

SPECIFIC GRAVITY OF LATEX AND OF RUBBER

BY

H. FAIRFIELD SMITH

Summary

The specific gravity of the rubber phase in latex of *Hevea brasiliensis* has formerly been estimated at values varying from 0.901 to 0.914. It is now shown that seemingly discrepant values obtained by various workers can be accounted for by differences in the preparation of latex, in the temperature of observation, and in the methods of estimating the specific gravity of the dispersed phase. Allowing for these differences, all available data conform to relative specific gravities (d_4^t at 29°C) of about 1.022 for undiluted fresh serum, and 0.910 for the crude rubber phase, "crude rubber" being defined as the mixture of substances usually included in observations of the dry-rubber-content of field latex. The specific gravity of a purified rubber phase containing about 0.15 per cent N may be as low as 0.905; that of the pure hydrocarbon is presumably still lower.

Within the limits of accuracy of available data there is no evidence that density of the rubber phase is affected by the presence of ammonia in such concentrations as are used for preservation. The density of the rubber phase is similar to, and may be actually equal to, the density of solid rubber of corresponding purity.

The relationship between specific gravity of latex and temperature is discussed in an appendix.

In the light of these results the following problems have been reviewed:

- (A) to calculate a conversion table for different ways of expressing d.r.c.;
- (B) to estimate specific gravity of latices ammoniated in different ways; and
- (C) to estimate dry-rubber-content from the specific gravity of latex-water mixtures.

The above values of specific gravity for rubber and serum should not be considered as finally established. The main purpose of the paper is to direct attention to methods of evaluating them with attention to possible effects of varying soils, clones, temperatures and physico-chemical conditions.

1. Introduction

From observations on specific gravity and dry rubber content of latex, of centrifugal concentrates, and of latex water mixtures,

a number of attempts have been made to deduce the specific gravity of the rubber phase. Such estimates, after allowing for criticisms and adjustments which have been put forward, range from 0.901 to 0.914. But writers have made no attempt to consider how their calculations would be affected by treatments of the latex such as ammoniating and centrifuging, by different ways of evaluating the results, and by variations in temperature. When consideration is given to such matters almost all observations published during the last 20 years are found to be in good agreement one with another.

Specific gravity, the ratio of the mass of a certain volume of a substance at the temperature t_2 , to that of the same volume of water at temperature t_1 , is commonly designated $d_{t_1}^{t_2}$. To avoid excess affixes, when temperature of the substance does not require to be stated, let:—

S indicate specific gravity relative to water at the same temperature as the observed substance ($=d_t^t$)

S' indicate specific gravity relative to water at 4°C ($=d_4^t$)

ρ indicate relative density of water at the temperature of the observed substance.

V indicate the reciprocal of S .*

Let different substances be indicated by suffixes which will usually be obvious: in particular

R = the rubber phase in latex

S = serum

L = latex = a mixture of rubber and serum

LM = a mixture of latex and ammonia, etc.

Let x be the weight concentration of rubber in latex = d.r.c. per cent by weight divided by 100, and

„ x' be the weight of rubber in 1 ml. of latex at the temperature of observation.

„ $R = S'_S / S'_R = S_S / S_R$

We will assume that there is no physico-chemical interaction among ingredients of fluids considered in this paper, so that the volume of a mixture is equal to the sum of the volumes of its constituents (that is, we assume that the “law of mixtures” is

* Throughout this paper it is immaterial whether V be taken as $1/S$ or as $1/S'$, provided, of course, that it be defined in the same way throughout any one equation. To avoid confusion it should be noted that specific volume is usually defined as the mass of unit volume, and is equal to the reciprocal of density. It is, for most practical purposes, equal to $V' = 1/S'$, but differs from it in proportion as c.c. differs from ml. By this definition it is not equal to $1/S$, but presumably it might be specifically so defined in a special context, as has been assumed by implication in the use of the term by van Gils (1939).

applicable). The magnitude of errors which may be thus introduced is examined in appendix 1. With this assumption the following formulae may be derived:

$$S_L' = S_s' - (R - 1)x' \quad (1)$$

$$= \frac{S_s'}{1 + (R - 1)x} \quad (2)$$

and

$$S_L = S_s - (R - 1)\rho^{-1}x' \quad (3)$$

$$= \frac{S_s}{1 + (R - 1)x} \quad (4)$$

$$V_L = V_s + (V_R - V_s)x \quad (5)$$

Formulae (1) and (2), or (3) and (4), are, with changes in notation, those presented by de Vries and used by Rhodes (1935) except that de Vries ignored the distinction between (1) and (3). Relative to the accuracy of data at present available differences in numerical value between the two formulae are not important (putting $\rho=1$ in equation (3) at 29°C would lead to underestimating S_k by about 0.0004); but to avoid ambiguity and possible confusion it is advisable to retain the distinction in the formulae; and to avoid bias it should be included in calculations. Equation (5) has been given by van Gils (1939).

Numerical estimates of the constants in these equations have been derived from observed data by the method of least squares (see appendix 2).*

II. Rhodes' Data (Ammoniated Latex)

Rhodes (1934) observed 852 samples of ammoniated latex from commercial tasks on nine estates. The dry-rubber-contents

* Note on statistical terms used:

A *regression* is a curve representing the relationship between two or more variates; it differs from equations of physics or of elementary mathematics in that it implies that observations may deviate from the curve for reasons other than mere experimental error; it is intended to represent the *mean* value of one (the dependent) variate for given values of the others. Readers unfamiliar with the term may, without serious error, replace it in this paper by "the equation representing the relationship between S and x ". The estimated *regression coefficients* are estimates of the constants (or parameters) of the equation.

Standard errors may be interpreted as follows: If the true value of a parameter is β and our estimate of it (termed a "statistic") is b , the difference $|b - \beta|$, ignoring sign, has one chance in twenty (or a probability of .05) of being greater than twice the standard error. If we have two comparable statistics say b and b' , or a statistic b and a hypothetical value β which we think might be its true value, then P is the probability that $|b - b'|$ or $|b - \beta|$ might by chance be greater than the difference observed. Unless P is less than .05 it is not usually considered that we have obtained *significant* evidence against the hypothesis that $b = b'$ (or β).

were fairly evenly distributed from 28 to 50 per cent by weight. Specific gravity was observed at about 29°C relative to water at the same temperature. In his second paper (1935) Rhodes assumed that equation (4) would be applicable to ammoniated as well as to fresh latex and fitted to his data an equation of the form

$$S_{LM} = \frac{a}{1 + bx_m} \quad (6)$$

where a and b are arbitrary constants, and x_m is d.r.c. in gm. rubber per gm. of ammoniated latex. Extrapolating this to $x_m=1$, he took as his estimate of S_R

$$\frac{a}{1 + b} \quad (6a)$$

Observations were made on latex which had been ammoniated by adding, to every 100 ml. of fresh latex, 2.8 ml. of ammonia containing 25 per cent NH_3 by weight. Let v_M be the volume of another fluid mixed with unit volume of latex, the specific gravity of the fluid, M , being S_M . Then for the circumstances of Rhodes observations v_M is a constant and, following out the implications of the law of mixtures as outlined in Section I, we find that equation (6) is indeed still applicable; but whereas b remains the same as in (4), viz. $(R-1)$, we now have:

$$a = \frac{S_S + v_M S_M}{1 + v_M}$$

=the specific gravity of a mixture of v_M ml. of M with 1 ml. of serum.

Equation (6) therefore represents

$$S_{LM} = \frac{S_S + v_M S_M}{(1 + v_M) [1 + (R-1)x_m]} \quad (7)$$

and

$$S_R = \frac{a}{1 + b} + \frac{v_M (S_S - S_M)}{R(1 + v_M)}$$

When the added fluid M is ammonia (S_M at 29°C=0.9060) S_S is greater than S_M , and (6a) would underestimate S_R . (For the conditions of Rhodes' work the error is about 0.003).

Fitting by least squares equation (7) we obtain

$$S_S = 1.0228 \pm 0.000919^*$$

$$S_R = 0.9097 \pm 0.001137^*$$

The estimated standard deviation of single observations about the regression is 0.00376*, but this figure may have been substantially inflated by heterogeneity of the data (see below).

Substituting these statistics in (3) we estimate that the regression of S_L on x' in original fresh latex was

$$a_{29}^{29} = 1.0228 - 0.1248 x' \quad (8)$$

The standard errors of the coefficients are respectively $\pm 0.000919^*$ and $\pm 0.002405^*$.

S_S and S_R are arbitrary constants, estimated by fitting equation (7) to Rhodes' data (Table II, 1934); they can be assumed to be estimates of the specific gravities of the serum and rubber phases only on the hypothesis that equation (7) truly represents the physical relationships, (see Section VI). Their standard errors are estimated from the variation of the data (means of classes of 2 per cent d.r.c.) about the fitted line; they are strictly valid only if variation about the regression can be assumed to be at random. Unfortunately at least two types of systematic errors may be present in Rhodes' data.

(1) Concentrated ammonia solution being rather volatile and difficult to handle, the actual values of v_M and S_M may have deviated systematically from the theoretical values.

(2) The observations on 852 samples from nine estates have been summarised in classes of two per cent d.r.c. Table II (Rhodes, 1934) gives the mean and standard deviation of specific gravities in each class. For heterogeneity of standard deviations about the regression (column 10 of Table II) $\chi^2 = 94.55$, with $n = 10$ (Bartlett, 1937); therefore these standard deviations vary more than can be expected by random sampling. Now samples from each estate are represented in varying proportions in each class, and inspection shows that the five classes which contain samples from estate no. 5 have standard deviations greater than the other six classes. We may therefore presume that, for corresponding values of d.r.c., latices from estate no. 5 differ from others in specific gravity.

The mean square for means of classes about the regression is 0.1415×10^{-4} , whereas the mean variance within classes, also about

* Since the only data now available are the 11 figures given in the published paper, these errors are determined from only 9 degrees of freedom and should be interpreted in conjunction with the table of t (Fisher, 1925-36). For $n = 9$, $t(0.05) = 2.262$, $t(0.01) = 3.250$. The 95 per cent confidence limits of S_R , as determined from these data, are therefore .9072 and .9122.

the regression (not about means of classes), is only 0.0238×10^{-4} . This situation has evidently arisen because means of classes are not independent for reasons given in the preceding paragraph; therefore in these data a comparison of estimates of variance derived from internal and from external consistency (Deming, 1938) is only to be taken as indicating heterogeneity of the data; it does not indicate a poor fit of the regression.

Unfortunately the original data were lost in the fire at the Institute so that variation within and between estates cannot now be evaluated. Owing to the heterogeneity of the data, statistics derived from the extant summary may be biased, and valid estimates of error are not obtainable. From the general configuration of the data we may guess that the average bias is slight; errors of regression coefficients are probably over-estimated.

III. De Vries' Data (Fresh Latex)

The principal data* upon which de Vries' conclusions have been based are presented in *Archief* 3 200-201, Tables IV and V, which give d.r.c. and d_t^t at an average temperature of about 27°C , for two groups of trees in an experimental area on 19 or 20 successive days. Following a resting period the d.r.c. was 40-45 gm. per 100 ml., fell rapidly to below 30, and then more gradually to about 18 gm. per 100 ml. Fitting to these data equation (3) we obtain:—

$$\text{from Table IV : } d_{27}^{27} = 1.0202 - 0.1204 x'; \quad (9)$$

$$S_R = 0.9109 \pm 0.00144; S_S = 1.0202 \pm 0.00069;$$

$$\text{from Table V : } d_{27}^{27} = 1.0218 - 0.1239 x'; \quad (9a)$$

$$S_R = 0.9094 \pm 0.00193; S_S = 1.0218 \pm 0.00071.$$

The mean standard deviation of single observations about the regressions is 0.00078, and the standard errors of the regression coefficients (0.1204 and 0.1239) are 0.00230 and 0.00286 respectively.

These results are in excellent agreement with equation (8) evaluated from Rhodes' data. Comparison of the mean estimates

* Earlier data given by de Vries and others, *Archief* 1 and 2 appear to contain too many samples diluted with water to be of any use for our present purpose.

The values of S_R thus estimated* from data given in Tables III to V (*loc. cit.*) varied inversely with the d.r.c. of the latex from 0.910 to 0.925. They are graphed in fig. 1.

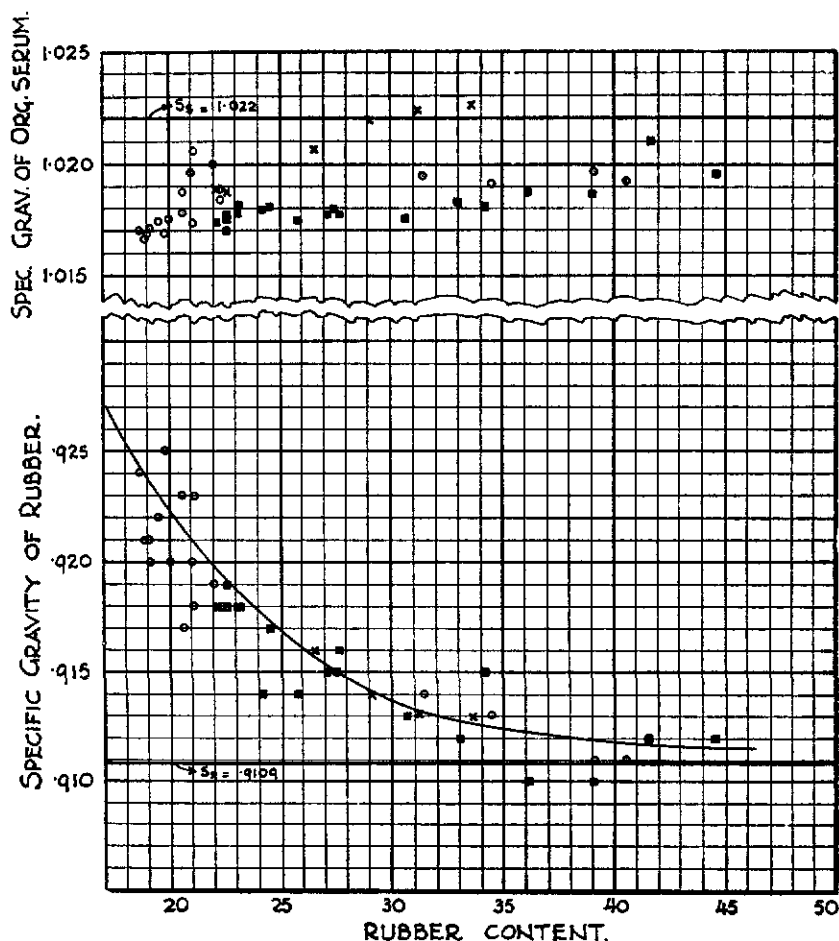


FIG. 1. Relation between specific gravity of Rubber and Serum phases and d.r.c. (gm. per ml.) of latex. Data from de Vries (1919),
 × Table III, ■ Table IV, ○ Table V.

*De Vries assumed that ρ was equal to unity, a not unreasonable approximation in these formulae. At 27-29°C S_R would be underestimated by about 0.0003, S_c would be overestimated by less than 0.00001.

On the hypothesis that S_R tends towards a constant for high values of x' both this asymptotic value and the standard deviation of the observations may be estimated from an equation of the form

$$y = k + (a + bx' + cx'^2)^{-1}$$

A first approximation to the least squares solution is

$$S_R = 0.91092 + (634.68 - 6271.2 x' + 17694 x'^2)^{-1} \quad (12)$$

with standard deviation of observations about the regression = 0.00171; whence the limiting value of S_R for high d.r.c. is estimated to be 0.9109 ± 0.00091 .

The estimates of S_S are also shown in fig. 1, where it can be seen, without the labour of fitting a complex curve, that for high values of x' they tend towards a value somewhere between 1.020 and 1.022.

IV. Other Data

I am indebted to Dr. Rhodes and Mr. Sekar for a further set of unpublished data on latex (other characteristics of which have been published by Rhodes, 1939) from a single small-holding, under the control of the Rubber Research Institute of Malaya. There were 29 observations for 29 tapping days from May to October, 1938. Since all the samples came from the same source variation is small (d.r.c. varied only from 36.5 to 42.3 per cent); consequently errors in the estimates of the constants in which we are interested are relatively high.* These observations (at about 29°C) gave:—

$$S_S = 1.0212 \pm 0.0190$$

$$S_R = 0.9113 \pm 0.0267$$

and standard deviation of S_L about the regression = 0.00363.

Scholz and Klotz (1931b) observed the specific gravities (presumably d'_t at about 29°C) and d.r.c. (per cent by weight) of 91 samples of fresh latex drawn from single trees and from tree groups on one estate in Malaya. D.r.c. varied from 30 to 56 per cent. When evaluating d.r.c. they washed the coagula more thoroughly than is customary (1931a), thus obtaining an estimate of what they term "crepe content." Reading their observations from the published graph (perhaps none too accurately) and fitting equations (3) and (4), we estimate

$$S_S = 1.0228 \pm 0.00172$$

$$S_R = 0.9084 \pm 0.00209$$

* Furthermore, relative to the small range, experimental errors in observing d.r.c. may not here be negligible; by assuming so (see appendix 2) we may overestimate S_R and underestimate S_S .

with standard deviation of observations of S_L about the regression $=0.00209$. These statistics differ by less than their standard errors from the corresponding statistics derived from Rhodes' and from de Vries' data, but even so the slightly lower value for S_R is in accordance with expectation for the "crepe rubber" observed by Scholz and Klotz in contrast to the "crude rubber" observed by Rhodes and de Vries. (Compare results for purified and centrifugal latices, below.)

Stamberger and Schmidt (1937) purified rubber by cataphoresis and investigated the specific gravity of dispersions of this purified rubber in 0.6 per cent ammonia at 18°C. From this they estimated, by extrapolation on a linear regression of density on d.r.c. per cent by weight, that the density of the disperse phase was 0.905. But as we have already seen, this regression is not linear, a fact which can be empirically demonstrated by graphing their data* Fitting an equation of form (5) we obtain

$$V' = 1.0034 + 0.09706 \ x$$

with standard deviation about regression $=0.0036$. This gives $S'_R = 0.9087 \pm 0.00059$ at 18°C. For pure rubber obtained by drying they observed the practically identical value $d_4^{18} = 0.909$. Adjusted by the figures for expansivity of rubber reported by Bekkedahl (1934),† this becomes 0.9045 for d_4^{25} ; it is therefore slightly lighter than rubber purified by chemical methods and observed by McPherson (1932) to have $d_4^{25} = 0.9060$.‡ (See further p. 232 below.)

V. Centrifugal Concentrates‡

Rhodes (1934) and van Gils (1939) have observed the specific gravities of centrifugal concentrates and have derived from the results estimates of S_R by extrapolating regressions of specific gravity on d.r.c. between the skim and concentrate from individual

*The diagram published by the authors does not correctly represent the data given in their Table 1.

† Selected by Wood (1938) as probably the most reliable observations of their class. Purification was by digestion with water at about 190°C, followed by extraction with water and with alcohol, and drying in an atmosphere of inert gas.

‡ By mischance van Gils' paper did not come to my attention until this paper was going to press; the paper by de Vries (1939) was received still later. Consequently the bulk of this section was written after the rest of the paper was already in type. Van Gils gives data for the original ammoniated samples of latex from which the concentrates were derived, but the regression of specific volume on d.r.c. may be suspected of curvature (concave downward, P about 0.06—omitting sample no. 97, whose deviation from the regression is nearly seven times the standard deviation of a single observation). Consequently it is doubtful if the estimate of S_R (viz. 0.9067) by the method of Section II is valid.

parent latices. This procedure would be justified if the serum and rubber phases were homogeneous fluids which could not be centrifugally separated into fractions of different density; but if the serum, or the rubber phase, or both, can be separated into sub-fractions, it is meaningless to extrapolate a regression of specific gravity on d.r.c. beyond the observed values of the skim and concentrates themselves.

For example: Suppose a skim had 15 per cent d.r.c. with $S_s = 1.020$, and the cream had 55 per cent d.r.c. with $S_s = 1.010$, S_R in both being 0.906, extrapolation as described would lead to estimates of specific gravity at 0 and 100 per cent d.r.c. of 1.0222 and 0.8961 respectively.

It cannot be proved, from data at present available, that either the serum or the rubber phase can be separated centrifugally into sub-fractions; but a hypothesis that serum at least can be fractionated enables all the relevant data to be reconciled; whereas a hypothesis that the respective densities of serum and of rubber are equal in both skim and concentrate leads to conflicting estimates of the specific gravities of these phases.

Van Gils apparently assumed that the gravitational settlement of the latex was sufficient to reduce the serum to a homogeneous fluid which would not be further separated; whilst Rhodes apparently assumed that after the deposition of the sludge in the centrifuge, the remaining serum would be homogeneous. It seems unlikely however that separation would be complete in either case, and further separation between the remaining fluids might be anticipated. There may also be differences between the two fractions of the rubber phase, since it is known that the skim tends to have smaller particles which may carry a higher proportion of adsorbed substances.

Ignoring the possible curvature and fitting the reciprocal of equation (6) (again omitting sample 97) we obtain

$$V_{LM} = 0.9777 + 0.1274 x_m \\ \pm 0.00172 \quad \pm 0.00474$$

which may be compared with the corresponding equation derived from Rhodes' data, viz.

$$V_{LM} = 0.9806 + 0.1233 x_m \\ \pm 0.00087 \quad \pm 0.00225$$

Having regard to differences in the ammoniation of the two groups of latex these equations are in good agreement. The difference in slope is 0.0051 ± 0.0052 , where 0.00014 is to be expected; the difference in ordinate at the mean d.r.c. (37 per cent) is 0.0010 ± 0.00027 , where 0.00091 is to be expected. We may assume therefore that van Gils' original samples of latex were similar to those observed in other work reviewed above.

I am grateful to the Director of Research at the Proefstation West-Java, for information on the method of ammoniation used by Dr. van Gils, viz. 20 ml. of 20 per cent "ammonia liquida" per litre of fresh latex.

Rhodes (1934), Table VIII, gives the specific gravities and the d.r.c. of the skim and cream from one parent latex and also for 12 mixtures of these. Since they are mixtures of fluids which had formerly been mechanically separated, they must obey the law of mixtures, and indeed equation (4) fits the observations very closely, the standard deviation of single observations about the fitted regression being only 0.0004. The regression is

$$S = 1.0171 (1 - 0.1280 x)^{-1}$$

and its extrapolated values at $x=0$ and 1 are 1.0171 ± 0.00035 and 0.9017 ± 0.00046 respectively. In view of other evidence it is difficult to accept the latter figure as a likely value for S_R (compare figures derived for a theoretical example above) and there is a *prima facie* case for suspecting that a hypothesis which leads to this as an estimate of S_R may be invalid.

Van Gils' experimental material differed from that of Rhodes in that, before centrifuging, he diluted his latex to five per cent d.r.c. with 0.25 per cent ammonia, whereas Rhodes centrifuged his latex without dilution. In the following discussion "serum" refers to the dispersion medium comprising a mixture of serum and the water resulting from dilution.

Assuming that the reciprocal of the specific gravity of a rubber serum mixture is given by the expression

$$V = V_S + (V_R - V_S)x$$

where x is the d.r.c. of the mixture, van Gils estimated V_R by taking the values of V and of x observed for the skim and concentrate from one parent latex, and solved the two equations thus formed for the two unknowns V_R and V_S . As pointed out above, this assumes that V_S and V_R have the same values in the skim and in the concentrate; and if this assumption is incorrect the consequent error would be in the direction of underestimating V_S and overestimating V_R . We may therefore take van Gils' figure viz. 0.9042 ± 0.00009 , as an estimate of the lower limit for the mean specific gravity of the rubber phases in his concentrates. The corresponding estimate of the mean specific gravity of the sera is 1.0013.

On the other hand if we consider the hypothesis that the specific gravity of serum in a concentrate may be less than that of the serum in the corresponding skim, we cannot then estimate V_R and V_S from existing data, but we can assume that the serum in a concentrate cannot be less dense than water, that is V_S is

not greater than unity; and substituting $V_s = 1$ in the above equation we can obtain estimates of the lower limit of V_R for each concentrate. This procedure gives

$$S_R \leq 0.9052 \pm 0.00016$$

Adjusted for temperature these limits become, at 29°C, 0.9045 and 0.9055. The potential error in van Gils' data is less than in Rhodes' data discussed above, because dilution with water reduces the possible difference of specific gravities of sera in the two fractions even if all serum solids were thrown out with the skim, and because the greater difference in rubber contents between concentrates and skim (51.37 per cent in van Gils' data as compared with 41 per cent in Rhodes' data) reduces the extent to which differences may be exaggerated by extrapolation.

De Vries (1939) has pointed out that S_R as estimated by van Gils for each sample is correlated with the d.r.c. of the original (ammoniated) latex. The regression coefficient of S_R on x_m , in the units adopted throughout this paper is -0.00532 ± 0.00161 , and is highly significant (P less than .01). It appears therefore that the observed rubber content is still contaminated with heavier ancillary substances more or less in proportion to the amount of serum in the original latex.

For van Gils' 23 concentrates the regression of reciprocal of specific gravity on d.r.c. is:

$$V = 0.9973 + 0.1099x \\ \pm 0.0038$$

The slope is greater (although not significantly so) than the mean slope between skims and concentrates (viz. 0.1072).

Rhodes (1934), Table VII, reported specific gravities of 68 Dunlop centrifugal concentrates, for which the regression of the reciprocals on d.r.c. is

$$V = 0.9508 + 0.1821x \\ \pm 0.0142$$

The slope of this regression is substantially steeper than any others reviewed in this paper; and extrapolation to $x=0$ and 1 gives 1.0518 and 0.8827 respectively, figures which cannot be accepted as at all likely for values of S_s and S_R .

The only assumption compatible with these data therefore seems to be that the density of serum and/or of observed rubber

varies with the degree of concentration. In these circumstances no estimate of the specific gravities of the phases can be obtained from a regression among ordinary centrifugal concentrates.

For further research consideration might be given to repeated dilution and centrifuging of samples of latex from different sources. After two or three dilutions it would probably be safe to assume that the disperse medium was homogeneous in both skim and concentrate.

VI. Discussion

In Section III and Fig. 1 we have seen that direct evaluation of the specific gravity of the crude rubber phase in individual samples of latex indicated values of S_R from 0.925 to 0.910 depending on the d.r.c. of the latex. Pending more chemical and physical data to elucidate the reason for this variation, further statistical work on a speculative basis is scarcely worth doing. Meantime for the sake of discussion, let us assume that the specific gravity of the rubber phase may be constant but may seem to vary owing to association with serum solids of greater specific gravity (as was suggested by de Vries, 1935, and is corroborated by observations on purified latex). When estimating S_R in such circumstances, Rhodes' method (by extrapolation of the regression S_L : d.r.c.) would be affected only by the error in the d.r.c. and might either over- or under-estimate S_R depending on the relation between d.r.c. and the amount of serum solids precipitated; De Vries' method would be affected by errors both in d.r.c. and in specific gravity of the serum, overestimates of d.r.c. (x') and underestimates of S_{SA} would both tend to increase the estimate of S_R .

Data at our disposal do not permit a really satisfactory evaluation of average figures for S_S and S_R ; various estimates derived in Sections II to IV are of unequal value, and there is no way of assigning to them rationally determined weights. The work of de Vries (1919), in which the standard deviation of single observations about the regression was only 0.0008, shows that quite few observations can yield accurate figures for any given group of trees. Therefore, if observations be properly planned, it should not be difficult to obtain evidence and quantitative estimates of changes in the regression of S_L on d.r.c. for different estates (or fields), manures, clones, etc. For the solution of problems such as those discussed below the regression coefficients should be evaluated to four decimal places with attention to temperature (appendix 3).

Meantime available data indicate that the relative specific gravity (d_4^t) at 29°C of the "crude rubber" phase* in latex may be about 0.910, of undiluted fresh serum about 1.022. For a purified rubber phase d_{29}^{29} appears to be about 0.9056.

Observations on the specific gravity of solid rubber, adjusted for temperature to give d_{29}^{29} , are as follows (derived from the review by Wood, 1938):—

	Commercial Raw Rubber	Purified Rubber
Selected by Wood as most reliable value	... 0.912	0.9072
Mean of 21 raw and of 5 purified values	... 0.914	0.913
Range of 21 raw and of 5 purified values	... {0.906 {0.929	{0.906 {0.922
Stamberger and Schmidt (see above)	... —	0.9057

These figures indicate specific gravities of both crude and purified rubber about 0.002 greater than our estimates of the more or less corresponding phases in latex. There is no way of telling at present in how far this may be due to differences in the material observed rather than to a change of state. We have shown above (Section IV) that in at least one experiment (Stamberger and Schmidt, 1937) purified rubber had the same density in both dispersed and solid states. It is possible however, although we have no reason to suppose it at all likely, that changes from the natural state in raw latex may already have taken place during purification by cataphoresis.

Within the limits of accuracy of our data the "law of mixtures" appears to be adequate as an empirical rule for estimating the specific gravities of latices of varying concentrations (=mixtures of rubber and serum) and of mixtures of latex with other fluids, such as water, ammonia, and dilute acetic acid solutions. Pending more adequate experimental treatment, the application of this law, along with the above estimates of S_R and of S_S , may enable us to make intelligent estimates on some outstanding problems.

* In a recent paper, de Vries (1939) renews his suggestion (1935) that the rubber content determined after coagulation with acid in the usual way may be called "crepe rubber". However, as indicated in Section IV above, the term "crepe content" was originally put forward by Scholz and Klotz (1931a) to specify a d.r.c. determined after unusually thorough washing of the coagulum, assumed to be somewhat analogous to the extra washing received by crepe as opposed to sheet rubber. In my opinion the term should be restricted to the sense intended by these authors, consequently throughout this paper I have used "crude rubber" to indicate the mixture observed in ordinary routine work.

A. The original object of this investigation was to seek data on which to found a conversion table between d.r.c. per 100 ml. of latex and d.r.c. per cent by weight. Given $S_R = 0.910$ and $S_S = 1.022$ the conversion formula at 29°C is

$$x = \frac{x'}{1.018 - 0.1231 x'}$$

A few typical values are shown in Table I. It must be remembered, however, that this relationship is subject to alteration for varying values of S_R and S_S , and is inapplicable when latex is mixed with an unknown quantity of water. (A somewhat similar table, but with the addition of per cent by volume and based on $S_R = 0.914$, $S_S = 1.020$, has been given by de Vries, 1926).

TABLE I

Table for converting grammes of rubber per 100 ml. to d.r.c. per cent by weight in undiluted latex at 27-29°C.

gms. per 100 ml.	-	15	20	25	30	35	40	45	50
per cent by weight	-	15.01	20.14	25.33	30.58	35.90	41.30	46.75	52.28

B. The main purpose of Rhodes' work was to prepare a table of specific gravities of ammoniated latex. But in estate practice latex is usually ammoniated with gas, whereas Rhodes' samples were treated with ammonia in solution. What may be the effect on specific gravity of these different procedures?

Supposing that the specific gravity of ammonia water may be estimated by the mixing law as a mixture of water with a hypothetical liquid ammonia, and given that the specific gravity of one-per-cent ammonia is $d_4^{29} = 0.9920$, then the specific gravity of the hypothetical liquid ammonia is $d_4^{29} = 0.7113$. For a latex of specific gravity 0.975* the amount of ammonia gas to be added to 1 ml. of latex to give a concentration of 0.5 per cent ammonia would have a hypothetical liquid volume of $0.975 \rho / (199 \times 0.7113) = 0.00686$ ml. Whence, using the values of S_S and S_R given by Rhodes' data, we estimate that in equation (6) (and in the corresponding

*The amount of gas required to produce a given per cent by weight would vary with the specific gravity of the latex. The variation is however negligible, the error thus introduced into estimates of S_{LM} over a range of 20 per cent d.r.c. being only of the order of 0.00005.

equation of form 3) for ammonia "gassed" latex $a = 1.0207$; whereas for the equations fitted direct to Rhodes' data $a = 1.0195$. It seems likely therefore that the increase in specific gravity for latex preserved with gaseous ammonia, over that prepared with concentrated liquid ammonia, will be of the order of 0.0012 when compared on the basis of gms. per 100 mls. (or lb. per gallon) or 0.118 per cent when compared on the basis of per cent of rubber by weight. Pending further direct observations the figures for specific gravity in Rhodes' table should be multiplied by 1.00118 when intended for use with latex ammoniated with gas.

C. We may consider the problem of estimating d.r.c. from specific gravity. The method is chiefly of interest when specific gravity can be determined with a hydrometer; a thing which can be done for undiluted fresh latex only when the d.r.c. is less than 20 to 24 per cent. To overcome this difficulty a latex of higher d.r.c. is commonly diluted with water, and the d.r.c. estimated from the specific gravity of the latex-water mixture.

Unfortunately, despite warnings in the literature, there is still in many quarters a tendency to assume that a "Metrolac," "Simplexometer" or "Latexometer" measures d.r.c. directly. This is incorrect; these instruments can measure nothing except relative specific gravity. If the scale appears to give a reading in terms of d.r.c. this merely means that the figures marked on the instrument incorporate a more or less arbitrary conversion table relating specific gravity to d.r.c. To avoid confusion the real nature of such tests should be kept clearly in mind. Since water and serum differ in specific gravity, there can be no one-to-one correspondence in latex-water mixtures between specific gravity and d.r.c. The point has been fully expounded by de Vries (1919), and he (1917), Hartjens (1918) and Rutgers and Maas (1917) have demonstrated empirically that direct readings from Metrolacs and Latexometers in latex-water mixtures are unreliable.

A modified procedure sometimes used to obtain a latex-water mixture of approximately standard d.r.c., usually 1.5 lb. per gallon, is to adjust a hydrometer (or Metrolac, etc.) to come to rest at a given mark when inserted in a particular latex-water mixture of the required d.r.c. Then on future occasions when a latex is to be diluted to this standard it is mixed with water until the hydrometer stands at the mark. The method will serve well for latex similar to the latex used for calibration. Otherwise it may give results which are appreciably in error as shown in Table II.

TABLE II

Rubber Content of latex used for calibrating hydrometer; gm. p. 100 ml. (=100 x')	Sp. Grav. (d_{28}^{28}) of latex-water mixture having 15 gm. p. 100 ml. (= S_{LW})	Latices containing originally 100 x' gm. p. 100 ml., when mixed with water so that the mixture has a sp. grav. equal to that given in the 2nd column, may be expected to have rubber contents as follows:						
		100 x'						
		25	30	35	40	45	50	55
30	.9925	21.2	15.0	12.4	11.0	10.1	9.5	9.0
35	.9909	25.6*	18.1	15.0	13.3	12.2	11.4	10.9
40	.9897	28.9*	20.5	16.9	15.0	13.8	12.9	12.3

* Impossible cases, water would require to be *withdrawn* from the latex to satisfy the conditions.

As a rough empirical test of these deductions, Mr. Hastings tried out this procedure on eight latices having initial d.r.c.'s of 28—39 per cent. I am indebted to him for the following figures:

d.r.c. of original latex	gm.									
p. 100 ml.	...	...	28.2	28.4	29.5	33.8	34.9	37.9	38.4	38.6
d.r.c. of latex-water mixture										
when Metrolac read 15										
(approx.*) gm. p. 100 ml.	...	—†	—†	—†	15.8	15.1	13.5	13.6	14.1	

* Estimated from readings at nearby concentrations.

† No reading with Metrolac obtainable.

These observations agree well with the above table if the Metrolac used was calibrated in latex of about 35 per cent original d.r.c.

By the methods set forth in this paper the specific gravity of a latex: water mixture may be given by

$$S_{LW} = \frac{1}{1 + d_v} \left\{ d_v + S_s - (R - 1) \rho^{-1} x' \right\} \quad (13)$$

$$= \frac{1}{1 + d_v} \left\{ d_v + \frac{S_s}{1 + (R - 1)x} \right\} \quad (14)$$

$$= \frac{(1 + d_v) S_s}{1 + d_v S_s + (R - 1)x} \quad (15)$$

where d_v = dilution factor measured as $\frac{\text{volume of water}}{\text{volume of latex}}$,

d_w = dilution factor measured as $\frac{\text{weight of water}}{\text{weight of latex}}$,

x' = gm. rubber per ml. latex = lb. per gallon $\times 0.099886$.
(lb. p. gal. = $10.0114x'$).

x = weight of rubber/weight of latex = d.r.c. per cent by weight $\div 100$.

Inserting our estimates of S_R and S_s , and (in 13) the value of ρ_{29} , and re-arranging, we obtain as formulae to estimate d.r.c. from specific gravity at about 29°C:—

$$x' = \frac{1.022 + d_v - (1 + d_v) S_{LW}}{0.1236} \quad (13a)$$

$$x = \frac{1.022 + d_v - (1 + d_v) S_{LW}}{0.1231 [(1 + d_v) S_{LW} - d_v]} \quad (14a)$$

$$= \frac{(1 + d_w) - (.9785 + d_w) S_{LW}}{0.1204 S_{LW}} \quad (15a)$$

Since one volume of latex: two volumes of water ($d_v = 2$) is a dilution commonly used, we give in Table III values of the d.r.c. for varying values of specific gravity at this dilution. Tables for other dilutions can be easily prepared from the above equations.

TABLE III

Estimated relationship between Specific Gravity of fresh latex diluted with twice its volume of water and Dry-Rubber Content of original latex.

Relative Specific Gravity at 29°C. of 1:2 latex- water mixture	Dry-Rubber-Content of original latex	
	lb. per gal.	per cent by weight
0.986	5.185	54.28
0.987	4.942	51.57
0.988	4.699	48.88
0.989	4.456	46.21
0.990	4.213	43.55
0.991	3.970	40.91
0.992	3.727	38.29
0.993	3.484	35.68
0.994	3.241	33.09
0.995	2.998	30.52
0.996	2.754	27.96
0.997	2.511	25.41
0.998	2.268	22.88
0.999	2.025	20.37
1.000	1.782	17.87
1.001	1.539	15.39

Note: lb. p. gall. = gm. p. 100 ml. \times 0.100114
 gm. p. 100 ml. = lb. p. gall. \times 9.9886

Given equal errors in measuring S_{LW} , the error of estimating d.r.c. of the latex-water mixture is independent of the amount of dilution; but errors of estimating d.r.c. of the original latex will be increased in proportion to the dilution of the mixture, since observed values must be multiplied by $(d+1)$.

If workers wish to use specific gravity as a reliable guide to d.r.c. of latex and of latex-water mixtures they need more accurate determinations of S_S and S_R and of their variation with time and place. If (as Rhodes' figures suggest) S_S and S_R are found to vary significantly with locality, but do not change much for any given source of latex over reasonably long periods of time, it would be easy for an estate to ascertain the constants and to prepare tables for its particular conditions.

The accuracy obtainable will depend very much on the accuracy of calibrating hydrometers and on the care with which they are used. Existing instruments and usage apparently leave much to be desired. For example two instruments used by Hartjens (1918) and by de Vries (1917, p. 246) gave readings of specific gravity differing by 0.002; and there is reason to fear that instruments are no more standardised to-day. Temperature "corrections" (for instruments and tables at present in use, cf. p. 247) are greater than 0.0003 per °C, and consequently are often important.

Theoretically a hydrometer scale can be prepared to give direct readings of d.r.c. if used in latex diluted with a fluid having a specific gravity of 1.022. But the technical difficulties of maintaining stocks of such a fluid would probably be troublesome, and on other grounds it is undesirable to have anything except specific gravity (d_4^t) graduations on a hydrometer. In the words of Stott (1923), whose article may be consulted for fuller information on the theory and use of hydrometers: "For very rough work there may sometimes be an advantage in a hydrometer graduated to indicate the property of a liquid in which the user is directly concerned; [but] in most cases the necessity arises sooner or later of using tables of correction in conjunction with the hydrometers. Once this necessity arises, it is equally easy and more satisfactory for all purposes to use a standard type of instrument, graduated to indicate *densities*." A thorough review of the problem, with plans for a revision of instrument scales and tables, should incorporate an investigation of surface tension effects in rubber water mixtures.

When latex has been diluted with unknown amounts of water (e.g. by rain) only a very rough estimate of d.r.c. can be obtained from specific gravity.

Acknowledgement

I wish to express my thanks to Mr. Evan Guest for assistance with the writing of this paper, and to Mr. W. S. Davey for suggestions during revision. Messrs. Ong Yoke Fong and Lee Yoke Heng have assisted with the computations.

Literature Cited

- BARTLETT, M. S. (1937). *J. Roy. Stat. Soc. Suppl.* 4 158
 BEKKEDAHL, N. (1934). *J. Res. Natl. Bur. Standards* 13 411 (also *Rubber Chem Techn.* 8 5)
 DAWSON, T. R. and PORRITT, B. D. (1935). *Rubber: Physical and Chemical Properties* (p. 6) Research Assoc. Brit. Rubber Manufacturers, Croydon
 DEMING, W. EDWARDS (1938). *Some Notes on Least Squares*. U.S.D.A. Graduate School, Washington

- FISHER, R. A. (1925-38). *Statistical Methods for Research Workers*. Oliver and Boyd, Edinburgh
- GILS, G. E. VAN (1939). *Arch. voor de Rubber Cultuur* **23** 130-139
- HARTJENS, J. C. (1918). *Arch. voor de Rubber Cultuur* **2** 261
- International Critical Tables* (1928). McGraw Hill, N. Y.
- MCPHERSON, A. T. (1932). *Bur. Standards J. Res.* **8** 751 (also *Rubber Chem. Techn.* **5** 523)
- RHODES, E. (1934). *J.R.R.I.M.* **5** 234-250
- RHODES, E. (1935). *India Rubber Journ.* **89** 397 (Reprinted *J.R.R.I.M.* **6** 150-160)
- RHODES, E. (1939). *J.R.R.I.M.* **9** 126-141
- RUTGERS, A. A. L. and MAAS, J. G. J. A. (1917). *Arch. v. d. Rubber Cultuur* **1** 289-312
- SCHOLZ, P. and KLOTZ, K. (1931a). *Kautschuk* **7** 66-68
- SCHOLZ, P. and KLOTZ, K. (1931b). *Kautschuk* **7** 142-144
- SCHMIDT, E. and STAMBERGER, P. (1937). *Recueil Intern. Rubber Congr.*, Paris: 42-43 (Abstract: *Rubber Age*, N.Y. **41** 237, also *Rubber Chem. Techn.* **11** 479-481)
- STEVENS, H. P. and STEVENS, W. H. (1935). *India Rubber Journ.* **89** 400-401
- STOTT, V. (1923). "Hydrometers" in *Dictionary of Applied Physics*, **3** 431-444: McMillan, London
- VERNET, G. A. (1910). *Le Caoutchouc et la Gutta Percha* (1910) 4549-54
- VRIES, O. DE (1917). *Arch. v. d. Rubber Cultuur* **1** 242-279
- VRIES, O. DE (1918). *ibid* **2** 241-255 and 437-455
- VRIES, O. DE (1919). *ibid* **3** 183-206
- VRIES, O. DE (1926). *ibid* **10** 18
- VRIES, O. DE (1920). *Estate Rubber* (pp. 15 and 56-62): Batavia
- VRIES, O. DE (1935). *India Rubber Journ.* **89** 343 (Reprinted *J.R.R.I.M.* **6** 143-149)
- VRIES, O. DE (1939). *ibid* **98**: 422-423
- WOOD, L. A. (1938). *Proc. Rubber Techn. Conf.* pp. 933-954: Heffer, Cambridge (also *Rubber Chem. Techn.* **12** 130-149).

Kuala Lumpur,

20th July, 1939.

Revised

28th November, 1939.

APPENDIX I

The "Mixing Law" in Latex Problems

If there be no physical or chemical interaction of two or more substances ($i, j \dots$) when mixed, the specific gravity of a mixture, relative to water at 4°C, must be

$$S'_{ij\dots} = \frac{w_i + w_j + \dots}{v_i + v_j + \dots}$$

where w is measured in grammes and v in millilitres. But if the volume of the mixture is not equal to $v_i + v_j + \dots$, its specific gravity will not conform exactly to this law. We have assumed that the law is valid for mixtures of all substances used in the work discussed, and it is advisable to obtain some idea of the magnitude of errors made by this assumption.

De Vries (1917, p. 248) has presented data to indicate that the assumption is true, within the range of a fairly low experimental error, for mixtures of *latex and water*; and (1919, pp. 189 and 204) for *serum and acetic acid*.

LATEX AND AMMONIA: (i) We assume by hypothesis that ammonia has no influence on the specific gravity of the rubber phase, this being one of the points which require to be tested by observations on fresh and on ammoniated latex. So far as present evidence goes there is no indication that this hypothesis may be untrue. For a critical test however it would be desirable to observe both fresh and ammoniated samples from the same parent latices.

(ii) There is, so far as I know, no data available to test whether or not the law provides a reasonable approximation for mixtures of ammonia with latex regarded in bulk as a homogeneous fluid, or with serum (assuming the hypothesis that the rubber phase may be unaffected). Such data might be obtained along with a critical test of (i) above. Meantime we may note the error which would be made in estimating the specific gravity of one per cent ammonia as a mixture of 1 gm. of 25 per cent ammonia with 24 gm. of water. The following are values for d_4^t :

	Estimated by "mixing law"	True value as given by "Critical Tables"	Difference
at 15°C	0.9952	0.9948	0.0004
„ 20°C	0.9942	0.9939	0.0003
„ 25°C	0.9930	0.993	0.000+

Values of d_4^{29} for solutions from 1 to 30 per cent ammonia, obtained by *extrapolation* from Critical Tables (1928) vol. 3 p. 59, are described by the formula

$$0.99679 - 0.46358x + 0.46526x^2 - 0.48846x^3 \quad (16)$$

where x = proportionate concentration of ammonia by weight. By the "mixing law" for mixtures of 25 per cent ammonia ($d_4^{29} = 0.9023$) with water we would have

$$S_4^{29} = 0.99597 (1 + 0.0041525x)^{-1} \quad (17)$$

(17) is slightly greater than (16) for $x = 0.02$ to 0.25 , slightly less than (16) from 0 to 0.02 . At $x = 0.01$, the difference is 0.00035 ; at $x = 0$, (16) is too high by 0.00082 . Between $x = 0.005$ and 0.01 , the region of especial interest to us, it is not possible with available data to say which equation may be more correct.

There remain for consideration changes caused by precipitation of serum solids by ammonia. I know of no data however to show the effect of these on the specific gravity of latex so long as the precipitates are held in suspension.

In the data discussed in this paper there is no evidence against the mixing law so long as all constituents are retained in the mixture; but when ammoniated latex is clarified by gravitational settlement the specific gravity may be lowered by 0.001 to 0.005 (Rhodes, 1934, Table VI). This will suggest further points for investigation to anyone who may conduct a thorough research on the subject.

APPENDIX 2

Note on Statistical Methods used to fit Regression Lines

Although equations (4) and (2) can be fitted directly to a set of observations, it is much simpler to work with reciprocals of specific gravities and fit the linear equation (5). Consequent changes of weighting are negligible. It is also possible to calculate $r' = xS_L\rho$ and fit (3) or (1), but this method is less desirable because it introduces experimental errors in the observation of specific gravities into both variates.

In all computations we have treated specific gravity (or its reciprocal) as the dependent variate (y), and d.r.c. as the independent variate (x); and have minimised vertical deviations from the fitted curve. Theoretically this means that observations of x have been assumed free from error relative to the error of observations of y .

For theoretically more correct treatment we must recognise two sources of variation: (a) errors of observation, which, although not ascertained, may be of more or less equal magnitude for both variates; and (b) biological variation independent of the average relationship between the two characters. Proper treatment of observational errors (group a) should take account of the error in both variates (see, for example, Edwards Deming, 1938); whereas the treatment of biological variation from the mean curve depends on whether the argument of the investigation calls for the regression of y on x or of x on y . When studying specific gravity for varying d.r.c. the former (as computed) is correct; but when we go on, as in Section VI, to consider the estimation of d.r.c. from specific gravity we should use the regression of x on y .

However, in work here reported the residuals are usually sufficiently small so that the distinction between our more or less false solutions and the correct ones can be assumed to be negligible, or at least to be less than variations which might be introduced by different methods of averaging the findings of different workers, a problem with which we have dealt in an entirely arbitrary manner. In the principal groups of data covering a reasonably wide range of d.r.c. the alternative extreme assumption (that y was entirely free from error) would reduce the estimates of S_R by 0.0002 (Rhodes' data) or 0.0004 (de Vries' data). For Stam-berger and Schmidt's data the alteration would be only 2.4×10^{-5} .

APPENDIX 3

Effect of Temperature on Specific Gravity of Latex

Most writers, reporting data for specific gravity of latex, have failed to indicate the temperature at which observations were taken, and whether specific gravity is referred to water at the same or at some fixed temperature. Among seven text books which quote figures for specific gravity of latex, and sometimes for the rubber and serum phases, I have seen only one* mention of temperature conditions. Some give false information since they quote figures for d_4^t under the title of "density."

*The temperature conditions are however indicated at only two places and the description of hydrometers as "densimeters" might mislead a casual reader, on referring only to individual sections, to assume that specific gravity means d_4^t , whereas in fact no determination of density is ever intended and all references are to d_4^t .

That the temperature conditions are not negligible may be illustrated by the specific gravity of purified rubber (estimated from figures given by Wood, 1938) as follows:—

t	d_4^t	d_1^t
15°C	9121	.9129
30°C	.9030	.9069

Thermal variations of the specific gravity of latex are smaller, being intermediate between those for rubber and for water, but these figures are relevant since debate centres largely around the derivation of estimates for the rubber phase.

The confusion is the more remarkable since workers in latex technology have to deal with both tropical and temperate conditions, and differences between observations at the two places might have been expected to attract attention. As an example of the existing confusion we may instance discussion on the comparison of Rhodes' data with the specific gravity table adopted by the Rubber Trade Association, London (Rhodes, 1934; de Vries, 1935; Stevens and Stevens, 1935). Although Rhodes' table was constructed for d_1^t ($t=29^\circ\text{C}$) and the R.T.A. table, if correct for its purpose, is for $d_{40}^{t'}$ ($t_0=62^\circ\text{F}=16.7^\circ\text{C}$), not one of the three contributors to the discussion noted that the two tables should differ owing to temperature effects, even if there were no other variables as well.†

Almost the only data on the variation of volume (or of density) of latex with temperature seem to be those given by Vernet (1910). Unfortunately he has published only a mean curve for an unspecified number of latices and gives no information on expansivity of latices of varying concentrations except the remark: "The curves which we have been able to obtain with latices of different con-

† If we were to derive from Rhodes' data a table showing the relation between d.r.c. and the specific gravity appropriate for conversions to weight per gallon at 62°F , the resulting figures would differ from Rhodes' table by more than does the R.T.A. table. For example, for 35 per cent d.r.c. the R.T.A. table gives specific gravity 0.977, and Rhodes' table gives $d_{29}^{29} = 0.9772$ from which we would estimate $d_{62^\circ\text{F}}^{62^\circ\text{F}} = 0.979$ (or 0.980 for latex ammoniated with gas). Satisfactory figures for R.T.A. purposes can however only be derived from observations of latex as received in England.

Much of the comparison of different sets of data has centred around estimates of S_R derived from them. But, since correct estimation of S_R by extrapolation of a regression depends on knowledge of the quantity and specific gravity of admixtures in the observed latices, it is useless to estimate this character from an empirical table based on observations for which such conditions are unknown.

centrations do not vary sensibly among themselves." His mean curve indicates that the coefficient of expansivity at 25°C was 0.00055 which, although higher than we might expect, is possible for rich latex. His figures however increase surprisingly with temperature and at 29°C his coefficient of expansivity (0.00075) is greater than that for pure rubber (0.000673; Bekkedahl, 1935). (Vernet's curve shows $\frac{d}{dt} \left(\frac{1}{v} \frac{dv}{dt} \right)^*$ of latex = 50×10^{-6} ; compare 17×10^{-6} for water, and 0.7×10^{-6} for purified rubber.)

Table 2 in Critical Tables 2 p. 255, and Table 14 in Dawson and Porritt (1935), purport to give the "Temperature coefficient of specific gravity of latex" based on data by Hartjens (1918). Actually, these tables are of little use except to illustrate the chaotic state of the subject. The two columns (or rows) are entitled respectively, "Sp. gr. of latex" and "Correction per 1°C." Since the subject of the tables is variation of specific gravity with temperature, a reader might be pardoned if, in the absence of further guidance, he expects different figures for specific gravity to be associated with varying temperatures. But in the first column, specific gravity is really only a secondary character, which is intended to imply "d.r.c. as indicated by specific gravity." A reader might be able to infer this from the preceding table in each book, but only knowledge of the original paper, and acquaintance with the hydrometers which were the immediate subject of discussion, can disclose that specific gravity is defined as d_4^t , t being taken to be constant at about 29°C. The figures under the heading "Correction per 1°C" were originally given as correction for hydrometer readings to estimate d_4^t at the temperature (about 29°C) for which a hydrometer had been graduated.† This however, is not the same as the "temperature coefficient of specific gravity," although it is nearly equal to it if specific gravity be defined as d_4^t . Therefore, in so far as the table has any meaning, its two parts are based on different (and undisclosed) definitions of specific gravity for which (as table IV shows) the temperature coefficients are not at all similar! Finally, since no temperature conditions are stated, there is no warning to readers who may be concerned with room temperatures in a temperate climate, or with high temperatures in some industrial process, that the figures are derived only from observations at tropical room temperatures near 29°C.

*That is rate of change of the coefficient of expansivity with varying temperature.

†Data behind Hartjens' table have not (so far as I can discover) been published, but they appear to be a revision of observations exemplified by de Vries (1917) p. 246. The method of deriving average corrections for varying sp. grav. (or d.r.c.) is not stated.

If a hydrometer, graduated to show d'_t when immersed in a fluid at $t^\circ\text{C}$, reads $u_{t'}$ when used at $t'^\circ\text{C}$, then the true value of $d''_{t'}$ is given by

$$\frac{u_{t'} \rho_t}{\rho_{t'} \left\{ 1 + \alpha (t' - t) \right\}}$$

α being the coefficient of cubical expansion of the material of which the hydrometer is made (Stott, 1923, p. 435). Assuming that all observations were made with glass hydrometers having $\alpha = 26 \times 10^{-6}$, we may use this formula to obtain from Hartjens' hydrometer corrections, estimates of thermal changes in specific gravity for latices of varying concentration. Estimates obtained in this way are shown in rows 3—4 of Table IV. Now it is unlikely that the thermal expansivity of latex of $d_{29}^{29} = 1$ would be as low as water, or that that of latex of $d_{29}^{29} = 0.96$ would be as great as pure rubber. Therefore, pending confirmation, Hartjens' figures must be rejected, on the ground that they show an unreasonably high value for $d^2S'/(dt \cdot dx)$ —that is, rate of change with varying rubber content (x) of rate of change of density with temperature. (Possibly the data have been affected by observation of latices diluted with water to varying degrees, a practice which, according to de Vries, seems to have been common at the time of these observations.)

As an alternative method to obtain some estimate of the variation of specific gravity of latex with temperature, consider latex as a mixture of serum and rubber. By differentiating equations (2), (4) or (5)* with respect to t we obtain the rate of change of the specific gravity of latex with temperature in terms of the rates of change for rubber and serum. Since we have observed that the specific gravity of the rubber phase in latex is equal to that of solid rubber we may assume, as a working hypothesis, that its thermal expansivity is also equal. Unfortunately we have no data on expansivity of serum; presumably it is slightly greater than that of water, so as a first approximation consider — $dS'_s/dt \cong -d\rho/dt$. Estimates of dS_L/dt obtained by this method are given in rows 5 and 6 of Table IV. They agree quite well with the values derived from Hartjens' data for $S_L = 0.98$ to 0.99 (in which range most of Hartjens' observations were probably taken) and are rather more reasonable outside this range. We have therefore adopted these as the best estimates at present obtainable.

* Equations (2), (4) or (5) are here more convenient than (1) and (3) because, for a given latex, d.r.c. per cent by weight is constant independent of temperature, whereas d.r.c. expressed as weight per volume is not independent of temperature. This is a point which seems to be not generally appreciated. The variation is not large, but for some purposes is appreciable. For example, latex of 50 per cent d.r.c. by weight would have about 4.800 lb. p. gall. at 29°C and 4.831 lb. p. gall. at 15°C (or 47.94 and 48.25 gm.p.100 ml. respectively).

TABLE IV

Estimates of thermal variation per °C of the specific gravity of latex around 29°C

1. Estimates from Hartjens' data for hydrometer corrections.					
For latex having $S_{29}^{29} =$	1.00	0.99	0.98	0.97	
(H) $-\delta u_i/\delta t$	0.26	0.34	0.42	0.50×10^{-3}	
(Ha) $-\delta S_4'/\delta t$	0.29	0.36	0.44	0.52	"
(Hb) $-\delta S_i'/\delta t$	(-0.01)	0.07	0.15	0.24	"
2. Estimates from dS'/dt of water and of rubber.					
S_{29}^{29} as above, d.r.c. =	17.9	26.3	34.8	43.6	per cent
(18b) $-dS_4'/dt$	$\cong 0.37$	0.40	0.43	0.46×10^{-3}	
(18c) $-dS_i'/dt$	$\cong 0.07$	0.11	0.14	0.17	"

Notes: In this table and in the following notes we use S with temperature affixes to indicate specific gravity, in place of the standard $d_{t_2}^{t_1}$ in order to avoid confusion with the d of differentials.

Hartjens' data for hydrometer corrections conform to the formula

$$(S_i' - u_{it'}) = (0.00826 - 0.008 S_i') (t' - t) \quad (\text{H})$$

where t , the graduation temperature of the hydrometer, is about 29 to 31°C for instruments used by Hartjens and de Vries. From this we deduce

$$(S_4' - S_4'') = (0.00823 - 0.00794 S_i') (t' - t) \quad (\text{Ha})$$

$$(S_i' - S_i'') = (0.00826 - 0.00827 S_i') (t' - t) \quad (\text{Hb})$$

The general formulae for the thermal coefficient of specific gravity of latex, related to those for serum and rubber phase, are:—

$$\frac{dS_L'}{dt} = \frac{s^2 dr/dt - r^2 ds/dt}{rs(s-r)} S_L' - \frac{sdr/dt - rds/dt}{rs(s-r)} S_1'^2 \quad (18)$$

$$\frac{dS_L}{dt} = \left\{ \frac{s^2 dr/dt - r^2 ds/dt}{rs(s-r)} - \frac{d\rho/dt}{\rho} \right\} S_L - \frac{sdr/dt - rds/dt}{rs(s-r)} \rho S_L^2 \quad (18a)$$

Where r and s are S_i' for rubber and serum respectively (i.e. S_R' and S_S' of former notation). Substituting values for 29°C

(viz. $\rho = 0.99597$, $r = 0.910\rho$, $s = 1.022\rho$,

$dr/dt = -0.000623$, $-ds/dt \cong -d\rho/dt = 0.000295$), the formulae used for estimating values in the above table are:—

$$-dS_L'/dt_{29} \cong (0.00392 - 0.00356 S_L') S_L' = (0.00390 - 0.00353 S_L) S_L \quad (18b)$$

$$-dS_L/dt_{29} \cong (0.00362 - 0.00355 S_L) S_L \quad (18c)$$

Formulae directly in terms of d.r.c. can be most easily obtained by working with specific volumes and differentiating equations of the form of (5).

For variation of S_s and S_R with temperature of observation we have

$$\frac{dS_R}{dt} = \frac{dS'_R/dt - S_R d\rho/dt}{\rho}$$

$$-\frac{dS_s}{dt} = \frac{(S_s - 1) d\rho/dt}{\rho}$$

whence, substituting values for 28°C we obtain expectations quoted on p. 224.

Throughout this paper I have dealt mainly with d_4^t because that is the observation usually made in the East and for which tables have been drawn up. The theory of the subject would, however, be appreciably simpler if we concerned ourselves only with density (or with d_4^t); because the relative density of water (ρ) would no longer require to be considered (compare equations (1) and (3), or (18) and (18a)). Furthermore, temperature corrections for hydrometers (as distinguished from real changes in specific gravity) are smaller for hydrometers graduated to indicate d_4^t than for those graduated d_1^t ; in practice the correction is often negligible (cf. Stott., 1923). For many purposes it is also simpler to deal with specific volume than with specific weight (cf. equation 5).