Formula Sheet PHYC/ECE 463 Advanced Optics 1 UNM

Harmonic wave: $E = Re\{E_0 \exp(-i\omega t + ik \cdot r + \phi)\}$ $k = \frac{n\omega}{c} = \frac{2\pi n}{\lambda_0}$; $\frac{1}{\mu_0 \mu \varepsilon_0} = c^2$

Poynting vector $\vec{S} = \frac{1}{\mu_0} \vec{E} \times \vec{B}$ Irradiance $I = \langle S \rangle = \frac{\varepsilon_0 nc}{2} |E_0|^2$

Harmonic waves: $\vec{B} = \frac{1}{\omega} \vec{k} \times \vec{E} = \frac{1}{c} \hat{k} \times \vec{E}$ ($\hat{k}$ unit vector along $\vec{k}$);

Snell: $n_i sin\theta_i = n_t sin\theta_t$ Critical/pol. angles: $sin\theta_C = tan\theta_B = n_2/n_1$

De Broglie Wavelength $\lambda = h/p$

Relativistic Momentum $p = \sqrt{E^2/c^2 - m^2c^2}$

Relativistic Velocity $v = \frac{pc^2}{E} = c\sqrt{1 - m^2c^4/E^2}$

Relativistic mass $m_{rel} = \frac{m}{\sqrt{1 - v^2/c^2}}$ (Photon: $m = 0$)

<u>Huygens</u>: Each point on the surface of a wavefront may be a source of spherical waves, which themselves progress with the speed of light in the medium ($v = c/n$) and whose envelope at a later time constitutes the new wavefront.

<u>Fermat</u>: Light travels between two points along the path that requires the least time,(or extremizes the optical path length), as compared to other nearby paths.

<u>Imaging</u>:

Thin lens (Lens maker) $\frac{1}{f} = \frac{(n_L - n)}{n}\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$

Thin lens $\frac{1}{f} = \frac{1}{s} + \frac{1}{s'}$ (Mirror: $f = -R/2$)

Refraction surface $(n_1 \to n_2)$ $\frac{n_2 - n_1}{R} = \frac{n_1}{s} + \frac{n_2}{s'}$

Sign. Conv.
s, s'>0 (Real)
s, s'>0 (Virtual)
R>0 (convex)
R<0 (concave)

Magnification $|m| = \left|\frac{h'}{h}\right|$; $m = \frac{-s'}{s}$

Interface $(n_1 \to n_2)$ $m = -n_1 s'/n_2 s$

Angular mag. $|m| = \left|\frac{\alpha_M}{\alpha_{unaided}}\right| = \left|\frac{np}{s}\right|$

2-Lens system (L) $\frac{1}{f_{eff}} = \frac{1}{f_1} + \frac{1}{f_2} - \frac{L}{f_1 f_2}$

Achromatic Doublet $f_1 V_1 + f_2 V_1 = 0$

$V = \frac{n_d - 1}{n_f - n_c}$ (Abbe number)

ABCD matrices $\begin{pmatrix} A & B \\ C & D \end{pmatrix}$ (det[.]=1) $\begin{pmatrix} r_2 \\ r_2' \end{pmatrix} = \begin{pmatrix} A & B \\ C & D \end{pmatrix} \begin{pmatrix} r_1 \\ r_1' \end{pmatrix}$

Paraxial ray tracing matrices. (ABCD MATRICES)

Thin lens (mirror R) $\begin{pmatrix} 1 & 0 \\ -\frac{1}{f} & 1 \end{pmatrix}$

Interface $n \to n'$ $\begin{pmatrix} 1 & 0 \\ 0 & \frac{n}{n'} \end{pmatrix}$

Propagation $\begin{pmatrix} 1 & d \\ 0 & 1 \end{pmatrix}$

Refractive surface $n \to n'$ $\begin{pmatrix} 1 & 0 \\ \frac{n - n'}{n'R} & \frac{n}{n'} \end{pmatrix}$ R>0 (convex) R<0 (concave)

Cavity s-round trip

$r_s = \frac{1}{sin\theta}\{[Asin(N\theta) - \sin(N-1)\,\theta]r_0 + B\sin(N\theta)\,r_0'\}$

$$-1 \le cos\theta = (A+D)/2 \le 1$$

GRIN system

Refractive index

$n(r) \approx n_0[1 - r^2/2l^2\,]$

r.- distance from OA

l.- rate of change of n

ABCD

$$\begin{pmatrix} \cos(d/l) & l\sin(d/l) \\ -1/l\ \sin(d/l) & \cos(d/l) \end{pmatrix}$$

d.- prop distance

Trigonometry

$\sin^2\theta + \cos^2\theta = 1$

$\sin(a+b) = \sin(a)\cos(b) + \cos(a)\sin(b)$

$\cos(a+b) = \cos(a)\cos(b) - \sin(a)\sin(b)$

$\cos 2\theta = 1 - 2\sin^2\theta;\quad \sin 2\theta = 2\sin\theta\cos\theta$

$\sin\theta = \cos(\pi/2 - \theta);\quad \cos\theta = \sin(\pi/2 - \theta)$

$\tan\theta = \dfrac{\sin\theta}{\cos\theta} = \dfrac{1}{\cot\theta}$

Physical Constants

c=2.998 $\times 10^{8}$ m·s^{-1}	h=6.63 $\times 10^{-34}$ J·s	e=1.6 $\times 10^{-19}$ C
k_B=1.380 $\times 10^{-23}$ J·K^{-1}	ε_0=8.85$\times 10^{-12}$ F/m	m_e=9.1 $\times 10^{-31}$ kg

1G = 10^{-4} T, 1 eV = 1.602 x 10^{-19} J, 1 dyne = 10^{-5} N, 1 erg = 10^{-7} J

Near distance (near point) of normal eye: 250 mm

Prism with apex angle α and minimum deviation angle: $n = \dfrac{\sin\left(\dfrac{\alpha+\delta}{2}\right)}{\sin\left(\dfrac{\alpha}{2}\right)}$

(Dispersive power)

$\Delta = \dfrac{D}{\delta} = \dfrac{n_f - n_c}{n_d - 1}$

D: dispersion

δ: deviation

Numerical aperture for fiber $n_0\sin(\theta_{\max}) = \sqrt{{n_f}^2 - {n_c}^2}$: f# (f-number) = f/D