of unirradiated electrets it appears that storage in an aluminum box greatly enhances charge retentivity, which agrees with the findings of Anderson et al.$^{13}$ The aluminum box presumably prevents atmospheric electromagnetic radiation from interacting with the electret i.e. limits the ion-pairs created and also stops these energy sources from exciting molecules within the teflon material, thus causing detrapping and assisting the charges to drift at a faster rate. Charge decay curves showed that electrets charged by the breakdown field method yielded a higher "final" charge density than that of corona-charged electrets when both sets of samples were charged to about the same initial charge level; also the charge-decay rates were not the same for the two charging methods. This latter difference would suggest that charge removal due to surface ion compensation was not the sole mechanism of charge decay, providing, of course, that the nature of both the charges and the traps were the same for samples prepared by both charging methods. Again with this latter proviso, it does not appear that charge decay by SCL drift is the only mode of charge loss as such a mechanism would lead to "stabilized" charge levels of similar magnitude for samples charged to similar initial levels. Thus, on the basis of the charge-decay measurements
it is not possible to enumerate the relative magnitudes of the contributions from surface-ion recombination and SCL drift, nor can it be unequivocally stated that the trapped charges and their trapping sites are the same for both methods. High temperature and high relative humidity both speed up the decay of electret charge. The temperature increase would cause thermal excitation and charge detrapping; in fact, the technique of TSC (thermally stimulated currents) relies on this mechanism. The mechanism of decay enhancement on account of high relative humidity is not well-defined even though the effect has been known for a long time. Presumably the effect is related to water condensation on the electret surface, thus providing short circuiting leakage paths. The electrets fabricated in this work were stored in the open circuit condition; while for dipolar electrets the short circuit condition is invariably used. Short circuiting the homopolar electrets leads to a rapid annihilation of the electret charge, as is perhaps to be expected from the fact that the charge apparently resides at, or very close to, the surface.

The results of the X-ray irradiation studies showed that electrets formed by both methods of charging showed a linear response of charge decay to X-ray exposure when the decrease in charge density was 70% or less. A dependence of the charge decay on X-ray energy cannot conclusively be inferred from the data (fig. 4.3 and 4.4) owing to the limited accuracy of the measurements, however some dependence may be expected and this fact would lead to a slight limitation in the event of practical implementation of electret dosimeters, namely some confusion as to the actual exposure received would result in cases where there was exposure to X-rays of widely different energies.
Fabel and Henisch\textsuperscript{2} found for 50 kV X-rays the working exposure range (governed by the rate of charge decay) was $1 - 10^4$ mR. Homopolar electrets used in the present work were only studied over the range $1 - 15$ mR, but presumably are sensitive also in the milli-R region. These figures refer to unshielded electrets and the exposure would appear to be of the right magnitude as far as personnel dosimetry is concerned. For example, the maximum permissible dose (for the skin of the whole body) of ionizing radiation is about 30 rads ($=33$ R)\textsuperscript{*} in any period of 52 consecutive weeks and for the whole body blood-forming organs and eyes is about 3 rads ($=3.3$ R)\textsuperscript{*} in any periods of 13 consecutive weeks\textsuperscript{27}. Extension of the maximum dosage range to around 1600 to 2000 R was shown to be possible by the use of aluminum shielding. Complete dosimeter fabricated in this fashion would have the advantage of better storage properties but would only be accurately effective in monoenergetic X-ray environments.

In Fabel and Henisch's\textsuperscript{2} recent work on polymer, dipolar electret dosimeters a charge recovery of 5\% after 500 storage hours was found. In the present work no such recovery was ever observed even after storage at $36^\circ$C and 100\% R.H. for 150 hours. Only a slight charge decay (less than 2\%) was observed. Breakdown field-charged electrets were generally slightly more stable than corona-charged electrets, but the former electrets performed very badly in environments of high humidity. As a result corona charged electrets would be perhaps be more preferable to breakdown field charged-ones in X-ray dosimeter application\textsuperscript{5}.

\textsuperscript{*}The conversion from the stated absorbed dose in rads to an equivalent air exposure in roentgen was made assuming a value of 0.9 for the conversion factor\textsuperscript{29}. 
CONCLUSIONS

Corona- and breakdown field-charging have been found to be simple methods for producing semi-permanent charge densities in metal-backed teflon films. The decay of electret charge is greatly affected by the storage medium, but can be much reduced by enclosing the electret in a box.

The electrets prepared in this work appear to be useful as possible X-ray dosimeters with attractive features being:-

(1) charge decay is linear with X-ray exposure rate (up to a loss of 70% of the initial charge),
(2) no recovery in electret charge between radiation exposure (at least over radiation intervals of 6 days),
(3) simple non-destructive read-out procedure,
(4) suitability to personnel dosimetry in that doses of health hazard proportions are easily detectable and the material used is compatible with human tissue as regards absorption properties.

The undesirable features that need to be remedied or allowed for in order to permit widespread use are:-

(1) possible slight dependence of charge decay on X-ray energy level,
(2) rapid decay in hot, humid and / or unshielded environments.
BIBLIOGRAPHY


