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A revised dispersion method for determining the composition of olivine, orthopyroxene, augite, and plagioclase

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For a solid immersed in a liquid, if the solid's refractive index (RI) matches that of the liquid at the wavelength λ_0, Su (1993) has derived the following equation, assuming the variation of RI with wavelength obeys the Hartmann dispersion relationship (Hallimond, 1970):

$$n_D^S = n_D^L + (\Delta^L - \Delta^S)k_D \tag{1}$$

where n_D^S is the RI of a solid at 589 nm; n_D^L, the RI of the liquid at 589 nm; Δ^L, the dispersion coefficient of the liquid, $n_F^L - n_C^L$; Δ^S, the dispersion coefficient of the solid, $n_F^S - n_C^S$; and k_D equals $[(\lambda_0 - 200)^{-1} - (589 - 200)^{-1}]/[(486 - 200)^{-1} - (656 - 200)^{-1}]$ or $[(\lambda - 200)^{-1} - 0.002571]/0.001304$. A conversion table (Table 1) was computed to facilitate the conversion of λ_0 to k_D.

For olivine, orthopyroxene, and augite, Berg and Morse (1981) have established

$$\Delta^S = n_F^S - n_C^S = z + wn_D^S \tag{2}$$

where z and w are constants listed by them and given in the equations below.

Substituting Equation 2 into Equation 1, we have

$$n_D^S = n_D^L + (\Delta^L - z - wn_D^S)k_D$$

or

$$n_D^S = [n_D^L + (\Delta^L - z)k_D]/(1 + wk_D). \tag{3}$$

For evaluating $X_{\text{end-member 1}}$, which represents the mole fraction of the end-member 1 in a solid-solution series formed between end-members 1 and 2, we have

$$X_{\text{end-member 1}} = (n_D^{\text{end-member 2}} - n_D^{\text{unknown}}) \div (n_D^{\text{end-member 2}} - n_D^{\text{end-member 1}}). \tag{4}$$

Using the data of Berg and Morse (1981), respective equations can be derived for three mafic solid-solution series.

For olivine, if $n_D^S = \beta$, we have

$$n_D^S = [n_D^L + (\Delta^L + 0.12265)k_D]/(1 + 0.07911k_D) \tag{5}$$

and

$$X_{Fo} = (1.8650 - n_D^S)/0.2140 \tag{6}$$

where X_{Fo} is the mole fraction of forsterite in the forsterite-fayalite series.

For orthopyroxene, if $n_D^S = \gamma$, we have

$$n_D^S = [n_D^L + (\Delta^L + 0.07526)k_D]/(1 + 0.05047k_D) \tag{7}$$

and

$$X_{En} = (1.7886 - n_D^S)/0.1236 \tag{8}$$

where X_{En} is the mole fraction of enstatite in the enstatite-ferrosilite solution series.

For augite, if $n_D^S = \beta$, we have

$$n_D^S = [n_D^L + (\Delta^L + 0.09479)k_D]/(1 + 0.06236k_D) \tag{9}$$

and

$$X_{En} = (1.7447 - n_D^S)/0.0686 \tag{10}$$

where X_{En} is the mole fraction of enstatite in the augite solid solution.

Using Equations 9 and 10 and the data for KI-4 augite ($n_D^L = 1.69313$, $\Delta^L = 0.0356$, and $\lambda_0 = 548$ nm or $k_D = 0.2338$: Stoiber and Morse, 1992, Fig. 16-5, p. 293), X_{En} was calculated to be 0.668 or 66.8%, which is in exact agreement with the result obtained by Stoiber and Morse (1992, Fig. 16-5, p. 293).

A similar derivation can be applied also to the plagioclase series. The data of Tsuboi (1923) for the low (α') RI on (001) cleavage flakes suggested to Stoiber and Morse (1992) that

$$10^4(n_F - n_C) = 83 + 21X_{An}$$

where $n = \alpha'$ and X_{An} is the mole fraction of anorthite in the albite-anorthite series (Ab-An), or

$$\Delta^S = (n_F - n_C) = 0.0083 + 0.0021X_{An}. \tag{11}$$

We know also for the Ab-An series as a whole

$$X_{An} = (n_D^S - n_D^{Ab})/(n_D^{An} - n_D^{Ab})$$

where n_D^S is the low (α') RI on (001) cleavage flakes.

For individual compositional ranges, Stoiber and Morse (1992, p. 294) established

$$X_{An} = (n_D^S - n_0)/\Delta n \tag{12}$$

where the following applies:

An range	n_0	Δn
0–24	1.5287	0.05165
24–31	1.5277	0.05587
31–84	1.5290	0.05144
84–100	1.5328	0.04688

Substituting Equation 11 into Equation 1, we obtain

$$n_D^S = n_D^L + (\Delta^L - 0.0083 - 0.0021X_{An})k_D. \tag{13}$$

Substituting Equation 13 into Equation 12, we have

$$X_{An} = [n_D^L + (\Delta^L - 0.0083 - 0.0021X_{An})k_D - n_0]/\Delta n$$

or

TABLE 1. Conversion from λ_0 to k_D

λ_0	0	1	2	3	4	5	6	7	8	9
400	1.8649	1.8458	1.8269	1.8082	1.7897	1.7713	1.7532	1.7352	1.7174	1.6997
410	1.6822	1.6649	1.6478	1.6308	1.6140	1.5973	1.5808	1.5644	1.5482	1.5321
420	1.5162	1.5004	1.4848	1.4693	1.4539	1.4387	1.4236	1.4087	1.3939	1.3792
430	1.3646	1.3502	1.3359	1.3217	1.3076	1.2937	1.2798	1.2661	1.2525	1.2390
440	1.2257	1.2124	1.1993	1.1862	1.1733	1.1604	1.1477	1.1351	1.1226	1.1102
450	1.0978	1.0856	1.0735	1.0615	1.0495	1.0377	1.0259	1.0143	1.0027	0.9912
460	0.9798	0.9685	0.9573	0.9462	0.9351	0.9242	0.9133	0.9025	0.8918	0.8811
470	0.8706	0.8601	0.8497	0.8393	0.8291	0.8189	0.8088	0.7988	0.7888	0.7789
480	0.7691	0.7594	0.7497	0.7401	0.7305	0.7210	0.7116	0.7023	0.6930	0.6838
490	0.6746	0.6656	0.6565	0.6476	0.6387	0.6298	0.6210	0.6123	0.6036	0.5950
500	0.5865	0.5780	0.5695	0.5612	0.5528	0.5446	0.5363	0.5282	0.5201	0.5120
510	0.5040	0.4961	0.4881	0.4803	0.4725	0.4647	0.4570	0.4494	0.4418	0.4342
520	0.4267	0.4192	0.4118	0.4044	0.3971	0.3898	0.3826	0.3754	0.3682	0.3611
530	0.3541	0.3470	0.3400	0.3331	0.3262	0.3194	0.3125	0.3058	0.2990	0.2923
540	0.2857	0.2791	0.2725	0.2660	0.2595	0.2530	0.2466	0.2402	0.2338	0.2275
550	0.2212	0.2150	0.2088	0.2026	0.1965	0.1904	0.1843	0.1783	0.1723	0.1663
560	0.1604	0.1545	0.1486	0.1427	0.1369	0.1312	0.1254	0.1197	0.1140	0.1084
570	0.1028	0.0972	0.0916	0.0861	0.0806	0.0751	0.0697	0.0643	0.0589	0.0535
580	0.0482	0.0429	0.0377	0.0324	0.0272	0.0220	0.0168	0.0117	0.0066	0.0015
590	−0.0035	−0.0086	−0.0136	−0.0185	−0.0235	−0.0284	−0.0333	−0.0382	−0.0431	−0.0479
600	−0.0527	−0.0575	−0.0622	−0.0670	−0.0717	−0.0764	−0.0810	−0.0857	−0.0903	−0.0949
610	−0.0995	−0.1040	−0.1086	−0.1131	−0.1175	−0.1220	−0.1265	−0.1309	−0.1353	−0.1397
620	−0.1440	−0.1484	−0.1527	−0.1570	−0.1612	−0.1655	−0.1697	−0.1740	−0.1782	−0.1823
630	−0.1865	−0.1906	−0.1947	−0.1988	−0.2029	−0.2070	−0.2110	−0.2151	−0.2191	−0.2231
640	−0.2270	−0.2310	−0.2349	−0.2388	−0.2427	−0.2466	−0.2505	−0.2543	−0.2582	−0.2620
650	−0.2658	−0.2695	−0.2733	−0.2771	−0.2808	−0.2845	−0.2882	−0.2919	−0.2955	−0.2992
660	−0.3028	−0.3064	−0.3100	−0.3136	−0.3172	−0.3208	−0.3243	−0.3278	−0.3313	−0.3348
670	−0.3383	−0.3418	−0.3452	−0.3486	−0.3521	−0.3555	−0.3589	−0.3622	−0.3656	−0.3690
680	−0.3723	−0.3756	−0.3789	−0.3822	−0.3855	−0.3888	−0.3920	−0.3953	−0.3985	−0.4017
690	−0.4049	−0.4081	−0.4113	−0.4144	−0.4176	−0.4207	−0.4238	−0.4270	−0.4301	−0.4331
700	−0.4362	−0.4393	−0.4423	−0.4454	−0.4484	−0.4514	−0.4544	−0.4574	−0.4604	−0.4633
720	−0.4952	−0.4980	−0.5009	−0.5037	−0.5065	−0.5093	−0.5120	−0.5148	−0.5176	−0.5203
740	−0.5498	−0.5525	−0.5551	−0.5577	−0.5603	−0.5629	−0.5655	−0.5680	−0.5706	−0.5731
760	−0.6006	−0.6030	−0.6055	−0.6079	−0.6103	−0.6127	−0.6151	−0.6175	−0.6199	−0.6222
780	−0.6478	−0.6501	−0.6524	−0.6546	−0.6569	−0.6591	−0.6613	−0.6636	−0.6658	−0.6680
800	−0.6919	−0.6940	−0.6961	−0.6983	−0.7004	−0.7025	−0.7045	−0.7066	−0.7087	−0.7108

$$X_{An} = [n_D^L + (\Delta^L - 0.0083)k_D - n_0]/(\Delta n + 0.0021k_D). \quad (14)$$

Using Equation 14 and the PG-721 plagioclase data (assuming the broadest range of $An_{31\text{-}84}$: $n_0 = 1.5290$, $\Delta n = 0.05144$, $n_D^L = 1.5542$, $\Delta^L = 0.01764$, and $\lambda_0 = 538$ nm or $k_D = 0.2990$: Stoiber and Morse, 1992, Fig. 16-8, p. 297), X_{An} was calculated to be 0.537 or 53.7%, which is in exact agreement with the result obtained by Stoiber and Morse (1992, Fig. 16-8, p. 297).

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APPENDIX 1. DERIVATION OF EQUATIONS

This method is illustrated in Figure 1. Because of the similar triangular relationship between $\Delta n_F^L n_0 n_F^S$ and $\Delta n_D^L n_0 n_D^S$, we have

$$(n_F^L - n_F^S)/(n_D^S - n_D^L) = (X_F - X_0)/(X_0 - X_D). \quad (A1)$$

Furthermore, because of the similar triangular relationship between $\Delta n_D^L n_0 n_D^S$ and $\Delta n_C^L n_0 n_C^S$, we have

$$(n_C^S - n_C^L)/(n_D^S - n_D^L) = (X_0 - X_C)/(X_0 - X_D). \quad (A2)$$

By adding Equations A1 and A2 together, we have

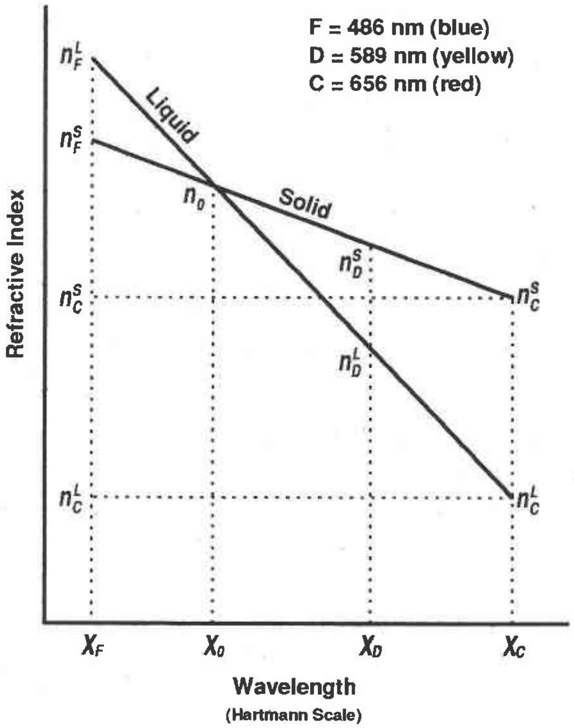
$$[(n_F^L - n_C^L) - (n_F^S - n_C^S)]/(n_D^S - n_D^L) = (X_F - X_C)/(X_0 - X_D). \quad (A3)$$

Let $\Delta^L = (n_F^L - n_C^L)$, $\Delta^S = (n_F^S - n_C^S)$, and $k_D = (X_0 - X_D)/(X_F - X_C)$, and Equation A3 becomes

$$n_D^S = n_D^L + (\Delta^L - \Delta^S)k_D. \quad (A4)$$

By a similar derivation, a general form of Equation A4 can be derived for any given wavelength i:

$$n_i^S = n_i^L + (\Delta^L - \Delta^S)k_i, \quad (A5)$$



Appendix Fig. 1. The dispersion curves of a liquid and a solid. The abscissa is plotted according to the Hartmann equation and is proportional to X or $(\lambda - 200)^{-1}$, where λ is wavelength in nanometers. The subscripts F, D, and C denote Fraunhöfer spectral lines.

where n_i^S is the RI of the solid at wavelength i (nm); n_i^L, the RI of the liquid at wavelength i (nm) and $k_i = [(\lambda_0 - 200)^{-1} - (i - 200)^{-1}]/[(486 - 200)^{-1} - (656 - 200)^{-1}]$ or $[(\lambda_0 - 200)^{-1} - (i - 200)^{-1}]/0.001304$.