Experiments on the Viscosity of a Solution of Saponine

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have employed we see that, at distances from the end of the magnet very small compared with the length of the core, the wire should all be coiled up at the near end of the core, as in fig. 4 ; to create a field at a distance from the end of the magnet equal to about a third of the length of the magnet, it is better to coil the wire uniformly over one half of the core, as in fig. 2, than to cone it up at the near end as in 4 ; while for distances from the end of the magnet equal to, or greater than, about $\frac{1}{2}$ of the length of the core, the uniform mode of winding is the best.

We have to thank two of our students, Messrs. Sayers and Pink, for most cordial assistance rendered us in this investigation.

XXVII. *Experiments on the Viscosity of a Solution of Saponine.* By W. H. STABLES and A. E. WILSON, *Yorkshire College, Leeds* *.

M. PLATEAU has shown (*Statique des Liquides*, t. 2, ch. vii.) that a body placed in a liquid and wetted on one side only, experiences in many cases a greater resistance to its motion than if it were completely immersed. Some controversy has arisen between Marangoni and himself as to the cause of this phenomenon, which M. Plateau explains by the assumption that the liquids in question possess a surface viscosity greater than that of the interior. The liquid in which the surface resistance is in most striking contrast to that of the interior is a solution of saponine in water.

Oberbeck (Wiedemann's *Annalen*, Bd. 11, S. 634) has repeated and extended Plateau's experiments, using an oscillating disk instead of a magnetic needle. He made no observations upon saponine solution. The object, therefore, of the following investigation is to study the movements of a disk when oscillating in or near the surface of a solution of this substance.

Oberbeck found that the resistance of a water-surface increased largely with exposure to the air ; but he also proved that even with fresh distilled water the resistance is considerable. As he points out, we are therefore led to one of

* Read April 14, 1883.

two conclusions—namely, that either water has a surface viscosity different from that of the interior, or else that a pure water surface cannot be obtained.

The apparatus used in our experiments was similar to that employed by Grottrian (*Pogg. Ann.* Bd. 157, S. 237).

It is fully described by him; and it is therefore unnecessary to figure here the connexions of the different parts. The diagrammatic representation in fig. I. may, however, conduce to clearness.

It consists of a circular disk A of nickel-plated brass 76·25 millim. in diameter and 2 millim. thick. In the centre is screwed a brass rod, to which a concave mirror B and a small iron bar C (used to set the apparatus in motion by means of a magnet) are attached. A wire (119·8 centim. long), employed to put the apparatus in motion by torsion, is firmly gripped between two small plates at D.

The brass rod by which the plate was suspended could be unscrewed and replaced by others of different sizes.

The plate was suspended in the centre of a circular glass dish 15·5 centim. in diameter and 8 centim. deep. This was fitted with a wooden cover, through which a thermometer was introduced. The whole was surrounded by a case having glass sides, which served to ward off air-currents. The time of the oscillations was measured by a stop-watch indicating quarter-seconds.

Three rods were used in turn to suspend the plate. They were of the same length, but of different radii.

The radius of (1) was ·1337 centim.

„ (2) „ ·2360 „

„ (3) „ ·3362 „

The scale on which the beam of light was reflected was about 2·5 metres from the mirror; the maximum half-amplitude was about 200 millim.; so that the half-oscillation was about 2°·3.

The moment of inertia of the apparatus was determined by means of a brass ring of the same external diameter as the plate, and was found to be 753·09 (C.G.S.).

The plate was first carefully levelled, and distilled water poured into the vessel to within a few millimetres of the bottom of the plate. Water was then added with a pipette until the bottom of the plate and the surface of the water touched.

By a simple calculation the difference in height caused by the addition of a measured quantity of water was determined. An addition of 2 cubic centim. of water was found to cause a rise of $\cdot 1$ millim. in the level.

The elevation was of course increased when the disk was in the surface; but the change is allowed for in the calculations.

The temperatures of the air and of the water were carefully noted at the commencement of each observation, and were found to remain nearly constant. To attain this end the experiments were conducted in a cellar, and special precautions were taken to prevent any marked variations in temperature. The variations therefore did not exceed 1° C.; and the small corrections thus rendered necessary were made by means of the table of the values of the coefficient of viscosity of water at different temperatures given by Grottrian (*Pogg. Ann. Bd. 157, S. 242*). All the observations were thus reduced to 16° as a standard temperature. The time of oscillation was ascertained by observing the time of 10 swings. This operation was repeated a number of times and the mean taken. The logarithmic decrement was calculated from the readings obtained from the graduated scale.

The plate was suspended by each of the three rods in turn immersed to a depth exceeding 1 centim., and the logarithmic decrement and mean time of oscillation determined for each. The following table shows the results obtained with the saponine solution and with water:—

TABLE I.

Water.			Saponine.	
Rod.	Time of oscillation.	Log. dec.	Time of oscillation.	Log. dec.
1.....	sec. 5·19	·0477	sec. 5·24	·0785
2.....	5·20	·0479	5·26	·1424
3.....	5·22	·0483	5·26	·2045

The great difference between the surface-properties of saponine and those of water is here made very evident. The alterations in the dimensions of the rod which produced a slight effect only in the case of water increased the logarithmic decrement in the case of saponine two and a half times, a result which could only have been due to the increase of the section in contact with the surface.

If we assume that the disk oscillated under the influence of two forces, one of which (that of torsion) is proportional to the angular displacement from the position of rest, while the other, due to the viscosity of the liquid, is proportional to the velocity, the latter is measured by $M\lambda/T$, where M is the moment of inertia, λ the logarithmic decrement, and T the time of an oscillation. If, as in the case of a saponine solution, the surface resistance be so great that the friction between the surface layer and the interior may be neglected with regard to it, $M\lambda/T$ would be approximately of the form $a + br^2$, where r is the radius of the rod and a and b are constants.

The values of these, determined from the above equations by the method of least squares, are $a = 8.42$, $b = 191.6$.

Using these coefficients to calculate the value of $M\lambda/T$ from the observations on the saponine solution, we obtain the following results:—

TABLE II.

r .	$M\lambda/T$.	
	Observed.	Calculated.
0		8.42
.1337	11.27	11.85
.2360	20.37	19.07
.3362	29.36	30.07

The numbers are perhaps in as good agreement as could be expected, if we remember that the theory on which they are calculated is only approximate. If in the case of water we neglect b , the value of a is 6.92.

After the above preliminary observations a careful series of

experiments was made in which the plate was gradually immersed to a greater depth in water.

The following are the results obtained :—

Position of plate.	Time of oscillation.	Log. decrement.
	sec.	
Upper edge of plate 7 mm. } above level of water	5.06	.0258
.56 millim. above	5.10	.0259
.28 " "	5.10	.0260
.14 " "	5.11	.0262
Top of plate level with sur- } face of water	5.10	.0266
.1 below	5.12	.0272
.2 "	5.11	.0272
.3 "	5.13	.0285
.4 "	5.17	.0298
.5 "	5.18	.0329
.7 "	5.20	.0366
.9 "	5.20	.0415
1.3 "	5.20	.0479
1.7 "	5.20	.0488

In the above results, the level of the liquid is corrected for the displacement of the liquid by the plate.

Similar experiments were next made on the saponine solution ; but it was at once seen that the apparatus used in the previous experiment with the water was quite unsuitable on account of the great resistance offered by the surface. Certain modifications were therefore introduced. In this second

form (fig. II.) a steel piano-wire was used, the length of which was 98.35 centim. and the diameter 1.025 millim. Suspended by this wire was a stout brass rod, E, terminating in a disk, F, upon which rested a similar movable disk, G ; and between the two disks could be fitted a brass plate, H, carrying heavy brass rings, I. To the bottom of the lower disk an (unmagnetized) steel bar K was attached, by means of which the apparatus was set in oscillation by the use of a

Fig. II.

magnet. The apparatus used in the water experiment was attached to the centre of this bar by a strip of metal attached to D (fig. I.) and soldered to the bar. Great care was taken to render the junction perfectly firm, so that no torsion could possibly take place at this point. The moment of inertia was determined as before, and found to be 186653 (C.G.S.).

The first fact which was evident from the experiments was that, although the apparatus when suspended in water oscillated isochronously, it did not do so when suspended in the saponine solution. The following table gives the results of a number of experiments on the time of two long and two short swings respectively in that solution:—

Large amplitude.	Small amplitude.
10·90 sec.	10·28 sec.
10·70 "	10·28 "
10·75 "	10·35 "
10·52 "	10·35 "

With a thicker rod:—

10·42 sec.	9·85 sec.
10·52 "	9·73 "
10·33 "	9·90 "

Similar experiments in the case of water gave for two long oscillations, 10·25; for two short, 10·30; for three long oscillations, 15·5 and 15·75; and for three short, 15·6 and 15·75 seconds.

The amplitudes denoted long and short are not all of equal size; and as those called "large" are much larger than those actually used in the experiments, the correction which might otherwise have been necessary has been neglected.

The following are the results of the experiments on saponine solution:—

Position of plate. Upper surface	Time of oscillation.	Log. decrement.
·14 millim. above liquid... level.....	9·51 sec.	·1960
·1 below surface	9·50 "	·2520
·2 "	9·55 "	·0067
·3 "	9·60 "	·0045
·4 "	9·63 "	·0039
·6 "	9·58 "	·0034
1·0 "	9·55 "	·0030
1·4 "	9·62 "	·0025
2·4 "	9·63 "	·0022
3·65 "	9·62 "	·0020
	9·59 "	·0019

These results are shown on the accompanying curve (p. 241).

With regard to the first two observations, in which the plate was oscillating in the surface of the liquid, only two complete oscillations were obtainable for each determination; and as the logarithmic decrement was found to diminish considerably as the amplitude increased, a number of observations at different amplitudes were taken. These were plotted down in the form of a curve, showing the amplitudes and logarithmic decrement; and from these curves the logarithmic decrement for an arbitrary standard initial amplitude of 500 divisions was taken. The slope of these curves was so considerable that our observations can only be considered as giving an inferior limit to the resistance of the surface of the saponine solution. When the plate was once immersed below the surface, it was found that twenty or more oscillations were readily obtained, and that the magnitude of the original amplitude had little or no effect. The variations of temperature were small (the difference being only $0^{\circ} \cdot 7$ C.); and as their effect on the surface-viscosity is unknown, no correction was made for them. The error thus introduced would, however, as the regularity of the curve shows, be small.

These observations, then, enable us to compare the resistance offered to a disk when oscillating in, or just below, the surface of a saponine solution and of water.

Thus we get for the surface of saponine,

$$\frac{M\lambda}{T} = \frac{186653 \times \cdot 252}{9 \cdot 5} = 4951;$$

and for the surface of water,

$$\frac{M\lambda}{T} = \frac{753 \times \cdot 0266}{5 \cdot 1} = 3 \cdot 927.$$

At $\cdot 1$ millim. below the surface these numbers change to 131 and 4 respectively. At the surface, therefore, the ratio of the resistances is 1261; and at $\cdot 1$ millim. below it is 33; while in the interior it is, as has been shown, $\frac{\cdot 842}{6 \cdot 93}$, or 1.2. Although, therefore, these numbers can only be taken as approximations to the truth, we think that they enable us to make an estimate of the magnitude of the resistance offered to a body

oscillating in the surface of saponine solution, for which no previous experiments afforded the required data.

They show that whereas the resistance offered to an oscillating disk, 2 millim. thick, in the surface of water is only about half what it is in the interior, at the surface of a 2-per-cent. saponine solution it is at least 600 times greater than in the interior, but that this ratio is reduced to 16 by immersing the upper surface of the disk to a depth of 0.1 millim.

Special experiments proved that the logarithmic decrement in air was so small that the resistance of the air might safely be neglected when the comparisons of the various resistances were made as above described.

Explanation of the Curves.

Fig. III. is the curve given by the logarithmic decrements obtained from the experiments on water. The abscissæ are expressed in terms of hundredths of a millimetre; they represent the distance of the upper edge of the plate from the surface, and are negative when it is above it. The ordinates represent the logarithmic decrement in terms of .0001, the lowest horizontal line corresponding to the value of .0250.

The gradual increase in the value of the logarithmic decrement as the plate is more deeply immersed is clearly shown.

Fig. IV. refers to the observations made on the saponine solution. In this case the values of the ordinates are to be taken from the small figures. The positions corresponding to the numbers obtained when the disk was in the surface cannot be shown on the scale of the diagram. Fig. V. therefore has been drawn on one tenth of the scale of fig. IV. To avoid confusion it has been displaced to a convenient distance along the line of abscissæ. The enormous increase of resistance as soon as the disk touches the surface is very strikingly shown; and it must be remembered that the increase for a very small oscillation would be very much greater.

The conclusion may be drawn from figs. III. and IV., that both in water and in the saponine solution the effect of the surface disappears when the edge of the disk is about a millimetre and a half below it.

We cannot conclude without expressing our sincere thanks to Prof. Rücker for his kind assistance in our experiments.