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Bjerknes has shown* that the oscillations in a Hertz resonator are not damped out so quickly as those in the primary exciting circuit. My photographs also show that the oscillations in all neighbouring circuits continue long after the unidirectional spark in the primary or exciting circuit has ceased. This is true whether there is resonance or not, and is more marked when the circuits are not in tune, except so far as electrical beats tend to damp the oscillations of the secondary circuit.

I am inclined to believe, therefore, that the conclusions of Bjerknes are true only for open circuits or circuits in which no sparks occur. When sparks occur in two circuits which are in resonance the duration of time-sparks appears to be the same. With periods ranging from $\cdot 00001$ to $\cdot 000001$ of a second, I have found it impossible to tune two circuits in which sparks occurred to perfect resonance. There were always indications of beats due, I believe, to the capacity not rising immediately to its full value.

The method which I have outlined in this paper seems to offer a fruitful one for investigation; for a large number of comparative photographs can be taken with far greater ease than by the arrangement of apparatus employed by Feddersen.

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XX. *The Attraction of Unlike Molecules.*—II. *The Surface-Tension of Mixed Liquids.* By WILLIAM SUTHERLAND†.

THE most direct method of measuring the attractions of unlike molecules seems to be by obtaining a theoretical expression for the surface-tension of mixed liquids involving the attractions of the unlike molecules of the liquids as well as the attractions of the like molecules for one another, and then by experimental determinations of the surface-tensions of mixtures to obtain the data wherewith to calculate the attractions of the unlike molecules from the theoretical expression. The present paper contains both a theoretical and an experimental part, of which the theoretical had better come first as indicating the lines on which the experiments are to be discussed.

In a paper on the Law of Molecular Force (Phil. Mag. [5] vol. xxvii. p. 305), which has been largely superseded by

* *Ann. der Physik und Chemie*, xlv. 1891; xlvii. 1892.

† Communicated by the Author.

a later one on the Laws of Molecular Force (Phil. Mag. March 1893, [5] vol. xxxv. p. 211), there is given the establishment of an expression for the surface-tension of a liquid whose molecules attract one another with a force inversely as the fourth power of the distance between them. If $3Am^2/r^4$ denotes the molecular attraction between two molecules of mass m at distance r apart in a liquid of density ρ , then it is shown that the surface-tension

$$\alpha \propto A\rho^2e, \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

where e is a length of the order of magnitude of the average distance of a molecule from its nearest neighbours and proportional to that distance; for it represents the distance to be left between two continuous distributions of matter on opposite sides of a plane in order that the attraction between them may be the same as that between two molecular distributions, the density and law of attraction in the continuous and molecular distributions being the same.

Suppose we have a gramme of a mixture of which a fraction p_1 is a liquid of density ρ_1 and molecular mass m_1 , and the fraction p_2 a liquid of density ρ_2 and molecular mass m_2 , producing a liquid of density ρ ; if there is no shrinkage on mixing the liquids 1 and 2, then

$$1/\rho = p_1/\rho_1 + p_2/\rho_2. \quad . \quad . \quad . \quad . \quad (2)$$

Now in the mixture p_1 grammes of liquid 1 are distributed through a volume $1/\rho$, and by themselves form a medium of density

$$p_1\rho, \text{ to be denoted by } \rho_1';$$

similarly the other liquid 2 has in the mixture a density

$$p_2\rho, \text{ to be denoted by } \rho_2'.$$

Thus, then, if we draw a plane in the mixed liquid and seek to represent the attraction between the molecules on the opposite sides of the plane, the problem reduces itself to that of finding the attraction between a liquid 1 of density ρ_1' on one side (say the left side) on the liquid 1 of density ρ_1' on the right side, and the similar attraction between the parts of liquid 2 of density ρ_2' on the left and right sides, and the attraction of liquid 1 of density ρ_1' on left on liquid 2 of density ρ_2' on right, and the attraction of liquid 2 of density ρ_2' on the left on liquid 1 of density ρ_1' on the right. The last two attractions are equal; thus in place of the expression $A\rho^2e$ in the surface-tension of a single liquid we shall have for the mixture

$$_1A_1\rho_1'^2e_1' + _2A_2\rho_2'^2e_2' + 2_1A_2\rho_1'\rho_2'_{1e_2'}, \quad . \quad . \quad . \quad (3)$$

where e_1' , e_2' , and ${}_1e_2'$ are distances corresponding to e and representing the distances to be left between continuums which may be supposed to replace the molecular mediums whose attractions have just been enumerated. For a single liquid, for instance liquid 1 for which the value of e may be denoted by e_1 , e_1 is proportional to $(m_1/\rho_1)^{\frac{1}{3}}$; and then for its surface-tension relation (1) may be written

$$\alpha_1 = k {}_1A_1 \rho_1^2 (m_1/\rho_1)^{\frac{1}{3}}, \quad . \quad . \quad . \quad . \quad . \quad (4)$$

where k is the same for all liquids. Similarly for liquid 2,

$$\alpha_2 = k {}_2A_2 \rho_2^2 (m_2/\rho_2)^{\frac{1}{3}}. \quad . \quad . \quad . \quad . \quad . \quad (4)$$

Now if e_1 is taken as represented by $(m_1/\rho_1)^{\frac{1}{3}}$, we cannot take e_1' as represented by $(m_1/\rho_1')^{\frac{1}{3}}$; because if we did so and then in (3) put $p_1 = p_2$ and suppose liquid 2 to become identical with liquid 1, in which case $e_1' = e_2' = {}_1e_2'$, we should find that (3) would not reduce to ${}_1A_1 \rho_1^2 e_1$, as it ought. The most appropriate way in which to represent e_1' is to take it as given by $(m_1/\rho_1')^{\frac{1}{3}}$ reduced in the ratio of the cube root of the space p_1/ρ_1 occupied by liquid 1 to the cube root of the total space $1/\rho$. Thus e_1' is represented by $(m_1/\rho_1')^{\frac{1}{3}} (p_1/\rho_1)^{\frac{1}{3}}$, e_2' by $(m_2/\rho_2')^{\frac{1}{3}} (p_2/\rho_2)^{\frac{1}{3}}$, and ${}_1e_2'$ by $(e_1' + e_2')/2$; so that for the surface-tension of the mixture we get

$$\begin{aligned} {}_1\alpha_2 = k \left[{}_1A_1 \rho_1'^2 \left(\frac{m_1 p_1 \rho}{\rho_1' \rho_1} \right)^{\frac{1}{3}} + {}_2A_2 \rho_2'^2 \left(\frac{m_2 p_2 \rho}{\rho_2' \rho_2} \right)^{\frac{1}{3}} \right. \\ \left. + 2 {}_1A_2 \rho_1' \rho_2' \left\{ \left(\frac{m_1 p_1 \rho}{\rho_1' \rho_1} \right)^{\frac{1}{3}} + \left(\frac{m_2 p_2 \rho}{\rho_2' \rho_2} \right)^{\frac{1}{3}} \right\} / 2 \right]; \quad (5) \end{aligned}$$

$$\begin{aligned} \therefore {}_1\alpha_2/\rho^2 = p_1^2 \alpha_1/\rho_1^2 + p_2^2 \alpha_2/\rho_2^2 \\ + \frac{2 {}_1A_2}{({}_1A_1 {}_2A_2)^{\frac{1}{2}}} p_1 p_2 (\alpha_1 \alpha_2)^{\frac{1}{2}} \frac{(m_1/\rho_1)^{\frac{1}{3}} + (m_2/\rho_2)^{\frac{1}{3}}}{2 \{ (m_1/\rho_1)^{\frac{1}{3}} (m_2/\rho_2)^{\frac{1}{3}} \}^{\frac{1}{2}}}; \quad (6) \end{aligned}$$

which is an equation for determining the ratio ${}_1A_2/({}_1A_1 {}_2A_2)^{\frac{1}{2}}$ by a measurement of the surface-tension of a mixture of the liquids 1 and 2 of known surface-tensions α_1 and α_2 . In these expressions, if we put $p_1 = p_2 = 1/2$ and suppose liquid 2 to become identical with 1, we get the identity ${}_1\alpha_1 = \alpha_1$ as we ought; also if we put $p_2 = 0$ and $p_1 = 1$ we get the same identity. There is doubtless something arbitrary in the manner in which we have fixed the values of e_1' , e_2' , and ${}_1e_2'$, but we must remember that, in the original establishment of the relation $\alpha = k A \rho^2 e$, there is an arbitrary step in the

replacement of summation for separate molecules by integration for a continuum; the step is a piece of approximation whose justification is this, that even if we endeavoured to carry out the process of summation we should have to make arbitrary arrangements of the molecules. If we tried to sum for the molecules of a mixture, our suppositions as to the arrangement of the molecules would be still more markedly arbitrary; as, for instance, if we tried to represent the space-distribution of the spheres in a mixture of equal numbers of two sets of spheres of different sizes. These considerations seem to me to make the above expression for the surface-tension of a mixture satisfactory enough for present applications. When a higher degree of accuracy is required, it will be an interesting piece of mathematics to devise arrangements of molecules as in nature and convenient methods of summation.

In the paper on the Diffusion of Gases we have seen reason to believe that ${}_1A_2 = ({}_1A_1{}_2A_2)$; and as the arithmetical mean of the molecular radii $\{(m_1/\rho_1)^{\frac{1}{3}} + (m_2/\rho_2)^{\frac{1}{3}}\}/2$ of most pairs of liquids is little different from the geometrical mean $\{(m_1/\rho_1)^{\frac{1}{3}}(m_2/\rho_2)^{\frac{1}{3}}\}^{\frac{1}{2}}$, we can write approximately

$${}_1\alpha_2/\rho^2 = (p_1\alpha_1^{\frac{1}{3}}/\rho_1 + p_2\alpha_2^{\frac{1}{3}}/\rho_2)^2$$

as the law which rules the surface-tension of mixtures if ${}_1A_2 = ({}_1A_1{}_2A_2)^{\frac{1}{2}}$. But equation (6) is the fundamental one to be used in the discussion of the experiments, as it gives directly a value of ${}_1A_2/({}_1A_1{}_2A_2)^{\frac{1}{2}}$, which is the thing sought in these investigations on the attraction of unlike molecules.

A fair amount of experimental work on the surface-tension of mixtures has been published, but hardly any of it is of immediate use in connexion with the present inquiry. For instance, Traube (*Ber. deut. chem. Ges.* xvii.; *Ann. der Chem.* cclxv.; *Journ. für prakt. Chem.* xxxiv.) has investigated the surface-tension of mixtures of water, and a large number of organic liquids such as alcohols, acids, and amines; but as water and the alcohols and acids are exceptional in their molecular structure in the liquid state, the surface-tensions of these mixtures cannot be appropriately discussed at the outset of this inquiry; but Traube's numerous experiments will doubtless be of great value when the exceptional nature of these substances is under systematic examination. But before Traube, Rodenbeck (*Wied. Beibl.* iv.) measured the rise in capillary tubes of a certain number of mixtures, of which only one set relates to strictly normal liquids, the

others involving the exceptional alcohol or complex petroleum. Before proceeding with an account of my own experiments on normal liquid pairs, I will illustrate the application of equation (6) to Rodenbeck's mixtures of the normal pair of liquids ethyl oxide and chloroform. The following table contains the data for the two liquids and five mixtures along with the value of ${}_1A_2/({}_1A_1{}_2A_2)^{\frac{1}{2}}$ calculated by equation (6) from the data for each mixture:—

	Ethyl Oxide.	Mixture. I.	Mixture. II.	Mixture. III.	Mixture. IV.	Mixture. V.	Chloro- form.
p_1	1.0	.68	.44	.262	.125	.064	0.0
p_2	0.0	.32	.56	.738	.875	.936	1.0
ρ .....	.727	.870	1.020	1.170	1.320	1.400	1.494
α	1.83	2.01	2.22	2.44	2.52	2.60	2.78
${}_1A_2/({}_1A_1{}_2A_2)^{\frac{1}{2}}$		1.02	1.05	1.07	.97	.89	

In the table ethyl oxide is liquid 1 and chloroform is 2, and the surface-tensions are given in mgrms. weight per millim. The mean value of ${}_1A_2/({}_1A_1{}_2A_2)^{\frac{1}{2}}$ is 1.0; or, excluding mixtures IV. and V., in which the proportion of ethyl oxide is too small to favour an accurate value of ${}_1A_2/({}_1A_1{}_2A_2)^{\frac{1}{2}}$ from equation (6), the mean value is 1.05. Thus the theoretical formula (6) is proved to apply well to mixtures of ethyl oxide and chloroform, for which also ${}_1A_2$ is proved to be equal to $({}_1A_1{}_2A_2)^{\frac{1}{2}}$.

Two other sets of Rodenbeck's experiments may be discussed here, although they relate to mixtures involving petroleum, which is itself a mixture, for the equation

$${}_1\alpha_2/\rho^2 = (p_1\alpha_1^{\frac{1}{2}}/\rho_1 + p_2\alpha_2^{\frac{1}{2}}/\rho_2)_2$$

can be generalized so as to apply to any mixture of any number of liquids. Suppose a gramme of any such mixture to contain $p_1, p_2, p_3 \dots$ gramme of liquids 1, 2, 3 ..., and have a density ρ and surface-tension α , then

$$\alpha/\rho^2 = (p_1\alpha_1^{\frac{1}{2}}/\rho_1 + p_2\alpha_2^{\frac{1}{2}}/\rho_2 + p_3\alpha_3^{\frac{1}{2}}/\rho_3 + \dots)^2.$$

If the liquids 2, 3, 4 ... in proportions $p_2, p_3, p_4 \dots$ are supposed to form a separate liquid n , as for instance Rodenbeck's petroleum, then

$$\alpha/\rho^2 = \{p_1\alpha_1^{\frac{1}{2}}/\rho_1 + (p_2 + p_3 + \dots)\alpha_n^{\frac{1}{2}}/\rho^n\}^2;$$

so that the law for a mixture of mixtures is the same as for a mixture of pure liquids, and we ought to be able to apply equation (6) to a mixture of mixtures. Thus we can utilize Rodenbeck's measurements on mixtures of rectified petroleum and chloroform, and also of ordinary petroleum and ethyl

oxide, treating the petroleum as a single liquid. Arranging the data and results as before, we have :—

	Rectified petroleum.	Mixture I.	Mixture II.	Mixture III.	CHCl ₃ .
p_1	1.0	.633	.378	.1575	0.0
p_2	0.0	.367	.622	.8425	1.0
ρ.....	.767	.934	1.100	1.300	1.494
α	2.59	2.73	2.82	2.80	2.78
${}_1A_2/({}_1A_1{}_2A_2)^{\frac{1}{2}}$		1.1	1.11	1.06	

	Ordinary petroleum.	Mixture I.	Mixture II.	(C ₂ H ₅) ₂ O.
p_1	1.0	.723	.461	0.0
p_2	0.0	.277	.539	1.0
ρ.....	.803	.780	.760	.727
α	2.66	2.41	2.22	1.83
${}_1A_2/({}_1A_1{}_2A_2)^{\frac{1}{2}}$.....		.96	.99	

In these cases the theoretical formula (6) is again verified by the approximate constancy of ${}_1A_2/({}_1A_1{}_2A_2)^{\frac{1}{2}}$, and again the ratio ${}_1A_2/({}_1A_1{}_2A_2)^{\frac{1}{2}}$ has values close to 1.

In my own experiments the method adopted for measuring surface-tensions was by means of the rise in capillary tubes, but carried out in a special manner. Elsworthy (Journ. Chem. Soc. liii.) suggested inclining the capillary tube at a large angle to the vertical, say θ , so that a liquid which would rise a height h in the tube when vertical, while still rising only h vertically, in the inclined tube rises a distance $h/\cos \theta$ measured along the tube; so that the accuracy of reading is increased in the ratio 1 to $\cos \theta$. It seemed to me that the best way to take advantage of this method for a number of liquids was to engrave a fixed mark on the tube, and then in each case to vary the inclination till the liquid rose as nearly as possible to the mark, reading the inclination in each case. The advantage of this method is that it makes one almost independent of variation in the bore of the capillary tube. It would have improved the accuracy of the method if a fine scale had been engraved on the tube near the fixed mark, so that one could read in each case the small departure from the fixed mark and allow for it in the calculations, but this was not done. The capillary tube was fitted tightly into one leg of a V-tube of 6 millim. internal diameter, the joint being protected by a piece of india-rubber tube slipped over it: the angle of the V was such that the other leg was nearly vertical in the experiments with most liquids. A second mark was engraved on the capillary a little above where it entered the V-tube, and at a distance of 184 millim. from the other fixed mark; the level of the free surface of the liquid in the V-tube

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was always brought to the level of this second mark, so that the length of the column raised by capillary action in the tube was always 184 millim. The open limb of the V-tube was provided with a loose cork to prevent evaporation. The capillary tube was clamped to a wooden lath hinged at one end to a stand, and provided at the other end with an index whose terminal point was 610 millim. from the hinge, and to the lath was hinged a wooden piece by which it could be supported at any angle. Instead of reading the angle of inclination of the lath and its attached tube, I read on a vertical scale the height of the index above the point indicated by it when the tube was lowered to a horizontal position. The readings thus obtained were accordingly directly proportional to the capillary heights. In the case of water at 15° C. the reading was 196 millim.; and as the mean result of previous experimenters is that at 15° C. in a tube of 1 millim. radius water rises 14.9 millim., it was only necessary for me to multiply my readings for various liquids and mixtures at 15° (really 14° to 16°) by $14.9/196$ to obtain the capillary height h as usually given, namely, number of millim. rise in a tube of 1 millim. radius.

The chief objection that I found to the method of experimenting was that I had two adjustments to make that depended on one another, namely, that of the level of the liquid in the wide tube and the level of the liquid in the capillary tube. In any further experiments I will take steps to make these two independent of one another.

The capillary tube and the liquids (except chloroform) in a state of sufficient chemical purity were given to me by Mr. W. Percy Wilkinson, analyst, of Melbourne. The following are the capillary heights h of the separate liquids in millim. in a tube of 1 millim. radius, their densities ρ and their surface-tensions $\alpha = h\rho/2$ all at 15° C.

	Water, H_2O .	Ethyl oxide, $(\text{C}_2\text{H}_5)_2\text{O}$.	Carbon di- sulphide, CS_2 .	Acetone, $(\text{CH}_3)_2\text{CO}$.	Methyl iodide, CH_3I .	Amyl acetate, $\text{CH}_3\text{CO}_2\text{C}_5\text{H}_{11}$.	Ethyl, acetate, $\text{CH}_3\text{CO}_2\text{C}_2\text{H}_5$.
h	14.9	5.4	5.7	6.4	3.3	6.2	5.9
ρ	1.0	.723	1.269	.802	2.29	.879	.902
α	7.45	1.95	3.6	2.55	3.8	3.5	2.7
	Ethyl aceto- acetate, $\text{C}_6\text{H}_{10}\text{O}_3$.	Chloroform, CHCl_3 .	Benzene, C_6H_6 .	Nitro- benzene, $\text{C}_6\text{H}_5\text{NO}_2$.	Anilin, $\text{C}_6\text{H}_5\text{NH}_2$.	Dimethyl- anilin, $\text{C}_6\text{H}_5\text{N}(\text{CH}_3)_2$.	
h	6.9	4.0	7.3	7.9	8.9	7.9	
ρ	1.017	1.484	.878	1.209	1.030	.955	
α	3.5	3.0	3.2	3.25	4.6	3.8	

In working with mixtures of these liquids the general procedure was to make three mixtures in the proportions of

about 3 or 2 to 1, 1 to 1, and 1 to 2 or 3 parts by weight of the two liquids, to measure the capillary height of each mixture immediately after it was made, and then to measure the density. In some cases where one of the liquids was very volatile, and for any reason the level of the liquid in the V-tube took longer than usual to adjust, so that the cork was off too long, evaporation of the volatile ingredient altered the proportions of the two ingredients a little from their original values and altered the specific gravities a little. On account of this occasional source of error, the values of p_1 and p_2 will be given only to two figures, though measured to three; as $p_1 + p_2 = 1$, it is necessary to give only p_2 .

Mixtures with ethyl oxide as liquid 1.

2.		p_2 .	ρ .	h .	α .	$1A_2/(1A_1 + 2A_2)^{\frac{1}{2}}$.	
CS ₂ .	I.	.19	.791	5.2	2.07	.8	Mean. ·9
	II.	.28	.826	5.2	2.15	.9	
	III.	.43	.893	5.1	2.23	.9	
	IV.	.73	1.063	5.1	2.71	.8	
	V.	.83	1.122	5.2	2.92	.8	
(CH ₃) ₂ CO.	I.	.32	.748	5.7	2.13	1.0	1.0
	II.	.58	.763	5.8	2.21	1.0	
	III.	.84	.787	6.1	2.40	1.0	
CH ₃ I.....	I.	.33	.937	4.5	2.11	.9	·9
	II.	.52	1.165	4.1	2.39	.9	
	III.	.72	1.430	3.7	2.64	.9	
CH ₃ CO ₂ C ₃ H ₁₁ .	I.	.40	.777	5.5	2.14	.9	·9
	II.	.52	.801	5.6	2.24	.9	
	III.	.82	.844	6.1	2.53	1.0	
CH ₃ CO ₂ C ₂ H ₅ .	I.	.37	(.798)	5.5	2.20	1.0	1.0
	II.	.51	.807	5.5	2.22	.9	
	III.	.73	.844	5.7	2.40	1.0	
C ₆ H ₁₀ O ₃ .	I.	.30	.817	5.4	2.21	.8	·9
	II.	.50	.867	5.5	2.33	1.0	
CHCl ₃	I.	.54	.998	4.8	2.39	1.1	1.1
C ₆ H ₆	I.	.22	.752	5.7	2.14	1.0	1.0
	II.	.53	.798	6.5	2.59	1.1	
	III.	.79	.840	6.6	2.77	.9	
C ₆ H ₅ NO ₂ .	I.	.48	.938	5.7	2.67	.7	
	II.	.68	(1.033)	5.8	2.98	.6	
	III.	.80	1.089	5.9	3.21	.4	
C ₆ H ₅ NH ₂ .	I.	.44	.850	5.9	2.51	.7	·7
	II.	.52	.879	6.2	2.73	.7	
	III.	.74	.934	6.5	3.03	.6	
C ₆ H ₅ N(CH ₃) ₂ .	I.	.32	(.796)	5.6	2.23	.8	·8
	II.	.48	.832	5.9	2.45	.8	
	III.	.53	.849	6.0	2.55	.8	
	IV.	.68	.880	6.2	2.73	.7	

Mixtures with carbon disulphide as liquid 1.

2.		p_2	ρ	h	a	$A_2/(A_1 A_2)^{\frac{1}{2}}$	
$(CH_3)_2CO$	I.	·44	1·000	5·6	2·80	·9	·9
	II.	·51	(·979)	5·8	2·84	·9	
	III.	·61	·923	6·0	2·77	1·0	
CH_3I	I.	·32	1·496	4·8	3·61	·9	
	II.	·43	1·603	4·4	3·52	·8	
	III.	·55	(1·716)	3·8	3·19	·6	
$CH_3CO_2C_5H_{11}$	I.	·26	1·124	5·8	3·26	1·0	1·0
	II.	·53	1·003	5·9	2·96	1·0	
	III.	·82	·920	6·3	2·90	1·1	
$CH_3CO_2C_4H_9$	I.	·42	1·084	5·5	2·98	·9	·9
	II.	·71	·984	5·7	2·80	·9	
	III.	·90	(·929)	5·8	2·69	·9	
$CHCl_3$	I.	·82	(1·441)	4·3	3·10	1·0	1·0
$C_6H_{10}O_3$...	I.	·36	(1·164)	5·8	3·37	·9	·9
	II.	·51	1·104	6·1	3·36	1·0	
	III.	·67	1·072	6·2	3·32	·9	
C_6H_6	I.	·23	1·148	6·0	3·44	1·0	1·1
	II.	·51	1·028	6·7	3·44	1·1	
	III.	·69	·966	7·0	3·38	1·1	
$C_6H_5NO_2$	I.	·16	1·260	6·0	3·78	1·0	·9
	II.	·40	1·242	6·5	4·04	1·0	
	III.	·58	1·230	6·4	3·94	·8	
$C_6H_5NH_2$	I.	·20	1·202	6·4	3·85	1·0	1·0
	II.	·56	1·123	7·2	4·04	·9	
	III.	·78	1·072	8·1	4·33	1·0	
$C_6H_5N(CH_3)_2$	I.	·21	1·168	6·4	3·73	1·1	1·1
	II.	·44	1·093	6·9	3·78	1·1	
	III.	·72	1·012	7·1	3·59	1·0	

Mixtures with chloroform as liquid 1.

C_6H_6	I.	·48	(1·115)	5·8	3·23	1·1	1·1
$C_6H_5NH_2$	I.	·54	(1·198)	6·3	3·78	·9	·9
$C_6H_{10}O_3$	I.	·34	(1·283)	5·3	3·40	1·1	1·1

Mixtures with benzene as liquid 1.

$C_6H_5NH_2$	I.	·46	(·942)	7·6	3·58	·9	·9
$OH_3CO_2C_5H_{11}$...	I.	·15	(·878)	7·0	3·07	·9	·9

Mixtures with anilin as liquid 1.

$C_6H_5NO_2$	I.	·32	(1·081)	8·6	4·64	1·0	1·0
$OH_3CO_2C_4H_9$	I.	·39	(·977)	7·2	3·52	·9	·9

The densities enclosed in brackets were not observed, but calculated from the densities of other mixtures or of the component liquids on the supposition of no shrinkage in mixing.

Of the 28 pairs of liquids examined, 24 show a value of the ratio ${}_1A_2/({}_1A_1{}_2A_2)^{\frac{1}{2}}$ lying between .9 and 1.1, while of the remaining 4, 2 (ethyl oxide and anilin and ethyl oxide and dimethylanilin) show what appears to be a constant value of the ratio having in one case the value .7 and in the other .8; in the other two cases, namely, those of ethyl oxide and dimethyl anilin and carbon disulphide and methyl iodide, the theoretical equation (6) does not apply as the value of ${}_1A_2/({}_1A_1{}_2A_2)^{\frac{1}{2}}$ is not constant for different values of p_1 . Some mixtures of ethyl oxide and CS_2 gave a precipitate disappearing only with shaking; so that perhaps they ought not to rank as genuine mixtures of two liquids. We will not enquire at present more closely into these exceptional cases, nor discuss the great class of exceptions formed by watery solutions and mixtures. In the "Laws of Molecular Force" the method of treating watery solutions was pointed out, and the method will be improved and developed in another paper devoted to the surface-tensions of watery solutions alone. As to watery mixtures it will suffice to instance as the most extreme case of exceptional capillary behaviour the well-known one of mixtures of water and amyl alcohol, water with a surface-tension of 7.4 when mixed with only 2.5 per cent. of amyl alcohol having a surface-tension of 3.7 has its surface-tension reduced to 2.8, which is even lower than that of the small amount of added alcohol. It is clear that cases of this sort are complicated with quite another class of phenomena from those we are discussing in connexion with normal liquid mixtures, and that we have a right to set them apart for separate study.

The result ${}_1A_2 = ({}_1A_1{}_2A_2)^{\frac{1}{2}}$, which is the outcome of this investigation on the attraction of unlike molecules, has an important bearing on the interpretation of the data as to the attraction of like molecules contained in the "Laws of Molecular Force;" for evidently the expression Λm^2 for the attraction of two like molecules must be regarded as the product of two parameters $\Lambda^{\frac{1}{2}}m$ characteristic of each molecule. The investigation of the attraction of like molecules from this point of view will be taken up in my next paper, "Further Studies on Molecular Force."

Melbourne, January 1894.