

## Dielectric properties of some cadmium and mercury amino alcohol complexes at low temperatures

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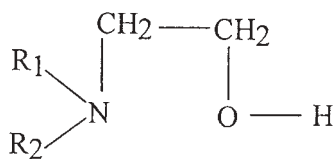
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**Abstract:** The dielectric properties of some cadmium and mercury amino alcohol complexes were studied within the temperature range of 100–300 K at the frequencies of 100, 300 and 1000 kHz. The polarization mechanisms are suggested and the dependence of both  $\epsilon$  and  $\tan \delta$  on both temperature and frequency are analyzed. The analysis of the data reveals semi-conducting features based mainly on the hopping mechanism.

**Keywords:** amino alcohol complexes, Hg, Cd, dielectric properties.

### INTRODUCTION

Amino alcohol complexes find progressive application in different fields: buffers,<sup>1</sup> catalysts,<sup>2</sup> inhibitors,<sup>3</sup> ion exchangers,<sup>4</sup> additives in building materials,<sup>5</sup> electroplating<sup>6</sup> and dyes.<sup>7</sup> In our laboratory, their structural chemistry have been investigated in depth using different spectroscopic and thermal methods of analysis.<sup>8–24</sup> As a continuation of this work, the dielectric properties of the entitled complexes were studied as a function of both temperature and frequency. This gives deeper insight into the structure of these complexes. The following skeleton is given for the ligands:



|   |  |                  |       |
|---|--|------------------|-------|
| $\text{R}_1 = \text{H};$                        | $\text{R}_2 = \text{H}$                        | Monoethanolamine | (MEA) |
| $\text{R}_1 = \text{H};$                        | $\text{R}_2 = \text{CH}_2\text{CH}_2\text{OH}$ | Diethanolamine   | (DEA) |
| $\text{R}_1 = \text{CH}_2\text{CH}_2\text{OH};$ | $\text{R}_2 = \text{CH}_2\text{CH}_2\text{OH}$ | Triethanolamine  | (TEA) |

## EXPERIMENTAL

The solid metal-amino alcohol complexes were prepared by mixing the required weight of the metal salt ( $\text{Cd}^{\text{II}}$  and  $\text{Hg}^{\text{II}}$ ) dissolved in the least amount of water with the calculated amount of the ligand saturated with ethanol. The mixture was refluxed for about 5 min. The complexes were precipitated and filtered, washed several times with a mixture of  $\text{EtOH-H}_2\text{O}$  solvent and then dried in a vacuum desiccator over anhydrous  $\text{CaCl}_2$ .

The metal ion contents were determined by complexometric titration procedures.<sup>25,26</sup> The halogen content was determined by titration with a standard  $\text{Hg}(\text{NO}_3)_2$  solution using diphenyl carbazone as the indicator,<sup>24,25</sup> the sulphate content was determined gravimetrically as  $\text{BaSO}_4$ .<sup>26</sup> The analytical data and m.p. of the prepared complexes are collected in Table I.

TABLE I. Analytical data and m.p. ( $^{\circ}\text{C}$ ) of the metal amino alcohol complexes.

| Complex                              | Geometry  | M.p./ $^{\circ}\text{C}$ | % Found (% Expected) |                |                |
|--------------------------------------|-----------|--------------------------|----------------------|----------------|----------------|
|                                      |           |                          | M                    | Cl             | $\text{SO}_4$  |
| $\text{Cd}(\text{MEA})\text{SO}_4$   | <i>Td</i> | > 300                    | 41.1<br>(41.1)       | –              | 35.5<br>(35.6) |
| $\text{Cd}(\text{MEA})_2\text{SO}_4$ | <i>Oh</i> | 265                      | 34.3<br>(34.4)       | –              | 29.0<br>(29.0) |
| $\text{Cd}(\text{DEA})\text{SO}_4$   | <i>Td</i> | 225                      | 35.8<br>(35.8)       | –              | 30.5<br>(30.6) |
| $\text{Cd}(\text{DEA})_2\text{SO}_4$ | <i>Oh</i> | 200                      | 26.8<br>(26.8)       | –              | 22.9<br>(22.9) |
| $\text{Cd}(\text{TEA})\text{SO}_4$   | <i>Td</i> | 220                      | 31.4<br>(31.4)       | –              | 26.8<br>(26.8) |
| $\text{Cd}(\text{TEA})_2\text{SO}_4$ | <i>Oh</i> | > 300                    | 22.1<br>(22.2)       | –              | 18.9<br>(18.9) |
| $\text{Hg}(\text{MEA})_2\text{Cl}_2$ | <i>Oh</i> | 290                      | 50.9<br>(50.9)       | 18.1<br>(18.0) | –              |
| $\text{Hg}(\text{DEA})_2\text{Cl}_2$ | <i>Oh</i> | 200                      | 41.6<br>(41.6)       | 14.7<br>(14.7) | –              |

*Td* = Tetrahedral, *Oh* = Octahedral

The complexes were pressed into discs of 10 mm diameter and 1–2 mm thickness at a pressure of  $9.8 \times 10^8$  Pa. Silver paste was painted on the major faces of each test piece as electrodes. The measurements of the permittivity and the dielectric loss were performed at the frequencies of 100, 300 and 1000 kHz in the temperature range 100–300 K using an LCR meter (4275A) (Institute of Physics, A. Mickiewicz University, Poznan, Poland).

## RESULTS AND DISCUSSION

The permittivity values of the *Td* [ $\text{Cd}(\text{MEA})\text{SO}_4$ ] complex, Fig. 1, were constant up to 215 K, after which they increased successively with increasing temperature, the relative permittivity values ranged from 10 to 70. The behaviour of the dielectric loss values indicates a polar polarization mechanism, where its values are affected by both temperature and frequency, Fig. 1. However, the relative permittivity values of the *Oh* [ $\text{Cd}(\text{MEA})_2\text{SO}_4$ ]

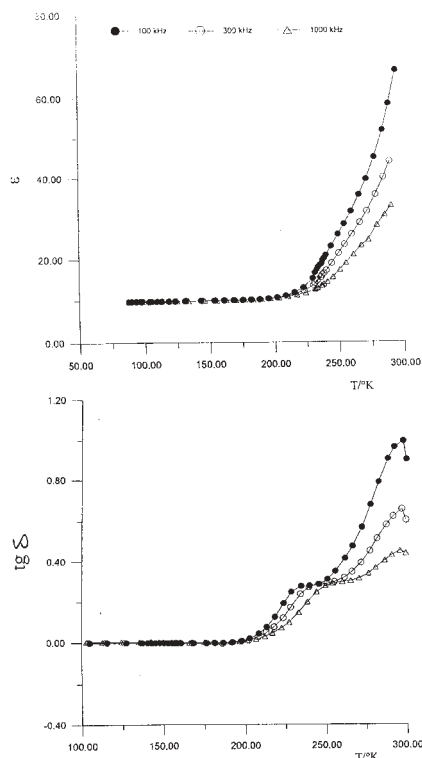


Fig. 1. Permittivity and dielectric loss dependence on temperature at different frequencies for the *Td*  $[\text{Cd}(\text{MEA})\text{SO}_4]$  complex.

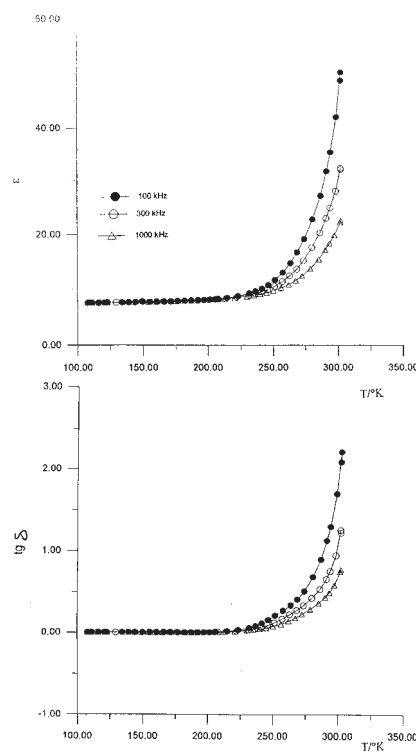


Fig. 2. Permittivity and dielectric loss dependence on temperature at different frequencies for the *Oh*  $[\text{Cd}(\text{MEA})_2\text{SO}_4]$  complex.

complex, Fig. 2, are in the range of 10–50, *i.e.*, less than that of the *Td*  $[\text{Cd}(\text{MEA})\text{SO}_4]$  complex. This remarkable feature was observed for both the mono- and triethanolamine complexes, Figs. 1, 2, 5 and 6. This finding is opposite to that of the zinc complexes.<sup>27</sup> Comparing the behaviour of the diethanolamine complexes, Figs. 3 and 4, it is found that both  $\epsilon'$  and  $\text{tg } \delta$  are higher in case of the *Td* complex than those of the *Oh* complex. This may be due to the *Td* complex existing in two different phases. This is confirmed from the sudden drop in the  $\epsilon'$  values at 150–160 K.

In a similar way, the following conclusions can be made for the mercury complexes:

i) The  $\epsilon'$  values of the *Oh*  $[\text{HgL}_2\text{Cl}_2]$  complexes, L = MEA, DEA, Figs 7 and 8, ranged between 4.5–8.0 and 4.0–4.4 for MEA and DEA complexes, respectively. Such values increase with increasing temperature and decrease with increasing frequency.

ii) The dielectric loss values of the *Oh*  $[\text{Hg}(\text{MEA})_2\text{Cl}_2]$  complex, Fig. 7, ranged from zero to 0.15, increasing with increasing temperature and decreasing with increasing frequency.

iii) The dielectric loss values of the *Oh*  $[\text{Hg}(\text{DEA})_2\text{Cl}_2]$  complex, Fig. 8, are very small ( $\approx 0.025$ ) and are affected by neither temperature nor frequency.

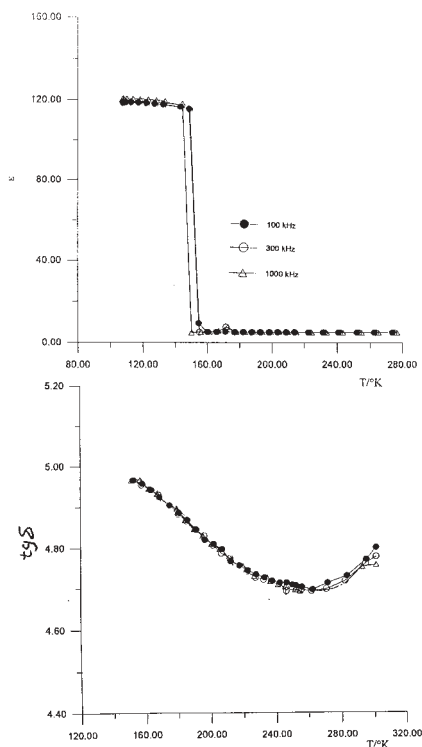


Fig. 3. Permittivity and dielectric loss dependence on temperature at different frequencies for the *Td* [Cd(DEA)SO<sub>4</sub>] complex.

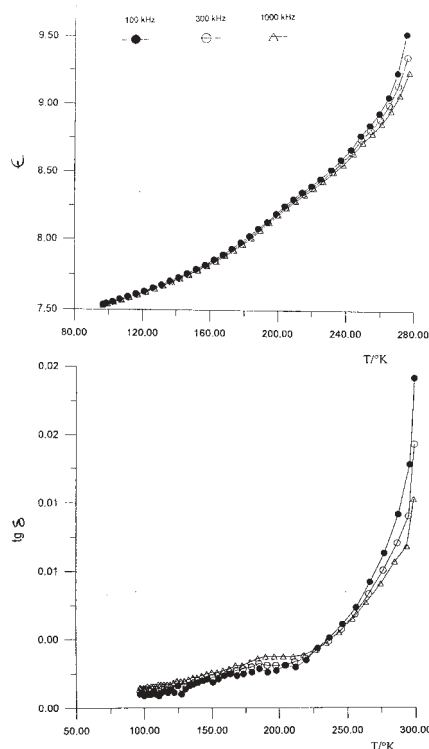


Fig. 4. Permittivity and dielectric loss dependence on temperature at different frequencies for the *Oh* [Cd(DEA)<sub>2</sub>SO<sub>4</sub>] complex.

In conclusion, the position of the metals in the periodic table plays a major role in controlling their behaviour. The gradual change from 4d to 5d (*i.e.*, from Cd to Hg) results in the stepwise decrease of the permittivity and dielectric loss values.

The temperature dependence of  $\tau$  can be expressed for thermally activated processes as:<sup>28</sup>  $\tau = \tau_0 \exp(E_0/RT)$ , where  $\tau_0$  is a constant characteristic relaxation time and represents the time of a single oscillation of a dipole in a potential well.  $E_0$  is the energy of activation of the relaxation of a dipole and represents the average or most probable value of a spread of relaxation time.

From the analysis of the dielectric data of Cd-, and Hg-amino alcohol complexes, the relationships between the different dielectric parameters are obtained and are given in Table II.

By comparing the dielectric properties of the *Oh* [Zn(MEA)<sub>2</sub>Cl<sub>2</sub>]<sup>27</sup> and *Oh* [Hg(MEA)<sub>2</sub>Cl<sub>2</sub>] complexes, the effect of changing the central metal ion on both  $\epsilon$  and  $\text{tg } \delta$  can be seen. In both complexes the relative permittivity values increase with increasing temperature. The relative permittivity value ranges were found to be 12 – 24 and 4 – 8 and the  $\text{tg } \delta$  ranges were 0 – 0.4 and 0 – 0.15 for the *Oh* [Zn(MEA)<sub>2</sub>Cl<sub>2</sub>] and *Oh* [Hg(MEA)<sub>2</sub>Cl<sub>2</sub>] complexes, respectively. On the other hand, changing the central metal ion from 3d to 5d, the relative permittivity and the dielectric loss values decrease. The data are fairly in harmony with the physical properties of the metal, especially from its electronic structure.

TABLE II. Dielectric parameters obtained from the analysis of Cole-Cole diagrams for the cadmium and mercury amino alcohol complexes.

| $T$  | $U$ | $V$ | $\phi$ | $\alpha$ | $f$    | $\epsilon_0$ | $\epsilon_0$ | $\epsilon_{00}$ | $\epsilon$ |
|--|-----|-----|--------|----------|--------|--------------|--------------|-----------------|------------|
| Td [Cd(MEA)SO <sub>4</sub> ]               |     |     |        |          |        |              |              |                 |            |
| 210  | 4.7 | 2   | 28     | 24.2     | 100    | 6E+05        | 13           | 10.5            | 6E+05      |
| 220  | 3.6 | 2   | 48     | 30.57    | 500    | 11280        | 18.5         | 11              | 9756       |
| 230  | 3.5 | 2.7 | 41     | 26.11    | 100    | 1.078        | 28           | 11              | 0.86       |
| 240  | 4   | 3.3 | 50.51  | 32.17    | 200    | 0.32         | 28           | 12              | 0.259      |
| 250  | 4.6 | 3.5 | 36     | 22.93    | 200    | 0.319        | 47           | 5               | 0.224      |
| 260  | 3.3 | 2.5 | 33.5   | 21.34    | 500    | 0.09         | 26.5         | 12.5            | 0.074      |
| 280  | 7.5 | 1.4 | 9      | 5.732    | 500    | 0.897        | 31           | 14              | 0.733      |
| 290  | 7.7 | 1.6 | 2.073  | 1.32     | 500    | 5E-04        | 414          | 100             | 4E-04      |
| 300  | 7.7 | 2   | 0      | 0        | 500    | 8e-05        | 50.22        | 19.35           | 7E-05      |
| $\Delta E = 15.7$ kJ/mol                   |     |     |        |          |        |              |              |                 |            |
| Oh [Cd(MEA) <sub>2</sub> SO <sub>4</sub> ] |     |     |        |          |        |              |              |                 |            |
| 300  | 5   | 2   | 23     | 14.65    | 100    | 430.3        | 5.51         | 5.05            | 418.3      |
| 280  | 2.5 | 4   | 31     | 19.75    | 13000  | 2E-09        | 5.85         | 5.3             | 2E-09      |
| 270  | 4   | 4   | 30     | 19.11    | 13000  | 1E-05        | 5.86         | 5.31            | 1E-05      |
| 260  | 3.5 | 4   | 33     | 21.02    | 13000  | 8E-07        | 5.825        | 5.3             | 8E-07      |
| 250  | 3.5 | 3.8 | 34     | 21.66    | 130000 | 2E-06        | 5.835        | 5.23            | 2E-06      |
| 240  | 3.4 | 3.6 | 35     | 22.29    | 13000  | 4E-06        | 5.832        | 5.33            | 4E-06      |
| 230  | 3.5 | 4   | 34     | 21.66    | 13000  | 8E-07        | 5.825        | 5.3             | 8E-07      |
| 220  | 3.5 | 3.8 | 34     | 21.66    | 13000  | 2E-06        | 5.85         | 5.3             | 2E-06      |
| 210  | 5.2 | 3   | 29     | 18.47    | 12000  | 0.198        | 5.89         | 5.31            | 0.191      |
| $\Delta E = 14.1$ kJ/mol                   |     |     |        |          |        |              |              |                 |            |
| Td [Cd(DEA)SO <sub>4</sub> ]               |     |     |        |          |        |              |              |                 |            |
| 160  | 4.6 | 2.5 | 34     | 10.83    | 12000  | 0.005        | 5.77         | 5.375           | 0.005      |
| 170  | 2.5 | 1.5 | 54     | 17.2     | 5000   | 0.125        | 0.326        | 0.12            | 0.099      |
| 180  | 2.8 | 1.3 | 50     | 10.33    | 5000   | 0.041        | 0.306        | 0.12            | 0.033      |
| 190  | 2.5 | 1.3 | 55     | 17.52    | 5000   | 1.561        | 0.267        | 0.036           | 1.112      |
| 200  | 1.7 | 2   | 54     | 17.2     | 11000  | 1E-06        | 0.864        | 0.304           | 8E-07      |
| 210  | 1.4 | 2.5 | 16     | 5.096    | 12000  | 1E-06        | 0.128        | 0.144           | 1E-06      |
| 220  | 2.5 | 1.5 | 55     | 17.52    | 8000   | 0.092        | 9.4          | 1.875           | 0.067      |
| 230  | 2   | 2.5 | 50     | 15.92    | 11000  | 5E-07        | 0.752        | 0.1             | 4E-07      |
| 240  | 3.5 | 2   | 20     | 6.369    | 11000  | 3E-04        | 2.118        | 0.706           | 2E-04      |
| 280  | 4   | 3   | 37     | 11.78    | 35096  | 1E-04        | 1.854        | 0.417           | 7E-05      |
| $\Delta E = 8.8$ kJ/mol                    |     |     |        |          |        |              |              |                 |            |

TABLE II. Continued

| $T$   | $U$ | $V$ | $\phi$ | $\alpha$ | $f$   | $\iota_0$ | $\epsilon_0$ | $\epsilon_{00}$ | $\iota$ |
|---|-----|-----|--------|----------|-------|-----------|--------------|-----------------|---------|
| <i>Oh</i> [Cd(DEA) <sub>2</sub> SO <sub>4</sub> ] |     |     |        |          |       |           |              |                 |         |
| 210   | 4.7 | 2   | 38     | 24.2     | 100   | 6E+05     | 13           | 10.5            | 6E+05   |
| 300   | 4.6 | 2   | 39     | 24.84    | 3000  | 22325     | 317          | 117             | 17630   |
| 290   | 4.1 | 2.9 | 40     | 25.48    | 3000  | 0.255     | 250          | 98              | 0.203   |
| 270   | 3.1 | 2.4 | 48     | 30.57    | 3000  | 0.103     | 175          | 78              | 0.084   |
| 250   | 2.6 | 1.7 | 57     | 36.31    | 500   | 1042      | 265          | 66              | 781.1   |
| 240   | 3.1 | 1.7 | 54     | 34.39    | 200   | 4E+05     | 290          | 70              | 3E+05   |
| 230   | 3.1 | 2   | 53     | 33.76    | 300   | 911.6     | 91           | 43              | 751.3   |
| 220   | 3   | 2.2 | 52     | 33.12    | 200   | 16.89     | 122          | 50              | 13.57   |
| 210   | 4.4 | 2.2 | 41     | 26.11    | 200   | 28925     | 230          | 50              | 21379   |
| 200   | 3.5 | 2.2 | 50     | 31.85    | 700   | 377.7     | 55           | 30              | 320.5   |
| 190   | 2   | 2.5 | 57     | 36.31    | 300   | 2E-07     | 43           | 27.3            | 2E-07   |
| $\Delta E = 9.6$ kJ/mol                           |     |     |        |          |       |           |              |                 |         |
| <i>Td</i> [Cd(TEA)SO <sub>4</sub> ]               |     |     |        |          |       |           |              |                 |         |
| 300   | 2.5 | 2   | 50     | 31.85    | 7000  | 0.022     | 9.33         | 8.617           | 0.022   |
| 290   | 3.2 | 1.8 | 25     | 15.92    | 7000  | 0.122     | 9.77         | 9.1             | 0.119   |
| 280   | 2.5 | 2.6 | 43     | 27.39    | 8000  | 7E-06     | 9.8          | 9.15            | 7E-06   |
| 260   | 2   | 2.8 | 45     | 28.66    | 8000  | 2E-09     | 9.9          | 9.3             | 2E-09   |
| 250   | 2   | 2.1 | 35     | 22.29    | 10000 | 6E-06     | 10.9         | 9.323           | 5E-06   |
| 240   | 3.6 | 3.6 | 34     | 21.66    | 13000 | 1E-05     | 10.07        | 9.47            | 1E-05   |
| 230   | 3.3 | 3.3 | 42     | 26.75    | 13000 | 1E-05     | 10.7         | 9.85            | 1E-05   |
| 220   | 3.8 | 3.4 | 38     | 24.2     | 13000 | 2E-04     | 10.63        | 9.7             | 2E-04   |
| 210   | 3.7 | 3.4 | 39     | 24.84    | 13000 | 9E-05     | 10.6         | 9.7             | 9E-05   |
| 200   | 4.1 | 3.3 | 33     | 21.02    | 13000 | 9E-04     | 10.8         | 9.8             | 9E-04   |
| 190   | 4   | 3.4 | 35     | 22.29    | 13000 | 4E-04     | 10.7         | 9.7             | 4E-04   |
| 160   | 5.3 | 3.6 | 31     | 19.75    | 12000 | 0.019     | 10.4         | 9.47            | 0.018   |
| $\Delta E = 10.8$ kJ/mol                          |     |     |        |          |       |           |              |                 |         |
| <i>Oh</i> [Cd(TEA) <sub>2</sub> SO <sub>4</sub> ] |     |     |        |          |       |           |              |                 |         |
| 300   | 4.6 | 2.3 | 20     | 12.74    | 3000  | 0.181     | 15.27        | 13.1            | 0.173   |
| 290   | 3   | 3.5 | 40     | 25.48    | 7000  | 5E-07     | 14.7         | 12.5            | 5E-07   |
| 280   | 7.3 | 3.5 | 0      | 0        | 2000  | 4E-05     | 15.3         | 11.5            | 4E-05   |
| 270   | 3.6 | 3.8 | 20     | 12.74    | 13000 | 6E-06     | 13.65        | 10.5            | 6E-06   |
| 260   | 6.5 | 3.5 | 10     | 6.369    | 12000 | 4E-04     | 13.1         | 10              | 3E-04   |
| 250   | 2.8 | 2.7 | 23     | 14.65    | 11000 | 2E-05     | 12.45        | 9.65            | 2E-05   |
| 240   | 3.5 | 3.8 | 23     | 14.65    | 13000 | 4E-06     | 11.35        | 9.75            | 4E-06   |
| 230   | 6.4 | 3.4 | 15     | 9.554    | 10000 | 0.004     | 11.5         | 9.2             | 0.003   |

TABLE II. Continued

| $T$   | $U$ | $V$ | $\phi$ | $\alpha$ | $f$   | $\epsilon_0$ | $\epsilon_\infty$ | $\epsilon_0$ | $\epsilon_\infty$ | $\epsilon_0$ |
|---|-----|-----|--------|----------|-------|--------------|-------------------|--------------|-------------------|--------------|
| 220   | 4.4 | 3.4 | 9      | 5.732    | 13000 | 4E-05        | 10.8              | 9.6          | 4E-05             |              |
| 210   | 4.3 | 5   | 20     | 12.74    | 1000  | 3E-05        | 10.35             | 9.1          | 3E-05             |              |
| 200   | 5.7 | 4.5 | 11     | 7.006    | 12000 | 5E-05        | 11.15             | 9.75         | 5E-05             |              |
| 130   | 5.7 | 4   | 14     | 8.917    | 13000 | 2E-04        | 10.48             | 9.2          | 2E-04             |              |
| $\Delta E = 23.9$ kJ/mol                          |     |     |        |          |       |              |                   |              |                   |              |
| <i>Oh</i> [Hg(MEA) <sub>2</sub> Cl <sub>2</sub> ] |     |     |        |          |       |              |                   |              |                   |              |
| 300   | 4.3 | 4   | 27     | 17.2     | 13000 | 4E-05        | 18.8              | 12.6         | 4E-05             |              |
| 290   | 6   | 4   | 8      | 5.096    | 6E-05 | 18.2         | 12.9              | 6E-05        |                   |              |
| 280   | 6   | 3   | 19     | 12.1     | 3000  | 0.117        | 15.8              | 12.6         | 0.109             |              |
| 270   | 6.4 | 3   | 14     | 8.917    | 100   | 0.642        | 15.15             | 12.36        | 0.602             |              |
| 260   | 7   | 2.2 | 10     | 6.369    | 100   | 0.796        | 15.3              | 12.35        | 0.745             |              |
| 250   | 6   | 3.5 | 12     | 7.643    | 100   | 0.057        | 14.45             | 12.25        | 0.054             |              |
| 240   | 1.6 | 4   | 40     | 25.48    | 11000 | 3E-15        | 14.2              | 12.7         | 3E-15             |              |
| 230   | 1.4 | 2.5 | 47     | 29.94    | 5000  | 2E-12        | 14.7              | 13.55        | 2E-12             |              |
| 220   | 5.2 | 3   | 26     | 16.56    | 13000 | 0.064        | 16                | 14           | 0.061             |              |
| 210   | 3   | 3.5 | 26     | 16.56    | 12000 | 1E-06        | 15.1              | 13.5         | 1E-06             |              |
| $\Delta E = 13.9$ kJ/mol                          |     |     |        |          |       |              |                   |              |                   |              |
| <i>Oh</i> [Hg(DEA) <sub>2</sub> Cl <sub>2</sub> ] |     |     |        |          |       |              |                   |              |                   |              |
| 190   | 6   | 3.3 | 15     | 9.554    | 11000 | 0.002        | 11.95             | 10.1         | 0.002             |              |
| 200   | 6   | 3.4 | 19     | 12.1     | 11000 | 0.008        | 12.1              | 10.2         | 0.008             |              |
| 210   | 7   | 2.5 | 11     | 7.006    | 11000 | 0.007        | 12.2              | 10.4         | 0.007             |              |
| 230   | 4.5 | 3.5 | 31     | 19.75    | 13000 | 0.001        | 11.95             | 10.4         | 0.001             |              |
| 240   | 5.5 | 5.5 | 22     | 14.01    | 12000 | 1E-05        | 12.29             | 10.45        | 1E-05             |              |
| 260   | 4.5 | 3   | 33     | 21.02    | 12000 | 0.044        | 12.9              | 10.35        | 0.042             |              |
| 280   | 4.7 | 2.7 | 34     | 21.66    | 2000  | 7.475        | 17.5              | 10           | 6.407             |              |
| 290   | 3.5 | 3   | 42     | 26.75    | 500   | 0.017        | 15.7              | 10           | 0.015             |              |
| 300   | 4.5 | 4.4 | 22     | 14.01    | 70    | 0.003        | 29                | 14.4         | 0.003             |              |
| $\Delta E = 9.7$ kJ/mol                           |     |     |        |          |       |              |                   |              |                   |              |

A similar trend was observed by comparing the dielectric behaviour of the *Oh* [Zn(MEA)<sub>2</sub>SO<sub>4</sub>] and *Oh* [Cd(MEA)<sub>2</sub>SO<sub>4</sub>] complexes.

#### Methods of calculations

The locus  $\epsilon'$ , real value of permittivity, and  $\epsilon''$ , imaginary value of permittivity, for various frequencies in rectangular axes of coordinates  $\epsilon'$ ,  $\epsilon''$  should form a semi-circle for polar compounds, with the center lying axis with coordinates  $(\epsilon_0 \pm \epsilon_\infty)/2$ .<sup>28</sup>

$\epsilon_0$  is the static permittivity at direct voltage and  $\epsilon_\infty$  is the optical permittivity for very high frequencies approaching the frequencies of light oscillators.<sup>28</sup>

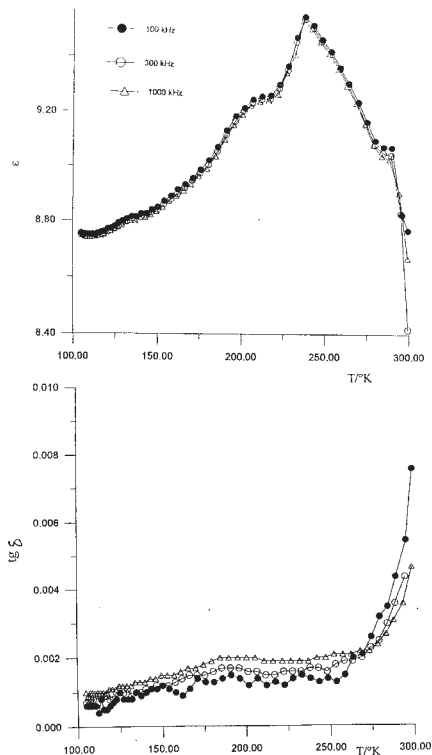


Fig. 5. Permittivity and dielectric loss dependence on temperature at different frequencies for the *Td*  $[\text{Cd}(\text{TEA})\text{SO}_4]$  complex.

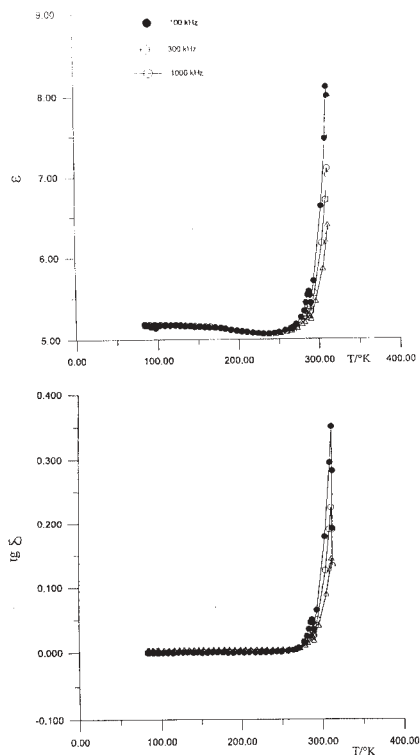


Fig. 6. Permittivity and dielectric loss dependence on temperature at different frequencies for the *Oh*  $[\text{Cd}(\text{TEA})_2\text{SO}_4]$  complex.

The dielectric loss,  $\text{tg } \delta$ , value depends on various external factors. The behaviour of the dielectric loss at the low frequencies is related to the character of the phase transition. In some cases, nucleation of a new phase and the further growth of the nuclei are regarded as the main source of the peak value for  $\text{tg } \delta$  at the phase transition temperature.

The familiar dielectric function,  $\epsilon$ , may be expressed in terms of:  $\epsilon = \epsilon' - i\epsilon''$  ( $i = \sqrt{-1}$ ,  $\epsilon'$  and  $\epsilon''$  have both been defined before).

A semi circle is obtained on plotting  $\epsilon'$  against  $\epsilon''$  for each temperature. The centers of the semi-circles lie below the abscissa axes. This semi-circle Cole-Cole diagram has been used to determine the distribution parameter  $\alpha$ , the macroscopic relaxation time  $\tau_0$  and the molecular relaxation time  $\tau$ .<sup>28,29</sup> Knowing  $\alpha$ ,  $\tau_0$  can be determined using the relation:  $U/V = (\omega\tau_0)^{1-\alpha}$ .  $U$  is the distance on the Cole-Cole diagram between the static dielectric constant  $\epsilon_0$  and the experimental point,  $V$  is the distance between that point and the optical dielectric constant,  $\epsilon_\infty$  and  $\omega$  is the angular frequency,  $\omega = 2\pi\nu$ . The parameter  $\alpha$  equals zero when the compound has only one relaxation time, whereas, for a series of relaxation times, the value of  $\alpha$  varies between 0 and 1. The extent of the distribution of relaxation times increases with increasing parameter  $\alpha$ . On the other hand, the value of  $\tau_0$  decreases with increasing temperature.<sup>29</sup> The molecular relaxation



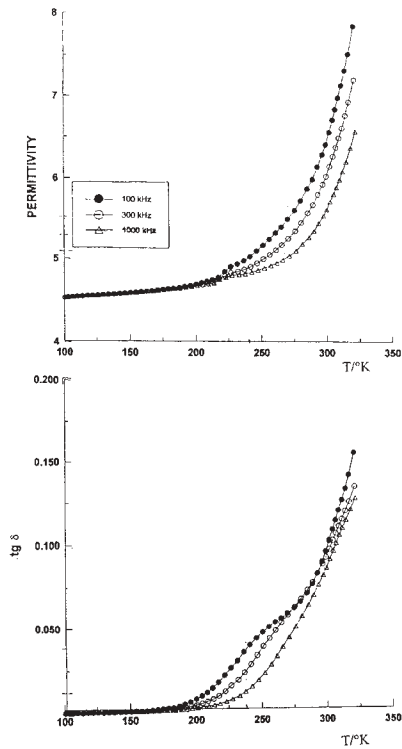


Fig. 7. Permittivity and dielectric loss dependence on temperature at different frequencies for the  $Oh$   $[\text{Hg}(\text{MEA})_2\text{Cl}_2]$  complex.

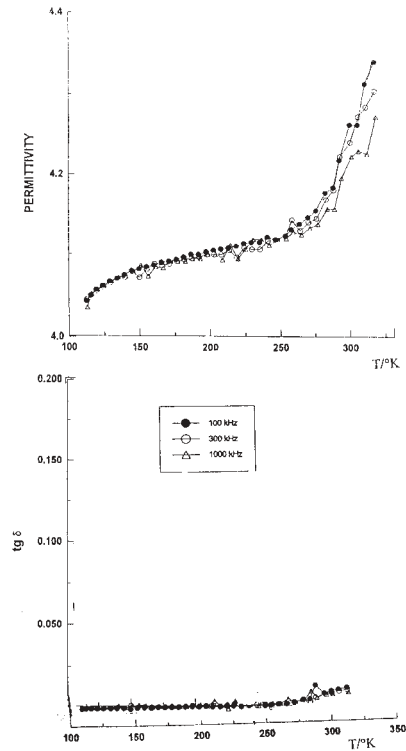


Fig. 8. Permittivity and dielectric loss dependence on temperature at different frequencies for the  $Oh$   $[\text{Hg}(\text{DEA})_2\text{Cl}_2]$  complex.

time  $\tau$  could be determined based on the following equation:<sup>29</sup>

$$\tau = \frac{2\varepsilon_0 + \varepsilon_\infty}{3\varepsilon_0} \tau_0$$

The temperature dependence of  $\tau$  can be expressed by a thermally activated process in the frame of an Arrhenius concept of the type:<sup>30,31</sup>  $\tau = \tau_0 \exp(-E_0/kT)$ , where  $\tau_0$  is a constant characteristic of the relaxation time and represents the time of a single oscillation of a dipole in a potential well.  $E_0$  is the energy of activation for the relaxation of the dipole,  $\tau$  represents the average or most probable value of the spread of the relaxation times.

In conclusion, the relative permittivity and dielectric loss values for the amino alcohol complexes indicate a dipolar mechanism of polarization.

The data reveals semi-conducting features based mainly on the hopping mechanism.

## ИЗВОД

ДИЕЛЕКТРИЧНЕ ОСОБИНЕ НЕКИХ КОМПЛЕКСА КАДМИЈУМА И ЖИВЕ СА  
АМИНО–АЛКОХОЛИМА НА НИСКИМ ТЕМПЕРАТУРЕАМАMAMDOUH S. MASOUD<sup>a</sup>, AHMED M. HAFEZ<sup>b</sup>, M. SH. RAMADAN<sup>a</sup> and ALAA E. ALI<sup>c</sup><sup>a</sup>Chemistry Department, Faculty of Science, Alexandria University, Alexandria, Egypt, <sup>b</sup>Physics Department, Faculty of Science, Alexandria University, Alexandria, Egypt and <sup>c</sup>Physics & Chemistry Department, Faculty of Education "Damanhour", Alexandria University, Egypt

Проучаване су диелектричне особине неких комплекса кадмијума и живе са аминокиселинама у области температуре 100 – 300 K и на фреквенцијама од 100, 300 и 1000 Hz. Предложени су механизми поларизације, а анализирани су и зависности  $\epsilon$  и  $\tan \delta$  од температуре и фреквенције. Анализа података указује на полупроводничке особине одређене првенствено механизмом прескока.

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