ART. XLVIII.—*On the Viscosity of Mixtures of Liquids*; by
C. E. LINEBARGER.

I. *Historical. Object of Investigation.*

THE earliest investigations of note on the viscosity or internal friction of solutions were carried out by Girard* and Poiseuille.† “The isolated discovery of M. Poiseuille, that diluted alcohol has a point of maximum retardation, coinciding with the degree of dilution at which the greatest condensation of the mixed liquids occurs,” induced Graham‡ to investigate mixtures of other liquids with water as regards their rate of transpiration, as this appeared to him “to depend upon chemical composition, and to afford an indication of it.” He made a number of determinations of the internal friction of aqueous solutions of nitric, sulphuric, acetic, butyric, valeric, formic, and hydrochloric acids, as well as of ethyl alcohol and acetone, finding that usually a maximum of the property in question was observable. “It is remarkable,” he writes, “that hydrated liquid compounds appear in general to show only one decided transpiration maximum, as with the 1-hydrate in sulphuric acid, the 2-hydrate in acetic acid, the 3-hydrate in nitric acid, the 6-hydrate in alcohol, and the 12-hydrate in hydrochloric acid.”

Wijkander§ determined the viscosity of mixtures of acetic acid and water, aniline and benzene, ether and chloroform, ether and carbon bisulphide, ether and alcohol, and benzene and alcohol at temperatures between 0° and 60°. His results for the mixtures of water and acetic acid corroborated those by Graham for the same mixtures as regards the occurrence of a maximum of the property in question; the position of this maximum, however, varied with the temperature at which the determinations were carried out, a relation of any definiteness between chemical constitution and viscosity seeming not to exist. Mixtures of such of the liquids employed by Wijkander as were composed of normal molecules were found not to exhibit a maximum of the property in question; generally

* *Mouvement des fluides dans les tubes capillaires*, Mémoires de l'Institut, 1813, 1814, 1815 and 1816.

† *Recherches experimentales sur le mouvement des liquides dans les tubes de très petits diamètres*, Annales de Chimie et de Physique, III, vii, p. 50, and xxi, p. 76, 1848; also in Pogg. Ann., lviii, 424, 1843.

‡ On the Capillary Transpiration of Liquids in Relation to Chemical Composition, Chemical and Physical Researches, p. 601; and Philosophical Transactions, 1861, pp. 373–386.

§ Ueber die Reibung der Flüssigkeiten, Lunds. Physiog. Sällsk. Jubelskrift, 1878; Wied. Beiblätter, iii, 8, 1879. Only the reference in the “Beiblätter” has been accessible to me.

they had a less degree of fluidity than that calculable by the rule of mixtures, and, in the case of the mixtures of ether with chloroform and carbon bisulphide, points of inflection were present in the curves representing the phenomena.

Pagliani and Battelli* made some determinations at 0° and 10° of the internal friction of mixtures of methyl, propyl, and ethyl alcohols with water. They discovered that these mixtures all presented a maximum in viscosity, but that "La ricchezza procentica alla quale corrisponde il massimo di attrito diminuisce col crescere della temperatura, per cui si ha ragione di credere che ad una data temperatura non si abbia più questo massimo, ma che il coefficiente di attrito delle mescolanze alcoliche vada continuamente crescendo col crescere della proporzione di alcool in esse contenute."

As a continuation of the work of these Italian physicists may be considered the investigations of J. Traube,† who determined the viscosities of a number of aqueous solutions of several of the organic acids and alcohols.

S. Arrhenius‡ also has measured the fluidity of some organic liquids dissolved in water; his solutions were dilute, containing 10 per cent or less of the dissolved liquid; he observed that usually the viscosity of water is increased by the addition of small proportions of non-electrolytic liquids, but, in a foot note, states that a little acetone, ethyl ether, or methyl alcohol, when added to ethyl alcohol, lowers the degree of viscosity.

An inspection of the determinations of the viscosity of liquids recorded in the papers just mentioned brings to light the fact that all mixtures, which have a maximum of internal friction, contain at least one liquid which is known to be composed of associated molecules; also, that such mixtures as do not present this maximum are made up of normal liquids. It seems legitimate to infer, then, that there is an intimate relationship between the occurrence of a maximum of viscosity in liquid mixtures and the molecular polymerization of the liquids composing them; indeed, it may be said that it is probable that the maximum will be found only in such mixtures as contain associated liquids. Another circumstance which increases the probability of this statement is the fact that the higher the temperature, the less pronounced the maximum, and also, as is well known, the less the degree of molecular complexity. The curves given in Traube's paper are instructive in this respect; they are drawn with concentrations of the axis

* Sull'attrite interno nei liquidi, *Annali del R. Istituto Tecnico Germano Sommeiller in Torino*. XIII. Anno, 1884-1885.

† Ueber die innere Reibungsconstante und die spezifische Zähigkeit organischen Flüssigkeiten und ihrer wässrigen Lösungen, *Ber. deutschen chem. Gesell.*, xix, 871-892, 1886.

‡ *Zeitschr. f. phys. Chem.*, i, 284, 1887.

of abscissas and viscosities on the axis of ordinates for mixtures of water with some of the alcohols of the fatty series, and include the data communicated by Pagliani and Battelli. An inspection of them shows that the most considerable maximum of viscosity is present at the lowest temperature, and that, as the temperature rises, the maximum becomes less and less pronounced. The determinations were not made at temperatures above 60° , but even at this temperature the maximum has in most cases nearly disappeared. But it is known that at 60° the association of the molecules of water and the lower alcohols is still not inconsiderable, so that it is perhaps permissible to assume that at higher temperatures the maximum of viscosity may disappear entirely.

The curves also show that the position of the maximum with respect to the axis of abscissas varies in a regular way, so that it is not allowable to conclude that there is any definite relation between the maximum of viscosity and chemical composition, that is, the interpretation of these data in favor of the hypothesis that the maximum marks the existence of a "hydrate" is untrustworthy.

Now, the only data we possess on the internal friction of mixtures of normal liquids are to be found in Wijkander's paper (*loc. cit.*) and these are not very numerous or accessible. The object of this paper is the determination of this physical constant for a number of mixtures of normal liquids.

II. *Method of Determination of Viscosity.*

The apparatus used in the determinations of the internal frictions of the liquids and their mixtures was that devised by Ostwald.* Two such instruments were used, one emptying itself of pure water at $25^{\circ}0$ in 105.6 seconds, the other in 203.5 seconds. One or the other was taken so as to make the time of transpiration at least more than 100 seconds. The time was taken by means of a chronometer to within a few tenths of a second. Never less than three and generally from five to ten determinations were made for each mixture, and their average set down as the true time of transpiration. The apparatus was kept in all determinations at the temperature of $25^{\circ}0$ by immersing it in several quarts of water of that temperature contained in a large jar of clear glass. As the coefficient of internal friction varies considerably with the temperature, great care was taken to keep the temperature uniform, and it is believed that during an experiment it did not vary more than $\pm 0^{\circ}02$. The thermometer used was graduated in tenths of degrees and permitted the estimation of a fiftieth of

* Lehrbuch der allgemeinen Chemie, i, 550, 1889.

a degree; it had been shortly before tested by the "Physikalische Reichsanstalt," and had been found to be without appreciable error in the neighborhood of 25°0.

In order to convert the relative coefficients of viscosity, obtained directly from the experimental data furnished by the apparatus, into coefficients of viscosity expressed in dynes per square centimeter, the former were multiplied by the factor 0.00895; this number being the average of the results obtained for water at 25°0 by Poiseuille, Sprung, Slatte, and Thorpe and Rodger.*

III. *Experimental Results.*

In the following tables are recorded the experimental results obtained. In the first two columns are given the percentage composition, in the second two the molecular percentage composition, of the mixtures of liquids investigated. These mixtures were prepared by weighing out to less than a milligram the liquids in tared flasks or bottles fitted with the best corks. The fifth column contains the specific gravities at 25°0 referred to water at the same temperature. In the sixth column are placed the viscosities of the mixtures as calculated from those of their component liquids by the rule of mixtures, while in the seventh are set the viscosities as actually determined. The eighth column finally shows the differences between the calculated and observed viscosities; a plus sign indicates that the calculated viscosity is greater than that determined; a minus sign, the contrary.

TABLE I.
Viscosity of Mixtures of Benzene (a. II) and Ethyl Ether (b.)
Temperature —25°0

Percentage composition.		Molecular percentage composition.		Specific gravity.	Calculated viscosity.	Observed viscosity.	Diff.
C ₆ H ₆	C ₄ H ₁₀ O	C ₆ H ₆	C ₄ H ₁₀ O				
0.000	100.000	0.000	100.000	0.70942		0.00230	
28.576	71.424	27.502	72.498	0.75369	0.00335	0.00282	+0.00052
56.924	43.076	55.627	44.373	0.79972	0.00440	0.00362	+0.00078
75.691	24.309	74.709	25.291	0.83179	0.00509	0.00438	+0.00071
100.000	0.000	100.000	0.000	0.83390		0.00599	

(a. II.) About five pounds of "chemically pure" benzene were treated repeatedly with sulphuric acid to remove last traces of thiophene, and fractionally crystallized many times. It was then distilled over some scraps of sodium, the whole of it boiling at 80°12 (corr.) under a pressure of 757.3^{mm} of mer-

* See Thorpe and Rodger "On the Relations between the Viscosity (Internal Friction) of Liquids and Their Chemical Nature" (Bakerian Lecture), Phil. Trans., 449, 1894.

cury. The distillate was collected in three portions of somewhat over a pound each, and their melting points found to be $5^{\circ}39$ (corr.), $5^{\circ}40$ (corr.), and $5^{\circ}42$ (corr.) respectively.

(b.) Five pounds of ether were washed about twenty times with small portions of water, dried over fused calcium chloride, allowed to stand over mercury for a few days, and finally distilled over sodium. Almost the total quantity distilled within $0^{\circ}1$. The portion which had boiled almost constant was again distilled, this time over phosphoric anhydride, and the distillate collected in two portions, whose specific gravities at $25^{\circ}0$ referred to water of the same temperature were found to be 0.70940 and 0.70942 respectively.

TABLE II.
Viscosity of Mixtures of Benzene (a. I) and Toluene (c. I)
Temperature $-25^{\circ}0$

Percentage composition.		Molecular percentage composition.		Specific gravity.	Calculated viscosity.	Observed viscosity.	Diff.
C_6H_6	C_7H_8	C_6H_6	C_7H_8				
0.000	100.000	0.000	100.000	0.86288		0.00541	
10.991	89.009	12.719	87.281	0.86434	0.00547	0.00555	-0.00008
30.588	69.412	34.229	65.771	0.86635	0.00558	0.00558	0.00000
66.576	33.424	70.240	29.760	0.87143	0.00579	0.00579	0.00000
91.556	8.444	92.750	7.250	0.87528	0.00594	0.00594	0.00000
100.000	0.000	100.000	0.000	0.87661		0.00599	

(a. I.) About three pounds of benzene were treated with sulphuric acid, and then subjected to fractional crystallization until a little more than a pound was obtained melting at $5^{\circ}3$ (uncorr.). Most of this, when distilled over sodium, boiled at $80^{\circ}1$ (uncorr.) under a pressure of 756^{mm} of mercury.

(c. I.) Of the quantity of toluene taken for purification (about two pounds) more than four-fifths distilled at $109^{\circ}8$ to $110^{\circ}1$ (uncorr.). After a couple of distillations over a little sodium, more than a pound was obtained boiling almost constantly at $110^{\circ}1$ (uncorr.) under a pressure of 758^{mm} of mercury.

TABLE III.
Viscosity of Mixtures of Benzene (a. I) and Carbon Bisulphide (d).
Temperature $-25^{\circ}0$

Percentage composition.		Molecular percentage composition.		Specific gravity.	Calculated viscosity.	Observed viscosity.	Diff.
C_6H_6	CS_2	C_6H_6	CS_2				
0.000	100.000	0.000	100.000	1.25958		0.00358	
8.872	91.127	8.675	91.325	1.20897	0.00379	0.00376	+0.00003
34.858	65.142	34.270	65.730	1.09314	0.00456	0.00446	+0.00010
75.886	24.114	75.409	24.591	0.94176	0.00541	0.00544	-0.00003
100.000	0.000	100.000	0.000	0.87661		0.00599	

(*d.*) The carbon bisulphide was purified by distillation over dehydrated copper sulphate and mercury, when it was found to have a constant boiling point.

TABLE IV.
Viscosity of Mixtures of Benzene(a. I.) and Carbon Tetrachloride(e).
Temperature 25°0

Percentage composition.		Molecular percentage composition.		Specific gravity.	Calculated viscosity.	Observed viscosity.	Diff.
C ₆ H ₆	CCl ₄	C ₆ H ₆	CCl ₄				
0.000	100.000	0.000	100.000	1.58828		0.00683	
13.727	86.273	23.860	76.140	1.42900	0.00843	0.00808	+0.00035
40.780	59.220	57.551	42.449	1.19309	0.00766	0.00706	+0.00060
58.600	41.400	73.605	26.395	1.07615	0.00715	0.00660	+0.00055
100.000	0.000	100.000	0.000	0.87661		0.00599	

(*e.*) The carbon tetrachloride had been fractionally distilled over phosphoric anhydride after first being treated with strong sulphuric acid; it boiled at 76°·7 (uncorr.) under a pressure of 754^{mm} of mercury.

TABLE V.
Viscosity of Mixtures of Benzene(a. I.) and Acetic Ether(f. I.)
Temperature -25°0

Percentage composition.		Molecular percentage composition.		Specific gravity.	Calculated viscosity.	Observed viscosity.	Diff.
C ₆ H ₆	C ₄ H ₈ O ₂	C ₆ H ₆	C ₄ H ₈ O ₂				
0.000	100.000	0.000	100.000	0.89663		0.00434	
15.594	84.406	17.250	82.750	0.89311	0.00459	0.00442	+0.00017
51.404	48.596	54.411	45.589	0.88506	0.00519	0.00487	+0.00032
80.803	19.197	82.605	17.395	0.87982	0.00567	0.00551	+0.00016
100.000	0.000	100.000	0.000	0.87661		0.00599	

(*f. I.*) A kilogram of *c. p.* ethyl acetate was fractionally distilled until about a third of it was found to boil within a few tenths of a degree.

TABLE VI.
Viscosity of Mixtures of Benzene(a. I.) and Nitrobenzene(g).
Temperature -25°0

Percentage composition.		Molecular percentage composition.		Specific gravity.	Calculated attrition.	Observed attrition.	Diff.
C ₆ H ₆	C ₆ H ₅ NO ₂	C ₆ H ₆	C ₆ H ₅ NO ₂				
0.000	100.000	0.000	100.000	1.20200		0.01834	
14.394	85.606	20.956	79.044	1.14200	0.01656	0.01417	+0.00239
37.610	62.390	48.735	51.265	1.05620	0.01369	0.01017	+0.00372
80.653	19.347	86.355	13.645	0.92764	0.00845	0.00681	+0.00164
100.000	0.000	100.000	0.000	0.87661		0.00599	

(*g.*) Commercial nitrobenzene was repeatedly crystallized in fractions until an almost colorless product was obtained, which, when solidified, showed the same temperature during the remelting, viz: 3°·6 (uncorr.)

TABLE VII.

Viscosity of Mixtures of Benzene (a. I.) and Chloroform (h).
Temperature -25°C

Percentage composition.		Molecular percentage composition.		Specific gravity.	Calculated viscosity.	Observed viscosity.	Diff.
C_6H_6	CHCl_3	C_6H_6	CHCl_3				
0.000	100.000	0.000	100.000	1.48069		0.00540	
6.967	93.033	10.290	89.710	1.41165	0.00544	0.00546	-0.00002
23.010	76.990	31.411	68.589	1.27568	0.00554	0.00557	-0.00003
72.780	27.220	80.370	19.630	0.98485	0.00582	0.00581	$+0.00001$
85.831	14.169	90.289	9.711	0.92965	0.00590	0.00587	$+0.00003$
100.000	0.000	100.000	0.000	0.87661		0.00599	

(h.) The chloroform had been fractionated to constant boiling point, and was finally distilled over phosphoric anhydride; its boiling point was 61°C (uncorr.) under a pressure of 759^{mm} of mercury.

TABLE VIII.

Viscosity of Mixtures of Toluene (c. II.) and Acetic Ether (f. II.)
Temperature -25°C

Percentage composition.		Molecular percentage composition.		Specific gravity.	Calculated viscosity.	Observed viscosity.	Diff.
C_7H_8	$\text{C}_4\text{H}_8\text{O}_2$	C_7H_8	$\text{C}_4\text{H}_8\text{O}_2$				
0.000	100.000	0.000	100.000	0.89156		0.00462	
15.708	84.292	15.129	84.871	0.88588	0.00474	0.00466	$+0.00008$
45.301	54.699	44.202	55.798	0.87529	0.00497	0.00481	$+0.00016$
71.255	28.745	70.335	29.665	0.86436	0.00517	0.00509	$+0.00008$
100.000	0.000	100.000	0.000	0.85680		0.00539	

TABLE IX.

Viscosity of Mixtures of Toluene (c. II.) and Ethyl Benzoate (i. I.).
Temperature -25°C

Percentage composition.		Molecular percentage composition.		Specific gravity.	Calculated viscosity.	Observed viscosity.	Diff.
C_7H_8	$\text{C}_{10}\text{H}_{10}\text{O}_2$	C_7H_8	$\text{C}_{10}\text{H}_{10}\text{O}_2$				
0.000	100.000	0.000	100.000	1.04843		0.01954	
15.282	84.718	22.726	77.274	1.01458	0.01737	0.01495	$+0.00242$
47.322	52.678	59.450	40.550	0.94937	0.01284	0.00939	$+0.00345$
76.170	23.830	83.918	16.082	0.89667	0.00876	0.00679	$+0.00197$
100.000	0.000	100.000	0.000	0.85680		0.00539	

(i.) Ethyl benzoate was prepared by the action of hydrochloric acid on a mixture of benzoic acid and absolute alcohol. It was repeatedly rectified, and the fraction boiling at 210°C – 210°C employed in the determinations.

TABLE X.
Viscosity of Mixtures of Toluene (c. I) and Carbon Bisulphide (d).
 Temperature $-25^{\circ}0$

Percentage composition.		Molecular percentage composition.		Specific gravity.	Calculated viscosity.	Observed viscosity.	Diff.
C_7H_8	CS_2	C_7H_8	CS_2				
0.000	100.000	0.000	100.000	1.25958		0.00358	
7.269	92.731	6.082	93.918	1.21783	0.00377	0.00370	+ 0.00007
39.992	62.008	33.605	66.395	1.06759	0.00427	0.00417	+ 0.00010
63.242	36.758	58.699	41.301	0.97217	0.00473	0.00469	
100.000	0.000	100.000	0.000	0.86288		0.00541	

TABLE XI.
Viscosity of Mixtures of Toluene (c. II.) and Turpentine (k).
 Temperature $-25^{\circ}0$

Percentage composition.		Molecular percentage composition.		Specific gravity.	Calculated viscosity.	Observed viscosity.	Diff.
C_7H_8	$C_{10}H_{16}$	C_7H_8	$C_{10}H_{16}$				
0.000	100.000	0.000	100.000	0.85970		0.01343	
6.791	93.209	9.724	90.276	0.85948	0.01275	0.01192	+ 0.00083
20.654	79.346	27.464	72.536	0.85838	0.01177	0.00978	+ 0.00199
53.701	46.299	63.162	36.838	0.85682	0.00911	0.00701	+ 0.00200
75.091	24.909	89.884	20.116	0.85654	0.00739	0.00607	+ 0.00131
100.000	0.000	100.000	0.000	0.85680		0.00539	

(*k.*) The sample of turpentine used was kindly furnished me by Prof. J. H. Long of the North Western University, who had had it prepared in his laboratory from pure spruce gum. It had been rectified over sodium and boiled at $156^{\circ}5-157^{\circ}0$ (uncorr.) under a pressure of 745^{mm} of mercury.

TABLE XII.
Viscosity of Mixtures of Ether (m. b) and Carbon Bisulphide (d).
 Temperature $-25^{\circ}0$

Percentage composition.		Molecular percentage composition.		Specific gravity.	Calculated viscosity.	Observed viscosity.	Diff.
$C_4H_{10}O$	CS_2	$C_4H_{10}O$	CS_2				
0.000	100.000	0.000	100.000	1.25958		0.00358	
13.100	86.900	13.407	86.593	1.14280	0.00341	0.00338	+ 0.00003
34.367	65.633	34.969	65.031	0.99380	0.00313	0.00306	+ 0.00007
62.759	37.241	63.380	36.620	0.84689	0.00277	0.00269	+ 0.00008
100.000	0.000	100.000	0.000	0.70942		0.00230	

TABLE XIII.
Viscosity of Mixtures of Acetic Ether (f. II) and Ethyl Iodide (n).
 Temperature $-25^{\circ}0$

Percentage composition.		Molecular percentage composition.		Specific gravity.	Calculated viscosity.	Observed viscosity.	Diff.
$C_4H_8O_2$	C_2H_5I	$C_4H_8O_2$	C_2H_5I				
0.000	100.000	0.000	100.000	1.93015		0.00577	
21.799	78.201	33.073	66.927	1.52760	0.00552	0.00408	+ 0.00144
67.427	32.573	78.585	21.415	1.07553	0.00499	0.00462	+ 0.00037
100.000	0.000	100.000	0.000	0.89156		0.00462	

n. The ethyl iodide was made by the action of iodine and red phosphorus on absolute alcohol; by a couple of distillations, a constant boiling product was obtained, which when again distilled gave two fractions having specific gravities at 25°0 referred to water at the same temperature, 1·93012 and 1·93015 respectively.

TABLE XIV.

*Viscosity of Mixtures of Acetic Ether (f.I) and Nitrobenzene (g).
Temperature —25°0*

Percentage composition.		Molecular percentage composition.		Specific gravity.	Calculated viscosity.	Observed viscosity.	Diff.
$C_6H_5NO_2$	$C_4H_8O_2$	$C_6H_5NO_2$	$C_4H_8O_2$				
0·000	100·000	0·000	100·000	0·89663		0·00434	
22·896	77·104	17·530	82·470	0·95669	0·00755	0·00582	+ 0·00173
56·100	43·900	47·770	52·230	1·05318	0·01219	0·00889	+ 0·00350
75·530	24·470	68·870	31·130	1·11618	0·01491	0·01204	+ 0·00287
100·000	0·000	100·000	0·000	1·20200		0·01834	

TABLE XV.

*Viscosity of Mixtures of Carbon Tetrachloride (e) and Chloroform (h).
Temperature —25°0*

Percentage composition.		Molecular percentage composition.		Specific gravity.	Calculated viscosity.	Observed viscosity.	Diff.
CCl_4	$CHCl_3$	CCl_4	$CHCl_3$				
0·000	100·000	0·000	100·000	1·48069		0·00540	
19·269	80·731	15·663	84·337	1·49872	0·00610	0·00569	+ 0·00041
57·277	42·723	50·989	49·011	1·53772	0·00736	0·00659	+ 0·00077
81·172	18·828	76·985	23·015	1·56489	0·00818	0·00761	+ 0·00057
100·000	0·000	100·000	0·000	1·58828		0·00883	

TABLE XVI.

*Viscosity of Mixtures of Acetic Ether (f. II) and Carbon Bisulphide (d).
Temperature —25°0*

Percentage composition.		Molecular percentage composition.		Specific gravity.	Calculated viscosity.	Observed viscosity.	Diff.
$C_4H_{10}O$	CS_2	$C_4H_{10}O$	CS_2				
0·000	100·000	0·000	100·000	1·25958		0·00358	
16·359	83·641	14·451	85·549	1·16956	0·00375	0·00367	+ 0·00008
39·246	60·754	35·811	64·189	1·06877	0·00398	0·00389	+ 0·00009
66·413	33·587	63·069	36·931	0·97681	0·00427	0·00416	+ 0·00011
100·000	0·000	100·000	0·000	0·89156		0·00462	

(*c. II.*) Five pounds of toluene were fractionally distilled over sodium a half dozen times or so until the larger portion boiled almost at a constant temperature. Three fractions of nearly a pound each were then made, boiling: *a* at 109°·90–109°·94; *b* at 109°·94–110°·00; and *c* at 110°·00–110°·03 under a pressure of 757·7^{mm} of mercury. Their specific gravities at 25°0 referred to water at 25°0 were: *a*, 0·85678; *b*, 0·85681 and *c*, 0·85680.

(*f. II.*) Five pounds of commercial acetic ether were dried over fused calcium chloride for a few days; and after filtration from this salt were made to stand over phosphoric anhydride for some time. The ether was then distilled, the distillate being collected in two portions, one of which boiled at $71^{\circ}0$ – $71^{\circ}3$ (uncorr.), the other at $71^{\circ}3$ – $71^{\circ}4$ (uncorr.) Each of these distillates was again distilled over phosphoric anhydride, and both were found to boil at identical temperatures. The specific gravity of one sample at $25^{\circ}0$ referred to water at the same temperature was determined to be 0.89155; that of the other under similar conditions, 0.89157.

IV. *Discussion of Results.*

The data in the preceding section are seen to be in corroboration of Wijkander's (*loc. cit.*) results; in no instance does a maximum of viscosity appear. The observed viscosities are all less than those calculated by the rule of mixtures, except in certain mixtures of benzene and chloroform (Table VII) and of benzene and carbon bisulphide (Table III); in these mixtures, however, the differences are less than those detectible by the apparatus, so that they cannot be really counted as exceptional.

With mixtures of certain liquids, as of benzene and toluene (Table II), benzene and carbon bisulphide (Table III), benzene and chloroform (Table VII), toluene and carbon bisulphide (Table X, ether and carbon bisulphide (Table XII) and acetic ether and carbon bisulphide (Table XVI) the differences are so slight that they may be due principally to experimental errors, and, consequently, these liquids may be said to preserve their viscosities without appreciable change in mixture. In other mixtures, on the contrary, considerable differences between the theoretical and found values of the viscosities present themselves, the greatest differences occurring when about equal proportions of the liquids are mixed.

The greater the differences between the viscosities of the pure liquids, the greater is found to be the differences between the calculated and observed values of the viscosities of their mixtures. This is easily seen in the mixtures of benzene, whose viscosity is 0.00599, and nitrobenzene, whose viscosity is 0.01834, differences amounting to 0.00372 being found (Table VI); also, in mixtures of toluene (viscosity = 0.01954), where the differences, found and calculated, are as large as 0.00345.

Yet, even when the viscosities of the pure liquids are nearly the same, the differences between the theoretical and observed values of the viscosities of their mixtures is not inconsiderable; thus the mixtures of acetic ether (viscosity = 0.00577) and ethyl iodide (viscosity = 0.00462) there are differences of as much as 0.00144.