Issued April 24, 1911.

U. S. DEPARTMENT OF AGRICULTURE,

BUREAU OF ANIMAL INDUSTRY.—BULLETIN 134.

A. D. MELVIN, CHIEF OF BUREAU.

THE ESTIMATION OF TOTAL SOLIDS IN MILK BY THE USE OF FORMULAS.

BY

R. H. SHAW,

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AND

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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Animal Industry,
Washington, D. C., November 26, 1910.

Sir: I have the honor to transmit herewith, and to recommend for publication in the bulletin series of this bureau, a manuscript entitled "The Estimation of Total Solids in Milk by the Use of Formulas," by R. H. Shaw, of the Dairy Division of this bureau, and C. H. Eckles, of the Missouri Agricultural Experiment Station. The experimental work herein described forms a part of the investigations concerning milk which are being conducted at the Missouri station in cooperation with this bureau.

Owing to the necessity for some more rapid method of calculating the solids in milk than the usual laboratory procedure, the estimation of these constituents by means of formulas has been a common dairy practice for some years; and while a certain amount of error was known to exist in such calculations, it was assumed to be small enough to be negligible for most practical purposes. Inasmuch, however, as a number of formulas are in use, each differing slightly in results from the others, it became a question of some importance to determine which of them was the most accurate.

With the object of solving this problem the authors have made searching tests under exacting conditions of several of the best known formulas, and have in addition devised an improved lactometer which, with a table based upon the results of the work described in this bulletin, is believed to furnish a method which is more nearly accurate than any at present in use.

Respectfully,

A. D. Melvin,
Chief of Bureau.

Hon. James Wilson,
Secretary of Agriculture.

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INTRODUCTION.

Various formulas have been in use for a number of years as a means of determining the total solids in milk when the specific gravity and percentage of fat are known. This rapid estimation of the total solids is a useful and convenient method for purposes where exactness is not required. Among the more common uses that have been made of this method is the preliminary examination of market milk by inspectors and the detection of adulterations at cheese factories.

Recently certain organizations representing the dairy breeds of cattle have considered the advisability of reporting the percentage of total solids as well as of fat in making official tests of individual cows. It therefore became a question as to whether the determination of the total solids by means of the formulas and the instruments in common use for finding the specific gravity was feasible and accurate enough.

In view of this question Mr. Ed. H. Webster, then Chief of the Dairy Division of the Bureau of Animal Industry, requested the authors to take up the problem with the view of testing the accuracy of the estimation of total solids by the several formulas in common use and to suggest improvements looking toward greater accuracy in finding the specific gravity without making the determination impracticable for use by such men as usually have charge of official testing.

For the present purpose milk may be regarded as composed of fat and milk plasma, the latter being made up of water and the various milk solids not fat, such as the proteins, sugar, ash, and other solids. Fat, having a specific gravity less than water, has the effect of lowering the specific gravity of milk, while the plasma solids, having a specific gravity greater than water, have the effect of raising it. It is clear, then, that a relation exists between the specific gravity of milk and its percentage of fat and solids not fat. The various formulas for calculating total solids or solids not fat, when the other two factors are given, are based upon this relation.

It is not the purpose of this bulletin to bring out a new formula or to suggest modifications or revisions of those already in use. The main objects of the investigation herein reported were: (1) To compare the percentages of total solids calculated by means of certain formulas in general use with those obtained gravimetrically in the laboratory; (2) to test under more exacting conditions the formula which yields results closest to gravimetrically determined total solids, and (3) to devise a new or modify an existing lactometer with which the specific gravity may be more accurately determined.

The authors desire to acknowledge their indebtedness to A. E. Perkins and G. C. Payne, of the Dairy Division and Missouri Agricultural Experiment Station, for assistance rendered in obtaining the data included in this bulletin.

SYNOPSIS OF FORMULAS IN VOGUE.

Behrend and Morgen [1] published in 1879 the first formula of which there is any record which attempts the calculation of total solids from the specific gravity and the percentage of fat. They were closely followed in the same year by Clausnitzer and A. Mayer,[2] who published another formula. These two formulas were, however, based on inaccurate data and have since been abandoned. Since that time numerous other formulas have been proposed, among them being one by Fleischmann and Morgen.[3] In this formula the specific gravity of butter fat was assumed to be 0.94. This was changed to 0.93 by Fleischmann,[4] and the formula thus revised is still in general use and is one of those compared in this investigation. Hehner's [5] formula appeared in 1882, that of Halenke and Moeslinger [6] in 1886, and that of Hehner and Richmond [7] in 1888. The latter formula was revised in 1894 by Richmond,[8] and the revised form is known as Richmond's new formula. Babcock [9] published his formula in 1891, but changed it four years later.[10]

Comparisons of the various formulas with gravimetrically determined total solids have appeared from time to time. Such comparisons were made in 1889 by Woll,[11] who worked with the Fleischmann and the Hehner and Richmond formulas. In his conclusions, which are in favor of the Fleischmann formula, he states that it may

[1] Journal für Landwirtschaft, Band 27, p. 249. Berlin, 1879.

[2] Forschungen auf dem Gebiete der Vieh-haltung und ihrer Erzeugnisse, p. 265. Bremen, 1879.

[3] Journal für Landwirtschaft, Band 30, p. 293. Berlin, 1882.

[4] Journal für Landwirtschaft, Band 33, p. 251. Berlin, 1885.

[5] Analyst, Vol. VII, p. 129. London, 1882.

[6] Chemiker-Zeitung, Jahrg. 10, semester 1, Chemisches Repertorium, p. 8. Cöthen, 1886.

[7] Analyst, vol. 13, p. 26. London, 1888.

[8] Proceedings of the Eleventh Annual Convention of the Association of Official Agricultural Chemists, Washington, D. C., Aug. 23–25, 1894, United States Department of Agriculture, Bureau of Chemistry, Bulletin 43, p. 181.

[9] Eighth Annual Report of Wisconsin Agricultural Experiment Station, 1891, p. 292. Madison, 1892.

[10] Twelfth Annual Report of Wisconsin Agricultural Experiment Station, 1895, p. 120. Madison, 1896.

[11] Agricultural Science, vol. 3, p. 129. State College, Pa., 1889.

be used to advantage for calculation of total solids if the specific gravity of milk is taken at 15° C.

In the early nineties the Association of Official Agricultural Chemists made some comparisons of the Fleischmann, the Hehner and Richmond, the Babcock (original), and the Richmond formulas. Their results are published in the proceedings of their tenth [1] and eleventh [2] annual conventions, and in commenting on the same they state that the Hehner and Richmond formula gave figures which compared best with those obtained gravimetrically.

EXPERIMENTS TO COMPARE THE ACCURACY OF EXISTING FORMULAS.

In a cooperative experiment between the Missouri Agricultural Experiment Station and the Dairy Division of the Bureau of Animal Industry, United States Department of Agriculture, a study was made of the changes in chemical composition which milk undergoes during the natural period of lactation. Among many other factors the specific gravity and the percentages of fat and total solids were determined under controlled conditions. These determinations were made on 12 animals through one entire lactation period, and on 2 of the animals through two entire lactation periods. Having these data at hand, it became purely a matter of substitution to apply the figures obtained for the specific gravities and the percentages of fat in some of the most frequently used formulas for determining total solids when these two factors are known, and comparing the figures so obtained with the corresponding percentages of total solids determined gravimetrically. As stated in the introduction, several formulas have been published, but perhaps of these the four most used are those derived by Babcock (revised), Hehner and Richmond,[3] Richmond, and Fleischmann. In the general lactation experiment above referred to the samples were taken from the very beginning of the lactation period to the very end of the period, but since the purpose of this investigation is to show the application of various formulas in determining total solids in normal milk, it was thought best to exclude the extremes from the comparisons, and so the figures, except when otherwise stated, refer to milk of normal composition.

The 12 animals used in the investigation included 3 each of 4 breeds—Holstein-Friesian, Jersey, Ayrshire, and Shorthorn. According to the general plan these animals were kept on a uniform ration

[1] Proceedings of the Tenth Annual Convention of the Association of Official Agricultural Chemists, Chicago, Aug. 24-26, 1893. U. S. Department of Agriculture, Bureau of Chemistry, Bulletin 38, p. 107.

[2] Proceedings of the Eleventh Annual Convention of the Association of Official Agricultural Chemists, Washington, D. C., Aug. 23-25, 1894. U. S. Department of Agriculture, Bureau of Chemistry, Bulletin 43, p. 182.

[3] The formula of Hehner and Richmond was compared in the same way as the others, but the results were so nearly identical with those of the Babcock formula that it was thought best to omit them from this bulletin.

throughout the entire milking period in order to eliminate possible changes in the composition of the milk due to feed. This ration consisted of alfalfa hay, three-fifths, the other two-fifths being made up of corn 8 parts, bran 1 part, and oats 1 part. The ratio between the hay and the grain was kept the same at all times. The cows were kept in the barn during the night and in an adjoining lot having no grass or other food during the day. The animals were fed and milked twice daily, at 5 a. m. and 4 p. m. The ration served to keep the animals in good condition, and the production of milk was about typical of the breeds, although not equal to that produced previously by the same animals when opportunity was given to vary the ration and adapt it to the needs of the individual.

METHODS OF CALCULATION AND TERMINOLOGY.

In preparing the mass of calculations involved in this bulletin free use was made of tables prepared by the several authors of the formulas. In calculating and averaging percentages the rule followed was to discard the third decimal figure when it was less than 5, and to increase the second by one when it was 5 or more. This will explain what may appear to be discrepancies in some of the tables.

To be strictly accurate the average of a series of specific-gravity determinations must be made by first converting the result for each determination into terms of specific volume. These figures may then be averaged in the usual manner and the resulting average converted back into terms of specific gravity. The error introduced, however, by simply dividing the sum of the specific gravities by the number of determinations was so very small that the averages given in this bulletin were all made in this way.

In order to avoid confusion, the term "plasma" is employed to designate whole milk minus the fat; "plasma solids" to designate the solids in milk minus the fat; and "total solids" the solids including the fat.

METHOD OF SAMPLING.

The milk was weighed after milking and mixed by pouring it back and forth from one pail into another. A sample of about 1 quart was placed in a glass jar bearing the number of the cow and the number of pounds for that particular milking, and delivered to the laboratory. A certain number of cubic centimeters per pound were then measured out and placed in a covered receptacle to make up a composite sample to represent a week's milk from that particular cow. Formaldehyde was added in the proportion of 1 part to 5,000 to preserve the sample. At the end of the week the composite sample was thoroughly mixed and a subsample taken for chemical analysis.

METHOD OF DETERMINING SPECIFIC GRAVITY AND TOTAL SOLIDS.

The specific gravity of the milk was determined at 15° C. by means of a Westphal balance.

The determinations of fat and total solids were made by the Babcock asbestos method. A woolly asbestos was used in perforated copper cylinders, and the determinations were conducted according to the official method as described in Bulletin 107 (revised) of the Bureau of Chemistry, United States Department of Agriculture.

COMPARISON OF THE FORMULAS WITH GRAVIMETRICALLY DETERMINED RESULTS.[1]

The main table showing the comparisons of the three formulas in the individual cases is found in the appendix. Tables 1, 2, and 3, immediately following, are made up of averages from figures in the main table. No explanation will be needed to show how the various figures are obtained. A study of the tables will show that in the case of every cow, regardless of breed or individuality, the Babcock formula yielded results closest to those obtained by gravimetric determination of the total solids. A comparison of the results obtained by the Babcock formula with the gravimetric results shows that 256, or 59.53 per cent, of the 430 cases agree within 0.25 per cent, and that 389, or 90.46 per cent, agree within 0.5 per cent. Using Richmond's formula in the same way, 360, or 83.7 per cent, of the cases fall within the prescribed limit of 0.5 per cent. Likewise Fleischmann's formula shows 309 cases of agreement, or 71.85 per cent. With the Hehner and Richmond formula, the figures of which are omitted from this publication for reasons previously stated, there was a similar agreement in 387, or 89.99 per cent, of the cases, showing that this formula yields results practically identical with those derived from the Babcock formula.

A study of Table 4 will reveal the fact that the calculated figures from the Babcock formula do not differ from the gravimetric figures in any uniform direction, but that the plus and minus differences nearly counterbalance. That they do nearly counterbalance is shown conclusively in Table 3, where it will be seen that the average figure for the calculated solids for the entire series of comparisons differs only 0.07 per cent from the corresponding average figure determined gravimetrically.

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[1] In some cases in this bulletin the specific gravities are given in terms of Quevenne degrees. These degrees, of course, refer to the arrangement of the scale on the style of the lactometer known as the Quevenne lactometer. Quevenne degrees are converted into specific gravity by dividing by 1,000 and then adding 1 to the quotient. For example, if the Quevenne reading is 32.5 the specific gravity is 1.0325.

TABLE 1.—*Number of instances where the total solids calculated by the Babcock, Richmond, and Fleischmann formulas lie within stated limits of the gravimetrically determined total solids.*

[Number of cases.]

Cow No.	Between 0 and 0.24 per cent.			Between 0.25 and 0.49 per cent.			Between 0.50 and 0.74 per cent.			Between 0.75 and 1 per cent.			Over 1 per cent.		
	Babcock.	Richmond.	Fleischmann.	Babcock.	Richmond.	Fleischmann.	Babcock.	Richmond.	Fleischmann.	Babcock.	Richmond.	Fleischmann.	Babcock.	Richmond.	Fleischmann.
4	20	15	10	4	6	9	1	4	4	....	....	2	....	....	....
99	15	14	10	16	9	7	6	12	11	....	2	9	....	....	....
118	15	18	14	16	11	11	2	4	8	....	....	....	....	....	....
Total for breed	50	47	34	36	26	27	9	20	23	....	2	11	....	....	....
205	30	26	16	12	13	17	3	6	10	1	1	2	1	1	2
206	20	17	16	15	15	12	5	7	7	....	1	5	....	....	....
209	30	26	23	6	10	13	9	6	2	1	3	7	....	1	1
Total for breed	80	69	55	33	38	42	17	19	19	2	5	14	1	2	3
300	12	15	15	11	9	5	3	1	5	....	1	1	....	....	....
300	14	14	8	9	7	9	1	3	6	....	....	1	....	....	....
301	17	14	11	5	9	8	3	2	4	....	....	2	....	....	....
301	23	22	16	12	11	12	1	3	7	1	....	1	....	1	1
302	9	8	4	2	2	6	1	1	1	....	1	1	....	....	....
Total for breed	75	73	54	39	38	40	9	10	23	1	2	6	....	1	1
400	23	21	14	11	10	14	1	3	5	....	1	2	....	....	....
402	21	17	11	7	10	10	1	2	7	....	....	1	....	....	....
403	7	3	3	7	8	5	....	3	6	....	....	....	....	....	....
Total for breed	51	41	28	25	28	29	2	8	18	....	1	3	....	....	....
Total cases	256	230	171	133	130	138	37	57	83	3	10	34	1	3	4

TABLE 2.—*Data of Table 1 expressed in percentages.*

[Per cent of cases.]

Cow No.	Between 0 and 0.24 per cent.			Between 0.25 and 0.49 per cent.			Between 0.50 and 0.74 per cent.			Between 0.75 and 1.00 per cent.			Over 1 per cent.		
	Babcock.	Richmond.	Fleischmann.	Babcock.	Richmond.	Fleischmann.	Babcock.	Richmond.	Fleischmann.	Babcock.	Richmond.	Fleischmann.	Babcock.	Richmond.	Fleischmann.
4	80	60	40	16	24	36	4	16	16	....	....	8	....	....	....
99	40.54	37.84	27.03	43.24	24.32	18.92	16.22	32.43	29.73	....	5.41	24.32	....	....	....
118	45.45	54.55	42.42	48.49	33.34	33.34	6.06	12.12	24.24	....	....	....	....	....	....
Per cent for breed	52.64	49.48	35.80	37.89	27.37	28.41	9.47	21.05	24.21	....	2.10	11.58	....	....	....
205	63.83	55.33	34.04	25.54	27.66	36.16	6.38	12.76	21.27	2.13	2.13	4.26	2.13	2.13	4.26
206	50	42.50	40	37.50	37.50	30	12.50	17.50	17.50	....	2.50	12.50	....	....	....
209	65.21	56.52	50	13.04	21.74	28.26	19.56	13.05	4.35	2.17	6.52	15.22	....	2.17	2.17
Per cent for breed	60.15	51.87	41.35	24.80	28.57	31.51	12.77	14.29	14.29	1.50	3.67	10.52	.75	1.50	2.26
300	46.15	57.69	57.69	42.32	34.61	19.23	11.53	3.85	19.23	....	3.85	3.85	....	....	....
300	58.33	58.34	33.33	37.50	29.17	37.50	4.17	12.50	25	....	....	4.17	....	....	....
301	68	56	44	20	36	32	12	8	16	....	....	8	....	....	....
301	62.16	59.46	43.24	32.44	29.73	32.44	2.70	8.11	18.92	2.70	....	2.70	....	2.70	2.70
302	75	66.68	33.34	16.66	16.66	50	8.34	8.33	8.33	....	8.33	8.33	....	....	....
Per cent for breed	60.49	59.68	43.55	31.46	30.65	32.26	7.26	8.07	18.55	.81	.81	4.84	....	.81	.81
400	65.70	60	40	31.44	28.57	40	2.86	8.57	14.29	....	2.86	5.71	....	....	....
402	72.41	58.62	37.93	24.14	34.48	34.48	3.45	6.90	24.14	....	....	3.45	....	....	....
403	50	21.43	21.43	50	57.14	35.72	....	21.43	42.85	....	....	....	....	....	....
Per cent for breed	65.39	51.29	34.61	32.05	37.18	37.18	2.56	10.26	24.36	....	1.28	3.85	....	....	....
Total per cent	59.53	53.48	39.76	30.93	30.23	32.09	8.60	13.25	19.30	.70	2.32	7.90	.23	.70	.93

TABLE 3.—*Average specific gravity, nitrogen, sugar, fat, and total solids for each cow, each breed, and the total average.*

Cow No.	Specific gravity of milk.	Total nitrogen.	Sugar.	Fat.	Solids not fat.	Total solids—gravimetric.	Total solids—Babcock.	Total solids—Richmond.	Total solids—Fleischmann.
	Degrees.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
4	33.4	0.61	4.79	4.88	9.23	14.19	14.21	14.35	14.47
99	32.9	.53	4.99	4.70	8.95	13.65	13.87	14.02	14.13
118	34.2	.65	4.87	5.39	9.66	15.05	15.02	15.16	15.28
Average for breed	33.5	.60	4.88	4.99	9.28	14.30	14.37	14.51	14.63
205	32.9	.47	5.09	3.23	8.78	11.99	12.10	12.24	12.37
206	29.8	.44	4.25	2.96	7.98	10.94	11	11.16	11.26
209	31.4	.52	4.29	3.09	8.45	11.51	11.54	11.70	11.80
Average for breed	31.4	.48	4.54	3.09	8.40	11.48	11.55	11.70	11.81
300	33.3	.60	4.86	4.20	9.23	13.43	13.38	13.52	13.64
300	31.8	.48	4.84	3.49	8.56	12.05	12.12	12.28	12.39
301	33.1	.54	5.02	4.28	9.11	13.39	13.41	13.54	13.67
301	32.6	.51	5	3.84	8.85	12.72	12.77	12.93	13.04
302	31.7	.55	4.78	4.49	8.77	13.24	13.32	13.48	13.58
Average for breed	32.5	.54	4.90	4.06	8.90	12.96	13	13.15	13.26
400	33.9	.53	5.09	3.86	9.22	13.08	13.12	13.24	13.38
402	33.8	.54	4.97	4.04	9.16	13.20	13.28	13.41	13.55
403	33.2	.49	5.23	3.34	8.79	12.12	12.31	12.49	12.50
Average for breed	33.6	.52	5.10	3.75	9.06	12.80	12.90	13.05	13.14
Total average	32.8	.54	4.86	3.97	8.91	12.89	12.96	13.10	13.21

THE SPECIFIC GRAVITY OF MILK SOLIDS.

Assuming that milk is a mixture of milk plasma and fat, it will be seen at once that if the specific gravities of the fat and of the plasma solids were constant quantities the relation of the specific gravity of the milk, the percentage of fat, and the percentage of plasma solids could be expressed mathematically. From such a mathematical relation it would be but a step to derive a formula for finding any one of these factors when the other two were given.

The specific gravity of butter fat is about 0.93 at 15° C., the variation from this figure in different samples being so slight as to be negligible for all practical purposes. It may then be considered as a constant, and is so treated in the formulas compared in the previous part of this bulletin.

The specific gravity of the plasma solids is not a constant, but varies in different samples of milk. This variation is, however, not a large one, being generally within comparatively narrow limits in normal milk. It is because of these narrow limits that formulas are admissible.

Richmond,[1] working in England, found from the analyses of over 200 samples of milk the average specific gravity of the plasma solids to be 1.616. Fleischmann [2] obtained the figure 1.6007 from the average of a large number of samples from cows in North Germany. The

[1] Richmond's Dairy Chemistry, p. 6. London, 1899.

[2] Fleischmann's Book of the Dairy, p. 33. London, 1896.

latter investigator has published a formula for calculating the specific gravity of the plasma solids when the specific gravity of the milk, the percentage of fat, and the percentage of total solids are known, thus:

$$n=\frac{s\times o\,(t-f)}{100\times o-s\times o\,(100-t)-sf}$$

The values for the specific gravity of plasma solids, the specific gravity of milk, the percentage of total solids, the percentage of fat, and the specific gravity of the fat in this formula are denoted, respectively, by the letters n, s, t, f, and o.

Applying this formula to the average of the 430 determinations given in Tables 1, 2, and 3 it is found that 1.638 is the average specific gravity of the plasma solids.

It has already been noted that the Fleischmann formula gave figures higher than the Richmond, which in turn gave figures higher than the Babcock. Since the average of the total solids determined by the latter agreed very closely with our gravimetrically determined total solids, it may be inferred that if Babcock had given a figure for the specific gravity of plasma solids to correspond with his revised formula, it would have been very close to our figure. It may be seen that the difference between these three formulas is largely due to the difference in the specific gravity of the plasma solids of the milk chosen by the respective investigators to represent the normal.

As previously noted, Babcock's original formula appeared in 1891 and its corrected form in 1895. As it originally stood it was:

$$\text{Plasma solids}=\left(\frac{100\,S-Sf}{100-1.0753\,Sf}-1\right)\times(100-f)\,2.6$$

In the above, S represents the specific gravity and f the percentage of fat. Subsequent to its publication Babcock found the constant, 2.6, too high and changed it to 2.5, so that the formula as it now stands is:

$$\text{Plasma solids}=\left(\frac{100\,S-Sf}{100-1.0753\,Sf}-1\right)\times(100-f)\,2.5$$

This revised form is the one used in the former part of this bulletin.[1] In deriving this formula Babcock assumes that the difference between the specific gravity of water and that of milk plasma is nearly in direct proportion to the solids which the plasma contains,[2] and that if this difference be divided by a constant factor which

[1] With the exception of the introduction of a few intermediate steps and the substitution of the term plasma for serum, the subject-matter showing the derivation of the Babcock formula was taken almost verbatim from his original article, to which reference has already been made. When the revised formula was published no figures for the values of x and a were given. Rather than use his original figures, which are now obsolete, it was thought advisable to use our own figures for the purposes of illustration; hence the factor 2.47 will be found in the resulting formula instead of 2.5.

[2] Dr. Babcock calls attention to the fact that this assumption is not quite correct (see Twelfth Annual Report, Wisconsin Agricultural Experiment Station, p. 121), since if the plasma solids were always of the same composition the specific gravity of the plasma solids and the plasma would change at different rates. This error, he states, is a very small one and is counterbalanced by the variation in the composition of the plasma solids in normal milk.

represents the increase in specific gravity caused by 1 per cent of plasma solids the result will be the percentage of solids in the plasma. If the percentage of solids in the plasma found in this way be multiplied by the percentage of plasma in the milk and the product divided by 100, the result will be the percentage of plasma solids in the milk Let

f = percentage of fat in any milk.
$100-f$ = percentage of plasma in any milk.
S = specific gravity of milk at 60° F.
0.93 = specific gravity of butterfat at 60° F.
x = specific gravity of plasma at 60° F.
a = increase in the specific gravity of the plasma caused by 1 per cent of plasma solids.

Then, I.—

$$\text{Percentage of plasma solids in any milk} = \frac{x-1}{a} \times \frac{100-f}{100}$$

$\frac{100}{S}$ = volume in c. c. of 100 grams of milk.

$\frac{100-f}{x}$ = volume in c. c. of plasma in 100 grams milk.

$\frac{f}{0.93}$ or $1.0753f$ = volume in c. c. of fat in 100 grams milk.

Since the volume of the milk equals the sum of the volumes of fat and plasma, then

$$\frac{100}{S} = \frac{100-f}{x} + 1.0753f$$

Clearing of fractions and reducing

$$100x = 100S - Sf + 1.0753Sfx$$

Transposing and combining

$$x(100 - 1.0753Sf) = 100Sf - Sf$$

$$\text{Or } x = \frac{100S - Sf}{100 - 1.0753Sf}$$

II. By first getting a value for x from a large number of analyses a is found. Subtract 1 from x and divide the remainder by the percentage of solids which the plasma contains. The percentage of solids in the plasma is found by dividing the percentage of plasma solids in the milk by the percentage of plasma $(100-f)$ and multiplying by 100.

The value of a in our work is 0.004044.

Substituting the value of x and a in I.

$$\frac{\frac{100S - Sf}{100 - 1.0753Sf} - 1}{.004044} \times \frac{100-f}{100}$$

then

$$\left(\frac{100S - Sf}{100 - 1.0753Sf} - 1\right) \times (100 - f) \times 2.4703 = \text{percentage of plasma solids in the milk.}$$

The percentage of total solids is found by adding the percentage of fat to the percentage of plasma solids.

It will readily be seen that Babcock's value of representing the increase in specific gravity of the plasma caused by 1 per cent of the plasma solids depends directly upon the specific gravity of the plasma solids. This is a common point of weakness in all formulas derived for the same purpose.

Since the plasma solids are composed of several solids, chief of which are milk sugar, proteins, and ash, the specific gravity of the plasma solids must depend upon the specific gravity of the various components taken individually. Richmond [1] states that the specific gravity of milk sugar is 1.666, that of the proteins 1.346, and that of the ash 4.12. A change in the ratio of the milk sugar and the proteins will affect the specific gravity of the plasma solids and consequently the value of *a*. With a milk containing an abnormally high percentage of sugar the total solids calculated by the formulas would be theoretically too high. They would be too low under the reverse condition.

This is very well shown in the table below, the results in which are obtained from milk of a cow of the Shorthorn breed at the parturition period. As is well known, the milk taken at this time is abnormally high in proteins, while the milk sugar is abnormally low. The cow freshened on the morning of October 23.

TABLE 4.—*Showing application of the Babcock formula to colostrum milk.*

Date.	Total nitrogen.	Fat.	Sugar.	Total solids.	
				Gravimetric.	Babcock formula.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Oct. 23—a. m.	2.26	1.30	2.65	22.22	12.86
Oct. 24—a. m.	1.24	3.26	3.81	15.78	12.55
Oct. 24—p. m.	1.09	4.57	4.41	16.53	14.06
Oct. 25—a. m.	.98	5.42	4.89	17.19	15.04
Oct. 25—p. m.	.93	5.08	4.63	16.34	14.67
Oct. 26—a. m.	.87	6.23	4.79	17.04	16.01
Oct. 26—p. m.	.82	5.35	5.40	16.06	14.88
Oct. 27—a. m.	.79	5.87	5.53	16.85	15.53
Oct. 27—p. m.	.73	5.60	4.96	15.26	15.18

Table 5 was prepared from averages given in Table 3. The specific gravity of the plasma and the increase in specific gravity of the plasma caused by 1 per cent of plasma solids (Babcock's value *a*) were calculated by means of the Babcock formula. The specific gravity of the plasma solids was calculated by the formula of Fleischmann, to which reference has already been made. The last column of figures shows the factor which would result in each case were our figures for the value of *a* substituted for Babcock's in his formula.

[1] Richmond's Dairy Chemistry, p. 65.

TABLE 5.—*Average data for each breed of cows.*

Breed.	Number of analyses.	Average specific gravity of milk.	Average fat content.	Average total solids.	Average specific gravity of plasma.	Average specific gravity of plasma solids.	Average value for *a*.	Factor.
			Per cent.	*Per cent.*				
Jersey	95	1.0335	4.99	14.30	1.03958	1.648	0.004052	2.468
Holstein	133	1.0314	3.09	11.48	1.03500	1.624	.004038	2.477
Ayrshire	124	1.0325	4.06	12.97	1.03734	1.637	.004025	2.485
Shorthorn	78	1.0336	3.75	12.80	1.03811	1.650	.004049	2.469
All breeds	430	1.0328	3.97	12.89	1.03752	1.638	.004044	2.470

It will be noted that there is no great variation in the figures in the last three columns, and also that the factor is but slightly different from Babcock's 2.5. This would, of course, follow from the close agreement between the grand average figures for the gravimetric total solids and that calculated by the Babcock formula.

EXPERIMENTS TO DETERMINE ACCURACY OF LACTOMETERS.

Having found which formula was best adapted for the purpose, the next question which naturally suggests itself is whether the ordinary lactometer when used to determine the specific gravity of milk is sufficiently accurate.

Thirteen lactometers were available for comparison; 11 of these were Quevenne lactometers and 2 were of the type known as the New York Board of Health lactometer. These were thought to represent fairly well the ordinary lactometers on the market. They were compared with the Westphal balance on three different samples of milk, with the following results:

TABLE 6.—*Showing comparisons of various lactometers with Westphal balance.*

Instrument.	Specific gravity of milk samples.			Instrument.	Specific gravity of milk samples.		
	Skim milk.	Holstein.	Holstein fresh.		Skim milk.	Holstein.	Holstein fresh.
Quevenne lactometer 1	1.0345	1.0315	1.0325	Quevenne lactometer 9	1.0350	1.0320	1.0330
Quevenne lactometer 2	1.0340	1.0310	1.0320	Quevenne lactometer 10	1.0335	1.0310	1.0318
Quevenne lactometer 3	1.0340	1.0315	1.0325	Quevenne lactometer 11	1.0350	1.0320	1.0330
Quevenne lactometer 4	1.0335	1.0300	1.0320	New York Board of Health lactometer 1	1.0328	1.0307	1.0319
Quevenne lactometer 5	1.0330	1.0300	1.0315	New York Board of Health lactometer 2	1.0299	1.0281	1.0290
Quevenne lactometer 6	1.0340	1.0310	1.0325	Westphal balance	1.0345	1.0313	1.0325
Quevenne lactometer 7	1.0360	1.0330	1.0340				
Quevenne lactometer 8	1.0370	1.0335	1.0350				

A glance at the foregoing figures will show discrepancies which are sufficient in some cases to account for as much as 1 per cent of total solids calculated from the Babcock formula. Of course, much of the discrepancy is due to the fault of the manufacturer in not properly calibrating the instruments. However, in none of the lactometers tested was the scale divided into less than whole Quevenne degrees. Fractions of degrees could be read only by interpolation, and then the divisions were generally so narrow that a closer interpolation than one-half of a degree was impossible; in fact, in some cases it was hardly possible to read closer than whole degrees. One Quevenne degree with a Babcock formula will account for 0.25 per cent of total solids. It is therefore obvious that the ordinary lactometer is unsuited for other than very gross results.

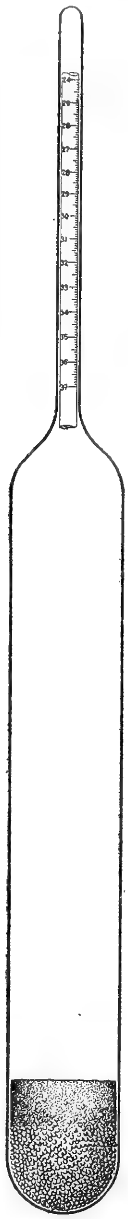

FIG. 1.—Lactometer designed for use in experimental work.

The sensitiveness of the hydrometer, or lactometer, as it is termed when made for the special purpose of determining the specific gravity of milk, depends upon the ratio of the size of the bulb to the diameter of the stem. The larger the bulb is in proportion to the diameter of the stem, the more sensitive will be the lactometer, or, in other words, the longer will be the spaces representing units on the scale. A lactometer, then, may be made more sensitive by either diminishing the size of the stem or by enlarging the bulb. But the smaller the stem the more fragile is the instrument, and the larger the bulb, the more cumbersome.

In designing a lactometer for our work several points were taken into account: (1) That it should accommodate the usual ranges of normal milk; (2) that it should have scale divisions representing tenths of Quevenne degrees; and (3) that it must be neither too fragile nor too cumbersome for practical use outside of a chemical laboratory.

After considerable experimenting in the laboratory the dimensions of an instrument were decided upon and several were made to order from our specifications. (See fig. 1.)

In order to test these lactometers against the Westphal balance, salt solutions were used, and the following results were obtained:

TABLE 7.—*Comparison of new lactometers with Westphal balance, using salt solutions.*

Solution.	Westphal.	Lactometer I.	Lactometer II.
I	1.0245	1.0248	1.0248
II	1.0283	1.0287	1.0287
III	1.0315	1.0318	1.0319
IV	1.0352	1.0351	1.0352

Little comment is required on the above figures, as it is seen that the results obtained with the lactometers are practically identical with those of the Westphal balance.

TESTS OF BABCOCK FORMULA AND NEW LACTOMETER WITH INDIVIDUAL MILKINGS.

Since the figures given in the first part of this bulletin were all based on results obtained on composite samples from individual cows, it was deemed desirable at this point to test the Babcock formula on milk from individual milkings and at the same time to compare the figures obtained by the new lactometers and the Westphal balance on the same milk. The only change in the laboratory procedure was that the percentage of fat was obtained by the Babcock test instead of by the extraction method.

Four cows were selected with which to make the tests under conditions comparable with those found in making official tests of dairy cattle. For this purpose pure-bred cows were used, representing four breeds. These cows were milked and fed three times daily—at 5 a. m., 1 p. m., and 8 p. m. The animals remained in the barn the greater part of the time. They were allowed the freedom of a lot from two to four hours in the forenoon and from one to two hours in the afternoon. Each animal was fed according to her individual capacity and characteristics. The cows were on official test at the time these samples were secured and were receiving such treatment as, in the judgment of the herdsman, would give the best results for this purpose. The rations consisted of corn, silage, alfalfa hay, corn meal, bran, oats, and oil meal in somewhat varying proportions. Table 8 gives more specific data regarding the four cows used. The duration of the test was seven days, the average yields of milk and of butter fat for this period being as follows:

TABLE 8.—*Milking records of cows used in tests.*

No. of Cow.	Breed.	Days in milk.	Average yield of milk per day.	Average yield of fat per day.
			Pounds.	*Pounds.*
16	Jersey	367	10.9	0.57
204	Holstein	119	16.7	.57
300	Ayrshire	20	13.7	.53
401	Shorthorn	258	10.5	.43

The results of the work on the individual milkings from the cows described in the above table are found in Tables 9, 10, 11, and 12, next following.

TABLE 9.—*Lactometer results on individual milkings from Holstein-Friesian cow No. 204.*

Sample No.	Specific gravity—			Fat.	Percentage of total solids—			
	Westphal balance.	Lactometer I.	Lactometer II.		Gravimetric.	Westphal.	Lactometer I.	Lactometer II.
				Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
L1	1.0310	1.0321	1.0320	2.9	11.59	11.23	11.52	11.49
L2	1.0320	1.0326	1.0324	3.2	12.26	11.85	12	11.95
L3	1.0315	1.0315	1.0312	4.3	12.93	13.05	13.05	12.97
L4	1.0308	1.0312	1.0310	3.5	11.91	11.91	12.01	11.96
L5	1.0317	1.0319	1.0317	2.9	11.57	11.41	11.46	11.41
L6	1.0316	1.0320	1.0318	3.8	12.72	12.47	12.57	12.52
L7	1.0336	1.0335	1.0336	3.4	12.70	12.49	12.47	12.49
L8	1.0321	1.0323	1.0324	3.3	12.23	12	12.05	12.07
L9	1.0299	1.0300	1.0301	3.5	12.32	11.69	11.71	11.74
L10	1.0320	1.0325	1.0322	3.5	12.26	12.21	12.34	12.26
L11	1.0341	1.0337	1.0335	2.93	11.95	12.08	11.98	11.93
L12	1.0318	1.0316	1.0314	4	12.62	12.76	12.71	12.66
L13	1.0318	1.0320	1.0320	3.3	12.07	11.92	11.97	11.97
L14	1.0327	1.0322	1.0322	2.75	11.39	11.49	11.36	11.36
L15	1.0303	1.0298	1.0298	4.2	12.84	12.63	12.50	12.50
L16	1.0304	1.0312	1.0308	4.23	13.17	12.71	12.91	12.81
L17	1.0327	1.0324	1.0322	2.8	11.59	11.55	11.47	11.42
L18	1.0312	1.0312	1.0309	3.95	12.60	12.55	12.55	12.48
L19	1.0313	1.0320	1.0317	3.70	12.61	12.28	12.45	12.38
L20	1.0313	1.0321	1.0319	3.35	12.07	11.86	12.08	12.01
L21	1.0310	1.0317	1.0317	3.78	12.44	12.32	12.50	12.50

TABLE 10.—*Lactometer results on individual milkings from Jersey cow No. 16.*

Sample No.	Specific gravity—			Fat.	Percentage of total solids—			
	Westphal balance.	Lactometer I.	Lactometer II.		Gravimetric.	Westphal.	Lactometer I.	Lactometer II.
				Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
L22	1.0325	1.0329	1.0327	5.2	14.92	14.39	14.49	14.44
L23	1.0346	1.0348	1.0348	5.1	14.97	14.79	14.84	14.84
L24	1.0325	1.0330	1.0329	5.6	15.45	14.88	15	14.98
L25	1.0342	1.0347	1.0347	4.88	14.65	14.45	14.58	14.58
L26	1.0346	1.0350	1.0348	4.6	14.38	14.19	14.30	14.24
L27	1.0333	1.0335	1.0333	5.18	14.89	14.59	14.64	14.59
L28	1.0340	1.0351	1.0349	5.25	15.25	14.82	15.11	15.05
L29	1.0332	1.0338	1.0336	5.20	14.56	14.56	14.71	14.66
L30	1.0327	1.0333	1.0333	5.68	15.33	15.05	15.20	15.20
L31	1.0345	1.0348	1.0349	5.40	15.28	15.14	15.21	15.24
L32	1.0355	1.0357	1.0355	5	14.85	14.91	14.96	14.91
L33	1.0344	1.0348	1.0346	5	14.87	14.62	14.72	14.67
L34	1.0340	1.0342	1.0341	5.23	14.86	14.82	14.87	14.85
L35	1.0350	1.0350	1.0348	4.93	14.62	14.72	14.72	14.66
L36	1.0330	1.0333	1.0330	5.75	15.50	15.18	15.26	15.18
L37	1.0351	1.0354	1.0354	5.15	14.93	14.99	15.06	15.06
L38	1.0343	1.0347	1.0346	5.25	15.09	14.90	15	14.97
L39	1.0332	1.0333	1.0335	5.55	15.20	14.99	15.02	15.07
L40	1.0351	1.0345	1.0344	5.20	15.19	15.05	14.89	14.86
L41	1.0354	1.0347	1.0346	5.25	15.26	15.18	15	14.97
L42	1.0333	1.0333	1.0333	5.30	15.59	14.71	14.71	14.71

TABLE 11.—*Lactometer results on individual milkings from Shorthorn cow No. 401.*

Sample No.	Specific gravity—			Fat.	Percentage of total solids—			
	Westphal balance.	Lactometer I.	Lactometer II.		Gravimetric.	Westphal.	Lactometer I.	Lactometer II.
				Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
L43	1.0340	1.0342	1.0342	3.8	13.44	13.08	13.13	13.13
L44	1.0344	1.0345	1.0344	3.65	13.22	13	13.03	13
L45	1.0340	1.0342	1.0342	4.5	14.43	13.92	13.97	13.97
L46	1.0350	1.0352	1.0351	3.9	13.80	13.45	13.50	13.48
L47	1.0352	1.0354	1.0353	3	12.76	12.41	12.46	12.44
L48	1.0340	1.0343	1.0342	4.4	14.29	13.80	13.88	13.85
L49	1.0344	1.0348	1.0347	4	13.54	13.42	13.52	13.50
L50	1.0357	1.0363	1.0363	3.7	13.82	13.39	13.54	13.54
L51	1.0335	1.0337	1.0336	4.8	14.31	14.16	14.21	14.18
L52	1.0308	1.0316	1.0317	3.55	11.92	11.97	12.17	12.20
L53	1.0355	1.0360	1.0360	2.95	12.67	12.43	12.55	12.55
L54	1.0344	1.0351	1.0349	4.45	13.59	13.96	14.15	14.09
L55	1.0347	1.0348	1.0345	4.50	14.14	14.10	14.12	14.05
L56	1.0349	1.0352	1.0350	4.45	13.92	14.09	14.17	14.12
L57	1.0337	1.0339	1.0338	5	14.48	14.46	14.49	14.47
L58	1.0335	1.0339	1.0338	4.65	14.23	13.98	14.07	14.05
L59	1.0350	1.0355	1.0354	3.60	12.73	13.09	13.22	13.19
L60	1.0362	1.0360	1.0359	4.60	14.56	14.60	14.55	14.52
L61	1.0355	1.0359	1.0360	4.40	14.37	14.19	14.28	14.31
L62	1.0358	1.0363	1.0364	4.15	14.04	13.96	14.09	14.11
L63	1.0344	1.0351	1.0349	4.30	14.	13.78	13.97	13.91

TABLE 12.—*Lactometer results on individual milkings from Ayrshire cow No. 300.*

Sample No.	Specific gravity—			Fat.	Percentage of total solids—			
	Westphal balance.	Lactometer I.	Lactometer II.		Gravimetric.	Westphal.	Lactometer I.	Lactometer II.
				Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
L64	1.0320	1.0327	1.0325	3	11.52	11.61	11.79	11.74
L65	1.0300	1.0303	1.0301	5.10	13.38	13.63	13.71	13.66
L66	1.0322	1.0323	1.0321	2.50	10.79	11.05	11.08	11.03
L67	1.0325	1.0327	1.0327	4.05	12.99	13	13.06	13.06
L68	1.0326	1.0331	1.0328	2.65	11.21	11.33	11.47	11.38
L69	1.0304	1.0310	1.0308	4.25	12.40	12.71	12.86	12.75
L70	1.0315	1.0315	1.0313	2.75	11.01	11.18	11.18	11.13
L71	1.0317	1.0323	1.0322	3.10	11.72	11.66	11.81	11.78
L72	1.0313	1.0309	1.0305	3.15	11.45	11.62	11.51	11.42
L73	1.0295	1.0294	1.0294	5	13.42	13.39	13.36	13.36
L74	1.0308	1.0310	1.0308	3.25	11.53	11.61	11.66	11.61
L75	1.0320	1.0322	1.0319	4.25	13.41	13.12	13.17	13.09
L76	1.0315	1.0317	1.0316	4.90	13.61	13.77	13.82	13.79
L77	1.0327	1.0327	1.0327	3.80	12.49	12.75	12.75	12.75
L78	1.0320	1.0322	1.0320	4.90	13.67	13.90	13.95	13.90
L79	1.0322	1.0324	1.0322	4.50	13.54	13.47	13.52	13.47
L80	1.0326	1.0329	1.0326	3.75	12.06	12.66	12.74	12.66
L81	1.0295	1.0290	1.0287	4.75	12.48	13.09	12.96	12.89
L82	1.0330	1.0328	1.0328	3.30	12.	12.22	12.17	12.17
L83	1.0296	1.0298	1.0297	4.25	12.51	12.51	12.56	12.54
L84	1.0278	1.0280	1.0278	5.40	13.15	13.44	13.49	13.44

EFFECT OF TEMPERATURE ON SPECIFIC GRAVITY OF MILK.

An increase in temperature is accompanied by a lowering of the specific gravity as determined by the lactometer. To show the importance of maintaining the proper temperature when using the lactometer and at the same time to determine the size of the error introduced by the difference of a few degrees in temperature, specific gravity determinations were made at different temperatures on several samples of milk. Only ordinary precautions were taken in this experiment, and the results are about such as would be obtained were the lactometers in practical use.

Samples of milk were taken from representatives of the four breeds of cows previously used.

TABLE 13.—*Effect of temperature on specific gravity of milk when determined with new lactometer.*

Temperatures.	Jersey milk.		Shorthorn milk.		Ayrshire milk.		Holstein-Friesian milk.	
	Specific gravity.	Difference.	Specific gravity.	Difference.	Specific gravity.	Difference.	Specific gravity.	Difference.
9° C	1.0364		1.0365		1.0330		1.0291	
11° C	1.0360	0.0004	1.0361	0.0004	1.0327	0.0003	1.0287	0.0004
13° C	1.0356	.0004	1.0357	.0004	1.0323	.0004	1.0283	.0004
15° C	1.0351	.0005	1.0352	.0005	1.0318	.0005	1.0279	.0004
17° C	1.0345	.0006	1.0347	.0005	1.0313	.0005	1.0275	.0004
19° C	1.0338	.0007	1.0341	.0006	1.0308	.0005	1.0270	.0005
21° C	1.0331	.0007	1.0335	.0006	1.0302	.0006	1.0265	.0005
Average		.0006		.0005		.0005		.0004

TABLE 14.—*Showing composition of milk used in Table 13.*

Milk.	Fat.	Total solids.
	Per cent.	*Per cent.*
Jersey	5.2	15.21
Shorthorn	4	13.78
Ayrshire	3.7	12.28
Holstein-Friesian	2.7	10.02

It will at once be seen that the variation is different in different samples and also at different temperatures with the same sample. The greatest variation is in the Jersey, milk where the percentage of total solids is highest, and least in the Holstein-Friesian milk, where the percentage of total solids is lowest. As the temperature rises the variation for each degree increases.

The average variation per centigrade degree counting all four breeds, is 0.00025, which would account for an error of about 0.08 per cent total solids if calculated with the Babcock formula. Reduced to Fahrenheit degrees the error would be five-ninths of 0.08, or about 0.044 per cent for each degree.

RECKNAGEL'S PHENOMENON.

Milk when freshly drawn contains numerous bubbles of gas, and it is not until these have disappeared that the specific gravity can be determined. It has been demonstrated by Recknagel[1] and con-

[1] Milchzeitung, Band 12, p. 419, Bremen, 1883.

firmed by other investigators that the specific gravity of milk changes on standing. On taking the specific gravity of milk after the air bubbles had escaped and again several hours later he found an increase. This peculiarity is called the Recknagel phenomenon. He ascribes the increase to a change in the volume of the proteins. The increase begins two or three hours after milking, and if the milk is held at about 15° C. continues with decreasing rapidity for two days. The amount of the increase is between 0.0008 and 0.0015, depending on the richness of the milk. This change is accelerated by lower temperatures, and the normal specific gravity, or the point where no further change takes place, may be obtained by keeping the milk at 5° C. or lower for six hours.

HOW TO USE THE MODIFIED LACTOMETER AND TABLE.

This section is designed to assist those who may desire to make use of the modified lactometer described in the preceding section and who are not accustomed to using delicate lactometers.

Materials required: 1. The lactometer. 2. A pan of warm water. 3. An accurate dairy thermometer. 4. A suitable cylinder to contain the sample while making the reading.

The cylinder may be made of tin or copper and should have the following dimensions: Inside diameter, 1¾ inches; height, 13 inches. To prevent it from tipping over it should have a base of the same material about 2¾ inches in diameter.

METHOD.

Immediately after milking the milk should be thoroughly mixed and a sample of about 1 pint placed in a cream bottle. This should then be put into the refrigerator and kept there for ten or twelve hours, or until the next milking. It is then removed from the refrigerator and again well mixed by pouring back and forth several times from the bottle into another bottle or cup. At this point care must be taken not to mix air with the milk. This can be avoided by pouring against the sides of the receptacle to prevent foaming. After mixing, the bottle is placed in a pan of warm water and heated while being constantly stirred with the thermometer until the temperature reaches 60° F. The milk is then poured into the cylinder, which should also have been warmed in the pan so that it will not cool the milk. The lactometer is now quickly lowered into the milk, of which there should be a sufficient quantity in the cylinder to overflow it, and allowed to come to rest. The point on the graduated scale which is at the same level as the surface of the milk is then read. This reading gives Quevenne degrees, which may be converted into specific gravity if desired by dividing by 1,000 and then adding 1 to the quotient.

Owing to the tendency of the milk to form a meniscus about the stem of the lactometer, it is impossible to read directly the exact point on the scale that is at the same level as the surface of the milk. A safe rule for obtaining a very close approximation to the correct figure is to add 0.2 to the reading taken where the top of the meniscus strikes the scale. For example, if the scale reads 31.8 at the top of the meniscus, the corrected reading in Quevenne degrees would be 32 and the specific gravity 1.032.

Care must be taken that the temperature of the milk when the lactometer is read is exactly 60° F.; otherwise a very considerable error will be introduced. After using the lactometer it should be rinsed in clean water, wiped dry, and restored to its case.

The percentage of fat should be determined by the Babcock test either on the sample used for the specific gravity determination or on another taken at the same time.

Having by this procedure found the specific gravity of the milk and the percentage of fat, the total solids can be found by referring to Table 15, which is a modified form of one published by Babcock.[1] In our table the percentage of total solids is given. If percentage of plasma solids is wanted, it can be found by subtracting the percentage of fat from the percentage of total solids.

DIRECTIONS FOR USING THE TABLE.

If the specific gravity as expressed in Quevenne degrees is a whole number, the percentage of total solids is found at the intersection of the vertical column headed by this number with the horizontal column corresponding to the percentage of fat.

If the specific gravity as expressed in Quevenne degrees is a whole number and a decimal, the percentage of total solids corresponding to the whole number is first found and to this is added the fraction found opposite the tenth under "Proportional parts." Two examples may suffice for illustration: (1) Fat, 3.8 per cent; specific gravity, 32. Under column headed 32 we find 12.57 per cent, corresponding to 3.8 per cent fat. (2) Fat, 3.8 per cent; specific gravity, 32.5. The percentage of total solids corresponding to this percentage of fat and a specific gravity of 32 is 12.57. Under "Proportional parts" the fraction 0.13 appears opposite 0.5. This added to 12.57 makes 12.70, which is the desired percentage.

An inspection of the table shows that the percentage of total solids increases practically at the rate of 0.25 for each lactometer degree and 1.2 for each per cent of fat. This gives rise to Babcock's simpler formula

$$\text{Total solids} = \tfrac{1}{4} L + 1.2 f$$

(L = lactometer reading in Quevenne degrees, and f = percentage fat).

[1] Twelfth Annual Report of the Wisconsin Agricultural Experiment Station, p. 124.

This simple formula can be used in cases not provided for in the table, and the error introduced will be inconsiderable.

TABLE 15.—*Table for determining total solids in milk from any given specific gravity and percentage of fat.*

Percentage of fat.	Lactometer reading at 60° F. (Quevenne degrees).										
	26	27	28	29	30	31	32	33	34	35	36
	Per cent total solids.	*Per cent total solids.*	*Per cent total solids.*	*Per cent total solids.*	*Per cent total solids.*	*Per cent total solids.*	*Per cent total solids.*	*Per cent total solids.*	*Per cent total solids.*	*Per cent total solids.*	*Per cent total solids.*
2.00	8.90	9.15	9.40	9.65	9.90	10.15	10.40	10.66	10.91	11.16	11.41
2.05	8.96	9.21	9.46	9.71	9.96	10.21	10.46	10.72	10.97	11.22	11.47
2.10	9.02	9.27	9.52	9.77	10.02	10.27	10.52	10.78	11.03	11.28	11.53
2.15	9.08	9.33	9.58	9.83	10.08	10.33	10.58	10.84	11.09	11.34	11.59
2.20	9.14	9.39	9.64	9.89	10.14	10.39	10.64	10.90	11.15	11.40	11.65
2.25	9.20	9.45	9.70	9.95	10.20	10.45	10.70	10.96	11.21	11.46	11.71
2.30	9.26	9.51	9.76	10.01	10.26	10.51	10.76	11.02	11.27	11.52	11.77
2.35	9.32	9.57	9.82	10.07	10.32	10.57	10.82	11.08	11.33	11.58	11.83
2.40	9.38	9.63	9.88	10.13	10.38	10.63	10.88	11.14	11.39	11.64	11.89
2.45	9.44	9.69	9.94	10.19	10.44	10.69	10.94	11.20	11.45	11.70	11.95
2.50	9.50	9.75	10.00	10.25	10.50	10.75	11.00	11.26	11.51	11.76	12.01
2.55	9.56	9.81	10.06	10.31	10.56	10.81	11.06	11.32	11.57	11.82	12.07
2.60	9.62	9.87	10.12	10.37	10.62	10.87	11.12	11.38	11.63	11.88	12.13
2.65	9.68	9.93	10.18	10.43	10.68	10.93	11.18	11.44	11.69	11.94	12.19
2.70	9.74	9.99	10.24	10.49	10.74	10.99	11.24	11.50	11.75	12.00	12.25
2.75	9.80	10.05	10.30	10.55	10.80	11.05	11.31	11.56	11.81	12.06	12.31
2.80	9.86	10.11	10.36	10.61	10.86	11.11	11.37	11.62	11.87	12.12	12.37
2.85	9.92	10.17	10.42	10.67	10.92	11.17	11.43	11.68	11.93	12.18	12.43
2.90	9.98	10.23	10.48	10.73	10.98	11.23	11.49	11.74	11.99	12.24	12.49
2.95	10.04	10.29	10.54	10.79	11.04	11.30	11.55	11.80	12.05	12.30	12.55
3.00	10.10	10.35	10.60	10.85	11.10	11.36	11.61	11.86	12.11	12.36	12.61
3.05	10.16	10.41	10.66	10.91	11.17	11.42	11.67	11.92	12.17	12.42	12.68
3.10	10.22	10.47	10.72	10.97	11.23	11.48	11.73	11.98	12.23	12.48	12.74
3.15	10.28	10.53	10.78	11.03	11.29	11.54	11.79	12.04	12.29	12.55	12.80
3.20	10.34	10.59	10.84	11.09	11.35	11.60	11.85	12.10	12.35	12.61	12.86
3.25	10.40	10.65	10.90	11.16	11.41	11.66	11.91	12.16	12.42	12.67	12.92
3.30	10.46	10.71	10.96	11.22	11.47	11.72	11.97	12.22	12.48	12.73	12.98
3.35	10.52	10.77	11.03	11.28	11.53	11.78	12.03	12.28	12.54	12.79	13.04
3.40	10.58	10.83	11.09	11.34	11.59	11.84	12.09	12.34	12.60	12.85	13.10
3.45	10.64	10.89	11.15	11.40	11.65	11.90	12.15	12.40	12.66	12.91	13.16
3.50	10.70	10.95	11.21	11.46	11.71	11.96	12.21	12.46	12.72	12.97	13.22
3.55	10.76	11.02	11.27	11.52	11.77	12.02	12.27	12.52	12.78	13.03	13.28
3.60	10.82	11.08	11.33	11.58	11.83	12.08	12.33	12.58	12.84	13.09	13.34
3.65	10.88	11.14	11.39	11.64	11.89	12.14	12.39	12.64	12.90	13.15	13.40
3.70	10.94	11.20	11.45	11.70	11.95	12.20	12.45	12.70	12.96	13.21	13.46
3.75	11.00	11.26	11.51	11.76	12.01	12.26	12.51	12.76	13.02	13.27	13.52
3.80	11.06	11.32	11.57	11.82	12.07	12.32	12.57	12.82	13.08	13.33	13.58
3.85	11.12	11.38	11.63	11.88	12.13	12.38	12.63	12.88	13.14	13.39	13.64
3.90	11.18	11.44	11.69	11.94	12.19	12.44	12.69	12.94	13.20	13.45	13.70
3.95	11.24	11.50	11.75	12.00	12.25	12.50	12.75	13.00	13.26	13.51	13.77
4.00	11.30	11.56	11.81	12.06	12.31	12.56	12.81	13.06	13.32	13.57	13.83
4.05	11.36	11.62	11.87	12.12	12.37	12.62	12.87	13.12	13.38	13.63	13.89
4.10	11.42	11.68	11.93	12.18	12.43	12.68	12.93	13.18	13.44	13.69	13.95
4.15	11.48	11.74	11.99	12.24	12.49	12.74	12.99	13.25	13.50	13.76	14.01
4.20	11.54	11.80	12.05	12.30	12.55	12.80	13.05	13.31	13.56	13.82	14.07
4.25	11.60	11.86	12.11	12.36	12.61	12.86	13.12	13.37	13.62	13.88	14.13
4.30	11.66	11.92	12.17	12.42	12.67	12.92	13.18	13.43	13.68	13.94	14.19
4.35	11.72	11.98	12.23	12.48	12.73	12.98	13.24	13.49	13.74	14.00	14.25
4.40	11.78	12.04	12.29	12.54	12.79	13.04	13.30	13.55	13.80	14.06	14.31
4.45	11.84	12.10	12.35	12.60	12.85	13.10	13.36	13.61	13.86	14.12	14.37
4.50	11.90	12.16	12.41	12.66	12.91	13.16	13.42	13.67	13.92	14.18	14.43
4.55	11.97	12.22	12.47	12.72	12.97	13.22	13.48	13.73	13.98	14.24	14.49
4.60	12.03	12.28	12.53	12.78	13.03	13.28	13.54	13.79	14.04	14.30	14.55
4.65	12.09	12.34	12.59	12.84	13.09	13.34	13.60	13.85	14.10	14.36	14.61
4.70	12.15	12.40	12.65	12.90	13.15	13.40	13.66	13.91	14.16	14.42	14.67
4.75	12.21	12.46	12.71	12.96	13.21	13.46	13.72	13.97	14.22	14.48	14.73
4.80	12.27	12.52	12.77	13.02	13.27	13.52	13.78	14.03	14.28	14.54	14.79
4.85	12.33	12.58	12.83	13.08	13.33	13.58	13.84	14.09	14.34	14.60	14.85
4.90	12.39	12.64	12.89	13.14	13.39	13.64	13.90	14.15	14.40	14.66	14.91
4.95	12.45	12.70	12.95	13.20	13.45	13.70	13.96	14.21	14.46	14.72	14.97

TABLE 15.—*Table for determining total solids in milk from any given specific gravity and percentage of fat*—Continued.

Per cent-age of fat.	Lactometer reading at 60° F. (Quevenne degrees).										
	26	27	28	29	30	31	32	33	34	35	36
	Per cent total solids.	*Per cent total solids.*	*Per cent total solids.*	*Per cent total solids.*	*Per cent total solids.*	*Per cent total solids.*	*Per cent total solids.*	*Per cent total solids.*	*Per cent total solids.*	*Per cent total solids.*	*Per cent total solids.*
5.00	12.51	12.76	13.01	13.26	13.51	13.76	14.02	14.27	14.52	14.78	15.03
5.05	12.57	12.82	13.07	13.32	13.57	13.83	14.08	14.33	14.58	14.84	15.09
5.10	12.63	12.88	13.13	13.38	13.63	13.89	14.14	14.39	14.64	14.90	15.15
5.15	12.69	12.94	13.19	13.44	13.69	13.95	14.20	14.45	14.70	14.96	15.21
5.20	12.75	13.00	13.25	13.50	13.75	14.01	14.26	14.51	14.76	15.02	15.27
5.25	12.81	13.06	13.31	13.56	13.81	14.07	14.32	14.57	14.82	15.08	15.33
5.30	12.87	13.12	13.37	13.62	13.87	14.13	14.38	14.63	14.88	15.14	15.39
5.35	12.93	13.18	13.43	13.68	13.93	14.19	14.44	14.70	14.95	15.20	15.45
5.40	12.99	13.24	13.49	13.74	14.00	14.25	14.50	14.76	15.01	15.26	15.51
5.45	13.05	13.30	13.55	13.80	14.06	14.31	14.56	14.82	15.07	15.32	15.57
5.50	13.11	13.36	13.61	13.86	14.12	14.37	14.62	14.88	15.13	15.38	15.63
5.55	13.17	13.42	13.67	13.93	14.18	14.43	14.69	14.94	15.19	15.44	15.69
5.60	13.23	13.48	13.73	13.99	14.24	14.49	14.75	15.00	15.25	15.50	15.75
5.65	13.29	13.54	13.79	14.05	14.30	14.55	14.81	15.06	15.31	15.56	15.81
5.70	13.35	13.60	13.85	14.11	14.36	14.61	14.87	15.12	15.37	15.62	15.87
5.75	13.41	13.66	13.91	14.17	14.42	14.68	14.93	15.18	15.43	15.68	15.93
5.80	13.47	13.72	13.97	14.23	14.48	14.74	14.99	15.24	15.49	15.74	15.99
5.85	13.53	13.78	14.04	14.29	14.54	14.80	15.05	15.30	15.55	15.80	16.06
5.90	13.59	13.84	14.10	14.35	14.60	14.86	15.11	15.36	15.61	15.86	16.12
5.95	13.65	13.90	14.16	14.41	14.66	14.92	15.17	15.42	15.67	15.92	16.18
6.00	13.71	13.96	14.22	14.47	14.72	14.98	15.23	15.48	15.73	15.98	16.24
6.05	13.77	14.02	14.28	14.53	14.78	15.04	15.29	15.54	15.79	16.04	16.30
6.10	13.83	14.08	14.34	14.59	14.84	15.10	15.35	15.60	15.85	16.10	16.35
6.15	13.89	14.14	14.40	14.65	14.90	15.16	15.41	15.66	15.91	16.16	16.42
6.20	13.95	14.20	14.46	14.71	14.96	15.22	15.47	15.72	15.97	16.22	16.48
6.25	14.01	14.26	14.52	14.77	15.02	15.28	15.53	15.78	16.03	16.28	16.54
6.30	14.07	14.32	14.58	14.83	15.08	15.34	15.59	15.84	16.09	16.34	16.60
6.35	14.13	14.38	14.64	14.90	15.14	15.40	15.65	15.90	16.15	16.40	16.66
6.40	14.19	14.44	14.70	14.96	15.20	15.46	15.71	15.96	16.21	16.46	16.72
6.45	14.25	14.50	14.76	15.02	15.26	15.52	15.77	16.02	16.27	16.52	16.78
6.50	14.31	14.56	14.82	15.08	15.32	15.58	15.83	16.08	16.33	16.58	16.84
6.55	14.37	14.62	14.88	15.14	15.38	15.64	15.89	16.14	16.39	16.64	16.90
6.60	14.43	14.68	14.94	15.20	15.44	15.70	15.95	16.20	16.45	16.70	16.96
6.65	14.49	14.74	15.00	15.26	15.50	15.76	16.01	16.26	16.51	16.76	17.02
6.70	14.55	14.80	15.06	15.32	15.56	15.82	16.07	16.32	16.57	16.82	17.08
6.75	14.61	14.86	15.12	15.38	15.62	15.88	16.13	16.38	16.63	16.88	17.14
6.80	14.67	14.92	15.18	15.44	15.68	15.94	16.19	16.44	16.69	16.94	17.20
6.85	14.73	14.98	15.24	15.50	15.74	16.00	16.25	16.50	16.75	17.00	17.26
6.90	14.79	15.04	15.30	15.56	15.80	16.06	16.31	16.56	16.81	17.06	17.32
6.95	14.85	15.10	15.36	15.62	15.86	16.12	16.37	16.62	16.87	17.12	17.38

PROPORTIONAL PARTS.

Lactometer fraction.	Fraction to be added to total solids.	Lactometer fraction.	Fraction to be added to total solids.	Lactometer fraction.	Fraction to be added to total solids.
0.1	0.03	0.4	0.10	0.7	0.18
.2	.05	.5	.13	.8	.20
.3	.08	.6	.15	.9	.23

SUMMARY AND CONCLUSIONS.

1. For purposes where exact percentages of total solids are demanded the use of any formula will not fulfill the requirements.

2. Of the formulas in general use that known as the Babcock (revised) formula gave results closest to those obtained gravimetrically. In 430 composite samples analyzed for total solids 256, or nearly 60 per cent, when calculated with this formula agreed within 0.25 per cent of the figures obtained gravimetrically, and 389, or over 90 per cent, agreed within 0.50 per cent. In another test with 84 samples of milk obtained from four individual cows under official testing conditions, determinations made on each milking showed that the total solids calculated by the formula in 53 cases, or 63 per cent of the total, agreed within 0.25 per cent of the gravimetrically determined figures; and in 78 cases, or 93 per cent of the total, they agreed within 0.50 per cent.

3. Neither individuality nor breed in the cows seemed to exert any notable influence upon the application of the formulas.

4. The Babcock formula may be safely used with normal milk where only comparatively close approximations are required. It must be left to the decision of those in need of such figures as to whether or not the formula will fulfill their particular requirement.

5. The lactometers in common use for determining specific gravity of milk are not sufficiently sensitive to be used in connection with the Babcock fat test for estimating total solids in milk by formula. A modification of the Quevenne lactometer was, however, devised which was found to yield results quite as accurate as those obtained with the Westphal balance and at the same time so constructed that it may be used successfully by those unskilled in the use of chemical apparatus.

APPENDIX.

TABLE 16.—*Comparative determinations of total solids in milk.*

Test No.	Cow No.	Specific gravity (Quevenne degrees).	Fat.	Total solids.			
				Gravimetric.	Babcock.	Richmond.	Fleischmann.
			Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
1	4	33.2	5.07	14.39	14.38	14.51	14.65
2	4	34.5	4.66	14.40	14.22	14.40	14.48
3	4	33.7	5.06	14.54	14.50	14.63	14.76
4	4	33.0	4.93	14.41	14.17	14.27	14.43
5	4	33.6	4.83	14.18	14.20	14.27	14.46
6	4	34.5	4.80	14.26	14.39	14.52	14.65
7	4	34.0	5.02	14.31	14.52	14.63	14.79
8	4	33.7	4.83	13.99	14.22	14.27	14.48
9	4	33.0	5.14	14.18	14.42	14.51	14.68
10	4	34.0	5.00	14.11	14.50	14.63	14.76
11	4	31.5	4.97	13.98	13.84	14.02	14.10
12	4	33.5	4.68	13.85	13.99	14.15	14.25
13	4	32.5	4.77	13.88	13.85	14.02	14.11
14	4	33.0	4.50	13.76	13.65	13.79	13.91
15	4	32.2	4.38	13.48	13.31	13.42	13.57
16	4	33.1	4.44	13.61	13.60	13.67	13.87
17	4	33.0	4.26	14.23	13.36	13.55	13.63
18	4	33.6	4.57	13.96	13.88	14.03	14.15
19	4	33.0	4.65	13.29	13.83	14.03	14.09
20	4	34.0	4.85	14.03	14.32	14.51	14.58
21	4	34.0	5.15	14.70	14.68	14.87	14.94
22	4	34.0	4.82	14.55	14.28	14.39	14.55
23	4	32.8	5.39	14.75	14.67	14.87	14.93
24	4	34.0	5.68	14.80	15.32	15.47	15.58
25	4	33.6	5.61	15.15	15.13	15.23	15.40
26	99	33.3	4.37	13.09	13.57	13.79	13.83
27	99	33.4	4.55	13.54	13.81	14.03	14.07
28	99	33.0	4.51	13.49	13.66	13.79	13.93
29	99	34.0	4.53	13.43	13.94	14.03	14.20
30	99	32.6	4.14	12.72	13.12	13.18	13.38
31	99	32.3	4.50	13.20	13.48	13.66	13.74
32	99	32.7	3.86	12.87	12.81	12.94	13.07
33	99	32.9	4.74	13.50	13.91	14.03	14.18
34	99	32.4	4.50	13.04	13.50	13.66	13.76
35	99	32.0	4.39	12.84	13.27	13.42	13.53
36	99	33.0	4.32	12.95	13.43	13.55	13.70
37	99	32.7	4.31	12.88	13.35	13.42	13.61
38	99	31.0	4.28	12.99	12.89	13.06	13.15
39	99	31.8	4.32	12.87	13.13	13.30	13.40
40	99	32.2	4.23	12.84	13.13	13.18	13.39
41	99	30.5	4.43	12.90	12.94	13.05	13.20
42	99	31.0	3.90	12.42	12.43	12.58	12.69
43	99	31.0	4.27	13.04	12.87	13.06	13.14
44	99	30.9	3.93	12.67	12.44	12.58	12.70
45	99	32.0	4.30	12.50	13.16	13.30	13.42
46	99	33.0	4.42	13.13	13.55	13.67	13.82
47	99	33.0	4.07	12.95	13.13	13.31	13.40
48	99	34.0	4.37	13.13	13.74	13.91	14.01
49	99	32.5	4.80	13.34	13.89	14.02	14.15
50	99	32.7	4.70	13.66	13.82	13.90	14.08
51	99	32.0	4.63	13.26	13.56	13.66	13.82
52	99	32.4	4.74	13.85	13.79	13.90	14.05
53	99	35.5	4.71	14.00	14.53	14.64	14.79
54	99	34.5	5.08	14.55	14.72	14.88	14.98
55	99	32.5	5.39	14.66	14.59	14.74	14.86
56	99	34.0	5.26	14.83	14.81	14.99	15.08
57	99	35.0	5.78	15.32	15.69	15.84	15.95
58	99	36.0	6.00	15.61	16.20	16.32	16.46
59	99	32.3	5.42	14.85	14.58	14.74	14.84
60	99	34.6	5.99	15.89	15.84	15.96	16.10
61	99	33.5	6.15	16.11	15.76	15.95	16.02

TABLE 16.—*Comparative determinations of total solids in milk*—Continued.

Test No.	Cow No.	Specific gravity (Quevenne degrees).	Fat.	Total solids.			
				Gravimetric.	Babcock.	Richmond.	Fleischmann.
			Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
62	99	34.9	6.07	16.24	16.01	16.20	16.27
63	118	30.0	5.06	13.93	13.57	13.77	13.83
64	118	31.0	5.10	14.19	13.87	14.02	14.13
65	118	29.7	5.77	14.12	14.35	14.48	14.61
66	118	32.0	5.58	14.55	14.70	14.86	14.96
67	118	34.0	5.80	15.10	15.46	15.59	15.72
68	118	35.0	5.60	15.40	15.47	15.60	15.73
69	118	34.5	5.69	15.41	15.45	15.60	15.72
70	118	34.5	5.76	15.30	15.54	15.72	15.80
71	118	34.2	5.44	14.71	15.08	15.11	15.34
72	118	34.0	5.86	15.28	15.53	15.71	15.80
73	118	34.5	5.87	15.49	15.67	15.84	15.93
74	118	34.5	6.10	15.50	15.95	16.08	16.20
75	118	35.0	5.95	16.12	15.89	16.08	16.15
76	118	35.0	5.28	15.35	15.09	15.24	15.35
77	118	34.0	5.86	15.47	15.53	15.71	15.80
78	118	35.0	5.37	15.36	15.19	15.36	15.46
79	118	33.8	5.41	15.20	14.94	15.11	15.21
80	118	34.0	4.89	14.55	14.37	14.51	14.63
81	118	33.4	4.99	14.06	14.34	14.51	14.60
82	118	32.0	4.51	13.98	13.41	13.54	13.68
83	118	35.0	4.83	14.83	14.55	14.64	14.81
84	118	34.2	5.00	14.53	14.55	14.63	14.81
85	118	34.2	4.61	14.33	14.08	14.15	14.35
86	118	35.4	5.15	14.65	15.03	15.24	15.29
87	118	35.0	4.57	14.29	14.23	14.40	14.50
88	118	35.0	5.21	14.55	15.00	15.12	15.26
89	118	36.0	4.86	14.93	14.83	15.00	15.09
90	118	34.5	5.54	15.25	15.27	15.36	15.54
91	118	37.0	5.49	15.58	15.84	15.97	16.10
92	118	35.0	5.74	16.30	15.64	15.72	15.90
93	118	35.0	5.42	15.75	15.25	15.36	15.52
94	118	39.5	5.14	16.26	16.04	16.14	16.30
95	118	33.5	6.29	16.18	15.92	16.07	16.19
96	205	34.0	3.19	12.08	12.33	12.47	12.59
97	205	34.0	2.69	11.32	11.73	11.87	11.99
98	205	34.0	3.30	10.95	12.46	12.59	12.72
99	205	34.0	3.05	11.88	12.16	12.35	12.42
100	205	32.5	3.14	11.80	11.89	11.98	12.16
101	205	33.0	3.38	11.59	12.31	12.47	12.57
102	205	31.4	3.00	11.03	11.45	11.62	11.71
103	205	32.0	2.81	12.00	11.37	11.50	11.64
104	205	34.5	3.01	11.67	12.24	12.36	12.50
105	205	33.0	3.17	11.66	12.05	12.23	12.32
106	205	31.5	3.07	11.46	11.56	11.74	11.82
107	205	32.5	3.10	11.95	11.85	11.98	12.11
108	205	33.0	3.10	11.64	11.97	12.11	12.23
109	205	33.5	3.58	12.45	12.67	12.83	12.93
110	205	31.4	3.21	11.76	11.70	11.86	11.97
111	205	32.1	3.33	12.20	12.02	12.10	12.29
112	205	31.2	3.34	11.95	11.81	11.86	12.07
113	205	32.5	3.32	11.96	12.11	12.22	12.37
114	205	34.0	3.17	12.34	12.30	12.47	12.57
115	205	33.7	3.01	11.66	12.04	12.11	12.30
116	205	32.8	3.30	11.70	12.16	12.35	12.42
117	205	33.0	2.87	11.77	11.69	11.87	11.96
118	205	32.5	3.06	11.96	11.80	11.98	12.06
119	205	33.0	3.54	12.19	12.50	12.59	12.76
120	205	32.0	3.21	11.76	11.85	11.98	12.12
121	205	32.0	3.38	12.13	12.06	12.22	12.32
122	205	34.0	2.89	11.83	11.97	12.11	12.23
123	205	33.0	3.26	11.99	12.16	12.35	12.43
124	205	32.7	3.19	12.10	12.00	12.10	12.27
125	205	32.7	3.38	12.25	12.23	12.34	12.50
126	205	34.6	3.15	12.31	12.43	12.60	12.69
127	205	33.6	3.17	12.06	12.20	12.35	12.47
128	205	32.5	3.28	12.04	12.06	12.22	12.33
129	205	33.0	2.94	11.74	11.78	11.87	12.04
130	205	32.5	3.23	12.01	12.00	12.10	12.27
131	205	32.2	3.36	12.10	12.08	12.22	12.35
132	205	31.7	3.38	12.15	11.98	12.10	12.24
133	205	32.5	3.26	12.20	12.04	12.22	12.30
134	205	33.0	3.25	11.90	12.15	12.35	12.41
135	205	33.0	3.27	12.27	12.17	12.35	12.44
136	205	33.7	3.22	12.42	12.29	12.35	12.55
137	205	32.0	3.50	12.19	12.20	12.34	12.64
138	205	33.5	3.74	12.71	12.86	12.95	13.13

TABLE 16.—*Comparative determinations of total solids in milk*—Continued.

Test No.	Cow No.	Specific gravity (Quevenne degrees).	Fat.	Total solids.			
				Gravimetric.	Babcock.	Richmond.	Fleischmann.
			Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
139	205	33.6	3.20	12.70	12.24	12.35	12.50
140	205	33.5	3.63	12.96	12.73	12.83	12.99
141	205	33.4	3.40	11.64	12.43	12.59	12.84
142	205	32.6	3.82	12.99	12.73	12.82	13.00
143	206	31.5	3.48	11.97	12.05	12.22	12.31
144	206	29.0	3.17	11.04	11.05	11.24	11.32
145	206	28.2	2.58	9.95	10.15	10.27	10.41
146	206	29.0	3.06	10.84	10.92	11.12	11.18
147	206	29.2	2.63	10.10	10.46	10.52	10.72
148	206	29.0	2.76	10.04	10.56	10.76	10.82
149	206	29.0	2.29	9.62	10.00	10.16	10.26
150	206	29.5	2.70	11.02	10.62	10.76	10.88
151	206	30.0	2.58	10.04	10.60	10.77	10.86
152	206	27.5	2.94	10.23	10.40	10.51	10.66
153	206	28.2	2.76	9.99	10.36	10.51	10.62
154	206	27.5	2.96	10.27	10.43	10.63	10.69
155	206	29.0	2.71	10.57	10.50	10.64	10.76
156	206	30.0	3.10	10.57	11.22	11.37	11.48
157	206	30.0	2.72	10.43	10.76	10.89	11.03
158	206	29.0	2.94	10.67	10.78	10.88	11.04
159	206	29.0	2.78	10.49	10.59	10.76	10.85
160	206	29.0	3.06	10.40	10.92	11.12	11.18
161	206	30.0	3.13	10.86	11.26	11.37	11.52
162	206	27.8	3.01	10.80	10.56	10.75	10.82
163	206	28.6	3.05	10.87	10.81	10.99	11.07
164	206	28.1	3.05	10.82	10.69	10.87	10.94
165	206	29.0	3.08	10.83	10.95	11.12	11.21
166	206	29.0	3.01	10.92	10.86	11.00	11.12
167	206	29.0	2.39	10.44	10.12	10.28	10.38
168	206	29.5	3.08	10.63	11.07	11.24	11.33
169	206	29.0	2.86	10.71	10.68	10.88	10.94
170	206	29.0	2.82	11.00	10.63	10.76	10.90
171	206	29.0	3.23	10.85	11.13	11.24	11.39
172	206	29.5	3.09	10.87	11.08	11.24	11.34
173	206	29.3	3.13	11.05	11.08	11.24	11.34
174	206	31.0	2.70	10.93	10.99	11.14	11.25
175	206	31.0	3.06	11.19	11.42	11.62	11.69
176	206	30.0	2.93	11.28	11.02	11.13	11.28
177	206	31.0	3.35	12.10	11.77	11.98	12.03
178	206	32.6	3.03	12.18	11.79	11.86	12.05
179	206	32.4	3.03	12.03	11.74	11.86	12.00
180	206	33.8	3.39	12.87	12.52	12.71	12.78
181	206	34.3	3.44	13.09	12.70	12.84	12.97
182	206	35.3	3.40	13.09	12.91	13.08	13.17
183	209	31.0	3.95	12.84	12.49	12.70	12.75
184	209	32.0	3.14	11.23	11.77	11.86	12.03
185	209	32.0	2.59	10.44	11.11	11.26	11.37
186	209	32.0	2.80	10.45	11.36	11.50	11.62
187	209	32.0	2.40	10.20	10.88	11.02	11.14
188	209	30.0	2.64	10.09	10.67	10.77	10.93
189	209	30.0	2.68	10.22	10.72	10.89	10.98
190	209	29.8	2.67	10.41	10.65	10.89	10.92
191	209	29.0	2.54	10.99	10.30	10.40	10.56
192	209	30.3	2.72	10.21	10.84	11.01	11.10
193	209	31.0	2.96	10.63	11.30	11.50	11.57
194	209	29.5	2.72	10.70	10.64	10.76	10.90
195	209	30.5	3.00	10.77	11.23	11.37	11.49
196	209	31.5	3.09	11.39	11.58	11.74	11.85
197	209	28.5	2.96	11.04	10.68	10.87	10.94
198	209	28.6	3.00	10.81	10.75	10.87	11.01
199	209	29.8	3.14	11.18	11.22	11.37	11.48
200	209	29.5	3.35	11.21	11.40	11.60	11.66
201	209	31.0	3.05	11.41	11.41	11.62	11.67
202	209	30.8	2.54	10.81	10.75	10.90	11.01
203	209	31.0	3.24	11.46	11.64	11.74	11.90
204	209	30.0	2.73	10.93	10.78	10.89	11.04
205	209	29.5	2.74	10.62	10.66	10.76	10.92
206	209	30.5	3.00	11.20	11.23	11.37	11.49
207	209	30.0	2.95	10.97	11.04	11.25	11.30
208	209	30.0	3.08	11.44	11.20	11.37	11.46
209	209	31.4	2.72	11.20	11.11	11.26	11.38
210	209	31.0	3.15	11.34	11.53	11.74	11.79
211	209	29.8	2.95	10.87	10.99	11.25	11.25
212	209	30.9	3.08	11.39	11.42	11.62	11.68
213	209	30.7	2.87	11.30	11.12	11.25	11.38
214	209	31.5	2.94	11.53	11.40	11.50	11.67
215	209	31.5	3.06	11.57	11.55	11.74	11.81

TABLE 16.—*Comparative determinations of total solids in milk*—Continued.

Test No.	Cow No.	Specific gravity (Quevenne degrees).	Fat.	Total solids.			
				Gravimetric.	Babcock.	Richmond.	Fleischmann.
			Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
216	209	31.0	3.18	11.59	11.57	11.74	11.83
217	209	31.3	2.85	11.62	11.25	11.50	11.51
218	209	31.3	3.69	12.49	12.25	12.46	12.52
219	209	32.2	3.75	12.68	12.55	12.62	12.81
220	209	33.0	3.32	12.61	12.23	12.35	12.50
221	209	33.3	3.33	12.53	12.32	12.47	12.58
222	209	32.6	3.29	12.28	12.10	12.22	12.36
223	209	33.5	3.27	12.76	12.30	12.47	12.56
224	209	35.6	3.52	13.20	13.12	13.20	13.39
225	209	36.0	3.74	13.70	13.49	13.56	13.75
226	209	34.4	3.75	13.70	13.10	13.25	13.36
227	209	37.0	3.76	13.98	13.76	13.93	14.02
228	209	34.4	4.05	13.56	13.46	13.68	13.72
229	300	33.0	5.19	14.53	14.48	14.63	14.74
230	300	33.3	4.54	13.76	13.77	13.91	14.04
231	300	33.4	4.18	13.76	13.37	13.55	13.63
232	300	33.5	4.49	13.94	13.76	13.91	14.03
233	300	33.4	4.38	13.93	13.61	13.79	13.87
234	300	33.5	4.22	13.51	13.44	13.55	13.70
235	300	33.5	4.46	13.42	13.73	13.91	13.99
236	300	33.1	4.07	13.76	13.16	13.31	13.42
237	300	33.7	4.23	13.53	13.50	13.55	13.76
238	300	33.6	4.22	13.53	13.46	13.55	13.73
239	300	33.5	4.05	13.41	13.24	13.43	13.50
240	300	33.7	4.01	13.20	13.24	13.31	13.50
241	300	33.0	4.16	13.24	13.24	13.43	13.51
242	300	32.8	4.08	13.39	13.10	13.31	13.36
243	300	32.7	4.11	13.44	13.11	13.18	13.37
244	300	32.4	3.98	13.26	12.88	13.06	13.14
245	300	32.6	3.55	12.89	12.41	12.58	12.67
246	300	32.0	4.13	13.42	12.96	13.06	13.22
247	300	31.8	4.29	13.13	13.10	13.30	13.36
248	300	32.0	4.20	12.69	13.04	13.18	13.30
249	300	34.0	4.10	13.04	13.42	13.55	13.68
250	300	33.4	4.12	13.07	13.29	13.43	13.56
251	300	34.0	4.02	13.44	13.32	13.43	13.59
252	300	35.0	4.13	13.40	13.71	13.80	13.97
253	300	35.0	4.22	13.13	13.81	13.92	14.08
254	300	35.0	4.08	13.34	13.65	13.80	13.91
255	300	34.0	4.17	13.76	13.50	13.67	13.77
256	300	33.0	4.32	13.39	13.43	13.55	13.70
257	300	33.0	3.89	12.56	12.92	13.07	13.18
258	300	31.5	3.65	12.57	12.26	12.46	12.52
259	300	33.0	3.22	12.04	12.11	12.23	12.38
260	300	32.0	3.94	12.40	12.73	12.82	12.99
261	300	33.0	3.65	12.35	12.63	12.83	12.89
262	300	32.0	3.61	12.28	12.33	12.46	12.60
263	300	32.5	3.31	12.13	12.10	12.22	12.36
264	300	32.9	3.37	12.28	12.27	12.47	12.53
265	300	33.0	3.45	12.17	12.39	12.59	12.65
266	300	32.0	3.38	11.98	12.06	12.22	12.32
267	300	31.4	3.36	12.07	11.88	12.10	12.15
268	300	30.2	3.50	11.89	11.75	11.85	12.01
269	300	31.2	3.23	11.70	11.68	11.74	11.94
270	300	30.5	3.35	11.57	11.65	11.85	11.91
271	300	30.4	3.15	11.58	11.38	11.61	11.64
272	300	31.3	3.47	11.96	11.99	12.22	12.25
273	300	32.0	3.30	11.70	11.96	12.10	12.22
274	300	31.6	3.35	11.38	11.92	12.10	12.18
275	300	30.1	3.44	11.26	11.65	11.73	11.92
276	300	31.0	3.40	11.38	11.83	11.98	12.09
277	300	30.2	2.98	11.40	11.13	11.25	11.39
278	300	30.2	3.20	11.34	11.39	11.49	11.65
279	301	34.0	4.22	13.38	13.56	13.67	13.83
280	301	33.0	4.15	13.43	13.23	13.43	13.49
281	301	32.3	4.66	13.55	13.67	13.90	13.93
282	301	32.0	4.44	13.43	13.33	13.42	13.59
283	301	33.0	4.29	13.41	13.40	13.55	13.66
284	301	32.4	4.72	13.44	13.76	13.90	14.03
285	301	32.9	4.22	13.36	13.29	13.43	13.55
286	301	32.5	4.37	13.35	13.37	13.54	13.63
287	301	32.8	4.61	13.51	13.73	13.91	14.00
288	301	31.5	4.72	13.78	13.54	13.66	13.80
289	301	34.2	4.16	12.98	13.54	13.67	13.81
290	301	33.2	4.40	13.33	13.58	13.67	13.84
291	301	32.2	4.31	13.54	13.22	13.30	13.49
292	301	33.0	4.42	13.67	13.55	13.67	13.82

TABLE 16.—*Comparative determinations of total solids in milk*—Continued.

Test No.	Cow No.	Specific gravity (Quevenne degrees).	Fat.	Total solids.			
				Gravimetric.	Babcock.	Richmond.	Fleischmann.
			Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
293	301	33.7	4.02	13.47	13.25	13.31	13.51
294	301	33.5	3.88	13.41	13.03	13.19	13.29
295	301	34.2	3.92	13.27	13.25	13.31	13.52
296	301	34.0	4.09	13.99	13.41	13.55	13.67
297	301	34.0	4.24	13.31	13.59	13.67	13.85
298	301	33.5	4.20	12.83	13.42	13.55	13.68
299	301	33.0	4.34	13.37	13.46	13.55	13.72
300	301	33.0	3.72	12.91	12.71	12.83	12.98
301	301	33.0	4.23	13.46	13.33	13.43	13.59
302	301	34.0	4.25	13.36	13.60	13.79	13.86
303	301	33.0	4.32	13.23	13.43	13.55	13.70
304	301	35.5	4.11	13.71	13.81	13.92	14.07
305	301	34.0	3.89	13.34	13.17	13.31	13.43
306	301	34.0	3.56	12.94	12.77	12.95	13.04
307	301	33.5	3.90	12.80	13.06	13.19	13.32
308	301	34.0	3.98	13.02	13.28	13.43	13.54
309	301	31.7	3.58	12.54	12.22	12.34	12.48
310	301	31.1	3.69	12.37	12.20	12.34	12.47
311	301	33.8	3.71	12.05	12.90	13.07	13.17
312	301	32.0	3.75	12.36	12.50	12.70	12.76
313	301	33.0	3.83	12.61	12.85	12.95	13.11
314	301	32.5	3.80	12.64	12.69	12.82	12.95
315	301	33.0	3.85	12.66	12.87	13.07	13.13
316	301	32.0	3.71	12.74	12.45	12.58	12.72
317	301	32.5	3.75	12.67	12.63	12.82	12.89
318	301	32.0	4.01	12.80	12.81	12.94	13.08
319	301	33.0	3.75	12.53	12.75	12.95	13.01
320	301	32.5	4.12	13.11	13.07	13.18	13.33
321	301	32.6	3.86	12.93	12.78	12.94	13.05
322	301	33.6	4.24	13.31	13.49	13.55	13.75
323	301	32.4	4.09	13.01	13.01	13.18	13.27
324	301	32.8	4.00	12.74	13.00	13.19	13.26
325	301	33.6	3.71	13.01	12.85	12.95	13.12
326	301	32.9	3.65	12.77	12.61	12.83	12.87
327	301	33.0	3.76	12.90	12.76	12.95	13.03
328	301	32.6	4.07	12.90	13.03	13.18	13.30
329	301	33.0	3.77	12.50	12.77	12.95	13.04
330	301	32.1	4.00	12.26	12.83	12.94	13.09
331	301	32.0	3.96	12.85	12.75	12.94	13.02
332	301	31.2	4.16	12.38	12.79	12.94	13 06
333	301	31.4	3.76	12.71	12.36	12.58	12.63
334	301	32.7	3.76	12.67	12.69	12.82	12.95
335	301	32.5	4.07	12.79	13.01	13.18	13.27
336	301	32.9	3.55	12.86	12.49	12.71	12.75
337	301	31.5	3.84	12.16	12.48	12.58	12.75
338	301	31.3	3.61	12.09	12.16	12.34	12.42
339	301	32.5	3.67	12.84	12.53	12.70	12.79
340	301	31.2	3.71	12.34	12.25	12.34	12.52
341	302	31.8	4.88	13.98	13.81	14.02	14.07
342	302	31.0	4.73	13.70	13.43	13.54	13.69
343	302	32.0	3.92	12.80	12.70	12.82	12.97
344	302	31.6	4.08	12.88	12.80	12.94	13.06
345	302	32.0	4.47	12.97	13.36	13.54	13.63
346	302	32.9	4.11	12.52	13.16	13.31	13.42
347	302	32.8	4.48	13.45	13.58	13.79	13.84
348	302	31.8	4.48	13.31	13.33	13.54	13.59
349	302	31.6	4.71	13.67	13.55	13.66	13.82
350	302	32.8	4.07	12.87	13.08	13.31	13.35
351	302	31.0	4.71	13.15	13.40	13.54	13.67
352	302	29.5	5.18	13.54	13.59	13.76	13.85
353	400	34.5	4.48	14.16	14.00	14.16	14.26
354	400	35.5	4.07	13.83	13.76	13.92	14.02
355	400	36.0	3.88	13.51	13.66	13.80	13.92
356	400	36.0	4.03	13.35	13.84	13.92	14.10
357	400	34.0	4.33	13.58	13.70	13.79	13.96
358	400	31.3	3.95	13.25	12.57	12.82	12.83
359	400	33.7	3.92	12.98	13.13	13.19	13.39
360	400	33.6	4.17	13.35	13.40	13.55	13.67
361	400	33.0	4.13	13.58	13.21	13.31	13.47
362	400	32.5	4.31	13.23	13.30	13.42	13.56
363	400	33.5	3.99	12.87	13.16	13.31	13.43
364	400	34.0	3.54	12.52	12.75	12.83	13.01
365	400	32.0	3.30	12.05	11.96	12.10	12.22
366	400	33.0	3.99	12.81	13.04	13.19	13.30
367	400	34.0	3.57	12.11	12.78	12.95	13.05
368	400	32.8	3.73	12.96	12.68	12.83	12.94
369	400	33.1	3.53	12.91	12.51	12.71	12.78

TABLE 16.—*Comparative determinations of total solids in milk*—Continued.

Test No.	Cow No.	Specific gravity (Quevenne degrees).	Fat.	Total solids.			
				Gravimetric.	Babcock.	Richmond.	Fleischmann.
			Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
370	400	35.1	3.92	13.28	13.48	13.56	13.74
371	400	34.0	3.78	12.94	13.04	13.19	13.30
372	400	35.0	3.55	13.11	13.01	13.20	13.27
373	400	34.6	3.62	13.17	12.99	13.08	13.26
374	400	33.4	3.72	13.01	12.81	12.95	13.08
375	400	33.7	3.61	13.01	12.76	12.83	13.02
376	400	34.3	3.79	13.00	13.12	13.32	13.39
377	400	35.0	3.52	12.69	12.97	13.08	13.24
378	400	34.0	4.07	12.99	13.38	13.55	13.65
379	400	34.0	3.85	13.18	13.12	13.31	13.38
380	400	33.2	3.95	12.97	13.04	13.19	13.30
381	400	33.7	3.53	12.88	12.66	12.71	12.92
382	400	34.4	3.90	13.26	13.28	13.44	13.54
383	400	34.6	3.96	13.34	13.40	13.56	13.66
384	400	34.7	3.53	12.85	12.94	12.96	13.17
385	400	32.6	3.43	12.40	12.27	12.34	12.53
386	400	32.0	3.91	13.03	12.69	12.82	12.96
387	400	34.0	4.52	13.48	13.92	14.03	14.19
388	402	36.0	4.49	14.06	14.39	14.52	14.65
389	402	35.0	5.14	14.32	14.92	15.00	15.18
390	402	32.9	4.48	13.62	13.60	13.79	13.87
391	402	32.6	4.08	12.94	13.05	13.18	13.31
392	402	32.8	4.31	13.18	13.37	13.55	13.64
393	402	33.0	4.20	13.34	13.29	13.43	13.55
394	402	34.5	4.20	13.41	13.67	13.80	13.93
395	402	34.0	3.96	13.23	13.25	13.43	13.52
396	402	34.0	4.21	13.46	13.55	13.67	13.82
397	402	33.5	3.92	12.91	13.08	13.19	13.34
398	402	32.5	3.77	12.83	12.65	12.82	12.91
399	402	34.0	3.99	13.07	13.29	13.43	13.55
400	402	33.7	3.61	12.78	12.76	12.83	13.02
401	402	34.0	4.03	13.41	13.34	13.43	13.60
402	402	34.4	3.69	13.01	13.03	13.20	13.29
403	402	34.0	3.86	13.06	13.13	13.31	13.40
404	402	33.0	3.92	13.06	12.95	13.07	13.22
405	402	34.0	3.84	13.26	13.11	13.19	13.37
406	402	34.4	3.80	13.21	13.16	13.32	13.42
407	402	33.4	3.80	13.11	12.91	13.07	13.17
408	402	33.7	3.79	13.15	12.97	13.07	13.24
409	402	34.0	3.93	12.94	13.22	13.31	13.48
410	402	34.4	3.78	12.86	13.14	13.32	13.40
411	402	33.6	4.16	12.94	13.39	13.55	13.66
412	402	32.7	3.94	13.10	12.90	12.94	13.17
413	402	32.7	4.12	12.69	13.12	13.18	13.38
414	402	33.4	3.76	13.02	12.86	13.07	13.13
415	402	34.5	4.09	13.26	13.53	13.68	13.80
416	402	34.0	4.20	13.46	13.54	13.67	13.80
417	403	35.8	4.06	13.63	13.82	14.04	14.08
418	403	36.0	3.53	12.85	13.24	13.32	13.50
419	403	33.8	3.45	12.42	12.59	12.83	12.85
420	403	33.4	3.27	12.49	12.27	12.47	12.54
421	403	33.3	3.35	12.21	12.35	12.59	12.61
422	403	32.7	3.35	12.07	12.20	12.34	12.46
423	403	33.3	3.45	12.12	12.47	12.71	12.73
424	403	32.0	3.36	12.22	12.03	12.22	12.30
425	403	32.0	3.33	11.61	12.00	12.10	12.26
426	403	32.3	2.96	11.86	11.63	11.86	11.89
427	403	32.9	3.16	11.53	12.02	12.23	11.28
428	403	33.6	3.26	12.00	12.31	12.47	12.58
429	403	32.3	3.01	11.32	11.69	11.86	11.95
430	403	31.6	3.19	11.40	11.73	11.86	11.99

NOTE.—Cows Nos. 4, 99, and 118 are Jerseys; Nos. 205, 206, and 209 are Holstein-Friesians; Nos. 300, 301, and 302 are Ayrshires, and Nos. 400, 402, and 403 are Shorthorns.

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