Optical Sciences PhD Qualifying Exam: Instructions and Post-2026 Equation Sheets

Answer all four questions on the following pages. Start each answer on a new sheet of paper.

In the upper right hand corner of each sheet, write your code number (NO NAMES PLEASE) and the problem number (course number) that you are answering. Attach together all sheets for a given problem in order.

When finished, insert your answers into the envelope provided. Also insert all scratch paper, the equation sheets, the exam problems, and any other items that were distributed to you in the envelope.

The following are some helpful items:

$h = 6.625 \times 10^{-34}\ \mathrm{J \cdot s} = 4.134 \times 10^{-15}\ \mathrm{eV \cdot s}$

$e = 1.6 \times 10^{-19}\ \mathrm{C}$

$c = 3.0 \times 10^{8}\ \mathrm{m/s}$

$k_B = 1.38 \times 10^{-23}\ \mathrm{J/K}$

$\sigma = 5.67 \times 10^{-8}\ \mathrm{W/K^4 \cdot m^2}$

$\epsilon_0 = 8.85 \times 10^{-12}\ \mathrm{F/m}$

$\mu_0 = 1.26 \times 10^{-6}\ \mathrm{H/m}$

$\sin(A \pm B) = \sin A \cos B \pm \cos A \sin B$

$\cos(A \pm B) = \cos A \cos B \mp \sin A \sin B$

$2\cos A \cos B = \cos(A-B) + \cos(A+B)$

$2\sin A \sin B = \cos(A-B) - \cos(A+B)$

$2\sin A \cos B = \sin(A+B) + \sin(A-B)$

$2\cos A \sin B = \sin(A+B) - \sin(A-B)$

$\sin 2A = 2\sin A \cos A$

$\cos 2A = 2\cos^2 A - 1$

$\cos 2A = 1 - 2\sin^2 A$

$\sin^2(\frac{A}{2}) = \frac{1}{2}(1 - \cos A)$

$\cos^2(\frac{A}{2}) = \frac{1}{2}(1 + \cos A)$

$\sinh x = \frac{1}{2}(e^{x} - e^{-x})$

$\cosh x = \frac{1}{2}(e^{x} + e^{-x})$

$\nabla(\phi + \psi) = \nabla\phi + \nabla\psi$

$\nabla\phi\psi = \phi\nabla\psi + \psi\nabla\phi$

$\nabla \cdot (\mathbf{F} + \mathbf{G}) = \nabla \cdot \mathbf{F} + \nabla \cdot \mathbf{G}$

$\nabla \times (\mathbf{F} + \mathbf{G}) = \nabla \times \mathbf{F} + \nabla \times \mathbf{G}$

$\nabla(\mathbf{F} \cdot \mathbf{G}) = (\mathbf{F} \cdot \nabla)\mathbf{G} + (\mathbf{G} \cdot \nabla)\mathbf{F} + \mathbf{F} \times (\nabla \times \mathbf{G}) + \mathbf{G} \times (\nabla \times \mathbf{F})$

$\nabla \cdot (\phi\mathbf{F}) = \phi(\nabla \cdot \mathbf{F}) + \mathbf{F} \cdot \nabla\phi$

$\nabla \cdot (\mathbf{F} \times \mathbf{G}) = \mathbf{G} \cdot \nabla \times \mathbf{F} - \mathbf{F} \cdot \nabla \times \mathbf{G}$

$\nabla \cdot (\nabla \times \mathbf{F}) = 0$

$\nabla \times (\phi\mathbf{F}) = \phi(\nabla \times \mathbf{F}) + \nabla\phi \times \mathbf{F}$

$\nabla \times (\mathbf{F} \times \mathbf{G}) = \mathbf{F}(\nabla \cdot \mathbf{G}) - \mathbf{G}(\nabla \cdot \mathbf{F}) + (\mathbf{G} \cdot \nabla)\mathbf{F} - (\mathbf{F} \cdot \nabla)\mathbf{G}$

$\nabla \times (\nabla \times \mathbf{F}) = \nabla(\nabla \cdot \mathbf{F}) - \nabla^2\mathbf{F}$

$\nabla \times \nabla\phi = 0$

$\oint_{\mathrm{S}}(\mathbf{F} \cdot \mathbf{n})\, da = \int_{\mathrm{V}}(\nabla \cdot \mathbf{F})\, d^3x$

$\oint_{\mathrm{C}} \mathbf{F} \cdot d\ell = \int_{\mathrm{S}}(\nabla \times \mathbf{F}) \cdot \mathbf{n}\, da$

$\oint_{\mathrm{S}} \phi\mathbf{n}\, da = \int_{\mathrm{V}} \nabla\phi\, d^3x$

$\oint_{\mathrm{S}} \mathbf{F}(\mathbf{G} \cdot \mathbf{n})\, da = \int_{\mathrm{V}}[\mathbf{F}(\nabla \cdot \mathbf{G}) + (\mathbf{G} \cdot \nabla)\mathbf{F}]\, d^3x$

$\oint_{\mathrm{S}}(\mathbf{n} \times \mathbf{F})\, da = \int_{\mathrm{V}}(\nabla \times \mathbf{F})\, d^3x$

2026 Written Qualifying Exam
Equation Sheet

$$nsin(\theta) = n'\sin(\theta')$$

$$\omega = nu$$

$$\rho = \left(\frac{n'-n}{n'+n}\right)^2$$

$$\phi = \phi_1 + \phi_2 - \phi_1\phi_2\tau$$

$$BFD = d' + f_R' \qquad FFD = d + f_F$$

$$OPL = nL$$

$$\delta' = \frac{d'}{n'} = -\frac{\phi_1}{\phi}\tau$$

$$d = t(\frac{n-1}{n})$$

$$\delta = \frac{d}{n} = \frac{\phi_2}{\phi}\tau$$

$$\tau = \frac{t}{n}$$

$$\omega' = \omega - y\phi \qquad n'u' = nu - y\phi$$

$$\phi = \frac{n'-n}{R} = (n'-n)C$$

$$\phi = -\frac{\omega_k'}{y_1} \qquad BFD = -\frac{y_k}{{\omega_k}'}$$

$$\frac{n'}{z'} = \frac{n}{z} + \phi$$

$$y' = y + \omega'\tau' \qquad y' = y + u't'$$

$$f_e = \frac{1}{\phi} = -\frac{f_f}{n} = \frac{f_R'}{n'}$$

$$\text{Sag} \approx \frac{y^2}{2R}$$

$$m = \frac{h'}{h} = \frac{z'/n'}{z/n} = \frac{\omega}{\omega'}$$

$$f/\# = f/D_{EP} \qquad NA = n|\sin(u)|$$

$$f/\#_w = \frac{1}{2NA} \approx (1-m)f/\#$$

$$\overline{m} = \frac{n'}{n}m^2$$

$$MP_{magnifier} = \frac{250\ mm}{f} \qquad MP = \frac{\alpha\prime}{\alpha}$$

$$\frac{\Delta z'/n'}{\Delta z/n} = m_1 m_2$$

$$MP = \frac{1}{m} \qquad MP_t = -\frac{f_{OBJ}}{f_{EYE}}$$

$$P'N' = PN = f_F + {f_R}'$$

$$MP_{r,t} = m_r MP_t = (\frac{z_r'}{z_r})(-\frac{f_{OBJ}}{f_{EYE}})$$

$$H = n\bar{u}y - nu\bar{y}$$

$$m_v = m_{OBJ}MP_{EYE} = \frac{z_{OBJ}'}{z_{OBJ}}\frac{250mm}{f_{EYE}}$$

$$\bar{u} = \tan(\theta_{1/2})$$

$$m_{v,inf} = m_{OBJ}MP_{EYE} = -\frac{f_{TUBE}}{f_{OBJ}}\frac{250mm}{f_{EYE}}$$

$f_{OBJ} = -\frac{OTL}{m_{OBJ}}$ [Finite Tube length]

2026 Written Qualifying Exam
Equation Sheet

$a \geq |y| + |\bar{y}|$ Unvignetted

$$D_{airy} = 2.44\,\lambda f/\#_w = \frac{1.22\lambda}{NA}$$

$a = |\bar{y}|$ and $a \geq |y|$ Half Vignetted

$$DOF = +/- B' f/\#_w$$

$a \leq |\bar{y}| - |y|$ Full Vignetted

$$L_H = \frac{-fD}{B'} \qquad L_{near} = \frac{L_H}{2}$$

$$n = \frac{\sin[(\alpha - \delta_{min})/2]}{\sin\left(\frac{\alpha}{2}\right)}$$

$$\frac{\alpha_1}{\delta} = -\left(\frac{1}{\nu_1 - \nu_2}\right)\left(\frac{\nu_1}{n_{d1} - 1}\right)$$

$$\theta_c = sin^{-1}\left(\frac{n_s}{n_R}\right)$$

$$\frac{\alpha_2}{\delta} = \left(\frac{1}{\nu_1 - \nu_2}\right)\left(\frac{\nu_2}{n_{d2} - 1}\right)$$

$$\delta = -(n-1)\alpha$$

$$\frac{\epsilon_1}{\delta} = \left(\frac{P_1 - P_2}{\nu_1 - \nu_2}\right)$$

$$\nu = \frac{\delta}{\Delta} \qquad P = \frac{\epsilon}{\Delta} \qquad \nu = \frac{n_d - 1}{n_f - n_c} \qquad P = \frac{n_d - n_c}{n_f - n_c}$$

$$\frac{\delta\phi}{\phi} = \frac{\delta f}{f} = \frac{1}{\nu} \qquad \frac{\phi_1}{\phi} = \frac{\nu_1}{\nu_1 - \nu_2} \qquad \frac{\phi_2}{\phi} = \frac{-\nu_2}{\nu_1 - \nu_2}$$

$$TA_{CH} = \frac{r_p}{\nu} \qquad TA_{CH} = \frac{r_p}{\nu}$$

$$\Phi = LA\Omega$$

$$\frac{\delta\phi_{dC}}{\phi} = \frac{\delta f_{Cd}}{f} = \frac{\Delta P}{\Delta\nu}$$

$$\Omega = \frac{A}{d^2}$$

$$E' = \frac{\pi L}{4(1-m)^2(f/\#)^2} = \frac{M}{4(1-m)^2(f/\#)^2}$$