

measured from the normal boiling point to the critical point and of pure liquid oxygen from 0.2 to 21 atmospheres. The following equations have been fitted to the data: oxygen, $\log_{10} P$ (atm.) = $-372.808/T + 4.18939 - 0.0006195T$; nitrogen, $\log_{10} P$ (atm.) = $-316.824/T + 4.47582 - 0.0071701T + 2.940 \times 10^{-5}T^2$. The following simpler equations, while not quite as good as the above equations, also reproduce the data very well: oxygen, $\log_{10} P$ (atm.) = $-366.523/T + 4.06295$; nitrogen, $\log_{10} P$ (atm.) = $-304.494/T + 3.93352$. It has also been shown that the linear $\log P$ against $1/T$ equations hold exceedingly well for nitrogen over the whole liquid line from the triple point to the critical point, and for oxygen over an even wider range of pressures, namely, from 0.05 to 49.7 atmospheres (critical pressure).

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[CONTRIBUTION FROM GENERAL LABORATORIES, UNITED STATES RUBBER COMPANY]

VOLUME CHANGES ATTENDING THE FORMATION OF RUBBER SOLS. I¹

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The purpose of the present investigation was to discover: (1) whether or not there is a volume change when rubber goes into solution, and (2) whether the condition of the rubber has any effect on this.

Introduction

It is well known that the formation of a solution is in general attended by a change in the total volume of the constituents. This volume change usually takes the form of a contraction, but may in some cases be an expansion, for example, sodium palmitate-water;^{1a} *p*-nitrotoluene-carbon disulfide.² Volume changes may be referred to three effects:³ to the cohesive affinities involved, to the effect of polymerization or association of one or both of the substances concerned and to their compressibilities. The first effect is comparable to the volume change which solids and liquids undergo on chemical combination, and includes the tendency to formation of complex molecules between solute and solvent, that is, solvation. There is considerable evidence indicating that dilution of a substance brings about a gradual depolymerization in a polymerized substance, and that solution tends to diminish the degree of polymerization.

¹ This paper was read at the meeting of the Rubber Division of the American Chemical Society held at Akron, Ohio, February 22-23, 1926.

^{1a} McBain, "Third Report on Colloid Chemistry and Its General and Industrial Applications," 1920, p. 14.

² Hyde, THIS JOURNAL, **34**, 1507 (1912).

³ Richards and Chadwell, *ibid.*, **47**, 2283 (1925).

The compressibilities of the cohering substances will also affect the volume change. When two substances possessing a given cohesive affinity are mixed, an increase in the compressibility should result in a greater observed contraction.

Obviously, any change affecting such a fundamental property as density must have special significance in its bearing upon physical and chemical constitution and upon the nature of the process which is associated with such a change. Its measurement by this method has a peculiar value in the case of colloidal solutions to which the ordinary criteria of solubility and molecular weight have so little applicability.

In the case of colloidal systems, a fourth factor must be taken into consideration, namely, the effect of surface tension in increasing the density and decreasing the volume of the dispersed phase.⁴

The medium at the interface of the two phases constituting a colloid system exists in a special condition with regard to surface tension, concentration, molecular arrangement and possibly molecular complexity.⁵ Wilhelm Ostwald has shown that as the result of contractile surface tension, drops of water 3μ in diameter are 0.005% more dense than water *en masse*. This value increases with further subdivision so that drops of water 0.03μ in diameter, that is, in colloidal degree of dispersion, possess a density 0.5% greater than water in bulk.

In addition to the capillary pressure, we have to take into account the several compressibilities, namely, that of the solvent, the disperse phase and that of the system as a whole. The density of a suspensoid sol varies linearly with concentration,⁶ and the formation of the sol is attended by a small increase in density.⁷ H. Rodewald, H. Quincke⁸ and Van Bemmelen,⁹ working with starch and water, egg albumen and water, and with gels of silicic acid, respectively, found that the volume change varied relatively with the concentration (g. per 100 cc.). G. Quincke,¹⁰ in the case of gelatin hydrosols, found that the function is slightly curvilinear, which is in agreement with the work of Röntgen and Schneider¹¹ and H. Gilbert.¹² W. Ostwald¹³ suggests this as a method for distinguishing between emulsoids and suspensoids. On the other hand, Davis and Oakes¹⁴

⁴ Ostwald-Fischer, "A Handbook of Colloid Chemistry," P. Blakiston's Son and Co., Philadelphia, Pa., 1919, 2nd English ed., p. 120.

⁵ Ostwald, "Grundriss der allgemeinen Chemie," 1910, p. 533.

⁶ Linder and Picton, *J. Chem. Soc.*, 67, 71 (1895).

⁷ Rodewald, *Z. physik. Chem.*, 24, 193 (1897).

⁸ Quincke, *Pflüger's Arch.*, 3, 332 (1870).

⁹ Van Bemmelen, *Dissertation*, "Die Absorption," Dresden, 1910, p. 337.

¹⁰ Quincke, *Ann. Physik*, 9, 800 (1907).

¹¹ Röntgen and Schneider, *Wied. Ann.*, 29, 165 (1886).

¹² Gilbert, *Z. physik. Chem.*, 24, 385 (1897).

¹³ Ref. 5, p. 149.

¹⁴ Davis and Oakes, *THIS JOURNAL*, 44, 464 (1922).

and Taffel,¹⁵ working with gelatin-water, found the density-concentration curve to be a linear one. Katz¹⁶ studied the system casein-water, and found that the contraction per gram increased with the amount of water taken up. He worked with amounts of water up to 0.22 g. per gram of casein, distinctly in the gel range.

A number of organosols and gels of cellulose esters and resins have been investigated by E. W. J. Mardles¹⁷ with reference to the Tyndall number and viscosity. An analysis of the density data taken from his own and papers of several other workers,¹⁸ led him to the following important conclusions: (1) The volume changes associated with the formation of the organosols and gels considered are in general smaller than those in the case of hydrosols; (2) the volume changes are greatest with the best solvent, and with mixed solvents the maximum volume change is coincident with the optimum solvent mixture and lowest Tyndall number; (3) the relatively densest solution has the least viscosity, in which case the mixture has the highest solvent power; (4) rise in temperature generally brings about an increase in the volume change; (5) the volume change in many cases is larger with the more dilute solutions, while with some (such as acetone sols), it remains about the same with varying concentration; (6) freezing-point determinations indicated an increase in the degree of molecular complexity of the disperse phase with increasing concentration.

In general, the volume changes are highest the more nearly the colloidal solution approaches in character that of a true solution, that is, at very low concentrations, at higher temperatures, and with the best solvents. As Mardles points out, the degree of dispersion and degree of solvation are greatest under these conditions.

Posnjak,¹⁹ in connection with his study of the swelling of rubber by various solvents, found that the swelling was accompanied by a slight diminution in total volume.

From the foregoing we see that there is apparently a definite although by no means a simple relationship between the volume contraction and the degree of solvation, or degree of dispersion, or both. In the case of rubber the problem seemed still more interesting for the following reasons. (a) The large variety of rubber solvents possessing a wide range of physical and chemical properties affords an opportunity for studying the effect which the nature of the solvent has on volume change. (b) Rubber

¹⁵ Taffel, *J. Chem. Soc.*, **122**, 1974 (1922).

¹⁶ Katz, *Kolloidchem. Beihefte*, **9**, 70 (1917).

¹⁷ Mardles, *Trans. Faraday Soc.*, **18**, 365 (1923).

¹⁸ (a) Barr and Bircumshaw, *Aeronautical Research Comm. Rept.*, **1921**, No. 746. (b) Gibson and McCall, *J. Soc. Chem. Ind.*, **39**, 172T (1920). (c) Knoevenagel and others, *Kolloidchem. Beihefte*, **13**, 193, 233 (1921); **14**, 1 (1921). (d) Baker, *J. Chem. Soc.*, **103**, 1653 (1913). (e) Visser, *Aeronautical Research Comm. Rept.*, **1922**, No. 758.

¹⁹ Posnjak, *Kolloidchem. Beihefte*, **3**, 417 (1912).

as a colloid has many of the properties ordinarily possessed only by the colloidal substance plus solvent, that is, it has the character of an isocolloid (compare Caspari's work).²⁰ On the other hand, the gels of unmilled or unbroken rubber retain to a remarkable degree the rubber-like properties of the original substance, even at considerable dilutions, and the solution itself is comparable to the caoutchouc-like systems of Ostromislensky.²¹ Looked at from this point of view, a rubber solution over a range of concentration, somewhat resembles an homologous series of caoutchouc-like bodies possessing extremely minute gradation in properties. There is no definite concentration to mark a gel-sol transformation. (c) In the case of rubber, the properties of the colloid and of its sols vary enormously with the preliminary mechanical treatment which the rubber has received. While this is true, to some extent, of certain other lyophilic colloids, rubber is *par excellence* a substance whose behavior depends largely on its past history. This is of course implied in the statement just made, that rubber is an "isocolloid." The great variations in the rate of dispersion of rubber and the degree of swelling, viscosity and optical properties of its solutions occasioned by mechanical treatment, point to a study of its fundamental properties in "solution" as the most fruitful method for gaining an insight into the nature of this important change. The same may be said for the phenomena associated with vulcanization both in the dry state and in solution. The present article, however, is limited to a consideration of unvulcanized rubber.

Experimental Part

Since our purpose was to compare the volume changes associated with the dissolution of unbroken-down and broken-down rubber, it was desirable to obtain in the former case as material, rubber in the highest state of purity obtainable, consistent with the least possible change in its physical and chemical properties.

Films varying in thickness from 0.254 to 0.762 mm. were laid down from ammonia-preserved latex on porous plates, and allowed to evaporate at room temperature. These films were immersed in running water at the ordinary temperature for 24 hours in order to remove as much as possible of the water-soluble constituents. The final drying was accomplished in a vacuum over concd. sulfuric acid. The rubber yielded the following results on analysis: moisture, none; acetone extract, 2.7%; water extract, 0.7%; ash, 0.3%.

Portions of these films selected with care for freedom from air bubbles were cut into small squares and the density was determined in the usual way, using boiled distilled water, precautions being taken to avoid the inclu-

²⁰ Caspari, *J. Soc. Chem. Ind.*, **32**, 1041 (1913).

²¹ Ostromislensky, *J. Russ. Phys.-Chem. Soc.*, **47**, 1401-1441 (1915).

sion of air. The pycnometers employed in this work were of the flask pattern with a ground-in thermometer graduated in 0.2°C . and provided with a capillary side piece fitted with a ground-glass cap. They were carefully calibrated with water, the bulb having a capacity of about 25 cc., being brought to a constant temperature by immersion in a large water thermostat. All determinations were made after immersion for about one hour to ensure that the pycnometer and its contents had reached the temperature of the bath. The temperature readings were taken on a separate thermometer, by means of a cathetometer, and are accurate to $\pm 0.02^{\circ}$. The actual variation in temperature of the thermostat, at any particular temperature, however, was considerably less. On removal from the bath the pycnometers were carefully dried and then placed inside the balance case until the temperature of the latter was attained. The density determinations were subsequently corrected for weighings in a vacuum.

The value obtained for the density of latex films at 35° as the result of ten determinations was 0.90241 ± 0.00057 . The somewhat large differences observed were undoubtedly due to variations in the rubber films themselves and on this account average samples were used for the preparation of the sols.

The sols were prepared, using c. p. xylene, d_4^{35} (found) 0.84806, in a round-bottomed flask equipped similarly to a wash bottle. The flask was inverted and the space above the sol could be evacuated, in order to remove air bubbles and to prevent oxidation, or pressure could be applied to force the solution through the delivery tube underneath into a pycnometer attached to receive it.

The sols were stored in the dark several weeks, with gentle agitation from time to time, in order to facilitate dissolution of the rubber. Excessive agitation was avoided in the case of the sols prepared from unmilled rubber in order to prevent any breaking-down effect due to this cause.

The breakdown, 10 to 18 minutes, received by the samples of latex film designated as "broken down" was, for the small quantity of material taken, 10-30 g., equivalent to an hour's breakdown for a regular 600g. test batch. The milling was done in the usual way, but on a cold mill.

The sols of broken-down rubber were occasionally shaken violently during the process of solution and by the time they were used for the following determinations no structure was visible. The sols of unmilled rubber, on the other hand, contained a considerable amount of structure, the outlines of the greatly swollen sheets of rubber being plainly visible to the naked eye.

It is remarkable that this lack of homogeneity apparently had little or no effect on the density of the sol, since good checks were obtained to the fourth and often the fifth place of decimals, irrespective of the quantity of structure contained by the portion of the sol under consideration. The

values for the densities of the sols at any one temperature, given in Tables I-VI, are the results obtained from independent determinations with different pycnometers carried out on portions of the same sol.

The experimental difficulties with the more concentrated sols, especially with unmilled rubber, were considerable, and at the time this work was carried out it was believed to be impractical to use more concentrated sols. This difficulty has since been overcome, as will appear in a subsequent paper.

No reliable value could be obtained for the density of milled rubber, owing to the difficulty of handling and of securing an air-free sample.

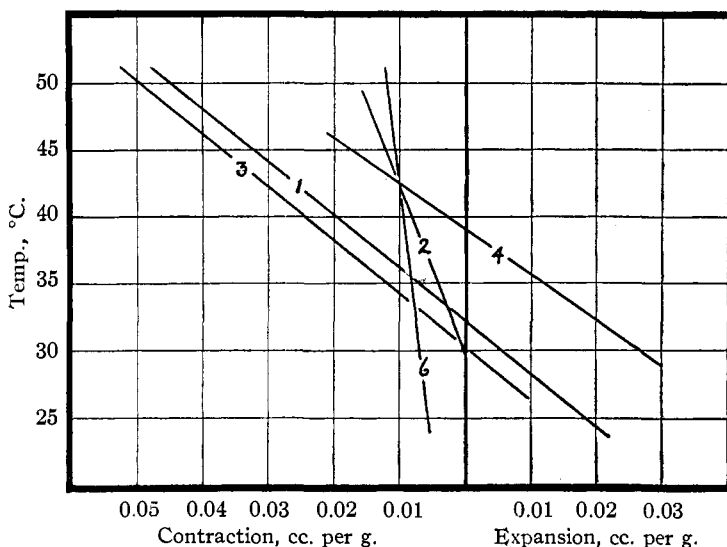


Fig. 1.—Volume changes in rubber xylene sols. 1, Unmilled rubber, 1.27%; 2, unmilled rubber, 4.90%; 3, milled rubber, 1.41%; 4, milled rubber, 1.43%, prepared by dilution of 5.7% sol; 6, milled rubber, 19.3%.

The value of d_4^{35} (0.9024) for rubber was employed in all the calculations, and Rüssner's²² values over the range 0–53°, $a = 0.000636$, $b = 0.00000150$, were used in the equation $V_t' = V_t [1 + a(t' - t) + b(t'^2 - t^2) - a^2 t(t' - t)]$ for the calculation of the specific volume at the several temperatures. This value agrees very nearly with a determination made more recently in these Laboratories, for this kind of rubber.

For xylene²³ (0–100°) the values $a = 0.0009506$ and $b = 0.000001632$ were taken. The concentrations of the sols were found by evaporation at 75–80° of that portion actually used in the density determination, care being taken to avoid oxidation.

²² Rüssner, *Carl Repert.*, 18, 152 (1882).

²³ Zander, *Ann.*, 224, 56 (1884).

TABLE I
UNMILLED RUBBER IN XYLENE

Temp., °C.	Concn., 1.271%				
	Spec. vol., cc.	Spec. vol. calcd., cc.	Diff., <i>D</i> , cc.	<i>D</i> per g., rubber	<i>D</i> per g., rubber, av.
25.0	1.16645	1.16630	+0.00015	+0.012	+0.014
	1.16650		+ .00020	+ .016	
25.3	1.16678	1.16666	+ .00012	+ .0094	+ .0094
27.0	1.16871	1.16866	+ .00005	+ .0039	+ .0094
	1.16885		+ .00019	+ .0149	
30.0	1.17229	1.17222	+ .00007	+ .0055	+ .0095
	1.17239		+ .00017	+ .0135	
35.0	1.17811	1.17825	- .00014	- .0106	- .0063
	1.17822		- .00003	- .0020	
39.0	1.18289	1.18314	- .00025	- .0197	- .0197
45.0	1.19014	1.19057	- .00043	- .0331	- .0309
	1.19021		- .00036	- .0286	
49.0	1.19491	1.19560	- .00069	- .0543	- .0522
	1.19497		- .00064	- .0500	

Av. coeff. of expansion at 30-45° = 0.0008069.

TABLE II
UNMILLED RUBBER IN XYLENE

Temp., °C.	Concn., 4.900%				
	Spec. vol., cc.	Spec. vol. calcd., cc.	Diff., <i>D</i> , cc.	<i>D</i> per g., rubber	<i>D</i> per g., rubber, av.
30.0	1.16970	1.16972	-0.00002	-0.0004	-0.0002
	1.16973		+ .00001	+ .0002	
25.0	1.17535	1.17568	- .00033	- .0067	- .0064
	1.17538		- .00030	- .0061	
40.0	1.18134	1.18171	- .00037	- .0075	- .0075
	1.18134		- .00037	- .0075	
45.0	1.18723	1.18784	- .00061	- .0124	- .0124
	1.18724		- .00060	- .0123	

TABLE III
MILLED RUBBER IN XYLENE
Concn., 1.411%; 10 min., cold mill

Temp., °C.	Spec. vol., cc.	Spec. vol. calcd., cc.	Diff., <i>D</i> , cc.	<i>D</i> per g., rubber	<i>D</i> per g., rubber, av.
30.0	1.17214	1.17213	+0.00001	+0.0007	0.0000
	1.17212		- .00001	- .0007	
32.6	1.17507	1.17525	- .00018	- .0128	- .0139
	1.17504		- .00021	- .0149	
35.0	1.17793	1.17815	- .00022	- .0156	- .0147
	1.17796		- .00019	- .0138	
37.0	1.18027	1.18057	- .00030	- .0213	- .0213
	1.18027		- .00030	- .0213	

TABLE III (Concluded)

Temp., °C.	Spec. vol., cc.	Spec. vol. calcd., cc.	Diff., <i>D</i> , cc.	<i>D</i> per g., rubber	<i>D</i> per g., rubber, av.
39.0	1.18263	1.18203	- .00040	- .0284	- .0256
	1.18271		- .00032	- .0227	
41.0	1.18431	1.18523	- .00092	- .0652	- .0418
	1.18497		- .00026	- .0184	
45.0	1.18990	1.19047	- .00057	- .0404	- .0404
	1.18990		- .00057	- .0404	
49.0	1.19475	1.19549	- .00074	- .0525	- .0493
	1.19484		- .00065	- .0461	

Mean coeff. expansion 30-49° = 0.001005.

TABLE IV

MILLED RUBBER IN XYLENE

Concn., 1.43%; 18 min. on mill prepared by dilution of 5.7% sol.

Temp., °C.	Spec. vol., cc.	Spec. vol. calcd., cc.	Diff., <i>D</i> , cc.	<i>D</i> per g., rubber	<i>D</i> per g., rubber, av.
30.0	1.17254	1.17212	+0.00042	+0.0294	+0.0273
	1.17248		+ .00036	+ .0252	
35.0	1.17826	1.17811	+ .00015	+ .0105	+ .0081
	1.17819		+ .00008	+ .0056	
39.0	1.18309	1.18301	+ .00008	+ .0056	+ .0028
	1.18301		.00000	.0000	
45.0	1.19022	1.19046	- .00024	- .0168	- .0175
	1.19020		- .00026	- .0182	

TABLE V

MILLED RUBBER IN XYLENE

Concn., 5.700%; 18 min. on mill

Temp., °C.	Spec. vol., cc.	Spec. vol. calcd., cc.	Diff., <i>D</i> , cc.	<i>D</i> per g., rubber	<i>D</i> per g., rubber, av.
30.0	1.16893	1.16918	-0.00025	-0.00439	-0.00474
	1.16889		- .00029	- .00509	
35.0	1.17499	1.17510	- .00010	- .00175	- .00175
	1.17499		- .00010	- .00175	
45.0	1.18658	1.18724	- .00066	- .0116	- .0118
	1.18656		- .00068	- .0119	

Av. coefficient of expansion at 30-45° = 0.001007.

TABLE VI

MILLED RUBBER IN XYLENE

Concn., 19.33%; 10 min. on mill

Temp., °C.	Spec. vol., vol.	Spec. vol. calcd., cc.	Diff., <i>D</i> , cc.	<i>D</i> per g., rubber	<i>D</i> per g., rubber, av.
27.0	1.15519	1.15644	-0.00125	-0.00647	-0.00637
	1.15523		- .00121	- .00626	
30.0	1.15842	1.15978	- .00136	- .00698	- .00711
	1.15838		- .00140	- .00724	

TABLE VI (Concluded)

Temp., °C.	Spec. vol., vol.	Spec. vol. calcd., cc.	Diff., <i>D</i> , cc.	<i>D</i> per g., rubber	<i>D</i> per g., rubber, av.
35.0	1.16383	1.16543	-.00160	-.00828	-.00831
	1.16382		-.00161	-.00833	
39.0	1.16837	1.17001	-.00164	-.00848	-.00851
	1.16836		-.00165	-.00854	
45.0	1.17494	1.17700	-.00206	-.0107	-.0105
	1.17501		-.00199	-.0103	
49.0	1.17947	1.18173	-.00226	-.0117	-.0119
	1.17942		-.00231	-.0120	

Discussion of Results

It is seen that in most cases, there is a definite change in volume, usually a contraction, associated with the formation of a xylene-rubber sol. This contraction is in general considerably smaller at comparable temperatures than that observed with most hydrosols, for example, hydrosols of gelatin.

Comparing the volume changes for the several rubber sols at any one temperature above 30°, we find that in general the sols of broken-down rubber show somewhat more contraction than those of unbroken-down rubber. Other experiments with a variety of solvents, which will be reported later, show in some cases a much greater difference between broken-down and unbroken-down rubber. Some solvents have a pronounced swelling effect, some a pronounced softening and dispersing effect. We should expect the more powerful softening type to act in nearly the same manner toward both broken-down and unbroken-down rubber. The fact that there is no marked difference between milled and unmilled rubber in xylene in respect to the volume change may be attributed to the pronounced swelling and dispersing action of this solvent which, therefore, behaves more nearly in the same manner toward rubber in the different states.

At and below 30°, in the more dilute sols, the volume change passes over from a contraction to an expansion. This is especially noticeable with the most dilute unmilled rubber sol and also the one prepared by dilution of a more concentrated sol.

The concordance between results of experiments on the same solution and at the same temperature is in general rather good, considering the nature of the substance under investigation. The individual results of experiments at different temperatures, although they show quite definitely that with rising temperature the contraction is increased or expansion diminished, do not, except for the higher concentrations, lie on a smooth curve. This is probably because the structure and previous history of the sol are factors influencing the density. We are not dealing with a system in equilibrium, but are concerned with the state of the sol at an arbitrary and entirely random point in its life curve.

In this connection it is perhaps significant that E. Bunschoten²⁴ and Van Rossem²⁵ found that samples of Plantation sheet rubber which had been stored for some time in the cold suffered a decrease in density on heating in the neighborhood of 30°, which amounted to 0.018 over the original value at 15°. Bunschoten discovered also that on repeated bending, the density of a sample of hard rubber similarly decreases to about the same extent, which transformation he attributes to the heat effect. H. Feuchter²⁶ noted a volume contraction associated with adiabatic stretching of rubber, amounting to about 5%, which he refers to the formation of anisotropic caoutchouc systems. The results obtained with Sol No. 4, which was prepared from No. 5 by dilution, are noteworthy in that this sol behaves more nearly like No. 1 (unmilled rubber) than No. 3 (milled rubber), the volume change being smaller and amounting to an expansion at the lower temperatures. In other words, the original sol retains its own structure, and its individuality persists in contact with fresh solvent behaving, in fact, like a fresh sol prepared from unbroken-down rubber.

If the values for the contraction per gram of rubber (abscissas) are plotted against temperatures (ordinates) it will be seen that the relation can be represented fairly well by a straight line. The slope of the curve is much greater with the more concentrated sols in the case of both milled and unmilled rubbers.

These volume changes will be discussed more completely in a future paper, where further experiments with a variety of solvents will be reported. It is desired to point out here, however, that in general the increasing contraction with increasing dilution and temperature indicates quite definitely that the degree of dispersion of the rubber in the sol is increasing at the same time. In this connection it is interesting to note that the view of Thomas Graham that "dilution weakens the colloidal character of substances," seems to some extent to have been verified by these experiments.

Examination of the sols by optical method revealed the fact that the sols of unmilled rubber were optically empty, whereas the sols of milled rubber displayed complete heterogeneity, indicating a diminished ability on the part of the particles of milled rubber to absorb solvent as compared with the structure forming particles of the unmilled substance. Klein and Stamberger²⁷ have since established a parallelism between decrease in viscosity and increase in optical resolvability.

Summary

1. The volume changes associated with the formation of some xylene sols of milled and unmilled rubber have been measured.

²⁴ Bunschoten, "Mededeelingen van den Rijksrubberdienst," 3rd series, 1921.

²⁵ Van Rossem, *Rubber Age*, 4, No. 12 (1924).

²⁶ Feuchter, *Gummi-Ztg.*, 39, 1167 (1925).

²⁷ Klein and Stamberger, *Kolloid-Z.*, 362, 366 (1924).

2. In general, the volume change is a contraction which is largest (a) at higher temperatures and (b) at lower concentrations.

3. The increase in volume change (contraction) with temperature is greater at lower concentrations.

4. Below 30° the volume change tends towards an expansion in volume, which is in agreement with the fact that under some circumstances rubber suffers a change in density in the neighborhood of 30°.

5. In the case of xylene sols, here considered, the condition of the rubber as regards milling or plasticizing appears to have no marked effect on the volume change.

NEW YORK, N. Y.

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THE PREPARATION AND PROPERTIES OF COLLOIDAL AND MONOCLINIC SULFUR IN ORGANIC LIQUIDS¹

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Among the first studies of non-aqueous colloids were those of Graham,² in which he replaced the water in silicic acid jelly by alcohol, and sulfuric, nitric and formic acids. More recent workers have studied non-aqueous sols but only a few of them have selected sulfur as the substance to be dispersed.

Svedberg³ prepared a dispersion of sulfur in *isobutyl* alcohol and in ethyl ether by means of an oscillatory electric discharge. Von Weimarn and Kagan⁴ prepared sulfur sols in alcohol by freezing supersaturated solutions and then allowing them to melt. Von Weimarn⁵ prepared dispersions of sulfur in various alcohols and studied their colors and other properties. Sekera⁶ prepared colloidal sulfur by spraying solutions into carbon disulfide.

The purpose of this investigation is to study the factors affecting the production of sulfur dispersions in organic liquids and to determine the properties of such dispersions, also to identify crystals which were formed in some of the dispersions.

Preparation of the Dispersions

Experiments were carried out to determine the liquids most suitable for dispersion media, and the best method for the production of the sulfur dis-

¹ This paper is an abstract of a thesis submitted by Florence M. Colt in partial fulfillment of the requirements for the degree of Master of Science at Rutgers University.

² Graham, *Proc. Roy. Soc. (London)*, **13**, 335 (1864).

³ Svedberg, *Ber.*, **39**, 1705 (1906).

⁴ Von Weimarn and Kagan, *J. Russ. Phys.-Chem. Soc.*, **42**, 480 (1910).

⁵ Von Weimarn, *ibid.*, **45**, 1689 (1913); **47**, 2133 (1915).

⁶ Sekera, *Kolloid Z.*, **31**, 148 (1922).