Introduction:

The dielectric materials are broadly classified into polar and non-polar materials. The polar material gets polarized when subject to an external static field. The polarization is composed of 3 constituents, which are electronic, atomic and orientation polarizations respectively.

1. The electronic polarization (due to distortion of electronic charge distribution)

2. The atomic polarization (due to distortion of molecular bond distances and angles) are caused by the molecular distortion. These distortions are independent of temperature and pressure, but they do depend on density.

3. The third of polarization ‘orientation polarization’, is one in which the dipoles of a polar substance tend to orient along with direction of the applied field, as
schematically shown in Fig. 4.1., the process of orientation polarization requires a longer time compared with that of the almost inertia less phenomena of deformational polarization. This time duration also depends on the size of the molecule, temperature as well as viscosity of the medium. In other words the orientation polarization belongs to a ‘relaxation’ type of polarization.

Fig. 4.1: (i) A polar (dipole) molecules (ii) A polarized dielectric (iii) (1) before polarization, (2) after polarization
When the applied field has low frequency, then all the polarization components remain in phase with the external field, thus giving rise to no losses.

The dielectric constant measured low frequency of the applied field is termed as the static dielectric constant denoted by $\varepsilon_0$. But gradually as the frequency of the applied field is increased, one of the components of polarization, the orientation polarization begins to lag behind or is unable to match with the applied field. Thus orientation polarization becomes out of phase, while the remaining two components remain in phase with the applied field. Under such circumstances, the displacement current gets a conductance component, which ultimately leads to energy loss (in the form of thermal energy). This absorption gives rise to dielectric dispersion. When the frequency of the applied field is further raised, then the atomic polarization runs out of phase, but the electronic polarization remains in phase with the frequency of the applied field even through the frequency is raised too much higher value.
This deviation or lagging from equilibrium is termed as relaxation. The relaxation time is defined as that value of time which is required for molecules of a system to undergo a transition from polarized configuration (equilibrium) to unpolarized configuration.

4.2.1 Dielectric constant and dielectric absorption:

Microscopic theories distinguish between the induced polarization $P_1$ and the orientation part $P_2$ which arise from the atoms and molecules.

A differentiation between $P_1$ and $P_2$ is possible because of the different molecular dynamic behavior. So the reorientation of the induced polarization is much faster than $10^{-11}$ second because of the high mobility of the electrons in a molecule. If we neglect the atomic polarization and the dispersion of refractive index [8], we can write at high frequencies

$$\varepsilon^* = \varepsilon_x(P\|E) \quad \ldots \quad (4.1)$$

Or according to Maxwell
\[ \varepsilon_\infty = n^2 \quad (n = \text{refractive index}). \]

The orientation part \( P_2 \) arises from the partial orientation of the permanent molecular dipole moments in the direction of the external electrical field.

4.2.2 The Cole-Cole arc:

Many materials particularly long-chain molecules and polymers show, a broader dispersion curve and lower maximum loss than would be expected from the Debye relationships. In such cases the \( \varepsilon''-\varepsilon' \) curve falls inside the Debye semicircle. K.S. Cole and R.H. Cole (11) suggested an empirical distribution about a mean relaxation time, leading to

\[
\varepsilon^*(\omega) = \varepsilon_s + \frac{\varepsilon_\infty - \varepsilon_s}{1 + (i\omega \tau_{\alpha})^{1-\alpha}} \quad \ldots (4.12)
\]

Where \( \alpha \) is distribution parameter for a particular relaxation. Here \( 0 < \alpha < 1 \). Splitting it into real and imaginary parts using

\[
j^{(1-\alpha)} = \exp \{j\pi(1-\alpha)/2\}
\]

We obtain
\[\varepsilon' = \varepsilon_\infty + \frac{1}{2}(\varepsilon_0 - \varepsilon_\infty) \left[ 1 - \frac{\sinh(1 - \alpha) \ln(\omega \tau)}{\cosh(1 - \alpha) \ln(\omega \tau) + \sin \frac{\alpha \pi}{2}} \right] \] ... (4.13)

\[\varepsilon'' = \frac{1}{2}(\varepsilon_0 - \varepsilon_\infty) \left[ \frac{\cos \left[ \frac{\alpha \pi}{2} \right]}{\cosh(1 - \alpha) \ln(\omega \tau) + \sin \frac{\alpha \pi}{2}} \right] \] ... (4.14)

Fig. 4.3: Cole-Cole plot [11]

The above relation may be proved by writing

\[\frac{\nu^2}{u^2} = \frac{(\varepsilon_0 - \varepsilon')^2 + \varepsilon''^2}{(\varepsilon' - n^2)^2 + \varepsilon''^2} = \frac{(\varepsilon_0 - n^2 - (\varepsilon' - n^2))^2 + \varepsilon''^2}{(\varepsilon' - n^2)^2 + \varepsilon''^2}\]

and using the expression for \((\varepsilon' - n^2)\) and \(\varepsilon''\) found above. The values of \(\alpha\) found experimentally show a tendency to increase with increasing number of internal degree of
freedom in the molecules, and with decreasing temperature. In the limit \( \alpha = 0 \), of course the Cole-Cole curve reduces to the Debye semicircle.

4.3 The Fuoss-Kirkwood Distribution:

Fuoss and Kirkwood [10] developed an empirical distribution function in terms of Kirkwood theory of permittivity, applying it in particular to (polymeric) polar molecules in a non-polar solvent. They found that the results of loss measurement on polymers could be represented very successfully by the empirical equation

\[
H(x) = H(o) \sec h \beta x
\]  ... (4.17)

their modification of the single relaxation time function is given by

\[
\varepsilon'''' = \varepsilon''''_{\text{max}} \text{Sech}\{\beta \ln(\omega/\omega_{\text{max}})\}
\]

where \( \beta \) is an empirical numerical factor \( 0 < \beta < 1 \).

The usual form of the Fuoss-Kirkwood relation for practical evaluation is

\[
\cos h^{-1}\left(\frac{\varepsilon''''_{\text{max}}}{\varepsilon''''}\right) = 2.303 \beta (\log f_{\text{max}} - \log f)
\]  ... (4.18)
An estimated $\varepsilon''_{\text{max}}$ allows a plot to be made against log $f$, the slope being 2.303 $\beta$ and the abscissa being intersected at log $f_{\text{max}}$. This procedure eliminates the need for $\varepsilon'$ values and so is particularly useful when they are uncertain or when they change only to a small extent in the dispersion. It must be remembered that because of the logarithmic nature of the functions used considerable distortion from a symmetrical curve is needed before Fuoss-Kirwood (or Cole-Cole) parameters fail to fit absorption.

Poley [12-18] has given the relation between the Fuoss-Kirkwood $\beta$ and the Cole-Cole $\alpha$ factors:

$$\beta \sqrt{2} = \frac{(1-\alpha)}{\cos\left\{(1-\alpha)\pi/4\right\}}$$

From Fuoss-Kirkwood we can find $f_{\text{max}}$ and $\beta$ as before by plotting $\cos h^{-1} (\varepsilon''_{m}/\varepsilon'')$ against ln $f$, and we shall have

$$\varepsilon''_{m}/(\varepsilon_0 - n^2) = \beta/2 \quad \ldots (4.19)$$

$$\beta = 2\varepsilon''_{m}/(\varepsilon_0 - n^2)$$
from which $\varepsilon_0$ can still be found. The value of the empirical equation for the analysis of results on polymers is therefore not destroyed by the uncertainty in the assumptions on which the original discussion was based [19].

4.4 Systems having more than one Relaxation Processes:

If more than one dielectric relaxation processes occur simultaneously as shown in fig4.4, then the observed behavior is obtained by adding their effects on dielectric behavior and the observed behavior can be used to calculate the relaxation time of each process. Thus for a system having two relaxation processes, the measured dielectric permittivity $\varepsilon'$ and the loss $\varepsilon''$ are represented by the following relations

$$\varepsilon^* = \varepsilon + \frac{(\varepsilon_0 - \varepsilon)}{1 + (i\omega\tau)^1} \quad \text{(4.20)}$$

$$\frac{\varepsilon^* - \varepsilon}{\varepsilon_0 - \varepsilon} = \frac{C_1}{1 + (\omega\tau_1)^2} + \frac{C_2}{1 + (\omega\tau_2)^2} \quad \text{(4.21)}$$

$$\frac{\varepsilon}{\varepsilon_0 - \varepsilon} = \frac{C_1 \omega\tau_1}{1 + (\omega\tau_1)^2} + \frac{C_2 \omega\tau_2}{1 + (\omega\tau_2)^2} \quad \text{(4.22)}$$
Where $C_1+C_2=1$

**Fig. 4.4: A hypothetical plot of a system having two relaxation times.**

If the probabilities for the occurrence of the two processes are equal then:

$$\frac{c_1}{c_2} = \frac{\mu_1^2}{\mu_2^2} \quad \text{... (4.23)}$$

where $\mu_1$ and $\mu_2$ are the effective dipole moments. This relationship does not hold universally.

### 4.7 Dielectric Constants of Nematic Liquid Crystals:

The dielectric constants measured along ($\epsilon_\parallel$) or normal ($\epsilon_\perp$) to the nematic axis are different. For a more general direction of the electric field $E$, the relation between electric displacement $D$ and field has the form.

$$D = \epsilon_\perp E + (\epsilon_\parallel - \epsilon_\perp) (n.E)n \quad \text{... (4.27)}$$
The difference

$$\varepsilon_a = \varepsilon_\parallel - \varepsilon_\perp$$

... (4.28)

may be positive or negative, depending on the detailed chemical structure of the constituent molecules:

4.9 Experimental Arrangement:

(1) For frequency range 2KHz to 4MHz (using Schering bridge and Wayne kerr bridge). General Radio Schering Bridge type 716 CS an a universal Wayne-Kerr RF Bridge type B601 [31,32] along with GR Tuned Amplifier Null Detector type 1232A and GR frequency Mixer type 1232 were used for the measurements of capacitance and conductance in the frequency range 2kHz to 100 kHz and 400 kHz to 4 MHz respectively. Figs. 4.5(a) and 4.5(b) show the block diagram of experimental set up for the two bridges.
4.10 Calculation of Dielectric Permittivity and Loss:

(i) **Schering Bridge Calculations:** The Fig. 4.6 shows a schematic diagram of the bridge. $C_N$ is a variable
capacitor (accuracy 0.2 pf, range 100-1150 pf) which is balanced against the unknown series capacitor $C_{XS}$. The unknown series resistance $R_{XS}$ is balanced by making a proper choice of resistance and then adjusting $C_A$ and $C_N$. The capacitor $C_A$ is calibrated to give the value of dissipation factor $D_X$ of the unknown sample.

By adjusting the capacitors $C_N$ and $C_A$ for the null position, the capacitance $C$ (obtained by adding the readings of drum and dial) and factor $D_m$ (obtained by addition of switch and dial readings of dissipation factor switch) of the unknown sample were determined. The values of the series equivalent $C_{XS}$ and dissipation factor $D_X$ are given by [33].

$$C_{XS} = MC - C_C - C_1 \quad \ldots (4.30)$$

and

$$D_X = D = D_m 0.01. f/f_O \quad \ldots (4.31)$$

where $M$: Range selector (taken to be one in all measurements); $C_C$: zero capacitance across the bridge terminals and equal to 1.1 pf; $C_1$: Capacitance of the leads between the unknown sample and the bridge +
dead space capacitance; \( f \): generator frequency and \( f_0 \) frequency to which range selector is set.

Fig. 4.6: (a) Schematic diagram of Schering Bridge.
(b) Series capacitance and resistance of unknown capacitor.
(c) Parallel capacitance and resistance of unknown capacitor.

The parallel capacitance and parallel resistance of the unknown capacitor can be calculated from the expressions (Fig. 4.6(b) and (c)):

\[
C_{XP} = \frac{C_{XS}}{1 + D_X^2} \quad \ldots \quad (4.32)
\]

\[
R_{XP} = \frac{1 + D_X^2}{C_{XS}D_X} = \frac{1}{C_{XP}D_X} \quad \ldots \quad (4.33)
\]

The fixed capacitance \(C_B\) across the ratio arms A and B, (Fig. 4.6 (a)) and the zero capacitance of \(C_A\), produce errors in both the capacitance and dissipation factor reading of the bridge, when the dissipation factor of the unknown capacitor is large as well as very small. Following corrections then become necessary:

(i) When \(D < 0.001\), a correction for the dissipation factor \(D_N\) of the internal standard, \(C_N\), is applied. The calculation of \(D_X\) is made with the equation

\[
D_X = D + D_N = D + \frac{0.01}{C} \quad \ldots \quad (4.34)
\]
where measured capacitance $C$ is in pf.

(ii) $D > 0.01$, calculation of $C_{XS}$ is done from equation

$$C_{XS} = C (1 - 0.026 (f/f_0)D) - C_{C} - C_{1}. \quad ... (4.35)$$

(iii) when $D > 0.1$, calculation of $D_X$ is done from the equation

$$D_X = D (1 - 0.026(f/f_0)D). \quad ... (4.36)$$

The parallel capacitances $C_{XP}$ and the parallel resistance $R_{XP}$ of the unknown capacitance as given in Eqs. 4.32 and 4.33 are now calculated after making the above proper corrections for $D_X$ and $C_{XS}$. In actual practice measurements are also made without sample. If $C_1$ and $D_1$ are the corresponding values without sample, then corresponding parallel capacitance $C_{XP1}$ and parallel resistance $R_{XP1}$ are calculated using equations:

$$C_{XP1} = \frac{C_{CS1}}{1 + D_{X1}^2}$$

... (4.37)

and

$$R_{XP1} = \frac{1 + D_{X1}^2}{c_{XS1}D_{X1W}} = \frac{1}{c_{XP1}D_{X1W}} \quad ... (4.38)$$
after making proper corrections for $D_{X1}$ and $R_{XS1}$ similar to that given in Eqs. 4.34 and 4.36. The electric permittivity ($\varepsilon'$) and dielectric loss ($\varepsilon''$) of the material are then given by the equations:

$$\varepsilon' = 1 + \frac{C_S}{C_0}$$  \hspace{1cm} ... (4.39) and

$$\varepsilon'' = \frac{1}{\omega R_S C_O}$$  \hspace{1cm} ... (4.40)

$S$where $C_S = C_{XP} - C_{XP1}$  \hspace{1cm} ... (4.41) and

$$R_S = \frac{R_{XP} R_{XP1}}{R_{XP1} - R_{XP}}$$  \hspace{1cm} ... (4.42)

where $C_O$ : the effective series capacitance of the empty cell.

(ii) Wayne Kerr Bridge Calculations: Let the capacitance and conductance of the cell with measuring sample be $C_M$ and $G_M$ respectively, the permittivity ($\varepsilon'$) and loss ($\varepsilon''$) are calculated by the following formulae [32, 33]:

$$\varepsilon' = \frac{C_M - C_E}{C_O} + 1$$  \hspace{1cm} ... (4.43)
and \[ \varepsilon'' = \frac{G_M - G_E}{\omega C_0} \] ... (4.44)

where \( G_E \) is the conductance of the empty cell and \( \omega \) is the angular frequency at which measurements are taken.

**Effect of dc loss on dielectric measurements:**

The loss obtained in Eqs. 4.40 and 4.44 composed of two parts [34] as:

\[ \varepsilon'' \text{ (total)} = \varepsilon'' \text{ (dielectric)} + \varepsilon'' \text{ (conductance)} \] ... (4.45)

The loss factor \( \varepsilon'' \) (conductance) is related to the d.c. conductivity \( \sigma \) (ohm\(^{-1}\) cm\(^{-1}\)) of the medium and is given by:

\[ \varepsilon'' \text{ (conductance)} = 1.8 \sigma \times 10^{10} \] ... (4.46)

Dc conductance is subtracted from Eq. (4.45) to yield the dielectric loss \( \varepsilon'' \)

(iii) **The Boonton Bridge (R–X meter type 250–A):**

This bridge is a wide frequency range impedance meter designed to determine the equivalent parallel resistance and parallel reactance of two terminal networks and
components. By paying strict attention in the design to adequate screening, etc., the Boonton bridge is capable of measuring at frequencies up to 250 MHz. At these frequencies, connecting leads must be as short and as rigid as possible to ensure accuracy. The frequency range used in this study was 20 MHz to 100 MHz and the quoted [35] uncertainties in the resistance and capacitance measurements are:

**Resistance:** $\pm (2 + f/200 + R/5000 + Q/20)\% \pm 0.2$

where $f =$ frequency in MHz, $R =$ equivalent parallel resistance in ohms indicated by the meter, and $Q = \frac{R}{C}$ as determined from the R-X meter readings. This gave an uncertainty of $\pm 2.6\% \pm 0.2$ at 50 MHz.

**Capacitance:** $\pm (0.5 + 0.5f^2C \times 10^{-5}) \pm 0.15 \text{pF}$

where $f =$ frequency in MHz, $C =$ meter reading in pF. This gave an uncertainty of $\pm 0.7\% \pm 0.15 \text{pF}$ at 50 MHz.

**Modification of C and R in Presence of Lead Effects:**
Leads connecting dielectric cell to bridge have resistance and inductance therefore bridge measures the effective parallel capacitance and resistance of a component placed in the circuit. The equivalent circuit of the cell and its leads may be depicted as:

![Equivalent Circuit Diagram]

**Fig. 4.7**

Where $C_p$ and $G_p$ are the capacitance and conductance of the measuring cell, and $R_s$ and $L_s$, the series resistance and inductance of the leads connected to the bridge, the circuit appears as:

![Equivalent Circuit Diagram]

**Fig. 4.8**

$R_s$ and $L_s$ where detained using the equations:
\[
\frac{G}{G^2 + W^2 C^2} = \frac{G_p}{G_p^2 + W^2 C_p^2} + \text{Rs} \quad \ldots \ (4.47)
\]

\[
\frac{C}{G^2 + W^2 C^2} = \frac{C_p}{G_p^2 + W^2 C_p^2} - \text{Ls} \quad \ldots \ (4.48)
\]

4.11 Design of Cell:

Fig. 4.9a: Design of Cell
Fig. 4.9b: The Fabricated Cell Placed in a Double Walled Glass Jacket
Calibration of Cell:

In order to calculate $\varepsilon'$ & $\varepsilon''$, the effective or geometric capacitances $C_0$ of both cells have to be determined for cells.

The cell is first properly calibrated, using standard liquid (benzene) of known dielectric constant at a given temperature. If the capacitance of the empty cell is $C_E$, then,

$$C_E = C_1 + C_0$$ \hspace{1cm} \text{(4.49)}

where $C_1$ is the capacitance composed of the capacitance of the connecting leads and the dead-space capacitance of the cell end; $C_0$ is the effective capacitance of the cell. Now we introduce a standard sample (benzene) of dielectric constant $\varepsilon_S$ inside the cell, then the capacitance measured from the bridge is $C_L$ which is given as:

$$C_L = C_1 + \varepsilon_S C_0$$ \hspace{1cm} \text{(4.50)}

From Eqs. (4.49) and (4.50) we get the effective capacity $C_0$ of the cell as
\[
C_0 = \frac{C_L - C_E}{\varepsilon_s - 1} \quad \text{... (4.51)}
\]

Effective capacitances for Cells used with Boonton bridge and Schering bridge/wayne Kerr Bridge is 0.934 PF and 4.7 PF respectively.

4.12 Experimental work done:

Two nematic liquid crystalline mixture namely E-80 and E-180 (procured from BDH (UK) and used as such) were used to carry out dielectric measurements. These mixtures are patented products used in commercial liquid crystal display products. No single component can meet various commercial requirements so upto 20 types of molecular species are used to create eutectic mixtures. These two mixtures contain Cynao substituted Cyclohexanes and Biphenyls. Measurements are carried out in

1. Parallel (E parallel to H)
2. Perpendicular (E perpendicular to H) configurations.
Fig. 4.10 shows typical curves for dielectric constant ($\nabla'$) and dielectric loss ($\Delta''$) for E-80 mixture at 43 °C vs frequency variation (from 2khz to 100Mhz in parallel configuration).

![Graph showing typical curves for dielectric constant and loss](image)

\[
\varepsilon_{11} = \frac{\sigma^* 1.8E10}{f} + \frac{1}{2} \sum_i^* S_i^* \left[ \cos \left( \frac{\alpha_i \pi}{2} \right) \cosh(1 - \alpha_i) \ln(\omega \tau_i) + \sin \frac{\alpha_i \pi}{2} \right]
\]  \hspace{1cm} \text{(4.52)}

1. Values of static dielectric constants are found for both parallel and perpendicular configurations.
2. Dielectric data is fitted in eq 4.52 using non linear least square fitting procedure to optimize various values such as dc conductivity $\sigma$, at different temperatures, Distribution parameters $\alpha_i$, and Dielectric strengths $S_i$ related to various dielectric loss mechanisms.

3. Activation energy of a relaxation process is given by

$$\tau = \tau_0 e^{\frac{E}{kT}}$$ taking natural log of both sides

$$\ln \tau = \ln \tau_0 - \left(\frac{E}{k}\right) \frac{1}{T}$$

Drawing a graph between $(\ln \tau)$ and $\frac{1}{T}$, where T is in kelvins, the gradient of the curve gives value of $\frac{E}{k}$, putting value of k (Boltzmann constant), we get activation energy in electron volts units.

4.12.1 E-80 mixture dielectric and conductivity results:

E-80 shows Nematic-isotropic clearing temperature at 58.5 C. Different results in homogeneous and homeotropic configuration are given in Table 1 and Table 2 respectively.
Table – 1

<table>
<thead>
<tr>
<th>Temp</th>
<th>$E_1$</th>
<th>$\sigma$</th>
<th>$B_1$</th>
<th>$T_m$</th>
<th>$L_m$</th>
<th>$B_2$</th>
<th>$T_m$</th>
<th>$L_m$</th>
</tr>
</thead>
<tbody>
<tr>
<td>38</td>
<td>11.865</td>
<td>4.25E-10</td>
<td>0</td>
<td>1.919E-7</td>
<td>4.59287</td>
<td>0.3127</td>
<td>1.4798E-6</td>
<td>4.6770</td>
</tr>
<tr>
<td>41.5</td>
<td>10.767</td>
<td>5.71E-10</td>
<td>0</td>
<td>1.112E-7</td>
<td>4.44802</td>
<td>0.1547</td>
<td>8.9976E-7</td>
<td>3.8999</td>
</tr>
<tr>
<td>47</td>
<td>9.8952</td>
<td>7.62E-10</td>
<td>0</td>
<td>4.647E-8</td>
<td>2.90367</td>
<td>0.1458</td>
<td>3.9889E-7</td>
<td>3.5677</td>
</tr>
<tr>
<td>51</td>
<td>8.2391</td>
<td>1.35E-09</td>
<td>0</td>
<td>2.579E-8</td>
<td>1.76989</td>
<td>0.0280</td>
<td>3.1129E-7</td>
<td>2.1935</td>
</tr>
<tr>
<td>53.5</td>
<td>6.5074</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>56.5</td>
<td>5.7895</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$E_{g1}=1.34\text{ev}$ $E_{g2}=1.07\text{ev}$

Table – 2

<table>
<thead>
<tr>
<th>Temp</th>
<th>$E_2$</th>
<th>$\sigma$</th>
<th>$B_1$</th>
<th>$T_1$</th>
<th>$S_1$</th>
<th>$B_2$</th>
<th>$T_2$</th>
<th>$S_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>38</td>
<td>4.4633</td>
<td>3.064E-10</td>
<td>0</td>
<td>8.10906E-7</td>
<td>0.2561</td>
<td>0.1951</td>
<td>2.72855E-8</td>
<td>1.63228</td>
</tr>
<tr>
<td>41.5</td>
<td>4.5951</td>
<td>4.242E-10</td>
<td>0</td>
<td>4.56499E-7</td>
<td>0.1388</td>
<td>0.1494</td>
<td>2.55994E-8</td>
<td>1.29207</td>
</tr>
<tr>
<td>47</td>
<td>4.6715</td>
<td>5.548E-10</td>
<td>0</td>
<td>3.71629E-7</td>
<td>0.0584</td>
<td>0.0750</td>
<td>2.34993E-8</td>
<td>1.18183</td>
</tr>
<tr>
<td>51</td>
<td>4.8528</td>
<td>1.069E-9</td>
<td>0</td>
<td>3.125E-7</td>
<td>0.04</td>
<td>0.0169</td>
<td>2.17779E-8</td>
<td>1.15862</td>
</tr>
<tr>
<td>53.5</td>
<td>5.4698</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>56.5</td>
<td>5.7574</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$E_{g1}=0.585\text{ev}$ $E_{g2}=0.148\text{ev}$

Fig. 4.11 shows Dielectric anisotropy ($E_1 - E_2$) of E-80.
Homogeneous configuration:

Referring to tables 1 & 2, Nematic mixture E-80 shows two relaxation peaks in homogeneous sample.

Dc conductivity is given in fig. 4.12.
First relaxation mechanism:

Distribution parameter B has very small value. Variations of dielectric strength and evaluation of activation energy (Eg=1.34ev) are shown in figs 4.13 & 4.14 respectively.
Fig. 4.13

![Graph showing activation energy]

**Fig. 4.14**

**Second relaxation mechanism:**

Variations of Distribution parameter B, dielectric strength and evaluation of activation energy (Eg=1.07 ev) are shown in figs 4.15, 4.16 & 4.17 respectively.
Fig. 4.15

![Graph showing the relationship between dielectric strength and temperature in Kelvin.](image)

Fig. 4.16
Homeotropic Configuration:

Dc conductivity Vs temperature is given in fig. 4.18.
First relaxation mechanism:

Distribution parameter B has very small value. Variations of dielectric strength and evaluation of activation energy (Eg=0.565ev) are shown in figs 4.19 & 4.20 respectively.
Fig. 4.19

Activation energy is 0.632ev
Second relaxation mechanism:

Variations of Distribution parameter B, dielectric strength and evaluation of activation energy (Eg=1.07ev) are shown in figs 4.21, 4.22 & 4.23 respectively.
Fig. 4.22

The graph shows a plot of Dielectric Strength against Temperature (°C) for different temperatures ranging from 36 to 52 °C. The data points are scattered with a trend indicating an increase in dielectric strength as the temperature increases.

Fig. 4.22

The second graph illustrates a plot of ln(tau) against 1/T (in kelvin). The graph exhibits a clear linear relationship, and the annotation indicates that the activation energy is 0.148 eV. The linearity in the plot supports this value as the slope of the line corresponds to the activation energy.
4.11.2 E-180 mixture Dielectric and Conductivity Results:

E-180 shows Nematic-isotropic clearing temperature at 68 C. Different results in homogeneous sample along with static dielectric constants in homeotropic sample, are given.

**Table – 3**

<table>
<thead>
<tr>
<th>Temp</th>
<th>E₁</th>
<th>E₂</th>
<th>B₁</th>
<th>Tau₁</th>
<th>S₁</th>
<th>B₂</th>
<th>Tau₂</th>
<th>S₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>38.5C</td>
<td>6.6316</td>
<td>3.7583</td>
<td>8.5E-4</td>
<td>7.701E-6</td>
<td>3.9151</td>
<td>0</td>
<td>5.962E-7</td>
<td>1.65794</td>
</tr>
<tr>
<td>46C</td>
<td>6.1500</td>
<td>3.3305</td>
<td>0.0063</td>
<td>1.799E-6</td>
<td>2.3499</td>
<td>0</td>
<td>5.539E-7</td>
<td>0.54689</td>
</tr>
<tr>
<td>52.5C</td>
<td>5.5264</td>
<td>3.1987</td>
<td>0.2774</td>
<td>1.790E-6</td>
<td>1.1169</td>
<td>0</td>
<td>4.474E-7</td>
<td>0.35542</td>
</tr>
<tr>
<td>59C</td>
<td>4.8081</td>
<td>3.1664</td>
<td>0.3095</td>
<td>1.165E-6</td>
<td>0.7613</td>
<td>0</td>
<td>3.098E-7</td>
<td>0.30954</td>
</tr>
<tr>
<td>62.5C</td>
<td>4.4</td>
<td>3.2504</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Dielectric anisotropy (E₁-E₂) is shown in fig. 4.23.
Fig. 4.23

Referring to table 3, Nematic mixture E-180 shows two relaxation peaks in homogeneous sample. Dielectric loss in homeotropic sample is very small so relaxation peaks could not be resolved.

**Homogeneous Sample:**

DC conductivity is shown in fig. 4.24
First Relaxation mechanism:

Variations of Distribution parameter B, dielectric strength S and evaluated value of activation energy (Eg=0.8327ev) are shown in figs 4.25, 4.26 & 4.27 respectively.
Fig. 4.25

Fig. 4.26
Second Relaxation Mechanism:

Value of Distribution parameter B is very low, Variations of dielectric strength S and evaluated value of activation energy (\(E_g = 0.2773\text{eV}\)) are shown in figs 4.28 & 4.29 respectively.
Fig. 4.28

Fig-4.29

Activation energy is 0.2773 ev
4.13 Result and Discussion:

In this chapter Dielectric Constant, Conductivity, Activation Energy, Dielectric anisotropy of two Nematic liquid crystal mixtures E-80, E-180 have been found out using schering, wayne kerr & RX type bridge. Results are satisfactory and useful.