Studies on the Oiliness of Liquids. IV. Measurements of the Static Friction Coefficients by the Method of Inclination.

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The measurements of the static friction coefficients by the balance method have already been described in one of the former papers.[1] In the present paper, the method of inclination and the results obtained therefrom are described. The method is based on the measurement of the critical angle of inclination of the sliding surface at which the slider begins to slide.

Fig. 1 shows the apparatus. A and B are brass plates joined together with a hinge at one end C. The other end of the plate B can be lifted by rotating the handle D and pulling the string fastened to E. Thus the plate B is made to incline from the horizontal plane, the angle of inclination being measured by the protractor G.

H is a glass plate on which a microscopic slide glass K is placed. L is the slider made of an optical lens of the diameter 2.5 cm. M is the brass discs pasted on the slider, which is used to adjust the weight of the slider. N is the supporter to keep the slider from going too far.

At first the liquid is applied on K and then the slider is put on it, the plate B and the sliding surface K being in horizontal position. Now rotate the handle D gently and make the plate B inclines gradually, until finally the slider L begins to slide down the inclined plane. At this instant the angle of inclination is read by the protractor G.

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(1) Sameshima, Kidokoro, and Akamatu, this Bulletin, **11** (1936), 659.

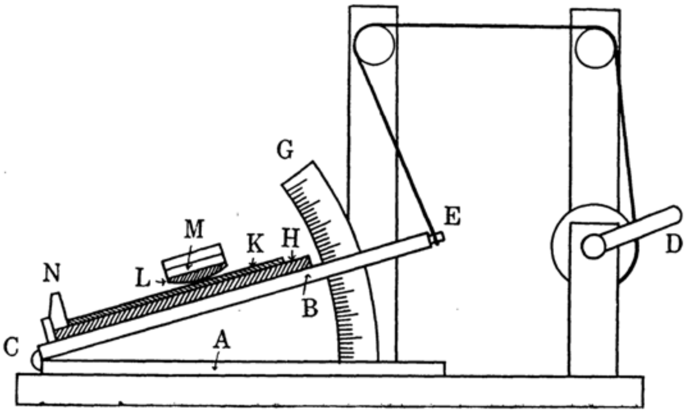

Fig. 1.

We shall denote the sliding angle with θ, the total weight of the slider and brass discs with w, and the force acting in the direction of parallel and normal to the sliding plane with F and W respectively. There are the relations:

$$F = w \sin \theta ,$$

$$W = w \cos \theta .$$

The friction coefficient μ is,

$$\mu = \frac{F}{W} = \tan \theta .$$

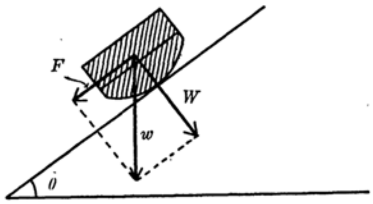

Fig. 2.

These relations are shown in Fig. 2.

The sliding angle θ decreases with increasing value of w when the weight of slider w is small. If w is sufficiently large, however, the angle θ is practically independent of w. The friction coefficient μ is to be calculated from such a constant sliding angle θ. The results of measurements are summarized in Table 1. The experiments have been done at the room temperature of 20–24°C.

The values of friction coefficient μ against the number of carbon atoms in the molecules are plotted in Fig. 3 and Fig. 4.

From Fig. 3 we see that the friction coefficients of aliphatic acids are nearly constant, while those of aliphatic alcohols diminish with the number of carbon atoms in their molecular formula. These facts have already been noticed in the results of the previous experiments.(2) We might

(2) Sameshima, Kidokoro, and Akamatu, this Bulletin, **11** (1936), 666.

Table 1.

Lubricant	w (g.)	$\tan\theta$	μ
Methyl alcohol	32	0.81	
CH_3OH	42	0.77	
	52	0.72	
	62	0.68	
	72	0.66	0.66
	82	0.66	
Ethyl alcohol	52	0.74	
C_2H_5OH	62	0.68	
	72	0.65	0.65
	82	0.65	
n-Propyl alcohol	52	0.67	
$CH_3(CH_2)_2OH$	62	0.66	
	72	0.64	0.635
	82	0.63	
n-Butyl alcohol	62	0.71	
$CH_3(CH_2)_3OH$	72	0.69	
	82	0.66	
	92	0.65	
	102	0.63	0.63
n-Amyl alcohol	62	0.66	
$CH_3(CH_2)_4OH$	72	0.64	
	82	0.60	
	92	0.60	0.60
	102	0.60	
n-Hexyl alcohol	92	0.65	
$CH_3(CH_2)_5OH$	101	0.61	0.61
	111	0.61	
n-Heptyl alcohol	82	0.68	
$CH_3(CH_2)_6OH$	92	0.66	
	102	0.65	
	112	0.62	
	122	0.60	0.60
	132	0.60	
n-Octyl alcohol	91	0.64	
$CH_3(CH_2)_7OH$	101	0.59	
	111	0.59	
	121	0.58	0.58
	131	0.58	
Acetic acid	82	0.65	
CH_3COOH	91.9	0.63	
	101.5	0.59	
	111.1	0.59	0.59
	121.1	0.59	
	131.2	0.59	
Propionic acid	101.5	0.63	
CH_3CH_2COOH	111.1	0.60	
	121.1	0.59	
	131.2	0.59	0.59
	140.6	0.59	
n-Butyric acid	111.1	0.64	
$CH_3(CH_2)_2COOH$	120.9	0.62	
	131.0	0.60	0.60
	140.6	0.60	
n-Valeric acid	111.1	0.61	
$CH_3(CH_2)_3COOH$	120.9	0.60	0.60
	131.0	0.60	
Caproic acid	111.1	0.59	
$CH_3(CH_2)_4COOH$	120.9	0.59	
	131.0	0.58	0.58
	140.6	0.58	
Heptylic acid	111.1	0.60	
$CH_3(CH_2)_5COOH$	120.9	0.60	
	131.0	0.58	0.58
	140.6	0.58	
Caprylic acid	111.1	0.59	
$CH_3(CH_2)_6COOH$	120.9	0.57	
	131.0	0.55	0.55
	140.6	0.55	
Nonylic acid	111.1	0.61	
$CH_3(CH_2)_7COOH$	120.9	0.61	
	131.0	0.60	
	140.6	0.58	
	152.2	0.58	0.58
	162.3	0.58	
Oleic acid	120.9	0.37	
$C_{17}H_{33}COOH$	131.0	0.36	0.36
	140.6	0.36	
Water	32	0.82	
H_2O	42	0.76	
	52	0.73	
	62	0.69	
	71.5	0.65	0.65
	81.5	0.65	
	72	0.74	
	82.2	0.69	0.69
	92	0.69	
		Mean	0.67

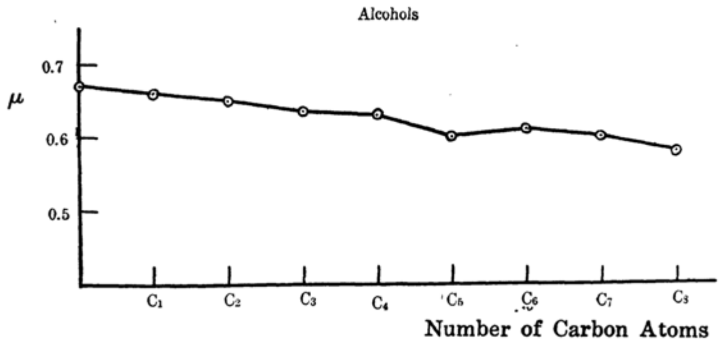

Fig. 3.

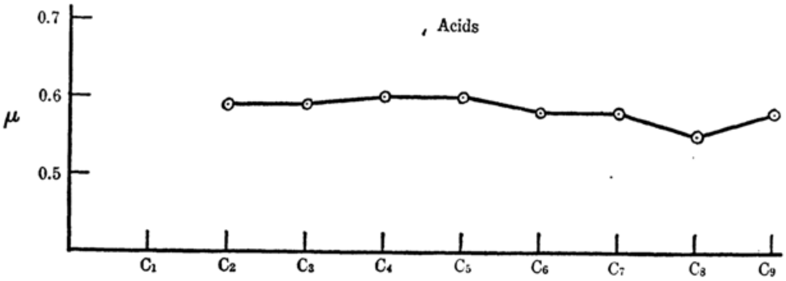

Fig. 4.

perhaps venture the following hypothesis to explain the observed results of the friction coefficient.

It has been proved that the coefficient of static boundary friction of the flooded liquid is practically the same with that of the monomolecular film of the substance.(3) So the friction coefficients obtained in the present experiments are considered to depend only on the properties of the monomolecular film attached to the glass surface.

The molecules of the aliphatic alcohols or the acids tested in the present experiments are composed from the hydrocarbon groups and the hydroxyl or carboxyl group, thus,

$$CH_3CH_2 \ldots\ldots\ldots\ldots CH_2(OH)\ ,$$

$$CH_3CH_2 \ldots\ldots\ldots\ldots CH_2(COOH)\ .$$

The hydrocarbon group is nonpolar, while hydroxyl or carboxyl group polar. The molecules, therefore, will take orientation on the sliding surface, the polar group being attached to the glass surface. The attraction force between glass and COOH group will be stronger than that

(3) Akamatu and Sameshima, this Bulletin, **11** (1936), 791.

between glass and OH group, for the glass is an alkaline substance. The acid molecules, therefore, will stand more firmly on glass surface than alcohol molecules.

Fig. 5 shows the model of the molecules of acid and alcohol standing on the glass surface.

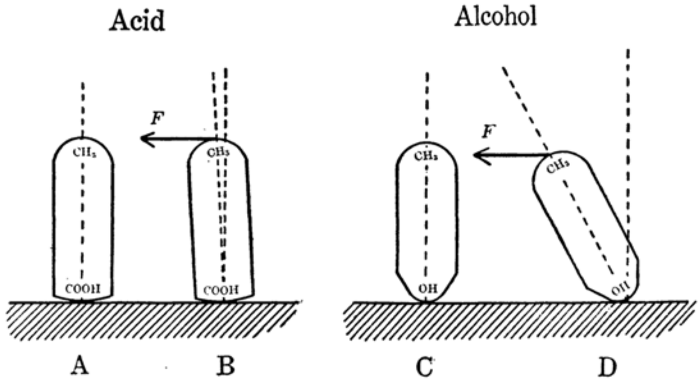

Fig. 5.

If the force F is applied at the heads, CH_3 group, of the molecules, then they will incline as shown in Fig. 5, B or D. The COOH or OH group will act as the hinge. The acid molecule has strong affinity with glass, or it may be considered that the hinge is stiff while alcohol molecule has weak affinity or the hinge is loose. So the acid molecule inclines in smaller angle by the force F than the alcohol molecule.

The force acting on the hinge point is the product of the pulling force and the length of the molecule. So the longer the molecule the greater is the angle of inclination of the molecule. Or the long molecule can be made incline at definite angle with the small pulling force. Thus the alcohols of long chain have small friction coefficients than those of short chain. The acid molecule, however, can hardly be made incline by the pulling force, as is shown in Fig. 5, B, so the friction coefficient is not practically change with the number of carbon atoms. If the length of molecule becomes very long, such as palmitic or stearic acid etc. then the force will act very strong on the COOH hinge and, moreover, the flexibility of the molecule may show some effect on the friction coefficient as is supposed by Adam[(4)] and others. In the present experiment, however, only comparatively short molecules are tested, so the flexibility of the molecule will not have serious effect on the friction coefficient.

(4) N. K. Adam, "The Physics and Chemistry of Surfaces," p. 227, Oxford (1930).

The lengths and the diameters of the molecule of octyl alcohol and nonylic acid are calculated as shown in Table 2.

Table 2.

Molecular formula	Density of liquid	Cross sectional area of molecule	Diameter of molecule	Length of molecule
$CH_3(CH_2)_7OH$	0.83	21.6 Å^2	4.6 Å	12.1 Å
$CH_3(CH_2)_7COOH$	0.91	20.5 Å^2	4.5 Å	14.1 Å

Thus the length of molecule is about three times of the diameter. So the molecule is comparatively short, and therefore, the molecule will not bend by the pulling force.

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