CHAPTER III

THAMO - ELECTRO
3.1 INTRODUCTION

There are certain theories which have been proposed by workers in the field of electret to explain the well established experimental results. But none of them has been found satisfactory. All existing theories or explanations are an attempt to explain the following:

(a) Formation of hetero and homo-charges.
(b) Longer life of the electrets.
(c) Phenomenon of charge reversal.

Surface charges of electret as that of the polarity of electrode in contact, are called homo-charges while opposite to it, are called hetero-charges (1). From Maxwell's theory it was believed that dielectric could neither sustain a persistent polarisation nor persistent surface or space charges. But in practice, charges have been found and polari-
sation thus produced is out of phase with field (2). The investigation of both is important to understand the dielectric behaviour and their structure.

First of all Adam (3) proposed a theory to explain the nature of the thermo-electret state. According to his theory, hetero-charges are due to internal field caused by dipole orientation only and homo-charges due to free charges held in position by internal field. Free charges decay by ohmic conduction, while the internal polarization decay exponentially. Failure of the theory indicates that the dipole orientation alone is insufficient to explain stability of the thermo-electret homo-charges.

Gemant (4) assumes two different mechanism to explain the development of homo and hetero-charges. The hetero-charge has been considered as an ionic effect due to displacement of ions and dipole orientation both, and homo-charge as due to the piezo-quadrupole charges as a result of freezing-in of transverse stresses in the oriented dipoles during cooling. Good et al.(6,6,7) observed independence of the magnitude of homo-charges from the stresses frozen into the electret. Thus they challenged the validity of Gemant's hypothesis of homo-charge. Explanation of homo-charge on the basis of contact electrification were also not successful.

According to Baldus (8) hetero-charge is due to "Freezing-in" of induced dipoles produced by external field. But his explanation is not very convincing. Thiesse et al(8)
gave the idea of mechanism (a) internal polarisation (b) external polarisation. Presence of hetero-charges are supposed due to ions displacement (internal polarisation) and homo-charges are due to external polarisation (due to the breakdown of air gap between the dielectric surface and electrode). Charge reversal was explained due to superposition of one type of charge over the other.

Gross (9-13) gave a new idea about the thermo-electret formation and origin of homo and hetero-charges. According to him hetero-charges are due to (a) hindered dipole orientation associated with rotation of dipole systems (b) displacement of ions over microscope distances in a microscopically heterogeneous structure giving rise to Maxwell - Wagner effect and (c) ionic conduction associated with the formation of space charges while homo-charges due to break-down of the interface between the dielectric and electrode material. According to Gross, the transformation of hetero-charge into the homo-charge is due to a more-rapid decay of the intrinsic hetero-charge in comparison to intrinsic homo-charges. The transformation may be checked at low temperature as the decay of the intrinsic hetero-charge is thermally induced. In case of P.V.A. (Poly Vinyl Acetate), Wiseman and Linden (14) have confirmed the two charge theory of Gross. Bogratiiskii and co-workers (15) explained the electret effect in non-polar dielectric by a relation-ship between the formation of colour centres at the shottky defects and the electret surface charge.
Taking the help of Gross's idea, Swann (16) extended Adam's theory. According to it certain distribution of real charges decay in accordance with ohmic law and distribution of internal polarisation named as "Semipermanent polarisation" decays exponentially. They are the main controlling factors of thermo-electret state. He also explained the charge reversal.

This theory explains successfully the case of dielectric with poor conductivity specially in the substance showing semipermanent polarisation due to dipole orientation. But in case of dielectric with high electrical conductivity, where the formation of hetero-charge is supposed due to ionic or electronic mechanism the theory is a failure.

Very recently Hanerck (17-21) gave a theory which speaks against the hitherto considered theories of simultaneous build-up of a real hetero and homo-charges during the polarisation process. According to this theory homo-charges in a thermo-electret do not develop during the polarisation. Heterocharges are produced during the polarisation, they contain the ionic and dipole components. This theory is supported by the Antenen (22) paper. The reversal from hetero to homo in thermo-electret made of nonpolar dielectric (23) can not be explained by this theory.

Gerson and Ahrhbraugh (24) worked on the non-polar materials and they ruled out dipole orientation as the origin of hetero-charge. They assume that hetero-charge is formed due to localisation of electrons in deep traps. A method of preparation of electret under X-Ray irradiation was suggested by them.
Belyaev et al. (25) worked on naphthalene and confirmed the Gerson and Kobbraugh hypothesis. Behaviour of naphthalene electret (thermo-pho- to) has again supported the Gerson and Kobbraugh hypothesis.

Thus in the present investigation the electret properties of \( \beta \)-Naphthol which is a derivative of naphthalene have been studied to understand the mechanism of electret formation. The investigation of electret behaviour requires a suitable method for preparation and preservation of thermo-electret and a method for surface charge measurement. Choice of method varies somewhat with the type of material and nature of the study.

3.2 GENERAL METHOD OF THERMO-ELECTRET PREPARATION

A dielectric material in the shape of a pellet, whose surface is free from cracks and other defects, when subjected to a d.c. electric field at an elevated temperature for a certain period, turns into a thermo-electret. Physical parameters together with the applied field and the thermal treatment play an important role in the formation of thermo-electret.

Polarisation of the dielectric is obtained even when the dielectric is subjected to a d.c. field at room temperature (5, 26, 27). But it was possible only under suitable conditions and the electrification of the electret thus formed is always weak. Thermal treatment in the presence of electric treatment, improves the permanency of electrification of the electret.
greatly. Many workers (10,11,27,28,29) prepared the thermo-electret at the temperature much below the melting point, but best electret are obtained when D.C. field is applied at the time when dielectric is in fluid state. Reproducible results have been obtained when the electrets were prepared at temperature a few degree below the melting point (30). No significant change was obtained at the temperature above melting point (31).

It was observed that the characteristics of thermo-electret are affected by the rate of cooling of dielectric under D.C. field (6). Charge density decrease in both cases, when the polarising field is either removed before complete solidification or is kept for too long a time after polarisation (32).

Keeping these preparation conditions in view thermo-electrets of organic and inorganic materials (6,7,8,33, 34-39) have been prepared. It was found that the condition for the best results, differs slightly from material to material.

3.3 **Preparative Parameters**

Properties of polarised samples depend on various parameters which are involved in the preparation. The following are the important parameters -

(a) Electrode material.
(b) Temperature.
(c) Thickness of the sample.
(d) Time of polarisation.
(e) Polarising field.
(f) Pressure.
(g) Mixture.
Some of them are discussed below:

(a) **Electrode material**

Homo charge appears only in the presence of metallic electrode and it can be totally suppressed by using non-metallic electrode. Type of contact (40) and electrode material decide the nature of charge carriers.

Type of contact either ohmic or rectifying, depends upon the work-function of electrode material and the substance taken under study. Thiessen (5) used nickel and tin as electrode separately in the case of wax and found that the order of magnitude of charge in the tin was greater than that of nickel. In camel sealing wax (41) magnitude of homo-charge varied with the electrode material when other parameters were invariant. Many workers (6, 8, 42) recommended the tin as a most satisfactory electrode material. It shows less evidence of electro chemical activity than other materials. Beldus (8) and Wagner (43) investigated the influence of electrode material and found variation in charge density with the electrode material.

(b) **Temperature**

The effect of temperature on the behaviour of polarised sample has been discussed in section (3.2) of this chapter. A relation between the hetero-charge and the temperature at which polarisation takes place has been reported by Froissan and Fridkin (42).

\[ q = q_0 \exp \left( - \frac{\Delta}{kT} \right) \]  

--- (3.1)
where \( a \) is the activation energy
\( \phi = \) Final charge
\( \phi_0 = \) Charge at 0°C

(c) **Thickness of the sample**

Schumann (44) found that the transition time for surface charge from hetero to homo-charge is a function of thickness of the sample. Sharma (45) has worked on sealing wax and found an increment in initial charge with thickness, while final charge remained unaffected. On the other hand, Mathew (46) and Khanna (47) have observed an increase in final homo-charge with thickness. Bhattacharya and Bhawalkar (48) have reported at 30% increase in charge when the thickness exceed 1 mm. and at polarising fields which exceed 10 kV/cm.

(d) **Time of Polarisation**

Time period during which the sample is kept at higher temperature under electric field and cooling time, are the parameters which are considered for time effects.

If a sample under the applied field is cooled rapidly by adding ice water, it does not form electret (6). Good and Stranathan (7) found the effect of cooling time on the charge density. Keeping the sample at elevated temperature for a short time, delayed the charge reversal. Yanson (49) found that initial charge depends appreciably on the rate of cooling. Discontinuous rise in charge with polarising time was reported by Gross (9). On the other hand, polarising time does not affect the electret.
behaviour (80). Duration of short circuiting and delay in short
circuiting also affect the properties of electrets.

(a) Polarising Field:

Transition time from hetero to homo-charge depends
directly on the polarising field and is reduced as the field
strength increases. The magnitude of discharge current of thermo-
electret is directly proportional to the polarising field.
Johnson (33) and Shatnagar (61) have reported the good results
are obtained when the magnitude of polarising field is above
10 kV/cm.

3.4 Present Method of Preparation of Thermo-electret:

Keeping in view all previous mentioned parameters, a
proper method was selected and accordingly an apparatus was
designed for the preparation of thermo-electret of β-Naphthol.
The description of apparatus and method for preparing the
thermo-electret are as follows:

(a) Assembly for the preparation of sample and thermo-electret:

Assembly used in the present investigation for the
preparation of thermo-electret of β-Naphthol is exactly the
same as used for the preparation of sample used for the study
of electrical conductivity. The assembly used in the present
work was somewhat different from that one which was used by
many workers in this laboratory, while designing this assembly
special care has been taken for applying uniform pressure on
the sample and this resulted in a samples with good surface
finish. The description of different parts of this assembly
has already been given in chapter II.

(b) **High Voltage Source**:

Fluctuations and instability in D.C. fields are
some of the factors which must be avoided, while preparing
thermo-electrets. To ensure stability of voltage and to
eliminate the possibility of fluctuation, ten ninety volts dry
batteries were used as a high voltage source.

(c) **Temperature control**:

The same thermostat was used in the present
study which was used in the measurement of electrical condutci-
ity. Description of this thermostat has given already in
chapter II.

(d) **Preparation of thermo-electret**:

Samples of β-Naphthol of thickness .6 mm. were
prepared in a similar manner as was done for measurement of
electrical conductivity. β-Naphthol filtered by glass wool was
used for preparation of samples.

A fresh and fine sample was placed in the assembly
with a freshly planed and smooth metal (tin) foil as electrodes
which were cleaned by Benzene. Complete assembly with sample is
heated for one minute on each side, so that there are no air
bubbles between the electrode and the surface of the sample.
This ensures an ideal contact between the electrode and the
surface of the sample.
Now the assembly with the sample is transferred to the thermostat. The assembly must be placed on a glass plate to avoid the short circuiting of two electrodes of the assembly. In thermostat, the assembly is allowed to attain a steady temperature. When the sample along with the assembly has attained the constant temperature, the D.C. field is switched on. Electric field is applied for four hours and is maintained at elevated temperature then the assembly is allowed to cool in the thermostat for six hours under the field. In this time, it cools down to room temperature. After the completion of ten hours polarisation period the field is switched off and the assembly is taken out from the thermostat. The metal foils are then gently separated from the spacer mica frame carrying the thermo-electret.

The surface charge of the thermo-electret thus prepared is then measured.

3.5 PRESERVATION OF THERMO-ELECTRET

The life of thermo-electret depends on the condition of its storage and on the nature of the material used. But the surface charge of electret is affected very greatly by the atmospheric conditions and seasonal changes. If an electret is exposed to atmosphere with humidity exceeding 80%, it is neutralised permanently (52). If the humidity is below 80%, charges will disappear temporarily and may again appear on drying (1, 53). Dry weather is suitable for the preparation and charge measurement
of electrets. For preservation they are kept in a desiccator with dry calcium chloride and freshly greased sides. Decay of electret charge is attributed to motion of free charges in thermo-electret under the action of its internal field (27, 54). Short circuiting of the electret reduces the internal field to a very small value because it is partly compensated by the charges induced at the electrodes and depolarisation is avoided considerably. The method of short circuiting the electret is illustrated in fig. (2.1). The electret which was prepared in the mica casket was wrapped in a tin foil. This tin foil was planed first and cleaned with benzene. To ensure a better contact between the tin foil and the electret surface, two cotton lined card board pieces of the same size as the sample are used on each side, and kept in position with the help of rubber bands. Strong stability was observed in some of inorganic material even with out short circuiting by Gubkin & Skanavi (55).

3.6 General Method of Charge Measurement:

Different methods (56-62) are available for surface charge measurement of electrets.

A method has been developed by (59-63) for continuously recording the electret charges. This method is based on the principle of electro static induction. Induction plates are raised by solenoids whose induced voltage is due to the field of electret. The induced voltage is filtered and amplified then applied to a recorder. The induction plates are automatically shorted when these are out of actual measurements.
Binder (64) developed a powder method to study the distribution of homo-charge on the surface of electret. Arzenan (68) measured the field and charge distribution as a function of time. This method is known as potential probe method.

In electron beam method (62) pulsed beam is made to fall on the dielectric surface. In this method decay can also be measured along with the charge density. A new method of measurement of surface charge density using electron beam has been devised very recently (65).

Jaeger (66) determined the distribution of space charges by dropping the samples into a Faraday cup. Dissectible capacitor is an improvement over it. It makes use of induction method.

Numerous workers (67 - 72) used this method in the measurement of surface charge of electrets or their fields. Electret is kept between two electrodes which are short circuited. One of them is fixed and one is lifted over it and connected to an electrometer. The charges spreading over the surface of sample in contact with the mobile electrode induce opposite charges on it. This induce charge is transferred to the electrode which is connected to an electrometer. Such a device is called a dissectible capacitor. It was described first by Benjamin Franklin. It is widely used for the measurement of contact potentials, static surfaces charges (39, 59) and surface states in insulator and semiconductors (68). A method almost similar to that of the electrostatic method has been used. In this
method the electret is placed on a grounded electrode and moved under a measuring electrode which is connected to an electrometer (73 & 74).

In another method the discharge current of electret was recorded which produced during depolarisation. Integration of the discharge current with respect to time gives charges. Thermal release method is preferable for quick observations. The electret should be heated slightly above the forming temperature (9,13,42,75,76).

Most of workers have used the electrostatic induction method using lifted electrode technique and method of depolarisation current measurement.

3.7 Present method of surface charge measurement:

In the present investigation the electrostatic induction method with lifted electrode technique has been found suitable for surface charge measurement. Mode of decay and tendency to persist with time can also be studied beside the measurement of density of surface charge. The apparatus and method used for charge measurement in the present work are given below:

(a) Charge measuring electrode assembly:

The basic principle of the charge measuring assembly used in the present studies, is the same as that of Gemant (1) and Gross (9). To describe it briefly, it consists a fixed electrode which is earthed and on which the electret rests. The upper
electrode is connected to a moving system. It is made first to touch the surface of the electret and then lifted to a constant height for the measurement of charge by induction.

The body of the assembly is a hollow brass cylinder having a outer diameter 10 cm. and from the lower part of it a portion of area 6 x 7 cm. cut out for a window. It is for convenience of inserting the electret. Upper and lower side of the cylinder are closed by brass plane sheets.

The lower fixed electrode is made of brass in the form of a circular disc 5 cm. in diameter and 4 mm. in thickness. It is fixed at the centre of the bottom of the assembly. This electrode is always kept earthed. The upper electrode of area 0.5 sq.cm. in the form of circular disc is also made of brass and attached to a long rod of 16 cm. in length and 6 mm. in diameter. To enable the lifting of the electrode, spring mechanism was devised. For the effective working of the assembly, two springs are kept on the both sides of a collared brass sheet. This rod is threaded at both the ends. It is screwed to a ebonite cylinder carrying the upper electrode at its lower end. An ebonite knob is screwed at the top of the brass rod for the convenience of handling. The connection of upper electrode is made to a terminal on the body through a shielded wire. This terminal is electrically insulated from the rest of the system by ebonite screw which is screwed in the brass cylinder.

The actual measurement of the surface charge was performed in the following way. The electret after removing the
short circuit was kept over the lower electrode. The measuring (upper) electrode was connected to a key system where it can be connected either to earth or to the electrometer as desired.

To measure the electret charge the upper electrode was pressed downwards and was arrested by a clamp in fig. (3.2). This compresses the upper spring to make it in effective. At this position the upper electrode is earthed immediately and is kept as such for one minute. As soon as the clamp is slightly turned out, the upper electrode is released and is lifted up quickly always up to a constant height depending upon the tension in the spring.

As the upper electrode is released, it is connected to the electrometer simultaneously. The charge induced on the upper electrode is transferred to the electrometer needle through a shielded wire as the upper electrode released. Needle of the electrometer receives a kick and is deflected.

(b) **Lindemann Electrometer**:

Lindemann electrometer is used for measuring the surface charges. This electrometer was manufactured and supplied by Cambridge Instrument Co. Ltd., London and it is shown in fig. (3.3).

The principle on which the instrument works is similar to the principle of quadrant electrometer. There is a slight difference between the two. In case of Lindemann electrometer the potential to be measured is applied to fixed system. The theory of operation of the instrument has been fully described.
Fig. 3. - Lindemann Electrometer.
by its designer (73). The period, which is less than one second and the capacity which is less than 2 cm. are the two important features of the Lindemann electrometer.

A brief sketch of structure is given below:

The quadrants are 1.5 cm. broad and one cm. high, with a slot of 2 mm. wide into which the needle may pass, cut in each. These plates are mounted 5 mm. apart on quartz rod. Needle is placed between the plates with the help of torsion fibre, so that the junction of the needle and torsion fibre is symmetrically located with respect to the four plates.

The needle is usually about 1 cm. long and the torsion fibre is 6 \( \mu \) in diameter. The needle and the torsion fibre are covered with a conducting coating of metal. The fixed potential is applied to the pair of quadrants by means of terminal "A" and "B", and the unknown potential to be measured is applied to the needle through terminal "C". The body of the electrometer is connected to the earth through the terminal "D" to eliminate the effect of stray electrostatic field. These terminals A, B, C & D are shown in Fig. (3.4).

At E a small cylindrical chamber is provided which contain the dry crystals which are used to absorb moisture from inside the instrument.

(c) Pneumatically operated earthing switch:

\[ ^{\text{74}} \] The earthing of the needle is made by connecting the needle to the earth directly through a key. There is an
another method of earthing the needle. It can be done with the help of Pneumatically earthing switch illustrated in fig. (3.5). The switch is shielded electro-statically and adds but slightly to the capacitance of the electrometer. The switch is operated by pressing a rubber bulb, thus preventing any movement of observer's hand being communicated to the electrometer. The electrometer is fitted with a bush A, through which passes an insulator carrying the needle terminal B and over which is fitted a short length of brass tubing to shield the lead in. When fitting the earthing switch, this shield is removed and replaced by the tubular body of the switch while the distance piece "E" takes the place of the terminal head. When rubber bulb is pressed, the rubber diaphragm "D" is depressed against a light spring, bringing the pin head "H" into contact with "S" and thereby earthing the needle. On releasing the bulb, the switch is opened. The construction avoids thermo-electric effects and satisfactory results are obtained at the highest sensitivities possible with the Lindemann electrometer.

(d) **Portable Projector for Lindemann electrometer** (79):

A Cambridge portable projector is used for observing the movement of the needle. A bracket carrying the Lindemann electrometer, a prefocused lamp, and an optical system to project a magnified image on a screen are the main parts of the portable projector. The scale on the screen is divided in the millimeters and zero lies in the middle.
The lamp is supplied from the power supply unit by connecting the connecting leads on the projector to the terminal marked "Lamp Supply". The lamp under the removable housing E is a 12 volt 24 watt horizontal filament type fitted into a special prefocous flange so that it can be inserted only in one position.

Four clips are provided with the main bracket, two of which have adjusting screws and the remaining two are spring loaded. Electrometer is adjusted in the centre with the help of these four clips.

Focusing knob is provided for the purpose of focusing the needle on the screen. The magnification in the projector is 100 x 1. In order to bring the needle back on the scale the focusing knob is pulled and out to conjunction with turning the adjusting screw until the needle of the electrometer is located on the screen D. During the setting up of the electrometer the needle and the plate terminals are earthed so that the system rests at its natural mechanical zero.

(a) Lindemann electrometer power supply

Ordinary battery is unable to supply a constant voltage for a long time. Thus a power supply was developed to facilitate the use of the Lindemann electrometer for long period. The voltage supplied by this power supply was free from the long term inconstance of the ordinary battery supply. The instrument consists of a highly stable voltage supply obtained from ordinary mains supplies.
The power supply makes use of a voltage reference tube 85 A₂ which enables a stabilized voltage of approximately 80 volts to be applied to a potential divider network. A control enables the efficiency of the stabilizing circuit to be easily tested. The quadrant voltage is applied through a coarse and fine potentiometer circuit enabling the sensitivity to be critically adjusted near the point of instability and is arranged so that the electrical zero does not appreciably alter as the quadrant voltage is varied.

A fine control is to adjust the electrical zero has been provided. A shorting switch has also been provided, so that the electrical and mechanical zeroes may be checked and set independently without altering the main controls.

In the setting of power supply the coarse and fine voltage controls are fully turned anticlockwise and mains switch is put to "off" and "check zero switch" to "on". There are two terminals, one for quadrants and the other one for earth on the power supply, connected to the quadrant and earth. Also the lamp supply terminals are connected to the electrometer projection lamp.

This unit works on 200 - 250 volt and 50 cps mains. The quadrant voltage required for a given sensitivity is obtained from the test certificate supplied with the apparatus. The fine control is turned to zero and the coarse control is adjusted to the nearest voltage below the value required sensitivity. After this the electrometer needle is set to zero with the help of
zero adjustment control.

To achieve the coincidence of mechanical and electrical zeros.

1) With the check zero switch in "on" position, mechanical zero is adjusted until the pointer reads zero.

2) Check zero switch is made to "off" position and electrical zero control is adjusted until the pointer again reads zero.

After achieving the above adjustment the power supply and Lindemann electrometer can be connected now to the circuit for measurement.

(f) Circuit:

Complete circuit is shown in fig.(3.6). All connections are made with flexible wires with metal grid shielding over them. All shielding are connected with each other and one of them is earthed. A three way key is used to connect the Lindemann electrometer needle to the upper electrode of charge measuring assembly and to the circuit, devised for calibration. Key is prepared by drilling four holes in a paraffin wax slab with the depth of holes equal to half of the thickness of the paraffin slab. Mercury is filled in the holes. Two connectors with wax handles are prepared. One out of the two is prepared in such a manner that all the four points are electrically connected to each other at a time. Another key is prepared to connect two of the terminals at a time.
Fig. 3. Circuit diagram used for charge measurement calibration.
Needle of the electrometer is connected to the one terminal of the wax key and the diagonally opposite terminal to the earth. One terminal from rest of two is connected to the upper electrode of charge measuring assembly discussed in section 3.7(a). Fourth terminal is either earthed or connected to a stand and charge feeding device for calibration of the Lindemann electrometer.

(g) **Method of electret charge measurement:**

Lindemann electrometer is connected to the power supply. After the adjustment of mechanical and electrical zero and the desired sensitivity, the connections are completed as discussed in section 3.7(f). The electret, which is under investigation, is kept at the lower electrode of charge measuring assembly with surface to be studied facing upwards. Upper electrode is pressed and touched to the surface of electret. Both the electrode are kept short circuit through the earth for one minute. Later on lower electrode is kept still earthed while upper electrode is lifted and connected to the electrometer through the wax key. Induced charge is recorded by the deflection of needle. Electrometer is calibrated for the deflection against known charge separately. Thus with the help of calibration curve, charge density may be calculated in terms of coul/cm² or in e.s.u. For opposite polarities needle is seen swinging to opposite direction.

In the present investigation the measurement were taken at the sensitivity 28 & 38 volts. In order to investigate
the mode of decay, the charge density was measured after each hour. For how many hours.

(h) **Calibration of electrometer**

A condenser of 33 pF is charged with the help of voltage reference source supplied by Heath Co., U.S.A. Known charges are fed to electrometer needle through condenser of 33 pF value and corresponding deflections are recorded. A curve between the deflection and voltage under which the condenser was charged was drawn. As the area of the upper electrode of charge measuring assembly is 0.5 sq. cm. \( p \), the charge density i.e. charge on electret surface per \( \text{cm}^2 \) is given by

\[
\rho = \frac{C \times V}{S} \quad \text{-------- (3.2)}
\]

\( C = 33 \times 10^{-12} \, \text{F} \)

\( S = 0.5 \, \text{cm}^2 \)

\( \rho = V \times 66 \times 10^{-12} \, \text{coul/cm}^2 \)

Lindemann electrometer was calibrated for the same sensitivity of 28 \& 33 volts at which the charge of electret was to be measured. Electrical circuit used in the calibration is shown in fig. (3.6).

3.8 **DETAILS OF MEASUREMENT**

(a) **Dielectric – Metal Contact**

To investigate the behaviour of dielectric-metal contact, a series of electret was prepared, allowing the
β-Naphthol samples to cool between tin electrodes without applying any electric field. The charge density of thus prepared electret, was measured. Many workers have found that some time, contact charges develop on the surface of the dielectric.

(b) **Electrode Effect:**

To see the electrode effect, thermo-electret were prepared with the different types of electrodes, non-metallic and metallic. Here the mica, aluminium, copper, nickel and tin were used as electrode material. It has been reported that the polarisation and nature of charge depend upon the nature of electrode. In this way, it is helpful in selecting the electrode material that gives best thermo-electret.

(c) **Field and Temperature Effect:**

To study the effect of the field and temperature on the nature and magnitude of charges and on the life period of thermo-electrets and mode of decay of charge, seven series, each consisting of 6 to 8 electrets were prepared under different fields and at different temperature conditions. Other parameters remain constant throughout the investigation. The surface charge density was measured after each hour for a long time in the case of each electret.

3.9 **RESULTS:**

(a) The samples of \( \text{A} \)-Naphthol are kept for 4 hours at higher temperature at like 90°C to 120°C then allowed to cool
Fig. 3.7 - Decay rate of beta-Naphthol thermo-electric.
Fig. 3.8: – Decay mode of Beta-Magneto thermo-glow test.
Fig. 3.9 - Decay mode of beta-Naphthal thermo-electrate.
FIG. 11. Decay mode of Ketone-Resinol thermoelectric.
Fig. 3.12 - Decay mode of Beta-Naphthol thermo-electric data.
Fig. 3.13 - Decay modes of B&H spherical thermo-electric.
upto room temperature in absence of electric field. The charge
density was measured immediately after the preparation. In
each sample hetero-charge was obtained. These surface charges
decay directly to zero value with in 2 or 3 hours without
exhibiting any irregularity in its variation.

(b) Thermo-electrets were prepared under the same
conditions using the copper, nickel, aluminium, tin and mica
as electrode material and surface charge was measured after an
interval of one hour continuously for a long time. Thermo-
electret were prepared at the temperature 80°, 90°, 100°,105°,
110°, 116° and 120°C and under the field 1.5, 3.0, 4.5,6.0,
7.5, 9.0, 10.5 KV/cm. It was found that average life period
of electret with tin electrode was greater than that with
other electrode material. Copper was second. In the case of
nickel and aluminium life period of electrets was not more
the 10 hours and with mica it shows no charge. But these results
enabled one to decide the electrode material. Thus we used the
tin foil as electrode material in this study.

(c) It has been reported that the behaviour and
properties of thermo-electret depend mainly on the temperature
and field at which the electrets were prepared. In present
investigation the same results were found also. The variation
of surface charge density with time is plotted in graphs
fig. (3.7 - 3.14). The conclusion obtained from the study
of graphs fig. No.(3.7 - 3.14), are given in the following
steps.
(i) Hetero-charge is obtained, when the measurement is made just after the preparation of thermo-electret in each case.

(ii) No charge reversal is obtained in the thermo-electret which are prepared under the field 1.5 kV/cm and at temperature 80°C to 120°C.

(iii) In the case of thermo-electret, prepared under the field 3.0, 4.5, 6.0, 7.5, 9.0, 10.5, 12.0 kV/cm and at the temperature 80°C, 90°C, 100°C, 105°C, 110°C, 115°C and 120°C, reversal of charge is obtained (charge reversal from hetero to homo-charge).

(iv) Time of transition from hetero to homo-charge directly depends on the polarising field & reduces as the field strength is increased at each temperature.

(v) Life period of thermo-electret is long for the middle range of the fields at each temperature.

(vi) Finally the value of charge reaches to zero value. Hence permanent electret can not be obtained from β-Naphthol.

(vii) In the present study, life time is found longest that is 88 hours for the electret prepared at temperature 100°C and under the field 7.5 kV/cm.

(viii) The highest value of hetero-charge (26.4 x 10^{-10} coul/cm²) is found for the thermo-electret, prepared at the temperature 105°C and 110°C and under the field 7.5 kV/cm and 10.5 kV/cm, respectively.
(ix) Highest value of homo-charge is found at 90°C and field 7.5 kV/cm and at temperature 115°C, field 6.0 kV/cm. So nothing conclusively is said about it.

(xi) The mode of decay in each case is irregular.

(xii) No definite relation is obtained between the initial value of charge and the field at different temperature.

(xii) Life period of thermo-electret increases first and then decreases as the field increased continuously.

3.10 DISCUSSION:

Results obtained in the present study are discussed systematically on the lines of the existing theories regarding the behaviour of the thermo-electrets. Wiseman and Feaster(34) extended the two charge theory of Gross (9) to explain the behaviour of thermo-electrets. The behaviour of electrets is discussed on the basis of the following points.

(a) That the hetero-charges and homo-charges are different in nature and co-exist, in the volume and on the surface of the thermo-electret (9,13).

(b) That the measured surface charge density of the thermo-electrets surface is the combine effect of homo and hetero-charges (9,13).

(c) That the hetero-charges decay quite rapidly initially and then the rate of decay of homo and hetero-charges are different (9,13).
In the present study of thermo-electrets of β-Naphthol, hetero-charge appeared first irrespective of preparative parameters like temperature and fields. The view behind the growth of hetero-charge is the localisation of electrons in deep traps under prolonged intense electric field. As expected the trapping of electrons into deep traps must be a rate process and as such strongly effective at high temperature. Heat treatment and duration of polarisation produce the same effect. This effect in the form of trapping of electrons into deep traps is possible under the polarising fields even at room temperature. The localisation of electrons in deep traps would account for a long-lived hetero-charge. But the life of hetero-charge was found in hours in the present case thus the possibility of deep trapping is ruled out and shallow trapping may be operative.

In the present work hetero-charge is obtained in the case of thermo-electret, prepared below the field 1.5 KV/cm and at each temperature in the temperature range of 80°C to 120°C. This hetero-charge decays to zero within 2 or 3 hours. Here it can be assumed that the homo-charge is also present but hetero-charge is dominating factor. As the field of polarisation increase the reversal of charge is obtained i.e. from hetero-charge to homo-charge. The value of homo-charge increases rapidly with the field of polarisation and polarising temperature. Both the temperature and field factors may be assumed to be contributing to the formation of more homo-charge during
thermo-electret preparation. Both the mechanism (a) dielectric-electrode interface breakdown and (b) charge carrier migration from electrode into dielectric and their freezing in during cooling, seems to be operative for homo-charge formation in the thermo-electrets, prepared at high polarising temperature.

Balázs (8) suggested that charge carriers of either sign from the electrode to the substance and their freezing-in during cooling, giving rise to observed homo-charge. The possibility of dielectric-electrode interface breakdown may be inferred from the presence of strong internal polarisation giving rise to the intrinsic hetero-charge of the thermo-electret. But in present case the internal polarisation is not so strong thus this mechanism may be ruled out from the formation of homo-charge.

The phenomenon of charge reversal is found in the case of each thermo-electret except that prepared below the field 1.5 kV/cm. Time of reversal is found longer for those electrets which have been prepared at lower temperature. The charge found on thermo-electret at any time is the difference between the two charges resulting from external and internal polarisation. The presence of hetero-charge just after the preparation of thermo-electret indicates that charges associated with external polarisation being over compensated by the charges due to internal polarisation. Short-time for charge reversal is due to the rapid decaying of hetero-charges. Decay of intrinsic hetero-charge tends to increase the net homo-charge, but the charges giving rise to homo-charge are free charges hence they
also decrease with time but at a different rate.

In the present investigation a quick charge reversal is obtained with in ½ to 1 hour. It may be explained with the help of fact that charges associated with external polarisation, penetrate in deep into the dielectric (β-Naphthol) and frozen inside during the cooling of dielectric. Thus they become more effective in neutralising the internal polarisation field. These frozen charges decay with time and the rate of decay depends on the resistivity phase of solid dielectric. In the case of β-Naphthol the life period of thermo-electrets is found in hours that is maximum 98 hours. This short period of life is due to the low resistivity phase of solid β-Naphthol. The rate of hetero-charges decay is much faster than that of homo-charges, so that the observed net homo-charge reaches its maximum value soon. Few flat portion of the decay curves shows the persistency of charge with time. But generally it was found that homo-charge decays continuously and reaches to zero fig. (3.7 - 3.13).

On the other hand the fast decay of homo-charges points out towards the absence of any freezing-in of these charges very deep inside the substance. Gross view (9) of dielectric electrode interface breakdown and the migration of the ions, so formed in the interface towards the dielectric, their penetration and freezing-in during cooling does not seem to find favour in this case.

Apart from this, the magnitude and life of the homo-charge depends on the surface properties or in other words
it depends on the concentration and depth of local levels. Present data of homo-charge show the lower concentration and small depth of local levels at the surface.

The presence of homo-charge at lower fields at high temperature, could be explained due to the improved value of dielectric constant with increase of temperature. Wiseman and Feaster (34) suggest that larger values of dielectric constant of the electret forming material decreases the effective electrical thickness of the thermo-electret so that even lower values of the applied potential difference are able to create the conditions in dielectric electrode interface favourable to the formation of homo-charge. In the next study the dependence of the dielectric constant on temperature has been investigated. Gemant's (53) theory takes into account dipoles orientation inside a dielectric for hetero-charge formation. The existence of long polar molecules in various electret forming materials led early workers to associate persistent polarisation with molecular orientation in the applied field. But this mechanism has been disapproved for several materials. In the case of β-Naphthol which is polar to some extent, it appears that polar molecules play its role in the formation of electret state but the effect seems to disappear soon after removal of applied field.

The values of homo-charges and life period, in present investigation using different electrode material, were
found to be different. Confirmation of the influence of different electrode material in the formation of thermo-electrets, homo-charge (7,8,90) are in agreement with the idea of migration of charge carriers from electrode material into the dielectric due to improper matching of work function between the two surfaces.

Thiessan and his co-worker (5) made the electret by allowing the wax-resin mixture to solidify between metallic electrode without application of any electric field. β-Naphthol is also able to form the electret state for a short period of life.
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