Journal of Engineering Physics and Thermophysics, Vol. 71, No. 2, 1998

REFLECTIONLESS ABSORPTION OF ELECTROMAGNETIC RADIATION IN POLAR MIXTURES

R. M. Kasimov, M. A. Kalafi,
Ch. O. Kadzhar, and E. R. Kasimov

UDC 621.3.035.222.7:621.317.335.3

An investigation is made of the conditions of occurrence of reflectionless absorption of electromagnetic radiation in a layer of polar mixtures deposited onto a reflecting metallic matrix.

In [1], conditions have been found for the occurrence of an experimentally observed effect of reflectionless absorption of electromagnetic radiation in a polar dielectric layer deposited onto a reflecting metallic surface. The effect occurs in a dispersion region of the substance and is realized at discrete resonance values of the incident-radiation frequency and thickness of the reflecting layer of a coating.

To directly verify the theoretical conclusions obtained, it is necessary to have data of experimental studies of frequency or temperature dependences of dielectric permittivity ε' and dielectric loss ε'' and to use them to search for such values of wavelength λ or temperature T at which ε' and ε'' of the investigated substances reach their resonance values ε'_0 and ε''_0. Plotting of the frequency dependences of ε' and ε'' of the substance is a rather laborious process that necessitates the use of a set of measuring devices in different wavelength ranges; realization of this effect by changing the substance temperature at a constant frequency of measuring depends considerably on the degree of proximity of ε' and ε'' of a chosen substance to ε'_0 and ε''_0, which cannot always be reached in practice. Therefore, to experimentally check the possibility of the existence of reflectionless absorption of radiation of polar dielectrics, it is easier to investigate dielectric properties and reflection characteristics of waves of their mixtures if only dispersion exists for one of the mixture components. In these cases, regulation of the composition of the mixtures can allow a shift of their dispersion and absorption dependences along the frequency scale and make it possible to reach resonance values of ε'_0, ε''_0 at specified λ and T.

To evaluate the conditions of occurrence of the effect of reflectionless absorption of electromagnetic radiation in mixtures of polar dielectrics, we will consider the dependences of resonance values of ε''_0 on ε'_0 (Fig. 1). They are constructed using the equations given in [1] and correspond to the first three minima of the dependence of the absolute value of the index of wave reflection ρ on the thickness l of a coating layer provided that at the points of the minimum ρ reaches its zeroth value.

The search for reflectionless absorption conditions becomes unambiguous if the dependences of ε' and ε'' of the mixtures on their compositions are known. When the compositiion of the polar mixtures changes, ε'' vs. ε' plots of the mixture at specified λ and T are depicted by arched curves in the $[\varepsilon', \varepsilon'']$ coordinate plane. Their positions are determined by the dielectric properties of individual pure components of the mixture. An appropriate choice of the components of the mixture can hypothetically allow intersection of the realistic dependences of ε'' on ε' of the mixture with one or several theoretical dependences determining the location of the calculated and depicted (in Fig. 1) resonance values of ε'_0 and ε''_0. For illustration, Fig. 1 displays the experimental ε'' vs. ε' curves of acetone solutions in chloroform and benzene simulating the behavior of similar dependences of solid-state mixtures of polar dielectrics. Dielectric properties of the above solutions are investigated in detail in the superhigh frequency range [2, 3]. The frequency dependences of ε' and ε'' of pure acetone and chloroform are described well by the Debye equations, which in the considered $[\varepsilon', \varepsilon'']$ coordinate system are transformed to the equations of semicircumferences with center on the abscissa axis and radius $(\varepsilon_0 - \varepsilon_\infty)/2$, where ε_0, ε_∞ are the low-frequency and high-

M. F. Nagiev Institute of Theoretical Problems in Chemical Technology, Academy of Sciences of Azerbaijan, Baku. Institute of Photoelectronics, Academy of Sciences of Azerbaijan, Baku. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 71, No. 2, pp. 282-285, March-April, 1998. Original article submitted December 28, 1995.

 1062-0125/98/7102-0284$20.00

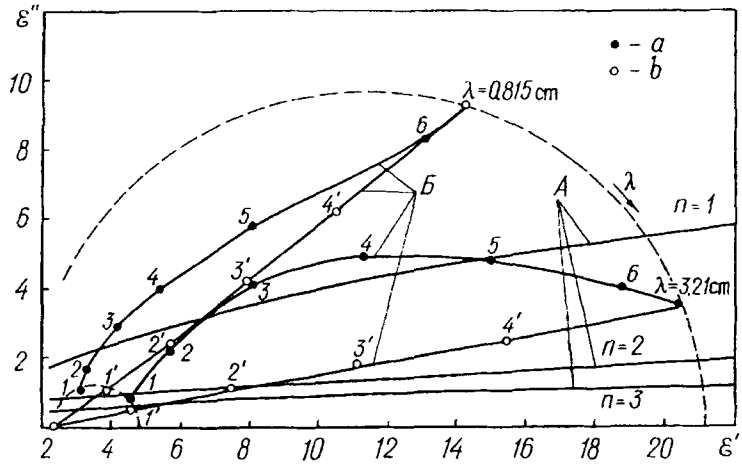

Fig. 1. Relationships between dielectric permittivity ε' and dielectric loss ε'' [A: conditions of reflectionless absorption of electromagnetic radiation in polar dielectrics; B: acetone–chloroform (a) and acetone–benzene (b) solutions at $T = 20^{\circ}C$]: 1) $\varphi_c = 100\%$; 2) 89.2; 3) 68.1; 4) 47.8; 5) 28.2; 6) 9.3; 1') $\varphi_b = 80\%$; 2' = 60; 3') 40; 4') 20.

TABLE 1. Resonance Values of the Layer Thicknesses l_0 and Molar Concentrations φ_0 of the Polar Component of Some Binary Solutions at Temperatures of 20 and 25°C (φ_0, %; λ, l_0, cm; τ, 10^{-12} sec)

n	Solution							
	anisole–benzene		nitrobenzene–hexane		acetone–benzene		water–dioxane (25°C)	
	4.39; 2.60 1.40; 12.3		35.9; 3.84 0.815; 49.0		21.6; 1.90 3.21; 3.20		80.1; 3.75 1.25; 10.1	
	φ_0	l_0	φ_0	l_0	φ_0	l_0	φ_0	l_0
1	–	–	72.5	0.012	–	–	54.0	0.15
2	–	–	27,5	0.039	48.0	0.80	28.0	0.53
3	59.2	1.03	17.3	0.068	27.8	1.74	19.5	0.92
4	39.0	1.49	12.6	0.096	18.6	2.64	15.2	1.31
5	29.2	1.94	9.6	0.125	13.6	3.66	12,6	1.71
6	23.6	2.36	7.9	0.16	11.4	4.62	10.8	2.10
7	19.8	2.84	6.8	0.18	9.2	5.68	9.0	2.50
8	17.1	3.33	5.7	0.21	8.0	6.71	7.7	2.90
9	15.2	3.77	5.1	0.24	6.8	7.75	7.0	3.29
10	13.5	4.27	4.7	0.27	6.1	8.80	6.4	3.68
11	11.8	4.72	4.3	0.30	5.6	9.82	5.8	4.10
12	10.8	5.19	4.0	0.33	5.2	10.8	5.4	4.50

Note: For the compositions of the solutions, ε_0, $\varepsilon_\infty/\lambda$, τ values are given, respectively.

frequency limits of the dispersion regions of the polar substances (the dashed lines in Fig. 1). The ε'' vs. ε' curves of the acetone solutions in chloroform lie in the region of the [ε', ε'']-plane located between the semicircumferences depicting the behavior of ε', ε'' of pure components of the solution (Fig. 1). With a decrease in the acetone concentration in the solution, the experimental ε'' vs. ε' plot built at $\lambda = 0.815$ cm and $T = 20^{\circ}C$ intersects the theoretical curve of resonance values ε'_0, ε''_0 constructed for the first zeroth minimum of ρ. The molar acetone concentration $\varphi = 13.2\%$ in the solution and the thickness l of the reflecting layer of the solution approaching

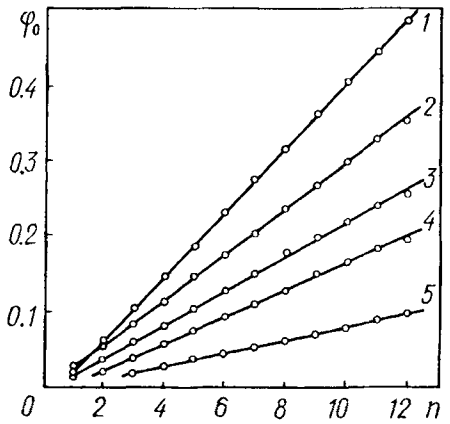

Fig. 2. Relationship between the resonance values of molar concentrations φ_0 of the polar component of the binary solutions and number n of the zeroth minimum of the dependence of the absolute value of the index of wave reflection on the thickness of the reflecting layer of the solutions: 1) acetone–benzene (λ = 0.815 cm); 2) methyl alcohol–benzene (λ = 3.20 cm); 3) nitrobenzene–hexane (λ = 0.815 cm); 4) acetone–benzene (λ = 3.21 cm); 5) anisole–benzene (λ = 1.4 cm). φ_0, %.

$\lambda_d/4$ (λ_d is the wavelength in the solution at a given radiation frequency) correspond to the point of intersection of both curves. In the same solution, but at λ = 3.21 cm and T = 20°C, reflectionless absorption of electromagnetic radiation occurs at three molar concentrations of acetone in solution, namely, φ = 53.9, 14.4, and 5.8%. The first two are realized at a reflecting layer thickness approaching $\lambda_d/4$, and according to the conclusions of [1] they belong to low-frequency and high-frequency branches of the spectrum of resonance values of λ_0 and l_0, respectively. Of particular interest is the behavior of the ε'' vs. ε' plots of binary solutions of the polar substance in a nonpolar filler, which is exemplified by the characteristic dependences of ε'' on ε' of acetone solutions in nonpolar benzene at λ = 3.21 and 0.815 [3].

Since, for the nonpolar solvent, ε'' = 0, with an increase in the acetone concentration in the solution the ε'' vs. ε' curve will originate from a point on the abscissa axis (φ = 0) and end in the upper right-hand part of the [ε', ε''] coordinate plane at the point corresponding to the pure polar component of the solution. If the magnitude of dielectric loss of the pure polar component of the solution is higher than the resonance values, then with an increase in the concentration of the nonpolar component in the solution, the coordinate of the working point in the [ε' ε''] coordinate plane intersects the dependences of the resonance values ε_0'' on ε_0' in moving to the abscissa axis at all values of n of the zeroth minima ρ. Considering such specific positions of the lines of resonance values ε_0', ε_0'', it should be expected that an infinite series of polar-component concentrations and thicknesses of the reflecting layer of the solution exists at which reflectionless absorption of incident radiation occurs.

The behavior of ε' and ε'' of the solutions with a change in their composition is difficult to express analytically. Therefore, in order to calculate resonance concentrations of components in a solution and the corresponding resonance values ε_0' and ε_0'', it is necessary to use computer methods of joint solution of the initial equations describing, according to [1], the dependences of resonance values ε' and ε'' of the substance and the polynomial equations approximating, with a sufficient accuracy, the behavior of the experimental dependences of ε' and ε'' of the binary solution on its composition.

Table 1 provides calculation results of resonance thicknesses l_0 of the reflecting layer of a solution and molar concentrations φ_0 of a polar component in binary solutions of some polar liquids (acetone, water, anisole, nitrobenzene) in nonpolar solvents (benzene, hexane, dioxane). They are obtained from the literature data [3] on ε' and ε'' of these solutions measured at temperatures ranging from 20 to 25°C in a wavelength range of 0.8–3.2 cm.

In the chosen solutions, values of the static dielectric permittivity ε_0 and relaxation time τ of pure components vary within wide ranges: 4–80 units for ε_0 and $(3-50)\cdot 10^{-12}$ sec for τ.

The data obtained are consistent with theoretical conclusions on the possibility of occurrence of the effect of reflectionless absorption of electromagnetic radiation in the solutions at definite compositions and layer thicknesses. With an increase in the resonance thickness of the solution layer, the zero minimum of ρ displaces toward low concentrations of the polar component: in this case the difference between resonance concentrations of the neighboring zeroth minima of ρ decreases and at large n tends to values close to zero. The existence of such resonance values of concentrations and thicknesses of the reflecting layer of solutions and mixtures is general in its nature. They can occur in any polar mixture or solution if a dispersion of waves exists in their polar components.

One of the important consequences of the investigations conducted is the establishment of a rather distinct functional relation between the resonance concentrations φ_0 of the polar component and the layer thickness l of the binary solution. Regardless of the nature of solution components, the product $(2n - 1)\varphi_0$ remains constant at specified λ and T values (Fig. 2). This dependence can be used for precision measurements of low concentrations of a polar substance in a nonpolar solvent.

NOTATION

l, thickness of the coating layer; n, number of the minimum of the reflected wave; T, temperature; ε_0, ε_∞, statistical and high-frequency dielectric permittivities; ε', ε'', dielectric permittivity and dielectric loss, respectively; λ, λ_d, wavelength in vacuum and in the substance, respectively; ρ, absolute value of the index of wave reflection; τ, relaxation time of the polar component; φ_0, molar substance concentration in the solution; φ_c, φ_b, volume concentration of chloroform and benzene, respectively. Subscript: 0, reflectionless absorption of electromagnetic radiation in the coating substance; d, dielectric.

REFERENCES

1. R. M. Kasimov, Inzh.-Fiz. Zh., 67, Nos. 5-6, 489-492 (1994).
2. Ya. Yu. Akhadov, Dielectric Properties of Pure Liquids [in Russian], Moscow (1972).
3. Ya. Yu. Akhadov, Dielectric Properties of Binary Solutions [in Russian], Moscow (1977).