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LXXXIII. *The Coalescence of Liquid Spheres—Molecular Diameters.* By WILSON TAYLOR, *Physics Laboratory, University of Toronto, Canada* *.

MOLECULAR phenomena are commonly considered as being caused by some kind of attraction which molecules have for each other when they are near together. This idea has been the basis for the explanation of such phenomena as the liquefaction of gases where the molecules near to each other are attracted so powerfully that they remain permanently in an aggregation. The idea was probably first suggested by Newton, and Laplace pointed out that the phenomena of surface-tension would result from the necessity for this attraction being unequally distributed among the molecules near the surface of the liquid. But he had to assume that this attraction ceased to be effective when the distance between the molecules was beyond a certain range. This has also been made the basis for the explanation of adhesion and solidification. Maxwell carried out Laplace's idea further, using it as a mathematical basis for the properties of the film in a soap-bubble. But he found difficulty in accounting for the formation of the black spots and the sudden changes in the tension of liquid films noticed by Rüker and Reinold in 1886. In recent years, however, the constitution of the soap and other films has been studied in great detail, and there has been expressed by various investigators some doubt as to the validity of the explanations which are based on the attraction of molecules as masses. From direct observation the soap-bubble appears to be composed of a number of strata whose multiples differ in thickness by steps which have been estimated to be from 1 to 10 $\mu\mu$ in height. The difficulty of explaining this by the attraction of molecules, or by any other hypothesis, has been so great that Perrin, who has made an exhaustive study of the bubble (*Annales de Physique*, Sept. 1918), speaks of it as an enigma.

This difficulty led the writer to study the action of two spheres of the same liquid when near to each other and when they came into contact; and the following may be considered as an attempt to consider an alternative basis for the explanation of molecular phenomena.

He was not able to find any direct evidence that such spheres attracted each other, no matter how small they were

* Communicated by the Author.

down to microscopic dimensions, nor how closely they approached each other so long as they did not touch. But when contact was made a powerful force instantly came into play that caused the two masses to coalesce and become one sphere. This was found to be the case with all liquids, independently of the relative sizes of the spheres, and at all temperatures of the liquids. With mercury the action was instantaneous and very powerful. Sometimes, however, two or more mercury spheres would apparently lie in contact without coalescing, but on examination with the microscope there was always found some foreign substance which had accumulated on their surfaces that prevented their coming into contact. The question arose: Is it not possible that the same enveloping force which causes visible spheres to coalesce also causes the free molecules of a gas to aggregate themselves into a liquid?

Now, in any self-contained system of material masses any change in energy is from potential energy, either directly or through kinetic energy of large masses, into kinetic energy of the molecules of the system, that is, into heat. For to produce any change the forces of the system must become statically unbalanced, so that the resultant force does work against the inertia of large and small masses causing them to acquire kinetic energy.

It has long been observed that in many respects surface-tension appears to act as though it were something of the nature of an elastic envelope about a liquid mass trying to compress the mass into a smaller volume by contracting the area of the envelope. This tendency to change the volume, however, is due solely to the curvature of the enveloping surface, which tends to cause compression on the concave side and expansion of volume on the convex side. If there is no curvature there is no tendency either way to alter the volume. The fundamental nature of the tension, then, is to tend to decrease the area of the surface.

Let us consider, then, a system of three spheres of water whose diameters are .3, .4, and .5 cm. The potential surface energy of the system is $T \times \pi\{(\cdot 3)^2 + (\cdot 4)^2 + (\cdot 5)^2\}$, or $50\pi T$ ergs. If these spheres be brought into contact, they will coalesce into one sphere whose diameter is .6 cm., and whose potential surface energy is $T \times \pi(\cdot 6)^2$, or $36\pi T$ ergs. The potential surface energy which has been transformed into heat by coalescence is, therefore, $14\pi T$ ergs. If we take, according to the best available data, $T = 73.3$ dynes per cm. at 15°C. , this energy amounts to 7.71×10^{-7} calorie, where $J = 4.184 \times 10^7$.

In the same way, if a large number of liquid spheres coalesce into a given mass, the heat produced would be considerable.

Let n = the number of these liquid spheres in a gram molecule,

d = the diameter of each sphere,

D = the diameter of the liquid gram molecule sphere,

m = the molecular weight.

ρ_θ = the density of the liquid at $\theta^\circ\text{A}$,

T_θ = the tension of the envelope about the liquid spheres at $\theta^\circ\text{A}$,

and L = the latent heat in calories of a gram mass of the gas at the boiling-point.

Equating the masses before and after coalescence we have

$$n \cdot \frac{\pi}{6} \cdot d^3 = \frac{\pi}{6} \cdot D^3,$$

from which

$$d = D \cdot n^{-\frac{1}{3}}.$$

Also, the potential surface energy has been reduced by coalescence from $n \cdot T \cdot n\pi d^2$ to $T \cdot \pi D^2$. Therefore the amount which has been transformed into heat is $T \cdot \pi(nd^2 - D^2)$, which by the relation above may be written $T \cdot \pi D^2(n^{\frac{2}{3}} - 1)$. Now, since n is very large in comparison with unity, $n^{\frac{2}{3}} - 1$ differs but little from $n^{\frac{2}{3}}$, and thus this amount is $T \cdot \pi D^2 n^{\frac{2}{3}}$. Further,

$\frac{\pi}{6} \cdot D^3 = \frac{m}{\rho}$, and we finally see that the potential surface energy of the n liquid spheres which is converted into heat by their coalescence is $\left(\frac{36\pi m^2 \pi}{\rho^2}\right)^{\frac{1}{3}} \cdot T \cdot n^{\frac{1}{3}}$, a quantity which

varies as the cube root of the number of spheres obeying the law of coalescence, provided that T remains constant. This will be the case if the temperature remains constant, that is, if the heat is transferred to other masses such as the surrounding air and adjacent bodies.

Now, when a gram mass of a substance condenses from a gas into a liquid at the same temperature, there is produced L calories of heat energy which is known as the latent heat of condensation. Equating, therefore, these two amounts of energy, we have

$$T \cdot \left(\frac{36\pi m^2 \pi}{\rho^2}\right)^{\frac{1}{3}} \cdot n^{\frac{1}{3}} = mLJ,$$

from which

$$n = \left(\frac{LJ}{T}\right)^3 \times \frac{m\rho^2}{36\pi}.$$

The latent heat of evaporation is commonly thought to be the energy due to the attraction of molecules for one another at close ranges in the liquid. In the interior, where the attractions on a particular molecule are balanced, this energy is not apparent or is unavailable. It is apparent only in regions near the surface where these attractions are unequally distributed. The latent heat, then, is the work done in bringing the molecules of a gram mass from the interior through the surface region of unequal attraction and separating them from one another beyond the range of their attraction. Surface energy is regarded as the energy belonging to the molecules in the surface layer only, and, consequently, is only a part of the latent heat. Various attempts to define the relation between these which assume a general form, $E \cdot V^{\frac{2}{3}} = kL$, have so far been unsatisfactory, the experimental data giving no consistent values for the quantities involved. Other attempts to connect the whole internal molecular energy with the latent heat have failed for the same reason. These consist of seeking to verify relations of the form $N \cdot E_m = kL$, where E_m is the energy of one molecule and k is some constant.

A more successful attempt, however, was recently made "to give precision" to the generally recognized relationship between surface energy and internal latent heat by Mr. D. L. Hammick in an article on "Latent Heat and Surface Energy," which he published in the 'Philosophical Magazine,' August 1919 and January 1920. He conceives the true molecular surface energy belonging to all the molecules in a gram molecule to be the potential energy they acquire in reaching their positions in the surface layer. He imagines the gram molecule spread out in a layer one molecular diameter in thickness on a surface of excess of the liquid. This energy

is equal to $E \cdot \frac{V}{d} \cdot \frac{1}{j}$ calories, where E is the surface energy

per sq. cm., d is the diameter of a molecule, and V is the volume of the liquid gram molecule. His argument to show that this surface energy is one-sixth of the internal latent heat is as follows:—The work done upon a molecule to bring it into the surface layer is not, as is commonly supposed to be the case, one-half of that required to bring it altogether out of its liquid state. For, since the molecule in reaching the surface layer moves perpendicularly to the surface, the work is done against only "one of the three components of internal pressure," and is, therefore, only one-third of this amount, or one-sixth of the work to bring it altogether from the liquid.

It is difficult to conceive, however, that the work done by either of the other two components of internal pressure parallel with the surface can be equal to that done by the one perpendicular to the surface. For in each of the former components the forces which attract the molecule on opposite sides are equal, and the energy is not available, since no work can be done by forces in equilibrium; whereas in the case of the latter component the forces which attract the molecule towards the interior are greater than those which attract it towards the exterior, and the energy is available, since work may be done by their resultant. Still, from the best available data for d , E , and L for low temperatures, the calculated values of these two expressions for twenty-nine substances bear out his statement that "the relation above fits these facts remarkably well."

Another objection, which applies also to similar reasoning by other writers, lies in the division of the latent heat into two parts. If the external layer of molecules contains potential energy equivalent to only one-sixth of the latent heat, would not the other layers within the range of molecular attraction contain the remaining five-sixths and the surface energy be $6E$ ergs per sq. cm.? Or, is the latent heat composed of two distinct kinds, or does it arise from two distinct sources?

Now it so happens that Mr. Hammick's formula itself suggests a means of completely meeting both these objections. For his expression $\frac{V}{d}$ for the area occupied by the molecules of a gram molecule when they are all arranged in the surface layer, assuming, as it does, that the molecules fill the whole volume, is also the expression for the area occupied by one molecule. This area is thus $\frac{\pi}{6} d^3/d$ or $\frac{1}{6} \cdot \pi d^2$, which is exactly one-sixth of the area of its free surface. If, therefore, we suppose that the surface of the free molecule possesses surface energy of the same intensity as that which he supposes the surface layer to have acquired, the whole surface energy would be six times as much as Mr. Hammick thinks, and his relation should be :

$$E \cdot \frac{6V}{d} \cdot \frac{1}{J} = L_i,$$

which may evidently be written

$$E \cdot N\pi d^2 \cdot \frac{1}{J} = L_i,$$

where N is Avogadro's constant. Also, since his molecules

occupy all the space in the liquid, we have

$$\frac{\pi}{6} \cdot d^3 = \frac{m}{\rho},$$

where ρ is taken at a low temperature. This enables his relation to be written :

$$E \cdot \left(\frac{36 \pi m^2}{\rho^2} \right)^{\frac{1}{3}} \cdot N^{\frac{1}{3}} \frac{1}{j} = mL,$$

where $L_i = mL$, which is identical with that we obtained by considering the surface energy given up by the coalescence of liquid spheres.

Thus the carefully compiled data supplied by Hammick's tables really account for the whole of the latent heat, and there is no need to employ the hypothesis of molecular attraction and the doubtful principle of equipartition of energy along the three geometrical axes to obtain a relation that fits in his experimental data.

In this connexion it is interesting to note that Einstein (*Ann. d. Physik*, iv. 3, p. 513 (1901)) has put forward a view that the surface energy of a liquid is of the nature of potential energy expressible by a certain equation, one of whose terms depends on the atomic weight. This is exactly what our formula does, which may be written

$$Lj = T \cdot \left(\frac{36 \pi N}{m \rho^2} \right)^{\frac{1}{3}},$$

the expression with the brackets being the whole area of the N free molecules of a gram molecule of the gas, and T the energy per sq. cm. which we have supposed to exist in the surface of the free molecules. This energy is potential, as Einstein predicted, for it is stored in the surface of the free molecule incapable of being released for doing work until two such molecules by coming into contact coalesce and lessen their total enveloping area.

Our formula, which was obtained above from the phenomena of the coalescence of liquid spheres and not from any hypothesis concerning molecular attraction, would seem, then, to indicate that this view of the connexion between the latent heat and surface energy is the correct one; and therefore, in addition to the confirmation furnished by Hammick, we shall examine some further experimental evidences in support of this view.

If n , which we may suspect is Avogadro's number, is constant for all substances, we should seek for those values of

T and ρ which are independent of variable conditions of temperature, that is, for those values which they have when the temperature is 0°A . But, as Hammick points out, the data for these are not available, or at least are very incomplete. The value of L , the latent heat at the boiling-point, which is equivalent to the work done in dissociating the molecules from the liquid, that is, in creating the free surface of the molecules of the gas and storing it as potential surface energy, may be taken as constant under all conditions after our determinations have been freed from all external work.

Now, it has been shown experimentally that the surface tension about large masses of any liquid is a linear function of the absolute temperature which holds very approximately for all temperatures of the liquid from its melting-point to the critical temperature θ_c . This result is expressed in the empirical formula

$$T_\theta = A + B\theta,$$

where A and B are constants for any particular liquid. For water the ordinary tables give $T_\theta = 0$ when $\theta = \theta_c = 638^\circ \text{A}$, and $T_\theta = 73.3$ as the best available value when $\theta = 288^\circ \text{A}$.

From these we have

$$T_\theta = 133.6 - .209\theta,$$

so that

$$T_0 = 133.6.$$

It is evident, however, that only in large spheres or masses can the tension of the envelope obey the law above, for only in these can the heat motion of the molecules next the envelope affect the tension. For spheres containing only a few molecules and for the free molecules themselves an altogether different condition exists, for the heat motion then is the motion of the sphere itself. The tension, therefore, of the envelope about the free molecule will be very approximately the tension about a large mass when the molecules are at rest, that is, the molecular tension T_m will be T_0 .

If, then, the law holds through the process of solidification and down to 0°A , we should have for the free water molecule $T_m = 133.6$. This seems to be a reasonable supposition when we remember that the forces which cause solidification are in the interior of the molecule or mass and would not, therefore, affect the tension of the envelope on the exterior of the molecule or mass. Moreover (see note at the end), there are experimental indications that the surfaces of solids

possess potential energy and consequently are affected by surface tension.

Hence, if we take $L=498$, which is the average of the values given in the tables corrected for external work amounting to 41 calories,

$$\rho_0 = \rho_{277} = 1, \quad m = 18, \quad \text{and} \quad T_m = 133.6,$$

the formula,

$$n = \left(\frac{L \cdot J}{T_m} \right)^3 \times \frac{m \rho_0^2}{36\pi},$$

gives by calculation

$$n = 6.05 \times 10^{23}.$$

Millikan's value for this number, obtained by his balanced drop method, is 6.065×10^{23} ; while Perrin's value, obtained by studying the motion of a colloidal sphere in water, is 6.86×10^{23} .

The result obtained above would seem to furnish an argument in favour of the view that the properties of surface tension can be considered as not depending upon the mutual attraction of molecules. For, if the free molecule has about it this elastic envelope, it is plain that the envelope cannot be material at all. It is simply a force and nothing more.

Since the force of gravity in its relation to potential energy is denoted by $\frac{dE}{dx}$, where x is the distance between the centres of the masses attracting each other, this force will be denoted by $\frac{dE}{dA}$, where A is the area of the mass about which it acts. Also, because of the curvature of this area the force acts to compress the interior of the sphere to a smaller volume; but the action is prevented by another force in the interior which must, therefore, be denoted by $\frac{dE}{dV}$, where V is the volume within the enveloping force.

It may be that all physical phenomena may be explained in terms of these three fundamental physical forces, of which beyond these distinguishing characteristics we know but little. What these forces are *per se* we have no idea.

The formula obtained above appears to hold for all spherical masses of liquids, whatever be their size. For, since it gives a value of N practically identical with those we already know, it suggests that the law of coalescence of water spheres does not break down at any point from the

coalescence of large spheres to the coalescence of small spheres down to the molecules themselves. The method of obtaining it embodies in its essence discontinuity, involving from the beginning to the end no fewer than p distinct acts of coalescence where $2^p = \frac{N}{18}$, so that $p=75$.

At first thought it would seem that in the latter stages of condensation, where large spheres coalesce, the decrease in T on account of the heat motion of the molecules next the surface would greatly modify our value of N . Whatever effect this would have, however, must necessarily be very slight. For, suppose the first act of coalescence is to form the molecules into pairs, so that the resulting spheres would each contain two molecules. Then, if we consider only a gram mass, the first act of coalescence may be proved to cause a transference of potential energy into heat amounting to $L(1-2^{-\frac{1}{3}})$ calories; the second act a transference of $L(1-2^{-\frac{1}{3}})(2^{-\frac{1}{3}})$ calories; the third act of $L(1-2^{-\frac{1}{3}})(2^{-\frac{1}{3}})^2$ calories; and so on, the q th act of $L(1-2^{-\frac{1}{3}})(2^{-\frac{1}{3}})^{q-1}$ calories. These results are calculated in the table below.

TABLE I.

q .	Energy transferred.
1	162.6 c.
2	81.4 c.
3	64.6 c.
4	51.2 c.
5	40.7 c.
...
21	1.0 c.
...
75 (final)	0.00000385 c.

At the completion of the fifth act the spheres each consist of 32 molecules, but the gram mass has suffered a change of potential surface energy into heat amounting to 340.5 calories, or of 68 per cent. of the whole. After the 21st act, which causes a change of only 1 calorie, the total surface energy remaining is only 3.91 calories, or considerably less than 1 per cent. Thus we see that the change in T on account of the heat motion in the large spheres towards the latter part of the process of condensation would not affect the value of N materially, causing only a slight increase.

Since the formula obtained above gives the value of N so

closely approximating the true value from data experimentally determined in connexion with water, we are led to think that the same value of N would be obtained from similar data in connexion with other substances which are chemically stable under the conditions involved in the determination of these data, though not to the same degree of approximation.

In the Tables II. and III. below are given the values of T_m and N as calculated along with the necessary data for ten of the more common substances, including water. L is the heat energy exclusive of that required for the external work necessary to vaporize a gram mass of the liquid at the boiling-point without change of temperature under atmospheric pressure.

TABLE II.

Substance.	Formula.	m .	θ_c° .	θ° .	T_θ .	$T_\theta - B\theta$.
Water	H_2O	18	638	288	73.3	133.6—2099
Propyl alcohol...	C_3H_8O	60	536.7	288.4	23.8	49.5—09250
Ethyl alcohol ...	C_2H_6O	46	516.1	293	22	50.9—09860
Methyl alcohol...	CH_4O	32	513	293	23	53.6—1059
Ether	$C_4H_{10}O$	74	466.8	293	16.5	44.3—0959
Chloroform	$CHCl_3$	119.4	533	288	27.2	59.3—1110
Nitrogen	N_2	28	127	77	8.5	21.6—1709
Oxygen	O_2	32	155	90	13.1	30.4—1979
Benzene.....	C_6H_6	78	561.5	290.5	29.2	60.0—1079
Mercury	Hg	200	(1734)*	290.5	547	657 —3799

* Theoretical.

TABLE III.

Substance.	Boil. Pt.	θ .	ρ_θ .	$T_m = T_\theta$.	L .	$N/10^{23}$.
	$^\circ$	$^\circ$				
Water	373	277	1.000	133.6	498	6.05
Propyl alcohol...	370.2	293	.804	49.5	152	7.28
Ethyl alcohol ...	351.3	288	.794	50.9	192	10.69
Methyl alcohol...	337.7	288	.796	53.6	246	12.68
Ether	307.6	290	.718	44.3	73.4	1.13
Chloroform	334.2	273	1.526	59.3	52.4	1.24
Nitrogen	77	77	.79	21.6	41.0	.79
Oxygen	90	38	1.27	30.4	47.5	1.28
Benzene.....	353.2	378.4	.879	60.0	86.5	1.19
Mercury	629.7	0	(14.25)	657	61.6	.21

The temperature coefficient of surface tension has been assumed to be constant down to 0°A , and in accordance with the reasons given in the case of water we have regarded the surface tension T_m about a free molecule equal to T_0 in the empirical formula $T_\theta = T_0 - B\theta$. However, the temperature coefficient is only approximately constant, and consequently T_m or T_0 is only approximately determined. These data have been taken from the ordinary tables and are subject to question in some cases. Especially in the case of mercury, where L was determined by Young in 1910, there is a probability that the vapour of mercury involved in the determination was not altogether of dissociated molecules. For example, if the spheres of the mercury vapour contain 32 molecules, the real value of L is seen from Table I. to be $498/(498 - 340.5)$ or 3.16 times the value in the Table III.; and consequently the value of N would be

$$(3.16)^3 \times 21 \times 10^{23} \quad \text{or} \quad 6.64 \times 10^{23},$$

which agrees with that we know.

But the greatest discrepancy is seen in the case of ether, chloroform, nitrogen, oxygen, and benzene. The values of N , however, are very uniform and equal to about one-fifth of the true value. One contributing cause may be in the high vapour pressures common to all of these substances. But the chief cause lies in the use of ρ_θ instead of ρ_0 , which in the absence of sufficient data could not be even approximately estimated. So far as we have evidence, ρ_θ increases for the liquid quite rapidly as θ decreases, suddenly increases at solidification, and continues to increase more slowly for the solid down to 0°A . It seems to be quite possible that for these substances the value of ρ_0 would be double the value used; in which case, as N increases with the square of ρ_θ , the values of N would approximate to the true value. For mercury the value 14.25 for ρ_0 was obtained on the supposition that the temperature coefficient of expansion of the liquid remained constant through the solid down to 0°A .

In the case of the alcohols, from considerations in regard to the arrangement of the atoms in the molecule the idea has arisen that the free molecule is not spherical, especially as one of the elements is carbon. If this be so, two such molecules coming into contact would give up less of their enveloping area than they would if they were spherical and coalesced in the same manner as two liquid drops. At first they would resemble two solid particles adhering, and afterwards the combined mass would gradually become spherical as more molecules were included in the enclosure. It would,

therefore, take a greater number of molecules in the initial stages of the condensation to produce the same amount of heat, which would account for the larger values of N for these substances. Another cause may be in the long range of temperature for which these substances are liquids.

It would appear, then, that the undetermined elements of these experimental data point to the idea that, if we knew the true values of T_m , ρ_0 , and L for all stable substances, the value of N calculated as indicated in our formula would be the true Avogadro's number, which would be a little greater than that obtained in the table for water. Also, the evidence from the data more carefully selected by Hammick points, under the same conditions and with the same limitations, to the same conclusion.

Assuming, therefore, that the conclusion is justifiable, we have, by equating the two expressions for the potential surface energy of the free molecule,

$$LJ \frac{N}{m} = T_m \times \pi d^2,$$

from which
$$d = \left(\frac{mLJ}{\pi T_m N} \right)^{\frac{1}{2}}.$$

This on substituting for LJ the value obtained previously reduces to

$$d = \left(\frac{6m}{\pi \rho_0 N} \right)^{\frac{1}{2}}.$$

The value of d will thus depend upon the value of ρ_0 and will be subject to the same uncertainty as that which belongs to ρ_0 . However, as ρ_θ is less than ρ_0 , d_θ will be larger than d_0 , so that d_θ may be regarded as the average diameter of the space which the actual molecule whose diameter is d_0 occupies at temperature θ° A. For water we are fairly certain that ρ_0 does not greatly exceed 1 and is not less than 1. The formula gives for water, where $\rho_0=1$, $d_0=3.85 \times 10^{-8}$. For mercury, where ρ_0 is taken equal to 14.25, $d_0=3.56 \times 10^{-8}$. As ρ_θ decreases with rising temperature, d_θ increases, thus making room for the heat vibrations of the real molecule in the solid or liquid.

The following is a brief summary of the views presented in the preceding pages:—

(a) Latent heat is the surface energy of the free molecules of the substance in its gaseous state.

(b) Surface tension extends to molecular masses causing them to coalesce in the same manner as liquid spheres.

(c) Since N is constant for all substances, if any two of the three quantities T_m , ρ_0 , and L can be found for any substance, the other may be calculated from the relation

$$N = \left(\frac{LJ}{T_m} \right)^3 \times \frac{m\rho_0^2}{36\pi}.$$

(d) It is assumed that the empirical law $T_\theta = T_0 - B\theta$ holds down to 0°A , and that $T_m = T_0$.

(e) The actual mass diameter of the molecule is

$$d_0 = \left(\frac{6m}{\pi\rho_0 N} \right)^{\frac{1}{3}},$$

and the average diameter of the space it occupies in the solid or liquid is

$$d_\theta = \left(\frac{6m}{\pi\rho_\theta N} \right)^{\frac{1}{3}}.$$

Note on the Surface Tension of Solid Bodies.

The idea that solid bodies possess surface tension is believed to be tenable. Van der Mensbrugge (*Anal. Soc. Sci. de Bruxelles*, B. xxix. (1904-5)), from consideration of the forces in the curved meniscus at the side of a vertical glass plate in water, concludes that a glass surface possesses an effective surface tension. M. Petrova (*Journ. Russk. Fizik. Chimecesk*, xxxvi. Phy. pt. pp. 203 (1905)), from the fact that enlarged photographs of mercury drops on glass taken before and after solidification when superimposed showed no appreciable change, inferred that solid mercury possesses surface tension. And, finally, M. Berggren (*Ann. d. Physik*, xlv. 1, pp. 61-80 (1914)), by measuring the velocity of deformation when amorphous bodies solidify in the case of threads hanging vertically, found that solid amorphous bodies possess surface tension of the same order of magnitude as that of liquids.