A chemical, optical, and X-ray study of nepheline and kaliophilite.

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(With Plates XXI and XXII.)

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SUMMARY.—Correlated data prove the approximate constancy of the number of oxygen atoms in the unit cells of several nepheline and elaeolite specimens. Thence the number of atoms of each kind per unit cell have been counted. The cell-volumes and optical properties have also been correlated with the chemical composition. An approximate structure is suggested which, together with the chemical work, explains the variable composition of nepheline. The contents of the unit cell may be written $Si_{16-n}Al_n(Na,K,\frac{1}{2}Ca)_n O_{32}$, where n ranges from 6·6 to 8·2. Kaliophilite is shown to possess a much larger cell than that of nepheline, and its Lauegram exhibits higher symmetry. 'Pseudonepheline' (rich in potassium) has a slightly greater cell-volume than normal nepheline, but its Lauegram is almost identical and its axial ratio only slightly less.

NEPHELINE.

The occurrence of nepheline as well-formed crystals is restricted to comparatively few localities, although as the massive variety elaeolite and more generally as a rock-forming mineral it is very widely distributed. Kaliophilite has been observed only in the ejected blocks from Mt. Vesuvius, Italy. Both minerals possess hexagonal symmetry and are generally represented by the simple formulae $NaAlSiO_4$ and $KAlSiO_4$ respectively, although in the former case it has long been recognized that some potassium is also present and the silica content is more than that indicated by the formula. With one or two exceptions, the careful chemical work that has already been carried out on nepheline has been directed to obtaining empirical molecular formulae in agreement with the analyses, and the scarcity of correlated chemical and physical data has so far hindered any attempt to relate variations of chemical composition with changes in physical properties.

The present work has been mainly undertaken to correlate changes in refractive index, birefringence, dispersion, density, and unit-cell dimensions of nepheline with changes in chemical composition, and also to trace the physical and chemical relationship between the minerals nepheline and kaliophilite. Nepheline, for which there has been much more material available for study, will first be dealt with. Nine specimens in all were selected from the British Museum collection, including two specimens of elaeolite from different localities. The well-known Monte Somma nephelines are represented by six specimens, these having been chosen in the first place because they showed sensible variations in refractive index and density. The ninth specimen is a nepheline from Capo di Bove near Rome. This probably corresponds to the nepheline first named 'pseudonepheline' and is of particular interest owing to the high potassium content.

I. Nepheline, Monte Somma, Mt. Vesuvius, Italy. Large glassy hexagonal prisms enclosing needles of hornblende, on a block containing sanidine, augite, hornblende, idocrase, and wollastonite. This specimen originally belonged to T. Monticelli, whose magnificent collection of Vesuvian minerals and rocks was acquired by the Trustees of the British Museum in 1823. B.M. 59691(24).

II. Nepheline, Monte Somma. Large clear crystals (one having a base-edge of 10 mm., height 7 mm.) associated with hornblende and idocrase on a sanidine block. B.M. 59846.

III. Nepheline, Monte Somma. Small crystals varying in dimensions from the size of a pea to large translucent crystals, one measuring 8 mm. in height, and having a base-edge of 12 mm., in augite-lined cavities of a mica-forsterite block. The crystals enclose flakes of a very pale green biotite. B.M. 59844(3).

IV. Nepheline, Monte Somma. Large, friable, milk-white prisms on a block containing green augite, brown biotite, hornblende, sanidine, and idocrase. The crystals vary from about the size of a pea up to 9 × 6½ mm. B.M. 51495.

V. Elaeolite, Ilmen Mts., Urals, Russia. This specimen (5 × 2½ × 2 cm.) was originally labelled 'cancrinite', but it lacks a perfect prismatic cleavage. The fragment has a faint pink colour and gave sufficient fresh material for chemical and physical work. B.M. 39946.

VI. Nepheline, Monte Somma. Clusters of perfect glassy crystals, varying from 5 to 10 mm. in length, the base-edge being in most cases about one-third the height, with large idocrase crystals on a carpet of augite covering a limestone block. B.M. 51493.

VII. Elaeolite, Larvig, Norway. A green slab (10 × 7 × 4 cm.) including hornblende and fluorspar. Fragments were taken from the fresh part of the specimen where the material seemed uniform except for a few white streaks. A well-defined cleavage parallel to (10$\bar{1}$0) was observed when preparing wedges for refractive index work. B.M. 94659.

VIII. Nepheline, Monte Somma. Glassy, translucent prisms about 1 cm. in height and ½ cm. across base, enclosing green biotite and associated with idocrase and hornblende on a large biotite-augite block. B.M. 40607.

IX. 'Pseudonepheline', Capo di Bove, Rome, Italy. This specimen consists of prismatic plates and skeletal crystals covering a slab of leucite-tephrite. The crystals vary from 0·5 to 3 mm. across the base and frequently contain a hornblende inclusion which distorts the crystal. B.M. 14285, acquired from H. Heuland in 1840. H. Traube[24] found needles of kaliophilite upon specimens from Capo di Bove, but I have failed to detect this association.

The preliminary measurements of the refractive index and density that were made on the Monte Somma specimens are given below. The refractive index was measured by the Becke line method, and the density by floating in heavy liquids with known indicators. The specimens are arranged in the order described above.

No.	Density.	Refractive indices.	
	d.	ω.	ϵ.
I.	2·61	>1·530	<1·530
II.	2·63	1·535	>1·530
III.	2·60	<1·535	1·530
IV.	2·59	1·530	<1·530
VI.	2·61	>1·535	<1·535
VIII.	2·58	>1·535	>1·535

Crystals were carefully selected from each specimen and where sanidine was intimately associated with the nepheline the crystals were separated by placing in a mixture of bromoform and benzene in which sanidine just floated. Suitable material, free from inclusions where possible, was then set aside for physical measurements, and the remaining crystals finely powdered. Two separations with bromoform and benzene were used for the nephelines associated both with sanidine and heavier minerals, such as mica, hornblende, or augite. Finally, small samples from each specimen after separation were examined under the microscope for any foreign materials. Fresh fragments of the elaeolites were similarly selected and material for study picked by hand. The powdered material was then handed over to Mr. M. H. Hey for chemical analysis.

Chemical Analyses (by M. H. Hey).

Owing to the care taken in selecting material the amount available for analysis after bromoform separations was less than 0·25 gram, for analyses I, II, and IV, and only 0·0641 gram for analysis IX.

The results are given in Table 1, and the molecular ratios calculated therefrom are given in Table 2. The specimens are arranged from nos. I to IX in order of increasing potassium content; nos. VIII and IX are relatively silica-rich and silica-poor respectively. Colorimetric estimates of the silica to alumina ratios were also made on these two specimens and found to be in substantial agreement with the analyses.

Table 1. *Chemical analyses of nepheline.*
(By M. H. Hey.)

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.
SiO_2 ...	44·08	44·79	44·07	43·55	43·40	42·20	44·09	48·53	40·2
Al_2O_3 ...	34·71	34·84	34·03	34·66	33·31	34·60	32·78	29·18	36·0
Fe_2O_3 ...	—	—	—	—	—	—	0·31	—	—
MgO ...	—	—	—	0·05	0·03	0·04	0·01	—	—
CaO ...	2·51	1·91	1·92	4·44	1·20	2·14	1·45	2·44	3·7
Na_2O ...	16·46	15·40	14·00	12·09	15·96	14·77	14·60	11·92	13·8
K_2O ...	3·17	4·06	4·82	4·87	5·09	5·22	5·66	7·53	8·7
H_2O+ ...	0·45	0·10	0·80	0·25	0·61	0·60	0·82	0·35	nil
H_2O-			0·25	0·25	0·16	0·23	0·16		
Total ...	101·38	101·10	99·89	100·16	99·76	99·80	99·88	99·95	102·4
% oxygen...	44·90	45·03	45·01	44·89	44·59	44·54	44·70	44·81	44·55

Table 2. *Molecular ratios and number of atoms per unit cell (calculated from Tables* 1 *and* 3).

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.
SiO_2 ...	0·7337	0·7455	0·7335	0·7249	0·7224	0·7024	0·7339	0·8078	0·669
Al_2O_3 ...	0·6810	0·6836	0·6677	0·6800	0·6535	0·6788	0·6431	0·5725	0·710
Fe_2O_3 ...	—	—	—	—	—	—	0.0039	—	—
MgO ...	—	—	—	0·0012	0·0007	0·0010	0·0002	—	—
CaO ...	0·0448	0·0341	0·0342	0·0792	0·0214	0·0382	0·0259	0·0435	0·066
Na_2O ...	0·5310	0·4968	0·4516	0·3900	0·5148	0·4765	0·4710	0·3845	0·445
K_2O ...	0·0673	0·0862	0·1023	0·1034	0·1081	0·1108	0·1202	0·1599	0·185
H_2O+	0·0500	0·0111	0·0888	0·0278	0·0677	0·0666	0·0910	0·0389	nil
H_2O-			0·0278	0·0278	0·0178	0·0255	0·0178		
Si ...	8·29	8·39	8·44	8·30	8·38	8·16	8·53	9·27	7·7
Al ...	7·69	7·70	7·69	7·78	7·58	7·89	7·47	6·57	8·1
Ca ...	0·51	0·38	0·39	0·91	0·25	0·44	0·30	0·50	0·8
Na ...	6.00	5·59	5·20	4·46	5·97	5·53	5·47	4·41	5·1
K ...	0·76	0·97	1·18	1·18	1·25	1·29	1·40	1·83	2·1
Si+Al...	15·98	16·09	16·13	16·08	15·96	16·05	16·00	15·84	15·8
ΣR ...	7·77	7·33	7·17	7·46	7·72	7·71	7·47	7·24	8·8

Hitherto, attempts to associate a molecular formula with every mineral have resulted in a large number of careful analyses on picked material. Recent work depending to some extent upon the results of X-ray investigations has, however, modified the goal of the mineralogical chemist. His attention is not now solely focused upon the molecule, but upon the unit cell; chemical analyses of minerals are no longer stretched beyond their elastic limits to fit the formula for a hypothetical molecule; they are more rightly utilized to obtain the number of atoms in the unit cell.

In order to proceed from the molecular ratios given in Table 2 to counting the atoms in the unit cell for each specimen analysed we must measure the densities and the cell-sides of the crystals set aside for physical work.

Density measurements.

The density of each sample of nepheline and elaeolite was measured by a flotation method. A small thermometer which could be totally immersed in a small vertical tube containing a mixture of bromoform and benzene was weighed first in air and then in toluene whose density at a known temperature had been previously determined by the pyknometer method. Each crystal or fragment was then carefully balanced in the tube of bromoform and benzene by adding sufficient of one or other of the two liquids and well shaking the corked tube. The small thermometer was then weighed in the liquid, the temperature noted, and the liquid again shaken thoroughly. The crystal remained in the liquid throughout the measurement so that it was known whether the density of the liquid had increased during the weighing operations. Until experience has been gained, the operation of balancing the crystal has to be repeated a few times until allowance can be made for the amount of benzene which evaporates during weighing. Sufficient material from the green elaeolite no. VII was available to obtain a pyknometer reading of its density. This measurement carried out by Mr. Hey is in good agreement with the result I obtained for a fragment by the flotation method. The densities obtained by the above method are given in Table 3.

X-ray measurements of the cell-sides of nepheline.

For the purpose of obtaining accurate cell-side measurements of *a* and *c*, those crystals were first chosen which showed good *m* and *c* faces. The presence of the latter allowed the setting up of the crystal by optical means so that an *a*-axis was exactly vertical. For this purpose the X-ray spectrometer was used as a goniometer with an ordinary light source. By oscillating the crystal through an angle of 5° for certain azimuths, X-ray diffractions with parallel-jawed slits could be obtained on a flat plate at a known distance from the axis of oscillation, corresponding to (0004) and (40$\bar{4}$0) respectively. At a plate distance of 4 cm., and taking care not to over-expose the plate, the Cu-$K_{\alpha 1}$ (λ = 1·537 Å.) and the Cu-$K_{\alpha 2}$ (λ = 1·541 Å.) diffractions were readily resolved, and in addition the Cu-K_{β} (λ = 1·389 Å.) and W-$L_{\alpha 1}$ (λ = 1·473 Å.) diffractions were also observed. The calculated spacings from these different wave-lengths agree very closely. In one case the diffractions (0002) and (20$\bar{2}$0) were obtained at two different plate distances on the same plate. These also confirmed previous measurements on the same crystal and confirmed the value of the distance of the plate to the axis of oscillation. The accuracy of such spacing measurements from one crystal to another is ±0.01 Å. for a cell-side of about 10 Å. The majority of the nepheline crystals were studied in this way. The elaeolite specimens were roughly oriented by observing the direction of the optic axis under the microscope. One or at the most two Laue photographs of short exposure were then sufficient to adjust the specimens for oscillation about the *a*- or *c*-axes. In this case the slits did not provide good diffractions, and accordingly the usual rotation photographs were taken with very small splinters of the specimens. The variations in the spacings calculated from the layer-lines due to crystal size were in this way minimized, but the cell-sides for elaeolite can be relied upon only to ±0·02 Å. The cell-sides thus measured are given in Table 3.

Table 3. Physical data for nepheline specimens.

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.
Density (D^{15}_{15}) ...	2·614	2·620	2·616	2·576	2·629	2·608	2·597*	2·591	2·647
ω	1·5341	1·5385	1·5355	1·5299	1·5391	1·5390	1·5394	1·5403	1·5461
ϵ	1·5301	1·5349	1·5322	1·5266	—	1·5355	1·5360	1·5371	1·5422
$\omega - \epsilon$	0·0040	0·0036	0·0033	0·0033	—	0·0035	0·0034	0·0032	0·0039
Cell-edge *a* ...	9·975	9·95	9·96	9·94	9·96	9·96	9·97	9·985	9·99Å.
Cell-edge *c* ...	8·33	8·36	8·34	8·31	8·36	8·345	8·37	8·35	8·38Å.
c/*a*	0·835	0·840	0·837	0·836	0·839	0·838	0·840	0·837	0·839
Axial ratio† ...	0·835	0·838	0·834	—	—	0·8385	—	0·837	—
a^2c Å.^{3}	827	827	827	821·5	829	829	832	833	837
Number of O atoms per unit cell.	31·9	32·0	32·0	31·1	31·9	31·6	31·6	31·7	32·4

* Mr. Hey's pyknometer figure for this elaeolite is D^{15}_{15} = 2·5965.

† Axial ratio determined goniometrically.

Counting the number of atoms per unit cell.

It is now possible to calculate from the physical and chemical data the number of atoms in the unit cell of each specimen and thence to discuss the analyses more adequately than was possible merely from a consideration of the molecular ratios. The measured cell-sides and densities for each specimen have been given in Table 3. From the former measurements one proceeds to calculate the values of a^2c, the volume of the rhomb-based cell being $(\sqrt{3}/2)\,a^2c$. From these volumes and the measured densities may be calculated the molecular weights of the unit-cell contents and thence from the oxygen percentage figures given in Table 1 the number of oxygen atoms per unit cell. The expression for this number is $[(x/16)d.\,(\sqrt{3}/2).a^2c]/1{\cdot}65$, where x is the oxygen percentage directly obtained from chemical analysis, d is the density, and 1·65 is the factor corresponding to the mass of a hydrogen atom. The tabulated values for the number of oxygen atoms can be seen to approximate to 32 with a maximum variation, excepting no. IV, of $2\frac{1}{2}$ %. This agreement is very good considering that the calculation is influenced by errors in no less than three measurements, viz. chemical analysis, density, and X-ray work. This result constitutes perhaps extra evidence in favour of W. L. Bragg's [60] underlying assumption in his structural work on the silicates, namely that no matter what variations are found to exist in the chemical composition of a naturally occurring mineral, the unit cell will be found to contain an integral number of oxygen atoms, that number being characteristic of each structure type. From the work of Gossner,[51] Gottfried,[52] Jaeger,[50] and Schiebold [56] it was of course to be expected that the number of atoms of oxygen in the unit cell of nepheline would be 32. Once this number is known the count of all the other atoms in the unit cell can be carried out simply from the chemical analyses, providing that the material analysed is pure nepheline. In the present instance, knowing the chemical composition of each nepheline studied in Table 1 we can then count the number of atoms of Si, Al, Na, K, and Ca per unit cell (Table 2). Mr. M. H. Hey is of opinion that, so far as his analyses are concerned, the iron and water content, if any, are not combined with the nepheline, but are present as impurity. A count of the atoms shows that the number of Si atoms varies from one nepheline to another, and is, with the possible exception of no. IX, generally greater than the number of aluminium atoms present. This is, of course, equally apparent from a consideration of the molecular ratios in Table 2. The sum of Si and Al atoms in each case, however, is approximately the same and equals 16. This is a remarkable fact, and suggests at once an explanation of the excess silica usually found in nepheline analyses.

It is interesting now to proceed to recalculate the large number of nepheline analyses already in existence assuming in each case that the unit cell contains 32 oxygen atoms. The sum of the Al and Si atoms always lies very close to 16, not only for modern analyses, such as those of Morozewicz,[53] but also for the older ones (see Table 4). From valency considerations, if the sum of the silicon and aluminium atoms equals one-half the number of oxygen atoms in the unit cell, then the sum $2Ca+K+Na = \Sigma R$ must also equal the number of aluminium atoms per unit cell. The following simple calculation makes this clear. Let the number of Si atoms be $16-n$, Al atoms n, Na atoms x, K atoms y, and Ca atoms z. The number of oxygen atoms associated with a monovalent term is $\frac{1}{2}$, a divalent term 1, &c., so that $2(16-n)+3n/2+x/2+y/2+z = 32$ = total no. of oxygen atoms per unit cell. Therefore $x+y+2z = n$. Furthermore, it can be shown that the difference $(2Ca+K+Na)-Al$ is four times the difference $(Si+Al)-16$. Hence we have a more sensitive indicator in the former expression of whether the sum of silicon and aluminium atoms equals 16 for all the recalculated analyses. For Mr. Hey's analyses the mean value of $(2Ca+K+Na)-Al = 0{\cdot}01$, i.e. $Si+Al = 15{\cdot}995$. For about a hundred previous analyses the mean values are respectively 0·02 and 15·995.

Variation in the chemical composition of nepheline.

If the number of Si atoms be plotted as abscissae and the number of Al atoms as ordinates a straight line is obtained sloping down to the right (fig. 1). The sum of the atoms $2Ca+K+Na$ should also fall on this line in each case. Now if the Na, K, and Ca atoms each be plotted separately as ordinates we should be able to trace whether the variation of Na, K, or Ca content of nepheline is connected in any way with the silicon content. For Mr. Hey's analyses there is a well-defined minimum shown by the potassium curve corresponding to about 8·4 atoms of silicon and 1·2 atoms of potassium per unit cell. If the same plot be carried out for the recalculated analyses then a similar result is obtained, the minimum corresponding to 1·25 atoms of potassium and 8·45 atoms of silicon. The variation in

Table 4. The number of atoms per unit cell calculated from previous analyses of nepheline.

Literature No.	Si.	Al.	Mg.	Ca.	Na.	K.	Si + Al.	ΣR.
1	8·42	7·59	—	—	7·57	—	16·00	7·57
2	8·15	7·81	0·13	0·10	6·07	1·46	15·96	7·79
,,	8·37	7·65	0·23	0·04	5·35	1·70	16·02	7·59
3	8·66	7·36	—	0·06	5·90	1·26	16·02	7·28
,,	8·65	7·35	—	0·05	5·94	1·30	16·00	7·34
,,	8·65	7·34	—	0·07	5·90	1·33	15·99	7·37
,,	8·64	7·38	—	0·07	5·74	1·44	16·02	7·32
,,	8·60	7·47	—	0·16	5·81	1·08	16·07	7·21
,,	8·76	7·25	—	—	5·99	1·23	16·01	7·22
,,	8·43	7·59	0·02	0·07	5·91	1·41	16·02	7·50
,,	8·50	7·53	—	0·05	5·87	1·40	16·04	7·37
,,	8·47	7·50	—	0·36	5·72	1·20	15·97	7·64
,,	8·52	7·49	—	0·37	5·56	1·16	16·01	7·46
,,	8·35	7·61	—	0·41	5·85	1·09	15·96	7·76
,,	8·51	7·42	—	0·17	5·97	1·39	15·93	7·70
4	8·44	7·39	0·032	0·74	5·31	1·24	15·83	8·09
5	8·47	7·37	0·04	0·06	6·12	1·77	15·84	8·09
6	8·52	7·43	—	0·08	6·12	1·35	15·95	7·63
7	8·78	7·12	0·16	0·18	5·66	1·23	15·90	7·57
8	9·03	6·94	—	0·22	4·97	1·66	15·97	7·07
9	8·59	7·47	—	—	6·03	1·23	16·06	7·26
10	8·45	7·77	—	0·10	5·61	1·08	16·22	6·89
,,	8·49	7·67	—	0·11	5·65	1·18	16·16	7·05
,,	8·46	7·69	—	0·14	5·63	1·19	16·15	7·10
,,	8·57	7·58	—	—	5·95	1·03	16·15	6·98
12	8·39	7·56	0·07	0·32	5·77	1·20	15·95	7·75
,,	8·43	7·48	0·04	0·36	5·95	1·10	15·91	7·85
,,	8·44	7·45	0·06	0·27	6·06	1·18	15·89	7·90
13	8·53	7·58	0·03	0·08	5·80	1·08	16·11	7·10
14	9·00	6·92	—	—	5·51	1·73	15·92	7·24
15	8·50	7·39	—	0·10	6·33	1·25	15·89	7·78
16	8·46	7·42	—	0·15	6·24	1·39	15·88	7·93
,,	8·22	7·85	—	0·10	5·72	1·67	16·07	7·59
17	8·33	7·62	—	0·31	6·96	0·22	15·95	7·80
18	8·36	7·77	—	—	6·16	1·11	16·13	7·26
22	8·70	7·40	0·05	0·41	4·69	1·40	16·10	7·01
23	8·35	7·64	—	0·03	6·30	1·32	15·99	7·68
25	8·51	7·54	—	0·09	5·81	1·34	16·05	7·33
26	8·34	7·70	0·03	0·52	5·38	1·12	16·04	7·60
27	8·91	7·12	—	0·07	5·49	1·39	16·03	7·02
28	8·66	7·41	—	—	6·00	1·12	16·07	7·12
29	8·29	7·61	0·02	0·42	5·74	1·42	15·90	8·04
,,	8·20	7·76	0·02	0·40	5·62	1·46	15·96	7·92
,,	8·31	7·62	0·05	0·44	5·84	1·08	15·93	7·90
,,	8·31	7·61	0·08	0·46	5·80	1·04	15·92	7·92
,,	8·42	7·57	—	0·10	6·00	1·42	15·99	7·62

Table 4—*continued.*

Literature No.	Si.	Al.	Mg.	Ca.	Na.	K.	Si+Al.	ΣR.
29	8·47	7·54	—	0·11	5·92	1·39	16·01	7·53
,,	8·45	7·54	—	0·06	6·11	1·36	15·99	7·59
,,	8·47	7·52	—	0·06	6·05	1·39	15·99	7·56
,,	8·45	7·54	—	0·05	6·02	1·48	15·99	7·60
,,	8·44	7·53	—	0·06	6·01	1·53	15·97	7·66
,,	8·36	7·63	—	0·07	6·10	1·44	15·99	7·68
,,	8·36	7·63	—	0·07	6·10	1·43	15·99	7·67
30	8·17	8·13	—	—	6·13	0·78	16·30	6·91
31	8·60	7·37	0·02	0·06	6·38	0·98	15·97	7·52
32	7·99	7·80	—	0·55	4·95	2·57	15·79	8·61
33	8·52	7·54	—	—	5·95	1·33	16·06	7·28
34	8·44	7·68	—	0·19	5·04	1·77	16·12	7·19
35	8·51	7·49	—	—	6·14	1·37	16·00	7·51
,,	8·52	7·49	—	—	6·08	1·38	16·01	7·46
,,	8·59	7·43	—	—	6·00	1·37	16·02	7·37
36	8·24	7·64	—	0·22	6·35	1·33	15·88	8·12
,,	8·41	7·57	—	0·19	6·22	1·04	15·98	7·64
39	8·33	7·57	—	0·12	6·32	1·44	15·90	8·00
,,	8·37	7·62	—	0·09	6·08	1·42	15·99	7·68
,,	8·36	7·66	—	0·06	6·08	1·38	16·02	7·58
,,	8·33	7·60	—	0·07	6·34	1·47	15·93	7·94
40	8·44	7·36	—	0·01	6·37	1·04	16·07*	7·43
41	8·42	7·65	—	0·18	6·12	0·86	16·07	7·34
42	8·28	7·70	—	0·45	5·46	1·42	15·98	7·78
45	8·10	8·10	—	0·13	5·48	1·55	16·20	7·29
46	8·18	8·11	—	0·01	5·54	1·41	16·29	6·97
53	8·34	7·60	—	0·06	6·13	1·55	15·94	7·80
,,	8·37	7·74	—	0·02	5·99	1·32	16·11	7·35
,,	8·46	7·50	—	0·03	6·02	1·60	15·96	7·68
Altered nephelines.								
31	8·67	7·61	0·02	0·05	5·62	0·76	16·28	6·52
,,	8·66	7·86	0·02	0·05	5·16	0·52	16·52	5·82

* No. 40 contains 0·58 atoms of beryllium counted in with the silicon and aluminium.

calcium content would also appear to follow the potassium curve, with a minimum at about 0·35 atoms of calcium and 8·5 atoms of silicon for Mr. Hey's analyses. There is one notable exception on this curve, however, namely no. IV, which has a very high calcium content of 0·906 atoms, and a silicon content of 8·297 atoms per unit cell. The conclusions that may be safely drawn then are:

(*a*) Naturally occurring nephelines always contain some potassium which is never less than 1 atom per unit cell For nephelines with greater or less silica content than 8·4 atoms the potassium content

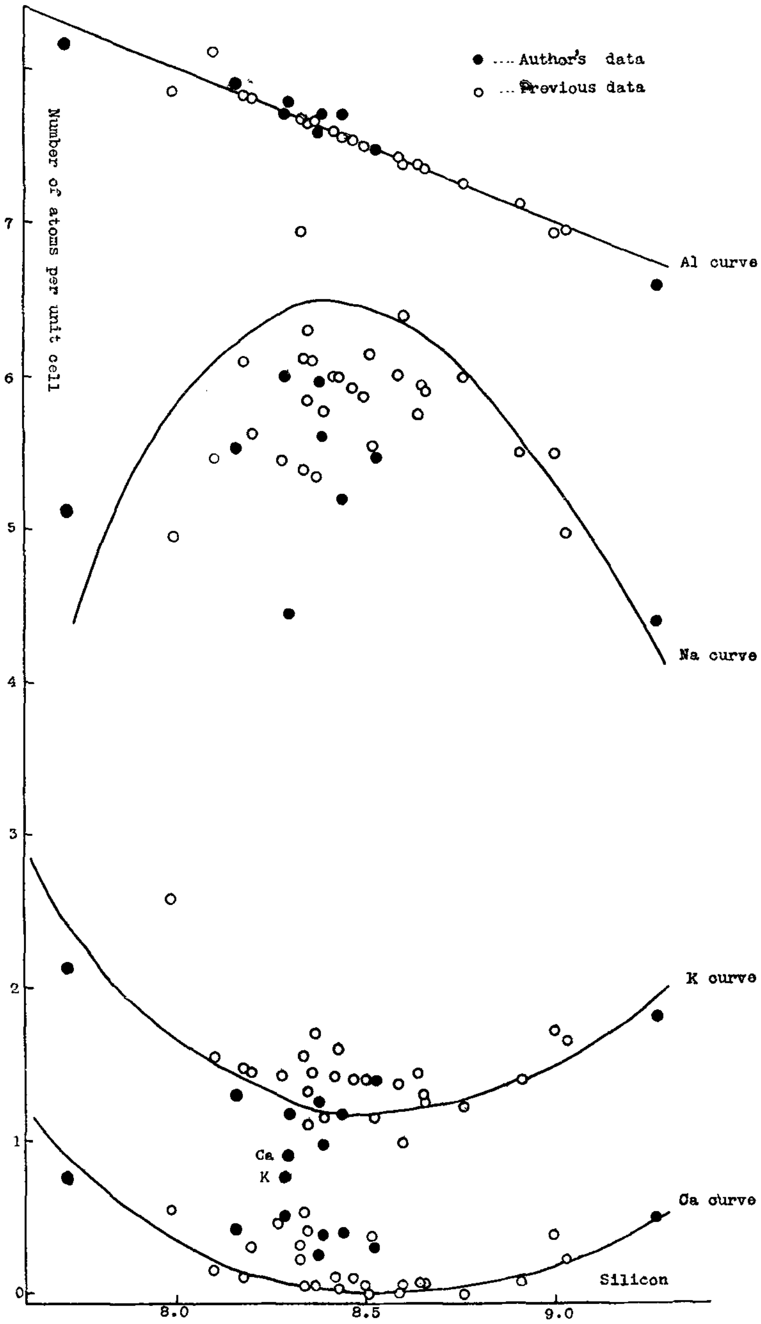

FIG. 1. Graphs plotting number of silicon atoms per unit cell of nepheline against number of aluminium, sodium, potassium, and calcium atoms per unit cell.

increases on both sides of the minimum to about 2 atoms per unit cell. There is no evidence to show, however, that this is a maximum content.

(*b*) The calcium content fluctuates more irregularly, but with one exception also shows a curve with a minimum.

(*c*) Mr. Hey[59] has concluded for the zeolites that the Si to Al ratio in the parent-magma is the controlling factor in the composition of the resulting zeolite. In the present case the potassium and calcium contents appear to be distinct factors of equal importance.

Morozewicz[53] has deduced from a large number of careful analyses of nepheline and elaeolite that the ratio of the K to Na content remains sensibly constant, although this ratio for the parent-rock exhibits considerable variations. The present work shows that this conclusion cannot be applied to all nephelines; in fact the variation of Na to K is represented more accurately by the curves in fig. 1. One final consideration of fig. 1 is of interest. The maximum in the sodium curve lies at about 8·4 atoms of silicon and 6·2 atoms of sodium. It is noteworthy that the two pronouncedly sodium-rich nephelines, no. 1 and no. 17 of Table 4, approach an 8·4 silicon atom content. This leads to the speculation as to whether the artificial nephelines so far studied have corresponded to this composition rather than the ideal $NaAlSiO_4$. If we take Bowen's[37] density figure, 2·619, for artificial nepheline and plot it with the density data and also the cell-volume data, we shall see that his figure agrees far more closely with existing mineralogical data when we assume 8·4 atoms of silicon rather than eight. (See figs. 2 and 3.)

Warren[57] has recalculated amphibole analyses on a basis of an integral number of oxygen atoms and hydroxyl groups per unit cell and has shown that chemical analyses formerly thought to be misleading are actually in closer agreement with the crystal-structure of amphiboles determined by X-ray work than the idealized formulae. The present work indicates that the majority of nepheline analyses recalculated to give the number of atoms per unit cell show a surprisingly constant number for the Si + Al content. The contents of the unit cell of nepheline may in fact be written $Si_{16-n}Al_n$ $(Na, K, \frac{1}{2}Ca)_n O_{32}$. In this connexion Mr. Hey has suggested a new method for assessing the value of chemical analyses. If a chemical analysis sums to a figure lying between 99·7 and 100·8 it is considered a first-class analysis. If in the present case the sum of Si and Al atoms recalculated from such an analysis also lies between 15·9 and

16·1 then we may consider that a first-class analysis has been performed on first-class material, namely, fresh nepheline free from impurities. The second criterion of the Si and Al atoms summing to 16 is thus another important check on chemical analysis. It is obvious that such a principle is of general application and Mr. Hey will no doubt develop the idea more fully in connexion with his work on zeolites.

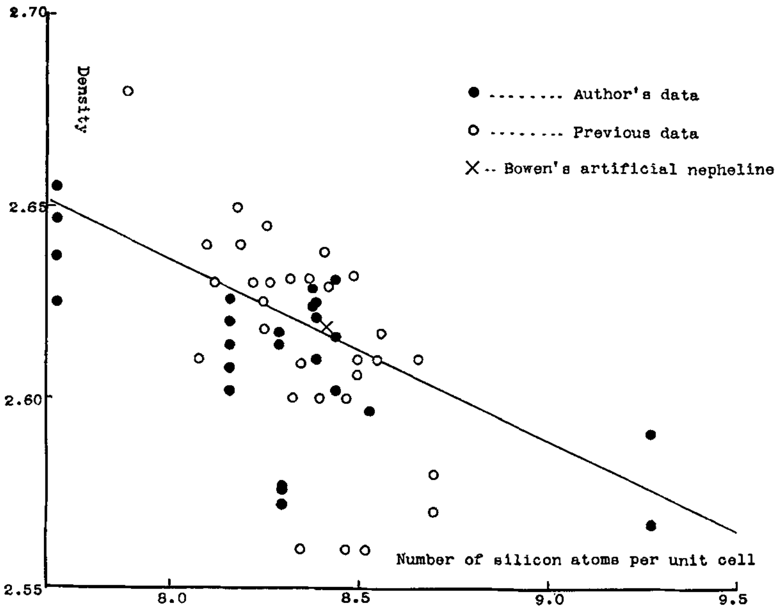

FIG. 2. Graph plotting the number of silicon atoms per unit cell against the density of nepheline. Series of points falling on the same ordinate give the density of individual crystals taken from each analysed specimen.

The correlation of density and the number of silicon atoms per unit cell.

The density data may now be used to correlate the variation of density with chemical composition. The measurements were of course carried out on more than one crystal from each specimen and the additional data used for the purposes of correlation are shown in Table 6. By plotting (fig. 2) the values obtained for each crystal it is found that a small decrease of density of 0·01 to 0·02 accompanies the increase of silicon by one atom per unit cell. From Table 5 the density of nepheline and its silicon content are also plotted for the correlated data of previous workers. The plotted values tend to lie about a straight line and the exceptions are probably to be attributed to errors in the density figure due to inclusions or flaws full of air. For water-clear crystals the errors of measurement are a minimum and the data for these follow the straight line relation more closely.

The correlation of cell-volume and the number of potassium atoms per unit cell.

It has not been possible to trace any relationship between the lengths of the cell-edges and the chemical composition, but if the cell-volumes $(\sqrt{3}/2)\,a^2c$ be considered there is a very small but definite increase with potassium content (Table 3 and fig. 3). Thus nepheline from Capo di Bove with the highest potassium content has the largest cell.

Reference will shortly be made to the variation in the refractive index of nepheline crystals taken from one and the same specimen. This has rendered the correlation of refractive index with chemical composition very difficult. It may justly be assumed that different crystals from the same matrix possessing different refractive indices are also different in chemical composition. Therefore the relation that has been deduced between cell-volume and the potassium content must be treated with reserve unless further evidence can be adduced. There are, as a matter of fact, three checks on the above results:

(*a*) No appreciable difference can be detected in spacings of nepheline crystals from the same specimen.

(*b*) The cell-volumes calculated from the chemical analyses and each density figure obtained show similar increase of cell-volume with potassium content. The increase in cell-volume per 1 K atom is 13·4 Å^3.

(*c*) Although previous chemical analyses of nepheline are seldom accompanied by complete physical data, density figures are often given (Table 5). Each of these analyses has already been recalculated (p. 576) so that the number of atoms in the unit cell is known (Table 4).

From the density figure and the atomic contents the volume of the unit cell may therefore be calculated (Table 5). It is of interest first to compare the range of volumes thus obtained. The calculated

a^2c values for forty analyses accompanied by density data range from 822 to 852 Å^3. For Hey's analyses calculated values of a^2c range from 824 to 846 Å^3. X-ray measurements yield a range 821·5 to 837 Å^3. The inaccuracy of the density data in a large number of cases prevents the use of older analyses for correlating potassium content with cell-volume. However, there is a definite grouping of the points in fig. 3 about the straight line obtained from direct measurement of a^2c. Anticipating a conclusion that the axial ratio of nepheline probably lies between the limits 0·837 to 0·841, it is

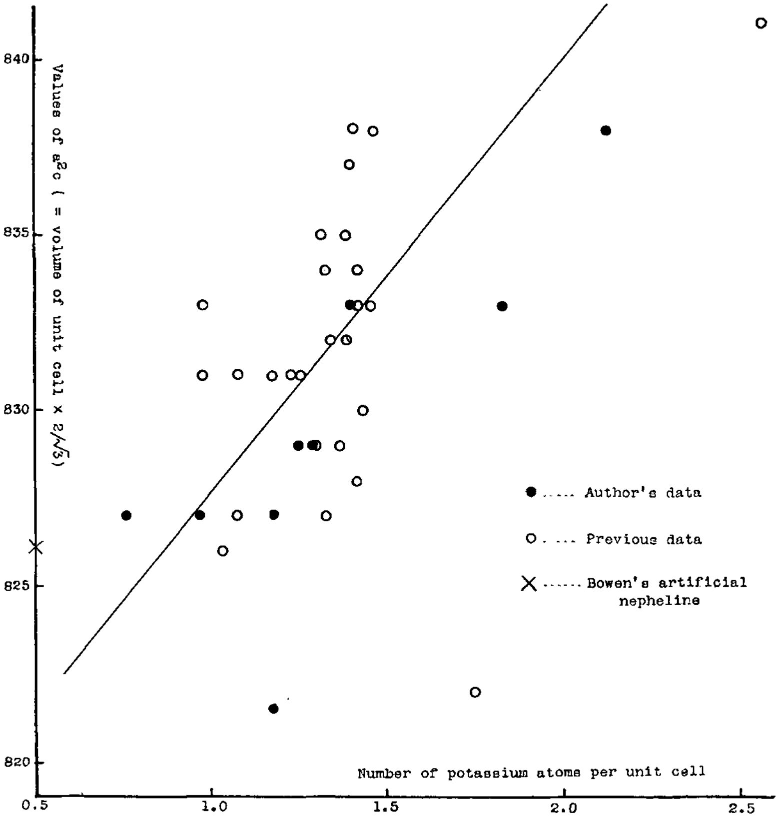

Fig. 3. Graph plotting the number of potassium atoms per unit cell against the cell-volume × $2/\sqrt{3}$. (Only the author's data, represented as black spots, were obtained directly by X-ray methods.)

Table 5. Cell dimensions calculated from previous chemical analyses of nepheline accompanied by density data.

Literature No.	Density, *d*.	No. of Si atoms.	Mass of unit cell.	$a^2 c$.	No. of K atoms.
3	2·617	8·66	1141	831 Å.^{3}	1·26
,,	2·617	8·65	1139	829	1·30
,,	2·610	8·65	1143	834	1·33
,,	2·610	8·64	1144	835	1·44
,,	2·610	8·60	1133	827	1·08
,,	2·610	8·76	1139	831	1·23
,,	2·600	8·43	1147	838	1·41
,,	2·600	8·50	1146	838	1·40
,,	2·560	8·47	1141	849	1·20
,,	2·560	8·52	1142	850	1·16
,,	2·560	8·35	1145	852	1·09
6	2·629	8·52	1148	832	1·35
10	2·600	8·45	1134	831	1·08
,,	to	8·49	1137	831	1·18
,,		8·46	1138	831	1·19
,,	2·6087	8·57	1135	831	1·03
16	2·600	8·46	1155	847	1·39
,,	2·630	8·22	1156	837	1·67
22	2·575	8·70	1135	838	1·40
23	2·621	8·35	1150	835	1·32
29	2·640	8·29	1154	833	1·42
29	2·640	8·20	1154	833 Å.^{3}	1·46
,,	2·640	8·31	1146	827	1·08
,,	2·640	8·31	1145	826	1·04
,,	2·631	8·42	1150	833	1·42
,,	2·631	8·47	1147	832	1·39
,,	2·6453	8·36	1152	830	1·44
31	2·606	8·60	1139	833	0·98
32	2·680	7·99	1183	841	2·57
35	2·635	8·51	1148	832	1·37
,,	2·635	8·52	1148	832	1·38
,,	2·635	8·59	1145	829	1·37
39	2·6295	8·32	1157	838	1·44
,,	2·6295	8·37	1151	834	1·42
,,	2·6295	8·36	1149	832	1·38
,,	2·6295	8·33	1157	838	1·47
40	2·60	8·44	1129	827	1·04
42	2·650	8·28	1151	828	1·42
45	2·664	8·10	1149	822	1·55
53	2·625	8·37	1146	832	1·32
,,	2·628	8·46	1154	837	1·60

possible to calculate the probable range in variation of *a* and *c* for the recalculated analyses. Assuming a mean value of 0·839 for *c*/*a*, it is found that *a* ranges from 9·93 to 10·05 Å., and *c* ranges from 8·33 to 8·43 Å. The X-ray measurements of the nephelines I have studied give *a* = 9·94 to 9·99 Å., and *c* = 8·31 to 8·38 Å. Existing X-ray data are not in complete agreement with these results. The following lower and higher figures have been quoted for Monte Somma nepheline:

	Cell-sides.			
	a.	*c*.	*c*/*a*.	*Density.*
B. Gossner[51] ...	10·05	8·43 A.	0·8388	2·64
C. Gottfried[52] ...	10·09	8·49	0·8414	2·60
F. M. Jaeger[50] ...	9·87	8·38	0·849	—
E. Schiebold[56] ...	10·1	8·51	0·8426	2·65

Schiebold's figures for nepheline seem to be too high. He has examined material analysed by F. Stella Starrabba.[42] Table 5, no. 42, shows that a^2c calculated from chemical analysis and density is 828·0 Å.^{3}, whereas Schiebold's measured a^2c value = 868·0 Å.^{3}.

Crystallographic measurements.

The direct measurements of the cell-sides also yield values of the axial ratio for each specimen of nepheline (Table 3), and it is interesting to see how they complete the values obtainable by direct measurement with the goniometer. The Monte Somma nepheline specimens generally yield well-developed crystals suitable for goniometric measurement and for deducing directly the axial ratio. In particular nos. VI and II provide crystals rich in faces all of which give single bright reflections. Crystals from the latter specimen show not only the common forms *m* $(10\bar{1}0)$, *c* (0001), p $(10\bar{1}1)$, but also *q* $(10\bar{1}2)$, whilst the former specimen is studded with numerous perfect hexagonal prisms exhibiting *m* $(10\bar{1}0)$, *c* (0001), *p* $(10\bar{1}1)$, *z* $(20\bar{2}1)$, *a* $(11\bar{2}0)$, *s* $(11\bar{2}1)$ all well developed, and *x* $(40\bar{4}1)$ and *t* $(20\bar{2}3)$ as small facets giving weak reflections. For those crystals capable of accurate measurement the axial ratio was calculated from all the possible pyramidal reflections *p*, *z*, *q*, &c. Large crystals vary much more in habit than do the small ones just described. The large prism already referred to under the description of specimen no. II shows very unequal development at its two ends. At one end *p* is well developed, but it cannot be observed at the bottom end of the crystal. Again, *s* is present as a large face, much larger than is usual, and quite predominating over the primary pyramid *p*. Under the conditions of slow growth, which we may assume accompanied the formation of this unusually large nepheline crystal, any change in composition of the mother-liquor or of the physical conditions would have every chance of affecting the relative rates of facial growth and therefore of the relative sizes of the faces. The unequal development of the pyramid-faces for the two ends of this crystal are probably to be referred to the polar nature of nepheline as exhibited by etch-figures and its pyro- and piezo-electric effects (see below). The small glassy nepheline crystals sometimes give only a very faint pyramid reflection due to the poor development of *p*; but the milk-white crystals, whether large or small, observed particularly on no. IV specimen, fall into an entirely different class and are unsatisfactory for goniometric measurement.

These milky crystals recall the fact that the name nepheline was conferred by Haüy on this mineral because the crystals lose their transparency and become cloudy when immersed in acid. The action of acid is to break up the surface layers and penetrate flaws, producing colloidal silica. It is conceivable that acid vapours produced during volcanic activity might readily attack nepheline crystals already formed and give rise to the cloudiness so typical of certain specimens. The corrosion would, of course, produce the greatest effect on the forms with high rate of growth. Thus the *p* faces which are always small would tend to disappear completely or become by far the most etched. This is exactly what is found in the milk-white crystals of no. IV. In attempting to obtain an axial ratio determination a number of crystals were minutely examined for *p* faces, but in most cases these were either absent or convex in shape. The *c* and *m* faces also showed signs of corrosion and gave numerous imperfect images. The flaws produced by corrosion undoubtedly contain air and also render the crystals friable; it is probable that the low density value for no. IV may thus be explained.

The remaining specimens, not from Monte Somma, yielded very poor material for work with the goniometer. The pseudonepheline' crystals are badly etched, and the *p* planes, when present, are very small. The crystals are frequently distorted by hornblende inclusions, and the angle *cm* sometimes differs from 90° by nearly ½ degree. The values for axial ratio as deduced from interfacial angles are given in Table 3 for five Monte Somma nepheline specimens; the sixth (no. IV) yields an approximate value only, owing to the presence of vicinal faces on *c* and *m*. Crystallographic values are of course lacking for the elaeolites; for these we have to rely upon X-ray measurements, and it is an important point that such determinations are not affected by the presence of vicinal faces nor prevented by the absence of pyramidal forms.

Numerous crystallographic measurements for nepheline are to be found in the literature, but it is only comparatively recently that such data have been published on analysed material. Confusion has also resulted from the fact that the interfacial angles for davyne are almost identical. Many of the early measurements given for nepheline undoubtedly refer to davyne. O. Mügge[49] states that even the classical measurements ($a:c = 1:0{\cdot}838926$) of N. I. Koksharov (1884) were made on the latter mineral. H. Baumhauer's[21] etching experiments, however, were certainly carried out on true nepheline. The mean value he deduces for $(10\bar{1}0):(20\bar{2}1) = 27°19'$ yields $a:c = 1:0{\cdot}8383483$. Using his measurements I have obtained for the mean value of $(0001):(10\bar{1}1) = 44°\,4'$, which yields $a:c = 1:0{\cdot}8383$.

The limits of variation for different crystals he measured are 0·8364 and 0·8418, corresponding to angles $cp = 44^\circ \tfrac{1}{4}'$ and $44^\circ 11\tfrac{1}{4}'$ respectively. J. Strüver[11] gives for nepheline from the Alban Mts., $cp = 43^\circ 50' 40''$, which yields $a : c = 1 : 0{\cdot}8318$ for one crystal, whilst measurements of the angles cp and cz yield an average value of $0{\cdot}8372 \pm 0{\cdot}0017$ for a second crystal. My measurements on the Monte Somma crystals yield a mean value of 0·8371 which varies for individual measurements on different crystals from 0·8324 to 0·8424. The available correlated data for axial ratio and chemical composition are contained in only three previously published papers. F. Stella Starrabba[42] has analysed nepheline crystals from Parco Chigi, Ariccia, Rome, Italy, and has measured the density, refractive index, and interfacial angles for many crystals. The weighted mean for the axial ratio derived from his measurements is 0·8370 and the individual measurements vary between 0·8339 and 0·8407, corresponding to angles $cp = 43^\circ 55'$ and $44^\circ 8'$. Correlated data for Monte Somma nephelines have not been hitherto available. Nepheline crystals in phonolite from Monte Ferru, Sardinia, have been measured and analysed by H. S. Washington and H. E. Merwin.[41] The weighted mean for a large number of measurements is $a : c = 1 : 0{\cdot}841$, and individual values fluctuate between 0·834 and 0·852. The remaining value for nepheline is given as $a : c = 1 : 0{\cdot}8368$ measured by F. Zambonini on 'pseudonepheline' from Capo di Bove, Rome, Italy, and analysed by A. Serra.[32]

X-ray measurements have now made it possible to complete the axial ratio determinations on material unsuitable for crystallographic work (Table 3). The ratios deduced from the spacings have in the case of specimens nos. V, VI, and VII been confirmed by measurements on the Laue photographs. Plotting these axial ratios with the potassium content shows definitely that the axial ratio changes very little, but probably decreases with increase in potassium. This conclusion is confirmed by the correlated data of Washington, Stella Starrabba, and Zambonini (Table 7). Their plotted values fall very close to the line which best represents my experimental data. The probable conclusion to be drawn from this and the preceding result is that the increase of potassium increases the cell-volume, but increases the length of the base more than the height, so that the axial ratio itself decreases with increasing potassium.

Refractive index and dispersion measurements.

Chemical analyses of nepheline accompanied by optical data are scarce. The available data for refractive index are given in Table 7 and the dispersion data are given in Table 8. A serious attempt has therefore been made in the present work to obtain sufficient data in order to correlate the optical constants of nepheline with its chemical composition. Two well-known methods have been utilized in the measurement of refractive index and the birefringence of the nepheline specimens nos. I to IX. Many of the crystals are perfect hexagonal prisms and even fragments with prism-faces enclosing an angle of 60° can often be picked out when fully developed crystals are not available. Such specimens have been found to give perfect refracted images and the method of minimum deviation has therefore been used whenever possible. In the position of minimum deviation, of course, for a completely developed 60°-prism the direct reflection from a prism-face should coincide exactly with the refracted image. For a small crystal, however, the direct reflection is not sufficiently powerful to mask the refracted image, and if a nicol be used in front of the eyepiece of the telescope the reflected image almost disappears when the nicol is transmitting only the ordinary ray. The polarization produced at the reflecting face is sufficient to give this effect. It was observed that the reflected image viewed through an oriented nicol is dim over a large range of angles and is practically extinguished for the critical angle of incidence. This method gives the position of the extraordinary and ordinary refracted beams and a direct measurement can be made of the birefringence.

When a small crystal with its prism-faces all equally developed is carefully centred and rotated about its axis there are of course six positions corresponding to the six prism-angles in which the two refracted images may be observed. These images remain fixed as the crystal rotates, if the prism-angles are all equal to 60° and if the crystal is uniformly refracting. The usual formula for minimum deviation $n = \sin \frac{1}{2}(A+D)/\sin \frac{1}{2}A$ yields on differentiation assuming n constant $dD/dA = [\tan \frac{1}{2}(A+D)/\tan \frac{1}{2}A] - 1$. In the present case $A = 60°$ and D about 40°. Thus $dD/dA = (\tan 50°/\tan 30°) - 1 = 1{\cdot}064$. Hence, if the crystal is uniform, the variations of the minimum angle of deviation for the ordinary image as the crystal is rotated should be of the same order as the variation in prism-angle. For small crystals this variation of prism-angle is never greater than 5 minutes.

Any variations in the angle D much greater than 5′ could only be attributed to variations in refractive index of the crystal. Measurements have been made on two nepheline crystals, one in which the angles differ very little from the true angle 60° and the other where larger variations had been observed. The results indicate quite clearly that the variation of refractive index in the same crystal is very small. The readings are all capable of very accurate measurement and are independent of the setting of the telescope for the direct beam.

For the elaeolites and one or two nepheline crystals which could not be measured in this way prisms parallel to the optic axis were cut and polished with the grinding apparatus of H. H. Thomas and W. Campbell Smith. Small-angled prisms were used because the elaeolites and milky nephelines are almost opaque. The method of minimum deviation was also used for obtaining the refractive indices of nepheline for various wave-lengths. The values for four crystals are given in Table 8 and the dispersive powers have also been calculated from the smoothed n and λ curves.

In one or two rather large crystal fragments, not showing the requisite prism-faces for the previous method, the total reflection method was used. Beautiful facets were present on the crystals which would have been removed by grinding a suitable prism. Such crystals were therefore measured with the Abbé-Pulfrich refractometer and the readings obtained are consistent with the approximate immersion figures already given (p. 571).

The variation of refractive index of different crystals from the same matrix.

Apart from correlating the refractive indices of the specimens with the results of chemical analysis, which will be dealt with later, it was discovered that for all six nepheline specimens from Monte Somma, crystals from the same matrix gave very different refractive index measurements. Even an intergrowth of two small crystals from specimen no. VI gave $\omega_{\text{Na}} = 1{\cdot}5367$ for one crystal and $\omega_{\text{Na}} = 1{\cdot}5381$ for the second. Crystallographic measurements have been averaged for different crystals by previous observers, but refractive index measurements are usually carried out on one crystal. Zambonini,[36] however, has noted that two crystals of nepheline from the same sanidine block possessed different refractive indices namely $\omega = 1{\cdot}5376$ and $\omega = 1{\cdot}5359$ (Na-light); and he also gives refractive

Table 6. *Densities and refractive indices of each nepheline crystal measured, together with* Si *and* K *content in atoms per unit cell from Tables* 2 *and* 3.

(See figs. 2 and 4.)

Specimen.	Crystal.	ω.	ϵ.	$\omega-\epsilon$.	*d*.	Si.	K.
I	1	1·5341	—	—	2·614	8·29	0·76
	2	1·5304	1·5264	0·0040	2·617		
II	1	1·5387	—	—	2·621	8·39	0·97
	2	1·5368	1·5331	0·0037	2·610		
	3	1·5385	1·5349	0·0036	2·620		
	4	1·5369	—	—	2·625		
III	1	1·5355	1·5322	0·0033	2·616	8·44	1·18
	2	1·5378	1·5342	0·0036	2·602		
	3	1·5379	1·5347	0·0032	—		
	4	1·5384	1·5354	0·0030	2·631		
IV	1	1·5344	1·5312	0·0032	—	8·30	1·18
	2	1·5316	1·5284	0·0032	2·572		
	3	1·5312	1·5279	0·0033	—		
	4	1·5390	1·5362	0·0028	2·577		
	5	1·5299	1·5266	0·0033	2·576		
	6	1·5347	1·5313	0·0034	—		
V	1	1·5386	1·5354	0·0032	2·624	8·38	1·25
	2	1·5354	—	—	2·629		
VI	1	1·5373	1·5338	0·0035	2·608	8·16	1·29
	2	1·5390	1·5355	0·0035	2·602		
	3	1·5349	1·5316	0·0033	2·614		
	4	1·5383	1·5347	0·0036	2·620		
	5	1·5367	1·5334	0·0033	2·620		
	6	1·5383	1·5349	0·0034	2·626		
	7	1·5364	1·5330	0·0034	2·613		
	8	1·5381	1·5347	0·0034	—		
VII	1	1·5394	1·5360	0·0034	2·597	8·53	1·40
VIII	1	1·5403	1·5371	0·0032	2·591	9·27	1·83
	2	1·5392	1·5358	0·0034	2·567		
IX	1	1·5439	—	—	2·637	7·7	2·1
	2	1·5443	1·5404	0·0039	2·625		
	3	1·5461	1·5422	0·0039	2·647		
	4	1·547	1·543	0·004	2·655		

indices for two other crystals, one from a hiortdahlite-bearing syenite with ω_{Na} = 1·5376, and one from a pyroxene block ω_{Na} = 1·5374. All these specimens were from Monte Somma, and the last two were analysed by F. Stella Starrabba. Although the two refractive index measurements are practically identical, the chemical composition of the two is quite different. The second is poorer in silica and richer in potassium than the first. Zambonini states that he was unable to correlate refractive index and chemical composition, and from measurements made before and after heating to 810° C. and then cooling he states that different heat treatment of different specimens may complicate the problem. He found that after heating, the refractive index rose from its initial value by about 0·002 (Na-light). However, different specimens did not behave in the same way and he drew no definite conclusions. Whilst allowing his conclusion on the different heat treatment of separate specimens, it is unlikely that differences of refractive index of crystals on the same matrix can be attributed to such a cause.

It is natural to assume that the variations in refractive index of crystals from the same matrix are an indication of differing chemical composition. F. Becke and J. E. Hibsch[48] have studied nepheline crystals from the phonolites of Bilin and Brüx, northern Bohemia, and found that they exhibit zonal growth. Their results, in the light of Bowen's[38] work on artificial calcium-rich nephelines, suggest that successive zones have different calcium contents thereby producing notable changes in birefringence. I have not found any signs of zonal growth in the nephelines I have studied and the variations in composition on the same matrix are presumably not restricted to calcium, but it is important to draw attention to the evidence that nepheline is extremely variable in composition as well as in refractive index.

The correlation of refractive index and the number of potassium atoms per unit cell.

In view of Zambonini's work and my own preliminary measurements I thought it advisable, in order to derive any relation between refractive index and chemical composition, to measure the refractive index for as many crystals as possible for each specimen chemically analysed (Table 6). In some cases it was impossible to detach more than two or three crystals suitable for exact measurement and it is not likely that the average value of refractive index for a few crystals would yield an accurate statistical mean. The value for each crystal has therefore been tabulated.

Fig. 4 shows graphically the marked difference in refractive index of crystals from the same matrix. It is also apparent that the refractive index increases with increase in potassium content. It can be seen that although the centre of each cluster defines the average composition and refractive index of the specimen, stragglers from one or two clusters approach each other and obviously correspond to a different composition. There are correlated data in existence for

Table 7. Correlated physical data of nepheline from the literature.

Lit. No.	Si atoms.	K atoms.	ω.	ϵ.	$\omega-\epsilon$.	d.	$a:c$.
32	7·99	2·57	1·5472	1·5435	0·0037	2·68	0·8368
36	8·24	1·33	1·5376	1·5339	0·0037	—	—
,,	8·41	1·04	1·5374	1·5341	0·0033	—	—
41	8·42	0·86	1·532–3	1·529	0·003–4	—	0·841
42	8·28	1·42	1·5417	1·5382	0·0035	2·65	0·837
45	8·10	1·55	1·540	1·538	0·002	2·664	—

Table 8. Refractive indices of nepheline for various wave-lengths.

Line.	Wave-length,	No. VI, crystal 1.		No. VI, crystal 2.	
	λ.	ω.	ϵ.	ω.	ϵ.
—	7200 Å.	—	—	1·5341	1·5307
Li_α	6708	1·5337	1·5307	1·5356	1·5321
H_α(C)	6563	1·5343	1·5313	1·5361	1·5328
—	6250	1·5354	1·5321	1·5372	1·5338
Na(D)	5893	1·5373	1·5338	1·5384	1·5351
Hg yellow	5780	1·5379	1·5346	1·5395	1·5360
Hg green	5461	1·5389	1·5354	1·5406	1·5373
Tl_α	5350	1·5398	1·5363	1·5413	1·5377
Hg blue	4916	1·5426	1·5391	1·5443	1·5407
H_β(F)	4861	1·5428	1·5394	1·5445	1·5410
Cs_β	4550	1·5464	1·5428	1·5475	1·5440
Hg violet	4358	—	—	1·5494	1·5462
H_γ(G′)	4340	—	—	1·5500	1·5462

Line.	Wave-length,	No. VII.		No. VIII, crystal 1.	
	λ.	ω.	ϵ.	ω.	ϵ.
—	7200 Å.	1·5357	—	1·5371	—
Li_α	6708	1·5363	1·5324	1·5377	1 5346
H_α(C)	6563	1·5371	1·5339	1·5380	1·5350
—	6250	1·5380	1·5349	1·5390	1·5363
Na(D)	5893	1·5393	1·5359	1·5406	1·5374
Hg yellow	5780	1·5404	1·5370	1·5417	1·5384
Hg green	5461	1·5417	1·5381	1·5426	1·5394
Tl_α	5350	1·5425	1·5384	1·5433	1·5402
Hg blue	4916	1·5454	1·5419	1·5462	1·5429
H_β(F)	4861	1·5453	—	1·5465	1·5431
Cs_β	4550	—	—	—	—
Hg violet	4358	1·5521*	1·5443*	1·5516	1·5486
H_γ(G′)	4340	1·5526*	1·5443*	1·5518	1·5485

* Approximate values.

Dispersive power, $P=(n_F-n_C)/(n_{Na}-1)$.

Specimen.	Crystal.	P_ω.	P_ϵ.
VI	1	0·0164	0·0163
	2	0·0165	0·0163
VIII	1	0·0163	0·0156
VII	–	0·0160	0·0158
No. 42 (F. Stella Starrabba)		0·0162	0·0160

only six nepheline specimens (Table 7). These points lie satisfactorily near the line drawn through the new data. The increase in refractive index for one potassium atom has been measured from fig. 4 as 0·006 to 0·008. The birefringence also appears to increase in the same direction, but the increase is too small to deduce any certain relations. It is noteworthy that the refractive index of 'pseudonepheline' is the highest recorded for nepheline and no analysis records a higher potassium content. Penfield[17a] has recorded a refractive index of $\omega = 1·5469$ for elaeolite from Arkansas, and from the data we have obtained this should have a potassium content of 2·55 atoms per unit cell. No analysis exists, however, to confirm this conclusion. The low refractive indices of the two nepheline specimens nos. I and IV are probably to be attributed to low potassium content. It will be noted also that one of these specimens, no. IV, yielded a low oxygen figure (Table 3). Its low density accounts in part for the low figure of 31·1, but the latter is influenced to a much greater extent by the percentage of oxygen

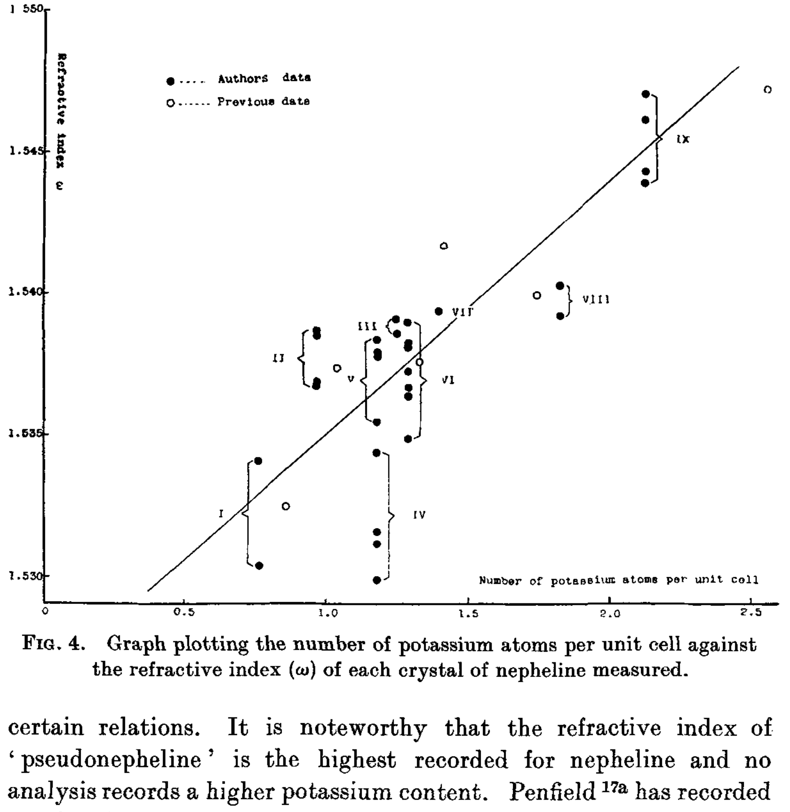

FIG. 4. Graph plotting the number of potassium atoms per unit cell against the refractive index (ω) of each crystal of nepheline measured.

given by chemical analysis. In other words the cell-volume measured by X-ray methods and the refractive index do not correspond to the material analysed. Such a conclusion must apply to each specimen here studied to a greater or less degree; if the number of oxygen atoms per unit cell is near 32, then the cell-volume, and presumably the refractive index, are associated with the given chemical composition.

The space-group and the structure-scaffolding of nepheline.

The section dealing with nepheline will be concluded with an account of the work which has been done on the space-group and the structure. Pl. XXI, fig. 7, shows a Laue photograph of a nepheline crystal (specimen no. VI, crystal 2) taken along the *c*-axis. The crystal is so oriented that an *a*-axis is horizontal. A gnomonic projection of this photograph has been made and the indices are given in Table 9. It is obvious that the Laue photograph possesses only a hexagonal axis and no planes of symmetry. Care has been taken in giving the relative intensities of the spots which reveal the lack of symmetry-planes, for since a pair of such spots corresponds to the same wave-length their relative intensities are a measure of the structure intensities for the two planes. All the spots observed correspond to wave-lengths ranging from 0·322 to about 4·0 Å. The short wave limit calculated from the voltage applied to the X-ray tube is 0·30 Å. In attempting to deduce any structure factors from the Laue photograph caution is necessary in particular for spots $(70\bar{7}3)$, $(44\bar{8}3)$, $(32\bar{5}1)$ and $(10.0.\overline{10}.3)$, $(72\bar{9}2)$, since their corresponding wave-lengths lie close to the absorption limits for bromine ($\lambda = 0{\cdot}918$ Å.) and silver ($\lambda = 0{\cdot}485$ Å.) respectively. In Table 10 I have also given the indices of the spots of a rotation photograph about the *c*-axis reproduced in Pl. XXII, fig. 9. The photograph was taken using a molybdenum anticathode and a zirconium filter.

A direct physical solution of the nepheline structure has not yet been offered, but the space-group of nepheline appears to be satisfactorily established. Gottfried,[52] Schiebold,[56] and Jaeger [50] have all found the space-group to be C_6^6, and this conclusion is in agreement not only with X-ray data but also with Baumhauer's [21] experiments on the etch-figures of nepheline. I have made oscillation photographs of nepheline crystals used for spacing measurements to obtain the odd orders of the base reflections (0001), (0003), &c., without success. Dr. W. A. Wooster has also detected the pyro-electric effect of nepheline crystals from nos. III, VI, and VIII immersed in liquid air. He states that a definite effect was observed, but owing to the small size of the crystals he failed to obtain the direction of the pyro-electric axis. There seems little doubt, therefore, that the space-group has been correctly chosen.

It has already been stated that the recalculation of nepheline analyses giving the number of atoms per unit cell all resulted in a constant sum of $Si+Al = 16$, and this may be interpreted as a result of the substitution of Si for Al in nepheline without alteration of structure and as we have seen without appreciable alteration in cell-size. If the substitution is carried to its logical conclusion then it appears that a form of silica would result. Gibbs[47] has studied the structures of the various forms of silica and his data for β-tridymite are $a = 5{\cdot}03$, $c = 8{\cdot}22$ Å., for the cell-edges of the unit hexagonal cell. The rhomb-based cell contains $4SiO_2$ and the structure consists of linked tetrahedra of Si surrounded by four oxygen atoms. If half the silicon atoms be replaced by aluminium the structure becomes polar (fig. 5). The disappearance of the vertical planes of symmetry might be explained in terms of a rotation of each tetrahedron of Si and O atoms and Al and O atoms about the trigonal axis, but this would not account for the a dimension now being doubled. A plan of the structure perpendicular to an a-axis (fig. 5 b) also shows obvious gaps for the alkali atoms, but symmetry conditions are not sufficient to fix either the exact position of the oxygen or the alkali atoms. The Si and Al atoms are fixed by symmetry on the trigonal axes and the alkali atoms are probably situated on and around hexad axes. The gaps shown in fig. 5 which probably accommodate the alkali atoms are about the diameter of an oxygen atom, i.e. 2·5 to 2·7 Å. The diameters of the sodium and potassium atoms are 2·0 and 2·6 Å. respectively. The disturbance caused by the entrance of large anions into the simple structure postulated in fig. 5 might very easily cause some distortion. The actual details of such distortion can only be studied by direct physical methods.

Prof. W. L. Bragg has been good enough to inform me that he has arrived at a similar structure by assuming Gottfried's determination of the space-group and the sizes of the atoms, whilst Schiebold[56] has recently published X-ray data on nepheline from Pargo Chigi, Ariccia, Italy. He has confirmed Gottfried's space-group determination and has suggested that the structure is derived from tridymite, thereby explaining the excess silica usually found in nepheline analyses. Although no detailed structure has been worked out, the scaffolding seems to be firmly established and it is interesting to note that the controversies on the interpretation of nepheline analyses change their aspect. Bowen's[37, 43] thermal work led him to conclude that natural nephelines are to be regarded as solid solutions of nepheline, kaliophilite, and plagioclase, whereas Morozewicz's[54] careful chemical analyses of elaeolite from the mariupolite rocks of Mariu-

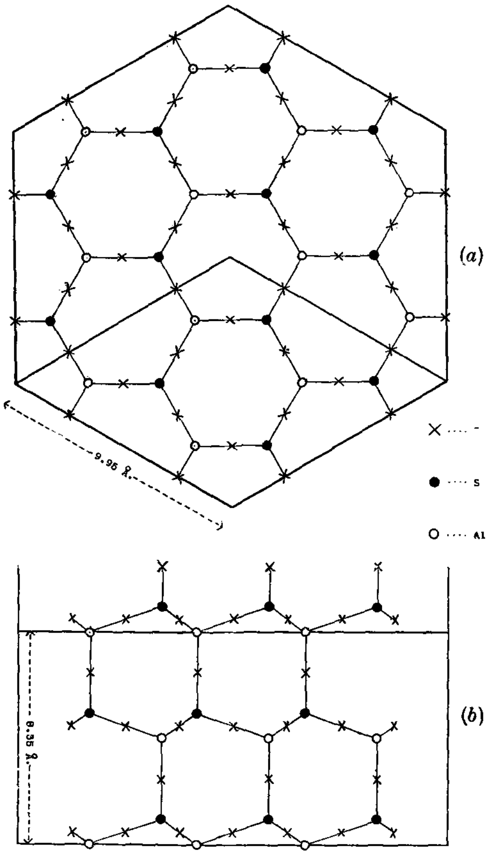

Fig. 5. Two views of the scaffolding of the nepheline structure: (*a*) perpendicular to the *c*-axis; (*b*) perpendicular to an *a*-axis.

pol, Russia, led him to write the formula $K_2Al_2Si_3O_{10}.4Na_2Al_2Si_2O_8$. Morozewicz looked upon nepheline as a double salt rather than an isomorphous replacement of potassium and sodium. Other views have been held too numerous to discuss here; references are to be found in the list of literature appended.

The work described in this paper enables us to write the contents of the unit cell of nepheline as $Si_{16-n}Al_n(Na,K,\frac{1}{2}Ca)_nO_{32}$ with the possible inclusion of Mg with the alkalis (p. 580). The variations in composition of nepheline may now be regarded as the replacement of Al by Si and Na by K and Ca in such a way that the nepheline structure is not altered and so that the valency conditions are fulfilled. It has been shown that the increase of potassium content increases the cell size. This may perhaps be referred to the size of the potassium atom being larger than that of sodium.

I have found that the 'pseudonepheline' crystals from Capo di Bove (specimen no. IX) with high potassium content yield Laue photographs typical for nepheline and have the same value for the axial ratio, namely 0·84. These photographs, however, do not show the lack of vertical symmetry-planes so clearly. Many spots of unequal intensity on the other nepheline Lauegrams are for the 'pseudonepheline' photographs of approximately equal intensity. There is a possibility that the problem thus presented is complicated by twinning. Baumhauer[21] has figured nepheline crystals twinned so that opposite ends of the *c*-axis of the separate individuals lie together. Such twinning from the suggested structure of fig. 5 seems highly probable and of course would account for the increase in symmetry of the Laue photograph. These crystals of 'pseudonepheline' are so small that it has not been possible to etch the faces and decide the matter.

Table 9. Indices and intensities of spots on a Laue photograph of nepheline (no. VI, crystal 2) taken perpendicular to the c*-axis.* (Pl. XXI, fig. 7.)

Index.	Intensity.	Index.	Intensity.	Index.	Intensity.	Index.	Intensity.
$(20\bar{2}1)$	*m*	$(8.3.\overline{11}.5)$	*s*	$(61\bar{7}3)$	*vvw*	$(1.11.\overline{12}.5)$	*vvw*
$(71\bar{8}4)$	*m*	$(3.8.\overline{11}.5)$	*m*	$(16\bar{7}3)$	*w*	$(10.2.\overline{12}.5)$	*m*
$(17\bar{8}4)$	*vvw*	$(90\bar{9}4)$	*w*	$(52\bar{7}3)$	*vw*	$(2.10.\overline{12}.5)$	*w*
$(11.0.\overline{11}.5)$	*vw*	$(72\bar{9}4)$	*m*	$(25\bar{7}3)$	*vvw*	$(8.4.\overline{12}.5)$	*vvw*
$(10.1.\overline{11}.5)$	*ms*	$(27\bar{9}4)$	*vw*	$(43\bar{7}3)$	*m*	$(4.8.\overline{12}.5)$	*ms*
$(1.10.\overline{11}.5)$	*m*	$(54\bar{9}4)$	*w*	$(34\bar{7}3)$	*w*	$(7.5.\overline{12}.5)$	*ms*
$(9.2.\overline{11}.5)$	*m*	$(45\bar{9}4)$	*vw*	$(7.7.\overline{14}.6)$	*ms*	$(5.7.\overline{12}.5)$	*ms*
$(2.9.\overline{11}.5)$	*ms*	$(70\bar{7}3)$	*vs*	$(11.1.\overline{12}.5)$	nil	$(6.6.\overline{12}.5)$	*vw*

Table 9—continued.

Index.	Intensity.	Index.	Intensity.	Index.	Intensity.	Index.	Intensity.
$(50\bar{5}2)$	*ms*	$(72\bar{9}3)$	*vs*	$(2.9.\overline{11}.3)$	*s*	$(14\bar{5}1)$	*vs*
$(41\bar{5}2)$	*w*	$(27\bar{9}3)$	*vs*	$(8.3.\overline{11}.3)$	*s*	$(7.3.\overline{10}.2)$	*ms*
$(14\bar{5}2)$	*vw*	$(21\bar{3}1)$	*s*	$(3.8.\overline{11}.3)$	*vw*	$(3.7.\overline{10}.2)$	nil
*$(32\bar{5}2)$	*w*	$(12\bar{3}1)$	*s*	$(40\bar{4}1)$	*m*	$(32\bar{5}1)$	*vs*
*$(23\bar{5}2)$	nil	$(9.6.\overline{15}.5)$	*vw*	$(71\bar{8}2)$	*ms*	$(23\bar{5}1)$	*vvs*
$(7.3.\overline{10}.4)$	*vvw*	$(6.9.\overline{15}.5)$	*vw*	$(17\bar{8}2)$	*m*	$(5.5.\overline{10}.2)$	*s*
$(3.7.\overline{10}.4)$	*w*	$(54\bar{9}3)$	*s*	$(10.2.\overline{12}.3)$	*m*	$(11.0.\overline{11}.2)$	*vvw*
$(12.1.\overline{13}.5)$	*vw*	$(45\bar{9}3)$	*s*	$(2.10.\overline{12}.3)$	*ms*	$(9.2.\overline{11}.2)$	*ms*
$(1.12.\overline{13}.5)$	nil	$(33\bar{6}2)$	*ms*	*$(31\bar{4}1)$	*vs*	$(2.9.\overline{11}.2)$	*vvw*
$(10.3.\overline{13}.5)$	*w*	$(9.7.\overline{16}.5)$	*w*	*$(13\bar{4}1)$	*vs*	$(8.3.\overline{11}.2)$	*ms*
$(3.10.\overline{13}.5)$	*m*	$(7.9.\overline{16}.5)$	*w*	$(8.4.\overline{12}.3)$	*vw*	$(3.8.\overline{11}.2)$	*m*
$(8.5.\overline{13}.5)$	*w*	$(8.8.\overline{16}.5)$	*w*	$(4.8.\overline{12}.3)$	*vw*	$(7.4.\overline{11}.2)$	*vw*
$(5.8.\overline{13}.5)$	*w*	$(11.2.\overline{13}.4)$	nil	$(53\bar{8}2)$	*vs*	$(4.7.\overline{11}.2)$	*vw*
$(80\bar{8}3)$	*m*	$(2.11.\overline{13}.4)$	*w*	$(35\bar{8}2)$	*vs*	$(6.5.\overline{11}.2)$	*vw*
$(71\bar{8}3)$	*w*	$(9.4.\overline{13}.4)$	nil	$(7.5.\overline{12}.3)$	*s*	$(5.6.\overline{11}.2)$	*m*
$(17\bar{8}3)$	*ms*	$(4.9.\overline{13}.4)$	*w*	$(5.7.\overline{12}.3)$	*s*	$(60\bar{6}1)$	*s*
$(62\bar{8}3)$	*m*	$(8.5.\overline{13}.4)$	*w*	$(22\bar{4}1)$	*vs*	$(51\bar{6}1)$	*vs*
$(26\bar{8}3)$	*w*	$(5.8.\overline{13}.4)$	nil	$(11.2.\overline{13}.3)$	*vvw*	$(15\bar{6}1)$	*vs*
$(53\bar{8}3)$	*w*	$(10.0.\overline{10}.3)$	*m*	$(2.11.\overline{13}.3)$	*vw*	$(42\bar{6}1)$	*s*
$(35\bar{8}3)$	*vvw*	$(9.1.\overline{10}.3)$	*s*	$(10.3.\overline{13}.3)$	nil	$(24\bar{6}1)$	*vs*
$(44\bar{8}3)$	*vs*	$(1.9.\overline{10}.3)$	*vvw*	$(3.10.\overline{13}.3)$	*vw*	$(7.5.\overline{12}.2)$	*w*
$(11.0.\overline{11}.4)$	*vw*	$(8.2.\overline{10}.3)$	*s*	$(9.4.\overline{13}.3)$	*w*	$(5.7.\overline{12}.2)$	*w*
$(9.2.\overline{11}.4)$	*vvw*	$(2.8.\overline{10}.3)$	*s*	$(4.9.\overline{13}.3)$	*vw*	$(33\bar{6}1)$	*s*
$(2.9.\overline{11}.4)$	*ms*	$(7.3.\overline{10}.3)$	*ms*	$(8.5.\overline{13}.3)$	*m*	$(70\bar{7}1)$	*s*
$(8.3.\overline{11}.4)$	*vvw*	$(3.7.\overline{10}.3)$	*ms*	$(5.8.\overline{13}.3)$	*m*	$(61\bar{7}1)$	*vw*
$(3.8.\overline{11}.4)$	*vw*	$(6.4.\overline{10}.3)$	*ms*	$(90\bar{9}2)$	*m*	$(16\bar{7}1)$	*m*
$(7.4.\overline{11}.4)$	*m*	$(4.6.\overline{10}.3)$	*vvw*	$(81\bar{9}2)$	*ms*	$(52\bar{7}1)$	*m*
$(4.7.\overline{11}.4)$	*w*	$(5.5.\overline{10}.3)$	*s*	$(18\bar{9}2)$	*s*	$(25\bar{7}1)$	*vvw*
$(14.0.\overline{14}.5)$	*w*	$(70\bar{7}2)$	*vvs*	$(72\bar{9}2)$	*s*	$(43\bar{7}1)$	*s*
$(12.2.\overline{14}.5)$	*w*	$(61\bar{7}2)$	*ms*	$(27\bar{9}2)$	*vs*	$(34\bar{7}1)$	*s*
$(2.12.\overline{14}.5)$	*w*	$(16\bar{7}2)$	*s*	$(63\bar{9}2)$	*m*	$(71\bar{8}1)$	*w*
$(11.3.\overline{14}.5)$	*vw*	$(52\bar{7}2)$	*s*	$(36\bar{9}2)$	*vvw*	$(17\bar{8}1)$	nil
$(3.11.\overline{14}.5)$	*m*	$(25\bar{7}2)$	*vs*	$(54\bar{9}2)$	*w*	$(62\bar{8}1)$	*w*
$(9.5.\overline{14}.5)$	*w*	$(43\bar{7}2)$	*s*	$(45\bar{9}2)$	*vs*	$(26\bar{8}1)$	*w*
$(5.9.\overline{14}.5)$	*m*	$(34\bar{7}2)$	*s*	$(9.5.\overline{14}.3)$	*vw*	$(53\bar{8}1)$	*m*
$(30\bar{3}1)$	*w*	$(7.7.\overline{14}.4)$	*vw*	$(5.9.\overline{14}.3)$	*w*	$(35\bar{8}1)$	*s*
$(81\bar{9}3)$	*m*	$(11.0.\overline{11}.3)$	*vvw*	$(50\bar{5}1)$	*vvs*	$(44\bar{8}1)$	*w*
$(18\bar{9}3)$	*m*	$(10.1.\overline{11}.3)$	*vs*	$(9.1.\overline{10}.2)$	*m*		
$(51\bar{6}2)$	*ms*	$(1.10.\overline{11}.3)$	*s*	$(1.9.\overline{10}.2)$	*m*		
$(15\bar{6}2)$	*ms*	$(2.9.\overline{11}.3)$	*w*	$(41\bar{5}1)$	*s*		

* Superposed upon the true Laue spots $(32\bar{5}2)$ and $(31\bar{4}1)$ are streaks due to diffracted characteristic radiation from copper and tungsten. $(32\bar{5}2)$ and $(23\bar{5}2)$ diffract Cu-K_α ($\lambda = 1{\cdot}539$ Å.); $(31\bar{4}1)$ and $(13\bar{4}1)$ diffract W-$L_{\beta 1}$ ($\lambda = 1{\cdot}279$ Å.). Distance of crystal to plate, 3·5 cm. *s* = strong, *m* = medium, *w* = weak, *vs* = very strong, &c.

Table 10. *Indices and intensities of spots on a rotation photograph of nepheline (no. VI, crystal* 2) *about the* c-*axis.* (Pl. XXII, *fig.* 9.)

Equator.	1st layer-line.	2nd layer-line.	3rd layer-line.	4th layer-line.	5th layer-line.	6th layer-line.
—	—	$(10\bar{1}2)$ *w*	$(10\bar{1}3)$ *vw*	$(10\bar{1}4)$ *m*	—	$(10\bar{1}6)$ *ms*
$(2\bar{1}\bar{1}0)$ *w*	$(2\bar{1}\bar{1}1)$ *vvw*	—	—	—	$(2\bar{1}\bar{1}5)$ *w*	—
$(20\bar{2}0)$ *m*	$(20\bar{2}1)$ *s*	$(20\bar{2}2)$ *vs*	$(20\bar{2}3)$ *s*	$(20\bar{2}4)$ *m*	$(20\bar{2}5)$ *vs*	—
$(3\bar{1}\bar{2}0)$ *vs*	$(3\bar{1}\bar{2}1)$ *w*	$(3\bar{1}\bar{2}2)$ *ms*	$(3\bar{1}\bar{2}3)$ *m*	$(3\bar{1}\bar{2}4)$ *w*	$(3\bar{1}\bar{2}5)$ *vw*	$(3\bar{1}\bar{2}6)$ *vw*
$(30\bar{3}0)$ *vs*	—	$(30\bar{3}2)$ *vw*	—	$(30\bar{3}4)$ *w*	—	$(30\bar{3}6)$ *s*
$(22\bar{4}0)$ *ms*	$(22\bar{4}1)$ *vw*	—	—	—	—	$(22\bar{4}6)$ *m*
$(4\bar{1}\bar{3}0)$ *s*	$(4\bar{1}\bar{3}1)$ *s*	$(4\bar{1}\bar{3}2)$ *m*	$(4\bar{1}\bar{3}3)$ *vw*	$(4\bar{1}\bar{3}4)$ *w*	$(4\bar{1}\bar{3}5)$ *ms*	$(4\bar{1}\bar{3}6)$ *m*
$(40\bar{4}0)$ *m*	—	$(40\bar{4}2)$ *w*	$(40\bar{4}3)$ *w*	$(40\bar{4}4)$ *vw*	$(40\bar{4}5)$ *w*	$(40\bar{4}6)$ *vw*
$(5\bar{2}\bar{3}0)$ *m*	$(5\bar{2}\bar{3}1)$ *m*	$(5\bar{2}\bar{3}2)$ *vw*	$(5\bar{2}\bar{3}3)$ *ms*	—	—	—
$(5\bar{1}\bar{4}0)$ *m*	$(5\bar{1}\bar{4}1)$ *w*	$(5\bar{1}\bar{4}2)$ *vw*	$(5\bar{1}\bar{4}3)$ *ms*	—	—	—
$(50\bar{5}0)$ *vw*	$(50\bar{5}1)$ *w*	$(50\bar{5}2)$ *w*	$(50\bar{5}3)$ *m*	—	$(50\bar{5}5)$ *ms*	—
$(6\bar{2}\bar{4}0)$ *ms*	$(6\bar{2}\bar{4}1)$ *vw*	$(6\bar{2}\bar{4}2)$ *w*	$(6\bar{2}\bar{4}3)$ *m*	—	$(6\bar{2}\bar{4}5)$ *w*	$(6\bar{2}\bar{4}6)$ *vw*
$(6\bar{1}\bar{5}0)$ *ms*	$(6\bar{1}\bar{5}1)$ *vw*	$(6\bar{1}\bar{5}2)$ *vw*	—	—	$(6\bar{1}\bar{5}5)$ *w*	—
$(60\bar{6}0)$ *vw*	$(60\bar{6}1)$ *vvw*	$(60\bar{6}2)$ *vw*	$(60\bar{6}3)$ *m*	$(60\bar{6}4)$ *w*	$(60\bar{6}5)$ *w*	$(60\bar{6}6)$ *m*
$(7\bar{2}\bar{5}0)$ *vs*	—	$(7\bar{2}\bar{5}2)$ *m*	—	$(7\bar{2}\bar{5}4)$ *vw*	—	—
$(7\bar{1}\bar{6}0)$ *w*	—	$(7\bar{1}\bar{6}2)$ *vw*	—	—	—	—
$(70\bar{7}0)$ *m*	$(70\bar{7}1)$ *vw*	$(70\bar{7}2)$ *ms*	$(70\bar{7}3)$ *m*	—	$(70\bar{7}5)$ *m*	—
$(8\bar{2}\bar{6}0)$ *w*	—	$(8\bar{2}\bar{6}2)$ *vw*	—	—	—	—

The distance of plate to crystal $=3{\cdot}9$ cm.
Molydenum radiation $\lambda=0{\cdot}71$ Å. was used filtered by zirconium.

KALIOPHILITE.

Owing to the lack of material it has not been possible to study a series of specimens of this mineral and thus correlate the physical properties with chemical composition. The attempt has been made rather to find the relation between nepheline and kaliophilite and to carry out X-ray and other physical measurements on material definitely shown by chemical analysis to be kaliophilite. Two good specimens of kaliophilite were available, one from the British Museum collection (B.M. 68763) and a very fine one, no. 673, kindly lent for study by Dr. K. W. Earle from the Johnston-Lavis collection at University College, London. These specimens are numbered X and XI respectively in Table 11. The original labels with these specimens bear the name 'Facellite' (E. Scacchi, 1888),[20] but, as will be shown below, the chemical and optical properties and the densities of fresh material from both specimens are those for kaliophilite (B. Mierisch, 1886).[19] In Hintze's 'Handbuch der Mineralogie', 1897, the two names are considered to represent distinct minerals, presumably on the density determination (2·4926) of E. Scacchi.[20]

The specimens examined consist of glassy acicular bundles of the mineral in cavities of a dark augite and brown biotite block. Material suitable for physical and chemical work was picked by hand, and, to avoid loss by bromoform separations, each fragment set aside for chemical analysis was carefully examined with a lens to make quite sure it was free from inclusions or adherent impurities. In the case of specimen no. X only 0·02 gram was available, but the analysis is sufficiently accurate to show that the mineral analysed is kaliophilite (Table 11). The densities were determined by the method already described. The refractive indices were first determined by the Becke line method, but in the case of specimen no. XI it was possible to grind a small-angle prism and determine the refractive index by the method of minimum deviation for five different wave-lengths. The dispersive power calculated from the smoothed n and λ curve is 0·016 (Table 12). The fragments of nos. X and XI used for density and refractive index work were then studied by X-ray methods.

Gossner[58] has already published X-ray data for kaliophilite, and he offers two alternatives for the cell size: $a = 27{\cdot}01$, $c = 8{\cdot}59$ Å., $c/a = 0{\cdot}318$; and $a = 15{\cdot}59$, $c = 8{\cdot}59$ Å., $c/a = 0{\cdot}55$. The second set of values he obtained by neglecting certain weak layer-lines on his rotation photographs and presumes that they are more likely to be correct since they are of the same order as those obtained for other silicates. In any case his preliminary measurements indicate a marked difference between the X-ray rotation photographs of nepheline and kaliophilite.

Laue and rotation photographs of the kaliophilite specimen no. X had been obtained before Gossner's work was published. Pl. XXI, fig. 8, shows the reproduction of the Laue photograph of kaliophilite, and it will be noted that it has planes of symmetry as well as hexagonal symmetry. It is also obvious from the closer array of spots in the kaliophilite picture that the unit cell is larger than that of nepheline. The rotation photograph about the c-axis reproduced in Pl. XXII, fig. 10, shows that the cell-height (Table 11) is about the same as that of nepheline. Whereas the layer-lines of both rotation photographs in Pl. XXII are similarly spaced, the row-lines are much closer together than in the nepheline photograph, indicating that the base of the hexagonal cell is larger, $a = 27{\cdot}0$ Å. This result has been checked by rotation and oscillation photographs about the a-axis and about an axis at 30° to a. Oscillation photo-

Table 11. *New chemical and physical data for kaliophilite.*

Chemical analyses.

	SiO_2.	Al_2O_3.	CaO.	Na_2O.	K_2O.	Total.	% oxygen.
X ...	38·0	28·8	0·5	trace	32·2	99·5	39·4
XI ...	39·2	33·36	0·47	2·88	24·13	100·04	42·77

The amount of material used for no. X, 0·0208 gram.

Molecular ratios.

	SiO_2.	Al_2O_3.	CaO.	Na_2O.	K_2O.
X ...	0·632	0·565	0·009	—	0·684
XI ...	0·6525	0·6545	0·0084	0·0929	0·5123

Number of atoms per unit cell.

	Si.	Al.	Ca.	Na.	K.	Si+Al.	ΣR.
X	55	50	1	—	60	105	62
XI	54·3	54·4	0·7	7·7	42·6	108·7	51·7

Physical data.

	Density, *d*.	Refractive Index, ω.	ϵ.	$\omega-\epsilon$.	Length of cell-edge *a*.	Length of cell-height *c*.	$\frac{c}{a}$
X	2·598	1·531	1·527	0·004	26·7 Å.	8·49 Å.	0·318
XI	2·606	1·5296	1·5258	0·0038	27·0	8·51	0·315

Table 12. *Refractive indices of kaliophilite (no. XI) for different wave-lengths.*

Line.	Wave-length.	ω.
— ...	6250 Å. ...	1·527
Na(D) ...	5893 ...	1·530
Hg green ...	5461 ...	1·532
Tl_α... ...	5350 ...	1·533
H_β(F) ...	4861 ...	1·536

Dispersive power, $P=(n_F-n_C)/(n_{Na}-1)$, obtained from the smoothed ω and λ curve, 0·016.

graphs to obtain the *a* and *c* spacings for nos. X and XI have been taken for the planes (0006) and $(12.0.\overline{12}.0)$.

A gnomonic projection of the Laue photograph has yielded the indices given in Table 14. This photograph was taken under the same conditions as the Laue photograph of nepheline and the wave-lengths range from 0·30 to about 4·0 Å., the short wave limit also agreeing with that calculated from the applied voltage. The same caution should be observed in utilizing the observed intensities of spots produced by different wave-lengths; it has not been possible in this case to indicate those spots corresponding to wave-lengths lying close to the absorption limits for bromine and silver, since the spots are so much closer together. The rotation photograph of kaliophilite is difficult to index completely owing to the large *a* dimension. The second and fourth layer-lines are weak, and the strong spots indexed with certainty are $(33\bar{6}0)$ *m*, $(33\bar{6}2)$ *vs*, $(90\bar{9}0)$ *vs*, $(5.5.\overline{10}.6)$ *s*, and $(6.6.\overline{12}.0)$ *s*.

From the unit cell and density measurements it has been possible to calculate the molecular weight of the unit-cell contents, and this approximates closely to $54KAlSiO_4$. The chemical analyses are not in this case sufficiently accurate to yield a direct determination of the number of oxygen atoms in the unit cell, but assuming from the above result 216 per unit cell, all previous analyses (Table 13) and Mr. Hey's (Table 11) give a reasonably constant figure for the Si + Al content. The sodium content of kaliophilite from this and previous work is less than the potassium content of nepheline.

Table 13. *Number of atoms per unit cell of kaliophilite, calculated from previous analyses.*

Lit. No.	Si.	Al.	Ca.	Na.	K.	Si + Al.	ΣR.	*d.*
19	52·7	53·8	3·3	6·2	48·8	106·5	61·6	2·602
20	53·3	55·1	—	1·0	52·8	108·4	53·8	2·493
36	54·4	53·6	trace	5·8	47·9	108·0	53·7	2·628
49	54·9	53·0	0·5	10·6	41·0	107·9	53·2*	2·61

* In the sum of the alkali atoms is included 0·3 atoms of magnesium.

For no. 49 (Mügge) ... ... $\omega = 1{\cdot}5316$, $\epsilon = 1{\cdot}5273$ (yellow).

The X-ray data yield axial ratios $c/a = 0{\cdot}318$ and $c/a = 0{\cdot}315$ for nos. X and XI respectively. Careful examination of the material at my disposal failed to reveal any pyramidal planes suitable for direct measurement of the axial ratio. Even the prism-faces show many neighbouring vicinal forms and I failed to observe a (0001) cleavage. F. Zambonini,[36] however, has succeeded in obtaining a reflection from a pyramidal plane of an isolated prism of kaliophilite. He gives $a : c = 1 : 0{\cdot}8382$, and I have calculated from his measurements the limits of error of this determination to be $\pm 0{\cdot}001$. My X-ray data do not agree with this figure, nor is there any simple ratio between the two.

Comparing the *a* dimensions of kaliophilite and nepheline it is clear that $27/10 =$ approximately $3(\sqrt{3}/2)$. In fact we may look upon the kaliophilite cell as built up from three nepheline cells in juxtaposition, the true *a* dimension not being trebled but fixed in a direction of 30° to the original nepheline cell-side. Fig. 6 shows this arrangement, and we must postulate that the presence of the large potassium atoms in the gaps in this structure has produced sufficient distortion to yield the large cell measured by X-ray methods. The distortion will probably prove to be of the same type as the distortion of the nepheline structure. The larger cell and the planes of symmetry of kaliophilite may then possibly be explained on the simple lines before suggested, namely a threefold 'twinning' or 'parallel growth' of the nepheline cell. In my work on nepheline it is shown that the cell-size increases with increase in potassium content. The kaliophilite structure may be regarded as built up from nepheline cells having the cell-sides $a = (27/3) \times (2/\sqrt{3}) = 10{\cdot}4$ Å., and $c = 8{\cdot}5$ Å. The almost complete replacement of sodium by potassium has stretched the cell to these dimensions and the consesequent distortion of the tetrahedral framework has resulted in the increase of the repetition distance of the more intricate atomic pattern from 10·4 to 27 Å. It will be noted, however, that the c spacing is still of the same order though larger. For nepheline the axial ratio appears to decrease with increase of potassium and the kaliophilite results give the same conclusion, namely that the replacement of sodium by potassium increases the a spacing more than the c spacing and therefore reduces the axial ratio (p. 587).

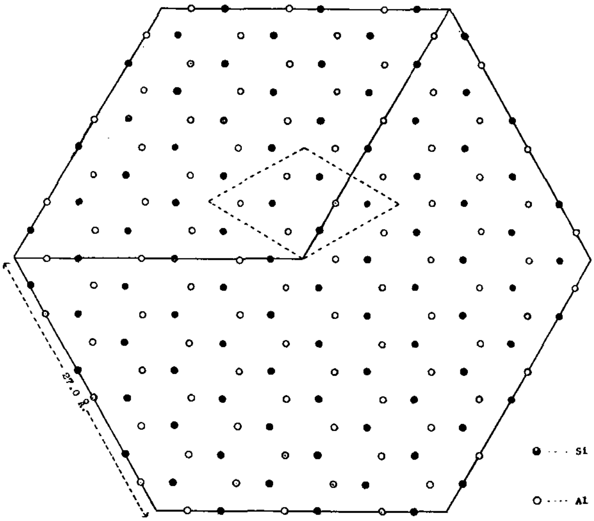

FIG. 6. Plan of a possible kaliophilite scaffolding built up from nepheline cells. The dotted outline is a nepheline unit cell.

In the interests of future workers, especially those using X-ray methods, I would draw attention to two unique specimens of kaliophilite in the Göttingen collection described by O. Mügge,[49] which consist of milky-white crystals on ejected blocks from Monte Somma, Vesuvius. The crystals reach a size of 5 mm. across and 17 mm. long and their chemical analysis and optical properties prove them to be kaliophilite. On the basis of Mügge's work the white crystals of nepheline low in refractive index found on specimens nos. I and IV were at first thought to be kaliophilite, but chemical analyses and Laue photographs have definitely shown them to be nepheline. Their low refractive index values have already been discussed. In view of the much smaller crystals of kaliophilite usually met with it would be desirable to possess further data on the Göttingen specimens. Such good crystals would be eminently suitable for work on X-ray structure. It is significant that the analyses of these crystals reveal a higher sodium content than is usual for kaliophilite, and that zoning of the crystals accompanied by variations in birefringence has also been observed.

Table 14. *Indices and intensities of spots on a Laue photograph of kaliophilite (no. X) taken perpendicular to the c-axis.* (Pl. XXI, fig. 8.)

Index.	Intensity.	Index.	Intensity.	Index.	Intensity	Index.	Intensity.
$(50\overline{5}1)$	*vvw*	$(61\overline{7}1)$	*w*	$(18.5.\overline{23}.3)$	*w*	$(10.7.\overline{17}.2)$	*w*
$(15.1.\overline{16}.3)$	*vvw*	$(17.4.\overline{21}.3)$	*vvw*	$(17.6.\overline{23}.3)$	*vw*	$(22.3.\overline{25}.3)$	*m*
$(15.2.\overline{17}.3)$	*vvw*	$(16.5.\overline{21}.3)$	*m*	$(15.8.\overline{23}.3)$	*vw*	$(21.4.\overline{25}.3)$	*w*
$(60\overline{6}1)$	*w*	$(52\overline{7}1)$	*vw*	$(14.9.\overline{23}.3)$	*w*	$(19.6.\overline{25}.3)$	*vw*
$(17.1.\overline{18}.3)$	*vw*	$(14.7.\overline{21}.3)$	*vvw*	$(12.11.\overline{23}.3)$	*vw*	$(18.7.\overline{25}.3)$	*w*
$(16{\cdot}2.\overline{18}.3)$	*vw*	$(13.8.\overline{21}{:}3)$	*vw*	$(80\overline{8}1)$	*vw*	$(16.9.\overline{25}.3)$	*w*
$(51\overline{6}1)$	*vw*	$(43\overline{7}1)$	*vw*	$(23.1.\overline{24}.3)$	*vw*	$(13.12.\overline{25}.3)$	*w*
$(14.4.\overline{18}.3)$	*w*	$(11.10.\overline{21}.3)$	*w*	$(22.2.\overline{24}.3)$	*m*	$(26.0.\overline{26}.3)$	*vw*
$(42\overline{6}1)$	*w*	$(7.7.\overline{14}.2)$	*w*	$(71\overline{8}1)$	*m*	$(23.3.\overline{26}.3)$	*vw*
$(7.5.\overline{12}.2)$	*vw*	$(21.1.\overline{22}.3)$	*m*	$(20.4.\overline{24}.3)$	*m*	$(17.9.\overline{26}.3)$	*vvw*
$(33\overline{6}1)$	*vvw*	$(19.3.\overline{22}.3)$	*w*	$(19.5.\overline{24}.3)$	*w*	$(14.12.\overline{26}.3)$	*vw*
$(12.1.\overline{13}.2)$	*vw*	$(18.4.\overline{22}.3)$	*m*	$(62\overline{8}1)$	*w*	$(90\overline{9}1)$	*w*
$(5.8.\overline{13}.2)$	*vvw*	$(16.6.\overline{22}.3)$	*m*	$(11.5.\overline{16}.2)$	*m*	$(81\overline{9}1)$	*w*
$(18.1.\overline{19}.3)$	*w*	$(15.7.\overline{22}.3)$	*m*	$(16.8.\overline{24}.3)$	*vw*	$(15.3.\overline{18}.2)$	*m*
$(15.4.\overline{19}.3)$	*vvw*	$(13.9.\overline{22}.3)$	*w*	$(53\overline{8}1)$	*vw*	$(20.7.\overline{27}.3)$	*vvw*
$(18.2.\overline{20}.3)$	*w*	$(12.10.\overline{22}.3)$	*w*	$(14.10.\overline{24}.3)$	*vw*	$(19.8.\overline{27}.3)$	*vvw*
$(15.5.\overline{20}.3)$	*vvw*	$(12.3.\overline{15}.2)$	*m*	$(13.11.\overline{24}.3)$	*m*	$(63\overline{9}1)$	*m*
$(12.8.\overline{20}.3)$	*vw*	$^*(9.6.\overline{15}.2)$	*m*	$(44\overline{8}1)$	*m*	$(11.7.\overline{18}.2)$	*w*
$(70\overline{7}1)$	*w*	$(23.0.\overline{23}.3)$	*vw*	$(17.0.\overline{17}.2)$	*m*	$(54\overline{9}1)$	*vvw*
$(20.1.\overline{21}.3)$	*m*	$(21.2.\overline{23}.3)$	*vw*	$(16.1.\overline{17}.2)$	*m*	$(9.9.\overline{18}.2)$	*m*
$(19.2.\overline{21}.3)$	*w*	$(20.3.\overline{23}.3)$	*w*	$(13.4.\overline{17}.2)$	*w*	$(28.0.\overline{28}.3)$	*w*

For explanation of asterisk (*) see end of Table.

Index.	Intensity.	Index.	Intensity.	Index.	Intensity.	Index.	Intensity.
$(19.9.\overline{28}.3)$	*w*	$(32.0.\overline{32}.3)$	*vw*	$(13.0.\overline{13}.1)$	*w*	$(14.3.\overline{17}.1)$	*w*
$(15.13.\overline{28}.3)$	*vvw*	$(29.3.\overline{32}.3)$	*vvw*	$(12.1.\overline{13}.1)$	*m*	$(13.4.\overline{17}.1)$	*w*
$(19.0.\overline{19}.2)$	*vw*	$(26.6.\overline{32}.3)$	*vw*	$(11.2.\overline{13}.1)$	*vw*	$(12.5.\overline{17}.1)$	*w*
$(17.2.\overline{19}.2)$	*s*	$(20.12.\overline{32}.3)$	*vw*	$(10.3.\overline{13}.1)$	*vw*	$(11.6.\overline{17}.1)$	*s*
$(16.3.\overline{19}.2)$	*w*	$(17.15.\overline{32}.3)$	*vw*	$(19.7.\overline{26}.2)$	*vvw*	$(10.7.\overline{17}.1)$	*w*
$(15.4.\overline{19}.2)$	*vvw*	$(10.1.\overline{11}.1)$	*vw*	$(9.4.\overline{13}.1)$	*m*	$(9.8.\overline{17}.1)$	*m*
$(14.5.\overline{19}.2)$	*m*	$(19.3.\overline{22}.2)$	*vw*	$(8.5.\overline{13}.1)$	*vw*	$(18.0.\overline{18}.1)$	*w*
$(13.6.\overline{19}.2)$	*w*	$(9.2.\overline{11}.1)$	*w*	$(7.6.\overline{13}.1)$	*m*	$(17.1.\overline{18}.1)$	*m*
$(11.8.\overline{19}.2)$	*m*	$(17.5.\overline{22}.2)$	*w*	$(13.13.\overline{26}.2)$	*m*	$(16.2.\overline{18}.1)$	*vw*
$(29.0.\overline{29}.3)$	*vw*	$(8.3.\overline{11}.1)$	*w*	$(18.9.\overline{27}.2)$	*vvw*	$(15.3.\overline{18}.1)$	*w*
$(27.2.\overline{29}.3)$	*vvw*	$(7.4.\overline{11}.1)$	*s*	$(16.11.\overline{27}.2)$	*vvw*	$(14.4.\overline{18}.1)$	*ms*
$(24.5.\overline{29}.3)$	*w*	*$(6.5.\overline{11}.1)$	*ms*	$(15.12.\overline{27}.2)$	*w*	$(13.5.\overline{18}.1)$	*m*
$(23.6.\overline{29}.3)$	*vvw*	$(11.11.\overline{22}.2)$	*w*	$(14.0.\overline{14}.1)$	*w*	$(11.7.\overline{18}.1)$	*w*
$(20.9.\overline{29}.3)$	*w*	$(22.12.\overline{34}.3)$	*vw*	$(13.1.\overline{14}.1)$	*w*	$(10.8.\overline{18}.1)$	*m*
$(15.14.\overline{29}.3)$	*vw*	$(23.0.\overline{23}.2)$	*vw*	$(12.2.\overline{14}.1)$	*w*	$(9.9.\overline{18}.1)$	*vw*
$(10.0.\overline{10}.1)$	*vw*	$(22.1.\overline{23}.2)$	*w*	$(11.3.\overline{14}.1)$	*w*	$(18.1.\overline{19}.1)$	*w*
$(19.1.\overline{20}.2)$	*w*	$(21.2.\overline{23}.2)$	*vvw*	$(10.4.\overline{14}.1)$	*w*	$(17.2.\overline{19}.1)$	*vw*
*$(9.1.\overline{10}.1)$	*m*	$(20.3.\overline{23}.2)$	*vvw*	$(9.5.\overline{14}.1)$	*m*	$(16.3.\overline{19}.1)$	*vw*
$(25.5.\overline{30}.3)$	*vw*	$(19.4.\overline{23}.2)$	*vw*	$(8.6.\overline{14}.1)$	*m*	$(15.4.\overline{19}.1)$	*m*
$(8.2.\overline{10}.1)$	*vs*	$(18.5.\overline{23}.2)$	*vvw*	$(7.7.\overline{14}.1)$	*w*	$(14.5.\overline{19}.1)$	*vvw*
$(15.5.\overline{20}.2)$	*w*	$(13.10.\overline{23}.2)$	*vvw*	$(15.0.\overline{15}.1)$	*m*	$(13.6.\overline{19}.1)$	*m*
*$(7.3.\overline{10}.1)$	*w*	$(12.0.\overline{12}.1)$	*w*	$(14.1.\overline{15}.1)$	*vvw*	$(12.7.\overline{19}.1)$	*m*
$(20.10.\overline{30}.3)$	*w*	$(11.1.\overline{12}.1)$	*w*	$(13.2.\overline{15}.1)$	*vw*	$(11.8.\overline{19}.1)$	*vw*
$(19.11.\overline{30}.3)$	*w*	$(21.3.\overline{24}.2)$	*w*	$(12.3.\overline{15}.1)$	*vw*	$(10.9.\overline{19}.1)$	*m*
*$(6.4.\overline{10}.1)$	*m*	$(10.2.\overline{12}.1)$	*w*	$(11.4.\overline{15}.1)$	*w*	$(17.3.\overline{20}.1)$	*vvw*
$(16.14.\overline{30}.3)$	*vw*	$(19.5.\overline{24}.2)$	*w*	$(10.5.\overline{15}.1)$	*w*	$(16.4.\overline{20}.1)$	*vw*
$(5.5.\overline{10}.1)$	*s*	$(9.3.\overline{12}.1)$	*vw*	$(9.6.\overline{15}.1)$	*w*	$(15.5.\overline{20}.1)$	*vw*
$(31.0.\overline{31}.3)$	*vvw*	$(8.4.\overline{12}.1)$	*w*	$(8.7.\overline{15}.1)$	*s*	$(14.6.\overline{20}.1)$	*vvw*
$(28.3.\overline{31}.3)$	*vvw*	$(15.9.\overline{24}.2)$	*m*	$(16.0.\overline{16}.1)$	*w*	$(12.8.\overline{20}.1)$	*vw*
$(25.6.\overline{31}.3)$	*vw*	$(7.5.\overline{12}.1)$	*m*	$(15.1.\overline{16}.1)$	*vw*	$(10.10.\overline{20}.1)$	*vvw*
$(24.7.\overline{31}.3)$	*vw*	$(6.6.\overline{12}.1)$	*m*	$(14.2.\overline{16}.1)$	*w*	$(17.4.\overline{21}.1)$	*vw*
$(22.9.\overline{31}.3)$	*w*	$(23.2.\overline{25}.2)$	*w*	$(13.3.\overline{16}.1)$	*s*	$(16.5.\overline{21}.1)$	*w*
$(21.10.\overline{31}.3)$	*w*	$(21.4.\overline{25}.2)$	*vw*	$(12.4.\overline{16}.1)$	*s*	$(14.7.\overline{21}.1)$	*w*
$(19.12.\overline{31}.3)$	*vw*	$(20.5.\overline{25}.2)$	*w*	$(11.5.\overline{16}.1)$	*m*	$(11.10.\overline{21}.1)$	*vw*
$(16.15.\overline{31}.3)$	*vw*	$(19.6.\overline{25}.2)$	*vw*	$(10.6.\overline{16}.1)$	*m*	$(21.21.\overline{42}.2)$	*w*
$(20.1.\overline{21}.2)$	*vw*	$(18.7.\overline{25}.2)$	*vvw*	$(9.7.\overline{16}.1)$	*s*	$(13.9.\overline{22}.1)$	*w*
$(19.2.\overline{21}.2)$	*vw*	$(17.8.\overline{25}.2)$	*w*	$(8.8.\overline{16}.1)$	*w*	$(12.10.\overline{22}.1)$	*w*
$(18.3.\overline{21}.2)$	*m*	$(16.9.\overline{25}.2)$	*vvw*	$(17.0.\overline{17}.1)$	*w*	$(12.11.\overline{23}.1)$	*vvw*
$(15.6.\overline{21}.2)$	*s*	$(15.10.\overline{25}.2)$	*vvw*	$(16.1.\overline{17}.1)$	*vvw*		
$(12.9.\overline{21}.2)$	*vs*	$(14.11.\overline{25}.2)$	*vw*	$(15.2.\overline{17}.1)$	*ms*		

* Streaks due to diffracted characteristic radiation from copper and tungsten were observed superposed upon the following Laue spots:

Index.	Line.	Wave-length.	Index.	Line.	Wave-length.
$(6.4.\overline{10}.1)$	Cu-K_{α}	1·539 Å.	$(9.1.\overline{10}.1)$ $(6.5.\overline{11}.1)$	W-L_{β_4}	1·299 Å.
$(7.3.\overline{10}.1)$	W-L_{α_1}	1·473	$(9.6.\overline{15}.2)$	W-L_{β_1}	1·279

Distance of crystal to plate, 3·5 cm. *s* = strong, *m* = medium, *w* = weak. *vs* = very strong, &c.

Synthetic nepheline and kaliophilite.

Before concluding this work mention must be made of the very interesting results obtained in synthesizing nepheline and kaliophilite. The possibility of preparing artificial crystals of silicates more suitable for physical measurements than natural material is of great importance to the mineralogist of the future. Bowen,[43] Eitel,[44] and others have synthesized $NaAlSiO_4$ and $KAlSiO_4$. The low-temperature products have been identified with nepheline and kaliophilite and their physical properties studied. Bowen has concluded from a thermal study of the intermediate products formed between the sodium and potassium salts that a complete range of mixed crystals exists between the two end-members, nepheline and kaliophilite. The X-ray work has already shown that the latter mineral possesses a unit cell much larger than nepheline. It is unlikely, therefore, that mixed crystals can occur at low temperatures; in other words low-temperature potassium-rich nepheline and kaliophilite containing some sodium are not isomorphous. The smaller crystals obtained by Bowen in his work could not be distinguished optically from the two end-members. It is desirable that this work should be repeated and X-ray photographs taken of the crystals formed by melts intermediate between nepheline and kaliophilite. In connexion with this study, powder photographs of synthesized nephelines richer in potassium than the Capo di Bove nepheline and of kaliophilites rich in sodium would, if accompanied by chemical analyses of the products formed, enable a more accurate correlation between cell-size and chemical composition to be carried out than has been possible with the available naturally occurring material.

In conclusion the author finds it difficult to acknowledge adequately the assistance he has received from so many quarters. To Dr. L. J. Spencer, Keeper of Minerals, who suggested the line of attack, I am indebted for his helpful criticism and encouragement. To Sir W. H. Bragg and past and present workers of the Davy-Faraday Laboratory I am also indebted for introducing me to the elements of X-ray crystal measurements. I wish to thank Dr. W. A. Wooster for his measurements on pyro-electricity and Mr. M. H. Hey, who has given me continuous assistance during the course of this work.

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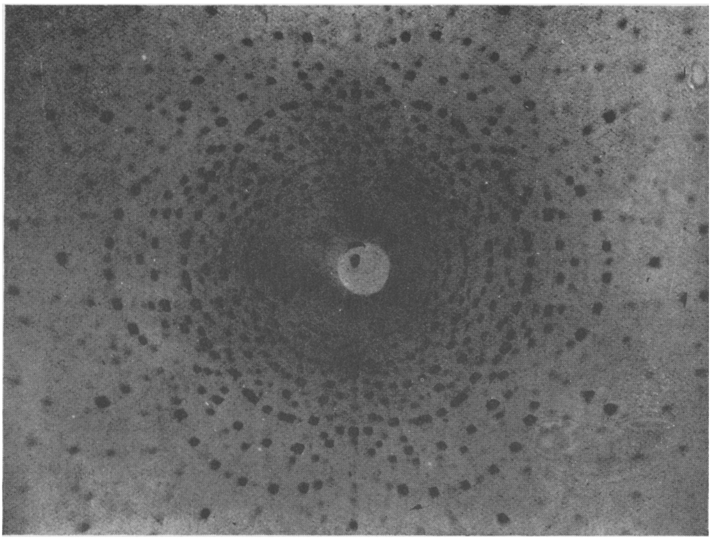

FIG. 7. Laue photograph of nepheline specimen no. VI (crystal 2) perpendicular to the c-axis and with an a-axis horizontal.

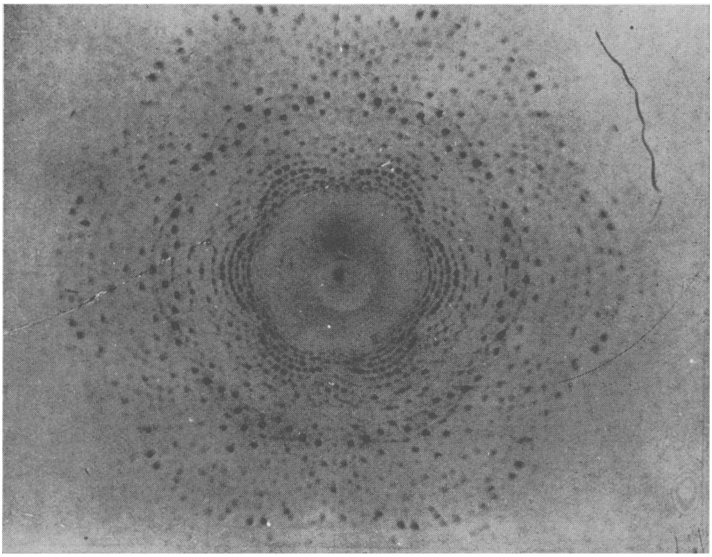

FIG. 8. Laue photograph of kaliophilite specimen no. X in same orientation as the nepheline specimen (fig. 7).

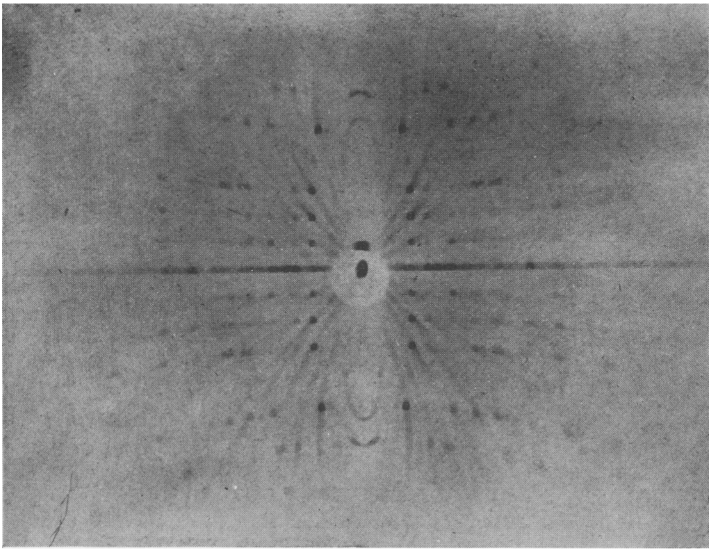

FIG. 9. Rotation photograph of nepheline specimen no. VI (crystal 2) about the *c*-axis.

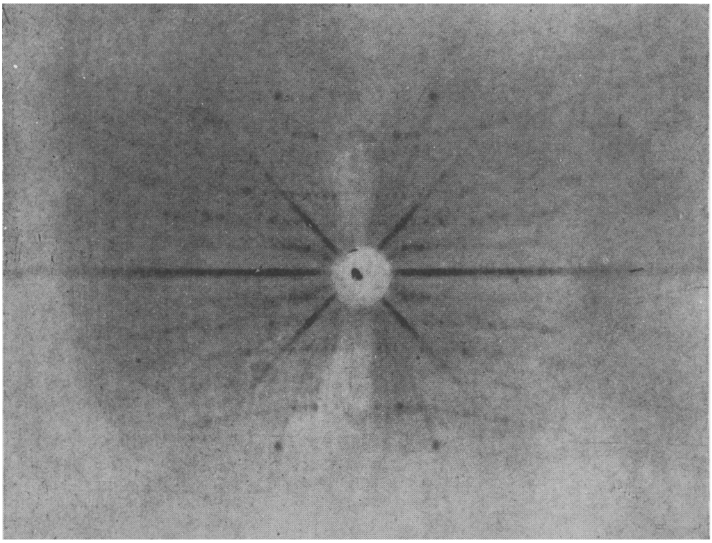

FIG. 10. Rotation photograph of kaliophilite specimen no. X about the *c*-axis.

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