TEMPERATURE DEPENDENCE OF DIELECTRIC RELAXATION OF ABSORPTION SPECTRA IN THE CHLOROBENZENE – IODOBENZENE SYSTEM

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The article presents the results of a study of the temperature dependence of the dielectric constant ε' and the dielectric loss index ε'' of the chlorobenzene-iodobenzene system at wavelengths λ = 6.32; 4.01; 3.21; 2.14; 1.18 and 0.75 V temperature range -40°C÷+30°C. The static dielectric constant was determined at a frequency of 7 MHz. The temperature dependence of the time of dielectric relaxation of molecules in the liquid state was determined. It was established that in the specified temperature-frequency range the dispersion region consists of two parts. Analysis of the temperature dependence of dielectric polarization relaxation in the system chlorobenzene-iodobenzene shows that the relaxation times of the components do not depend on their short-range order. It was also discovered that the rate graph showing the dependence of the logarithm of the relaxation time on the reciprocal of the temperature logτ ~ 1/T, consists of two parts and the value of the static dielectric permeability ε∞ is non-additive. To explain these results, it is assumed that clusters are formed in this system, the same as in the pure components.

Keywords: *Dielectric spectroscopy; Dielectric relaxation; Chlorobenzene; İodobenzene; Bromobenzene*
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INTRODUCTION

In polar liquids, dielectric relaxation is observed in the microwave range, which covers the spectrum of electromagnetic waves with a length from 1 mm to 30 cm [1]. Studying this range makes it possible to study relaxation properties. The interest in the liquids under study is explained by their relatively simple structure, which makes it possible to use existing theories to analyze experimental data. It is known that in chlorobenzene, iodobenzene and bromobenzene there is a small distribution of relaxation times, which decreases with increasing temperature [2]. It is also known that there is a single relaxation time for these same compounds. In this case, the high-frequency limit of the dielectric constant ε∞ of the Cole – Cole diagram turns out to be greater than the square of the refractive index n2 measured in the infrared range [3,4]. This fact is associated with the probable existence of an additional absorption region of a resonant nature in the sub millimeter range, which manifests itself already at wavelengths from 3 to 7 mm. In pure dipole liquids, increased dielectric relaxation times are usually observed compared to their values in dilute solutions. If in the first case the relaxation process is cooperative, then in dilute solutions the relaxation time, as a rule, characterizes an individual molecule. Therefore, studying the dependence of dielectric relaxation on the concentration of polar molecules is of great interest [5–9].

Using the example of earlier studies of binary systems, it can be argued that the concentration dependence of the ratio of relaxation time τ to viscosity η can be used to estimate the degree of clustering of polar molecules. As a result, it was possible to determine a special relaxation mechanism in the case of concentrated solutions of some cyclohexane derivatives in non-polar solvents [10, 11].

Monohalogen derivatives of benzene are compounds with small rigid molecules, the interactions between which are described predominantly by van der Waals forces. Knowledge of the equilibrium and dynamic dielectric properties of such relatively simple objects is necessary when deciphering the dielectric behavior of systems with different types of relaxers and complicated intermolecular interactions. Analysis of the temperature dependences of the dielectric coefficients of three members of the series chlorobenzene (C_6H_5Cl), bromobenzene (C_6H_5Br), iodobenzene (C_6H_5J), taken in the microwave range for pure liquids and their concentrated solutions in benzene (C_6H_6) and hexane (C_6H_{14}), showed that the kinetic units responsible for the observed absorption are individual molecules [7–11]. It should be noted that dipole – dipole forces do not have a significant effect on the shape of the absorption curve. In addition, indirect indications were obtained of the existence of another absorption region, a resonant type, at higher frequencies.

This work was carried out with the aim of further accumulating experimental data on the nature and mechanism of microwave absorption in the compounds under study. The choice of a polar mixture is explained by the desire to trace the kinetic behavior of each component separately, which is important for studying the influence of short-range order on the process of molecular relaxation.

MATERIALS AND RESEARCH METHODS

Dielectric constants ε′ and dielectric losses ε″ of the chlorobenzene – iodobenzene system were measured at wavelengths λ = 6.32; 4.01; 3.21; 2.14; 1.18; 0.75 cm in the temperature range –40° ÷ +30°C, with a volumetric ratio

of components of 1:1. Within the same temperature limits, the equilibrium dielectric constants ε_0 of the system were measured at a frequency of 7 MHz.

Measurements of dielectric constant ε' and dielectric losses ε'' were carried out using the variable thickness method [12 – 14] on six installations that differed only in the cross-sectional sizes of the waveguides. Particular attention was paid to eliminating impedance transformation in the measuring path and ensuring reliable thermal insulation of the measuring cell from the rest of the path and the environment. The measurement errors are: 1% for the dielectric constant ε' and 1 – 3% for the dielectric loss index ε'' at $\lambda = 6.32$; 4.01; 3.21; 2.14 cm, 2% for dielectric constant ε' and 3 – 5% for dielectric loss index ε'' at $\lambda = 1.18$ and 0.75 cm.

Equilibrium measurements were carried out using the resonance method [15– 7]. The measuring cell consisted of a silver-plated cylindrical capacitor equipped with a heat-insulating shell. The cell temperature was changed by continuous heating at a rate of 0.2 degrees/min. The capacitor was calibrated for hexane, benzene, chlorobenzene and acetone. The error in the equilibrium dielectric constant ε_0 did not exceed 1%. The temperature of the samples was measured with a copper constantan thermocouple with an error of ~0.3°. The components of the mixture and compounds taken for control measurements were carefully dried and distilled on a distillation column. The purity of the compounds was checked by boiling point values and optical refractive indices. All measurements were carried out only on samples of the "high grade" brand.

RESULTS AND DISCUSSION

Table 1 summarizes the measurement data for ε', ε'' and ε_0. The shift of the maximum in the $\varepsilon''(\lambda)$ curves towards shorter wavelengths with increasing temperature indicates the relaxation origin of the studied absorption (Fig. 1).

Table 1. Dielectric coefficients of the chlorobenzene – iodobenzene system

| T, °C	ε_0	$\lambda = 6.32$		$\lambda = 4.01$		$\lambda = 3.21$		$\lambda = 2.14$		$\lambda = 1.18$		$\lambda = 0.75$	
		ε'	ε''	ε'	ε''	ε'	ε''	ε'	ε''	ε'	ε''	ε'	ε''
30	5.19	4.69	0.98	4.25	1.21	4.00	1.26	3.55	1.23	3.00	0.96	2.79	0.73
20	5.29	4.65	1.09	4.20	1.26	3.94	1.28	3.48	1.21	2.98	0.91	2.79	0.69
10	5.38	4.57	1.19	4.10	1.31	3.82	1.31	3.39	1.19	2.96	0.86	2.78	0.65
0	5.48	4.49	1.20	4.00	1.36	3.72	1.31	3.32	1.14	2.94	0.81	2.78	0.61
-10	5.59	4.41	1.36	3.90	1.37	3.61	1.29	3.24	1.10	2.92	0.76	2.78	0.59
-20	5.70	4.34	1.41	3.77	1.35	3.20	1.25	3.17	1.03	2.90	0.70	2.78	0.55
-30	5.82	4.23	1.45	3.64	1.32	3.39	1.18	3.10	0.95	2.88	0.64	2.78	0.52
-40	5.95	4.12	1.49	3.50	1.29	3.28	1.12	3.04	0.89	2.86	0.58	2.78	0.49
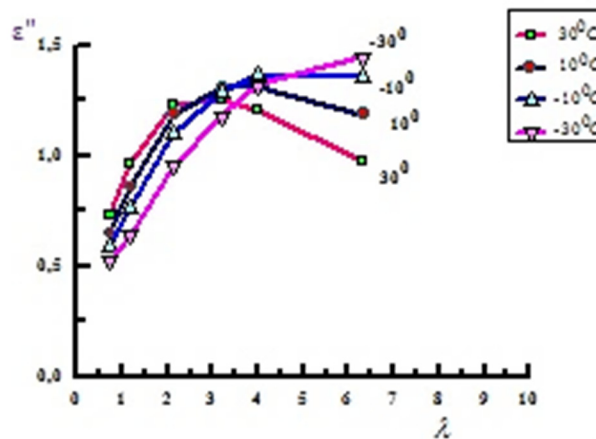
Figure 1. Dependence of the absorption index ε'' on the wavelength (λ cm) at different temperatures.

According to the arc diagrams, the frequency variation of the dielectric constant ε' and the dielectric losses ε'' of the mixture are described by the Cole – Cole equation [18]:

$$\varepsilon' - i\varepsilon'' = \varepsilon_\infty + (\varepsilon_0 - \varepsilon_\infty)\left[1 + (i\omega\tau)^{1-\alpha}\right], \tag{1}$$

or

$$\frac{\varepsilon' - \varepsilon_\infty}{\varepsilon_0 - \varepsilon_\infty} = \frac{1 + (\omega\tau)^{1-\alpha}\sin\frac{\alpha\pi}{2}}{1 + 2(\omega\tau)^{1-\alpha}\sin\frac{\alpha\pi}{2} + (\omega\tau)^{2(1-\alpha)}}, \tag{2}$$

$$\frac{\varepsilon''}{\varepsilon_0 - \varepsilon_\infty} = \frac{(\omega\tau)^{1-\alpha}\cos\frac{\alpha\pi}{2}}{1 + 2(\omega\tau)^{1-\alpha}\sin\frac{\alpha\pi}{2} + (\omega\tau)^{2(1-\alpha)}}, \tag{3}$$

where α is the parameter of the symmetric distribution of dielectric relaxation time values around the most probable value of the relaxation time τ, the equilibrium dielectric constant ε_0 and ε_∞ - low and high frequency dispersion limits.

The discrepancies between the measured values of the equilibrium dielectric constant ε_0 and those extrapolated from the arc diagrams are less than 1%, and for all temperatures the relation is satisfied with the same accuracy

$$\varepsilon_0 = \varepsilon_{01} x_1 + \varepsilon_{02} x_2, \tag{4}$$

where indices 1 and 2 refer, respectively, to iodine and chlorobenzene, x is the mole fraction.

Additively is violated for the high-frequency (HF) limit and the value of the dielectric constant of the high-frequency limit ε_∞ of the mixture coincides with the value of the dielectric constant of the high-frequency limit ε_∞ of pure chlorobenzene. Thus, at 20°C HF is the limit of the dielectric constant of chlorobenzene ($C_6H_5C_1$) $\varepsilon_\infty = 2.56$ HF is the limit of the dielectric constant of iodobenzene ε_∞ (C_6H_5J) = 2.76, HF is the limit of the dielectric constant of the chlorobenzene - iodobenzene system $\varepsilon_\infty = 2.57 \pm 0.02$. The values of ε_∞ and α found from arc diagrams are given in Table 2.

Table 2. High-frequency dielectric constants ε_∞ and distribution parameters α of the relaxation time of the chlorobenzene - iodobenzene system

T°C	30	20	10	0	-10	-20	-30	-40
ε_∞	2.53	2.57	2.60	2.62	2.64	2.66	2.69	2.71
α	0.030	0.032	0.038	0.039	0.042	0.046	0.049	0.050

Table 3 presents the values of relaxation time τ, determined from points on arc diagrams according to expression (5):

$$(\omega\tau)^{1-\alpha} = [(\varepsilon_0 - \varepsilon')^2 + \varepsilon''^2]^{1/2} \quad [(\varepsilon' - \varepsilon_\infty)^2 + \varepsilon''^2]^{-1/2} \tag{5}$$

Table 3. Relaxation time τ (10^{-12} sec) of the chlorobenzene–iodobenzene system according to equation (1) at different wavelengths

T°C \\ λ (cm)	6.32	4.01	3.21	2.14	1.18	0.75	τ_{cp}
30	15.1	15.3	15.2	14.7	14.4	13.9	15.1
20	17.6	17.0	16.9	16.6	16.0	15.1	17.0
10	20.5	19.5	19.6	18.8	17.9	16.8	19.6
0	23.6	22.1	22.2	21.4	20.2	18.6	22.3
-10	26.7	25.0	25.2	24.4	22.6	20.3	25.3
-20	29.8	29.3	29.5	28.4	26.1	23.0	29.3
-30	34.2	34.4	34.8	33.6	30.6	25.7	34.2
-40	39.2	40.3	41.1	39.6	36.0	28.7	40.1

The average values of relaxation time τ indicated in the last column of Table 3 were obtained by averaging the values of relaxation time τ at $\lambda = 6.32$; 4.01; 3.21; 2.14 cm. All these points fall into the maximum region on the curves of the dependence $\varepsilon''(\lambda)$ and the corresponding values of the relaxation time τ deviate from the average values of the relaxation time τ by only 3 – 6%. For two "short-wave" points much larger values are noted deviations that systematically increase with decreasing temperature, which suggests the presence of additional absorption. To check, it is convenient to use the method of linear diagrams. Transformations of equations (1) - (3) allow us to obtain a number of linear relationships:

$$\varepsilon' = -\{a[\varepsilon'' + (\varepsilon' - \varepsilon_\infty)b]\}\omega^{1-\alpha}\tau^{1-\alpha} + \varepsilon_0, \tag{6}$$

$$\varepsilon' - \varepsilon''b = \varepsilon'' \ (a\omega^{1-\alpha})^{-1}\ \tau^{-(1-\alpha)} + \varepsilon_\infty, \tag{7}$$

$$[(\varepsilon'')^{-1} - 2b(\varepsilon_0 - \varepsilon_\infty)^{-1}]\ \omega^{1-\alpha} = [a(\varepsilon_0 - \varepsilon_\infty)]^{-1}\omega^{2(1-\alpha)}\ \tau^{1-\alpha} + [a(\varepsilon_0 - \varepsilon_\infty)]^{-1}\ \tau^{-(1-\alpha)}, \tag{8}$$

$$[(\varepsilon'')^{-1} - 2b(\varepsilon_0 - \varepsilon_\infty)^{-1}]\ \omega^{-(1-\alpha)} = [a(\varepsilon_0 - \varepsilon_\infty)]^{-1}\omega^{-2(1-\alpha)}\ \tau^{-(1-\alpha)} + [a(\varepsilon_0 - \varepsilon_\infty)]^{-1}\ \tau^{1-\alpha}, \tag{9}$$

where $a = \cos\frac{\alpha\pi}{2}, b = tg(\frac{\alpha\pi}{2})$

At $\alpha = 0$, equations (6) – (7) transform into the equations previously obtained by Cole [18]:

$$\varepsilon' = -\varepsilon''\omega\tau + \varepsilon_0, \tag{10}$$

$$\varepsilon' = \varepsilon''(\omega\tau)^{-1} + \varepsilon_\infty. \tag{11}$$

If the experimental data follows equation (1), then graphs constructed using equations (6) – (9) should give straight lines with slopes and intercepts equal to the dispersion parameters.

Equations (7) and (9) allow us to trace in more detail the low frequency (LF) absorption edge, and equation (8) allows us to trace the HF edge.

In Fig. 2 – 5 show examples of line diagrams. In all cases, "long-wave" points ($\lambda = 6.32$; 4.01; 3.21; 2.14 cm) are placed on one straight line segment, the slope of which gives a relaxation time equal to the average relaxation time τ in Table 3. Intersections this segment with the ordinate axis in Fig. 2, 3 coincide with the values of ε_0 and ε_∞ extrapolated from arc diagrams.

Only two points fall on the other segment ($\lambda = 1.18$; 0.75 cm). Poor agreement between the relaxation times τ for them in Table. 3 and lower values of the relaxation time τ at $\lambda = 0.75$ cm mean that the true straight line should have a smaller slope.
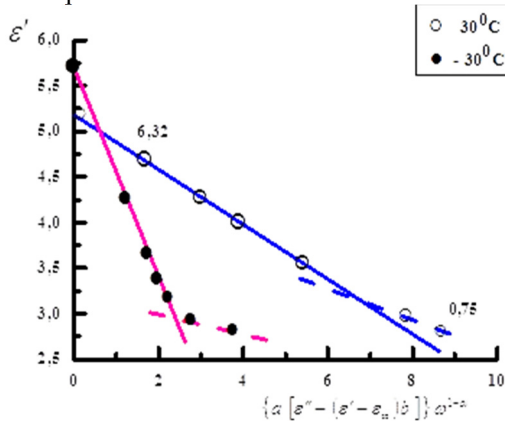
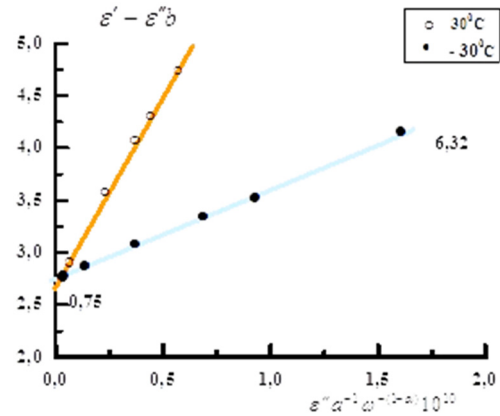**Figure 2.** Linear diagram according to equation (6). Numbers at dots – wavelength (cm)

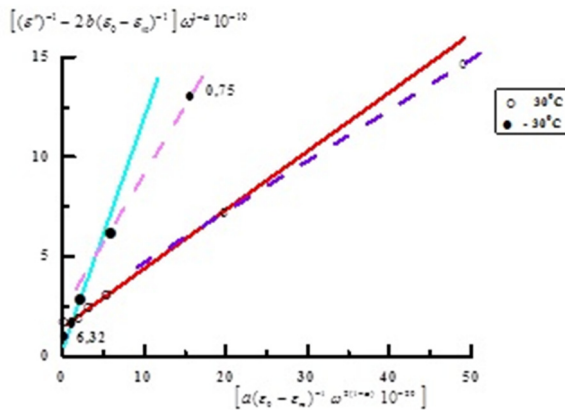**Figure 3.** Line diagram according to equation (7)

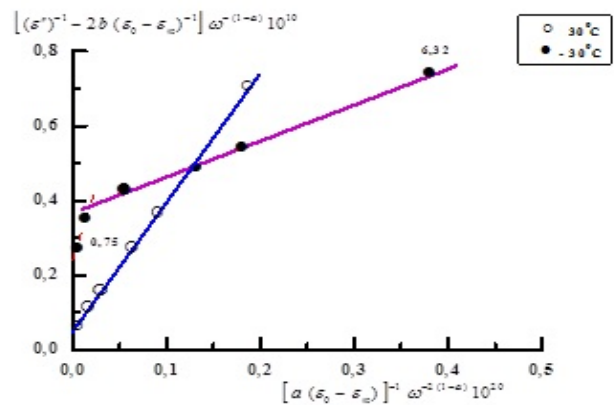**Figure 4.** Line diagram according to equation (8)

Figure 5. Line diagram according to equation (9)

From the above, we can conclude that the absorption described by the "long-wave" points is created by a single mechanism. Meanwhile, on the velocity graph plotted based on the average values of the relaxation time τ, a clear division into two regions is revealed (Fig. 6).
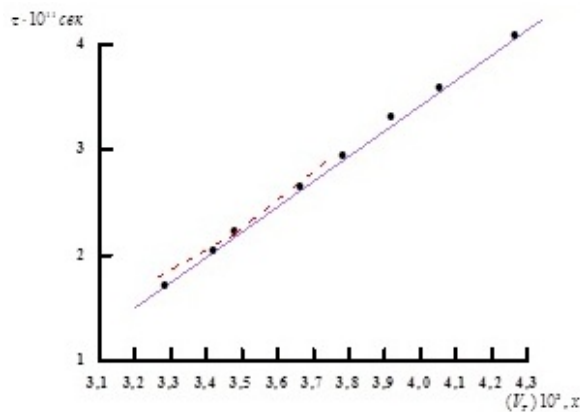

Figure 6. Speed graph built using τ values

In the case of additively of the contributions of both regions to the observed dispersion, we have:

$$\varepsilon' - \varepsilon_{\infty2} = \Delta_1(1 + \omega^2\tau_1^2)^{-1} + \Delta_2(1 + \omega^2\tau_2^2)^{-1}, \tag{12}$$

$$\varepsilon'' = \Delta_1\omega\tau_1(1 + \omega^2\tau_1^2)^{-1} + \Delta_2\omega\tau_2(1 + \omega^2\tau_2^2)^{-1}. \tag{13}$$

Here it is assumed that the HF limit $\varepsilon_{\infty1}$ of the high-temperature region is equal to the HF limit ε_{02} of the low-temperature region, ε_{01} and $\varepsilon_{\infty2}$ correspond to ε_0 and ε_∞ in equation (1), $\tau_1 > \tau_2$.

Equations (12) and (13) are equivalent to the following:

$$\varepsilon' - \varepsilon_{\infty2} = (\varepsilon_{01} - \varepsilon_{\infty2})[C_1(1 + \omega^2\tau_1^2)^{-1} + C_2(1 + \omega^2\tau_2^2)^{-1}], \tag{14}$$

$$\varepsilon'' = (\varepsilon_{01} - \varepsilon_{\infty2})[C_1\omega\tau_1(1 + \omega^2\tau_1^2)^{-1} + C_2\omega\tau_2(1 + \omega^2\tau_2^2)^{-1}], \tag{15}$$

where $C_{1,2}$ is the relative weight of the relaxation process,

$$C_1 + C_2 = 1. \tag{16}$$

Taking into account (12) – (13) and (14) – (15), we have:

$$C_1 = \Delta_1(\varepsilon_{01} - \varepsilon_{\infty2})^{-1}, C_2 = \Delta_2(\varepsilon_{01} - \varepsilon_{\infty2})^{-1}. \tag{17}$$

The results of data processing in terms of equations (12) – (13) and (14) – (15) are summarized in Table 4.

Table 4. Relaxation time ($\tau \cdot 10^{12}$ sec), dispersion amplitudes (Δ_1, Δ_2) and weighting factors according to equations (12)–(13) and (14)–(15)

T, °C	30	20	10	0	-10	-20	-30	-40
τ_1	24.4	27.8	32.0	37.0	43.6	52.5	63.0	77.0
τ_2	11.1	12.3	14.2	16.2	18.2	21.0	25.2	30.0
Δ_1^*	1.04	1.06	1.09	1.12	1.15	2.18	1.22	1.26
Δ_2^*	1.62	1.67	1.70	1.75	1.81	1.85	1.91	1.97
C_1	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39

Taken as initial values, the dispersion parameters of pure components were subject to slight variation [19,20]. The final selection of parameters was determined by the minima of the sum of the root-mean-square deviations of the coefficients calculated using these equations (ε'_{change}, ε''_{change}) from the measured ones (ε', ε''):

$$S = \sum \left\{ [(\varepsilon'_{change} - \varepsilon')(\varepsilon'\xi')^{-1}]^2 + [(\varepsilon''_{change} - \varepsilon'')(\varepsilon''\xi'')^{-1}]^2 \right\}. \tag{18}$$

where ξ', ξ'' are the errors in measuring the dielectric constant ε' and the dielectric loss index ε'' at a given wavelength λ.

To illustrate the degree of agreement between the measured and calculated dielectric coefficients, Table 5 presents the results of calculations assuming the presence of one dispersion region with a relaxation time distribution. And also two regions, each of which has a single relaxation time τ, with different weight factors. Approximately the same agreement is noted when using equations (2) – (3) or (14) – (15) $C_1 = 0.39$, determined by (17) using the estimated values ($\varepsilon_{01} - \varepsilon_{\infty1}$) and found from arc diagrams of values ($\varepsilon_{01} - \varepsilon_{\infty2}$) of dispersion amplitudes. When the value of C changes by ~ 0.1 and the relaxation time τ by 10–15%, the discrepancies with experiment go beyond the calculation errors, which for "long-wavelength" points do not exceed ~5% in the worst case [21,22].

Table 5. Comparison of dielectric constant ε' and dielectric loss index ε'' measured and calculated from (2) - (3) and (14) - (15) at 10°C ($\tau_{av} = 25.3 \cdot 10^{-12}$ sec, $\tau_1 = 43.6 \cdot 10^{-12}$ sec, $\tau_2 = 18.2 \cdot 10^{-12}$ sec)

λ (см)	Measured		Calculated for (2) – (3)		Measured for (14) – (15)					
					$C_1 = 0.39$		$C_1 = 0.48$		$C_1 = 0.39$; $\tau_2 = 16.4 \cdot 10^{-12}$ sec	
	ε'	ε''	ε'	ε''	ε'	ε''	ε'	ε''	ε'	ε''
6.32	4.41	1.36	4.48	1.33	4.46	1.31	4.35	1.33	4.53	1.27
4.01	3.90	1.37	3.89	1.36	3.90	1.34	3.80	1.31	4.00	1.33
3.21	3.61	1.29	3.62	1.30	3.63	1.29	3.54	1.24	3.73	1.29
2.14	3.24	1.10	3.21	1.07	3.22	1.10	3.26	1.03	3.30	1.13
S	----------------		4.87		3.54		24.83		34.72	

The most remarkable result of the analysis performed is the apparent independence of the relaxation time of the mixture components from the short-range order. According to existing theories, the relaxation time τ of a molecule is determined by its structure and short-range order, which is interpreted in terms of viscous inhibition or the degree of order of surrounding molecules, estimated by the entropy term. The relaxation times for chlorine and iodobenzene differ from each other by a factor of 2.2, the viscosity η by a factor of 1.9, while the difference between the molar volumes V is 10%.

Therefore, both within the framework of the Debye model and based on the free volume required to rotate the molecule, the relaxation time of chlorobenzene $\tau_{C_6H_5Cl}$ in the mixture should increase, and the relaxation time of iodobenzene $\tau_{C_6H_5J}$ should decrease, which contradicts experience.

The processes of molecular relaxation are accompanied by structural rearrangements of such large areas of the solution that the individuality of the components becomes insignificant. The exception is solutions composed of associated and non-associated compounds, where the short-range forces are large enough to maintain the stability of regions consisting of molecules of the same type. From this it was concluded that in systems with one relaxation time τ (mixtures of two associated or two unassociated liquids) there is complete solubility at the molecular level. Whereas in the presence of two relaxation times τ, the degree of mixing is determined by the magnitude of the deviation of the relaxation time and from the values for pure components.

It should be noted that the solution we are studying is of the normal type. According to the phase diagram, the components of the mixture have unlimited mutual solubility. Finally, the values of ε0 and η of the mixture obey the additivity rule. On the other hand, analysis of the equilibrium polarization of the mixture leads to the conclusion that there are deviations of the correlation parameter from unity, which are especially noticeable with decreasing temperature [23]. The presence of two relaxation times τ at room temperature does not necessarily contradict the low-temperature results, because with increasing temperature the lifetime and size of the regions covered by relaxation can become negligibly small. However, we also noted a division into two relaxation times τ at relatively low temperatures. Finally, it is hardly possible to explain on the basis of molecular mixing such facts as the curvature in the velocity graph and the non-additivity of ε∞. The assumption that the act of orientation is highly localized as a possible reason for the invariance of the relaxation time τ in solution also appears untenable. Since with the transition from chlorine - through bromine - to iodobenzene, the difference between the activation energies for viscous flow and rotational motion tends to zero.

CONCLUSIONS

1. For a consistent interpretation of the entire set of experimental facts, the presence of clusters that preserve the structure of pure components is accepted.
2. In the compounds under study, reorientation of the molecules included in the clusters is possible only after the disintegration of the latter.
3. The duration of existence of clusters should not significantly exceed the time of rotation of molecules, as a result of which the relaxation time is determined by the sum of these quantities.
4. In the series $C_6H_6 – C_6H_5Cl – C_6H_5J$ the values of V are in the ratio 0.9:1.0:1.1, and ~40% decrease in the relaxation time of chlorobenzene $\tau_{C_6H_5Cl}$ in an equimolar benzene solution correlates well with the same decrease upon transition from the relaxation time of iodobenzene $\tau_{C_6H_5J}$ to the average relaxation time τav of the system chlorobenzene – iodobenzene $C_6H_5Cl – C_6H_5J$.

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REFERENCES

[1] S.T. Azizov, AJP Phys. **2**, 18 (2020). http://physics.gov.az/physart/251_2020_02_20_en.pdf
[2] S.T. Azizov, Phys. New. **5**, 118 (2020). http://physics.gov.az/Transactions/2020/journal2020(5).pdf. (in Russian)
[3] S.T. Azizov, O.A. Aliyev, and K.E. Zulfugarzade, APJ Phys. **4,** 22 (2017). http://www.physics.gov.az/physart/164_2017_04_22_en.pdf
[4] S.T. Azizov, and O.A. Aliyev, AJP Phys. **3**, 14 (2018). http://physics.gov.az/physart/008_2018_03_14_az.pdf. (in Russian)
[5] D. Kumar, S. Nand, and S. Sahoo, J. Solution Chem. **50**, 690 (2021). https://doi.org/10.1007/s10953-021-01085-4
[6] T. Bachhar, S. Sit, S. Laskar, and S. Sahoo, Bull. Mater. Sci. **44**, 120 (2021). https://doi.org/10.1007/s12034-021-02366-w
[7] F. Kremer, and A. Schonhals, *Broadband Dielectric Spectroscopy*, **12**, 729 (2002). https://link.springer.com/book/10.1007/978-3-642-56120-7
[8] J.P. Poley, Appl. Sci. Res. **4,** 337 (1955). https://doi.org/10.1007/BF02920014
[9] S. Murakami, Y. Akutsu, S. Habaue, O. Haba, and H. Higashimura, Nat. Sci. **2,** 803 (2010). https://doi.org/10.4236/ns.2010.28101
[10] A.J. Van Eick, and J.Ph. Poley, J. Appl. Sci. Res. **6**, 359 (1957). https://doi.org/10.1007/BF02920392
[11] V.A. Durov, and O.G. Tereshin, J. Phys. Chem. B, **110**, 8441 (2006). https://doi.org/10.1021/jp056541y
[12] S.A. Abdel-Latif, and S.E. Mansour, Nat. Sci. **2**, 793 (2010). https://doi.org/10.4236/ns.2010.28100
[13] A. Pillay, M. Elkadi, F. Feghali, S.C. Fok, G. Bassioni, and S. Stephen, Nat. Sci. **2,** 809 (2010). https://doi.org/10.4236/ns.2010.28102
[14] E.Y. Salaev, E.R. Gasimov, S.T. Azizov, and Ch.O. Qajar, Turk. J. of Phys. **5**, 389 (1998). https://journals.tubitak.gov.tr/physics/vol22/iss5/4/
[15] D.M. Fouad, A. Bayoumi, M.A. ElGahami, S.A. Ibrahim, and A.M. Hammam, Nat. Sci. **2**, 817 (2010). https://doi.org/10.4236/ns.2010.28103
[16] A.H. Rageh, S.R. El-Shaboury, G.A. Saleh, and F.A. Mohamed, Nat. Sci. **2**, 828 (2010). https://doi.org/10.4236/ns.2010.28104
[17] S.R. Kasimova, Meas. Tech. **58**, 1372 (2016). https://doi.org/10.1007/s11018-016-0901-9
[18] R.H. Cole, The J. of Chem. Phys. **23**, 493 (1955). https://doi.org/10.1063/1.1742017
[19] R. Aipova, S.A. Aitkeldiyeva, A.A. Kurmanbayev, A.K. Sadanov, and O.B. Topalova, Nat. Sci. **2,** 841 (2010). https://doi.org/10.4236/ns.2010.28105

[20] C.D. Abeyrathne, M.N. Halgamuge, P.M. Farrell, and E. Skafidas, Phys. Chem. Chem. Phys. **16**, 13943 (2014). https://doi.org/10.1039/C4CP00716F

[21] T.M. Mohan, S.S. Sastry, and V.R.K. Murthy, J. of Molec. Struc. **12**, 157 (2010). https://doi.org/10.1016/j.molstruc.2010.03.065

[22] K. Sorimachi, Nat. Sci. **2,** 846 (2010). https://doi.org/10.4236/ns.2010.28106

[23] C.J.F. Böttcher, and P. Bordewijk, *Theory of Electric Polarization*, (Elsevier, Amsterdam, 1978).

ТЕМПЕРАТУРНА ЗАЛЕЖНІСТЬ ДІЕЛЕКТРИЧНОЇ РЕЛАКСАЦІЇ СПЕКТРІВ ПОГЛИНАННЯ У СИСТЕМІ ХЛОРБЕНЗОЛ – ЙОДОБЕНЗОЛ

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У статті наведено результати дослідження температурної залежності діелектричної проникності ε' та показника діелектричних втрат ε" системи хлорбензол-йодбензол в діапазоні довжин хвиль λ = 6,32; 4,01; 3,21; 2,14; 1,18 та 0,75 та у температурному інтервалі -40℃÷+30℃ Визначено статичну діелектричну проникність на частоті 7 МГц. Визначено температурну залежність часу діелектричної релаксації молекул у рідкому стані. Встановлено, що у вказаному діапазоні частот температури дисперсійна область складається з двох частин. Аналіз температурної залежності діелектричної релаксації поляризації в системі хлорбензол-йодбензол показує, що часи релаксації компонентів не залежать від їх ближнього порядку. Також виявлено, що графік швидкості, який показує залежність логарифму часу релаксації від величини, зворотної до температури logτ ~ 1/T, складається з двох частин, а значення статичної діелектричної проникності ε∞ є неаддитивним. Для пояснення цих результатів зроблено припущення, що в цій системі утворюються кластери, як і в чистих компонентах.

Ключові слова: *діелектрична спектроскопія; діелектрична релаксація; хлорбензол; йодобензол; бромбензол*