Influence of Magnetic Field on the Co-efficient of Viscosity of Liquids.*

BY

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ABSTRACT.

The paper gives a preliminary account of the results of the investigation on the influence of magnetic field on the co-efficient of viscosity of liquids. The following results have been noted:

(*i*) Liquids with long chain aliphatic molecules, *e.g.*, acetone and propyl alcohol (normal), show diminution of viscosity in a magnetic field.

(*ii*) Liquids of the aromatic class, *e.g.*, nitro-benzene and toluene and an alcohol with side chains, *e.g.*, iso-amyl alcohol, show increase of viscosity in a magnetic field.

(*iii*) Carbon tetrachloride, water and aqueous solution of cerium nitrate show no change of viscosity.

For nitro-benzene, the change $d\eta/\eta$ increases linearly with increase of magnetic field, no indication of saturation being observed. The thermal variation of $d\eta/\eta$ for the same liquid is also recorded.

The influence of electric and magnetic field on the so-called transference processes in liquids and gases, *viz.*, on the co-efficients of viscosity, conductivity and diffusion, has been the subject of many investigations in recent years. A concise summary of these investigations will be found in a paper by Trautz and Fröschel in the Ann. d. Phys. Bd. 22, p. 223, 1935. Most of the changes observed by the previous investigators lay within the limits of experimental error, and no definite conclusions could be drawn from them. Recently Senftleben [1] and

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his fellow-workers have investigated the influence of a magnetic field on the conductivity of paramagnetic gases, and have obtained definite results, *viz.*, a diminution of conductivity of O_2 in a magnetic field of maximum value of the order of 1·1%. Owing to the close relation between the diffusion and conduction in a gas, Engelhardt and Sack [2] investigated and found a definite diminution in the value of the co-efficient of viscosity of O_2, of the order of 0·4%, in a magnetic field of strength 6-8 K. G. Similar results have been found by Trautz and Fröschel.[3] On reading accounts of these investigations of Senftleben, Sack and Trautz, it appeared worth while to us to try similar experiments with liquids.

It is known that organic liquids like nitrobenzene exhibit strong magnetic birefringence (Cotton-Mouton effect), which shows that molecules of such liquids possess a large degree of magnetic and optical anisotropy. These molecules are also highly anisotropic in shape, and it appeared reasonable to us to expect that due to the orientation of these molecules in a magnetic field, the co-efficient of viscosity of the liquid containing these molecules will be altered. After a large number of preliminary investigations, it has been possible for us to detect a definite change in the co-efficient of viscosity of different liquids, in magnetic fields of the order of 25-35 K. G. We have also investigated the effect of such a field on the viscosity of a solution of cerium nitrate, whose magnetic birefringence has been observed by Chinchalkar [4] and Haenny.[5] We could not observe any measurable change of viscosity in this solution, which is in agreement with the negative result obtained by Konig, on the effect of a magnetic field (much weaker in strength as compared to ours) on the viscosity of a solution of manganese sulphate.

In the present paper a preliminary account of the results obtained so far will be given ; theoretical discussion of the effects observed will be postponed till a large amount of accurate results have been obtained.

Experimental Method.

The method used was to measure the time of flow of a given volume of liquid through a capillary tube, placed between the pole-pieces of a powerful electromagnet. The change in the time of flow, when the given volume of liquid falls through a constant height, is taken to be proportional to the change in the viscosity of the liquid under the influence of the given magnetic field; it being assumed that there has not been any appreciable change of temperature. The electromagnet used was of Rutherford type, by means of which a magnetic field of about 34 K. G., was produced, between the prismatic-shaped pole pieces, over a volume of 17 cms. $\times 0{\cdot}4$ cm. $\times 0{\cdot}4$ cm. This type of electromagnet has no arrangement for water cooling. Special arrangement had to be made, to keep the temperature of the pole-pieces and of the liquid flowing through the capillary tube constant, during the period of the experiment. The necessity of ensuring the constancy of temperature will be apparent from the following consideration: For nitrobenzene we obtained an increase of viscosity of 0·2% in a field strength of 36 K. G. and temperature 23·5C. The time of flow was 25 minutes. The temperature change of viscosity of nitrobenzene is 3% per degree, so that an increase in temperature of 0·1C would completely mask the increase in viscosity in the magnetic field.

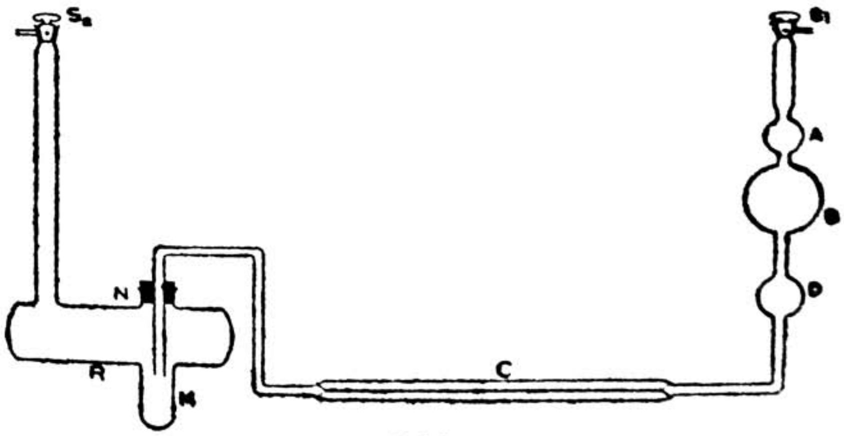


FIG. 1

The apparatus consisted essentially of a horizontal capillary tube C, (Fig. 1) of length 17 cms., and internal bore 0·5 mm., with two vertical limbs. One of these comprised of three glass bulbs, A, B, D, interconnected by means of slender glass tubes, while the other communicated with a receiving bulb R through a cork. A projecting glass tube M sealed to the lower end of the receiver, vertically below the cork N, allowed freedom of adjustment of the difference of level through which the liquid volume contained in A and B was intended to fall. The time of flow of the liquid could thus be regulated to a certain extent. Usually the time taken by the meniscus of the liquid head to flow across two specified marks on the narrow stems of the middle bulb B (about 1 inch in diameter) was observed. When, however, the viscosity of the liquid was large (*e.g.*, for iso-amyl alcohol and normal propyl alcohol), the time taken by the meniscus to travel across two marks on the narrow stems of the uppermost bulb A (about $\frac{1}{4}$ the size of the middle bulb)

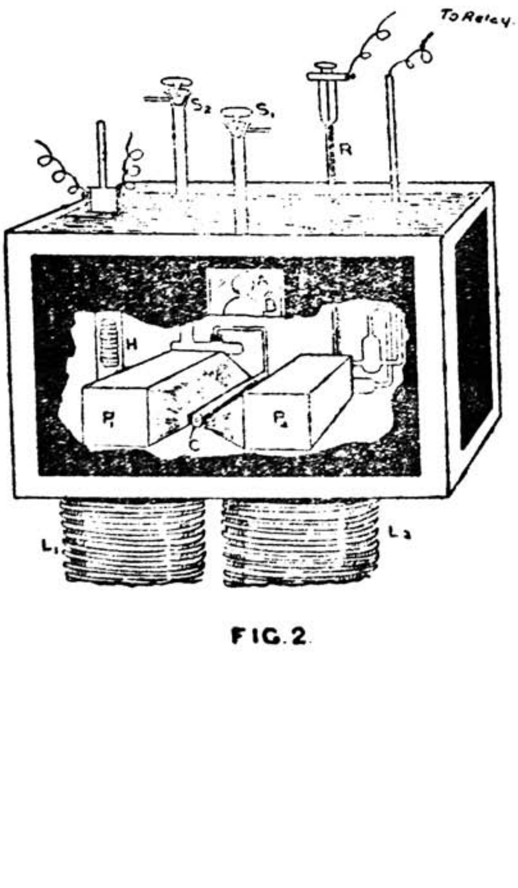


FIG. 2

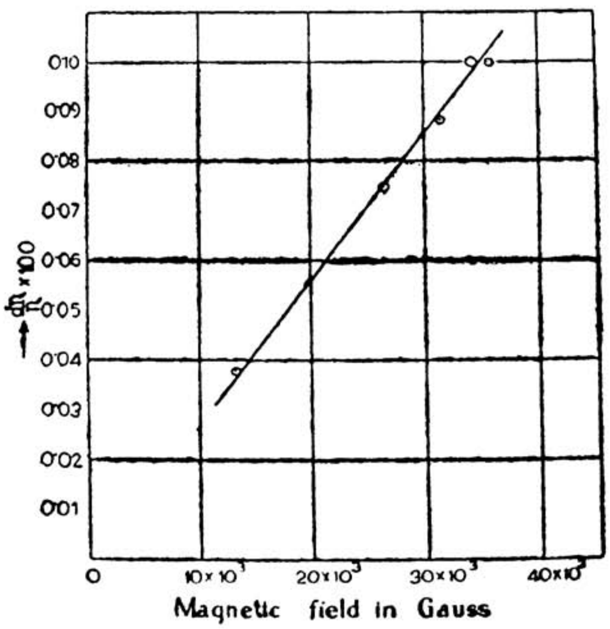
was observed. Two sides of the capillary tube were ground flat to a thickness of 2 mm. to enable its being placed in the narrow rectangular gap between the pole-pieces P_1 and P_2, leaving sufficient space between the ends of the latter and the sides of the tube for the circulation of water. By means of the stop-cock S_1, the apparatus could be connected through a calcium chloride tower, either to air or to a rotary oil pump. S_2 is connected to outside air through another calcium chloride tower. After each experiment, the liquid is sucked back to the bulbs A and B by connecting S_1 to the air pump and opening S_2.

The electromagnet consisted of two vertical limbs L_1 and L_2, (Fig. 2) round which the field coils were wound. On the top of these two limbs a thick brass plate was supported, through which the two rectangular ends of the cores of L_1 and L_2 project out and support the prism-shaped pole-pieces P_1 and P_2. On this brass-plate a thermostat, of dimensions $21'' \times 19'' \times 13''$, is built up. The bottom of the thermostat is fixed water tight on the brass plate by means of white paint, while the protruding corners are supported by suitable wooden supports. The bottom has two rectangular openings through which the cores of L_1 and L_2 project out. The outside of the thermostat, which is made of copper sheet, is covered with asbestos board fixed to a wooden frame. The front side is provided with a glass window to enable an observer to watch the motion of the liquid meniscus in the glass bulbs A and B, by means of a telescope and a metal filament lamp, the latter being placed above the thermostat. The glass apparatus is placed in the thermostat, with the capillary portion C between the pole-pieces P_1 and P_2, and only the stop-cocks S_1 and S_2 project above the level of water in the thermostat. The latter also contains a heater H, a toluene thermo-regulator R, a sensitive relay and a thermometer whose bulb lies above the capillary tube. With vigorous stirring, the temperature fluctuation is found not to exceed $0^\circ{\cdot}02$ C. The most accurate measurements are made, when the temperature of the bath is made equal to that of the surrounding air; then over the period of a series of observations there is no perceptible variation of temperature. Most of the observations are made under this condition.

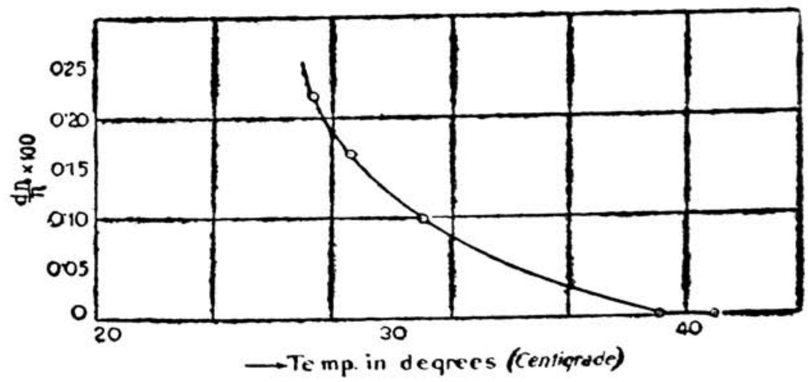
The procedure adopted for taking a set of readings, is as follows: First a set of readings are taken for the time of flow, without putting on the magnetic field. When the steady temperature state is reached, it is found that the consecutive readings do not vary by more than 0·1 sec. in 25 minutes. Then alternate readings are taken with the magnetic field on and off. Though the capacity of the thermostat is about 3 cubic feet, it is found that after taking two readings with the field on, the temperature of the pole-pieces and of the capillary tube rises and the percentage change in the time of flow in the magnetic field begins to diminish. So that in any set of observations, not more than two readings with the magnetic field on, are recorded.

Experimental Results.

In Table I is given the values of the readings taken for the time of flow of nitrobenzene through the given capillary tube,



with and without a magnetic field. This gives an idea of the accuracy with which the time of flow can be observed. The variation of $d\eta/\eta$ of nitrobenzene with field strength is given in Table II and the graph in Fig. 3. It will be seen that $d\eta/\eta$ increases directly with H, and there is no indication of saturation. With a given field strength, the variation of $d\eta/\eta$ with temperature of the same liquid is shown in Table III and in Fig. 4, apparently $d\eta/\eta$ becomes zero at about 35°C. That $d\eta/\eta$ diminishes with increase of temperature is definite, as the first three readings which were taken with thermostat working at the room temperature on different days indicate. Owing to the difficulty of keeping the temperature of the thermostat constant within the required range, when kept at temperature several degrees higher than the room-temperatures not much value can be attached to the readings taken at 35°C and 37°C. Table IV contains the values of $d\eta/\eta$ for different organic liquids, water, and a solution of cerium nitrate in water, of concentration 0·3 gms. per cc.



Only a limited number of liquids have been tried, but still indications of some regularity in the results appear.

(I) Liquids with long chain aliphatic molecules show a diminution of viscosity in a magnetic field.

(II) Liquids of the aromatic series and an alcohol with side chains show increase of viscosity in a magnetic field. Benzene monochloride seems to be an exception.

(III) Carbon tetrachloride, water and aqueous solution of cerium nitrate show no change in viscosity. The result is to be expected for a non-polar symmetrical liquid like CCl_4. Water has a dipole moment but has not a large molecular dimension. Cerium nitrate in aqueous solution shows magnetic birefringence of the same order of magnitude as organic liquids of the aromatic class. Evidently the mechanism of the production of birefringence is different in the case of liquid containing molecules belonging to the aromatic group and in aqueous solutions containing paramagnetic molecules.

TABLE I.

Temperature of the thermostat—27°C.
H—31 kilo-gauss.

Number of observations.	Field.	Time.
1	off	24 mins. 55·6 secs.
2	off	24 mins. 55·6 secs.
3	off	24 mins. 55·6 secs.
4	on	24 mins. 57·0 secs.
5	off	24 mins. 55·6 secs.
6	on	24 mins. 56·9 secs.
7	off	24 mins. 55·4 secs.

TABLE II.

Relation of $d\eta/\eta$ with H.

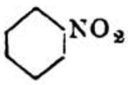
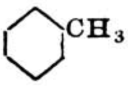
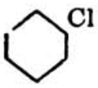
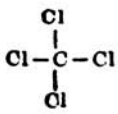
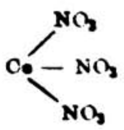
Substance	Temp.	Magnetic field in Gauss.	$d\eta/\eta \times 100$
Nitrobenzene	27°C	13,750	+0·0372
,,	,,	26,740	+0·0744
,,	,,	31,700	+0·0879
,,	,,	34,760	+0·100
,,	,,	36,400	+0·099

TABLE III.

Thermal variation of $d\eta/\eta \times 100$.

Substance	Magnetic field	Temp.	$d\eta/\eta \times 100$
Nitrobenzene	36 K.G.	23°·5C	+0·202
,,	,,	24°·6C	+0·160
,,	,,	27°C	+0·100
,,	,,	35°C	Inappreciable
,,	,,	37°C	,,

TABLE IV.

Substance	Structural Formula	Temp.	$d\eta/\eta \times 100$
Nitro benzene		27°C	+0·10
Toluene		25.°5C	+0·0703
Benzene monochloride		29.°5C 26.°3C	Zero
Acetone	$CH_3-CO-CH_3$	25.°5C	−0·085
Iso-amyl alcohol	$\frac{CH_3}{CH_3}\!>\!CH-CH_2-CH_2-OH$	26.°5C	+0·089
Propyl alcohol (normal)	$CH_3-CH_2-CH_2-OH$	26.°5C	−0·12
Carbon tetra-chloride		27°C	Zero
Water	$H-O-H$	27°C	Zero
Cerium nitrate solution		27°C	Zero

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[2] H. Engelhardt u. H. Sack. Phys. Zeit. *33*, p. 724 (1932); Leipziger Vorträge (1933).

[3] M. Trautz u. E. Fröschel. Ann. d. Physik, *22*, p. 223 (1935).

[4] S. W. Chinchalkar, Ind. Jour. Phys. *6*, p. 580, (1931).

[5] Haenny, Compt. Rend. *194*, p. 931 (931).

[6] W. Konig, Wied. Ann., *25*, p. 618 (1885).