THE DIELECTRIC PROPERTIES OF DAMMAR AND MASTIC RESINS

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ABSTRACT. The paper contains the results of measurement of dielectric properties of two natural resins, dammar and mastic, over a wide range of temperature and frequency. The results show typical polar characteristics. The measurement of viscosity of mastic resin within the range $90° - 120°C$ and of dammar resin within the range $120° - 150°C$ shows that they follow the logarithmic relation of a liquid with temperature. The d.c. conductance measurement for both these resins also shows that the same law holds good within the range of measurement, viz., $60° - 150°C$, with a discontinuity in the slope of the line obtained by plotting log K_0 against $1/T$ at $80°C$ for mastic and at $113°C$ for dammar. A distributed range of relaxation times in the molecules of both these resins has been established and the distribution coefficient calculated. The average radius of the rotating unit in the a.c. field has been calculated for each of these resins and the result shows that their polar units are bigger than those of lac. The average radius of the mastic rotating unit is 4.5 A.U. whereas that of dammar is only 2.7 A.U. The activation energy of both these resins has been calculated above and below the transformation point.

INTRODUCTION

In a previous paper (Bhattacharya, 1944a) on the dielectric properties of lac it has been observed that anomalous dispersion takes place near about its melting point and that the resin acts like a polar liquid when placed in an alternating current field. But the whole molecule being large and complex does not take part in the rotation, the hydroxyl groups only acting as rotators. In a subsequent paper (Bhattacharya, 1944b) it has been reported that lac constituents also behave in a more or less similar fashion and the rotating unit of soft lac resin in the alternating electric field is also the hydroxyl group. Hartshorn and co-workers (1940) also arrived at a similar conclusion working with some synthetic thermoplastic resins. It is therefore of interest to study a few other thermoplastic resins regarding their dielectric properties and to calculate therefrom the dimensions of the rotating unit.

Dammar and mastic are two important natural resins, which give very clear spirit varnishes largely used on account of their lustre and paleness as paper varnishes for the protection of pictures. Dammar is also used as a binder for moulded electrical insulation. These are thermoplastic resins and they have been selected here for the study of their dielectric properties chiefly owing to their comparatively low melting points among the important natural resins. Fossil resins, such as copals, although important from the standpoint of utility, were not selected for such a study as mesurement of their dielectric properties would have involved practical difficulties owing to their high melting points. This study therefore is a part of a general scheme for the study of electrical properties of natural resins of which lac probably occupies the most important position.

THEORETICAL

The dielectric properties of a substance may be expressed as

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

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where ϵ = the complex dielectric constant,

                ϵ' = the ordinary dielectric constant, specific inductive capacity or permittivity,

and ϵ'' = the dielectric loss factor.

The dielectric loss factor ϵ'' is related to the dielectric constant ϵ' through a factor, called power factor and expressed as tan δ, where δ is the loss angle. That is,

$$\epsilon'' = \epsilon' \tan \delta.$$

The current in phase with the applied voltage of a circuit may be expressed in terms of vectors as

$$I_r = I.\tan \delta$$

$$= \omega CV.\tan \delta, \text{ for a circuit containing a condenser C}$$

$$= 2\pi f CV \frac{\epsilon''}{\epsilon'}.$$

But for a parallel plate condenser of area A and thickness d the value of C is given by

$$C = \frac{A\epsilon'}{4\pi d \times 9 \times 10^{11}} \text{ farads.}$$

Therefore substituting this value of C

$$I_r = \frac{fA}{18 \times 10^{11} \times d} \epsilon''.$$

Now if K_t is the total conductance of the condenser this current can also be expressed as

$$I_r = \frac{AVK_t}{d}.$$

From the r.h.s. of these equations we therefore have

$$\epsilon'' = \frac{18 \times 10^{11} \times K_t}{f}.$$

This relation gives the value of total loss including that due to d.c. conductance of the dielectric of the condenser, the measure of which may similarly be written by substituting K_0 instead of K_t

$$i.e., \quad \epsilon''_{k_0} = \frac{18 \times 10^{11} \times K_0}{f}$$

Hence pure a.c. loss is expressed by

$$\epsilon'' = \frac{18 \times 10^{11}(K_t - K_0)}{f} = \frac{18 \times 10^{11} \times K}{f}.$$

EXPERIMENTAL

Apparatus.—The bridge method was employed for the measurement of capacity and power factor. For lower frequencies a Schering bridge, and for higher frequencies a General Radio—radio frequency bridge, type 516-C, were

used. For the latter ratio-arms and transformers were changed as advised by the manufacturers for different frequencies. Two oscillators, a beat frequency oscillator for audio-frequency currents and a General Radio modulated oscillator, type 684-A, for higher frequencies, were made use of. A wide-band amplifier in conjunction with a pair of high sensitivity headphones served as detector. The cell was the vertical type parallel plate gold condenser described earlier (Bhattacharya, 1944a). D.C. conductance measurements were made on the same assembly with D.C. voltage and a high sensitivity d'Arsonval galvanometer and a universal shunt. Viscosity measurements were made with a set of Lee's tar viscometers (Lee, 1934).

Materials.—The samples of dammar and mastic resins were supplied by Napier Paint Works Ltd., Calcutta. They were of ordinary commercial quality, but before use both of them were melted and filtered through two folds of muslin cloth to get rid of any dirt and woody matter, if present. The scum that floated on the surface of the molten resin was carefully removed and the clear liquid on the bottom taken for these experiments. The constants for these samples are as follows :

	Acid value.	Softening range (Mercury surface method.)	Melting range (Mercury surface method.)
Mastic	57.8	70-72°C	78-85°C
Dammar	39.5	100-104°C	112-117°C

METHOD OF PROCEDURE

The molten resins were poured into the experimental cell which had been kept heated in a circulating air-oven and the vertical plate condenser put into it. The precautions necessary to avoid air-bubbles adhering to the surface of the condenser plates as well as to avoid cracking of the experimental cell has already been dealt with in a previous paper (Bhattacharya, 1944c). The constancy of the capacity after several melting and stirring of the resin showed proper filling of the condenser. Capacity measurements were made by the substitution method on the radio-frequency bridge. D.C. conductance and viscosity measurements were made by the usual method.

CALCULATIONS

The standardisation of the experimental condenser was done by using pure and dry benzene, taking its dielectric constant at 25°C to be 2.2725. The 'Zero-capacity,' *i.e.*, the capacity for leads, etc., is given by

$$C_0 = \frac{C_A \epsilon_B - C_B}{\epsilon_B - 1}$$

where C_A= the capacity of the experimental condenser with air,

           C_B= the capacity of the same with benzene,

and ϵ_B= the dielectric constant of benzene.

The dielectric constant of the resin ϵ was obtained from the relation

$$\epsilon = \frac{C_B - C_0}{C_A - C_0}$$

where C_R = the capacity of the resin filled condenser.

The power factor and the dielectric loss factor were calculated from the bridge readings as reported earlier (Bhattacharya, 1944a).

RESULTS

TABLE I

Dielectric constant-temperature data at different frequencies

Resin	Temp. °C	Dielectric constant ϵ' at the frequency of				
		500 Kc/s.	100 Kc/s.	50 Kc/s.	10 Kc/s.	1 Kc/s.
Mastic	20	2.79	2.82	2.83	2.85	2.88
	30	2.82	2.84	2.86	2.88	2.91
	40	2.85	2.88	2.90	2.92	2.96
	50	2.90	2.94	2.96	2.98	3.04
	60	2.95	3.00	3.02	3.05	3.14
	70	3.03	3.10	3.12	3.18	3.33
	80	3.12	3.20	3.23	3.34	3.62
	90	3.20	3.32	3 39	3 58	4.12
	100	3.32	3.54	3.65	4.02	4.72
	110	3.50	3.83	4.02	4.50	5.08
	120	3.72	4.18	4.38	4.84	5.19
	130	3.96	4.44	4.64	4.92	5.10
	140	4.18	4.58	4.72	4.88	5.02
	150	4.36	4.64	4.72	4.82	4.96
Dammar	20	2.66	2.68	2.69	2.70	2.71
	30	2.66	2.68	2.69	2.70	2.71
	40	2.67	2.69	2.70	2.71	2.72
	50	2.68	2.70	2.70	2.72	2.72
	60	2.69	2.71	2.72	2.73	2.74
	70	2.71	2.73	2.74	2.74	2.76
	80	2.73	2.76	2.76	2.78	2.80
	90	2.76	2.78	2.79	2.81	2.86
	100	2.78	2.82	2.83	2.89	3.01
	110	2.83	2.88	2.91	3.00	3.25
	120	2.90	3.00	3.09	3.30	3.74
	130	2.99	3.17	3.28	3.58	3.97
	140	3.06	3.30	3.48	3 78	4.02
	150	3.20	3.52	3.66	3.85	3.97

TABLE II

Measured power factor data at various temperatures and frequencies

Resin	Temp. °C	Power factor at the frequency of				
		500 Kc/s.	100 Kc/s.	50 Kc/s.	10 Kc/s.	1 Kc/s.
Mastic	20	.0088	.0084	.0076	.0072	.0063
	30	.0097	.0089	.0085	.0077	·0064
	40	.0121	.0100	.0093	.0078	.0074
	50	.0150	.0117	.0116	·0094	.0095
	60	.0171	.0141	.0138	0134	.0148
	70	.0209	·0190	.0206	.0220	.0293
	80	.0254	.0267	.0271	.0367	.0568
	90	·0352	.0407	.0426	.0641	.0841
	100	.0495	.0619	.0802	0947	.830
	110	.0714	.0914	.0947	.1031	.0574
	120	.0935	.1037	.1031	.0760	.0310
	130	.1057	.0976	.0896	.0448	.0256
	140	1050	.0734	.0593	.0307	.0363
	150	.0890	.0510	.0371	.0242	.0779
Dammar	20	.0084	.0051	.0042	.0038	very low
	30	.0084	.0052	.0047	.0038	,,
	40	.0088	.0051	.0045	.0038	,,
	50	.0088	.0050	.0041	.0038	.0021
	60	.0089	.0050	.0041	.0039	.0022
	70	.0094	.0053	.0045	.0039	.0022
	80	.0103	.0061	.0054	.0061	.0062
	90	.0117	.0078	.0070	0088	.0135
	100	.0140	.0117	.0120	.0182	.0359
	110	.0178	.0186	.0224	.0358	.0561
	120	.0287	.0396	.0485	.0674	.0622
	130	.0432	.0627	.0669	.0787	.0449
	140	.0577	.0717	.0710	.0653	.0252
	150	.0754	.0763	.0690	0399	.0125

TABLE III

Corrected dielectric loss data at different temperatures and frequencies

Resin	Temp. °C	Dielectric loss ϵ'' at the frequency of				
		500 Kc/s.	100 Kc/s.	50 Kc/s.	10 Kc/s.	1 Kc/s.
Mastic	20	.0244	.0237	.0214	.0204	.0182
	30	.0275	.0254	.0244	.0221	.0186
	40	.0344	.0287	.0271	.0228	.0220
	50	.0436	.0343	.0344	.0279	.0290
	60	.0506	.0424	.0415	.0410	.0464
	70	.0634	.0588	.0642	.0699	.0975
	80	.0792	.0855	.0876	.1226	.2057
	90	.1126	.1350	.1444	.2295	.3463
	100	.1644	.2192	.2929	.3805	.3907
	110	.2500	.3500	.3805	.4637	.2881
	120	.3476	.4332	.4516	.3663	.1460
	130	.4185	4327	.4144	.2136	.0621
	140	.4386	.3344	.2769	.1345	.0308,
	150	.3873	.2326	.1667	.0758	—

TABLE III (contd.)

Resin	Temp.°C.	Dielectric loss ε" at the freqency of				
		500 Kc/s.	100 Kc/s.	50 Kc/s.	10 Kc/s.	1 Kc/s.
Dammar	20	.0222	.0135	.0113	.0103	very low
	30	.0223	.0140	.0125	.0103	,,
	40	0235	.0136	.0120	.0104	,,
	50	.0237	.0135	.0111	.0105	.0058
	60	.0239	.0136	.0113	.0105	.0059
	70	.0254	.0145	.0124	0106	.0060
	80	.0281	.0167	.0150	.0170	.0172
	90	.0323	0217	.0196	.0248	.0385
	100	.0389	.0330	.0340	.0525	.1081
	110	.0503	.0537	.0652	.1074	.1823
	120	.0832	.1187	.1499	.2223	.2323
	130	.1292	.1988	.2196	.2975	.1778
	140	.1764	.2367	.2472	.2467	.1004
	150	.2412	2684	.2524	.1544	.0473

TABLE IV

D.C. conductance data at different temperatures

Resin	Temperature		1000/T	D.C. conductance K_0	Log K_0
	t°C	T°K			
Mastic	60	333	3.003	very low	—
	70	343	2.915	8.84×10^{-15}	−14.05
	75	348	2.874	1.30×10^{-14}	−13.88
	80	353	2.833	2.53×10^{-14}	−13.60
	90	363	2.755	1.19×10^{-13}	−12.93
	100	373	2.681	5.44×10^{-13}	−12.26
	110	383	2.611	1.99×10^{-12}	−11.70
	120	393	2.545	8.20×10^{-12}	−11.09
	130	403	2.481	3.81×10^{-11}	−10.42
	140	413	2.421	8.40×10^{-11}	−10.08
	150	423	2.364	2.27×10^{-10}	− 9.64
Dammar	70	343	2.915	very low	—
	80	353	2.833	8.84×10^{-15}	−14.05
	90	363	2.755	1.39×20^{-14}	−13.86
	100	373	2.681	2.00×10^{-14}	−13.70
	110	383	2.611	3.00×10^{-14}	−13.52
	120	393	2.545	6.10×10^{-14}	−13.21
	130	403	2.481	2.20×10^{-1}	−12.66
	140	413	2.421	6.00×10^{-13}	−12.22
	150	423	2.364	1.35×10^{-12}	−11.87

DISCUSSIONS

The power factor—temperature curves (Figs. 1 and 2) of both these resins indicate that they behave as typical polar liquids. The dielectric constant and the dielectric loss-temperature curves (Figs. 3 and 4) also show the same characteristics. Both these resins therefore furnish very good examples of a typical polar resin. At temperatures below its softening range dammar resin has a very low value of power factor and it gives practically a horizontal straight line graph
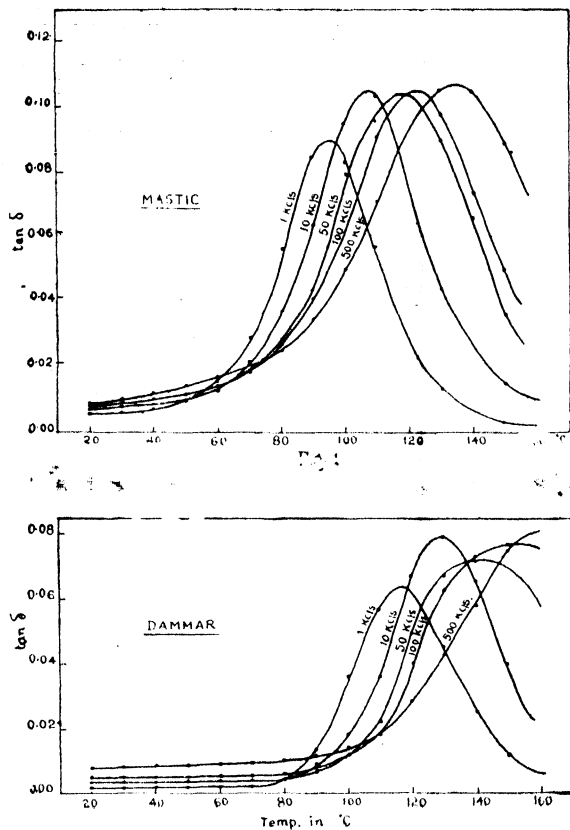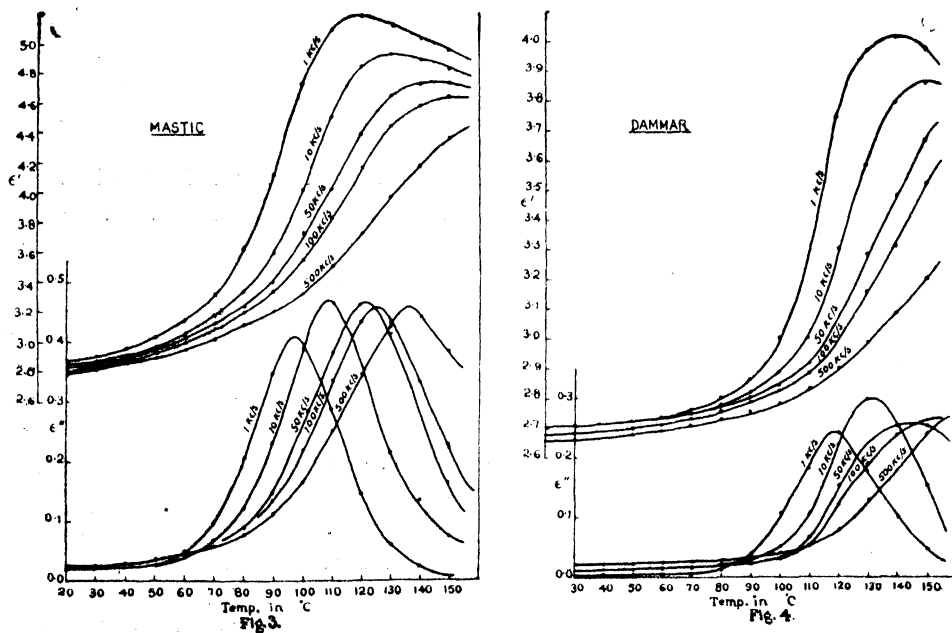
Fig. 2.

Fig. 3.

Fig. 4.

with the temperature axis. From the softening point power factor curves begin to rise, the slope of the curves depending on the frequency. For both these resins the temperature range 20°C to 150°C has been used and the frequency range extends from 1 Kc/s to 500 Kc/s. The temperature range was sufficient to bring out the characteristic nature of the curves and it was considered unnecessary to go beyond the higher limit of this range owing to the rapidly increasing d.c. conductance of these resins at high temperatures. The peak of any dielectric loss curve of these resins appears at a temperature at which there is maximum variation of dielectric constant at that frequency. This is in conformity with Debye's theory of polar molecules. The anomalous dispersion for these resins has been shown in figures 5 and 6. There is nothing special to comment on these curves except probably that they provide us with a beautiful and typical set of polar resin curves. Unlike lac which begins to harden at high
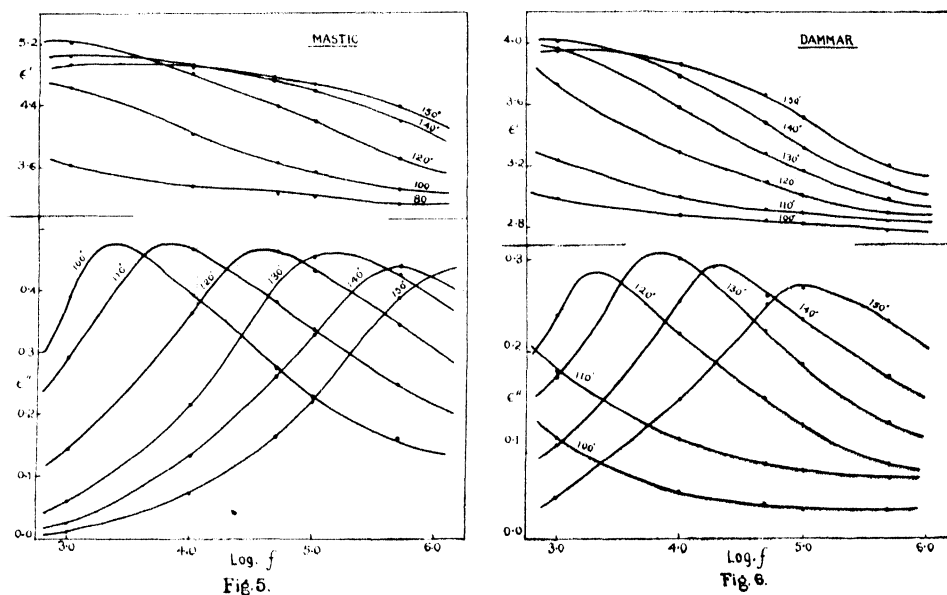

Fig.5.   Fig. 6.

temperatures these resins belong to the non-hardening class and that is why it has been possible to obtain such accurate data at various temperatures and frequencies.

Now it should be observed that mastic resin has a higher value of power factor maximum (Fig. 1) at any frequency than the peak of the corresponding dammar resin curve (Fig. 2). Obviously the loss maxima of mastic at different frequencies are also higher (Figs. 3 and 4). For example, the power factor maximum of mastic has a value of about 0.11 for practically all frequencies but 1 Kc/s in which case it is 0.09 only, whereas the corresponding figures for dammar resin are 0.08 and 0.06 approximately. Similarly the figures for loss-maximum of mastic are 0.45 and 0.40 at frequencies other than 1 Kc/s and at 1Kc/s respectively, whilst the same for dammar resin give 0.30 and 0.25 respectively. The first thing that strikes one for an explanation of this is the lower acid value of dammar compared with mastic resin. According to Glimman (1896) the important constituents of dammar resin consist of an acid
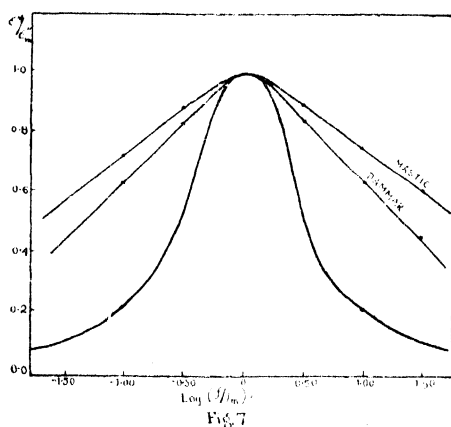
which is called dammarolic acid, $C_{54}H_{77}O_3$ $(COOH)_2$, and two other resins called
α-dammar resin, $C_{11}H_{17}O$ and β-dammar resin, $C_{31}H_{52}O$. The acid is
present to the extent of 23% only. In the case of mastic resin the chief cons-
tituents are also acids and resins. Tschirch and Reutter (1904) found a Chios
mastic sample to contain five acids, *viz.*, α- and β-masticic acids, $C_{23}H_{36}O_4$,
masticolic acid, $C_{33}H_{36}O_4$, and α- and β-masticonic acids, $C_{32}H_{48}O_4$, and two
resins, *viz.*, α-mastico-resin, $C_{35}H_{56}O_4$, and β-mastico-resin. The acids were
42·5% of the total resin. The resins are unclassifiable, inert, oxygenated
organic compounds of which very little is known at present. If these are left
out from our consideration for the present, we may see that the number of carb-
oxyls per unit volume are more in mastic resin than in dammar, although
dammarolic acid is a dicarboxylic acid. This may perhaps explain the lower
maximum of dielectric constant curves or loss curves of dammar resin.

It has already (Bhattacharya, 1944a) been stated that the maximum value
of dielectric loss of a pure polar liquid can be represented by

$$\epsilon''_{M} = \frac{\epsilon'_{0} - \epsilon'_{\infty}}{2}$$

where ϵ''_{M} = the maximum value of loss, ϵ'_{0} = the static dielectric constant,
and ϵ'_{∞} = the value of dielectric constant at very high frequencies.

In the case of lac as well as soft lac resin it has been noticed that the actual
loss-maximum falls far short of
the theoretical value demanded
by the above equation. From
this as well as the wide range of
anomalous dispersion obtained
experimentally for these materials
the natural conclusion is that
this is the effect of distributed
relaxation time in the molecules of
these substances. Similar effects
of distribution in the relaxation
time have been observed in the case
of a few synthetic thermoplastic

Fig. 7

resins such as, phenol-formaldehyde, cresol-formaldehyde, polyvinyl chloride,
polyvinyl chloroacetate, polychlorostyrene, etc. (Fuoss, 1941 ; Hartshorn,
et al, 1940). If we examine the loss-maximum values of dammar and mastic
resins in the light of the above relation, we shall find that here also they fall
far short of the calculated value and in fact the actual loss-maximum
of either of them is only about one-third of the theoretical value. The spread
of the anomalous dispersion for these resins can be seen from figures 5 and
6. We have reasons to conclude from all these, just as in the case of lac and
soft lac resin, that the rotating units have a distributed range of relaxation times.
A rough estimate of this distribution may be had, as we have seen previously,
from a comparison of the flatness of curves obtained by plotting $\epsilon''/\epsilon''_{M}$ against

f/f_m. Figure 7 shows these curves along with the Debye curve for pure-polar liquids. It will be seen that the effect of distribution in the relaxation times of rotating units of both these resins is clearly visible from this figure by the bluntness of these curves in comparison to the Debye curve. This distribution however is wider in the case of mastic resin than dammar,—a fact brought out by more flatness of the mastic curve than the dammar one. Actual calculation according to the method of Fuoss and Kirkwood (1941) for the determination of distribution coefficient of relaxation times gives a value of 0.49 for mastic and 0.54 for dammar. It may be recalled that lac gives a value of 0.35 whilst soft lac resin 0.40 and hard lac resin 0.26 for this distribution co-efficient. This means that the distribution of relaxation time around the most probable value is more concentrated for these resins than for the constituents of lac resin. Or, in other words, dammar and mastic resins conform better to the theoretical Debye curve than lac or its constituents.

We can now proceed to calculate the dimensions of the rotating unit for these resins as in previous cases. Making use of the relation $\tau = \xi/2kT$ and Stoke's law $\xi = 8\pi\eta a^3$, we can write as usual

$$\tau = \frac{4\pi\eta a^3}{kT},$$

where $\tau =$ relaxation time, $\xi =$ frictional torque, $k =$ Boltzmann constant,
         $T =$ absolute temperature, $\eta =$ coefficient of viscosity,
and $a =$ radius of the rotator.
τ may be calculated by means of the equation

$$\omega\tau = \frac{\epsilon'_\infty + 2}{\epsilon'_0 + 2}$$

TABLE V
Viscosity data at different temperatures

| Resin | Temperature | | 1000/T | Viscosity in poise | Log η |
	t°C	T°K			
Mastic	90	363	2.755	14670	4.166
	95	368	1.717	5940	3.774
	100	373	2.681	2305	3.362
	110	383	2.611	495	2.694
	120	393	2.545	130	2.114
Dammar	120	393	2.545	24290	4.386
	130	403	2.481	3716	3.570
	140	413	2.421	755	2.878
	150	423	2.364	196	2.292

at the point where the dielectric loss is maximum of any curve showing the variation of loss with temperature at constant frequency. But unless the viscosity coefficient at that temperature is known, the average radius of the rotating units cannot be found out. In order to collect viscosity data of these resins at various temperatures Lee's tar viscometers were employed. Measurements were

made by the usual mercury pressure as detailed in the original paper of Lee (1934). The results give a straight line plot with the reciprocal absolute temperature. This has been shown in figure 9. Measurements could not be pursued below 90°C for mastic and 120°C for dammar, as the viscosity attained a very high value, but there are reasons to believe from the d.c. conductance $-1/T$ graphs (Fig. 8) that a change of state takes place somewhat below these tempera-
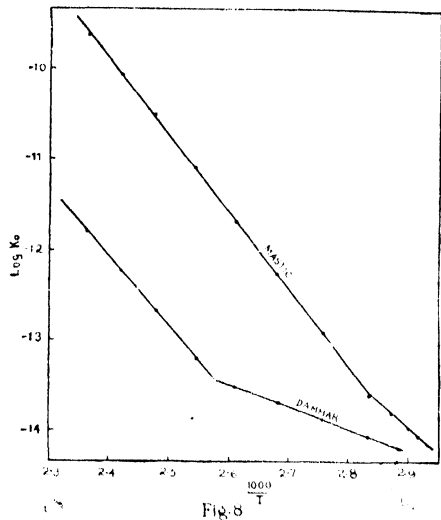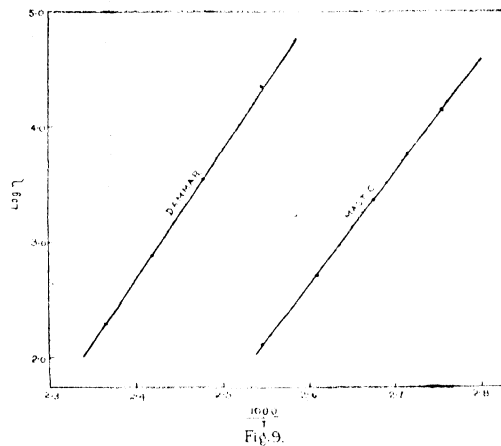

Fig.8.

Fig.9.

tures. Dammar shows a sharp break in the line near about 113°C in the graph (actually this may not be so sharp as shown and may extend over a few degrees). Similarly mastic has a linear graph till about 80°C when it changes its slope. Readings at lower temperatures than 70°C could not be taken owing to the very low conductivity of the material, but the lower two points clearly show the change of direction of the lower line. Thus the temperature 113°C for dammar or 80°C for mastic may be called ' transformation points ' according to Berger (1934). There may however be a ' transformation interval ' (Tammann, 1933) near-about these temperatures, but the range definitely is small in such a case as for example in selenium glass. The activation energy Q calculated from the slope of the d.c. conductance $-1/T$ straight line graph of mastic resin gives a value of 39.0 K-cal and 27.7 K-cal above and below 80°C respectively. From the viscosity $-1/T$ graph of the same resin a value of 42.1 K-cal is obtained. This is more or less in agreement with the value 39.0 K-cal obtained from d.c. conductance data above 80°C. But dammar shows slight difference in this respect. The value of Q obtained from d.c. conductance data is 37.0 K-cal whilst from viscosity data it is 46.7 K-cal, thus showing some difference. No comment on this difference can be made here, but we shall make use of the viscosity data obtained experimentally for our calculations of the dimensions of rotating units. High accuracy in the viscosity data is not necessary for this purpose since cube root of viscosity comes in the calculation of the radius of the rotator. The results of such calculations have been included in Table VI. It will be seen that the average radius of the rotator of mastic is about

TABLE VI

Calculated relaxation time and radius of the rotator

Resin	Frequency f	Loss-max. temp. t°_m	Relaxation time τ	Viscosity in poise η	Radius a
Mastic	1 Kc/s	97°	0.96×10⁻⁴ sec.	4217	4.5 × 10⁻⁸ cm.
	10 Kc/s	110°	0.96×10⁻⁵ ,,	495	4.3 × 10⁻⁸ cm.
	50 Kc/s	122°	1.92×10⁻⁶ ,,	89	4.5 × 10⁻⁸ cm.
Dammar	1 Kc/s	119°	1.16×10⁻⁴ sec.	25420	2.7 × 10⁻⁸ cm.
	10 Kc/s	132°	1.16×10⁻⁵ ,,	2985	2.6 × 10⁻⁸ cm.
	50 Kc/s	144°	2.32×10⁻⁶ ,,	501	2.8 × 10⁻⁸ cm.

4.5×10^{-8}cm., whereas dammar has a comparatively smaller rotating unit whose average radius is only 2.7×10^{-8}cm. Actual shape of these rotators may not be spherical, but this figure indicates the radius of the imaginary sphere which has the same volume as the average rotating unit. The constituents of these resins are all organic compounds having large molecules and their dimensions are expected to be bigger than 4.5Å or 2.7Å. The natural conclusion is that the whole molecule does not take part in the rotation, as we have already seen in the case of lac or lac constituents, but only some polar groups take part in the rotation. The position of these polar groups in the molecule determines their freedom to rotate and hence the extent to which they can contribute towards the polarisation. We see however that these rotators are much bigger in size than those of lac or its constituents.

The relaxation times of rotators of these resins are comparatively high both on account of their bigger size as well as greater inner friction at any particular temperature when compared with lac. For example, dammar rotating unit has an average relaxation time of 1.1×10^{-4} second at 120°C whereas at the same temperature mastic rotator has the value of 2.0×10^{-6} second and lac 1.5×10^{-8} second. The higher inner friction is generally the result of inter-molecular forces. If this factor can be reduced to a negligible figure, as for example in very dilute solutions of such a resin in a non-polar solvent, the relaxation time will give an idea of the size of rotating units from another side. An attempt will be made therefore to make such a study of very dilute solutions of some of these resins, and the result will be reported in another communication.

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REFERENCES

Berger, E., 1934, *Z. Tech. Physik.*, **15**, 443.

Bhattacharya, G. N., 1944, (a) *Ind. J. Phys.*, **18**, 1; (b) *ibid.*, **18**, 97; (c) *ibid.*, **18**, 116.

Fuoss, R. M., 1941, *J. Amer. Chem. Soc.*, **63**, 369.

Fuoss, R. M., and Kirkwood, J. G., 1941, *J. Amer. Chem. Soc.*, **63**, 385.

Glimmann, G., 1896, *Archiv. Pharm.*, **234**, 584.

Hartshorn, L , Megson, N J. and Rushton, E., 1940, *J. Soc. Chem. Ind.*, **59**, 129T.

Lee, A. R., 1934, *J. Soc. Chem. Ind.*, **53**, 69T.

Tammann, G., 1933, *Der Glaszustand,* 40.

Tschirch, A., and Reutter, L., 1904, *Archiv. Pharm.*, **242**, 104.