MINERAL DETERMINATION BY ABSORPTION SPECTRA. II.

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In the first instalment of this article[11] the minerals showing absorption spectra consisting of narrow bands were discussed. There remain to be considered those in which the bands are mostly broader, at least as seen with the microspectroscope; these will be grouped according to color. For particularly broad bands the wave-lengths of both margins and center will be given, and as before, positions of brilliant transmission will be indicated by parallel lines. When data obtained by other workers with larger spectroscopes are cited, only the lines of significance in the present connection will be tabulated.

PART 2. ABSORPTION SPECTRA CONSISTING OF BROAD BANDS

Group 1. Color red or pink.

Spectrum-zone	red		orange yellow	green	blue	
Corundum, pink	–700‖690–683–675	...	600–590–580	...	...	W.
" , ruby	–700‖**690–680–670**	...	600–575–550	...	...	W.
" , "	–696‖**693 679–676**	661	...	...	477	M.
" , " , syn.	–700‖**690–678–665**	...	600 — 555 — 510	...		W.
Element	Cr		Cr			

This highly diagnostic spectrum of the red corundums was first described by Moir,[12] and independently by Keeley.[13] The former, using a large spectroscope, observed several narrow absorption bands within the broad ones shown by the microspectroscope. The red line visible (in scattered light only) between the end of the spectrum and the band starting at about 690 is strikingly brilliant; in a later article, Keeley[14] gave evidence that it is connected with fluorescence. The width of the band in the orange and yellow varies markedly with the chromium content, and as synthetic ruby contains considerably more of this element than natural material of similar depth of color, this band can be turned to account for distinguishing them: when it extends well over into the green, the specimen is almost certainly synthetic.

11 *American Mineralogist*, **14**, pp. 299–308, 1929.

12 The spectrum of the ruby. *Trans. Royal Soc. S. Afr.*, **1**, 321, 1908; **2**, 271, 1912.

13 Microspectroscopic observations. *Proc. Acad. Nat. Sci. Phila.*, **1911**, 106–116.

14 Notes on absorption spectra of certain minerals. *Festschrift Victor Goldschmidt*, 170–171, 1928.

Spectr.-zone	orange	yellow	green	blue
Almandite	620 ...	**585–578–570**	530–525–520‖**510–503–495**	... W.
"	(615) ...	... **575**	... 530 ... **507–506–505**	(460) M.
"	... ...	... 571±4	... ... **503±3**	... W. & H.
Pyrope	620–590–560	...	... ...	... W.
"	... ... **561**	...	... ...	... W. & H.
Elements	Cr	Cr	V V	

The variations in the spectra of certain garnets are brought out by tabulating the results of observations with the microspectroscope along with those obtained with more elaborate instruments by Moir[15] and by Weigel and Habisch.[16] It is obvious that by this method pyrope can be readily distinguished from almandite, and both from ruby, even when they are cut and mounted so that other methods of testing are inapplicable. Spessartite shows the same bands as almandite, but fainter.

Spectrum-zone	yellow	green	blue	
Rose-quartz	... ...		(520–495–470)	H.
Ruby-spinel	(580–560–540) ...		... ...	W.
Rhodonite and	580–560–540 ...		... ...	W.
Rhodochrosite	... 554		... ...	W. & H.
Eudialyte	... ...	**535± 3**	... ...	W. & H.
Pink-topaz	(570–550–530) ...		... ...	W.
"	... ...	525±13	... ...	W. & H.
Thulite-zoisite	... 560–545–530		... ...	W.
Piedmontite, α	... ...	525 —	— — —	L.
" β	**590–560–530** ...		... ...	L.
" γ	600 — — —	—	— — —	L.
Rubellite-tourm.	... (560 —	525	— 490) ...	W.
"	... ...	**517±16**	... ...	W. & H.
Element	Mn	Mn	Mn	

The absorption bands of the manganese minerals just tabulated are mostly weak, but in certain cases species which resemble one another can be told apart by this means. The data tabulated are taken in part from articles by Holden,[17] Weigel and Habisch (*op. cit.*) and Laspeyres.[18]

[15] Notes on the spectra of the precious emerald and other gem stones. *Trans. Royal Soc. S. Afr.*, **2**, 273, 1912.

[16] Mineral colorations. 1. The absorption of red-colored minerals in the visible part of the spectrum. *Neues Jahrb. Min. Geol., Beil. Bd.*, **57A**, 1–56, 1928.

[17] The cause of color in rose quartz. *Amer. Mineral.*, **9**, 101, 1924.

[18] The crystallographic and optical properties of piedmontite. *Z. Kryst. Min.* **4**, 435–467, 1880, especially plate 11.

Spectrum-zone	ora.	yellow	green	
Cuprite	**630** . . .	. . . .	. . .	W.
Erythrite	. . . . . .	**560–550–540** . . .	(495)	W.
Roselite, etc.	. . . . . .	(570–555–540) . . .	. . .	W.
Vanadinite	. . .	580–565–550	. . .	W.
Ruby-glass	600–580–560	. . . .	. . .	W.
"	. . . . . .	. . . .	530±6 . . .	W. & H.
Elements	Cu Cu	V Co	Se? Co	

This table of miscellaneous compounds concludes the list of red materials showing noteworthy absorption bands thus far recognized.

Group 2. Color yellow or brown.

Spectrum-zone	yel.	green	blue	
Greenockite	. . .	**525–520–515**	. . .	W.
Corundum	. . .	. . . .	**455**	W.
Vesuvianite	. . .	. . . .	463	B.
Staurolite	(555)	. . . .	. . .	W.
Elements	Fe	Cd	Fe	

The most significant band in the spectrum of any of the few yellow minerals exhibiting restricted absorption is that in the blue; its cause is evidently ferric iron, and it shows up also in minerals colored green by this element. In vesuviantite, as noted by Becquerel[19] it appears only in the ordinary direction.

Group 3. Color green.

Spectrum-zone	red		ora.	vio.	
Hiddenite-spodumene	. . .	. . .	630	438	B.
Emerald-beryl	. . .	640 ‖	620	. . .	W.
"	680	(656)	(633)	. . .	M.
Demantoid-garnet	. . .	(640)	(620)	. . .	W.
Fuchsite-muscovite	. . .	(650)	. . .	. . .	W.
Cr-borate	680	. . .	. . .	. . .	M.
Element	Cr	Cr	Cr	Cr	

The bands of minerals colored green by chromium are not so intense as of those colored red by this element, yet are fairly characteristic. The data marked B. are taken from a paper by Bayley,[20] those marked M. from that by Moir, already cited.

[19] The absorption spectrum of epidote (etc.). *Compt. rend.*, **108**, 282–284, 1889; The laws of light absorption in crystals, *ibid.*, 891–894.

[20] X-ray coloration of kunzite and hiddenite. *Phys. Rev.*, **29**, 353, 1927.

Spectrum-zone	ora.	gre.		blue		vio.	
Emerald-corundum	...	...	...	...	**455**	...	W.
Spinel	...	...	(490)	...	(458)	...	W.
"	...	...	...	...	458	...	M.
Olivine	...	**500** –	**495** –	**490**	(460)	...	W.
Vesuvianite	...	...	...	...	463	...	B.
Epidote	...	...	(478)	...	**458**	...	W.
" α	...	...	...	...	**453**	...	B.
" β	...	...	474	...	**457**	427	B.
" γ	(603)	...	...	...	...	...	B.
Clinochlore, ε	...	...	493	...	...	...	B.
Element	Fe		Fe		Fe	Fe	

This second table of green minerals comprises those whose color is due to iron. The band toward the violet side of the blue is also shown, as above noted, by those colored yellow by the ferric form of this element; that toward the green side may be due to the ferrous form. The data attributed to Moir (M.) and to Becquerel (B.) are from papers by these authors already cited.

Spectrum-zone	red				ora.	yellow		blue	
Manganosite	...	...	...	‖**650**–	**615**–	**575**‖	...	...	F, W.
Alexandrite-chrys.	...	...	...	...	**600**–	**585**–	**570**	(480)	W.
" "	678	667	656	645	...	**585**	...	...	K.
Andalusite (gem)	...	...	...	...	...	...	**555**	525	W.
Elements	V	V	V	V	Mn	V	V	V	

The intense band in the orange produced by manganosite was first noted by Ford[21] and the four narrow ones in the red characteristic of alexandrite-chrysoberyl by Keeley (*op. cit.*, p. 171). That vanadium causes the color in this final list of green minerals is a suggestion only, and needs confirmation.

Group 4. Color blue.

Spectrum-zone	red	ora.	yellow	gre.		blue	
Sapphire-corundum	...	...	...	...	(478)	...	W.
" " , synth.	...	...	...	...	**478**	...	W.
Spinel	...	(590)	555–**550**–545	(510)	...	**465–460–455**	W.
Iolite	...	...	... **500**–	**495**–	**490**	...	W.
Blue glass	**655**	**590**	(550–540–530)	...	...	...	W.
Elements	Co	Co	Co	Ti	Ti	Co	

[21] The index of refraction of manganosite. *Am. J. Sci.*, **38**, 502–503, 1914.

The spectra of the four blue materials tabulated first are so dissimilar as to make this a suitable method for their identification. Synthetic sapphire shows a stronger band in the blue than the natural, making possible their distinction even when cut and mounted.

Spectrum-zone	ora. yellow	gre. blue	
Azurite	... ...	**510–495–480**	W.
Chalcanthite	(590–570–550)	... ...	W.
Linarite	(600–580–560)	... ...	W.
Element	Cu	Cu	

Rather unexpectedly, the stronger bands in these copper minerals are different in position. All show in addition general absorption in the yellow.

GROUP 5. COLOR VIOLET OR PURPLE.

Spectrum-zone	yellow	green	
Kunzite-spodumene	... ...	**560–540–520**	W.
" "	... ...	... **542** ...	W. & H.
Hexagonite-tremolite	(580–575–570)	... ...	W.
Hodgkinsonite	(590–580–570)	... ...	W.
Lepidolite	(580–575–570)	... ...	W.
Purple-glass	(590)	... (545) ...	W.
" "	... ...	 490	H.
Element	Mn	Mn	

Manganic manganese produces absorption bands in the yellow and green, but they are usually not very intense. Holden[22] found absorption in manganese glasses, however, to be at a maximum in the blue.

Spectrum-zone	red	ora.	yellow	green	blue	
Amethyst-corundum	–700‖690–683–675		(590–575–560)	...	... (475)	W.
Spinel	... ...	...	(590) ...	**555– 550 –545**	(460)	W.
Kaemmererite	... ...	...	(610–585–560)	... ...	...	W.
Amethyst-quartz	... ...	... ...	... ...	(520–505–490)		W.
" "	... ...	... ...	... (550– 535 –520) ...			H.
" "	... ...	... ...	... 553±2 ...	...	...	W. & H.
Elements	Cr	Cr	Cr Fe	Co,Fe	Fe Ti	

Both natural and synthetic amethyst-corundum, owing their color to two elements, show superimposed the spectra of ruby

[22] The cause of color in rose quartz. *Amer. Mineral.*, 9, 102, 1924.

and sapphire. Amethyst-quartz was studied by Holden[23] and by Weigel and Habisch (*op. cit.*) yielding the bands tabulated on the last two rows.

In conclusion, it may be pointed out that an apparatus which is capable of distinguishing so many similarly colored materials from one another, without requiring any physical or chemical treatment of the specimen, should certainly be a part of the equipment of every mineralogist's laboratory. To emphasize a few cases, the microspectroscope will distinguish almandite from pyrope, emerald-beryl from emerald-corundum, and gem-andalusite from alexandrite-chrysoberyl; it will tell ruby from every other red mineral, and decide whether it is natural or synthetic; and it will prevent glasses being mistaken for gem-stones of like colors, so that everyone who has gems brought to him for identification can use it. Students of sediment-petrography may find it helpful in identifying certain constituents of sands, especially monazite.

The microspectroscope is also serviceable in solving chemical problems, such as the presence of certain elements—chromium, vanadium, iron, titanium, manganese, etc.,—in colored materials; and there is room for additional research along this line. Besides the need of correlation of bands with composition in a number of cases mentioned above, the application of more intense light than heretofore employed will no doubt show many substances besides those here enumerated to possess characteristic absorption spectra. It is hoped, then, that the present article will encourage further investigation with this instrument.[24]

[23] The cause of color in smoky quartz and amethyst. *Amer. Mineral.*, **10**, 233, 1925.

[24] An attempt has been made to present a fairly complete summary of the relevant literature; the writer will appreciate the receipt of information as to any omissions which may be discovered.

In response to many requests, it may be stated that the observations recorded in this paper as due to the writer (marked W.) were made with an Abbe-Zeiss "Spectroscopic eyepiece," although other makes of microspectroscopes will no doubt also give good results.