

Formulas for the Dielectric Constant and Dissipation Factor of Mixtures and Their Application to the Cellulose System*

A. VENKATESWARAN,† *The Institute of Paper Chemistry,
Appleton, Wisconsin*

Synopsis

Formulas for the dielectric constant and dissipation factor of a dielectric mixture of many components have been derived assuming (1) that the dipoles can point only in two definite directions, along and opposite to the directions of the applied field, and (2) that the dipole is a highly anisotropic body having a needle shape. The formula for the dielectric constant is applied to calculate the dielectric constant of cellulose at any sheet density. The application of the Clausius-Mosotti relation for the dielectric constant-density relation is discussed.

INTRODUCTION

In his experiments on the dielectric constants of solids, Errera¹ found that solids, which after melting give polar liquids, show anomalous dispersion even in the solid state. His results were confirmed for ice by experiments of Wintsch² carried out in Debye's laboratory. Debye explained this observed anomalous dispersion of solids by assuming a very limited degree of freedom for the orientation of molecules. According to this assumption each molecule can point with its moment only in two definite directions, the direction of the applied field (F) and the opposite direction. It follows from this that the average electric moment of a molecule in the direction of F in a static field is given by

$$\bar{m} = \mu^2 F / kT \quad (1)$$

and

$$\bar{m} = (\mu^2 F / kT) [1 / (1 + i\omega\tau)] \quad (2)$$

in a variable field.

In eqs. (1) and (2) μ = the magnetic moment of the molecule, F = applied electric field, k = Boltzmann's constant, T = absolute temperature, ω = angular frequency, $2\pi f$, and τ = relaxation time of the molecule.

* This paper is a portion of the work done on a Postdoctoral Research Fellowship, 1961-1963.

† Present address: Empire State Paper Research Institute, College of Forestry, Syracuse, New York.

On the other hand, if it is assumed that the molecule can point in all directions, the mean electric moment is only one-third as great. In a static field, its value is

$$\bar{m} = \mu^2 F / 3kT \quad (1a)$$

and in a variable field

$$\bar{m} = (\mu^2 F / 3kT) [1 / (1 + i\omega\tau)] \quad (2a)$$

Jatkar, et al.,³ following Debye's assumption that a molecule can point only in two definite directions, along and opposite to the direction of F and also assuming that a dipole is a highly anisotropic body having a needle shape, derived a formula for the molar polarization of a single substance. For the static field the formula is

$$P = (\epsilon - 1)(M/d) = 4\pi N(\alpha_0 + \mu^2/kT) \quad (3)$$

where P = molar polarization, ϵ = the dielectric constant of the substance, M = its molecular weight, d = its density, N = the Avogadro number, α_0 = polarization due to distortion, and μ^2/kT = orientation polarization.

In a variable field, eq. (3) becomes

$$P = (\epsilon - 1)(M/d) = 4\pi N\{\alpha_0 + (\mu^2/kT)[1/(1 + i\omega\tau)]\} \quad (4)$$

Putting in eq. (4)

$$4\pi N\alpha_0 = (\epsilon_0 - 1)(M/d)$$

and

$$4\pi N(\alpha_0 + \mu^2/kT) = (\epsilon_s - 1)(M/d)$$

where ϵ_0 = the optical dielectric constant and ϵ_s = the static dielectric constant, we get

$$P = (\epsilon - 1)(M/d) = (M/d)[\epsilon_0 - 1 + (\epsilon_s - \epsilon_0)/(1 + i\omega\tau)] \quad (5)$$

or

$$\epsilon = \epsilon_0 + (\epsilon_s - \epsilon_0)/(1 + i\omega\tau) \quad (5a)$$

Separating into real and imaginary parts and taking ϵ to be complex, i.e.,

$$\epsilon = \epsilon' - i\epsilon''$$

we have

$$\epsilon' = \epsilon_0 + (\epsilon_s - \epsilon_0)/(1 + \omega^2\tau^2) \quad (6)$$

and

$$\epsilon'' = (\epsilon_s - \epsilon_0)\omega\tau/(1 + \omega^2\tau^2) \quad (7)$$

where ϵ' and ϵ'' are measured values of dielectric constant and loss factor, respectively.

FORMULA FOR A DIELECTRIC MIXTURE OF MANY COMPONENTS

Consider 1 cc. of the mixture in which there are n_1, n_2, n_3 , etc., numbers of molecules of different types of substances present, so that the total number of molecules is n , given by

$$n = n_1 + n_2 + n_3 + \dots$$

Let $\alpha_1, \alpha_2, \alpha_3$, etc., be the polarizabilities and μ_1, μ_2, μ_3 , etc., be the dipole moments of each type of molecule, respectively. It is assumed that these values of molecular properties, viz., the polarizability and dipole moment of each type of molecule, refer to the values when that particular substance is in the pure state.

Introducing mole fractions, we have

$$\begin{aligned} f_1 &= n_1/(n_1 + n_2 + n_3 + \dots) \\ &= n_1/\sum n_p \\ f_2 &= n_2/\sum n_p \\ f_3 &= n_3/\sum n_p \end{aligned} \tag{8}$$

so that

$$\sum_1^n f_n = 1 \tag{9}$$

we find the molar polarization of each type of molecule in a variable field is given by

$$P_q = (M_q/d_q)[\epsilon_{q0} - 1 + (\epsilon_{q\infty} - \epsilon_{q0})/(1 + i\omega\tau_q)] \tag{10}$$

where P_q is the molar polarization of the q th substance present in the mixture. We assume that the total molar polarization of the mixture is the sum total of the contribution of each type. We also assume that the components of the mixture are nonassociated, i.e., the molecules are moving totally independently of each other. Thus, we have

$$\begin{aligned} P &= P_1f_1 + P_2f_2 + P_3f_3 + \dots \\ &= \sum_1^n P_n f_n \end{aligned} \tag{11}$$

Putting in the values of P_1, P_2, P_3 , etc., from eq. (10) in eq. (11), P becomes

$$P = \sum_1^n (M_n f_n/d_n)[\epsilon_{n0} - 1 + (\epsilon_{n\infty} - \epsilon_{n0})/(1 + i\omega\tau_n)] \tag{12}$$

where t_1, t_2, t_3 , etc., refer to the relaxation time of each type of molecule and refer to that value of the substance in the pure state; also, the molar polarization of the mixture taken as a whole is:

$$P = (\epsilon - 1) \sum_1^n M_n f_n/d \tag{13}$$

where ϵ = the dielectric constant of the mixture, and d = density of the mixture.

The density of the mixture is given by

$$d = \sum_1^n M_n n_n / N \quad (14)$$

Equating the right-hand sides of eqs. (12) and (13) and substituting for the density of the mixture from eq. (14) and for f_1, f_2, f_3 , etc., from eq. (8) we have

$$\epsilon - 1 = \sum_1^n (M_n / N) (n_n / d_n) [\epsilon_{n_0} - 1 + (\epsilon_{n_s} - \epsilon_{n_0}) / (1 + i\omega\tau_n)] \quad (15)$$

Now $(M_n n_n / N d_n)$ is the volume fraction of n th substance present in the mixture, and is denoted by δ_n . With this, eq. (15) becomes

$$\epsilon - 1 = \sum_1^n \delta_n [\epsilon_{n_0} - 1 + (\epsilon_{n_s} - \epsilon_{n_0}) / (1 + i\omega\tau_n)] - \sum_1^n \delta_n \quad (16)$$

If $\epsilon = \epsilon' - i\epsilon''$, separating ϵ in eq. (16) into real and imaginary parts and by virtue of $\sum_1^n \delta_n = 1$, and eqs. (6) and (7), eq. (16) becomes:

$$\epsilon' = \sum_1^n \delta_n \epsilon_n' \quad (17)$$

$$\epsilon'' = \sum_1^n \delta_n \epsilon_n'' \quad (18)$$

$$D = \sum_1^n (\delta_n \epsilon_n'') / \sum_1^n (\delta_n \epsilon_n') \quad (19)$$

where ϵ' = measured dielectric constant of the mixture, ϵ'' = measured loss factor of the mixture, and D = dissipation factor of the mixture.

For a mixture of two components eqs. (17), (18), and (19) become, respectively,

$$\epsilon' = \delta_1 \epsilon_1' + \delta_2 \epsilon_2' \quad (17a)$$

$$\epsilon'' = \delta_1 \epsilon_1'' + \delta_2 \epsilon_2'' \quad (18a)$$

$$D = (\delta_1 \epsilon_1'' + \delta_2 \epsilon_2'') / (\delta_1 \epsilon_1' + \delta_2 \epsilon_2') \quad (19a)$$

In his paper dealing with dielectric properties of a mixture of two liquids in static field, Silberstein⁴ derived eq. (17a) from the consideration of thermodynamic equilibrium. Also in his paper on theories of mixtures for the field of stationary current, Wiener⁵ derived eq. (17) after obtaining mean value equations for force, polarization, and energy. In the present work the equations are derived for both static and oscillating fields.

APPLICATION OF EQUATION (17a) TO CELLULOSE SYSTEM

Equation (17a) is applied to calculate the dielectric constant of cellulose at any sheet density as follows.

Let cellulose and air or vacuum be the two components. Let component 1 be the solid portion of the sheet at the desired sheet density and component 2 the excess sheet voids. Let the values denoted with subscript zero represent the observed values of sheet as tested. ϵ' is the dielectric constant and d is the density. δ_1 and δ_2 are the volume fractions. With these, eq. (17a) can be written as

$$\epsilon_0' = \delta_1 \epsilon_1' + \delta_2 \epsilon_2' \quad (20)$$

Now d_0 is the weight of cellulose/(volume of cellulose + volume of air) = $W/(V_1 + V_2)$ in which "volume of air" includes the volume between the sheet and electrode surfaces.

$$d_1 = W/V_1$$

$$d_0/d_1 = V_1/(V_1 + V_2) = \delta_1 \quad (21)$$

and

$$\delta_2 = 1 - \delta_1 = (d_1 - d_0)/d_1 \quad (22)$$

Substituting eqs. (21) and (22) in eq. (20) we get

$$\epsilon_0' = (d_0/d_1)\epsilon_1' + [(d_1 - d_0)/d_1]\epsilon_2' \quad (23)$$

implying and taking $\epsilon_2' = 1$ (vacuum or air), we have

$$\epsilon_1' = (d_1/d_0)(\epsilon_0' - 1) + 1 \quad (24)$$

where ϵ' is the dielectric constant of the sheet at the desired sheet density. The "density" d_0 can be calculated from the ratio of the mass per unit area and the spacing between the electrodes, which can be measured by the auxiliary bridge arrangement,⁶ while the dielectric properties are being made. The equation is applied to bleached sulfite pulp, cotton, linters, and regenerated cellulose.

PREPARATION OF SAMPLES

A 100% bleached sulfite pulp and acetate-grade cotton linters were chosen for the present study. Both the pulps were of high α content. In order to prepare samples of satisfactory formation from unbeaten pulp, the sulfite pulp and cotton linters were first disintegrated in a British disintegrator for 300 revolutions and then further disintegrated in a Waring Blendor for 10 min. To prepare sheets from beaten samples the pulps were beaten in a Jokro mill. The sulfite pulp was beaten for 35 min. and the cotton linters were beaten for 75, 140, and 215 min.

In order to prepare sheets of uniform formation a sheet mold of 92 cm. in height, giving a sheet of 200 cm.² in area was used. The consistency of

slurry used was approximately 0.05%, giving handsheets of about 65 g./m.² basis weight.

The sheets immediately after formation were first pressed under 50 psi for 5 min. The blotters were changed and the sheets were further pressed at the same pressure for 3 min. The sheets were then air dried, by keeping them between rings in a room conditioned at 73°F. and 50% R.H.

DIELECTRIC CONSTANT MEASUREMENTS

Apparatus

A conjugate Schering Bridge designed according to ASTM standards was used in the present study. This equipment was built by Delevanti and Hansen^{7,8} and was described by them. The electrode arrangement used in the present work was built by Calkins.⁶ Briefly, the system consisted of a pair of electrodes of 44.2 cm.² area, so mounted that the electrode pressure could be varied for a considerable range. The electrode system was enclosed within a bell jar resting upon a base plate and could be evacuated to 0.1 μ .

Method of Measurement

Using the substitution method, dielectric constant and dissipation factor were measured. To measure the dielectric constant of the sample in vacuum the sample was placed between the electrodes. The test capacitor system was covered with the bell jar. The pressure in the system was reduced to 0.1 μ . It was found that the equilibrium state was reached after 35 hr. Steady values of the capacitance and loss factor dials were taken as an indication of the equilibrium state. Measurements were made at 1, 2, 5, and 10 kcycles/sec.

The weight of the vacuum-dried sample, to determine sheet density was obtained in the following manner. After measurements were made, dry air was let into the system. This was done by first passing air through a tube 24 in. long packed with glass beads and CaSO₄ and then through another tube of the same length packed with glass beads and P₂O₅. When the system reached atmospheric pressure, the bell jar was raised and the sample was transferred into a weighing bottle in a few seconds. The difference between the weights of the weighing bottle with and without the sample gave the weight of the sample. Since the CaSO₄ used was of the indicating type (changing color when moisture was absorbed), fresh CaSO₄ was used at suitable intervals.

Calculation of the Dielectric Constant and Loss Factor of the Fiber Alone

If C_2' and C_2 are the readings of the capacitance dial and C_4' and C_4 are the readings of the dissipation factor dial without and with specimen,

TABLE I
Bleached Sulfite Pulp

Sample treatment	Electrode pressure, psi	d_0 , g./cc.	Apparent dielectric constant at various frequencies					Apparent dielectric constant as calculated at standard density 1 using eq. (24), at various frequencies				
			1 cycle/ sec.	2 cycle/ sec.	3 cycle/ sec.	5 cycle/ sec.	10 cycle/ sec.	1 cycle/ sec.	2 cycle/ sec.	3 cycle/ sec.	5 cycle/ sec.	10 cycle/ sec.
Unbeaten	41	0.4848	1.912	1.906	1.900	1.895	1.873	2.882	2.869	2.857	2.847	2.800
	83	0.5060	1.970	1.967	1.963	1.958	1.946	2.916	2.910	2.903	2.892	2.868
	123	0.5170	1.983	1.980	1.977	1.976	1.972	2.901	2.899	2.890	2.888	2.880
Beaten for 35 min.	41	0.8476	2.709	2.699	2.692	2.680	2.667	3.016	3.004	2.996	2.982	2.967
	83	0.8700	2.750	2.744	2.736	2.729	2.716	3.016	3.005	2.995	2.987	2.972
	123	0.8790	2.780	2.776	2.775	2.768	2.756	3.025	3.020	3.010	3.010	2.997

TABLE II
Cotton Linters

Sample treatment	Electrode pressure, psi	d_p , g./cc.	Apparent dielectric constant at various frequencies										Apparent dielectric constant as calculated at standard density 1 using eq. (24), at various frequencies															
			1	2	3	5	10	1	2	3	5	10	1	2	3	5	10											
			keycycle/ sec.	keycycle/ sec.	keycycle/ sec.	keycycle/ sec.	keycycle/ sec.	keycycle/ sec.	keycycle/ sec.	keycycle/ sec.	keycycle/ sec.	keycycle/ sec.	keycycle/ sec.	keycycle/ sec.	keycycle/ sec.	keycycle/ sec.	keycycle/ sec.	keycycle/ sec.	keycycle/ sec.	keycycle/ sec.	keycycle/ sec.	keycycle/ sec.	keycycle/ sec.	keycycle/ sec.	keycycle/ sec.	keycycle/ sec.	keycycle/ sec.	keycycle/ sec.
Unbeaten	41	0.4040	1.740	1.737	1.729	1.715	1.689	2.832	2.824	2.804	2.770	2.656	2.832	2.824	2.804	2.770	2.656											
	83	0.4080	1.745	1.741	1.736	1.725	1.688	2.826	2.816	2.804	2.777	2.686	2.826	2.816	2.804	2.777	2.686											
	123	0.4230	1.746	1.743	1.739	1.735	1.709	2.760	2.753	2.750	2.733	2.672	2.760	2.753	2.750	2.733	2.672											
Beaten for 75 min.	41	0.6110	2.099	2.097	2.093	2.085	2.066	2.800	2.800	2.790	2.776	2.745	2.800	2.800	2.790	2.776	2.745											
	83	0.613	2.114	2.112	2.108	2.104	2.097	2.817	2.820	2.810	2.800	2.789	2.817	2.820	2.810	2.800	2.789											
	123	0.620	2.144	2.141	2.139	2.135	2.131	2.845	2.840	2.835	2.830	2.820	2.845	2.840	2.835	2.830	2.820											
Beaten for 140 min.	41	0.6960	2.332	2.330	2.326	2.314	2.304	2.914	2.911	2.905	2.890	2.874	2.914	2.911	2.905	2.890	2.874											
	83	0.699	2.353	2.351	2.346	2.342	2.331	2.935	2.932	2.920	2.920	2.904	2.935	2.932	2.920	2.920	2.904											
	123	0.701	2.387	2.384	2.380	2.377	2.371	2.978	2.974	2.964	2.964	2.955	2.978	2.974	2.964	2.964	2.955											
Beaten for 215 min.	41	0.829	2.657	2.657	2.648	2.642	2.608	3.000	2.999	2.988	2.981	2.940	3.000	2.999	2.988	2.981	2.940											
	83	0.834	2.684	2.677	2.670	2.664	2.640	3.002	3.001	3.000	2.995	2.966	3.002	3.001	3.000	2.995	2.966											
	123	0.840	2.726	2.719	2.717	2.717	2.706	3.054	3.046	3.044	3.039	3.030	3.054	3.046	3.044	3.039	3.030											

respectively, then the dielectric constant (ϵ') and dissipation factor (D) of the specimen were calculated from the following equations:

$$\epsilon = 4\pi d(C_2' - C_2)/1.11A \quad (25)$$

$$D = [C_2'/(C_2' - C_2)] 2\pi fR(C_4 - C_4') 10^{-12} \quad (26)$$

TABLE III
Regenerated Fibers^a

Electrode pressure, psi	d_0 , g./cc.	Apparent dielectric constant, frequency at 1 kcycle/sec.	Apparent dielectric constant at standard density 1 using eq. (24), frequency at 1 kcycle/sec.
510	0.447	1.91	3.04
565	0.467	1.95	3.04
685	0.488	2.01	3.07
700	0.498	2.03	3.07
760	0.505	2.04	3.06

^a Data of Wiener.⁵

TABLE IV
Kraft Pulp

No.	Apparent dielectric constant, frequency at .06 kcycle/sec.	Density d_0 , g./cc.	$(\epsilon - 1)/(\epsilon + 2)d_0$
1	1.28	0.242	0.3528
2	1.75	0.547	0.3656
3	2.51	0.848	0.3948

TABLE V
Regenerated Fibers

No.	Apparent dielectric constant, frequency at 1 kcycle/sec.	Density d_0 , g./cc.	$(\epsilon - 1)/(\epsilon + 2)d_0$
1	1.83	0.428	0.5063
2	1.91	0.447	0.5206
3	1.95	0.467	0.5150
4	2.01	0.488	0.5162
5	2.03	0.498	0.5133
6	2.04	0.505	0.5097

TABLE VI
Bleached Sulfite Pulp

No.	Sample treatment	Density d_0 , g./cc.	Apparent dielectric constant at various frequencies											
			$(\epsilon - 1)/\omega d_0(\epsilon + 2)$ at various frequencies											
			1	2	3	5	10	1	2	3	5	10		
			ky- cycle/ sec.	ky- cycle/ sec.	ky- cycle/ sec.	ky- cycle/ sec.	ky- cycle/ sec.	ky- cycle/ sec.	ky- cycle/ sec.	ky- cycle/ sec.	ky- cycle/ sec.	ky- cycle/ sec.	ky- cycle/ sec.	ky- cycle/ sec.
1	Unbeaten	0.4848	1.912	1.906	1.900	1.895	1.873	0.4808	0.4785	0.4759	0.4740	0.4649		
2		0.5060	1.970	1.967	1.963	1.958	1.946	0.4828	0.4818	0.4802	0.4782	0.4737		
3		0.5170	1.983	1.980	1.977	1.976	1.972	0.4774	0.4762	0.4753	0.4749	0.4733		
1	Beaten for 35 min.	0.8476	2.709	2.699	2.692	2.680	2.667	0.4273	0.4267	0.4255	0.4236	0.4215		
2		0.8700	2.750	2.744	2.736	2.729	2.716	0.4224	0.4216	0.4204	0.4193	0.4173		
3		0.8790	2.780	2.776	2.775	2.768	2.756	0.4237	0.4231	0.4229	0.4218	0.4200		

where A = area between the electrodes (in square centimeters), f = frequency (in cycles/second), and R in the present case = 10^4 ohms.

An edge correction was applied by using a formula described by Scott and Curtis.⁹

In Tables I-III are given the apparent dielectric constants and the calculated values of apparent dielectric constant at a standard density 1 by using eq. (24).

The polarizability of a nonpolar dielectric is given by

$$P = [(\epsilon - 1)/(\epsilon + 2)](M/d) \quad (27)$$

If polarizability is considered a constant characteristic of the molecule independent of density, the dielectric constant may be related to density, i.e.,

$$[(\epsilon - 1)/(\epsilon + 2)](1/d) = k \quad (28)$$

where k is a constant. This is one form of the well-known Clausius-Mosotti relation.

Van den Akker and his students at The Institute of Paper Chemistry applied eq. (26) successfully to demonstrate the relation between dielectric constant and density of cellulose. The relationship was verified for kraft pulp by Hansen,⁸ for native cellulose by Calkins,⁶ for regenerated fibers by Verseput,¹⁰ and for bleached sulfite pulp and cotton linters by Venkateswaran. Some of the results are given in Tables IV-VI.

DISCUSSION

It is seen from Tables I-III that the dielectric constant of cellulose at any sheet density can be computed by using eq. (24). The density of a sheet can be changed either by the application of pressure or by beating. Table I shows that while the calculated values of the apparent dielectric constant of the sheets (at standard density 1) whose densities are changed by pressure agree reasonably well, the calculated values of the apparent dielectric constant of unbeaten and beaten samples at the same standard sheet density do not show good agreement. This could be due to the fact that beating increases the accessible portion (amorphous) of the cellulosic material whose dielectric constant is greater than that of the inaccessible portion (crystalline) of cellulose. A more detailed account of this effect will be published later.

Tables IV-VI give the results of the application of the Clausius-Mosotti relation to cellulose. It should be noted that the constant $(\epsilon - 1)/(\epsilon + 2)d_0$ has different values for different pulps under various conditions. Consequently, to determine the dielectric constant of a given pulp at any sheet density, the constant has to be determined first in a particular case. Also, since the crystallinity of cellulose has a profound influence on the dielectric constant of cellulose, the calculated values of dielectric constant of a given pulp, using the Clausius-Mosotti relation (even if the constant

is determined in the particular case) gives an unreliable value. On the other hand, the measured value of apparent dielectric constant ϵ_0' appearing in eq. (24) describes the lateral order structure of the material under that condition and hence the dielectric constant of a sheet at any density calculated by eq. (24) could be a more reliable result.

Further application of eqs. (17) and (18) will be published in a subsequent paper.

The author wishes to thank Dr. Shiva Yogi Tiwari, Research Professor of Physics, Birla Institute of Technology, Pilani, India for helping in the derivation of equations and Dr. Van den Akker, Senior Research Associate, The Institute of Paper Chemistry for interesting discussions.

References

1. Errera, J., *J. Phys. Radium*, [6], **5**, 304 (1924).
2. Debye, P., *Polar Molecules*, Chemical Catalog Co., New York, 1929, p. 103.
3. Jatkar, S. K. K., B. R. Y. Iyengar, and N. V. Sathe, *J. Indian Inst. Sci.*, **28A**, 11 (1946).
4. Silberstein, L., *Ann. Physik*, **56**, 661 (1895).
5. Wiener, O., *Abhand. Sächs. Akad. Wiss.*, **32**, 509 (1912).
6. Calkins, C. R., Doctor's Dissertation, The Institute of Paper Chemistry, Appleton, Wis., 1949.
7. Delevanti, C. A., Jr., Doctor's Dissertation, The Institute of Paper Chemistry, Appleton, Wis., 1943.
8. Hansen, P. B., Doctor's Dissertation, The Institute of Paper Chemistry, Appleton, Wis., 1943.
9. ASTM Designation D150-61T. 1941. Supplement to ASTM Standards including tentative Standards Part III: 375-405.
10. Verseput, H. W., Doctor's Dissertation, The Institute of Paper Chemistry, Appleton, Wis., 1951.

Résumé

On a établi les formules de la constante diélectrique et du facteur de dissipation d'un mélange diélectrique à plusieurs composants en assumant (1) que les dipôles s'orientent seulement dans deux directions à savoir la direction parallèle et anti-parallèle au champ appliqué et (2) que le dipôle est un corps hautement asymétrique ayant la forme d'une aiguille. On applique cette formule au calcul de la constante diélectrique de la cellulose en feuille de densité variable. On discute également de l'application de la relation de Clausius-Mosotti que lie la constante diélectrique et la densité.

Zusammenfassung

Formeln für die Dielektrizitätskonstante und den Dissipationsfaktor einer dielektrischen Mischung aus vielen Komponenten wurden unter der Annahme abgeleitet (1), dass die Dipole nur in zwei definierte Richtungen zeigen können, nämlich in der und entgegengesetzt zur Richtung des angewandten Feldes und (2), dass der Dipol ein hochgradig anisotroper Körper von nadelförmiger Gestalt ist. Die Formel für die Dielektrizitätskonstante wird zur Berechnung der Dielektrizitätskonstanten von Zellulose bei beliebigen Filmdichten angewendet. Die Anwendung der Clausius-Mosotti-Beziehung für die Beziehung zwischen Dielektrizitätskonstante und Dichte wird diskutiert.

Received April 23, 1964