

This article was downloaded by:

On: 28 January 2011

Access details: *Access Details: Free Access*

Publisher *Taylor & Francis*

Informa Ltd Registered in England and Wales Registered Number: 1072954 Registered office: Mortimer House, 37-41 Mortimer Street, London W1T 3JH, UK



## Physics and Chemistry of Liquids

Publication details, including instructions for authors and subscription information:

<http://www.informaworld.com/smpp/title~content=t713646857>

### Study of the Effect of Temperature and Magnetic Field Variation on Dielectric Properties of Organic Liquids Using a Microwave Cavity Spectrometer

G. K. Johri<sup>a</sup>; Rajesh Sharma<sup>a</sup>; Akhilesh Tiwari<sup>a</sup>; M. Johri<sup>a</sup>; Saumya Saxena<sup>b</sup>; James A. Roberts<sup>c</sup>

<sup>a</sup> Department of Physics and Electronics, D.A-V. College, Kanpur, India <sup>b</sup> Department of Biochemistry, DVS-CAST, D.A-V. College Campus, Kanpur, India <sup>c</sup> Department of Physics, University of North Texas, Denton, TX, USA

**To cite this Article** Johri, G. K. , Sharma, Rajesh , Tiwari, Akhilesh , Johri, M. , Saxena, Saumya and Roberts, James A.(2001) 'Study of the Effect of Temperature and Magnetic Field Variation on Dielectric Properties of Organic Liquids Using a Microwave Cavity Spectrometer', *Physics and Chemistry of Liquids*, 39: 6, 711 – 722

**To link to this Article:** DOI: 10.1080/00319100108031687

**URL:** <http://dx.doi.org/10.1080/00319100108031687>

PLEASE SCROLL DOWN FOR ARTICLE

Full terms and conditions of use: <http://www.informaworld.com/terms-and-conditions-of-access.pdf>

This article may be used for research, teaching and private study purposes. Any substantial or systematic reproduction, re-distribution, re-selling, loan or sub-licensing, systematic supply or distribution in any form to anyone is expressly forbidden.

The publisher does not give any warranty express or implied or make any representation that the contents will be complete or accurate or up to date. The accuracy of any instructions, formulae and drug doses should be independently verified with primary sources. The publisher shall not be liable for any loss, actions, claims, proceedings, demand or costs or damages whatsoever or howsoever caused arising directly or indirectly in connection with or arising out of the use of this material.

# STUDY OF THE EFFECT OF TEMPERATURE AND MAGNETIC FIELD VARIATION ON DIELECTRIC PROPERTIES OF ORGANIC LIQUIDS USING A MICROWAVE CAVITY SPECTROMETER

G. K. JOHRI<sup>a,\*</sup>, RAJESH SHARMA<sup>a</sup>, AKHILESH TIWARI<sup>a</sup>,  
M. JOHRI<sup>a</sup>, SAUMYA SAXENA<sup>b</sup> and JAMES A. ROBERTS<sup>c</sup>

<sup>a</sup>*Department of Physics and Electronics, D.A-V. College, 119/91,  
Darshanpurwa, Kanpur – 208 012 (India);* <sup>b</sup>*Department of Biochemistry,  
DVS-CAST, D.A-V. College Campus, Kanpur – 208 001 (India);* <sup>c</sup>*Department  
of Physics, University of North Texas, Denton, TX – 76203 (USA)*

(Received 12 September 2000)

The temperature and magnetic field variation have been studied for the dielectric properties of 2-chlorobutane, acetonitrile and nitrobenzene in their pure state using microwave cavity spectrometer at 9.0 GHz. The analysis of the observed data of width, shift and amplitude of resonance profile has been carried out by using Slater perturbation equations for the computation of relaxation time, activation energy and for the relative study of permittivity and dielectric loss. This work provides fruitful information about the macroscopic structure of the organic liquids chosen.

**Keywords:** Dielectric properties; Organic liquids

## 1. INTRODUCTION

The dielectric properties [1, 2] are important to study the structure of the matter. The Microwave Cavity Spectrometer [3–6] is one of the accurate techniques and it is advantageous that this technique requires a very small volume of the sample ( $\approx 0.001 \text{ cm}^3$ ). The dielectric

---

\*Corresponding author.

relaxation of the organic liquid sample loaded in the microwave cavity can be related to the shift in the resonance frequency and to the change in the width of the resonance profile. The shift and width provide relative information about the permittivity and the dielectric loss respectively. In this paper we have measured amplitude, width of the resonance profile and shift of the resonance frequency by varying the magnetic field strength and the temperature. The cavity has been operated in  $TM_{010}$  mode at frequency 9.0 GHz. The relaxation time as well as activation energy are calculated for 2-chlorobutane, acetonitrile and nitrobenzene in their pure state.

## 2. EXPERIMENTAL

The experimental setup of the microwave cavity spectrometer has been described elsewhere [3–6]. A cylindrical microwave cavity is shown in Figure 1. The sample has been studied in a thin walled pyrex test tube of diameter 1.5 mm and then inserted in the cavity, operated in the

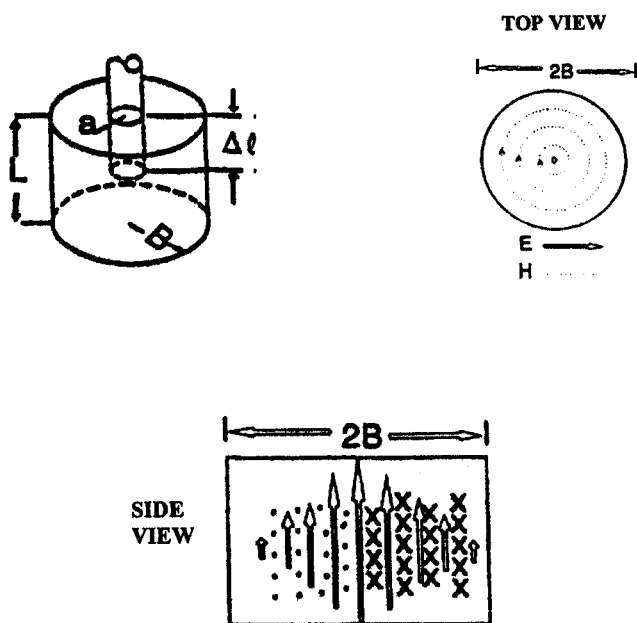


FIGURE 1 A sketch of the microwave cavity in the  $TM_{010}$  mode.

$TM_{010}$  mode. The data of shift in the resonance frequency, width and amplitude of the resonance profile have been measured for each sample of the organic liquids at a fix frequency 9.0 GHz. A permanent record of the signal and markers was produced on a dual pen chart recorder. The traces of the resonance profile of the cavity are displayed on one channel of the dual pen chart recorder while markers for calibration are displayed on the another one. A specific record is shown in Figure 2. In the present work two temperatures are chosen for each system. The temperatures set for 2-chlorobutane; acetonitrile and nitrobenzene are 19°C and 31°C; 19°C and 27°C and 19°C and 25.5°C respectively. The magnetic field in the range 0.0 to 1.5 kGauss was applied.

The permittivity ( $\epsilon'$ ) and the dielectric loss ( $\epsilon''$ ) are related [7, 8] to the relative shift in the resonance frequency ( $\Delta f$ ) and relative change in width of the resonance profile ( $\Delta w$ ) respectively. The loss tangent ( $\tan \delta$ ) gives the comparison of the permittivity and the dielectric loss

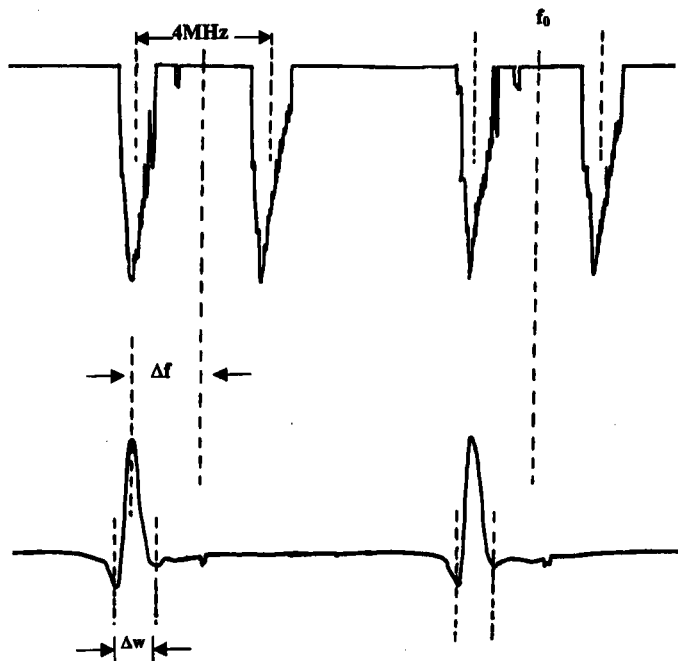


FIGURE 2 A dual pen chart trace of the second derivative of the absorption power for Nitrobenzene at 19°C. The markers are separated by 4 MHz.

and it is used to calculate the relaxation time by using Debye's single relaxation time mechanism [9].

The shift in the resonant frequency and width of the resonance profile are measured before and after putting the sample in the cavity. The observed data have been analyzed using Slater [7, 8] perturbation equations mentioned below:

$$\Delta f/f_0 = -[(\epsilon' - 1)/2]F(\mathbf{E}) \quad (1)$$

and

$$\Delta(1/Q) = \Delta w/f_0 = \epsilon''F(\mathbf{E}) \quad (2)$$

where  $\Delta f$  is the frequency shift,  $\Delta w$  is the width of the resonance profile and  $f_0$  is the cavity resonance frequency.  $\epsilon'$  and  $\epsilon''$  are permittivity and dielectric loss respectively for the material in the cavity.  $F(\mathbf{E})$  is the functional form of the field interacting with the sample loading the cavity and the energy stored per cycle in the cavity which is expressed as follows:

$$F(\mathbf{E}) = \frac{\int_V \mathbf{E}_s \cdot \mathbf{E}_0 dV}{\int_V \mathbf{E} \cdot \mathbf{E}_0 dV} \quad (3)$$

In this expression  $\mathbf{E}$  represents the electric field applied to the cavity,  $\mathbf{E}_0$  is the unperturbed component of the electric field in the cavity volume without the sample,  $v$  is the volume of the sample and  $V$  is the cavity volume.

Hence, the loss tangent is defined as follows

$$\tan \delta = (\epsilon''/\epsilon') \approx \Delta w/2\Delta f, \quad \text{for } \epsilon' \gg 1 \quad (4)$$

and the relaxation time using Debye's single relaxation time mechanism [9] is computed from the following relation

$$\tau = (1/\omega) \times (\Delta w/2\Delta f) \quad (5)$$

where  $\omega (= 2\pi f)$  is the angular frequency.

The relation between the relaxation time ( $\tau$ ) and the activation energy ( $\Delta G$ ) is given here below

$$\Delta G = 2.303RT \log (\tau kT/h) \quad (6)$$

where  $R$  is the molar gas constant,  $h$  is the Plank's constant,  $k$  is the Boltzmann constant and  $T$  is the absolute temperature.

### 3. RESULTS AND DISCUSSION

The observed data of  $\Delta f$ ,  $\Delta w$ ,  $\Delta h$ ,  $\tau$ ,  $\Delta G$  and  $(\Delta w/2\Delta f)$  for the organic liquids in their pure states are plotted against magnetic field strength at two different temperatures. The description of the observed data for each organic liquid as a function of magnetic field is given in the forthcoming paragraphs.

#### 3.1. 2-Chlorobutane [ $\text{CH}_3\text{—CH}(\text{Cl})\text{—CH}_2\text{—CH}_3$ ]

The variation of  $(\Delta f, \Delta w, \Delta h)$ ;  $(\Delta w/2\Delta f)$ ;  $\tau$  and  $\Delta G$  observed at  $19^\circ\text{C}$ , with respect to the magnetic field are plotted in the Figures 3(a)–(d).

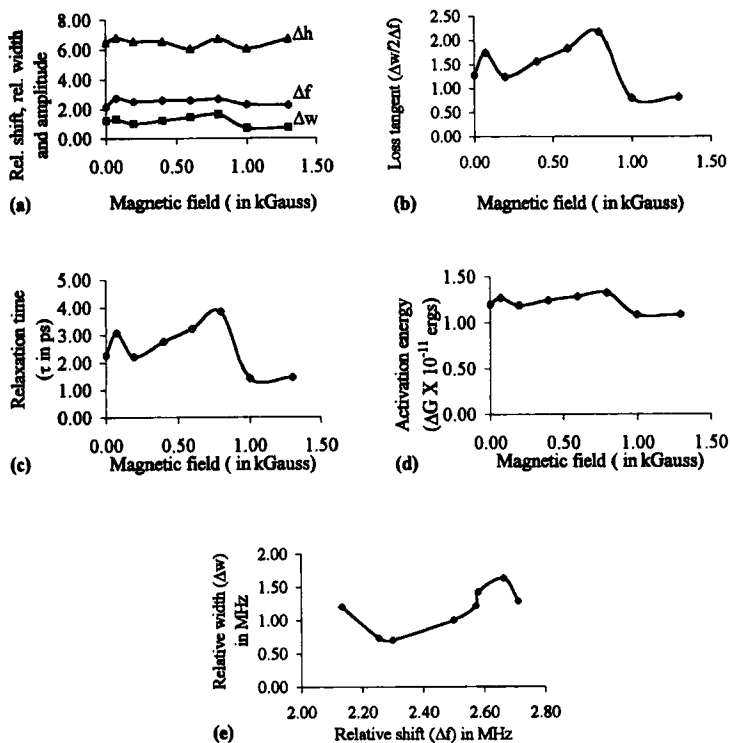


FIGURE 3 Variation of (a) amplitude ( $\Delta h$ ), width ( $\Delta w$ ), shift ( $\Delta f$ ); (b) loss tangent ( $\Delta w/2\Delta f$ ); (c) relaxation time ( $\tau$ ); (d) activation energy ( $\Delta G$ ) as a function of magnetic field; (e) relative width ( $\Delta w$ ) versus relative shift ( $\Delta f$ ) for 2-chlorobutane at  $19^\circ\text{C}$ .

The variation of  $\Delta w$  versus  $\Delta f$  is given in Figure 3(e). These data at 31°C are given in Figures 4(a)–(e) respectively.

The comparison of the data obtained at both temperatures reveal that the trend of variation of the shift, width, amplitude, loss tangent and activation energy as shown in Figures 3(a)–(d) respectively for 19°C temperature are similar to those for 31°C temperature as given in Figures 4(a)–(d) respectively. The variation of the width with respect to the shift correspondingly indicate the changes in dielectric loss ( $\epsilon''$ ) versus permittivity ( $\epsilon'$ ). The traces of width with respect to the shift at 19°C as indicated in Figure 3(e) for the shift in the range from 2.30 to 2.67 MHz and at 31°C as indicated in Figure 4(e) for the shift in the range from 2.28 to 2.61 MHz have the

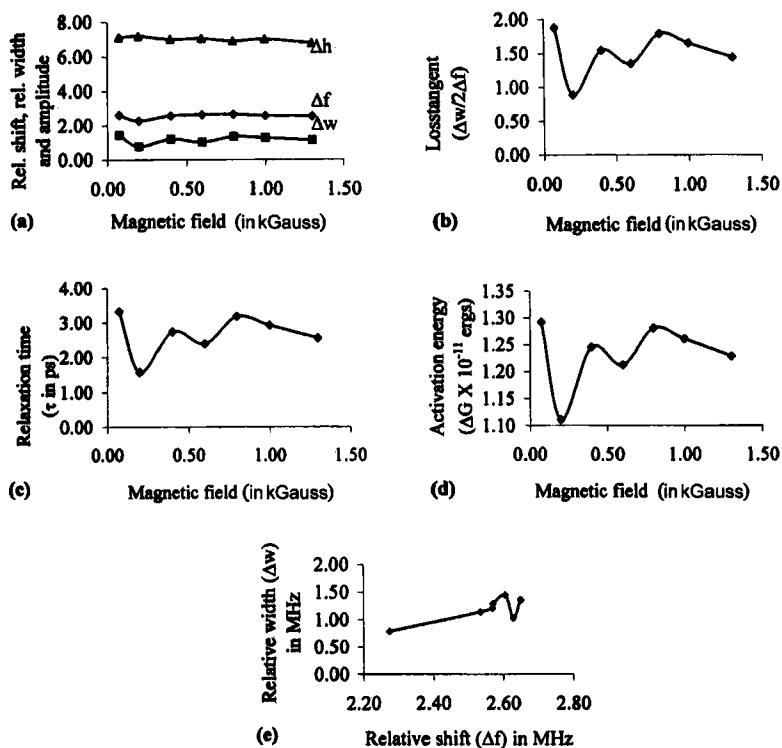


FIGURE 4 Variation of (a) amplitude ( $\Delta h$ ), width ( $\Delta w$ ), shift ( $\Delta f$ ); (b) loss tangent ( $\Delta w/2\Delta f$ ); (c) relaxation time ( $\tau$ ); (d) activation energy ( $\Delta G$ ) as a function of magnetic field; (e) relative width ( $\Delta w$ ) versus relative shift ( $\Delta f$ ) for 2-chlorobutane at 31°C.

same trend of variation. The overall response of the dielectric properties show that the values significantly change with temperature. From this analysis of the observed data, we infer that the permittivity, dielectric loss and relaxation time exhibit temperature and magnetic field effects.

### 3.2. Acetonitrile [ $\text{CH}_3\text{—C}\equiv\text{N}$ ]

The plots of the data of  $(\Delta f, \Delta w, \Delta h)$ ;  $(\Delta w/2\Delta f)$ ;  $\tau$  and  $\Delta G$  observed at  $19^\circ\text{C}$ , with respect to the magnetic field are shown in Figures 5(a)–(d). The variation of  $\Delta w$  versus  $\Delta f$  is given in Figure 5(e). These observations at  $27^\circ\text{C}$  are given in Figures 6(a)–(e) respectively.

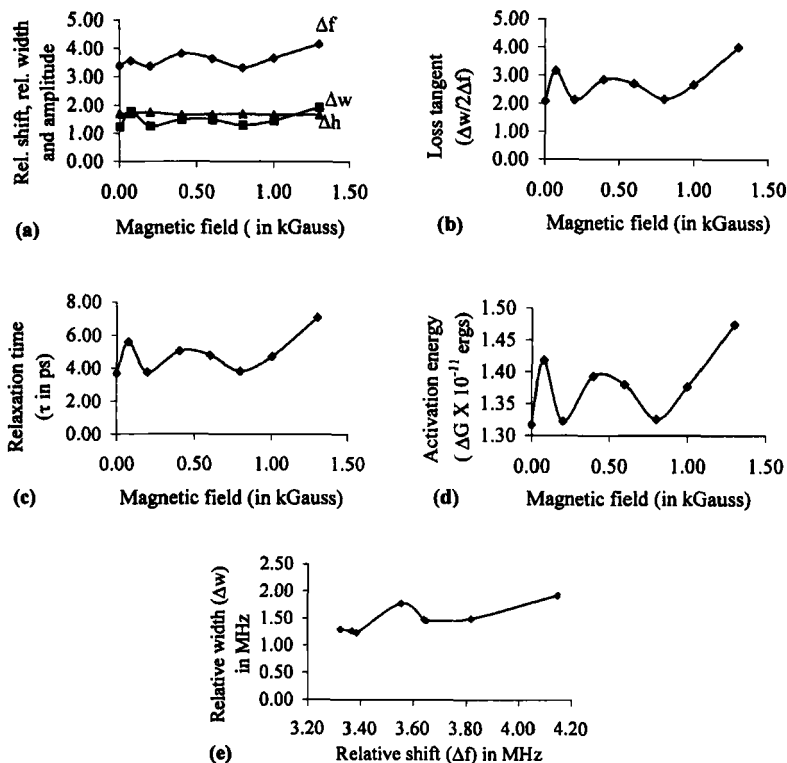


FIGURE 5 Variation of (a) amplitude ( $\Delta h$ ), width ( $\Delta w$ ), shift ( $\Delta f$ ); (b) loss tangent ( $\Delta w/2\Delta f$ ); (c) relaxation time ( $\tau$ ); (d) activation energy ( $\Delta G$ ) as a function of magnetic field; (e) relative width ( $\Delta w$ ) versus relative shift ( $\Delta f$ ) for Acetonitrile at  $19^\circ\text{C}$ .



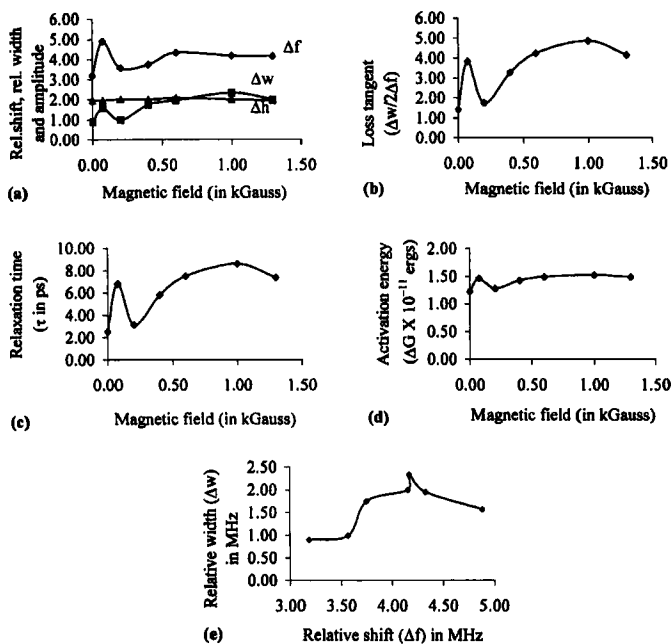


FIGURE 6 Variation of (a) amplitude ( $\Delta h$ ), width ( $\Delta w$ ), shift ( $\Delta f$ ); (b) loss tangent ( $\Delta w/2\Delta f$ ); (c) relaxation time ( $\tau$ ); (d) activation energy ( $\Delta G$ ) as a function of magnetic field; (e) relative width ( $\Delta w$ ) versus relative shift ( $\Delta f$ ) for Acetonitrile at 27°C.

The shift ( $\Delta f$ ), width ( $\Delta w$ ) and amplitude ( $\Delta h$ ) observed at 19°C and 27°C as a function of magnetic field are plotted in Figures 5(a) and 6(a) respectively. The shift variation have nearly same trend whereas the width ( $\Delta w$ ) at 19°C and 27°C show similar trend for the magnetic field in the range from 0.0 to 0.5 kGauss but as the magnetic field increases in the range from 0.5 to 1.5 kGauss, the width first decreases then increases for 19°C while at 27°C, the width increases first and then decreases. The plots of the amplitude ( $\Delta h$ ) for both the temperatures show a linear trend of change. The loss tangent ( $\Delta w/2\Delta f$ ) in Figure 5(b), relaxation time ( $\tau$ ) in Figure 5(c) and activation energy ( $\Delta G$ ) in Figure 5(d) for 19°C exhibit the same trend as those of 27°C in Figures 6(b)–(d) for the magnetic field range from 0.0 to 0.5 kGauss thereafter the plots at 19°C show first decreasing trend then increasing characteristics while the plots for 27°C show the increasing trend and then they decrease. The variation of the width versus shift

for 19°C in Figure 5(e) shows the non-linear behaviour having a peak ( $\Delta w = 1.78$  MHz) at shift ( $\Delta f = 3.56$  MHz) then the width first decreases thereafter it increases to a maximum value whereas for the temperature 27°C, in Figure 6(e), the width shows the increasing nature and attains a sharp peak ( $\Delta w = 1.96$  MHz) at shift ( $\Delta f = 4.33$  MHz) thereafter it acquires the decreasing trend.

The above inferences explain the temperature and magnetic field have influence on the values of the shift, width, amplitude, relaxation time, activation energy and correspondingly the dielectric properties are affected.

### 3.3. Nitrobenzene

The observations at 19°C for ( $\Delta f$ ,  $\Delta w$ ,  $\Delta h$ ); ( $\Delta w/2\Delta f$ );  $\tau$  and  $\Delta G$  versus magnetic field are exhibited in Figures 7(a)–(d). The changes in the  $\Delta w$  with  $\Delta f$  are illustrated in Figure 7(e) whereas the observed data at 25.5°C are plotted in Figures 8(a)–(e) respectively.

The amplitude at 19°C in Figure 7(a) shows nearly linear trend and remains approximately unaffected at 25.5°C. This indicates that the amplitude of the resonance profile is not disturbed by increasing temperature. The shift ( $\Delta f$ ) for 19°C in Figure 7(a) shows a peak ( $\Delta f = 2.43$  MHz) at 0.6 kGauss of the magnetic field while for 25.5°C in Figure 8(a), the shift has a peak ( $\Delta f = 2.18$  MHz) at 0.2 kGauss of the magnetic field. As the temperature is increased, the peak occurs earlier at lower value of the magnetic field than that at relatively lower temperature. The width ( $\Delta w$ ) in Figure 7(a) for the system at 19°C has a peak ( $\Delta w = 2.75$  MHz) at the magnetic field 0.075 kGauss while in Figure 8(a) for 25.5°C temperature, the peak ( $\Delta w = 2.18$  MHz) occurs at 0.2 kGauss. This reveals that by increasing temperature from 19°C to 25.5°C, the peak occurs at larger value of the magnetic field than that found at lower temperature. The loss tangent ( $\Delta w/2\Delta f$ ), relaxation time ( $\tau$ ) and activation energy ( $\Delta G$ ) at 19°C are shown in Figures 7(b)–(d) while for 25.5°C those observed parameters are given in Figures 8(b)–(d) respectively show non-linear trend of change with respect to magnetic field applied. More fluctuations are found at 25.5°C. There occurs a peak in the plot of loss tangent at 0.075 kGauss for 19°C, while for 25.5°C, there appears a dip in the plot. A similar characteristic is also found in the plots of the relaxation time and

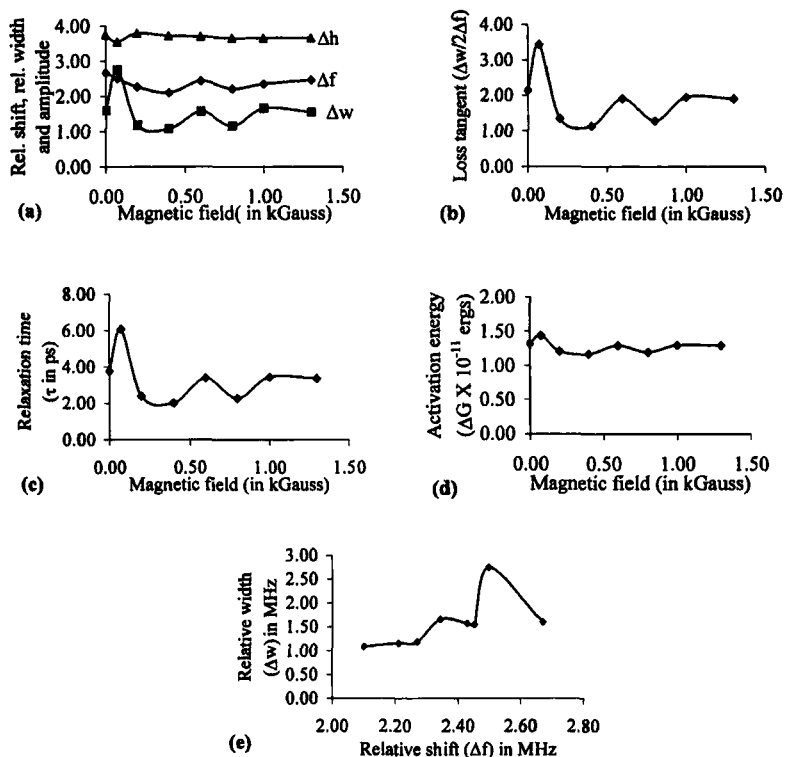


FIGURE 7 Variation of (a) amplitude ( $\Delta h$ ), width ( $\Delta w$ ), shift ( $\Delta f$ ); (b) loss tangent ( $\Delta w/2\Delta f$ ); (c) relaxation time ( $\tau$ ); (d) activation energy ( $\Delta G$ ) as a function of magnetic field; (e) relative width ( $\Delta w$ ) versus relative shift ( $\Delta f$ ) for Nitrobenzene at 19°C.

activation energy. This indicates that change in the temperature affects the loss, relaxation time and activation energy significantly. The plot of the width ( $\Delta w$ ) versus the shift ( $\Delta f$ ) in Figure 7(e) for 19°C and for 25.5°C in Figure 8(e) are entirely different. For 19°C temperature, the width shows an increasing trend and attains a peak ( $\Delta w = 2.75$  MHz) at the shift ( $\Delta f = 2.50$  MHz) then it decreases while for 25.5°C temperature, the width shows a decreasing nature and there comes a dip ( $\Delta w = 0.64$  MHz) at shift ( $\Delta f = 2.10$  MHz) then it acquires an increasing trend and attains a maxima in the curve. This significantly indicates that the dielectric loss ( $\epsilon''$ ) is changed entirely at higher temperature with respect to the permittivity ( $\epsilon'$ ).

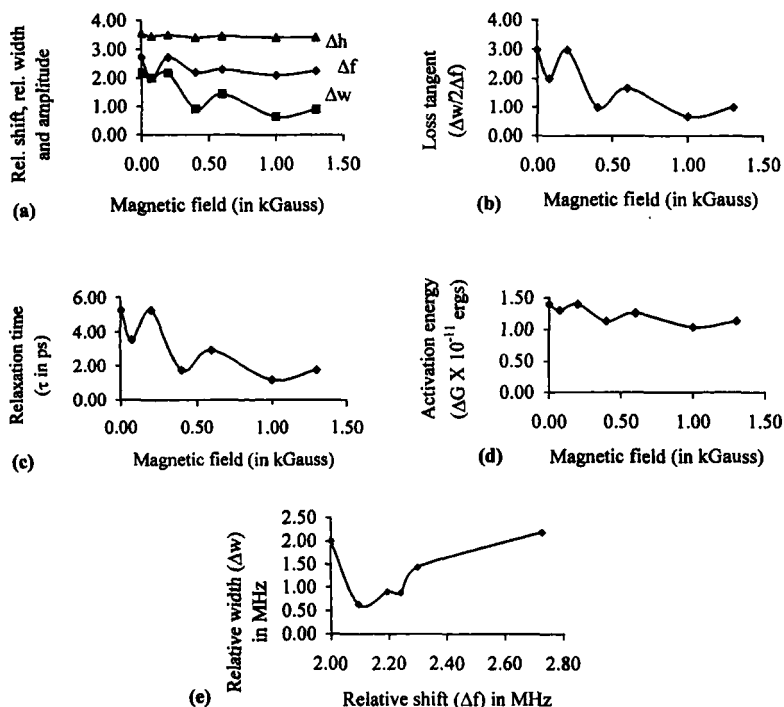


FIGURE 8 Variation of (a) amplitude ( $\Delta h$ ), width ( $\Delta w$ ), shift ( $\Delta f$ ); (b) loss tangent ( $\Delta w/2\Delta f$ ); (c) relaxation time ( $\tau$ ); (d) activation energy ( $\Delta G$ ) as a function of magnetic field; (e) relative width ( $\Delta w$ ) versus relative shift ( $\Delta f$ ) for NitroBenzene at 25.5°C.

The comparison of the data for nitrobenzene at temperatures 19°C and 25.5°C indicates that the shift, width, loss tangent, relaxation time and activation energy exhibit the increased values on the increment of the temperature.

It is also observed that the application of the magnetic field of 1.3 kGauss changes relaxation times in the order 1.45, 7.07 and 3.36 ps from those 2.26, 3.69 and 13.78 ps in the absence of the magnetic field for 2-chlorobutane, acetonitrile and nitrobenzene respectively. These polar organic liquids have molecular weights 92.5, 41 and 123 respectively showing that relaxation time is more sensitive to magnetic field in comparison to molecular weights of the systems considered. Further, nitrobenzene is relatively less affected in comparison to the other two organic liquids which may be due to more

degree of association of molecules and its highest molecular weight among the systems chosen.

#### 4. CONCLUSION

The work reported in this paper indicates that the temperature and magnetic field significantly influence the dielectric properties of the organic liquids considered. The relative variation of permittivity ( $\epsilon'$ ) and dielectric loss ( $\epsilon''$ ) and molecular collisions can fruitfully be studied using microwave cavity spectrometer. The form factor  $F(\mathbf{E})$  is required for the calculation of absolute values of  $\epsilon'$  and  $\epsilon''$  which may be done using the method [3] of fitting the data of dielectric response for the organic liquids chosen.

#### *Acknowledgement*

The author (MJ) is thankful to the University Grants Commission, New Delhi, India for financial assistance in the form of research project.

#### *References*

- [1] Böttcher, C. J. F. and Bordewijk, P., *Theory of Electrical Polarization* (Elsevier, 1978) Vol. II.
- [2] Hill, N. E., Vaughan, W. E., Price, A. H. and Davies, M., *Dielectric Properties and Molecular Behaviour*, Van Nostrand Reinhold Co. London, 1969.
- [3] Johri, G. K. and Roberts, J. A. (1990). *J. Phys. Chem.*, **94**, 7386.
- [4] Johri, G. K., Johri, M., Saxena, N. and Roberts, J. A. (1995). *Mol. Mat.*, **5**, 63.
- [5] Johri, G. K., Johri, M. and Roberts, J. A. (1995). *J. Microwave Power and Electromagnetic Energy*, **26**, 82.
- [6] Johri, G. K., Gupta, D. C., Johri, M. and Roberts, J. A., *Phys. Chem. Liqs.* (in press).
- [7] Slater, J. C. (1946). *Rev. Mod. Phys.*, **18**, 441.
- [8] Van Bladel, J., "*Electromagnetic Fields*", McGraw Hill Book Company, New York, 1964.
- [9] Debye, P., "*Polar Molecules, Chemical Catalog*", New York, 1929, Ch. 5.