THE VISCOSITY OF POLARIZED DIELECTRICS.

By A. Wilmer Duff.

THE list of changes observed in the mechanical properties of a non-conducting liquid on subjecting it to electrostatic stress is a very short one, and that notwithstanding the fact that the subject is one of the greatest importance, because of its bearing on the question of the nature of electrification and electrostatic stress.

Quincke[1] found that some liquid dielectrics expanded in volume and others contracted under electrostatic stress; but Röntgen,[2] on repeating the experiments, failed to find the contractions and explained the expansions as due to heat produced by the passage of electricity through the dielectric; hence no satisfactory conclusion has been reached. Kerr[3] discovered that a liquid dielectric became double refracting under electrostatic stress, some liquids acting "like glass extended in a direction parallel to the lines of electric force" and others "like glass compressed in a direction parallel to the lines of electric force." These phenomena of Kerr are, however, only inferentially mechanical. W. König,[4] Pagliani,[5] Noack,[6] examined the viscosity of the dielectric, but failed to find any alteration of it due to electrostatic stress. Faraday's observation[7] that fibers of silk in the polarized dielectric stretched themselves in the direction of the electric force is an illustration of the effect of different inductive capacities. Hence, it would seem that we still lack positive knowledge as to the effect of electrostatic stress on the mechanical properties (density, compressibility, viscosity, etc.) of liquid dielectrics.

[1] Wiedemann's Annalen, X., p. 521, 1880. [2] Wiede. Ann., XI., p. 780, 1880.
[3] Philosophical Magazine, Nov., Dec., 1875; Aug., Sept., 1879.
[4] Wiede. Ann., XXV., p. 618, 1885.
[5] Ac. Torino, 20, p. 615, 1885; 22, p. 1, 1887 (Winkelmann's Physik).
[6] Wiede. Ann., XXVII., p. 289, 1886 (Winkelmann's Physik).
[7] Experimental Researches, XII., 1350.

About a year ago I undertook to reëxamine the question of a possible viscosity variation, but at first failed to find evidence (at least conclusive evidence) of any such effect. The method employed was not that of measuring the flow through a capillary tube placed between condenser plates (König), but one depending on the rate of descent of small spheres through a viscous liquid. Failing to find the effect sought, I have lately repeated the experiments with more care, rather with a view to fixing a superior limit to a possible viscosity variation than with the hope of actually discovering such a variation. The results obtained seem, however, to point clearly to the existence of the variation in question. Not many liquids have as yet been examined, as it seemed of more importance at first to thoroughly test one liquid under varying conditions. The results given in the present paper will, therefore, be limited to two or three liquids; and the extension of the methods employed to other liquids, together with a study of the law of variation of the effect under varying intensity of stress, will be left to a future paper.

The capillary tube method seemed to me, at first, objectionable, because of the difficulty of maintaining a sufficiently constant temperature for the requisite length of time; for, as is well known, the viscosity of a liquid varies very greatly with its temperature (as much as 10 per cent per degree in glycerin), and even a small change of temperature might completely mask other considerable changes of viscosity. This will appear from the following figures given by König, carbon bisulphide being the liquid used.

Temperature.	Viscosity.		Temperature.	Viscosity.	
17.5	0.00413	Plates uncharged.	17.8	0.00422	Plates uncharged.
16.8	0.00447	Plates uncharged.	17.8	0.00420	Plates charged.
17.6	0.00418	Plates charged.	16.2	0.00410	Plates uncharged.
18.6	0.00411	Plates uncharged.	16.1	0.00414	Plates charged.

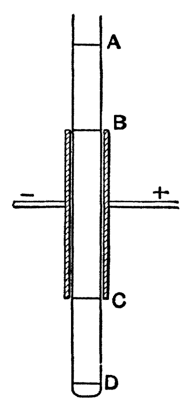
No doubt a much greater constancy of temperature than the above might be readily attained, but there seemed to be more hope in employing some method that would eliminate the effect of temperature variations.

The method adopted was to make use of the formula[1] found by Stokes for the rate of descent of a sphere through a viscous fluid. The steady velocity attained by a sphere falling through a fluid is:

$$V=\frac{2}{9}\frac{\rho-\sigma}{\eta}ga^2,$$

ρ being the density of the sphere, σ that of the fluid, a the radius of the sphere, and η the viscosity of the fluid. This is on the assumption that there is no finite slipping between the sphere and the liquid and that none such exists (at least in the case of such materials as are used in what follows) has been shown by Mr. O. G. Jones.[2] In the remainder of this paper the only assumption made from the above formula is that as the viscosity of a liquid increases, the time of descent of a sphere through a given distance in the medium also increases. (The possibility of a sufficient change in the density of the liquids used in my experiments or of an expansion of the glass tank employed will be adverted to later.)

If, then, a tube be filled with a viscous liquid and the time of descent of a small drop of mercury (the use of which will be justified later) through the length of the tube be noted and the tube be then inverted between the plates of a charged condenser, any change of viscosity would be shown by a change in the time of descent of the mercury drop. This would imply, of course, a constant temperature for the liquid, but such being unattainable, the following modification was made for approximately eliminating the temperature effect. Instead of the whole tube being placed between the condenser plates, the plates were placed opposite the middle half of the tube only, rings being etched around the tube to mark off the upper quarter, *AB*, the middle half, *BC*, and the lower quarter, *CD*, of the length through which the descent was observed. By means of two carefully tested stop watches, the ratio of the time of descent through *BC* to the sum of the



[1] Lamb's Motion of Fluids (1879), § 184.

[2] Proceedings Physical Society of London, 1894, or Nature, Feb. 22, 1894.

times of descent through AB and CD was obtained. This ratio would, of course, be independent of the actual size of the drop (providing its steady velocity was attained before reaching A), so that the inversion of the tube was unnecessary. Another drop was then allowed to descend, and the above ratio again obtained, the condenser being in this case charged. By this method of taking ratios, we get rid of the effect of any steady variation in temperature affecting the whole tube equally. Hence, barring local inequalities in temperature variation, if any change of the viscosity of the liquid between B and C were produced by the electrostatic stress, we should find a difference between the ratios obtained above.

Using the above method, I made seven series of observations on glycerin, which, though a very imperfect insulator, was chosen because of its suitable viscosity. The work was carried on in a room not artificially heated. Of the seven series of observations taken, two seemed to point clearly to the existence of the variation sought, three others showed one break each in the consistency of their indications, and the others were quite irregular, though giving a mean result of the same sign as before. These observations, therefore, were, in the absence of any previous knowledge as to such a variation, of little value in themselves; but, as they have become of some importance when taken in connection with later results by a more satisfactory method, I give the two following series as samples, the first being fairly representative of the consistent sets obtained, and the second of the semi-consistent sets. The condenser was kept charged by means of a small influence machine worked with a fair degree of uniformity. The distance between the condenser plates was 3.5 cm. As a rough indication of the potential I give the mean length of spark between the terminals of the influence machine.

Supposing for the moment that those results which were consistent among themselves were not misleading in their indications, the most probable source of the inconsistency of the others was irregular temperature fluctuations. Hence it seemed desirable to continue the observations under the following more favorable conditions: (1) in a room of more constant temperature, (2) with

Series I.

GLYCERIN.

Condenser.	T_1 = sum of times of descent through AB and CD.	T_2 = time of descent through condenser.	T_2/T_1.	Excess of T_2/T_1 when condenser was charged.	Temperature.	Remarks.
	min. sec.	min. sec.				
Uncharged .	4 15.60	4 12.40	0.9875	+0.0074	19.8	
Charged . .	4 7.75	4 6.50	0.9949			
Uncharged .	4 28.25	4 26.50	0.9935	+0.0044	19.8	
Charged . .	4 4.75	4 4.25	0.9979			
Uncharged .	5 1.75	4 54.75	0.9768	+0.0116	—	
Charged . .	3 36.50	3 34.00	0.9884			Interval.
Uncharged .	5 4.25	4 54.25	0.9761	+0.0030	20.9	
Charged . .	4 36.00	4 30.25	0.9791			
Uncharged .	3 6.25	3 2.50	0.9799	+0.0076	21.0	
Charged . .	4 0.50	3 57.50	0.9875			
Uncharged .	3 31.20	3 28.00	0.9846	+0.0048	21.0	
Charged . .	3 9.50	3 7.50	0.9894			
Uncharged .	4 6.20	4 1.50	0.9797	+0.0169	21.2	
Charged . .	3 53.00	3 52.20	0.9966			
Uncharged .	3 13.70	3 10.20	0.9819	+0.0083	—	
Charged . .	4 1.50	3 59.20	0.9902			

Mean length of spark, 1.6 cm.

a liquid less sensitive to temperature, but still of a suitable viscosity, (3) with the use of a large body of liquid whose temperature might not change so readily. I therefore made a large tank 60 cm. × 30 cm. × 2 cm. (internal dimensions). This was constructed of sheets of plate glass, solidly clamped on an open rectangle of hard wood, with rubber tubing between the glass and the wood. The tank was marked off into an upper quarter, a middle half, and a lower quarter, as in the case of the tube. Sheets of tin-foil glued to the middle halves of the plates served as a condenser, the edges of the tin-foil being thickly coated with paraffin wax. The observations were thenceforward made in a cellar of the Purdue Electrical Building. To protect the tank

SERIES II.

GLYCERIN.

Condenser.	T_1 = sum of times of descent through AB and CD.	T_2 = time of descent through condenser.	T_2/T_1.	Excess of T_2/T_1 when condenser was charged.	Remarks.
	min. sec.	min. sec.			
Uncharged . . .	1 7.2	1 7.7	1.007	−0.003	
Charged	1 17.2	1 17.5	1.004		
Uncharged . . .	1 36.0	1 36.0	1.000	+0.005	
Charged	1 37.5	1 38.0	1.005		
Uncharged . . .	1 49.0	1 49.5	1.005	+0.007	
Charged	3 11.2	3 13.5	1.012		
Uncharged . . .	1 38.2	1 39.2	1.010	+0.003	
Charged	1 17.2	1 18.2	1.013		
Uncharged . . .	1 31.0	1 32.0	1.011	+0.002	
Charged	1 42.2	1 43.5	1.013		
Uncharged . . .	1 21.7	1 21.7	1.000	+0.003	
Charged	0 58.2	0 58.5	1.003		

Mean length of spark, 1.3 cm.

from air currents, it was surrounded by glass screens. A bright background for the observation of the descending drops was obtained by reflecting sky light from tilted glass plates. The most suitable time for working was found to be between one and four o'clock in the afternoon, during which period the temperature of the cellar usually reached a maximum, and varied but slowly.

The results obtained were at first somewhat irregular, until the following simple modification was made. The drops were started in regular rapid succession, and in calculating, the ratio T_2/T_1, obtained with the condenser uncharged, was compared with the mean of the ratios obtained immediately before and immediately after with the condenser charged. This process nearly eliminated any uniformly progressive temperature variation from above or below. It also eliminated any steady variation in the rates of the stop watches used for taking time. Only days of normal temperature conditions were chosen for work. These conditions being observed, the observations showed thenceforward an almost invariable consistency.

The following series of readings seem to show that castor oil suffers an increase of viscosity under electrostatic stress.

Series III.

CASTOR OIL.

Condenser.	T_1 = sum of times of descent through highest and lowest quarters.	T_2 = time of descent through condenser.	T_2/T_1; condenser charged.	Mean of successive values of T_2/T_1; condenser charged.	T_2/T_1; condenser uncharged.	Excess of T_2/T_1; condenser charged.
	min. sec.	min. sec.				
Charged.	2 37.75	2 31.0	0.9572	—	—	—
Uncharged.	3 40.50	3 30.0	—	0.9564	0.9524	+0.0040
Charged.	3 40.25	3 30.5	0.9557	—	—	—
Uncharged.	3 7.75	2 58.5	—	0.9546	0.9507	+0.0039
Charged.	3 18.75	3 9.5	0.9535	—	—	—
Uncharged.	4 14.75	4 2.0	—	0.9534	0.9500	+0.0034
Charged.	3 39.75	3 29.5	0.9534	—	—	—
Uncharged.	3 21.75	3 11.5	—	0.9536	0.9492	+0.0044
Charged.	3 20.25	3 11.0	0.9538	—	—	—
Uncharged.	2 58.75	2 49.5	—	0.9537	0.9482	+0.0055
Charged.	2 31.00	2 24.0	0.9536	—	—	—
Mean					0.9501	+0.0043

Mean increase	0.45 per cent.
Mean spark length	3 cm.
Temperature of oil decreased from	17°.5 to 16°.8
Temperature of air decreased from	17°.5 " 17°.0

Series IV.

CASTOR OIL.

Condenser.	T_1 = sum of times of descent through highest and lowest quarters.	T_2 = time of descent through condenser.	T_2/T_1; condenser charged.	Mean of successive values of T_2/T_1; condenser charged.	T_2/T_1; condenser uncharged.	Excess of T_2/T_1; condenser charged.
	min. sec.	min. sec.				
Charged . .	1 19.25	1 16.25	0.9621	—	—	—
Uncharged .	2 8.00	2 3.00	—	0.9583	0.9609	−0.0026
Charged . .	1 50.00	1 45.00	0.9545	—	—	—
Uncharged .	2 42.00	2 35.00	—	0.9577	0.9568	+0.0009
Charged . .	1 55.00	1 50.50	0.9609	—	—	—
Uncharged .	1 52.50	1 47.00	—	0.9638	0.9511	+0.0027
Charged . .	1 56.00	1 52.25	0.9668	—	—	—
Uncharged .	2 27.25	2 21.25	—	0.9641	0.9593	+0.0048
Charged . .	2 36.00	2 30.00	0.9615	—	—	—
Uncharged .	2 30.00	2 23.00	—	0.9669	0.9533	+0.0136
Charged . .	3 0.40	2 55.40	0.9723	—	—	—
Uncharged .	2 39.25	2 33.75	—	0.9702	0.9655	+0.0047
Charged . .	2 44.75	2 39.50	0.9681	—	—	—
Uncharged .	2 42.75	2 36.75	—	0.9670	0.9631	+0.0039
Charged . .	2 34.00	2 28.75	0.9659	—	—	—
Uncharged .	2 11.25	2 6.00	—	0.9650	0.9600	+0.0050
Charged . .	1 58.50	1 54.25	0.9641	—	—	—
Uncharged .	1 45.90	2 36.75	—	0.9631	0.9595	+0.0036
Charged . .	2 5.75	2 1.00	0.9622	—	—	—
Uncharged .	2 5.75	2 0.50	—	0.9619	0.9583	+0.0036
Charged . .	2 23.75	2 18.25	0.9617	—	—	—
Mean					0.9587	+0.0040

Mean increase	0.42 per cent.
Temperature of air increased from	13° to 13°.5
Temperature of oil	not taken; light bad
Mean spark length	3.6 cm.

Series V.

CASTOR OIL.

Condenser.	T_1 = sum of times of descent through highest and lowest quarters.	T_2 = time of descent through condenser.	T_2/T_1; condenser charged.	Mean of successive values of T_2/T_1; condenser charged.	T_2/T_1; condenser uncharged.	Excess of T_2/T_1; condenser charged.
	min. sec.	min. sec.				
Charged . .	3 7.75	2 58.75	0.9521	—	—	—
Uncharged .	2 19.00	2 12.50	—	0.9598	0.9532	+0.0066
Charged . .	3 20.00	3 13.50	0.9675	—	—	—
Uncharged .	2 36.00	2 30.00	—	0.9636	0.9616	+0.0020
Charged . .	4 1.75	3 52.00	0.9597	—	—	—
Uncharged .	2 31.75	2 25.50	—	0.9612	0.9588	+0.0024
Charged . .	2 21.00	2 15.75	0.9628	—	—	—
Uncharged .	3 20.75	3 11.00	—	0.9640	0.9515	+0.0125
Charged . .	2 30.75	2 25.20	0.9652	—	—	—
Uncharged .	2 39.75	2 33.25	—	0.9613	0.9593	+0.0020
Charged . .	3 8.25	3 0.25	0.9575	—	—	—
Mean					0.9568	+0.0051

Mean increase . . . . 0.53 per cent.
Mean spark length . . . . 3.2 cm.

In these results it should be noted how extremely good the agreement between the differences is when the mean ratios in the fifth column are changing steadily and not irregularly. Series III. and the latter half of IV. show this especially well. The ratio .9545 (column 4, Series IV.) is so very different from the other ratios in the same column that it must be due to a blunder in taking time. This will account for the only negative difference obtained.

Two other series of readings were made, but were marked "rejected" after calculating the ratios obtained with the condenser uncharged and before calculating those obtained with the condenser charged. This rejection was made on the ground that the ratios obtained with the condenser uncharged varied irregularly among themselves, and hence would be unlikely to give consistent indications. These were all the readings so made.

I then proceeded to inquire into other possible explanations of this apparent increase of viscosity.

(1) Temperature. It is well known that heat is produced by rapidly charging and discharging a condenser. Hence an increase of temperature of the liquid might be produced by fluctuations of the potential to which the condenser was charged. This increase would, however, be very slight, owing to the mass of liquid employed, and to the fact that the influence machine was worked pretty uniformly. Very accurate readings of the temperature of the liquid were not possible in the cellar where I worked, for these would bring the body close to the tank, and thus produce a local heating of the liquid. Rough readings were, however, made, and showed no uniform variations. Any changes of temperature produced in the liquid itself by variations in the dielectric stress acting on it may be rejected at once as a sufficient cause for the phenomenon, for they would produce a decrease of viscosity. Variations in the temperature of the liquid, due to heat produced in the glass, might conceivably produce the effect observed; for, owing to the low conducting power of the liquid, the maximum of the temperature increase produced in the center of the liquid by heat transmitted from the glass might be postponed until the time of descent of the next drop. A glance, however, at the preceding results will show that the time of descent varied so widely that such a fluctuation could not be of a sufficiently periodic nature to account for the results. There were, moreover, frequent short interruptions of work.

An examination of Stokes' formula will show that an alteration of the difference of density of mercury and castor oil due to heating would affect the time of descent; but a short calculation will show that the requisite temperature change would be enormous.

Moreover, the radius of the mercury drop is contained in the formula; but a sufficient alteration of it would require at least 25° change of temperature.

A thermal expansion of the middle halves of the glass plates with a consequent alteration of the apparent time of descent may also be dismissed as insufficient.

(2) The drops might be deflected horizontally by the force of the field. This seemed very improbable, but to test it a small millimeter scale was placed at the bottom of the tank and the distances of the landing places of the drops from the center of the tank noticed. The following were the results:

Plates charged	$2\frac{1}{2}$		$2\frac{1}{2}$		$1\frac{1}{2}$		2
Plates uncharged		$2\frac{1}{2}$		2		2	

Hence there was no appreciable horizontal deflection.

(3) The shaking of the table when the machine was being worked to charge the condenser, might possibly affect the velocity of the drops. (The shaking, however, was slight, and the table a heavy one.) Hence, a series of observations were taken with the machine in action all the time during the descent of the alternate drops. The results (all positive) showed that the effect still remained when this possible cause was eliminated. As a further precaution, the rates of the stop watches were compared and found unaffected by the action of the machine. These observations need not be quoted, as the matter is sufficiently settled by the results obtained later with heavy paraffin oil.

(4) The effect might be due to a retardation of the drop where it left the field of the condenser. This seemed also a very improbable explanation, but to guard against it the condenser was discharged before the drop reappeared, the time of reappearance being estimated from the time of descent through the upper quarter of the tank.

(5) The drops of mercury, being conductors, might be deformed by the action of the field. If they became prolate along the lines of force, the time of descent would probably be increased. As this seemed a not unlikely source of fallacy, a series of observations were made with small shot instead of mercury drops. Care was taken to get shot as nearly perfectly spherical as possible, the sphericity being tested by examination with a magnifying glass, and by observing the degree of smoothness with which the shot rolled on a glass plate. The following series of readings seems to dispose of this source of suspicion. It will be noticed

that it gives nearly the same percentage alteration of viscosity as did the mercury drops.

Series VI.

Castor Oil.

(Tested by Descent of Small Shot.)

Condenser.	T_1 = sum of times of descent through highest and lowest quarters.	T_2 = time of descent through condenser.	T_2/T_1; condenser charged.	Mean of successive values of T_2/T_1; condenser charged.	T_2/T_1; condenser uncharged.	Excess of T_2/T_1; condenser charged.
	min. sec.	min. sec.				
Charged . .	2 15.00	2 7.50	0.9444	—	—	—
Uncharged .	1 44.40	1 38.75	—	0.9461	0.9459	+0.0002
Charged . .	1 36.40	1 28.25	0.9479	—	—	—
Uncharged .	2 24.75	2 17.00	—	0.9476	0.9465	+0.0011
Charged . .	2 8.25	2 1.50	0.9474	—	—	—
Uncharged .	2 39.75	2 31.50	—	0.9509	0.9484	+0.0025
Charged . .	2 22.50	2 16.00	0.9544	—	—	—
Uncharged .	2 4.25	1 57.75	—	0.9526	0.9477	+0.0049
Charged . .	3 18.75	3 9.00	0.9509	—	—	—
Uncharged .	2 41.75	2 33.25	—	0.9492	0.9474	+0.0018
Charged . .	2 23.00	2 15.50	0.9476	—	—	—
Uncharged .	2 16.25	2 8.75	—	0.9520	0.9450	+0.0070
Charged . .	2 17.75	2 11.75	0.9564	—	—	—
Uncharged .	2 15.75	2 8.25	—	0.9523	0.9448	+0.0075
Charged . .	2 20.00	2 12.75	0.9482	—	—	—
Mean					0.9465	+0.0036

Mean increase	0.38 per cent.
Mean spark length	2.5 cm.
Temperature of oil increased from	9° to 9°.2
Temperature of air decreased from	10° " 8°.8

(6) The shot, being not perfectly spherical, might, when within the condenser, take an average "set" with the greatest diameter parallel to the lines of force. That this cause could be sufficient seems improbable, the shot being so nearly perfectly spherical. Moreover, it seems very improbable that this and the deformation of the mercury drops should produce so nearly the same percentage change of velocity. If such a "set" of the shot occurred

within the condenser some trace of this would be likely to persist during the remainder of the descent, since the shot ordinarily rotated only very slowly in descending. A lengthy series of readings of the times of descent through the highest and the lowest quarter of the tank failed to show any such effect. A conclusive test would be to replace the shot by spheres of non-conducting material of about the same S.I.C. as the dielectric. To this end many kinds of beads, pills, and seeds were tested, but none were found sufficiently spherical and of suitable density. Finally, some carefully selected imitation pearls (so-called "Roman" pearls), made of hard wax were tried. They gave the following series of results, which seems to finally settle the question.

Series VII.

CASTOR OIL.

(Tested by Descent of Imitation Pearls.)

Condenser.	T_1 = sum of times of descent through highest and lowest quarters.	T_2 = time of descent through condenser.	T_2/T_1; condenser uncharged.	Mean of successive values of T_2/T_1; condenser uncharged.	T_2/T_1; condenser charged.	Excess of T_2/T_1; condenser charged.
	min. sec.	min. sec.				
Uncharged .	2 59.00	2 51.75	0.9595	—	—	—
Charged . .	2 35.25	2 29.25	—	0.9577	0.9613	+0.0036
Uncharged .	2 10.25	2 4.50	0.9559	—	—	—
Charged . .	1 58.25	1 53.25	—	0.9554	0.9577	+0.0023
Uncharged .	3 14.00	3 5.25	0.9549	—	—	—
Charged . .	2 20.00	2 13.75	—	0.9547	0.9554	+0.0007
Uncharged .	3 1.25	2 53.00	0.9545	—	—	—
Charged . .	2 33.75	2 28.50	—	0.9606	0.9659	+0.0053
Uncharged .	2 0.50	1 56.25	0.9667	—	—	—
Charged . .	3 5.10	2 58.75	—	0.9621	0.9657	+0.0036
Uncharged .	2 13.25	2 7.75	0.9576	—	—	—
Charged . .	2 59.50	2 51.50	—	0.9549	0.9554	+0.0005
Uncharged .	2 37.75	2 29.75	0.9523	—	—	—
Mean					0.9559	0.0027

Mean increase	0.28 per cent.
Mean spark length	2.6 cm.
Temperature of air increasing from	$8^\circ.75$ to $9^\circ.0$
Temperature of oil increasing from	$8^\circ.65$ " $8^\circ.8$

These results are, as might be expected, less regular than preceding ones. Omitting from the column of differences the numbers which vary widely from the mean, the average percentage increase of viscosity is roughly the same as before. This agreement is a further argument against the existence of finite slipping between the liquid and the descending sphere.

From all the preceding we seem justified in concluding that the viscosity of castor oil is increased by about one half of one per cent when the oil is subjected to the electrostatic stress produced by a potential gradient of about 27,000 volts per centimeter or 90 E.S., C.G.S. units of potential per centimeter.

With reference to the preceding statement, two remarks may be made; first, that the electrostatic field was only steady to the

SERIES VIII.

HEAVY PARAFFIN OIL.

(Tested by Descent of Mercury Drops.)

Condenser.	T_1 = sum of times of descent through highest and lowest quarters.	T_2 = time of descent through condenser.	T_2/T_1; condenser uncharged.	Mean of successive values of T_2/T_1; condenser uncharged.	T_2/T_1; condenser charged.	Excess of T_2/T_1; condenser charged.
	min. sec.	min. sec.				
Uncharged .	3 26.6	3 27.8	1.0058	—	—	—
Charged . .	2 40.3	2 42.0	—	1.0069	1.0075	+0.0006
Uncharged .	3 17.2	3 18.8	1.0081	—	—	—
Charged . .	2 7.9	2 9.2	—	1.0087	1.0102	+0.0015
Uncharged .	3 45.6	3 47.7	1.0093	—	—	—
Charged . .	2 47.4	2 48.0	—	1.0084	1.0036	−0.0048
Uncharged .	2 14.0	2 15.0	1.0075	—	—	—
Charged . .	1 51.5	1 52.4	—	1.0062	1.0081	+0.0019
Uncharged .	2 41.8	2 42.6	1.0049	—	—	—
Charged . .	2 20.8	2 21.4	—	1.0067	1.0043	−0.0024
Uncharged .	2 56.8	2 57.8	1.0086	—	—	—
Charged . .	2 7.8	2 8.4	—	1.0056	1.0047	−0.0009
Uncharged .	2 30.4	2 30.8	1.0027	—	—	—
Mean					—	−0.0008

Mean spark length . . . . 3 cm.
Temperature of oil decreasing from . . . . $5^{\circ}.1$ to 4°

extent that the influence machine was worked fairly regularly; second, that the estimate of the field strength, being made from the mean sparking distance and the equation deduced by Chrystal

Series IX.

HEAVY PARAFFIN OIL.

(*Tested by Descent of Mercury Drops.*)

Condenser.	T_1 = sum of times of descent through highest and lowest quarters.	T_2 = time of descent through condenser.	T_2/T_1; condenser uncharged.	Mean of successive values of T_2/T_1; condenser uncharged.	T_2/T_1; condenser charged.	Excess of T_2/T_1; condenser charged.
	min. sec.	min. sec.				
Uncharged .	4 49.4	4 49.0	0.9986	—	—	—
Charged . .	5 4.1	5 4.3	—	0.9993	1.0007	+0.0014
Uncharged .	4 56.0	4 56.0	1.0000	—	—	—
Charged . .	4 33.0	4 32.2	—	0.9986	0.9971	−0.0015
Uncharged .	3 30.8	3 30.2	0.9972	—	—	—
Charged . .	4 14.0	4 14.4	—	1.0002	1.0016	+0.0014
Uncharged .	5 4.0	5 5.0	1.0033	—	—	—
Charged . .	3 37.6	3 37.8	—	1.0040	1.0009	−0.0031
Uncharged .	4 33.7	4 35.0	1.0047	—	—	—
Charged . .	4 0.8	4 0.8	—	1.0028	1.0000	− 0.0028
Uncharged .	3 45.0	3 45.2	1.0009	—	—	—
Charged . .	4 30.8	4 31.0	—	1.0004	1.0007	+0.0003
Uncharged .	3 48.0	3 48.0	1.0000	—	—	—
Charged . .	3 25.8	3 25.6	—	1.0015	0.9990	−0.0025
Uncharged .	3 14.4	3 15.0	1.0031	—	—	—
Charged . .	4 32.4	4 32.2	—	0.9981	0.9993	+0.0012
Uncharged .	3 51.6	3 50.0	0.9931	—	—	—
Mean					—	−0.0007

Mean spark length	3.5 cm.
Temperature of air increasing from	7°.3 to 7°.50
Temperature of oil decreasing from	8°.2 " 7°.75

to represent Baille's results for the potential necessary to a given spark length, is only the roughest approximation.

It having now been shown pretty conclusively that at least one dielectric undergoes a change of viscosity under dielectric stress, it becomes an *a priori* probability that other dielectrics are similarly affected. Hence there is no longer any cause to doubt that the earlier experiments on glycerin (Series I. and II.) were reliable in their indications, and that glycerin also has an increased viscosity under electrostatic stress.

The only other liquid so far tested by the present method is heavy paraffin oil (specific gravity = .883). As will be seen by the series of readings VIII. and IX., the evidence as to this liquid is hardly conclusive. Mercury drops were used in this case.

From the above results it seems possible that heavy paraffin oil suffers a decrease of viscosity, the decrease being, however, much less than the increase in the preceding liquids, and much more difficult to determine. It should be noted that the failure to find an increase of viscosity in paraffin oil, or, still more, the discovery of a decrease is a strong evidence of the validity of the method employed in these experiments. The only detraction from this argument is that much smaller drops of mercury were used in the case of paraffin oil than in the case of castor oil. In all other particulars the method was the same.

The method described in this paper can only be applied to very viscous liquids. For testing less viscous liquids I have constructed two separate forms of apparatus, in which capillary tubes are used in such a way as to eliminate temperature effects. These have already been applied to testing several liquids, and to examining the effect of different intensities of dielectric stress and different degrees of unsteadiness or non-uniformity of field. These results will be given in another paper.

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