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Note

Determination of the Complex Dielectric Constant of Liquid Dielectrics in the Microwave Region

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Transmission of electromagnetic radiation through a waveguide is described by equations using as parameter the dielectric constant of the medium filling the waveguide. Liquids are particularly suitable for measurement because of their complete filling of the waveguide cross section. Thus equations of electromagnetic wave transmission need not be modified for losses through the gap between the waveguide and the sample. In the literature a similar measurement with solid samples[1] has been described which requires a knowledge of the dielectric constant in order to calculate dielectric conductivity. In liquids it is possible to change the thickness of the sample, whereby additional information needed for the simultaneous determination of the dielectric constant and dielectric losses is obtained.

The measuring equipment is shown in Fig. 1. The part of the waveguide filled with liquid is positioned vertically and connected to a container by a flexible tube. The thickness of the sample in the waveguide or the height

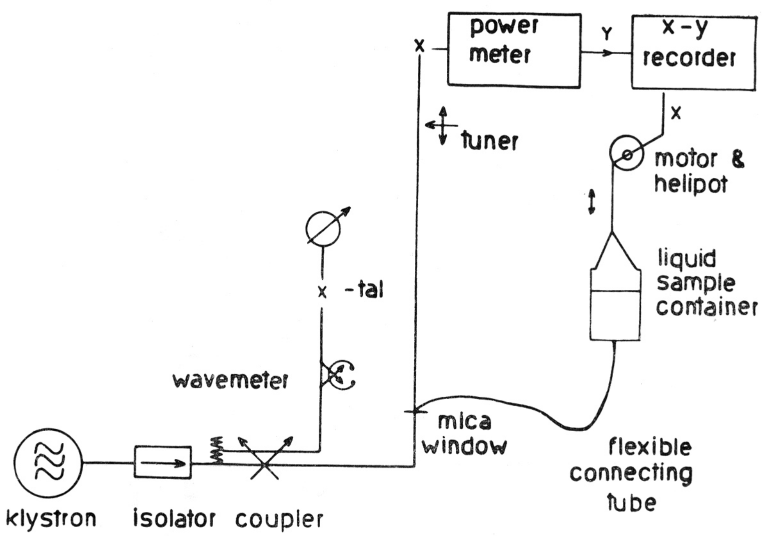

Figure 1. Equipment for microwave measurement of the complex dielectric constant of liquid dielectrics.

of the column of liquid is determined by the liquid level in the container. By moving the container vertically the liquid level in the waveguide may be changed. A change in level is equivalent to a change in thickness of the sample in the waveguide. The result of measurements is registered on an x—y recorder in such a manner that the voltage proportional to the thickness of the sample is applied to the x-axis, whilst the voltage proportional to the microwave power transmitted through the sample is applied to the y-axis. Figure 2 shows a diagram thus obtained for a mixture of benzene and ethanol.

Further on we shall show the procedure used to obtain the information presented in the diagram Fig. 2. Also, conditions will be given under which such a diagram may be used for the determination of the complex dielectric constant.

The microwave line in Fig. 1 should be adjusted so that the portion of the guide with sample is perfectly matched to the generator as well as towards the detector. Since the liquid fills the cross section of the waveguide, and the boundary surfaces of the sample are perpendicular to its axis, it is possible to apply the analysis of transmission line discontinuity.[2] This analysis gives the following relation for the microwave power on the detector

$$P_o = P_i \frac{1 - r^2}{1 - r^2 e^{-2\gamma d}} e^{-2\gamma d} \qquad (1)$$

where P_0 and P_i are the power output and power input of the sample, r is the complex coefficient of microwave reflection on the incident surface of the sample, d is the thickness of the sample and γ the complex propagation constant.

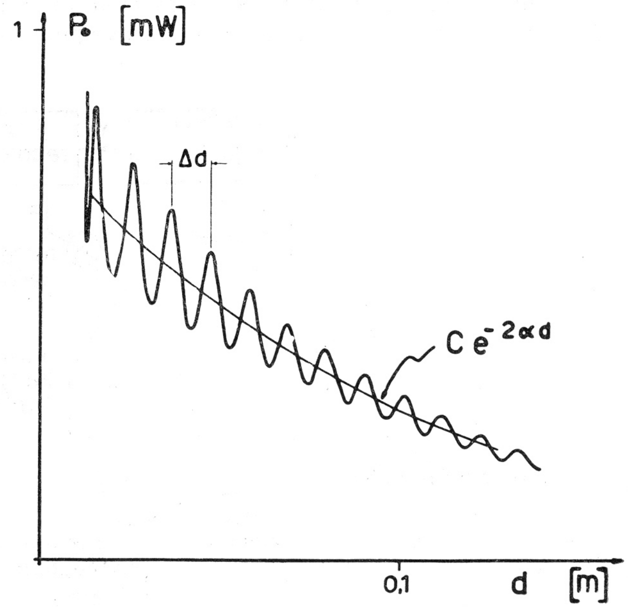

Figure 2. Dependence of the transmitted microwave power on the thickness of the sample. Sample was the mixture of the benzene and ethanol. Results of measurements on this model system are $\alpha = 4.27$ m.$^{-1}$, $\beta = 260.9$ m.$^{-1}$
$\sigma = 0.03$ mho m.$^{-1}$, $\varepsilon_t = 2.30$

Relation (1) describes the curve in Fig. 2 provided that the before mentioned matching conditions are satisfied and that losses in the walls of the waveguide are negligible, which is the case in the system under consideration. By analyzing relation (1) it may be shown that the harmonic mean of the envelope ordinates of the extremes of the curve shown in Fig. 1 satisfies the realtion

$$H = const\ e^{-2\alpha d} \tag{2}$$

where α is the attenuation constant of the complex propagation constant, d is the thickness of the sample. The constant in relation (2) does not depend on the thickness of the sample. From relation (2) it follows at once that when in the experimentally obtained diagram P_0 (d) (Fig. 2), the anvelopes of the extremes are drawn and used for the determination of the position of the curve (2) representing an exponential function, the constant α can easily be determined. The phase constant β of the complex propagation constant is defined as $\beta = 2\pi\lambda_g^{-1}$, where λ_g is the wavelenght of microwaves in the sample in the waveguide. β is determined from the distance between the neighbouring maxima Δ d according to the relation $\beta = \pi \Delta d^{-1}$. Analysis of relation (1) shows that,owing to attenuation in the sample, it is not permissible to use the distance between neighbouring maximum and minimum for determination of phase constant, since this distance depends on the thickness of the sample and on the attenuation constant. A knowledge of the attenuation constant and the phase constant is sufficient to determine the dielectric constant and dielectric conductivity from the relations

$$\sigma = \frac{2\,\alpha\beta}{\mu_0\omega}\,; \quad \varepsilon_r = \frac{\left(\dfrac{\pi}{a}\right)^2 + \beta^2 - \alpha^2}{\varepsilon_0\mu_0\omega^2} \tag{3}$$

Here μ_0 and ε_0 are the permeability and permittivity of the vacuum, ω is the angular frequency of microwaves, a is a larger dimension of the waveguide cross section, σ is the dielectric conductivity and ε_r the relative dielectric constant of the sample. If there were large dielectric losses in the liquid, the result obtained would be as illustrated in the diagram of Fig. 3. Figure 3 shows that the phase constant cannot be determined in this case. For this reason it is necessary to know the relative dielectric constant from some other measurements, in order to determine the dielectric conductivity of such samples. However, with such samples, the attenuation constant can be determined directly from the experimental curve. Owing to high attenuation, this curve is well described by relation (2). In liquids with small dielectric losses it is easy to determine the relative dielectric constant. The experimental curve obtained in this case is almost periodic, but if the complex dielectric constant is to be determined, the dielectric conductivity of such liquids must be known from other measurements.

The accuracy of the method described depends on the order of magnitude of the measured variables. Simultaneous determination of the dielectric constant and dielectric conductivity is possible within the region (1—10^{-3}) ohm m^{-1}). However, the higher the accuracy of the determination of the attenuation constant, the smaller the accuracy of the determination of the phase constant, and *vice versa.*

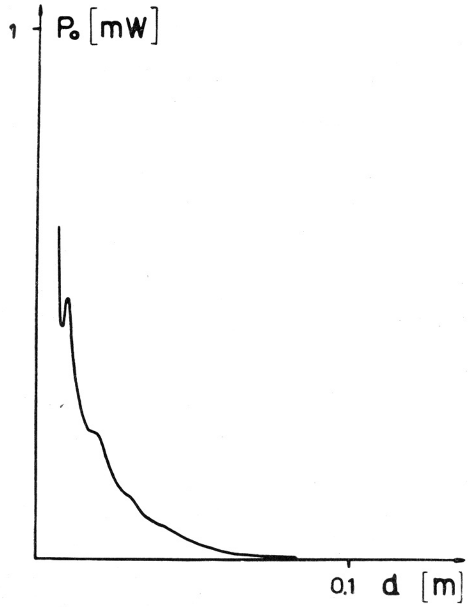

Figure 3. Dependence of the transmitted microwave power on the thickness of the sample in liquids with high dielectric losses.

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IZVOD

Određivanje kompleksne dielektrične konstante tekućih dielektrika kod mikrovalnih frekvencija

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Predložena je metoda mikrovalnog mjerenja kompleksne dielektrične konstante tekućina. Metoda se može primjeniti kod frekvencija za koje se upotrebljavaju valovodi. Suština je metode način na koji se iz grafički predočenih rezultata mjerenja dobije konstanta napredovanja mikrovalova u uzorku a na osnovu toga kompleksna dielektrična konstanta uzorka. Eksperimentalno dobiveni grafikon predočuje ovisnost mikrovalne snage koja prođe kroz uzorak o debljini uzorka. U takvom grafikonu sadržano je dovoljno informacija za simultano određivanje kompleksne konstante napredovanja. Konstanta prigušenja dobije se iz eksponencijalnog opadanja snage s promjenom dužine uzorka. Potrebna eksponencijala dobije se kao harmonična sredina anvelopa maksimuma i minimuma. Fazna konstanta odredi se iz periodičnosti relativnih ekstrema na eksperimentalnom grafikonu. Pri tome se moraju uzimati razmaci istoimenih ekstrema budući da atenuacija snage u uzorku modificira razmake raznovrsnih ekstrema (maksimum—minimum).

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