ART. XXIII.—*Tschermak's Theory of the Chlorite Group and its Alternative*; by F. W. CLARKE.

IN the micas, vermiculites, the clintonite group, and the chlorites, we meet a large number of minerals having similar properties. All are probably monoclinic, all are commonly foliated in structure, and within certain limits they shade into each other in composition. The resemblances between them are very close externally; and it is therefore a fair presumption that they are also alike in constitution. A satisfactory explanation of their chemical structure ought to emphasize their obvious relationships, and be sufficiently general to include all the individual species in a single definite theory. The problem is easily stated, but its solution can be effected only by slow degrees. Like other similar problems, it must be solved by a series of approximations; and every step towards order is a gain, even though it be not absolutely final.

Among the men who have advanced our knowledge of these minerals, no one is entitled to higher credit than Professor Tschermak. His successive papers upon the mica, clintonite, and chlorite groups have all been long strides forward; and whether his interpretations are ultimately confirmed or abandoned, they have none the less been of real service in the development of knowledge.

In his latest paper,* Professor Tschermak seeks to explain the chemical structure of the chlorites, and masses the available evidence most admirably. This group of minerals he divides into two sub-groups, called orthochlorites and leptochlorites respectively, and for each division a special explanation is offered. The orthochlorites, which include pennine, clinochlore, leuchtenbergite, prochlorite and corundophilite, are simply represented as mixtures of two end products, serpentine and amesite; and so far as the mere ultimate composition of the minerals is concerned, the interpretation is quite satisfactory. On theoretical grounds it leaves something to be desired, as will appear later. The leptochlorites, however, or chlorites outside of the main series, are less easily handled; and for these, in addition to the serpentine and amesite molecules, four other fundamental compounds are assumed; namely, two derivatives of amesite, strigovite and chloritoid. Six types of molecule are in all adopted; which, by mixtures in various proportions account for all the species. Written semi-empirically, these molecules are as follows:

* Die Chloritgruppe, II, Theil, Sitzungsab. Akad. d. Wiss. in Wien, 19 Feb., 1891.

Serpentine,	Sp.	$\text{MgSi}_2\text{O}_7 \cdot \text{H}_2 \cdot (\text{MgOH})_2$
Amesite,	At.	$\text{Al}_2\text{Si}_2\text{O}_7 \cdot \text{H}_2 \cdot (\text{MgOH})_2$
“ 1st deriv.,	At'.	$\text{Al}_2\text{Si}_2\text{O}_7 \cdot \text{H}_3 \cdot \text{MgOH}$
“ 2d “	At''.	$\text{Al}_2\text{Si}_2\text{O}_7 \cdot \text{H}_4$
Strigovite,	St.	$\text{SiO}_2 \cdot \text{Al}_2\text{Si}_2\text{O}_7 \cdot \text{H}_2 \cdot (\text{MgOH})_2$
Chloritoid,	Ct.	$\text{Al}_2\text{Si}_2\text{O}_7 \cdot \text{H}_2 \cdot \text{Mg}$

Of these compounds, four are represented by known minerals; although the amesite and strigovite formulæ rest each upon a single analysis. Two, the molecules At' and At'', are hypothetical. Empirically, all the chlorites of well established character correspond in composition to mixtures of these six molecules; but a few of the allied minerals, such as epichlorite and stilpnomelane, are unaccounted for. The latter are yet to be brought into line.

At a first glance the six molecules, as just written, appear to be remarkably alike in form. But when they are written structurally, as Tschermak himself writes them, they become somewhat dissimilar. Serpentine is then represented as a salt of the acid $\text{H}_4\text{Si}_2\text{O}_7$. Amesite, with its two derivatives and chloritoid, appear as basic orthosilicates. Strigovite is given as a salt of the acid $\text{H}_4\text{Si}_2\text{O}_6$. That is, three different silicic acids are involved in Tschermak's theory, and the first apparent simplicity of the scheme disappears. All of the six molecules, however, with the single exception of the non aluminous serpentine, are supposed to contain the structural nucleus

to which the remarkable similarities of the chlorites may be due. Through chloritoid the chlorites become affiliated with the clintonite group; but with the micas, at least as the latter have been interpreted by Tschermak hitherto, no special analogies of structure appear.

Now, admitting that Tschermak's theory accounts for the known facts as fully as he believes, the question arises whether his mode of interpretation is the only one possible. If it is, then the problem of the chlorite group is solved, and controversy is out of court. But if other schemes can be devised, representing the facts equally well, further investigation becomes necessary. Pending the acquirement of new experimental evidence, we may discuss rival systems upon philosophical grounds; and that which is simplest, most general, and best supported by analogies, should have preference. Ultimately, of course, the problem must be attacked by means of experiment; through which alone the questions at issue can be finally settled.

In several previous papers, some of them written in joint authorship with others,* I have sought to establish the hypothesis that the more complex silicates are merely substitution derivatives of normal salts. For instance, many minerals are easily and naturally represented as so derived from the normal aluminum compound $\text{Al}_4(\text{SiO}_4)_3$; successive aluminum atoms being equivalently replaced by other atoms or groups. Among these minerals, the micas seem to form a conspicuous family, and with them are found the clintonite group and some vermiculites. To this family I shall recur later.

In two quite recent papers, Schneider and I have tried, by experimental methods, to obtain some positive evidence as to the nature of the chlorites. That our results are not final, and that Tschermak's criticism of them is perfectly legitimate, I cheerfully concede, and yet we have found clues which are not without meaning. The reaction between dry hydrochloric acid and the hydromagnesian silicates we are still investigating, and its actual character and significance we hope to determine in due time. So far, however, in every case of a true chlorite examined by us, and in the case of serpentine also, we have found that the chemical constitution *may* be represented by a mixture of molecules of the general form $\text{Mg}_2(\text{SiO}_4)_2 \text{R}'_4$, in which R' may be either AlH_2O_2 , MgOH , or H , with of course the usual equivalent replacements of aluminum and magnesium by ferric and ferrous iron. These molecules are evidently substitution derivatives of the normal compound olivine, when the ordinary formula of the latter is doubled and made $\text{Mg}_2(\text{SiO}_4)_2$. Since we do not know the true molecular weight of any metallic silicate, this doubling of the simplest possible formula is perfectly allowable, and a reason for it will appear later. Here then, for a few chlorites at least, is a scheme of interpretation quite unlike Tschermak's; and we have to determine whether it is equally exact and equally general.

Taking Tschermak's paper as a basis for comparison, and discussing at first only the analyses discussed by him, I find that all of his orthochlorite series, except corundophilite and amesite, reduce sharply to the above given type of formula. Omitting amesite, which will be separately considered further on, every orthochlorite may be written $\text{R}''_2(\text{SiO}_4)_2 \text{R}'_4$, with various relations between the several components collectively represented by R'_4 . In fact, Tschermak's formulæ and mine, although quite dissimilar, are curiously parallel; as the following scheme, based upon his classification of the orthochlorites, plainly shows. His arrangement of the sub-group is this:

* See U. S. Geological Survey Bulletins, numbers 27, 42, 60, 64 and 78. Also this Journal for Sept., 1891.

Pennine,	Sp_3At_2 to SpAt
Clinochlore,	SpAt to Sp_2At_3
Prochlorite,	Sp_2At_3 to Sp_3At_7
Corundophilite,	Sp_3At_7 to SpAt_4

Transforming these expressions, and, for brevity, writing $\text{AlH}_2\text{O}_2 = \text{A}$, and $\text{MgOH} = \text{M}$, we have :

In the last case, corundophilite, Tschermak's formula agrees better with the actual analyses than any formula derived from my system. The cause of divergence will be considered in connection with the structure of amesite, later. Although the difference is small it ought not to be ignored.

In general, then, the orthochlorites may be provisionally regarded as mixtures of the three typical or generic salts $\text{Mg}_2(\text{SiO}_4)_2\text{A}_4$, $\text{Mg}_2(\text{SiO}_4)_2\text{M}_4$, and $\text{Mg}_2(\text{SiO}_4)_2\text{H}_4$. Whether these compounds exist separately in the mineral kingdom is an open question, and one not easy to answer. To each of them there are approximations; ekmannite for example is near $\text{Fe}_2(\text{SiO}_4)_2\text{H}_4$ in composition; but it is more probable that the chlorites proper are mixtures of intermediate salts. Some pennines, for instance, fall near the compound $\text{Mg}_2(\text{SiO}_4)_2\text{AMH}_2$; and other like substances appear among the minerals which Tschermak places in the subgroup of leptochlorites. A consideration of the latter must precede further discussion of theory.

According to Tschermak, the leptochlorites form three subgroups, as follows :

I. Daphnite,	$\text{At}_5\text{At}'_6\text{Sp}$
Chamosite,	$\text{At}_3\text{At}'_3\text{Sp}$
II. Metachlorite,	$\text{At}_6\text{St}_2\text{Sp}_3$
Klementite,	$\text{At}_4\text{St}_2\text{Sp}$
Cronstedtite,	AtSt
Thuringite,	AtSt
Euralite,	At_3St_4
Strigovite,	St
III. Diabantite,	Ct_4Sp_7
Aphrosiderite,	$\text{Ct}_6\text{At}_6\text{Sp}_4$ to $\text{Ct}_3\text{At}_4\text{Sp}_4$
Delessite,	$\text{Ct}_2\text{At}_2\text{Sp}_6$ to CtSp
Rumpfite,	$\text{Ct}_4\text{At}'_4\text{Sp}$

Epichlorite, grengesite, melanolite, etc., he regards as chlorites, but as not yet definable. The delessite from Friedrichs roda he places provisionally in the first division of the leptochlorites, along with daphnite and chamosite. The formulæ given are deduced from specific analyses, but when several

analyses exist for a species, a considerable variability becomes manifest, which must influence all attempts to fix the molecular structure.

Taking now the analyses as cited by Tschermak, a number of them reduce at once to the same type of substitution formula as that which I have assigned to the orthochlorites. Uniting like oxides, Fe_2O_3 with Al_2O_3 , MgO with FeO , etc., we get at once the following expressions from the analytical data. The name of the analyst follows the name of the species:

Daphnite, Zeynek,	$\text{Fe}_{39}''(\text{SiO}_4)_{40} \cdot \text{H}_{15}\text{A}_{44}\text{M}_{22}$
Chamosite, Boricky,	$\text{Fe}_{42}''(\text{SiO}_4)_{43} \cdot \text{H}_{25}\text{A}_{37}\text{M}_{23}$
Delessite, Pufahl,	$\text{Mg}_{40}''(\text{SiO}_4)_{50} \cdot \text{H}_{38}\text{A}_{40}\text{M}_{22}$
Thuringite, Gintl,	$\text{Fe}_{11}''(\text{SiO}_4)_{39} \cdot \text{H}_{11}\text{A}_{49}\text{M}_{18}$
“ Keyser,	$\text{Fe}_{44}''(\text{SiO}_4)_{40} \cdot \text{H}_{12}\text{A}_{60}\text{M}_{11}$

An approximation to close agreement with theory is evident at a glance; but a better conception of the agreement may be obtained by calculation, using the following formulæ:

Daphnite,	$\text{Fe}_3(\text{SiO}_4)_2\text{A}_2(\text{FeOH})_1\text{H}_1$
Chamosite,	“
Delessite,	$\left\{ \begin{array}{l} 1 \text{ Fe}_3(\text{SiO}_4)_2\text{A}_2(\text{FeOH})_1\text{H}_1 \\ 3 \text{ Mg}_2(\text{SiO}_4)_2\text{A}_2\text{M}_1\text{H}_1 \\ 1 \text{ Fe}_2(\text{SiO}_4)_2\text{H}_4 \end{array} \right.$
(Friedrichsroda)	
Thuringite,	$\left\{ \begin{array}{l} 3 \text{ Fe}_3(\text{SiO}_4)_2\text{A}_2(\text{FeOH})_1\text{H}_1 \\ 1 \text{ Fe}_2(\text{SiO}_4)_2\text{A}_4 \end{array} \right.$

To this list we may add the thuringite from Lake Superior, analyzed by Penfield and Sperry, which becomes $5\text{Fe}_2(\text{SiO}_4)_2(\text{FeOH})_4 + 9\text{Fe}_2(\text{SiO}_4)_2\text{A}_4$. The analyses, reduced to typical form and to 100 per cent, as is usual, are as follows:

	Daphnite. Zeynek.	Chamosite. Boricky.	Delessite. Pufahl.	Thuringite. Gintl.	Thuringite. Keyser.	Thuringite. P. & S.
SiO_2	23.44	25.17	29.75	23.58	24.15	21.35
Al_2O_3	22.08	18.41	20.58	25.11	25.44	24.02
FeO	43.41	45.37	19.42	40.08	39.39	43.88
MgO	----	----	17.53	----	----	----
H_2O	11.07	11.05	12.72	11.23	11.02	10.75
	100.00	100.00	100.00	100.00	100.00	100.00

Calculated from the formulæ just given they become:

	Daph. & Cham.	Deless.	Thuring. G. & K.	Thuringite, P. & S.
SiO_2	24.39	30.30	23.81	21.54
Al_2O_3	20.73	20.60	25.30	23.54
FeO	43.90	18.18	39.29	44.31
MgO	----	18.18	----	----
H_2O	10.98	12.74	11.60	10.61
	100.00	100.00	100.00	100.00

In short, these chlorites are apparently compounds of precisely the same type as the orthochlorites. Daphnite and chamosite vary from theory by small amounts in opposite directions, the one having a trifling excess of an FeOH salt, the other an excess of an AlH_2O_2 compound. Closer agreements could not be reasonably expected.

In order to properly interpret the remaining leptochlorites, we must return to the fundamental idea of the substitution hypothesis. Starting with the normal ortho-salt, we get at once the following probable series of derivatives.

In the first of these derivatives, the compound intermediate between the orthochlorite type and olivine, we find the key to most of the leptochlorites. Again discussing the analyses mainly considered by Tschermak, omitting strigovite and rumpfite for separate inspection, we get the subjoined semi-empirical expressions:

Metachlorite, at one end of this series, corresponds nearly to the orthochlorites; while aphrosiderite, at the other end, approaches the composition $\text{Fe}_3(\text{SiO}_4)_2\text{A}_4$. All the other minerals in the series fall between these extremes. Reduced to general form, the expressions become:

These ratios, of course, are not rigidly exact, but they vary no more from the analyses considered than the analyses of the different occurrences in any one species vary among themselves. In the last case, the actual analyses show small admixtures of the orthochlorite type; but the approximation is

* The delessite from Bowling Quarry. The samples from Dumbuck and Long Craig agree well with this.

nevertheless quite close to theory. It will be seen that the value of R'_4 in the second term of each expression is constant; that is, that we have either AlH_2O_2 or the corresponding ferrie radicle; but the values of the first term are somewhat different. In metachlorite, as in daphnite and chamosite, $R'_4 = A_2MH$; in cronstedtite it is A_4 , and in delessite it is H_4 . In klementite we have $R'_4 = A_3M$; in diabantite, $3R'_4 = M_4H_8$; and in euralite $7R'_4 = A_{22}H_6$. Such ratios, however, are difficult to fix sharply, because of the uncertainties in the water determinations. In Heddle's analyses, however, the water given off at 100° is distinguished from that retained at higher temperatures, and the results are correspondingly favorable to theory. In his delessite, for instance, the water becomes partly water of crystallization; and the mineral from Bowling Quarry agrees well with the formula $2Mg_3(SiO_4)_2A_4$, $2aq + Mg_2(SiO_4)_2H_4$; with about $\frac{2}{7}$ of the magnesium replaced by ferrous iron. Calculating the composition of each mineral from the formulæ given below, and comparing the results with the *reduced* analyses from which the expressions were derived, we can judge of the closeness with which the facts and the theory agree.

Metachlorite,	$4Fe_2(SiO_4)_2A_2(FeOH)H + Fe_3(SiO_4)_2A_2$
Euralite,	$7Mg_2(SiO_4)_2R'_4 + 3Mg_2(SiO_4)_2A_2$
Diabantite,	$4Mg_2(SiO_4)_2R'_4 + 3Fe_2(SiO_4)_2A_2$
Klementite,	$Mg_2(SiO_4)_2A_3M + Mg_3(SiO_4)_2A_2$
Delessite,	$Mg_2(SiO_4)_2H_4 + 2Mg_3(SiO_4)_2A_2, 2aq.$
Cronstedtite,	$Fe_2(SiO_4)_2(Fe''H_2O_2)_4 + 4Fe_3(SiO_4)_2(Fe''H_2O_2)_2$
Aphrosiderite,	$Fe_3(SiO_4)_2A_2$

	Metachlorite.		Euralite.		Diabantite.	
	Found.	Calc.	Found.	Calc.	Found.	Calc.
SiO_2	23.82	24.57	37.74	38.15	34.05	34.34
Al_2O_3	20.42	20.88	18.48	19.45	12.80	12.51
Fe_2O_3	----	----	----	----	----	----
FeO	45.76	44.23	----	----	26.32	26.49
MgO	----	----	30.91	29.24	16.70	16.35
H_2O	10.00	10.32	12.87	13.16	10.13	10.31
	100.00	100.00	100.00	100.00	100.00	100.00
	Klementite.		Cronstedtite.		Aphrosiderite.	
	Found.	Calc.	Found.	Calc.	Found.	Calc.
SiO_2	28.85	28.78	21.18	21.56	24.54	25.31
Al_2O_3	30.36	30.57	----	----	22.59	21.52
Fe_2O_3	----	----	35.74	34.48	----	----
FeO	----	----	35.19	36.20	43.87	45.57
MgO	28.73	28.78	----	----	----	----
H_2O	12.06	11.87	7.89	7.76	9.00	7.60
	100.00	100.00	100.00	100.00	100.00	100.00

	Delessite.	
	Found.	Calc.
SiO ₂	34.00	33.83
Al ₂ O ₃	19.34	19.17
MgO	30.24	30.08
H ₂ O	10.36	10.15
Aq	6.06	6.77
	<hr/> 100.00	<hr/> 100.00

In reducing the data, and in calculating the formulæ, I have commonly assumed R'' to be all magnesium or all iron according as one or the other predominated. Only in diabantite the relation between the Fe and Mg was so simple that it seemed desirable to keep both in view. I have also used relatively simple ratios between component molecules, rather than the more complex terms which might give a closer agreement between analyses and theory. That is, when Mg₂(SiO₄)₂R'₄ and Mg₃(SiO₄)₂A₂ stood actually in the relation of 11 to 10, I have computed on the basis of 1:1. Most of the divergences between "found" and "calculated" are due to this cause; but in the case of cronstedtite, which is least concordant of all, there is probably a small admixture of some more basic compound, of the character, possibly, of amesite.

There now remains to be considered, of all of Tschermak's typical chlorites, only strigovite, rumpfite, amesite, and in part corundophilite. Of these, the first three depend each upon a single analysis, and the available evidence is therefore not conclusive. To strigovite, the general formula H₄Fe''₂Al₂Si₂O₁₁ seems to apply; which, in the constitutional expression given to it by Tschermak has already been cited. This may also be written Fe₂(SiO₄)₂·H(AlH₂O₂)(AlOH), which is of the orthochlorite type with the bivalent group AlOH in place of R'. In rumpfite, which has the empirical formula H₂₈Mg₇Al₁₆Si₁₆O₆₈, the same group AlOH appears, and also a molecule of the form of the last derivative of olivine, Mg(SiO₄)₂R'. In detail, rumpfite agrees very nearly with the composition

which gives with the analysis by Firtsch reduced as usual, the following comparison:

	Rumpfite.	
	Found.	Calc.
SiO ₂	31.01	30.20
Al ₂ O ₃	42.02	42.79
MgO	13.73	13.42
H ₂ O	13.24	13.59
	<hr/> 100.00	<hr/> 100.00

It must be remembered that in order to account for rumpfite, Tschermak assumed the existence of the constituent molecule At'' , which appears in none of his other chlorites. Both in his scheme and in mine the mineral is exceptional, and undoubtedly it needs further study.

In amesite, which occurs with corundophilite, we find another chlorite of peculiar composition. It is the most basic member of the group, and contains more oxygen relatively to its silicon, than any other chlorite known. Its formula, as written by Tschermak, is $Al_2SiO_4 \cdot H_2(MgOH)_2$, which is the equivalent of his serpentine molecule, with Al_2 in place of $MgSi$. As we have no experimental evidence from which to reason, we may with equal propriety regard amesite as having the structure

when it becomes analogous in structure to the other chlorites, standing in a similar relation to them as that which the clintonite group bears toward the micas. On this supposition the micas and chlorites, as has already been shown elsewhere,* form two parallel series of compounds, as follows:

Normal orthosilicate,	$Al_4(SiO_4)_3$		$Mg_4(SiO_4)_2$
Whence derive—	<i>Micas</i>		<i>Chlorites</i>
Muscovite,	$Al_3(SiO_4)_3R_3$	Aphrosiderite,	$Mg_3(SiO_4)_2R_2$
Normal biotite,	$Al_2(SiO_4)_3R_6$	Orthochlorites,	$Mg_2(SiO_4)_2R_4$
“ phlogopite,	$Al_2(SiO_4)_3R_6$		$Mg(SiO_4)_2R_6$
Clintonite,	$Al < \begin{smallmatrix} O \\ O \end{smallmatrix} > R''$	Amesite,	$O < \begin{smallmatrix} Mg \\ Mg \end{smallmatrix} > SiO_4 = R_2$
	$\backslash SiO_4 \equiv R_3$		

In certain respects, this general scheme is not incompatible with Tschermak's views. The orthochlorites, for example, he regards as mixtures of serpentine and amesite, representing the structure of those compounds in a special way. But if serpentine be written $Mg_2(SiO_4)_2 \cdot H_2(MgOH)_2$, and amesite as I have just suggested, the theory of substitution is satisfied, and the orthochlorites may be classified as intermediate between the two end terms. Then, however, the leptochlorites fall less easily into line, and the slight gain in apparent simplicity in the ortho series is offset by loss elsewhere. It is quite probable, however, that corundophilite is a mixture containing amesite molecules; and the formula which I give the latter mineral is sustained to some extent by the fact that both minerals occur intimately associated with diaspore. At Chester, the only locality for either corundophilite or amesite represented by analyses, the chlorites are commonly found in seams

* Clarke and Schneider, this Journal, Sept., 1891.

with diaspore on one side and emery on the other. Hence the group AlH_2O_2 is at least as likely to be found in amesite as the magnesian compound MgOH .

Still another analogy between the micas and the chlorites remains to be noted. In the phengitic muscovites, in some phlogopites and in the lithia micas, the ratio of silicon to oxygen is less than 1:4, and often approaches 1:3. This variability, as I have shown in my paper upon "A theory of the mica group,"* is easily explained by supposing an admixture of molecules containing the group Si_3O_8 in place of SiO_4 . This equivalency is well recognized in the feldspar series; and among the micas it is forcibly emphasized by the existence of Lorenzen's polylithionite, in which the group Si_3O_8 replaces SiO_4 entirely. Does this group occur in chlorites also?

At the end of his discussion of the leptochlorites, Tschermak dismisses a number of minerals as doubtful in character, either because of unsatisfactory analyses, or uncertainty in the material described. In particular he names the species grengesite, hullite, melanolite and stilpnomelane, to which he adds epichlorite. All of these minerals, together with epiphanite and possibly strigovite, may be reduced to typical form by assuming the presence of Si_3O_8 . For grengesite and hullite the analyses are not satisfactory, and the formulæ deducible have therefore no weight. Strigovite has been already explained by assuming in it the group AlOH , but a reconsideration here is worth noting as offering an alternative formula to that previously given. The formulæ which I have obtained are as follows:

Here we find stilpnomelane and melanolite are orthochloritic in type; epiphanite is equivalent to aphrosiderite, and the other species are intermediate like most of the leptochlorites. The analyses discussed are these:

Stilpnomelane from Antwerp, N. Y., by Brush.

Melanolite, Somerville, Mass., by H. Wurtz.

* Bulletin, U. S. Geological Survey, No. 64.

Epichlorite, from the Hartz, by Rammelsberg.

Strigovite, Striegau, by Websky.

Epiphanite, Wernland, by Igelström.

The reduced analyses are as follows :

	Stilpnomelane.		Melanolite.	
	Found.	Calc.	Found.	Calc.
SiO ₂	42·85	41·80	34·25	33·46
Fe ₂ O ₃	24·74	26·01	29·32	29·74
FeO	23·69	23·41	26·48	26·76
H ₂ O	8·72	8·78	9·95	10·04
	<hr/>	<hr/>	<hr/>	<hr/>
	100·00	100·00	100·00	100·00
	Epichlorite.		Strigovite.	
	Found.	Calc.	Found.	Calc.
SiO ₂	43·94	45·50	29·51	30·20
Al ₂ O ₃	17·75	16·58	24·78	24·25
FeO	----	----	36·05	36·24
MgO	27·38	28·17	----	----
H ₂ O	10·93	9·75	9·66	9·31
	<hr/>	<hr/>	<hr/>	<hr/>
	100·00	100·00	100·00	100·00

For epiphanite Igelström's analysis needs no reduction, if we calculate with a ratio of Mg:Fe:7:5.

	Found.	Calc.
SiO ₂	37·10	37·66
Al ₂ O ₃	21·13	21·34
FeO	20·00	18·83
MgO	14·03	14·64
H ₂ O	7·83	7·53
	<hr/>	<hr/>
	100·09	100·00

The agreements are sufficiently close to establish the validity of the hypothesis upon which the calculations rest, although they are not as good in all cases as might be desired. Still, the formulæ offered bring some order out of chaos, and are therefore entitled to consideration until something better is proposed.

As between Tschermak's theory and mine, both representing the known facts fairly well, experimental research must be the final arbiter. Until experiment has given grounds for decision either theory may properly be used as a guide. Mine is offered as a possible simplification of the problem; but both may be supplanted by something more general still. Neither theory exhausts all the possibilities of the question, and neither can claim to be much more than a step forward in the series of approximations by which the truth may be at last attained.

Washington, Dec. 12, 1891.