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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 $\lambda_0$, Su (1993) has derived the following equation, assuming the variation of RI with wavelength obeys the Hartmann dispersion relationship (Hallimond, 1970):

$$n_D^S = n_D^L + (\Delta^L - \Delta^S)k_D \quad (1)$$

where $n_D^S$ is the RI of a solid at 589 nm; $n_D^L$, the RI of the liquid at 589 nm; $\Delta^L$, the dispersion coefficient of the liquid, $n_F^L - n_C^L$; $\Delta^S$, 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 $\lambda_0$ to $k_D$.

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

$$\Delta^S = n_F^S - n_C^S = z + w n_D^S \quad (2)$$

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

Substituting Equation 2 into Equation 1, we have

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

or

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

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

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

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

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

and

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

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

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

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

and

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

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

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

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

and

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

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 ($\alpha'$) 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

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

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 ($\alpha'$) RI on (001) cleavage flakes.

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

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

where the following applies:

| An range | $n_0$ | $\Delta n$ |
|---|---|---|
| 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

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

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

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**TABLE 1.** Conversion from $\lambda_0$ to $k_D$

| $\lambda_0$ | 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

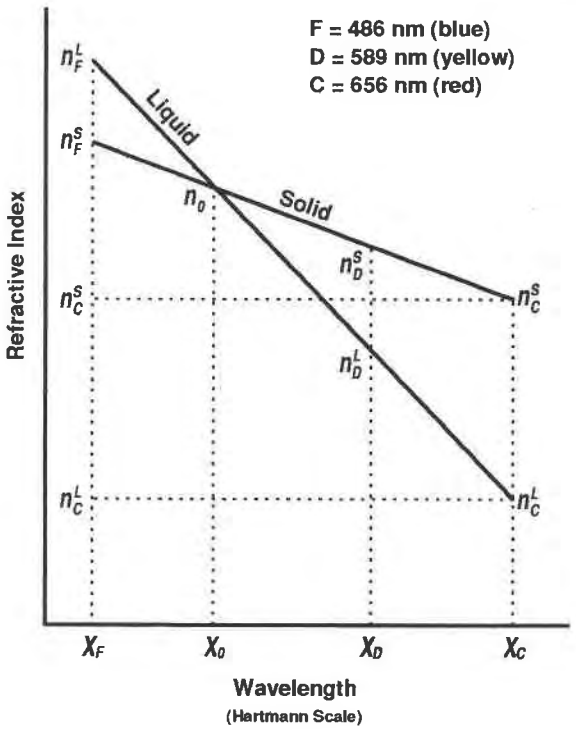
$$[(n_F^L - n_C^L) - (n_F^S - n_C^S)]/(n_D^S - n_D^L) = (X_F - X_C)/(X_0 - X_D). \quad (A3)$$

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 $\lambda$ 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 $[(\lambda_0 - 200)^{-1} - (i - 200)^{-1}]/0.001304$.