

*Determination of the composition of natural nephelines
by an X-ray method.*

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INTRODUCTION.

IN the course of the investigation of the nepheline-kalsilite system by Tuttle and Smith an X-ray method for determining the KAlSiO_4 content of synthetic nephelines of composition $(\text{Na},\text{K})\text{AlSiO}_4$ has been developed. This method is rapid and sensitive to about 1 % in composition; details will be given in a later publication.

Natural nephelines usually do not have the ideal composition $(\text{K},\text{Na})\text{AlSiO}_4$, for they often contain excess silica and certain substituted atoms like Ca and Fe. We have, however, used this X-ray method on natural nephelines to see whether it is also applicable to them. If the method proved satisfactory, information on the chemical composition of natural nephelines could be rapidly obtained.

METHOD AND ACCURACY OF MEASUREMENT.

The nepheline is mixed with pure silicon powder and ground until homogeneous. A small amount is then smeared on a glass slide with a weak solution of Duco cement in acetone. The resultant smear should be thin so that the X-ray reflections are sharp (if the smear is not quite opaque it is of the right thickness). The slide is mounted on a Geiger-counter focusing spectrometer and a record is made from $2\theta_{\text{Cu}} = 30^\circ$ to $2\theta_{\text{Cu}} = 26.5^\circ$ on the scale of one inch per degree of 2θ . The (20.2) and (21.0) nepheline peaks occur near 29.5° and 27.0° , respectively, with the Si line at 28.465° . The positions of the nepheline lines may be corrected by measuring the position of the Si line, for the geometrical errors of the spectrometer are equal for adjacent reflections.

It is mechanically possible to measure the position of each reflection

to an accuracy of 0.01° in 2θ . There is, however, one difficulty in measuring the lines, for at these angles the α_1 and α_2 components are only partially resolved, giving a slightly asymmetric peak. If all the peaks have the same sharpness and are measured in the same way, no additional error occurs. However, if the peaks have different sharpness (perhaps through zoning of the nephelines) it is possible to get an error unless the centre of gravity of the peak is measured each time. It is advisable, therefore, to measure the centre of gravity or to measure the centre of the peak at a height of one-half. The top of the peak should not be measured. It is probable that this error will not exceed 0.005° in 2θ , if the correct procedure is used.

We have taken four or six records (four by Smith and six by Sahama) for each sample in order to improve the accuracy. Between each record we have moved the slide a little. The mean of the four or six measurements of each reflection should be accurate to about 0.005° in 2θ . The calibration error of the silicon peak is 0.005° and must be added to the error of the nepheline peak, giving a combined random error of about 0.007° ($\sqrt{2} \times 0.005$) in the absolute position 2θ of a nepheline reflection.

Independent measurements were made by us on 13 of the samples (table I). The root-mean-square difference between our measurements of

TABLE I. Comparison of independent measurements of 2θ .

Sample.	$2\theta_{(21.0)}$	$2\theta_{(21.0)}$	$2\theta_{(20.2)}$	$2\theta_{(20.2)}$	Mean	Mean
	Sahama.	Smith.	Sahama.	Smith.	$2\theta_{(21.0)}$.	$2\theta_{(20.2)}$.
FEAE 49 ...	27.135°	27.120°	29.550°	29.545°	27.127°	29.547°
FEAE 86 ...	27.015	27.010	29.435	29.435	27.012	29.435
FEAE 87 ...	27.065	27.070	29.510	29.480	27.067	29.495
FEAE 88 ...	27.065	27.040	29.500	29.505	27.052	29.502
FEAE 89 ...	27.060	27.075	29.495	29.480	27.067	29.487
FEAE 90 ...	27.215	27.220	29.635	29.635	27.217	29.635
FEAE 92 ...	27.050	27.065	29.475	29.480	27.057	29.477
FEAE 93 ...	26.990	26.990	29.415	29.425	26.990	29.420
FEAE 170	27.265	27.265	29.700	29.680	27.265	29.690
FEAE 198	27.275	27.270	29.695	29.695	27.272	29.695
C 5549 ...	27.190	27.190	29.605	29.600	27.190	29.602
C 5550 ...	27.135	27.120	29.545	29.555	27.127	29.550
C 9956 ...	26.970	26.965	29.400	29.395	26.967	29.397

2θ (Sahama) is the mean of 6 measurements by Sahama }
 2θ (Smith) is the mean of 4 measurements by Smith } to nearest 0.005° in 2θ .
 Means to nearest 0.0025° in 2θ .

the 26 values of 2θ is 0.011° ($\sqrt{2} \times 0.0078$) in 2θ , in good agreement with the estimated random error. There is a mean difference of 0.003° in 2θ ,

but this may be caused by chance, for the error of the mean of 26 differences of standard deviation 0.011 is 0.002 (0.011/ $\sqrt{26}$).

TABLE II. Composition and 2θ values of synthetic nephelines.

Composition		2θ	2θ
NaAlSiO ₄ .	KAlSiO ₄ .	(21.0).	(20.2).
40.0 %	60.0 %	26.760°	29.235°
45.1	54.9	26.820	29.280
50.2	49.8	26.875	29.350
52.7	47.3	26.910	29.370
55.2	44.8	26.945	29.380
60.1	39.9	27.005	29.450
62.5	37.5	27.040	29.480
65.0	35.0	27.085	29.530
69.8	30.2	27.140	29.560
73.2	26.8	27.180	29.600
76.9	23.1	27.215	29.635
81.6	18.4	27.245	29.670
90.9	9.1	27.295	29.730

The measurements by Smith of the synthetic nephelines are listed in table II and fig. 1. Each set of 2θ values may be represented by two straight lines which meet near 75 % NaAlSiO₄.¹ For nephelines more potash-rich than Na₇₅K₂₅ an error of 0.01° in 2θ corresponds to a difference in composition of 0.8 % and 0.9 % for the (21.0) and (20.2) lines, respectively. For compositions less potash-rich than Na₇₅K₂₅, the corresponding values are 1.8 % and 1.5 %, giving a lower sensitivity in this region.

MEASUREMENTS OF THE NATURAL NEPHELINES.

The simplest way of comparing the data for the natural and synthetic crystals is to use the ratio $K/(K+Na+Ca)$,² for Ca and Na ions have the same size. The measurements of 2θ and the values of $K/(K+Na+Ca)$ for the natural nephelines are given in table III and plotted in fig. 1. The chemical analyses are listed in table IV, and the ratio $K/(K+Na+Ca)$ was determined directly from the oxides.

It will be seen from fig. 1 that there is good agreement between the data for the natural and synthetic nephelines. The maximum deviations are about 4 % in $K/(K+Na+Ca)$ and the average deviation is about 2 %. However, almost all the points for the natural nephelines are

¹ The breaks at 75 % NaAlSiO₄ correspond to the composition Na₃KS₄Al₄O₁₈, which is the ideal formula of nepheline (M. J. Buerger, G. E. Klein, and G. Hamburger, Amer. Min., 1947, vol. 32, p. 197). All compositions in the text are given as atomic %.

² Ca = 0 for the synthetic crystals.

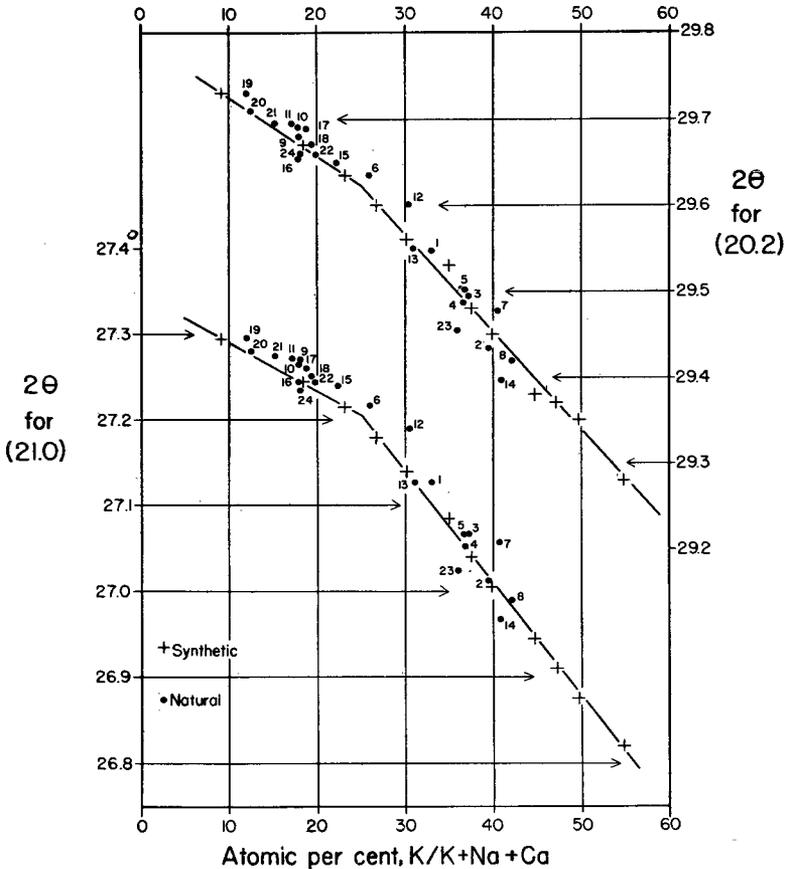


FIG. 1. The variation of $2\theta(21.0)$ and $2\theta(20.2)$ with $K/(K+Na+Ca)$. The data are given in numerical form in tables II and III. The points for the natural nephelines may be identified by the numbers which correspond to those in column 1 of table III. The curves give the least-squares solutions for the data on the synthetic crystals and their equations are given in the text.

displaced from the curves for the synthetic crystals in the direction of higher K content.

These deviations may be explained by the following possibilities: (a) Errors in the composition of the synthetic nephelines. Before growth of the nephelines, the weighed constituents were fused to a glass, during which process some alkali may have been lost. This loss is probably small and, as will be shown later, examination of the natural nephelines

TABLE III. X-ray measurements and chemical compositions of natural nephelines.

Specimen.	100 K/(K + Na + Ca).	100 K/T.	100 (Na + Ca)/T.	Vacant alkali sites.	Excess Si.	2θ (21-0).	2θ (20-2).	Observer.	Deviation in 2θ		
									(21-0).	(20-2).	Mean.
1. FEAE 49	39.0	29.0	59.0	12.0	0.5	27.127°	29.547°	AH	+0.025°	+0.015°	+0.020°
2. FEAE 86	33.5	37.5	57.3	5.2	0.3	27.012	29.435	AH	-0.005	-0.025	-0.015
3. FEAE 87	37.2	35.2	59.3	5.5	0.7	27.067	29.495	AH	+0.020	+0.010	+0.015
4. FEAE 88	36.8	34.9	60.0	5.1	0.1	27.052	29.502	AH	+0.000	+0.012	+0.005
5. FEAE 89	36.6	34.6	59.8	5.6	0.4	27.067	29.487	AH	+0.012	-0.005	+0.005
6. FEAE 90	25.9	24.3	69.5	6.2	5.5	27.217	29.635	AH	+0.025	+0.022	+0.025
7. FEAE 92	40.6	38.6	56.4	5.0	2.7	27.057	29.477	AH	+0.055	+0.030	+0.042
8. FEAE 93	42.1	39.7	54.5	5.8	1.9	26.990	29.420	AH	+0.007	-0.010	+0.000
9. FEAE 134	18.0	15.9	72.5	11.6	12.7	27.270	29.680	A	+0.025	+0.010	+0.017
10. FEAE 170	17.9	16.0	73.5	10.5	14.7	27.265	29.690	AH	+0.020	+0.017	+0.020
11. FEAE 198	17.1	15.5	75.1	9.4	13.4	27.272	29.695	AH	+0.022	+0.017	+0.020
12. C 5549	30.4	---	---	---	---	27.190	29.602	AH	---	---	---
13. C 5550	31.0	31.3	69.8	1.1	4.8	27.127	29.550	AH	+0.000	-0.005	+0.000
14. C 9956	40.8	38.7	56.1	5.2	-0.3	26.967	29.397	AH	-0.032	-0.047	-0.040
15. E 2	22.3	22.1	76.7	1.2	4.9	27.240	29.650	H	+0.020	+0.007	+0.012
16. 238	17.9	16.3	74.6	9.1	0.7	27.245	29.655	H	+0.000	-0.017	-0.007
17. 273	18.8	17.8	77.1	5.1	7.0	27.260	29.690	H	+0.020	+0.022	+0.022
18. 276	19.4	18.6	77.4	4.0	7.8	27.250	29.670	H	+0.010	+0.010	+0.010
19. 63197	12.0	11.3	82.5	6.2	16.9	27.295	29.730	H	+0.015	+0.017	+0.015
20. 34475	12.5	11.7	82.5	5.8	8.0	27.280	29.710	A	+0.002	+0.000	+0.000
21. 34480	15.2	14.5	80.8	4.7	8.2	27.275	29.695	A	+0.015	+0.005	+0.010
22. Ilvaara	19.8	18.6	75.6	5.8	-0.2	27.245	29.660	A	+0.010	+0.000	+0.005
23. R 118	36.0	35.0	62.2	2.8	0.8	27.025	29.455	H	-0.037	-0.045	-0.040
24. Gooderham	18.1	16.6	75.1	8.3	8.4	27.235	29.660	H	-0.010	-0.010	-0.010
			Average	6.0	4.9						

T = $\frac{1}{2}$ (Si + Al + Fe + Mn + Mg + Ti).
 Excess Si = Si - (Al + Fe + Mn + Mg + Ti)/(Al + Fe + Mn + Mg + Ti).
 Observer: A denotes Sahama and H denotes Smith.

TABLE IV. Chemical analyses of the natural nephelines.

Specimen	...	FEAE 49	FEAE 86	FEAE 87	FEAE 88	FEAE 89	FEAE 90	FEAE 92	FEAE 93
SiO ₂	...	41.30	40.81	41.01	40.89	41.01	42.12	41.14	41.05
TiO ₂	...	0.13	0.06	0.09	0.07	0.07	0.07	0.06	0.07
Al ₂ O ₃	...	33.07	33.39	33.59	33.54	33.52	32.96	32.89	33.27
Fe ₂ O ₃	...	1.77	1.05	0.89	1.03	1.08	0.65	1.02	0.84
FeO	...	0.28	0.28	0.18	0.18	0.18	0.52	0.25	0.18
MnO	...	0.01	0.01	0.01	0.01	0.00	0.01	0.02	0.01
MgO	...	0.30	0.16	0.17	0.22	0.22	0.08	0.18	0.16
CaO	...	0.51	0.88	0.78	0.89	0.91	0.91	0.87	0.90
Na ₂ O	...	12.25	11.57	12.08	12.17	12.14	14.21	11.35	10.95
K ₂ O	...	9.36	11.98	11.28	11.18	11.09	7.83	12.29	12.65
CO ₂	...	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
H ₂ O ⁺	...	0.87	0.12	0.12	0.07	0.09	0.47	0.13	0.08
H ₂ O ⁻	...	0.10	0.00	0.00	0.00	0.00	0.02	0.00	0.00
Total	...	99.95	100.31	100.20	100.25	100.31	99.85	100.20	100.16
Reference	...	1	2	2	2	2	1	2	2

Specimen	...	FEAE 134	FEAE 170	FEAE 198	C 5549	C 5550	C 9956	E 2	238
SiO ₂	...	45.04	44.47	44.26	—	40.78	40.20	42.23	41.98
TiO ₂	...	0.02	0.04	0.05	—	0.07	0.05	—	0.00
Al ₂ O ₃	...	33.25	32.10	32.25	—	30.95	32.51	34.08	35.09
Fe ₂ O ₃	...	0.55	0.94	0.97	—	2.41	1.82	0.12	0.16
FeO	...	0.28	0.18	0.29	—	0.57	0.57	—	—
MnO	...	0.01	0.01	0.01	—	n.d.	n.d.	—	—
MgO	...	0.07	0.03	0.01	—	0.07	0.10	0.00	0.14
CaO	...	0.00	0.47	0.32	—	0.78	1.44	0.15	1.74
Na ₂ O	...	15.89	15.54	15.96	13.23	13.93	10.86	16.21	15.15
K ₂ O	...	5.30	5.23	5.06	8.78	9.78	12.22	7.12	5.35
CO ₂	...	n.d.	0.00	0.00	—	n.d.	n.d.	—	—
H ₂ O ⁺	...	0.08	1.11	0.64	—	0.32	0.00	—	0.00
H ₂ O ⁻	...	0.00	0.04	0.00	—	0.00	0.00	0.03	0.29
Total	...	100.49	100.16	99.82	...	99.66	99.77	99.94	99.90
Reference	...	3	1	1	4	4	4	5	6

Specimen	...	273	276	63197	34475	34480	Iivaara	R 118	Gooderham
SiO ₂	...	43.29	43.33	44.65	43.42	43.24	41.48	40.74	43.60
TiO ₂	...	—	0.00	0.00	0.00	0.00	0.00	0.11	trace
Al ₂ O ₃	...	34.25	34.00	32.03	33.92	33.56	34.12	33.39	34.02
Fe ₂ O ₃	...	0.13	0.18	0.59	0.14	0.47	1.26	0.83	0.10
FeO	...	—	—	—	n.d.	n.d.	0.29	—	—
MnO	...	—	—	—	0.00	0.00	0.00	—	trace
MgO	...	0.00	0.00	0.00	0.08	0.05	0.12	0.25	0.04
CaO	...	0.51	0.26	0.71	1.37	0.77	trace	0.91	0.75
Na ₂ O	...	16.43	16.54	17.25	17.05	16.88	16.20	12.53	15.82
K ₂ O	...	5.86	6.10	3.66	3.85	4.71	6.06	11.13	5.47
CO ₂	...	0.08*	—	—	—	—	—	—	—
H ₂ O ⁺	...	—	—	0.96	—	—	0.17	0.23	0.16
H ₂ O ⁻	...	0.02	0.03	0.21	0.11	0.07	0.00	0.06	—
Total	...	100.57	100.44	100.06	99.94	99.75	99.70	100.18	99.97†
Reference	...	6	6	7	7	7	8	9	10

* Calcite.

† Including Li₂O 0.01.

1. To be published by Sahama. FEAE 49, collected by the Finnish East African Expedition, Nyamununka crater, Katwe-Kikorongo field, Uganda; FEAE 90, 0.5 km. E. of Mt. Goma, Congo; FEAE 170, Ol Esakut, Kenya; FEAE 198, 6.0 miles from Lumbwa on the Lumbwa-Kericho road, Kenya. Analyst, P. Ojanperä.
2. Sahama (Th. G.), Ann. Acad. Sci. Fennicae, 1953, ser. A, no. 35. [M.A. 12-372.] Analyst, P. Ojanperä.
3. To be published by Kai Hytönen. From natrolite-sodalite-linguaite, Toror Hills, Karimoja, Uganda. Analyst, H. B. Wiik.
4. Sahama (Th. G.), Amer. Journ. Sci., 1952, Bowen vol., p. 457. [M.A. 12-146.] Analyst, H. B. Wiik.
5. Tilley (C. E.), Geol. Mag., 1953, vol. 90, p. 148. [M.A. 12-268.] Analyst, J. H. Scoon.
6. To be published by C. E. Tilley. 238, York River, E. of Bancroft, Ontario; 273, $\frac{3}{4}$ mile E. of Bancroft, Ontario; 273, Temo, Nyasaland. Analyst, J. H. Scoon.
7. Tilley (C. E.), Amer. Journ. Sci., 1954, vol. 252, p. 65. [M.A. 12-371.] Anal. J. H. Scoon.
8. To be published by Mauno Lehighjärvi. From ijolite, Iivaara, Kuusamo, Finland. Analyst, M. Lehighjärvi.
9. Bowen (N. L.) and Ellestad (R. B.), Amer. Min., 1936, vol. 21, p. 363. [M.A. 7-29.] Analyst, R. B. Ellestad.
10. Yoder (H. S.) and Weir (C. E.), Amer. Journ. Sci., 1951, vol. 249, p. 683. [M.A. 11-491.] Analyst, E. G. Zies.

suggests that the lattice parameters are almost independent of loss of alkali. (b) The structure of synthetic nephelines may differ slightly from that of natural nepheline, thus giving different lattice parameters. This difference might arise from order-disorder between the ions in tetrahedral positions, such as is proposed for the high- and low-felspar series. (c) The nepheline might contain some kalsilite as an impurity, which would be difficult to detect optically. However, 1 % of kalsilite can be detected in X-ray patterns, because it has a strong reflection at $2\theta_{\text{Cu}} = 28.7^\circ$. No kalsilite was detected in the nepheline samples, showing that the error in the chemical composition is not more than 1 %. (d) Errors in the chemical analysis of the natural nephelines. These may be estimated from the paper by Fairbairn and Schairer (1952) which described tests on the chemical analyses of a glass of known composition. (e) The deviation of the chemical formula of the natural nephelines from $(\text{K},\text{Na})\text{AlSi}_3\text{O}_8$.

The compositions of the natural nephelines studied here deviate considerably from the ideal formula and allow consideration of the effect of these deviations on the X-ray reflection angles. All of the natural nephelines contain small amounts of Ca, Mg, Fe, Mn, and Ti which replace the dominant cations. In addition, all but one of the chemical analyses show a deficiency in the sum of the alkali ions in comparison with the number of ions in tetrahedral positions, and all but two of the analyses show an excess of silica. In view of these complex factors the problem of interpreting the data must be simplified.

The chemical analyses were converted from weight % of oxide to number of atoms (H_2O^+ was neglected because of the uncertainty of its determination and of its role). It is well known that Na and Ca have very similar ionic sizes, so they were added together. The K ion is much larger,

and this, of course, is the chief reason for the variation of X-ray spacing in the nephelines. The Feⁱⁱ, Feⁱⁱⁱ, Mn, Mg, and Ti ions were added to the Al ions because they have approximately the same size and the amounts of Fe, &c., were small anyway.

The sites for tetrahedra in the structure should be fully occupied, for the tetrahedrally bonded ions are tightly bound to the oxygen atoms, and a vacancy would lead to a large structural imperfection. A vacancy in an alkali site, however, would give a smaller imperfection since the alkali ions are less strongly bonded. The total number of sites for alkali ions may be obtained by dividing Si + (Al, &c.) by 2. In the ideal nepheline formulae, Si = Al; however, in the 23 analyses considered here, the excess of Si [taken as Si - (Al, &c.) / (Al, &c.)] varied from -0.3 to +16.9 % with an average excess of 4.9 %. A test of the accuracy of chemical analyses by 14 analysts (Fairbairn and Schairer, 1952)¹ showed that there was a tendency to underestimate SiO₂ by ~0.5 % and to correspondingly overestimate Al₂O₃. This suggests that the excess Si found in these 23 analyses should be an underestimate and *not* an overestimate, but the total of Si + Al should be correct. It should be noted that all the tetrahedral sites can be filled even when Si is in excess, for Si ions can occupy Al positions. Comparison of the number of alkali ions with the number of sites shows that there is a deficiency varying from -1.1 to +12.0 % with an average deficiency of 6.0 %.

This deficiency cannot be explained by analytical error, for the data of Fairbairn and Schairer (1952) showed no appreciable systematic bias in the determination of total alkali and total (Si + Al). Bannister² also found that natural nephelines usually have excess Si and a deficiency of alkali.

From the data of Fairbairn and Schairer¹ it is possible to estimate the analytical precision of the ratio K/(K + Na). This ratio was calculated for the 14 sets of K₂O and Na₂O. The root-mean-square error is 1.75 %; however, if one analysis is omitted the error is reduced to 0.75 %. The mean analytical value is 53.7 % compared with the value 54.3 % calculated from the weights of the pure constituents used in the test material. It is likely, therefore, that the chemical analyses given in this paper will give values of K/(K + Na) which have random errors of 1 to 2 % and a systematic bias of ~0.5 %.

The effects of alkali deficiency and of excess Si were studied by

¹ H. W. Fairbairn and J. F. Schairer, *Amer. Min.*, 1952, vol. 37, p. 744. [M.A. 12-33.]

² F. A. Bannister, *Min. Mag.*, 1931, vol. 22, p. 569.

examining the deviations of the natural nephelines from the curves of 2θ for the synthetic crystals. The quantity $\Delta = 2\theta_{\text{obs}} - 2\theta_{\text{calc}}$ was determined. ($2\theta_{\text{obs}}$ is the measured value; $2\theta_{\text{calc}}$ is the 2θ value for a synthetic crystal of composition $\text{K}/(\text{K} + \text{Na})$ equal to the value $\text{K}/(\text{K} + \text{Na} + \text{Ca})$ calculated from the chemical analysis of the natural nepheline.) It was

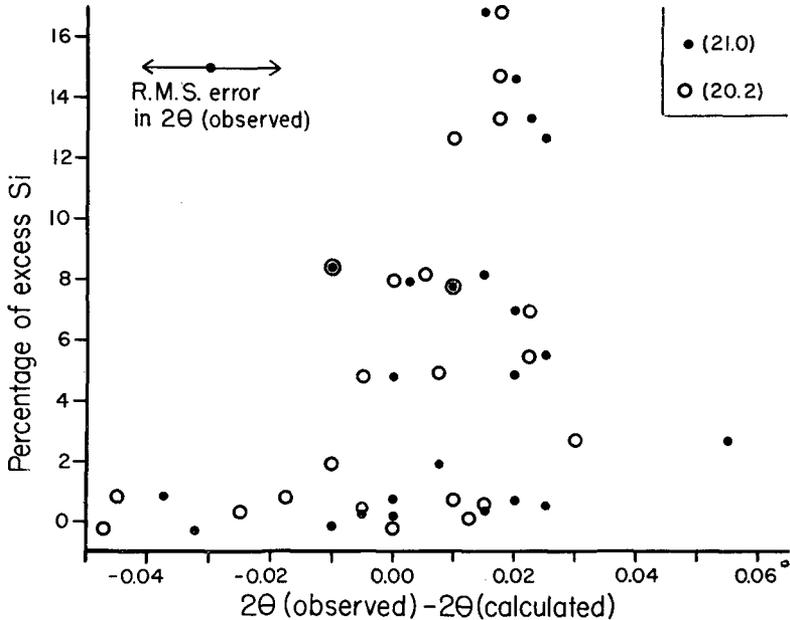


FIG. 2. The relation between excess silica and $2\theta_{\text{obs}} - 2\theta_{\text{calc}}$ for the natural nephelines. $2\theta_{\text{obs}}$ is the measured value whereas $2\theta_{\text{calc}}$ is the 2θ value of the synthetic nepheline whose $\text{K}/(\text{K} + \text{Na})$ ratio is equal to the $\text{K}/(\text{K} + \text{Na} + \text{Ca})$ ratio of the natural nepheline. The data are given in table III.

found that the values of Δ were, on the average, independent of the deficiency of alkali. This was rather surprising for it was expected that a vacant site would act as though it were occupied by a small ion like Na and thus reduce the value of $\text{K}/(\text{K} + \text{Na} + \text{Ca})$. Fig. 2 shows the relation between Δ and excess Si. The values of Δ for the (21.0) and (20.2) reflections are given in table III. It will be seen that the correlation between Δ (21.0) and Δ (20.2) is high; however, Δ (21.0) on the average is 0.004° greater than Δ (20.2). Examination of fig. 2 shows that there are large random deviations which are considerably larger than the experimental error in the 2θ measurements, and it is thus difficult to determine

whether Δ is a function of excess Si. There is a suggestion that both Δ (21.0) and Δ (20.2) increase by about 0.01° in 2θ for a 10 % increase in the excess Si, but a statistical analysis shows that there is a 5 % probability that it is caused merely by random fluctuations. The values of Δ for those nephelines which have only small amounts of excess Si have an average value close to zero and there is, therefore, no reason to suppose that natural nephelines which contain no excess Si have different lattice parameters from the pure synthetic nephelines. An increase in Δ corresponds to a decrease in the lattice parameters of the natural nephelines. As the ionic radius of Si is less than that of Al, Δ would be expected to increase with increasing excess Si, as suggested by the present data.

The natural nephelines fit quite well with the synthetic nephelines and there is no evidence for any appreciable systematic bias (other than the possible effect of excess silica). The random error of measurement of $K/(K+Na+Ca)$ is about 1 % for both the X-ray and chemical analysis methods. The largest observed deviation between the values of $K/(K+Na+Ca)$ for the two methods is 3.7 %. The curves for the synthetic crystals can therefore be used for the determination of $K/(K+Na+Ca)$ by the X-ray method. If the natural nepheline contains 10 % or more excess silica it is possible that the measured values of 2θ will be about 0.01° too high and the X-ray value for $K/(K+Na+Ca)$ will correspondingly be 1 to 2 % too high.

The following linear equations, calculated by least-square methods, represent the data for the synthetic nephelines:

(21.0) reflection for $100K/(K+Na)$ from 9 to 25 %:

$$100K/(K+Na) = 61.24 - 176.3 (2\theta_{Cu} - 27.00^\circ).$$

(21.0) reflection for $100K/(K+Na)$ from 25 to 60 %:

$$100K/(K+Na) = 118.02 - 77.26 (2\theta_{Cu} - 26.00^\circ).$$

(20.2) reflection for $100K/(K+Na)$ from 9 to 25 %:

$$100K/(K+Na) = 117.35 - 148.1 (2\theta_{Cu} - 29.00^\circ).$$

(20.2) reflection for $100K/(K+Na)$ from 25 to 60 %:

$$100K/(K+Na) = 79.94 - 88.13 (2\theta_{Cu} - 29.00^\circ).$$

It is recommended that these equations be used for the X-ray determination of the $K/(K+Na+Ca)$ ratio for natural nephelines.

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