cance of these facts would require more time than is at my disposal. Suffice it to say, that in terms of our present theory it takes twice as much electricity to set a bivalent atom free as to set a univalent atom free; three times as much for a trivalent atom, etc. How to conceive of one, two, three, or four charges of electricity on an ion I leave to the physicists to explain, though it must be said that they are not in the least called upon to explain.

The atom has thus been followed in its career down to to-day. The changes in our conceptions have been traced sufficiently for our purpose. It is at present a bundle of attributes and with these attributes it is a convenient nucleus for thought. Nothing has been said of the dynamics of the atom, by which I do not, of course, mean chemical dynamics in general. So far as the atom is concerned our knowledge of its motions may perhaps fairly be summed up by saying that it seems probable that it moves in some mysterious way, and perhaps the phenomena of chemistry are all due to this motion. But that carries us into the region of speculation pure and simple, and in this region the scientific worker feels uncomfortable. The atmosphere is too rarefied for him.

If you now ask what is the soul of the doctrine of atoms? I can only answer that this soul is still in the course of development. The doctrine has some immortal attributes, but what will live after its death is too early for any one to say.

"Prove all things. Hold fast that which is good."

[CONTRIBUTION FROM THE HAVEMEYER LABORATORIES OF COLUMBIA UNIVERSITY, NO. 74.]

ON THE COMPOSITION OF COWS' MILK.

BY H. C. SHERMAN.

Received October 10, 1902.

IN general the percentage of fat in cows' milk varies much more than that of the other constituents. It is probably safe to say that a variation of 3 per cent. in fat is as common as a variation of 1 per cent. in the total amount of other solids. Milk is apt to be regarded, therefore, as consisting of a serum of quite uniform composition in which is suspended a variable amount of fat. It is, however, a matter of some importance both from the physiological standpoint and as an aid in judging suspected samples, to define as accurately as possible the normal variations of each of the chief constituents and to determine whether any change in the amount or relative proportion of proteïds, sugar or ash is connected with the fluctuations in the fat content.

With the aid of friends connected with a large dairy farm, the writer has been able to obtain a considerable number of samples, the analyses of which seem of sufficient interest to warrant publication. These samples fall mainly into two groups: (1) periodical samples of the mixed milk of a large herd, intended to show the normal variations of composition during the year, and (2) samples above or below the average in fat or in solids-not-fat, analyzed to ascertain whether any other constituent varies with the fat, and to which constituent the variations in the solids-not-fat is chiefly due.

Methods of Analysis.—The analytical methods used were those of the Association of Official Agricultural Chemists[1] and the details of manipulation were uniform throughout. Fat was determined by the paper coil method, the milk being very thoroughly dried on the coil and then extracted with anhydrous ether. The percentages of proteïn[2] were obtained by multiplying the percentages of nitrogen found by the Kjeldahl method by 6.25, the digestion with sulphuric acid being continued for about two hours after the liquid had become colorless. Ash was determined by direct ignition at the lowest possible dull red heat. Milk-sugar was determined by difference, the sum of the percentages of fat, proteïn and ash being subtracted from the percentage of total solids found by drying to constant weight in a flat-bottomed dish at the temperature of boiling water. The samples were preserved by the addition of formaldehyde in the proportion of 1 drop of the commercial 40 per cent. solution to each ounce of sample. In the experience of this laboratory the use of such an amount of formaldehyde has not been found to have any appreciable effect upon the analytical results.

Source of Samples.—All of the samples analyzed were from one large farm in Westchester County, New York. The herd contained about 600 milk cows of which about 200 were pure bred Jerseys and the rest mainly "Jersey

[1] Bulletin 46, revised edition, Bureau of Chemistry, U. S. Department of Agriculture.

[2] In accordance with the terminology adopted by the American Association of Agricultural Colleges and Experiment Stations, the term "protein" is used to designate the value (nitrogen $\times$ 6.25).

grades." From 450 to 500 cows were usually milked at a time, the others either being dry or allowed to run with their young calves. Though divided into several groups, the entire herd was under one herdsman, who stated that throughout the year each cow received hay or green fodder and one and one-half pounds of oil meal per day, and in addition to this was fed with a mixture of one-half wheat bran. one-quarter crushed oats and one-quarter corn meal. The amount of this mixture fed depended upon the judgment of the feeder and to some extent upon the season and the demand for milk, but was always liberal. Exercise was allowed freely except in very severe weather and in summer there was pasturage, though this was never depended upon to the exclusion of other food. The cattle were always comfortably housed and were milked at 4.30 to 5.00 A.M., and 3.30 to 4.00 P.M.

Morning and Afternoon Milk.—Frequent tests of the mixed milk of the herd showed that the afternoon milk contained quite regularly about 0.4 per cent. more fat and practically the same solids-not-fat as the milk yielded in the morning. Similar results have constantly been found by Richmond[1] in the great numbers of analyses made yearly in his laboratory. Moreover, it has been found at the New York State Experiment Station[2] and by Fruhling and Schultze,[3] in each case as the resnlt of many analyses, that neither proteïn, sugar nor ash shows any distinct tendency to be higher at one milking than at the other, or, in other words, that the difference in composition between morning and evening milk is a difference in fat content only and does not extend to the other constituents. Linfield[4] has recently reached the same conclusion which is confirmed for the herd here studied in the following experiment by the writer.

On April 19, 1901, the milk obtained at each milking was carefully sampled and analyzed, with the following results:

	Fat.	Protein.	Sugar.	Ash.
Morning milk	4.85	3.68	4.85	0.74
Afternoon milk	5.22	3.65	4.90	0.73

Further experiments on this point were therefore considered

1 "Dairy Chemistry," p. 128 and papers in *The Analyst.*

2 Report for 1891; Abstracted in Experiment Station Record, 4, 257.

3 Quoted by Stohmann: "Milch und Molkereiprodukte," p. 166.

4 Utah Experiment Station Bulletin 68, p. 234.

unnecessary and in studying the variations of composition from month to month only the afternoon milk was sampled.

SEASONAL VARIATIONS IN COMPOSITION.

It is well known that milk tends to be richer, both in fat and in solids-not-fat, in winter than in summer, and Richmond's analyses have shown that the milk received from English farms varies in practically the same way each year, the difference between the highest and lowest monthly averages being about the same for fat as for solids-not-fat and amounting usually to 0.3 or 0.4 per cent.

For two years, beginning with April, 1900, the mixed milk of the herd above described was sampled and analyzed once each month. As the milk came to the dairy in cans of uniform size, an accurate sample was readily obtained by means of the Scovell sampling tube. The composition of these samples is shown in Table I, below.

TABLE I.—COMPOSITION OF MONTHLY SAMPLES.

Month.	Total solids.	Fat.	Solids-not-fat.	Proteïn.	Sugar.	Ash.
January, 1901	14.69	5.36	9.33	3.76	4.83	0.74
" 1902	14.82	5.35	9.47	3.82	4.89	0.76
" average	14.76	5.36	9.40	3.79	4.86	0.75
February, 1901	14.53	5.24	9.29	3.67	4.87	0.75
" 1902	14.73	5.38	9.35	3.72	4.88	0.75
" average	14.63	5.31	9.32	3.70	4.87	0.75
March, 1901	14.39	5.19	9.20	3.57	4.90	0.73
" 1902	14.52	5.37	9.15	3.57	4.84	0.74
" average	14.46	5.28	9.18	3.57	4.87	0.74
April, 1900	14.25	5.14	9.11	3.48	4.88	0.75
" 1901	14.43	5.13	9.30	3.66	4.89	0.75
" average	14.34	5.14	9.20	3.57	4.88	0.75
May, 1900	14.37	5.22	9.15	3.58	4.84	0.73
" 1901	14.25	5.12	9.13	3.54	4.84	0.75
" average	14.31	5.17	9.14	3.56	4.84	0.74
June, 1900	14.26	5.10	9.16	3.59	4.85	0.72
" 1901	14.64	5.38	9.26	3.59	4.91	0.76
" average	14.45	5.24	9.21	3.59	4.88	0.74
July, 1900	14.13	5.00	9.13	3.54	4.84	0.75
" 1901	14.23	5.29	8.94	3.50	4.71	0.73
" average	14.18	5.15	9.03	3.52	4.77	0.74
August, 1900	14.11	5.00	9.11	3.58	4.79	0.74
" 1901	14.34	5.28	9.06	3.54	4.78	0.74
" average	14.23	5.14	9.09	3.56	4.79	0.74
September, 1900	14.73	5.39	9.34	3.75	4.84	0.75
" 1901	14.34	5.27	9.07	3.56	4.77	0.74
" average	14.54	5.33	9.21	3.66	4.81	0.74

Month.	Total solids.	Fat.	Solids-not-fat.	Proteïn.	Sugar.	Ash.
October, 1900	14.46	5.23	9.23	3.73	4.75	0.75
" 1901	14.98	5.48	9.50	3.87	4.89	0.74
" average	14.72	5.36	9.36	3.80	4.82	0.74
November, 1900	14.78	5.35	9.43	3.82	4.86	0.75
" 1901	14.81	5.32	9.49	3.87	4.86	0.76
" average ..	14.80	5.34	9.46	3.84	4.86	0.76
December, 1900 . ..	14.52	5.20	9.32	3.77	4.79	0.76
" 1901	14.77	5.34	9.43	3.85	4.81	0.77
" average ..	14.65	5.27	9.38	3.81	4.80	0.77
General average.	14.71	5.26	9.25	3.66	4.84	0.75

During the time covered by these analyses there was no change in the system of feeding or management and samples were not taken during or immediately after very sudden changes in the weather. The large size of the herd and its divisions into separate groups would minimize any variations which might be due to individual peculiarities or accidental causes, and as there were few changes in the herd and the number of fresh cows did not fluctuate very greatly from month to month, it seems safe to conclude that the differences shown by the monthly averages are due to influences very closely connected with the season and that they may be called seasonal variations.

The diagram on the opposite page is designed to show the variations here found, together with those previously reported by Richmond[1] and by Van Slyke.[2]

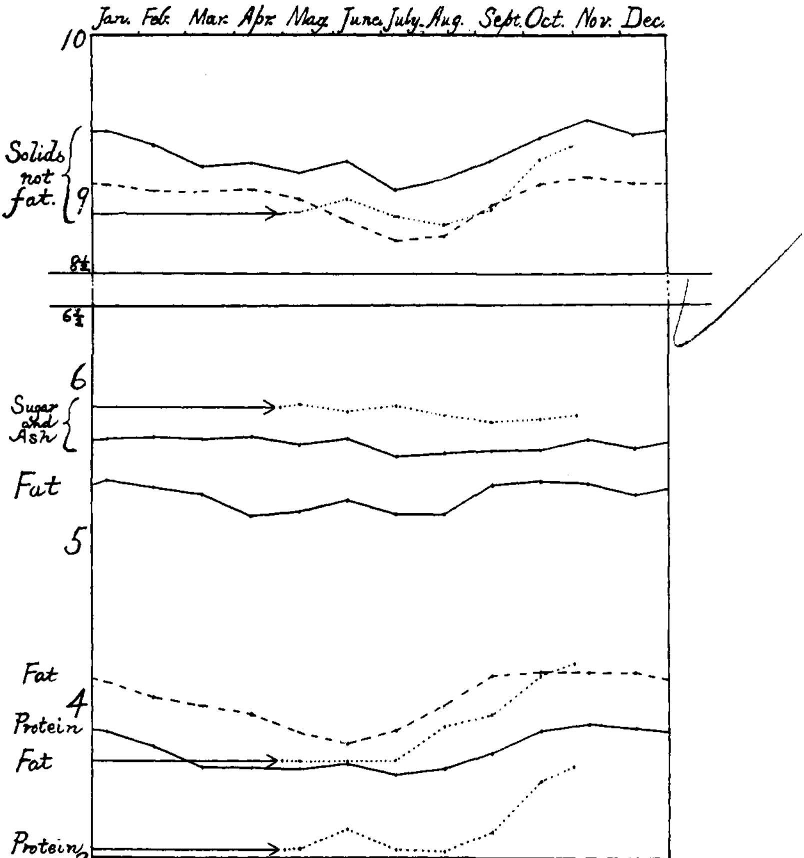
In the diagram the results above given are represented by solid, those of Richmond by broken, and those of Van Slyke by dotted lines. Richmond determined only fat and solids-not-fat. Van Slyke's analyses, while including the determination of proteïn, were made primarily for another purpose and cover only a part of the year.

Richmond's results for fat and for solids-not-fat run nearly parallel. As regards solids-not-fat the writer's results are practically parallel with those of Richmond. On fat, our results are similar to those of Richmond but show less decrease in midsummer. This is probably due to the fact that the herd here studied was managed with special reference to the production of milk of uniformly high fat content. The milk of this herd was

1 "Dairy Chemistry," p. 128 (afternoon milk for 1896). Richmond's more recent analyses show monthly variations of the same character.

2 Averages of data obtained by analysis of milk delivered to certain cheese factories during the summers of 1892–'94, summarized in the report of the New York State Experiment Station for 1894.

richer during the second summer than during the first. The results for the first twelve months would be found nearly parallel to Richmond's.



Van Slyke's results show a greater rise in both fat and solids-not-fat in the autumn, but this is explained by the fact that most of the cows in the herds observed by him had calved in the spring, so that in passing from summer to autumn we find the combined effects of season and of advancing lactation.

Considering the circumstances just mentioned, the three sets of curves show a very close agreement and in each case there is a very evident tendency for the fat and solids-not-fat to rise and fall nearly together.

Passing to the other curves we find the sugar-and-ash percentages[1] to be nearly uniform, the extreme variation between monthly averages being only about 0.1 per cent., while the proteïn runs parallel with the solids-not-fat. In other words, the seasonal variations in solids-not-fat are practically variations in proteïn, the percentage of sugar and ash remaining nearly uniform throughout the year.

COMPOSITION OF SPECIAL SAMPLES.

During the time covered by the monthly analyses recorded above several samples of milk from individual cows or from certain groups of cows in the herd were analyzed. For convenience, most of the samples from individual cows can be grouped in two classes.

Some Unusually Rich Samples.—These samples were taken at random from among many of similar richness. Table II shows the composition of these samples and, where ascertained, the daily yield of milk, and the number of months since the last calf.

TABLE II.—COMPOSITION OF SOME UNUSUALLY RICH SAMPLES.

No.	Months since last calf.	Milk per day. Pounds.	Total solids. Per cent.	Fat. Per cent.	Solids-not-fat. Per cent.	Proteïn ($N \times 6.25$). Per cent.	Milk-sugar. Per cent.	Ash. Per cent.
1	..	..	19.88	8.96	10.92	5.11	4.95	0.86
2	10	9½	19.21	8.94	10.27	4.92	4.55	0.80
3	10	4½	18.99	8.83	10.16	4.38	4.97	0.81
4	"nearly dry"		18.74	8.14	10.60	4.81	4.94	0.85
5	7	9	18.44	7.84	10.60	4.91	4.91	0.78
6	..	12	18.24	7.72	10.52	4.87	4.87	0.78
7	2½	21	17.81	8.04	9.77	3.97	4.96	0.84
8	12	6	17.70	7.42	10.28	4.80	4.66	0.82
9	9	11½	17.70	7.07	10.63	4.96	4.84	0.83
10	10	..	17.28	7.05	10.23	4.80	4.61	0.82
11	..	10	16.83	6.98	9.85	4.59	4.45	0.81
12	3½	14	16.81	6.61	10.20	4.51	4.84	0.85
13	9	8½	16.73	7.34	9.39	4.23	4.31	0.85
	Average		18.03	7.76	10.27	4.68	4.76	0.83

It will be noticed that richness in fat is accompanied in each of these cases by richness in solids-not-fat, while four of the thirteen samples equal or exceed in solids-not-fat the figure given by Richmond[2] as the highest which had come under his notice. This

[1] The writer's results for sugar and ash are here combined in order to facilitate comparison with those of Van Slyke. A small variation in ash following that in proteïn will be noted later.

[2] "Dairy Chemistry," 1899, p. 120.

increase in solids-not-fat occurs almost entirely in the proteïds, which average about 1 per cent. higher in this group of samples than in the mixed milk of the entire herd. In most cases the cows were well advanced in lactation and the yield of milk was rather small. Seven of the samples were from pure-bred Jersey cows and six from Jersey-grades.

Samples Low in Solids-not-fat.—The six samples shown in Table III were all from healthy cows. The first five were obtained during the hot weather of August, 1901. The sixth was from the same cow as the fifth, but was taken three months later. This is the only case in any of the tables where two samples from the same cow are given. While these samples vary considerably in fat content, they are alike in containing low percentages of solids-not-fat.

TABLE III.—SAMPLES LOW IN SOLIDS-NOT-FAT.

No.	Months since last calf.	Milk per day. Pounds.	Total solids. Per cent.	Fat. Per cent.	Solids not-fat Per cent.	Proteïn ($N \times 6.25$). Per cent.	Milk-sugar. Per cent.	Ash. Per cent.
1	6	10½	14.29	6.09	8.20	3.66	3.78	0.76
2	9½	11	11.97	3.71	8.26	3.55	4.00	0.71
3	2	26½	10.83	2.64	8.19	2.86	4.58	0.75
4	9	7	10.65	3.27	7.38	3.24	3.43	0.71
5	7	8	11.77	4.69	7.08	3.57	2.81	0.70
6	10	6½	9.66	2.97	6.69	3.17	2.86	0.66
	Average		11.53	3.90	7.63	3.34	3.59	0.71

The percentages of proteïds are here somewhat lower than in Table I, but are not low in proportion to the fat present. Averaging the six analyses it happens that the fat percentage is practically that which has been found as the general average for ordinary cows' milk. It is noticeable that the averages for proteïn and ash are also strikingly close to the estimated general averages, while the sugar is here considerably below the normal average. In other words, the deficiency of solids-not-fat is all in the milk-sugar. This is in accordance with Richmond's opinion[1] that "when genuine samples are low in solids-not-fat, the proteïds and ash are normal and the milk-sugar is the constituent on which the deficiency falls."

RELATIONS BETWEEN THE PRINCIPAL CONSTITUENTS.

Relation of Proteïn to Fat.—Timpe[2] announced in 1899, appar-

[1] *The Analyst*, **25**, 226.
[2] *Chem. Ztg.*, **23**, 1040.

ently on the basis of less than thirty analyses, that there exists a definite quantitative relation between the percentages of fat and proteïds in cows' milk which may be expressed by the formula proteïds $= 2 + 0.35$ fat. A similar conclusion, though differently expressed, had been reached by Cooke[1] some years earlier as the result of an extensive compilation of American analyses. Cooke found that in milks containing not less than 13 per cent. of total solids, the milk-sugar is nearly constant while "the proteïds increase with the total solids, being always about one-fourth." Since the other three-fourths of the increase is practically all fat it is evident that this relation might be expressed by a formula almost identical with that of Timpe. The work of the latter was, however, strongly criticized by Richmond,[2] who gives the average results of analyses of about fifty samples grouped according to fat content and concludes that while there is a tendency for the proteïds to be higher when the fat is high, this tendency is very much less than that indicated by Timpe's formula. Comparing the average results found by Woll[3] in testing cows of different breeds, it appears that he failed to find the differences in proteïn quite as large in proportion to the differences in fat as the formula would indicate.

Applying to the analyses given above the formula which expresses the conclusion reached by Cooke (proteïn $= 2 + {}^1/_3$ fat) we find that with samples from individual cows there may be considerable discrepancies, but if we take the average milk of the herd for the year or the average of Table II or of Table III, the figure for proteïn given by the formula is within 0.1 per cent. of the amount actually found. To test this point further the following samples were analyzed: (1) a composite sample of the milk of 14 cows taken at random from among those low in fat, (2) the mixed milk from a group of about 100 cows which had been regularly found below the average of the herd in fat content, (3) the mixed milk from a group of about 100 cows of which a large proportion were well advanced in lactation, and (4) a sample of the mixed milk of the entire herd taken in May, 1902, when fresh pasture and a change in the grain ration had produced a temporary rise in fat content. The analyses of these samples follow:

[1] Vermont Experiment Station Report for 1890, p. 97.
[2] *The Analyst*, **25**, 225.
[3] Wisconsin Experiment Station Report for 1901, p. 85.

No.	Total solids. Per cent.	Fat. Per cent.	Proteïn. Per cent.	Milk-sugar. Per cent.	Ash. Per cent.
1	12.78	3.91	3.25	4.92	0.69
2	14.34	5.07	3.64	4.89	0.74
3	15.39	5.67	4.03	4.87	0.82
4	15.05	5.76	3.77	4.75	0.77

In each of the first two samples the percentage of proteïn is within 0.05 per cent. of that which would be calculated from the formula. In (3), where the richness of the milk was due chiefly to advanced lactation, the increase in proteïn is more than one-third of the increase in fat, while in (4), where the fat content was temporarily increased by a change of food, the increase in proteïn is less than one-third as great.

The data at present available indicate that aside from the seasonal variation already noticed, the percentages of fat and proteïn tend to rise and fall together, though not to the same extent, that the average relation between the two is approximately expressed by the formula, proteïn $= 2 + {}^1/_3$ fat, but that the proteïn often shows less variation from the average than this formula would imply.

Relation of Ash to Proteïn.—According to Richmond[1] the percentage of ash may be deduced with fair accuracy from that of proteïn by the formula, ash $= 0.36 + 0.11$ proteïn. Most of the analyses given in this paper had been made and the tendency of the ash to vary with the proteïn had been noticed when the above formula was published. On applying it to our results, we find a very close agreement between the percentages of ash calculated and those actually found. The discrepancies were as follows: (1) In 24 samples of the mixed milk of the herd, from $+ 0.05$ to $- 0.01$, average $+ 0.015$ per cent; (2) In 7 samples of mixed milk from groups of 6 to 100 cows, from $+ 0.05$ to $- 0.02$, average $+ 0.021$; (3) In 23 samples of milk from individual cows, four of which contained over 5 per cent. of proteïn, from $+ 0.12$ to $- 0.08$, average $+ 0.033$. If the formula be modified to read ash $= 0.38 + {}^1/_{10}$ proteïn, an even better agreement is obtained, the above discrepancies becoming, respectively, (1) from $+ 0.03$ to $- 0.02$, average $+ 0.001$; (2) from $+ 0.02$ to $- 0.04$, average 0.000; (3) from $+ 0.09$ to $- 0.08$, average $+ 0.010$.

Relation of Milk-Sugar to Other Constituents.—The analyses do not indicate that the milk-sugar has any tendency to rise and

[1] *The Analyst*, **26**, 310.

fall with any other constituent. In normal milk the percentage of sugar in the serum seems to be very nearly constant. Certainly it shows smaller relative variations than any other of the principal constituents and such variations as occur are usually so irregular as to appear accidental. Analytical errors also would be larger here than elsewhere, inasmuch as the milk-sugar is usually estimated by difference. In milk showing an unusually low percentage of solids-not-fat, the deficiency is found to be principally in the milk-sugar. Such milk may be yielded by healthy cows and is most commonly but not exclusively found in hot, dry weather. Occasionally there may be in midsummer a sufficient number of such cases to cause an appreciable lowering in the sugar content of the mixed milk of a large herd, but ordinarily there seems to be no seasonal variation in the percentage of milk-sugar such as is found in the case of fat, of proteïn, and to some extent also of ash.

SUMMARY.

As all of the samples analyzed were from one herd of cattle, the following statements, while summarizing the results which we have obtained, may not be equally applicable to milk produced under other conditions.

Monthly analyses extending over two years showed the percentage of proteïn, like that of fat, to vary with the season, being higher in fall and winter than in spring and summer, while the percentage of milk-sugar remained nearly constant throughout the year.

In general, a milk rich in fat will also be rich in proteïn. In these analyses the excess of proteïn above the normal averaged about one-third as much as the excess of fat.

All of the results obtained accord with the conclusion recently reached by Richmond that any deficiency of solids-not-fat is chiefly due to a deficiency in the milk-sugar, while any excess above 9 per cent. is chiefly due to an excess of proteïn.

In practically all of the samples examined the relation between proteïn and ash was very nearly that found by Richmond and expressed by the formula, ash $= 0.36 + 0.11$ proteïn. To agree more exactly with our averages, the formula may be modified to read ash $= 0.38 + {}^{1}/_{10}$ proteïn.

NEW YORK CITY,
September, 1902.