

component mixture. Possibly more has been written concerning this in connection with the determination of the percentage of iron in an ore when the specific gravity is known.

In general determinations of percentages of any element from the specific gravity can probably not claim a greater accuracy than  $\pm 1$  per cent, but the difference between the arithmetical method and the graphic method will not be greater than 0.2 per cent. The method of determining the percentage of iron in a two component system consisting of quartz and magnetite is shown in figure 2.

In figure 2 the specific gravity of quartz is laid off as a vertical co-ordinate on the left and the specific gravity of magnetite on the right. The line  $ap$  gives the specific gravity of any and every mixture of these two by bulk. The line  $aq$  is the dividing line between quartz and magnetite. The line  $bh$  is the 100% line. Magnetite contains 72+per cent of iron.

$$\frac{cd}{ac} = \frac{fg}{eg} = \frac{72}{100}$$

Now for any mixture of quartz and magnetite (in the figure equal parts are taken) join the origin  $q$  with the point marked by the specific gravity  $l$  and produce to the 100 per cent line at  $h$ . Draw the line  $hk$ . Then

$$\frac{no}{lo} = \frac{jk}{hk} = 47.46\%$$

Arithmetical calculation gave 47.57%.

This graphic method provides an easy check on concentration and may be modified so as to introduce the average specific gravity of a rock instead of using that of quartz. In general it will not be applicable to mixtures of liquids for usually a change in volume is involved.

#### SPECTROGRAPHIC EXAMINATION OF SMOKY AND ORDINARY QUARTZ FROM RINCON, CALIF.

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Inasmuch as the color of smoky quartz is attributed by many investigators<sup>1,2,3,6</sup> to the presence of finely divided particles of

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<sup>1</sup> Holden, *Am. Mineral.*, vol. 10, pp. 203-52, 1925.

silicon, rather than to the presence of some other coloring substance, spectrographic analyses were made on samples of very pale and very dark smoky quartz obtained from different parts of the same crystal or specimen, in order to ascertain whether or not any variation in composition might be thus found.

Klemm and Wild,<sup>4,5</sup> on comparing the spark spectra of samples of clear (rock crystal) and smoky quartz which were fused in lithium carbonate, found that all the spectra showed the same lines. Excitation by means of a carbon arc revealed the presence of lithium and sodium in all the varieties of quartz examined. In a later paper Klemm<sup>6</sup> stated that smoky quartz always showed only the spectrum of silicon. By means of spectroscopic tests Holden<sup>1</sup> found traces of lithium and sodium, a trace? of potassium, but no strontium or barium, in a sample of smoky quartz. Unweighable amounts of sodium and lithium were detected spectroscopically in quartz by Königsberger.<sup>7</sup>

#### PREPARATION OF SAMPLES

Samples of various color types of ordinary and smoky quartz were selected from the following specimens, all of which had been collected personally at the Clark mine,<sup>8</sup> near Rincon, California. While transparent crystals were found which were water-white at one end, and slightly smoky at the other, the writer was unable to obtain crystals suitable for examination which showed a similar variation in color from water-white to very dark. Consequently, material was used in which the color varied in the same specimen from a very pale smoky tint to a very dark, smoky brown color.

Specimen no. 1. This was a singly terminated, transparent quartz crystal approximately 8 mm. in diameter and 3 cm. long, which showed well-developed prismatic and rhombohedral faces. The color varied fairly uniformly from very dark,

<sup>2</sup> A bibliography of important papers on smoky quartz and amethyst is given by Holden, *loc. cit.*, pp. 250-52.

<sup>3</sup> Hoffman, *Zeit. anorg. allgem. Chem.*, vol. 196, pp. 225-46, 1931.

<sup>4</sup> Klemm and Wild, *Centr. Mineral., Geol.*, 1925A, pp. 270-3.

<sup>5</sup> Wild, *Centr. Mineral., Geol.*, 1930A, pp. 428-31.

<sup>6</sup> Klemm, *Zeit. angew. Chem.*, vol. 40, pp. 221-4, 1927.

<sup>7</sup> Königsberger, *Tsch. min. Mit.*, vol. 19, p. 149, 1900. Doelter, *Handb. d. Mineralchemie*, II, 1, p. 120.

<sup>8</sup> This mine is located in the W.  $\frac{1}{3}$  of Sec. 36, T. 10 S., R. 1 W., S. B. B. & M., Ramona quad., and is north of the San Luis Rey River, on the southeasterly slope of the main ridge.

smoky brown at the terminated end to nearly colorless, but perceptibly smoky gray, at the other end. Sample no. 1-*a*, which was taken from the nearly colorless end, was apparently water-white when a thickness of 2 mm. was examined, but showed a very pale smoky color, somewhat lighter than 17<sup>''''</sup>*f*,<sup>9</sup> perhaps that of 17<sup>''''</sup>*g*, when 8 mm. thick. Sample no. 1-*b*, taken from near the dark end, was apparently opaque in the 8 mm. thickness when placed on a piece of white filter paper, and examined by reflected light, but was found transparent by strong transmitted light. The color, by reflected light, for a fragment 2 mm. thick, was similar to that of sample no. 4, but was slightly lighter.

Specimen no. 2 was an irregular-shaped mass of quartz approximately 7×5×4.5 cm. in size. One side of the specimen showed a very dark, smoky brown color; the other was very pale smoky gray. The color transition from light to dark was very abrupt, forming a well-defined plane of demarcation running lengthwise thru the specimen. By careful splitting and trimming, first with a steel hammer, and then with a lump of quartz, a piece of quartz approximately 11×10×7 mm. in size was obtained from the interior portion of the specimen. From this piece, half of which was dark, and the other half light, the final samples were obtained. No particular tendency was observed on crushing for this piece to split along the color plane, since a number of tiny fragments one to two mm. across were found to contain both the light and the dark material. Sample no. 2-*a*, from the light portion, appeared water-white in a thickness of 2 mm., but showed a very pale smoky color, somewhat lighter than 21<sup>''''</sup>*f*, perhaps that of 21<sup>''''</sup>*g*, when 8 mm. thick. This material was slightly less transparent than sample no. 1-*a*, which was very clear. Sample no. 2-*b*, from the dark portion, was similar in color to sample no. 4, but was slightly lighter.

Specimen no. 3 was a large, massive piece of very transparent quartz, approximately 11×7×3 cm. in size. This material was water-white in a thickness of 11 cm.

Specimen no. 4 was a massive piece 7×3.5×2.5 cm. The color was very dark smoky brown, or bister. Sample no. 4, which was taken from this fragment, showed a color approximating 15<sup>''''</sup>*m*.

Altho specimens nos. 3 and 4 were not originally parts of a larger, single piece of quartz, as far as known, they were selected as types of the clearest colorless quartz and the darkest smoky quartz, collected by the writer at this locality. Thus samples nos. 3 and 4 came from separate pieces of quartz obtained from the same locality, whereas samples nos. 1-*a* and 1-*b* came from parts of the same crystal not over 25 mm. distant from each other, and samples nos. 2-*a* and 2-*b* came from places not over 11 mm. apart in a massive piece of quartz. All of the material used was transparent in a 2 mm. thickness.

In preparing the samples, the large specimens of quartz were cracked by means of a steel hammer. Further trimming and crushing was done between large, nearly flat-surfaced, freshly split pieces of quartz from the same locality, using clear quartz to crush the small, selected portions of the clear quartz, and smoky quartz for

<sup>9</sup> The color designations are those given in Ridgway, *Color Standards and Color Nomenclature*, Washington, 1912.

the smoky material. Before crushing, the small, selected pieces were wrapped in ashless filter paper (Whatman No. 40), partly to prevent fragments of the crushing stones from being included in the sample, and partly to avoid scattering of the crushed material. The pieces selected for the final crushing were taken from interior portions of the specimen (for specimens Nos. 2, 3 and 4), thus avoiding metallic contamination from the steel hammer, and other surface contamination. Likewise, the crushing surfaces had been freshly exposed by splitting larger pieces.

After crushing, suitable fragments of quartz, the average weight of which was about 30 mg., were selected, washed twice in benzene to remove dust and tiny adhering particles, and examined microscopically. Only those fragments were retained which showed freshly broken surfaces and which were visibly free from large inclusions and surface contamination. Strips of filter paper (Whatman No. 2) were used in this handling, and the washed and selected material was kept on other pieces of paper until used.

All of the quartz examined showed the presence of a very few minute specks or inclusions, the nature of which was not determined, and which showed little characteristic shape under a magnification of  $385\times$ . The maximum diameter observed on any of the particles was 0.002 mm. Assuming the particles to be spherical, an estimation of the average number observed per fragment of quartz indicated that the volume percentage of the inclusions in the quartz was less than 0.000,04%. The various samples of clear and smoky quartz all showed approximately the same relative amounts of inclusions.

#### SPECTROGRAPHIC PROCEDURE

The spectra were excited by means of a vertical, 100 volt D.C. arc operated on a current of 10–12 amperes, and were photographed by means of a large Gaertner quartz spectrograph, using Eastman D.C. plates in the ultra-violet, and W. & W. Panchromatic plates in the visible portion of the spectrum. A slit width of 0.035 mm. was used. The arc was placed 38 cm. from the slit, and aligned vertically in such a manner that the light which entered the collimating system of the spectrograph came principally from the lower  $3/5$  of the arc. This arrangement had previously been found to result in increased sensitivity for many of the metallic elements. In order to maintain the desired arc alignment, an auxiliary convex

glass lens of approximately 21 cm. focal length was used to project an enlarged image of the arc upon a screen fastened on the wall on the opposite side of the room. Thus a shift in the position of the arc could be readily observed by watching the position of the projected image on the screen.

Acheson regraphitized graphite electrodes 9.5 mm. ( $3/8$  inch) in diameter were used. These electrodes customarily show lines of various metallic impurities, and the intensity of these impurity lines varies with different pairs of electrodes, indicating non-uniformity of composition. Inasmuch as it was particularly desired to compare pairs of samples (smoky and light colored), this non-uniformity was compensated by the following method of selection of electrodes.

The graphite rods, which had been purchased in 30.5 cm. (12 inch) lengths, were broken into six pieces of roughly equal lengths. The two end pieces were rejected, to be used in other work. The remaining four electrodes were used in pairs so that the arcs were struck between the ends *AD* and *BC* (Fig. 1), keeping either *A* and

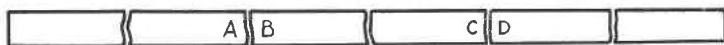


FIG. 1.

*B*, or else *C* and *D*, as the top of the lower electrode. Thus two matched pairs of electrodes were available for comparing two samples. This selection of matched pairs of electrodes was found to give far greater uniformity in the blanks, or spectra of the electrodes alone, than the use of electrodes selected at random. The upper end of the lower electrode was slightly hollowed, by means of a steel knife, so as to form a shallow cup. Tests showed that electrodes thus treated showed no more iron than those which had not been hollowed with the knife.

The procedure in all cases was as follows: After burning off each pair of electrodes for two minutes, the spectrum of the electrodes alone was photographed. The fragment of quartz was loaded by means of a strip of filter paper, and two or three successive exposures were made. The exposure time in photographing the spectrum was 30 seconds for the visible portion, and 40 seconds for the ultraviolet. The spectra of each pair of samples were placed on adjacent portions of the same photographic plate, thus insuring the same conditions of development. All samples were examined in duplicate.

In order to determine whether or not the benzene used in wash-

ing the samples left a detectable residue, a sample of the benzene was allowed to evaporate slowly from the end of an electrode. Upon examination, no new impurity lines were noted, nor were those already present strengthened.

The plates were interpreted by comparison with standard plates showing the dilution spectra of the various elements, and the results are given in Table 1. While the spectrographic interpretation was largely qualitative rather than quantitative, it was possible, however, to compare relative amounts of a given element without evaluating in terms of percentage composition. Since the different fragments examined varied somewhat in weight, this range of variation was allowed for in interpreting the spectrograms.

TABLE 1

Sample no.	Li	Al	V	Ti	Fe	Na	Ca	Mg	Si
1-a (light colored)	tr	tr	trtr	tr	bl	bl	trtr	trtr	l
1-a " "	tr	tr	trtr	trtr	bl	bl	trtr	trtr	l
1-b (dark colored)	trtr	tr	trtr	tr	bl	bl	trtr	trtr	l
1-b " "	trtr	tr	trtr	tr	bl	bl	trtr	trtr	l
2-a (light colored)	tr	tr	tr	tr	bl	bl	trtr	trtr	l
2-a " "	tr	tr	trtr	tr	bl	bl	trtr	trtr	l
2-b (dark colored)	trtr	tr	trtr	tr	bl	bl	trtr	trtr	l
2-b " "	trtr	tr	trtr	tr	bl	bl	trtr	trtr	l
3 (light colored)	tr	tr	trtr	trtr	bl	bl	trtr	trtr	l
3 " "	tr	tr	trtr	trtr	bl	bl	trtr	trtr	l
4 (dark colored)	trtr	tr	trtr	trtr	bl	bl	trtr	trtr	l
4 " "	—	tr	trtr	tr	bl	bl	trtr	trtr	l

Key to symbols:

- l=large amount.
- tr=trace.
- trtr=extremely minute trace.
- bl=lines not stronger than those in the blank.

### RESULTS

The lines due to iron and sodium were not stronger in the spectra of the samples than in the spectra of the electrodes alone. Hence extremely minute traces of these elements may have escaped detection. All of the elements, except vanadium, which are listed in Table 1 have been previously reported in smoky quartz from Colorado by Holden.

For aluminum, calcium, magnesium, vanadium and titanium, no significant differences in content between the various samples were found. Lithium was much more pronounced in all of the samples of light colored quartz than in the darker, smoky material, and was largest in content, in fact, in the colorless and very clear sample no. 3. All the fragments of the dark, smoky quartz, however, except one, showed the presence of an extremely minute trace of lithium.

From the data obtained, it appears that with increasing lithium content a decreasing amount of smokiness is to be expected in the quartz from this locality. Whether this inverse relationship holds for colorless and smoky quartz from other localities is not known to the writer. It is likewise unknown whether a decrease in lithium content is directly responsible for an increase in smokiness, or whether the conditions which favor an increase in depth of smoky color, may, perhaps indirectly, tend to reduce the lithium content in the crystal, or in the solution and/or vapor from which it may be formed. It has been suggested that sodium and lithium, in the form of silicates, or otherwise, may play some role in the coloration of smoky quartz,<sup>5,10</sup> or may even be responsible directly for the coloration.<sup>4,11,12</sup> If smoky quartz is colored by finely divided particles of silicon, produced by radioactivity, perhaps the presence of lithium compounds in the crystal lattice tends to prevent the decomposition which results in the finely divided particles. This possibility could be tested by subjecting samples of clear, colorless quartz, which have been found to show a difference in lithium content, to suitable radiations, and observing whether or not there is a difference in the rate at which they darken or become smoky.

It is possible that the inclusions in the samples may be responsible, in part at least, for the elements other than silicon which were found present. These inclusions may possibly be responsible for the variation in lithium content. This latter possibility appears very unlikely, however, since the inclusions in the various samples appeared to be similar in nature and relative amount, and also since the estimated total amount of the inclusions is very small.

<sup>10</sup> Doelter, *loc. cit.*, p. 144.

<sup>11</sup> Doelter, *Das Radium and die Farben*, pp. 124-125, Dresden. *Die Farben der Mineralien*, pp. 70-75, Braunschweig.

<sup>12</sup> Hoffmann, *Zeit. anorg. allgem. Chem.* vol. 219, pp. 197-202, 1934.

## SUMMARY

1. Colorless, very pale smoky, and dark smoky quartz specimens from Rincon, California, have been examined spectrographically.
2. The colorless, as well as the very pale smoky quartz samples were found to contain more lithium than the dark smoky quartz, regardless of whether or not the various colored types formed parts of the same crystal or crystalline mass.
3. No other significant difference in composition, as regards metallic constituents, was found. Aluminum, vanadium, titanium, calcium, magnesium, and, of course, silicon, were found to be present in all of the samples examined.
4. An improved spectrographic technique for examining minerals is described.

## TETRADYMITTE FROM INYO MOUNTAINS, CALIFORNIA

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Samples of a brilliant, foliated metallic mineral collected in the Cerro Gordo district, Inyo mountains, Inyo County, California, proved upon examination to be tetradymite. The occurrence of this mineral has not been reported, as far as the writer is aware, in the suite of minerals of the Cerro Gordo district.<sup>1</sup>

In a hand specimen the tetradymite occurs as myriads of brilliant tabular crystals about 1/16 inch in diameter. It is imbedded in an earthy, powdery, apple to pale green mineral identified as bismutite. Other associated minerals are quartz, and a straw yellow powder that has not as yet been positively determined.

The physical properties of the tetradymite are: luster, metallic, brilliant; color, tin white to light silver gray; hardness 1.5–2; perfect basal cleavage. No specific gravity determinations were made.

Qualitative chemical analysis indicates (a) trace of sulphur upon roasting, (b) no selenium, (c) presence of tellurium upon solution with concentrated sulphuric acid, (d) presence of bismuth upon fusion with potassium iodide and sulphur.

A polished section of the ore, prepared and examined by Mr. V. C. Kelley, of the California Institute of Technology, showed the

<sup>1</sup> Knopf, A., A Geologic Reconnaissance of the Inyo Range, etc., *U. S. Geol. Surv.*, Prof. Paper 110, pp. 108–16, 1918.

Eakle, A. S., Minerals of California, *Calif. State Min. Bur.*, Bull. 91, 1923.