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THE ACMITIC PYROXENES

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INTRODUCTION

Tschermak, in 1871, showed that the then supposedly distinct species of the pyroxene group, acmite and aegirite, are chemically alike, that is, essentially $Na_2O \cdot Fe_2O_3 \cdot 4SiO_2$. Both names have persisted. Brownish, slightly pleochroic crystals are usually called acmite, while those that are greenish and are decidedly pleochroic are called aegirite. Entirely homogeneous crystals, composed of only the brown or the greenish variety, are rare, and some of the megascopically brown acmite is colorless when seen in thin section. If both varieties occur in the same crystal the arrangement is generally zonal, most often the brown or colorless material forming the exterior: less often the distribution is irregular. The term aegirite-augite, proposed by Rosenbusch[1] to denote pyroxenes intermediate in chemical and optical characters between aegirite and augite occurs frequently in petrographic literature. Other names[2] have not met with general acceptance.

The present study was begun to test a suggestion[3] that the difference between the yellow-brown acmite and the greenish aegirite is connected with the presence of zirconia and oxides of cerium and of other rare earth metals in the former and their absence from the latter. This hypothesis was based on the usual yellowish or brownish color of the zirconia-bearing pyroxenes and of the minerals that contain much cerium and yttrium. The results of our investigation are not confirmatory of this hypothesis, although they show that zirconia and some of the rare earths are commonly present in acmite while they are usually absent from aegirite. Our investigation gradually extended beyond its original

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[1] Rosenbusch: MIKR. PHYSIOG., **1,** 537 (1892).

[2] (Urbanite), Sjögren: *Geol. För. Förh.*, 14, 251 (1892); (Federovite), Viola: *Neues Jahrb.*, **I,** 121 (1899).

[3] Washington: *Quart. Jour. Geol. Soc.*, **70,** 294 (1914).

object, and we have obtained and studied material that covers a considerable range in composition and diversity in locality. The preparation of material and the optical measurements have been done by Merwin and the new analyses and densities by Washington.

METHODS

All the material that was studied by us is considered to have been of a very high degree of purity and as homogeneous as was possible with the strong tendency to zonal structure shown by the pyroxenes.

The general methods used for the chemical analyses were those advocated by Hillebrand and by Washington. In the determination of ferrous oxide the powder was not ground very fine, so as to avoid oxidation. Titanium and manganese were determined colorimetrically. Zirconia and the rare earths were determined by the method (A) of Hillebrand,[4] with some slight modifications. The mineral powder was dried at 110° before analysis.

The density was determined on the fragments used for the chemical analysis with the pycnometer devised by Johnston and Adams,[5] and the values reported are regarded as accurate to the second decimal, although the quantity of the material was usually not suitable for very accurate density determinations.

The fragments used for the optical determinations were some of the material that was reduced to powder for the chemical analysis. Portions of the powders analyzed were used in determining the limits of homogeneity and for the final values of the general optical properties.

Extinction angles were determined on cleavage flakes and were measured from cleavage traces; therefore, errors of about ± 1° may be expected. Refractive indices were measured microscopically by immersion methods, and are given in Table IV. Measurements of dispersion were obtained by means of prisms. For these measurements the strong lines of mercury and helium and a spectrometer-monochromator were used. Because of strong absorption toward the ends of the spectrum the large angle prisms necessary for accurate measurements of dispersion must be sharp-edged, and account must be taken of the rounding of the

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[4] Hillebrand: *U. S. Geol. Survey, Bull.* **700,** 173 (1919).

[5] Johnston and Adams: *Jour. Amer. Chem. Soc.,* **34,** 566 (1912).

faces very near the edges. Results of the measurement of about a dozen suitable prisms of the purest acmites give dispersions that are practically the same. These are gathered into a single set which, together with those made on the augitic acmite of Laven, appear in Table III.

Color could not be designated satisfactorily for two reasons: (1), large variations were commonly found in single crystals; (2), the collection of the necessary quantitative data concerning light transmission of the crystals could not be undertaken. Yet an attempt has been made to designate the colors transmitted by microscopic grains, so that a fairly definite idea of them may be had. The transmitted colors were compared with the colors of Ridgway's standards[6] by viewing both simultaneously under diffused light and interchangeably with both eyes, one eye seeing the transmitted color and the other the diffused (standard) color, surrounded by a white background illuminated to match approximately the white field of the microscope. Grains of such thickness were selected as to show the greatest purity and brightness when in the position of greatest absorption. In these standards, hues from red to violet are numbered 1 to 59, but those that represent these pyroxenes fall between orange-yellow (14) and yellow-green (25), yellow being 17. Progressive darkening is shown by the letters *i* to *m*, whitening by *a* to *f*, and dulling or graying by the superscripts ′ to ′′′′′.

CALCULATION OF THE MOLECULAR COMPOSITION

All the specimens of acmitic pyroxene that we have examined, and those that have been described by others, are chemically complex, so that any calculation of the molecular composition from the chemical analysis demands the assumption of the presence of several different silicate molecules. The acmitic pyroxenes must be assumed to be composed essentially of metasilicate molecules, as has been assumed by other students of the pyroxene group. The chief molecules in the acmitic pyroxenes are: $Na_2O \cdot Fe_2O_3 \cdot 4SiO_2$ (acmite), $CaO \cdot MgO \cdot 2SiO_2$ (diopside), and $CaO \cdot FeO \cdot 2SiO_2$ (hedenbergite), which may crystallize as monoclinic pyroxenes, and may form series between the end-members. There may also be assumed to be present in some cases the mole-

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[6] Ridgway: Color Standards and Color Nomenclature, Washington, 1912. Appropriate, ordinary color names are used in addition to his names and symbols.

cules: $Na_2O \cdot Al_2O_3 \cdot 4SiO_2$ (jadeite), and a vanadous acmite, $Na_2O \cdot V_2O_3 \cdot 4SiO_2$. In a few cases, in which there is an excess of Na_2O over (R_2O_3), sodium metasilicate, $Na_2O \cdot SiO_2$, may be assumed to be present. The small amount of K_2O is computed with Na_2O and that of MnO with FeO, the optical effect of the members of each pair being very similar.

If there is an excess of FeO+MgO over CaO an arbitrary choice must be made as to which of these is to be given the preference. We give the preference to FeO, first calculating as much hedenbergite as possible, and then allotting the remaining CaO to MgO to form diopside. This procedure was adopted because it was found that, in most acmitic pyroxenes, and especially in those most nearly pure acmite, the hedenbergite molecule is more abundant than that of diopside.

In those cases in which there is an excess of either Fe_2O_3 or Al_2O_3, or both, over Na_2O, different methods of procedure, or different interpretations of the molecules present, are possible. The assumption of the molecules $FeO \cdot Fe_2O_3 \cdot 4SiO_2$ and $FeO \cdot Al_2O_3 \cdot 4SiO_2$ was made in discussing the composition of babingtonite,[7] which, however, is not like acmite in crystal structure. Another interpretation is that the excess ferric oxide and alumina may be regarded as forming the simple silicates $Fe_2O_3 \cdot 3SiO_2$ and $Al_2O_3 \cdot 3SiO_2$. We have adopted here, tentatively, the second interpretation, because of our ignorance of the roles played by these oxides when present in excess. In the acmitic pyroxenes excess $(Fe, Al)_2O_3$ cannot be regarded as present in solid solution uncombined with SiO_2, as we have assumed to be the case with augite.[8] In the specimens of acmitic pyroxenes studied by us this procedure leads to the presence of a large excess of SiO_2, whereas there is no, or only a slight excess of SiO_2 if (R_2O_3) be assumed to be combined with SiO_2 in the ratio of 1:3.

The small amount of "extraneous substances," as TiO_2, ZrO_2, and $(Ce,Y)_2O_3$, we have disregarded in our calculations because of the uncertainty as to their functions. That zirconia and the rare earths are present in readily determinable amounts and in larger percentages in the more acmitic members of the group is, for the present, the most interesting feature concerning them.

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[7] Washington and Merwin: *Am. Mineral.*, **8**, 221 (1923).

[8] Washington and Merwin: *Am. Jour. Sci.* **3**, 119 (1922).

NOMENCLATURE

Any nomenclature represents a point of view or an attempt at correlation—in mineralogy, particularly, a concept of the chemical composition and the crystallography of the mineral. The monoclinic pyroxenes are so complex from any point of view that, at present, no nomenclature can be generally acceptable. We venture, however, to suggest for them a nomenclature that seems, to us, to be rationally applicable to those species that may be considered to be pyroxenes with diopsidic structure.[9] In this paper we are dealing especially with pyroxenes that are rich in soda. Such pyroxenes can now, however, be classified only very roughly by optical or other physical means. Those suitably homogeneous specimens that have been analyzed chemically may be classified and named more definitely, but unless such a designation recognizes the physical characters it is not generally applicable.

As has been said, from the chemical standpoint the molecules: acmite ($Na_2O \cdot Fe_2O_3 \cdot 4SiO_2$), diopside ($CaO \cdot MgO \cdot 2SiO_2$), hedenbergite ($CaO \cdot FeO \cdot 2SiO_2$), and jadeite ($Na_2O \cdot Al_2O_3 \cdot 4SiO_2$), are the chief end-members in the pyroxenes under consideration. Diopside and hedenbergite are, in very different relative amounts, the chief constituents of augite. The term "augite" is limited by most authors to the pyroxenes of such general composition that contain Al_2O_3 (and Fe_2O_3) in indefinitely small amounts. This limitation does not seem to us to be desirable, inasmuch as recent studies indicate that, in these diopside-hedenbergite pyroxenes, the Al_2O_3 and Fe_2O_3 (above what may belong to jadeite or acmite molecules), are present in solid solution and that the so-called Tschermak molecule is non-existent.[10] Furthermore, critical examination of the older (and some of the modern) analyses of augite, as noted by various authors[11] and by ourselves, indicates the serious imperfections of many of them, especially in that the amount of Al_2O_3 reported is too high and that of MgO is correspondingly too low, because of a frequently committed and often mentioned analytical error. We, therefore, use the term "augite"

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[9] Wyckoff, Merwin, and Washington: *Am. Jour. Sci.*, **10**, 383 (1925).

[10] Washington and Merwin: *Am. Jour. Sci.*, **3**, 119 (1922). *Cf.* Boeke: Grundlagen Phys.-chem. Petrog., 190 (**1915**); and Gossner: *Zeits. Kryst.*, **60**, 76 (1924).

[11] Boeke: *Zeits. Kryst.*, **53**, 445 (1914); *Neues Jahrb. Cb.*, 1 (**1915**); Zambonini: *Atti Accad. Sci. Napoli*, **16**, No. 2, 9 (1914); Tschermak: *Neues Jahrb. Cb.*, 225 (1915); *ditto*, 1 (**1916**); Gossner: *Zeits. Kryst.*, **60**, 76 (1924).

to denote intermediate members of the diopside-hedenbergite series, disregarding their content in $(Al,Fe)_2O_3$. It would correspond to the term "olivine" as used to denote intermediate members of the forsterite-fayalite series.

In cases where the characterization is sufficiently definite, the nomenclature that we have adopted for the acmite-diopside-hedenbergite sub-group (the acmitic pyroxenes) is as follows. The divisions suggested are to be regarded as not mathematically sharp but as subject, to some extent, to the judgment of the observer. The pyroxenes are markedly zonal, so that, in most cases, optical methods or chemical analysis determine only approximate averages, and a chemical analysis is not always practicable. Even when this is possible the presence of what we have called "extraneous substances," although in small amount, is a disturbing factor.

(1). If there be present 80 percent or more of one of the end-members the mineral is called by the name of this end-member—acmite, diopside, or hedenbergite. (2). If only two end-members are present we use such names as acmitic diopside and diopsidic acmite, but members intermediate between diopside and hedenbergite, with 10 percent or less of acmite, we call augite. (3). If all three end-members are present in large amount the names acmitic augite and augitic acmite would apply.

When a thorough study of an acmitic pyroxene has been made such cumbrous terms as acmitic diopsidic hedenbergite may be used, but a formula such as $Ac20 \cdot Di30 \cdot Hd40 \cdot \Delta 10$ seems preferable. In this suggested type of formula the figures refer to the weight percentage of the chief molecules and the Δ to the difference between these and 100 percent.

DESCRIPTION OF SPECIMENS

In the description of the specimens examined by us we shall follow the order of the percentage of the acmite molecule, as calculated from the analysis. The various analyses are collected in Table I and the molecular compositions calculated from them are given in Table II. The results of some special measurements to determine dispersion are given in Table III, and the measured refractive indices and extinction angles are collected in Table IV.

ACMITE, ARTIFICIAL. Acmite is easily made synthetically.[12] We prepared it by fusing an intimate mixture of the proper mole-

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[12] *Cf.* Bäckström: *Bull. Soc. Geol. France,* **16**, 130 (1893); Weyberg: *Neues Jahrb. Cb.*, 717 (**1905**).

cular amounts of precipitated silica, ferric oxide, and $Na_2CO_3 \cdot H_2O$, with twice as much sodium chloride. The acmite was not analyzed because it was impracticable to obtain sufficient material of a proper degree of purity. Its optical properties agreed with those extrapolated from natural crystals. Attempts at making potassic acmite in a similar way failed.

The crystals of artificial acmite are very thin blades, about 0.05 mm. long and 0.01 wide, elongated parallel to the *c* axis and flattened parallel to *a* (100). Singly, the crystals are very faintly yellow, with slight pleochroism; but in mass the dry powder was dull orange-yellow (17‴c). The extinction angle, $\alpha \wedge c$, is approximately 8° for red and 10° for blue. The refractive indices determined were: $\alpha = 1.776 \pm .003$, and $\gamma = 1.836 \pm .004$. By inference, from observations on nearly pure natural crystals by Brögger, Wülfing, and ourselves, $-2V = 62°$ for deep red and 60° for blue, and $\beta = 1.819 \pm .004$; α is in the obtuse angle β. Inspection of our data on natural crystals shows that the artificial crystals are not much more refringent than the purest natural acmite. This is in accord with the nearly balanced effect of TiO_2 and excess Fe_2O_3 against silicates of alumina, lime, and magnesia. Ferrous metasilicate must have about the same refringence as acmite. The optical dispersion of pure artificial acmite is estimated to be about 6 percent greater than that of the Rundemyr and Quincy crystals.

ACMITE, QUINCY, MASSACHUSETTS. The crystals of the Quincy acmite that we studied were from the same lot as those described by Palache and Warren,[13] and were kindly given us by Professor Palache. These authors call the mineral aegirite.

The megascopically very dark green crystals show great variation in color by transmitted light, the color varying irregularly from the greatly predominating green to brown or yellow, often in the same crystal. The pleochroism of the greater part of the crystals is dull yellowish green and dull greenish yellow. The extinction angle, $\alpha \wedge c$, is 7° for blue and 5 1/2° for red, presumably in the obtuse angle β; Palache and Warren give 6° for white light. The refractive indices, measured on several prisms, vary about $\pm .002$ from: $\alpha = 1.767$, $\beta = 1.806$, $\gamma = 1.823$. The optic axial angle, $2V_{Na}$, measured with the microscope, is $60° \pm 3°$, and $\rho > \nu$. Near one optic axis the blue hyperbola is distinctly on the concave side, near the other axis it is barely on the convex side. For the dis-

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[13] Palache and Warren: *Am. Jour. Sci.*, **31**, 550 (1911); Warren and Palache: *Proc. Am. Acad.*, **47**, 157 (1911).

persion and for special measurements of the refractive indices see Table III.

The specific gravity, as determined by Palache and Warren, is 3.499 at 25°; we obtained the value 3.587 at 16°.

Warren states that the carefully selected material analyzed by him contained "only a little ilmenite and traces of octahedrite and quartz." An analysis was made by us of the material that had been used for the optical measurements, which contained none of the impurities mentioned by Warren: it was boiled with dilute hydrochloric acid to remove any parisite, a mineral that contains rare earths. The results of Warren's and our analyses are given here, the mean of the two being given in No. 1 of Table I. In this mean the Al_2O_3 of Warren's analysis is corrected for the zirconia and the rare earths found by us. In recalculating the molecular composition of this mean we have neglected the small amounts of impurities mentioned by Palache and Warren as present in their material.

ANALYSES OF QUINCY ACMITE

	Warren	H.S.W.		Warren	H.S.W.
SiO_2	51.73	52.48	MnO	0.60	0.10
TiO_2	0.64	0.57	MgO	0.14	0.15
ZrO_2	n.d.	0.41	CaO	0.87	0.28
Al_2O_3	1.91	0.96	Na_2O	11.43	12.05
$(Ce,Y)_2O_3$	n.d.	0.48	K_2O	0.40	0.35
Fe_2O_3	31.86	31.74	H_2O+	0.20	n.d.
FeO	0.87	0.93	F	none	n.d.
				100.65	100.50

ACMITE, ROCKALL. Acmite forms about 40 per cent of a peculiar granitic rock (rockallite) that occurs on the islet of Rockall, in the North Atlantic, quartz and albite, in about equal parts, making up the rest.[14]

Most of the small prisms of acmite are zonally colored, with a green interior and a brown border. The refractive indices, of the green portion as determined by Dr. F. E. Wright,[14] are: α = about 1.765, $\gamma > 1.80 < 1.82$, the refractive indices for the brown portion being "practically the same as the green, but possibly a little higher." The extinction angle, $\alpha \wedge c$, for the green varies from 3° to 5°, that of the brown being slightly higher.

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[14] Washington: *Quart. Jour. Geol. Soc. London*, **70**, 294 (1914). *Cf.* Lacroix: *C. R. Acad. Sci.*, **173**, 267 (1924).

The specimen of rockallite studied was too small to permit the separation of sufficient acmite for analysis, but its chemical composition was calculated from that of the rock. The result is shown in No. 2 of Table I. The high content in zirconia and the rare earths is noteworthy. The rock itself is high in these oxides, and in the calculation they have been assigned to the acmite because, in our specimen, there is no other mineral present of which they can form part.

Raoult also found zirconia and the rare earths in his analyses of the rocks from Rockall studied by Lacroix, who, in the paper cited above, suggests that the zirconia and the rare earths belong, not to acmite, but to eucolite and elpidite, small quantities of which Lacroix found in his specimens. A reëxamination of the thin sections of our specimen of rockallite failed to show the presence of either of these minerals, so that we believe that the Rockall acmite contains considerable amounts of zirconia and the rare earths. This view is strengthened because we have found quite notable amounts of these oxides in acmite from several other localities.

ACMITE, RUNDEMYR, NORWAY. The single crystal of acmite from Rundemyr that we especially studied came from the Brush Collection in New Haven and was kindly given to us by Professor Ford. Professor Jacob Schetelig, of Oslo, also kindly sent us several excellent crystals from this locality; as these agreed in their optical characters with that from the Brush Collection they were not further examined.

The crystal studied by us was about 3 centimeters long, flattened parallel to *a*(100), with good cleavage parallel to *m*(110) and fair cleavage parallel to *b*(010). It contained no inclusions. Although the crystal looked black, because of the dark greenish interior, an outer zone, one millimeter thick, was light yellow-brown. Prisms were cut for measuring dispersion (see Table III), and the brown exterior was found to be scarcely different from the greenish interior. The pleochroism of both the brown and the green portions was faint, α in olive-greens, and γ in yellow-browns. The refractive indices for the D lines were as follows: for the interior, $\alpha=1.770$, $\beta=1.811$, $\gamma=1.825$; for the exterior, $\alpha=1.771$, $\beta=1.811$, $\gamma=1.825$. The maximum extinction is 2° for red and 4° for blue.

About 3 grams of carefully picked material, made up of both the greenish inner and yellow outer portions, was available for analysis. Zirconia and the rare earths were determined in a separate portion weighing .9444 gram, and the high percentage of rare earths is noteworthy. The cerium oxide was reddish brown, presumably because of the presence of praseodymium, but the yttrium oxide was pure white. The results of the analysis are given in No. 3 of Table I.

ACMITE, KANGERDLUARSUK, GREENLAND. Our specimen, obtained from Foote and Co., consisted of stubby to elongate, squarish black prisms, with rounded terminations, from 3 to 5 millimeters long, implanted on a somewhat decomposed nephelite syenite. On the acmite crystals are implanted a few small, colorless and water-clear crystals of apatite, which show the prism, base, and unit pyramid. This occurrence does not seem to have been listed by Ussing.[15]

Transmitted light showed irregular variations in color, including dull yellows and yellow-greens. The extinction angle, $\alpha \wedge c$, is 3° for red (650 $\mu\mu$) and 5° for blue (500 $\mu\mu$), in the obtuse angle β. The refractive indices and dispersion (Table III) were obtained from oriented prisms, cut from near the free ends of the crystals. These gave the values: $\alpha_D = 1.769$, $\beta_D = 1.805$, $\gamma_D = 1.824$. Near the ends of the crystals (the portion analyzed) variations of 0.005 were observed. The density was found to be 3.509 at 21°.

The chemical analysis was made on 1.2630 grams of very carefully selected material, the results being given in No. 4 of Table I. Zirconia and the rare earths were determined in the mixed residues from the portions used for ferric oxide and titanium, ferrous oxide, and the alkalies, altogether amounting to 0.7162 gram. Three analyses of the Kangerdluarsuk acmite by Doelter[16] and by Lorenzen[17] resemble ours in general features, our figures for most of the constituents being about the mean of the three.

ACMITE, "BREVIK," NORWAY. The material studied by us was a rough crystal from the Brush Collection sent us by Professor Ford. The locality of the specimen is not definite, as "Brevik" is a dealer's name for the district.

The black crystal yields a light tea green (25''''b) powder, the grains showing faint pleochroism in dull yellowish green and olive buff. The extinction angle on cleavage flakes, $\alpha \wedge c$, is 0° for red

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[15] Ussing: *Medd. Groenl.*, 32, 211 (1905).

[16] Doelter: *Zeit. Kryst.*, 4, 35, 37 (1879).

[17] Lorenzen: *Min. Mag.*, 5, 55 (1882).

and 1° for blue. The refractive indices vary about ±.005 from the following: $\alpha = 1.76$, $\beta = 1.79$, $\gamma = 1.81$. The specific gravity is 3.591 at 21°.

Chemical analysis yielded the results given in No. 5 of Table I. The composition is much like that of other acmites of the district, and shows notable amounts of zirconia and the rare earths.

HEDENBERGITIC ACMITE, MAGNET COVE, ARKANSAS. The aegirite of Magnet Cove has been described by J. F. Williams.[18] We have studied material obtained from the U. S. National Museum, and also a portion of the powder used by Steiger for his analysis.[19]

The mineral forms long, many of them very large, prisms in a nephelite syenite pegmatite. The mass color of the crystals varies somewhat, but is generally a greenish black. Williams speaks of "a slight tendency toward brownish green in some of the specimens which are superficially weathered," but this is attributed by us rather to the presence of an exterior zone of brown acmite, as aegirite, in general, shows slight tendency to alteration. In powder most of the grains appeared yellowish green, some brown, and some nearly colorless. The pleochroism of the greenest portions is: α = dull yellowish green, and γ = dull yellowish. The pleochroism of the brown portions is: α = olive buff, and γ is lighter, nearly "grape green." Inhomogeneity of the material was indicated by variations of about ±.005 in the values for β—the light colored grains had the higher indices. Average values are about as follows: $\alpha = 1.763$, $\beta = 1.780$, $\gamma = 1.812$, for sodium light. The extinction angle is variable, and grains that showed differences of about 1° between blue and red may have either red or blue showing the maximum angle of about 3°. We obtained the value 3.545 at 22° for the specific gravity of our specimen, while J. Lawrence Smith found that of his to be 3.53.

Three chemical analyses of the Magnet Cove aegirite have been made. That by Steiger is given in No. 7 of Table I; in this are inserted determinations of TiO_2, ZrO_2, and $(Ce, Y)_2O_3$, made by Washington on some of the original powder, Steiger's figures for Al_2O_3 being corrected for these. An analysis by Washington of another specimen, obtained from the U. S. National Museum,

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[18] J. F. Williams: *Ann. Rep. Geol. Surv. Arkansas*, **2**, 248 (1891).

[19] Clarke and Steiger: *Am. Jour. Sci.*, **13**, 36 (1902); *U. S. Geol. Survey, Bull.* **207**, 47 (1902).

is shown in No. 8 of Table I. Smith's[20] analysis is as follows: $SiO_2 = 51.41$, $TiO_2 = 0.13$, $Al_2O_3 = 1.82$, $Fe_2O_3 = 23.30$, $FeO = 9.45$, $MgO = 0.31$, $CaO = 2.03$, $Na_2O = 11.88$, $K_2O =$ trace; Sum = 100.33.

The two analyses by Steiger and by Washington are much alike, and the differences between them may well be ascribed to different proportions of brown and green material in the samples analyzed. Smith's analysis differs more widely from these, especially in FeO, MgO, CaO, and Na_2O. From the variations in the physical properties and in the chemical composition it is apparent that, apart from the somewhat zonal and otherwise non-homogeneous structure of individual crystals, the aegirite of Magnet Cove is somewhat variable in composition, as was pointed out by Clarke and Steiger.

Hedenbergitic acmite, Arö Skjär, Norway. The specimen came from one of the small rocky islets between Gross Arö and Langoddelen, near the mouth of the Langesund Fjord,[21] and was kindly given to us by the collector, Dr. Olaf Andersen.

The material consisted of small black crystals in nephelite syenite, but it is not very satisfactory for optical study, as the crystals are irregularly zoned and blotchy. The color of the powder is a dull yellowish green (tea green, 25''''b). The extinction angle varies, being mostly from 1° to 6° for red and slightly less for blue. For the nearly colorless portions $\alpha = 1.765$ and for the strongly greenish portions $\alpha = 1.746$. The results of our analysis are shown in No. 9 of Table I. In chemical composition this aegirite more closely resembles Penfield's specimen from Laven than Washington's.

Vanadiferous diopsidic acmite, Libby, Montana. This mineral has been described by Larsen and Hunt,[22] who very kindly furnished us with material from the same locality.

The mass color is nearly black, but thin splinters are brown by transmitted light. According to Larsen and Hunt the pleochroism is: $\alpha =$ dark brown, $\beta =$ lighter brown, $\gamma =$ pale yellowish brown or amber. In our specimen α varies between snuff brown and dark Isabella color (14''j and 19'''i), and γ between olive buff and citron green (20'''h and 25''a). Larsen gives an average extinction angle of 1.4° for sodium light and 1.2° for white light. In our specimen $\alpha \wedge c$, varied from 1° for red and 2° for blue to 1° for

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[20] J. Lawrence Smith: *Am. Jour. Sci.*, **10,** 60 (1875).

[21] For map see Brögger: *Zeit. Kryst.*, **16,** Tafel 29 (1890).

[22] Larsen and Hunt: *Am. Jour. Sci.*, **36,** 290 (1913).

blue to 2° for red. Larsen's average values for the refractive indices are: $\alpha=1.745$, $\beta=1.770$, $\gamma=1.782$. The specific gravity is 3.55, as determined with a pycnometer by Larsen and Hunt.

The analysis by Hunt gave the results shown in No. 10 of Table I. Zirconia and the rare earths can be present, if at all, only in very small amount, because of the small percentage of Al_2O_3, with which they would be precipitated and weighed.

HEDENBERGITIC ACMITE, LAVEN, NORWAY. Two specimens from this islet in the Langesund Fjord, where the mineral occurs in coarse nephelite syenite pegmatite,[23] were studied by us. One was collected by Professor Penfield in 1894 and the other by Washington in 1897, both under the guidance of Professor Brögger. Penfield's specimen, which was kindly sent to us from the Brush Collection by Professor Ford, proved to contain too many inclusions to be satisfactory, so that we made a special study of only Washington's specimen.

The material consisted of several loose black crystals, up to 5 centimeters long, most of them flattened parallel to *b*(010). The material is not much zoned and is free from inclusions. The specific gravity is 3.549 at 22°.

The color in transmitted light is comparatively uniform in very dull greenish yellows. Pleochroism is not very marked. The extinction angle, $\alpha \wedge c$, is 10° for red and 9 1/2 for blue, presumably in the acute angle β. The refractive indices varied ±0.003 from the following values: $\alpha_D=1.744$, $\beta_D=1.768$, $\gamma_D=1.782$. The optic axial angle $-2V_{Na}=70°$ to 80°. One axis shows no distinct dispersion, the other gave a measured value in air of 4 1/2° between the hyperbolas for red (650 $\mu\mu$) and blue (500 $\mu\mu$), with $b \rightarrow r$. That is to say, the axis for red is beyond the axis for blue with respect to the acute bisectrix. Data as to dispersion of refractive indices will be found in Table III.

Penfield's specimen contains many minute inclusions and perhaps 3 per cent of biotite. The color varies much, the extinction angle varies from 2° for red and 3° for blue to 4° for red and 3° for blue. The refractive indices are so variable that it is not worth while to give our determinations.

Both of the specimens were analyzed, the material of Washington's specimen being from the same crystal that served for the optical determinations. The results are very discordant, as is

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[23] Brögger: *Zeit. Kryst.*, **16**, 121, 318, 329 (1890).

shown in Table I, Nos. 6 and 11. Washington's specimen is a hedenbergitic acmite, while Penfield's cannot be more definitely named than augitic acmite. From the data given here, and from the work of others, it is apparent that the aegirite of Laven is very variable in composition.

VANADIFEROUS ACMITIC DIOPSIDE, LIBBY, MONTANA. An "aegirite-augite" occurs with the diopsidic acmite near Libby, Montana, which also is notable for its content in vanadium. Dr. Larsen kindly supplied us with some of the material studied by him and Hunt.[24]

The mineral is pleochroic in dull yellowish and yellowish green, α being yellowish and greenish, while γ is greenish. This peculiar behavior of α, ranging from greener to yellower than γ, is probably due to the influence of the vanadium. The extinction angle, $\alpha \wedge c$, in our specimen is 24°. The refractive indices are $\alpha = 1.720$, $\gamma = 1.747$, according to Larsen, and according to Larsen and Hunt the specific gravity is 3.42. Hunt's analysis is given in No. 12 of Table I. It would appear, from the calculated molecular composition, that the mineral is a vanadiferous acmitic diopside.

ACMITIC-DIOPSIDIC HEDENBERGITE, SALEM NECK, MASSACHUSSETTS. This mineral has been described, as aegirite-augite, from thin sections of the nephelite syenite of Salem Neck,[25] in which it forms small prisms. From a large specimen of the nephelite syenite of Salem Neck, specially collected for us by Professor J. E. Wolff, a good sample of the pyroxene was obtained. Even these minute crystals were decidedly zoned. The refractive index β varied about ± 0.005 from 1.729. The observed maximum $\gamma = 1.759$, and the minimum $\alpha = 1.711; +2V = 75°–80°; \alpha \wedge c = 27°–32°$. The mineral was markedly pleochroic, γ being brownish and α and β being darker and greenish. The amount of material available was too small for a satisfactory determination of the specific gravity. An analysis, made on 0.9985 gram of selected material, is given in No. 13 of Table I; the amount available was too small to permit the determination of MnO, ZrO_2, etc.

MISCELLANEOUS. Brief notes are given here on some acmitic pyroxenes, that have been described by others, with optical data accompanying the chemical analyses, some of which we have been able to study optically.

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[24] Larsen and Hunt: *Am. Jour. Sci.*, **36**, 295 (1913).

[25] Washington: *Jour. Geol.*, **6**, 803 (1898).

LUJAVR-URT, KOLA. Hedenbergitic acmite occurs in the lujavrite (nephelite syenite) of this locality, a specimen of which rock was kindly sent us by the late Professor Pirsson, who obtained it from Ramsay. The rock has been described by Ramsay, with an analysis of the aegirite by Forsberg.[26]

We found the pleochroism of the acmite to be: α = dull green, β and γ dull yellow. The extinction angle $\alpha \wedge c$ is 4°–5° (Ramsay). We have noted that the angle is about 1° greater for red than for blue, so that α is probably in the acute angle β. The refractive indices for sodium light we found to be: $\alpha = 1.760$, $\beta = 1.782$, $\gamma = 1.816$, with variations of about ± 0.003. According to Ramsay the average specific gravity is 3.51. The analysis by Forsberg is not very satisfactory.

MONTREAL. Harrington[27] described the "aegirite" of the nephelite syenite at the Corporation Quarry, Montreal, and we studied part of Harrington's original specimen, which was kindly sent us by Professor F. D. Adams.

The hedenbergitic acmite forms black crystals in a coarse nephelite syenite pegmatite. The crystals are too much zoned for satisfactory optical study and we made no measurements of the refractive indices. The pleochroism is very strong in parts of the crystal: α = dull yellowish green, γ = dull yellow. The extinction angle of the most deeply colored portions is 6° for red and 5° for blue: that of the practically colorless portions is 6° for red and 6° for blue. Harrington's analysis is incomplete and his figure for MnO appears to be high.

FRENCH RIVER, ONTARIO. An acmite from this new nephelite syenite locality has recently been described by Walker and Parsons,[28] with an analysis by Rickaby and optical determinations by Larsen. The chemical composition is that of an acmite but, as remarked by Larsen, the refractive indices are lower than is to be expected from the composition: they approximate to those measured by us on the aegirite of Lujavr-Urt.

LIBBY, MONTANA. Goranson has described, in a recent number of this journal,[29] a non-vanadiferous acmitic pyroxene, with an analysis by Miss Vassar. Chemically it resembles our heden-

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[26] Ramsay: *Fennia*, **3,** 40 (1890).

[27] Harrington: *Trans. R. Soc. Canada*, **2,** (3), 25 (1905).

[28] Walker and Parsons: *Univ. Toronto Studies*, No. **22,** 12 (1926).

[29] Goranson: *Am. Mineral.*, **12,** 37 (1927).

bergitic acmite from Magnet Cove (No. 8 of Table I), although it is diopsidic rather than hedenbergitic, as are the two vanadiferous pyroxenes from Libby described by Larsen and Hunt.

GENERAL CHEMICAL CHARACTERS

The acmitic pyroxenes studied by us cover a wide range with respect to both composition and locality. The Tables point to the conclusion that acmite, diopside, and hedenbergite may mix in all proportions in crystals. The hedenbergitic, rather than diopsidic, tendency of the purer acmites is explained by the natural conditions in which they have been formed: the presence of notable amounts of ferrous iron is to be expected, while magnesia is much less abundant than iron in the sodic rocks in which the acmitic pyroxenes occur.[30]

A striking and seemingly constant feature of acmite proper is the notable content of zirconia and the rare earths, the acmitic pyroxenes that contain much diopside or hedenbergite carrying but traces or none of these. This richness in zirconia and the rare earths is in harmony with the tendency of these oxides to be associated with soda in minerals and rocks.[30]

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[30] Washington: *Trans. Am. Inst. Min. Eng.*, **39**, 735 (1909); *Proc. Nat. Acad. Sci.*, **1**, 574 (1915); Clarke and Washington: *U. S. Geol. Survey, Prof. Paper* **127**, 104 (1924).

TABLE I. ANALYSES OF ACMITIC PYROXENES.

	1	2	3	4	5	6	7	8	9	10	11	12	13
SiO_2	52.10	49.83	51.59	50.83	51.99	51.98	50.45	51.86	51.52	51.91	50.89	53.32	48.38
TiO_2	0.60	0.78	1.00	0.23	0.56	0.57	0.90	2.06	0.73	0.91	0.54	0.38	1.45
ZrO_2	0.41	2.68	0.20	0.15	1.34	n. d.	0.08	n. d.	n. d.	n. d.	0.02	n. d.	n. d.
Al_2O_3	0.99	none	2.06	1.76	1.32	0.99	1.78	1.12	1.07	0.38	2.81	1.40	4.51
$(Ce, Y)_2O_3$	0.48	0.84	1.02[1]	0.11	0.27	n. d.	none	n. d.	n. d.	n. d.	0.02	n. d.	n. d.
V_2O_3	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	3.98	n. d.	2.86	n. d.
Fe_2O_3	31.80	30.27	28.65	28.70	28.16	27.15	23.42	22.72	26.43	21.79	19.20	12.38	3.43
FeO	0.90	1.78	2.08	3.07	2.18	2.72	5.26	4.30	5.09	1.48	6.87	3.70	17 35
MnO	0.35	0.28	0.14	0.29	0.10	0.08	0.10	0.26	0.43	0.58	0.05	0.45	n. d.
MgO	0.14	0.27	0.35	0.34	0.44	2.19	1.48	2.27	0.60	3.08	2.28	7.01	3.18
CaO	0.57	1.65	0.30	1.30	1.59	4.40	5.92	5.95	4.59	5.53	8.55	12.18	18.07
Na_2O	11.74	11.62	12.66	12.63	11.68	9.69	9.84	9.36	8.72	10.46	8.01	6.26	3.30
K_2O	0.37	none	0.19	0.36	0.22	0.26	0.24	0.08	0.14	0.22	0.15	9.26	0.44
H_2O+	0.20	none	0.09	0.10	0.15	0.25	0.40	0.31	0.43	none	0.41	0.13	0.35
	100.65	100.00	100.33[2]	99.87	100.00	100.28	100.02[3]	100.29	99.75	100.51[4]	99.95[5]	100.40[6]	100.46
Sp. gr.	3.587			3.509	3.591			3.545		3.55	3.509	3.42	
	16°			21°	21°			22°			22°		

[1] $Ce_2O_3=0.61$, $Y_2O_3=0.41$. [2] Cr_2O_3 none. [3] $H_2O-0.15$. [4] $H_2O-0.06$, S 0.13. [5] Cr_2O_3 none, BaO 0.02, SrO 0.13. [6] $H_2O-0.07$.

1. Acmite, Quincy, Massachusetts. Mean of analyses by Warren and Washington; see page 240.

2. Acmite, Rockall Island. New calculation from rock analysis. Washington: *Quart. Jour. Geol. Soc.*, **70**, 300 (1914).

3. Acmite, Rundemyr, Norway. Washington analyst.

4. Acmite, Kangerdluarsuk, Greenland. Washington analyst.

5. Acmite, "Brevik," of Norway. Washington analyst.

6. Augitic acmite, Laven, Langesund Fjord, Norway. (Penfield specimen.) Washington analyst.

7. Hedenbergitic acmite, Magnet Cove, Arkansas. Steiger analyst, *Am. Jour. Sci.*, **13**, 36 (1902). TiO_2, ZrO_2, and $(Ce, Y)_2O_3$ by Washington, Al_2O_3 corrected for these.

8. Hedenbergitic acmite, Magnet Cove, Arkansas. Washington analyst.

9. Hedenbergitic acmite, Arö Skjär, Norway. Washington analyst.

10. Vanadiferous diopsidic acmite, Libby, Montana. Hunt analyst. Larsen and Hunt: *Am. Jour. Sci.*, **36**, 294 (1913).

11. Hedenbergitic acmite, Laven, Norway. (H. S. W.'s specimen.) Washington analyst.

12. Vanadiferous acmitic diopside, Libby, Montana. Hunt analyst. *Op. cit.*, 295.

13. Acmitic diopsidic hedenbergite, Salem Neck, Massachusetts. Washington analyst.

TABLE II. MOLECULAR COMPOSITION OF ACMITIC PYROXENES.

	1	2	3	4	5	6	7	8	9	10	11	12	13
$Na_2O\cdot Fe_2O_3\cdot 4SiO_2$	89.17	86.39	82.70	82.70	81.31	73.46	67.91	65.60	65.60	62.83	55.44	36.04	9.70
$Na_2O\cdot Al_2O_3\cdot 4SiO_2$	none	none	8.08	3.23	5.25	none	3.23	4.04	none	0.40	4.44	2.83	5.66
$Na_2O\cdot V_2O_3\cdot 4SiO_2$	none	none	none	none	none	none	none	none	none	11.75	none	8.59	none
$Na_2O\cdot SiO_2$	none	none	0.85	2.44	0.24	none	0.73	none	none	0.98	none	none	2.81
$CaO\cdot MgO\cdot 2SiO_2$	none	none	none	none	none	8.64	6.70	9.07	1.08	14.90	12.31	34.78	17.28
$CaO\cdot FeO\cdot 2SiO_2$	2.48	7.19	1.24	5.71	7.19	9.67	18.35	15.87	19.09	7.19	23.81	14.13	59.77
$MgO\cdot SiO_2$	0.40	0.70	0.90	0.90	1.10	1.50	0.60	1.50	1.00	0.80	none	1.40	none
$FeO\cdot SiO_2$	1.06	none	3.56	3.17	0.40	none	none	none	none	none	none	none	none
$Fe_2O_3\cdot 3SiO_2$	2.04	0.68	none	none	none	3.74	none	none	7.82	none	none	none	none
$Al_2O_3\cdot 3SiO_2$	2.82	none	none	none	none	2.10	none	none	2.82	none	1.69	1.97	none
Al_2O_3	none	none	none	0.92	none	0.20	1.02	none	none	0.31	1.01	none	3.06
Inclusive	1.49	4.30	2.22	0.49	2.17	0.57	0.98	2.06	0.73	1.04	0.73	0.38	.....
SiO_2	+0.96	+0.72	+0.42	.....	+2.22	.....	.....	+1.74	+1.08	.....	.....	+0.96	.....

1. Acmite, Quincy. Ac89·Hd3·Δ8.

2. 2. Acmite, Rockall. Ac87·Hd7·Δ6.

3. Acmite, Rundemyr. Ac83·Jd8·Hd1·Δ8.

4. Acmite. Kangerdluarsuk. Ac83·Jd3·Hd6·Δ8.

5. Acmite. "Brevik." Ac81·Jd5·Hd7·Δ7.

6. Augitic acmite. Laven (S. L. P.) Ac73·Di9·Hd10·Δ8.

7. Hedenbergitic acmite. Magnet Cove. Ac68·Jd3·Di7·Hd18·Δ4.

8. Hedenbergitic acmite. Magnet Cove. Ac66·Jd4·Di9·Hd16·Δ5.

9. Hedenbergitic acmite. Arö Skjär. Ac66·Di1·Hd19·Δ14.

10. Vanadiferous diopsidic acmite. Libby. Ac63·Jd1·Vac12·Di15·Hd7·Δ2.

11. Hedenbergitic acmite. Laven (H. S. W.) Ac55·Jd4·Di12·Hd24·Δ5.

12. Vanadiferous acmitic diopside. Libby. Ac36·Jd3·Vac9·Di35·Hd14·Δ3.

13. Acmitic diopsidic hedenbergite. Salem Neck. Ac10·Jd6·Di17·Hd60·Δ7.

GENERAL OPTICAL CHARACTERS

Dispersion. Measurements on the most transparent parts of crystals from Rundemyr, Kangerdluarsuk, and Quincy gave dispersions that were identical within 0.0005. For the Quincy crystal the more accurate values (within ±0.0001) of α and β were obtained between 668 He and F. The Laven crystal is No. 11 of Tables I and II.

Table III. Dispersions.

	Quincy			Laven		
	α	β	γ	α	β	γ
G′	1.801_7	1.854_4	1.877	1.778	1.804	1.822
436 Hg	1.800_0	1.852_4				
F	1.7853	1.8304	1.850+	1.762	1.787	1.802+
501 He	1.7818	1.8254				
546 Hg	1.7736	1.8142+				
588 He	1.7677+	1.8065				
D	1.7675	1.8062	1.823	1.743+	1.768	1.781+
C	1.7608	1.7474	1.813	1.736+	1.760	1.774
668 He	1.7597	1.7961				

Refractive indices and extinction angles. The presence of admixed hedenbergite, diopside, or jadeite modifies the optical properties of acmite. With decreasing content of acmite in the acmitic pyroxenes the refractive indices and their dispersions, and the birefringences (especially β-α), decrease markedly. 2V first increases from −60° to 90° and then decreases to about +70° or +60°. The extinction angle, $\alpha \wedge c$, decreases from 9° in the obtuse angle β to 0°, and then increases in the acute angle β to large values. The bisectrices, α_r and α_b, keep the same relative positions with respect to each other, but they are farthest apart in pure acmite. The optic axial angle dispersion, also, is greatest in pure acmite.

TABLE IV. REFRACTIVE INDICES AND EXTINCTION ANGLES.

No.	Locality	α	β	γ	$2V_{na}$	$\alpha \wedge c$
	Artificial	1.77_6*	1.81_6	1.83_6	−60°	8°|**
1	Quincy	1.767	1.806	1.823	−60°	6°|
2	Rockall	1.765	——	1.81_5	——	3°–5°
3	Rundemyr	1.77_0	1.81_1	1.82_5	——	3°−|
4	Kangerdluarsuk	1.76_9	1.80_5	1.82_4	——	4°−|
5	Brevik	1.76	1.79	1.81	——	0°
7–8	Magnet Cove	1.76_3	1.78_0	1.81_2	——	3°|3°
	Lujaur Urt	1.76_0	1.78_2	1.81_6	——	|4°
9	Arö Skjär	1.74+ 1.76+	——	——	——	0°–5°
10	Libby (acmite)	1.74_5	1.77_0	1.78_2	——	1°|2°
	Libby (Goranson)	1.74_2	1.76_8	1.78_7	−80° ±	2° ±
11	Laven (H.S.W.)	1.74_4	1.76_8	1.78_2	−70°–80°	|10°
12	Libby (diopside)	1.72_0	——	1.74_7	——	|24°
13	Salem Neck	1.72	1.73	1.75	+75°–80°	|27°–32°

* Subscripts in refractive indices indicate variations or errors of 0.003–0.005.

** 8°| etc. indicate that α is in obtuse angle β; |4° etc. indicate that α is in acute angle β.

THE SELENITE CAVES OF NAICA, MEXICO

WILLIAM F. FOSHAG, *U. S. National Museum.*[1]

A characteristic feature of many of the ore deposits of Mexico that are found in the Cretaceous limestones of the country is the presence of caves in close association with the ore. One such cave discovered in 1912 during mining operations in the Potosi Mine at Santa Eulalia, but now destroyed, was remarkable for the wonderful beauty of its calcite and gypsum crystal growths. It was the habit to illuminate this cavern with a multitude of candles and for sheer brilliance and delicacy it probably surpassed anything yet discovered. In many of these caves calcite predominates, sometimes as botyroidal masses, sometimes in coral-like groups of crystals or again as entire coatings of dogtooth spar. In a few, gypsum is the chief mineral and it is usually present in most of them.

Of the gypsum caves the most remarkable are those of Naica, a small mining camp in the state of Chihuahua. To reach them one goes to the station of Concho on the Mexican Central R. R. 130 kilometers south of the city of Chihuahua and from here by a narrow gauge line to Naica, a distance of about 30 kilometers.

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