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REFLECTIONLESS ABSORPTION OF SUPERHIGH-FREQUENCY RADIATION IN SOLUTIONS OF METHYL ETHYL KETONE AND METHYL ISOBUTYL KETONE IN *n*-HEPTANE

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Investigations of dielectric properties of solutions of methyl ethyl ketone and methyl isobutyl ketone in n-heptane in a microwave range established the existence, in these solutions, of a spectrum of concentrations and thicknesses of the solution layer at which resonant reflectionless radiation absorption originates.

The obtaining and study of materials absorbing electromagnetic radiation without its noticeable reflection, which are based on solutions of a polar substance in a nonpolar solvent, are of scientific and practical interest. They can be used as composite fillers for producing reflectionless coatings.

Analysis of results presented in [1, 2] showed that, in a polar dielectric exhibiting wave dispersion and applied to a metal substrate, total (reflectionless) absorption of electromagnetic radiation passing through it and reflected from the conducting surface may occur under certain conditions. Since the experimental detection of this effect in a pure dielectric is complicated by the need for employing more complex facilities, as the object of investigation we used solutions of polar substances in a nonpolar solvent. Reflectionless absorption is, in this case, attained by changing the composition and thickness of the solution.

According to experimental studies [3, 4] and taking into account that dispersion of methyl ethyl ketone and methyl isobutyl ketone occurs in the microwave region, reflectionless absorption of electromagnetic radiation was considered in their solutions with *n*-heptane at wavelengths λ = 4.28, 10.0, and 20.0 mm and a temperature of 20°C. Reflective characteristics of these solutions were measured using panoramic standing-wave meters R2-66, R2-67, and R2-69 and the attached measuring waveguide cells short-circuited at the end, which, in turn, contained a device for smooth control of the thickness of the solution layer. From experimental dependences of the modulus of the reflection coefficient ρ of the wave on the thickness l of the solution layer in a cell, the minimum values of the reflection coefficient of the wave $\rho_{\min}$ were determined and their dependence on the concentration of a polar component in the solution was constructed. Concurrently, dielectric properties of the considered solutions were evaluated using a measuring method [5] based on the determination of the dielectric permittivity ε' and the dielectric loss ε'' of the solution from experimental data for the standing-wave ratio η and the thickness l of the solution layer at extreme points of the dependence $\eta(l)$.

Results of measuring ε' and ε'' of solutions of methyl ethyl ketone and methyl isobutyl ketone in *n*-heptane are presented in Table 1. Dielectric properties of pure methyl ethyl ketone and methyl isobutyl ketone are fairly well described in the dispersion region by the Debye equations. At mean concentrations of a polar liquid in the considered solutions, the best approximation is given by the Debye–Cole equation [6].

The found experimental concentration dependences for ε' and ε'' at λ = 4.28, 10.0, and 20.0 mm and at a temperature of 20°C were used to calculate the conditions under which reflectionless absorption of electromagnetic radiation may arise in the considered solutions. According to [2], this effect might be realized at the points of minima of the dependence of the modulus of the reflection coefficient $\rho_{\min}$ on the thickness l of the substance layer when the following conditions are fulfilled:

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TABLE 1. Dielectric Permittivity ε′ and Dielectric Loss ε″ of Solutions of Methyl Ethyl Ketone and Methyl Isobutyl Ketone in *n*-Heptane at Wavelengths λ = 4.28, 10.0, and 20.0 mm

φ, %	Methyl ethyl ketone						Methyl isobuthyl ketone					
	λ = 4.28 mm		λ = 10.0 mm		λ = 20.0 mm		λ = 4.28 mm		λ = 10.0 mm		λ = 20.0 mm	
	ε′	ε″	ε′	ε″	ε′	ε″	ε′	ε″	ε′	ε″	ε′	ε″
100	6.31	7.65	11.76	9.54	15.20	8.60	4.38	2.98	6.50	4.38	9.71	5.10
80	4.59	4.64	9.06	6.12	11.85	5.03	4.05	2.28	5.12	2.82	6.67	3.05
60	4.13	3.13	7.15	3.79	8.24	3.23	3.66	1.73	4.26	2.02	4.94	2.20
50	3.93	2.52	6.25	2.83	6.72	2.50	3.46	1.53	3.91	1.73	4.15	1.76
40	3.59	1.95	5.35	2.04	5.58	1.95	3.23	1.32	3.59	1.44	3.86	1.49
20	2.86	0.83	3.32	0.89	3.50	0.82	3.02	0.78	3.12	0.80	3.24	0.84
10	2.45	0.45	2.51	0.47	2.64	0.42	2.90	0.53	2.92	0.57	2.97	0.50
5	2.23	0.27	2.26	0.27	—	—	2.62	0.33	2.65	0.31	—	—

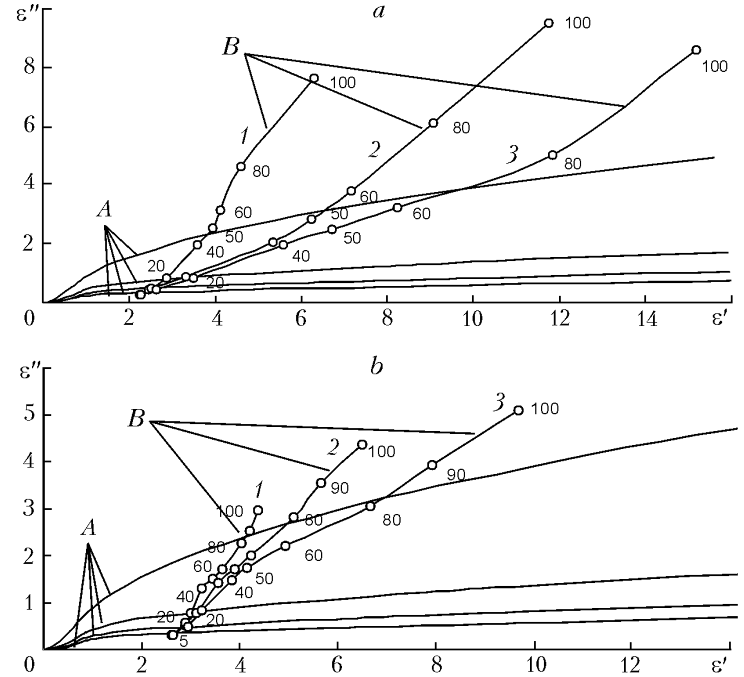

Fig. 1. Dependence of the dielectric loss ε″ on the dielectric permittivity ε′ of solutions of methyl ethyl ketone (a) and methyl isobutyl ketone (b) in *n*-heptane: *A*) when the condition of total or reflectionless absorption of the electromagnetic wave in a substance is fulfilled; *B*) at a temperature of 20°C and wavelengths λ = 4.28 (1), 10.0 (2), and 20.0 mm (3). Digits at the points indicate the values of φ.

$$(1+y^2)\frac{\lambda_1}{\lambda_{1d}}\tanh\left(\frac{2\pi y l_0}{\lambda_{1d}}\right)-y\tan\left(\frac{2\pi l_0}{\lambda_{1d}}\right),\quad y\sinh\left(\frac{4\pi y l_0}{\lambda_{1d}}\right)+\sin\left(\frac{4\pi l_0}{\lambda_{1d}}\right)=0\,, \tag{1}$$

where $y = \tan\frac{\Delta}{2}$. For convenience, we introduce the designation $p = \left(\frac{\lambda}{\lambda_c}\right)$. Then, $\Delta = \arctan\frac{\varepsilon''}{\varepsilon' - p}$ and $\lambda_1 = \frac{\lambda}{\sqrt{1-p}}$.

The parameter l_0 entering into expression (1) differs from $(2n-1)\lambda_{1d}/4$ only by a small magnitude dependent on properties of the substance and the number *n* of the minimum of the dependence $\rho(l)$. In the reduced coordinates

TABLE 2. Dielectric Permittivity ε'_0, Dielectric Loss ε''_0, Layer Thickness l_0, and Concentrations φ_0 of Methyl Ethyl Ketone and Methyl Isobutyl Ketone in Solutions with *n*-Heptane at the Points of Zero Minima of the Modulus of Reflection Coefficient ρ_{min} of the Wave at Wavelengths λ = 4.28, 10.0, and 20.0 mm and at a Temperature of 20°C

n	λ = 4.28 mm					λ = 10.0 mm					λ = 20.0 mm				
	ε'_0	ε''_0	l_0/λ	φ_0	$\varphi_{\tilde{a}}$	ε'_0	ε''_0	l_0/λ	φ_0	$\varphi_{\tilde{a}}$	ε'_0	ε''_0	l_0/λ	φ_0	$\varphi_{\tilde{a}}$
Methyl ethyl ketone															
1	3.82	2.30	0.14	43.8	46.3	6.53	3.10	0.11	53.1	52.2	9.33	3.77	0.09	60.1	61.6
2	2.83	0.78	0.46	17.9	16.8	3.19	0.81	0.42	18.4	18.4	3.59	0.86	0.40	19.3	18.5
3	2.47	0.46	0.80	9.9	8.9	2.49	0.46	0.80	9.9	8.7	2.78	0.48	0.76	10.3	11.3
4	2.30	0.32	1.16	6.3	4.7	2.32	0.33	1.16	6.5	5.7	—	—	—	—	8.1
Methyl isobutyl ketone															
1	4.16	2.42	0.13	85.7	84.6	4.99	2.68	0.12	76.9	75.0	6.95	3.21	0.10	82.7	81.1
2	3.02	0.80	0.44	21.2	22.7	3.12	0.81	0.43	20.6	23.1	3.22	0.82	0.42	19.8	19.9
3	2.85	0.48	0.75	8.7	8.3	2.84	0.48	0.75	8.2	8.3	2.97	0.49	0.73	10.1	11.7
4	2.63	0.33	1.09	5.1	5.6	2.68	0.34	1.08	5.8	5.6	—	—	—	—	—

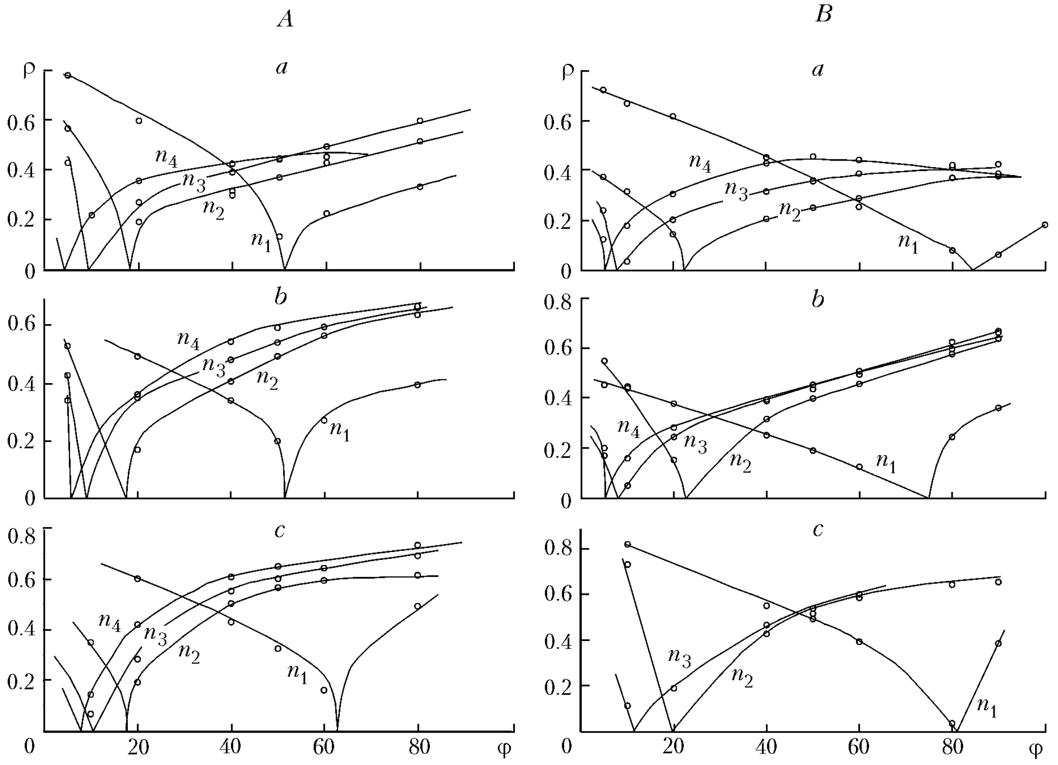

Fig. 2. Dependence of the modulus of the reflection coefficient ρ of the electromagnetic wave on the concentration φ of methyl ethyl ketone (*A*) and methyl isobutyl ketone (*B*) in solutions with *n*-heptane for the first minima ρ_{min} of curves for various thicknesses of the solution layer at wavelengths λ = 4.28 (a), 10.0 (b), and 20.0 mm (c) and a temperature of 20°C.

$\varepsilon_1 = (\varepsilon' - \rho)/(1 - \rho)$, $\varepsilon_2 = \varepsilon''/(1 - \rho)$, Eqs. (1) transform into a set of curves for specified numbers of the minima of the l dependences of ρ, at which the condition $\rho = 0$ is realized (Fig. 1, curves *A*). Characteristically, with increasing number n these curves approach the abscissa axis. The latter circumstance indicates the possibility of reflectionless absorption of electromagnetic radiation by a substance even with a very small value of the dielectric loss. As follows from Fig. 1, the phenomenon of reflectionless absorption is realized in such substances at significant thicknesses of their layer.

Experimental data for solutions of different concentrations, which are entered on the coordinate plane [ε', ε''], determine the behavior of the experimental dependence of ε'' on ε' of solutions of methyl ethyl ketone and methyl isobutyl ketone in *n*-heptane (Fig. 1, curves *B*).

Since for *n*-heptane $\varepsilon'' \approx 0$, with increasing concentration of a polar component in the solution the dependence of ε'' on ε' for solutions of methyl ethyl ketone and methyl isobutyl ketone in *n*-heptane should begin with the point lying on the abscissa axis and end in the upper part of the plane [ε', ε''] with the point with coordinates corresponding to pure methyl ethyl ketone and methyl isobutyl ketone. While moving to this coordinate point, the curve will intersect the set of lines of resonant reflectionless radiation absorption of solutions described by Eqs. (1).

Taking into account the indicated arrangement of lines of the resonance values of ε' and ε'', one should anticipate the existence of an infinite series of concentrations of a polar liquid in nonpolar *n*-heptane and of thicknesses of the reflecting solution layer, at which the effect of total absorption of reflected radiation originates. Regrettably, the behavior of ε' and ε'' of binary solutions with a change in their composition is difficult to express analytically. Therefore, the resonance concentrations φ_0 of a polar liquid in the solution and the corresponding resonance values of ε_0' and ε_0'' were calculated using a graphical analytical method [7] of solving Eqs. (1) with the application of experimental data for ε' and ε'' of solutions of methyl ethyl ketone and methyl isobutyl ketone in *n*-heptane at various concentrations. Results of these calculations for the first four zero minima $\rho_{\min}$ are given in Table 2.

Table 2 also gives the resonance concentrations φ_0 of a polar component in the solution, which were obtained from analysis of the concentration dependences of the modulus of the reflection coefficient of the wave at the points of minima of the experimental dependences $\rho(l)$ (Fig. 2). For each number *n*, the concentration dependences have the characteristic zero minimum $\rho_{\min} = 0$. With increase in *n*, it shifts toward low concentrations of a polar liquid. Here, the distances between neighboring extrema of the curves decrease and at larger values of *n* tend to zero.

Analysis of the data on the resonance value of φ_0 shows that it is proportional to $1/(2n - 1)$ and the relationship between φ_0 and *n* is retained at larger values of *n* when the conditions of smallness of the dielectric loss factor *y* are fulfilled. The sufficient closeness of the calculated φ_g and experimental values of the resonance concentrations φ_0 in solutions of methyl ethyl ketone and methyl isobutyl ketone in *n*-heptane justifies the performed calculations and once again proves that, in solutions of a polar substance in a nonpolar solvent, at a specified temperature and a certain frequency of incident radiation such concentrations exist at which total reflectionless absorption of incident electromagnetic radiation occurs. The presence of this effect allows these solutions to be used as fillers of thin-layer absorbers of superhigh-frequency radiation.

NOTATION

l, thickness of the solution layer, mm; l_0, thickness of the substance layer at which the wave reflection is absent, mm; *n*, number of the zero minimum; *y*, dielectric loss factor; Δ, deviation of the extremum position from a quantity that is a multiple of a quarter of the wavelength; ε', high-frequency dielectric permittivity; ε'', dielectric loss; φ, volume concentration of a polar component in the solution, %; φ_0, experimental value of φ corresponding to reflectionless absorption, %; φ_g, value of φ corresponding to reflectionless absorption of the electromagnetic wave and determined using a graphical analytical method, %; η, voltage standing-wave ratio; λ, wavelength in a free space, mm; λ_1, wavelength in an empty guide system, mm; λ_{1d}, wavelength in a guide system filled with the considered dielectric substance, mm; λ_c, critical wavelength of a guide system, mm; ρ, reflection coefficient of the waves; $\rho_{\min}$, minimum values of the reflection coefficient of the wave for the functional dependence $\rho(l)$. Subscripts: 0, values of the coefficients corresponding to total reflectionless absorption of electromagnetic radiation in the substance layer; *d*, dielectric; min, minimum values of coefficients; g, graphical analytical; c, critical.

REFERENCES

1. J. Preissner, Reflexionseigenschaften mehrschichtiger Medien und ihre Eignung als Radarabsorber, *NTZ Arch.*, Bd. 11, No. 4, 175–182 (1989).

2. R. M. Kasimov, Variational method of measuring the dielectric parameters of polar liquids in the microwave range, *Izmerit. Tekh.*, No. 10, 48–49 (1970).
3. M. I. Veliev, R. M. Kasimov, and Ch. O. Kadzhar, Dielectric properties and molecular structure of solutions of methylethylketone in *n*-heptane, *Izv. Akad. Nauk Azerbaidzhana*, *Ser. Fiz.-Tekh. Mat. Nauk*, No. 2, 123–129 (2005).
4. M. I. Veliev, R. M. Kasimov, and Ch. O. Kadzhar, Dielectric properties and molecular structure of methylisobuthylketone and of its solutions in *n*-heptane, in: *Proc. Int. Conf. "Physics-2005"* [in Russian], Baku (2005), p. 822–826.
5. R. M. Kasimov, A technique for measuring the dielectric coefficients of polar liquids based on reflection of an electromagnetic wave from a regulated layer of liquid, *Metrologiya*, No. 7, 45–51 (1987).
6. Ya. Yu. Akhadov, *Dielectric Parameters of Pure Fluids* [in Russian], MAI, Moscow (1999).
7. R. M. Kasimov, M. A. Kalafi, E. R. Kasimov, Ch. O. Kadzhar, and E. Yu. Salaev, Effect of quenching of the reflected electromagnetic radiation by polar dielectrics, *Zh. Tekh. Fiz.*, **66**, No. 5, 167–171 (1996).