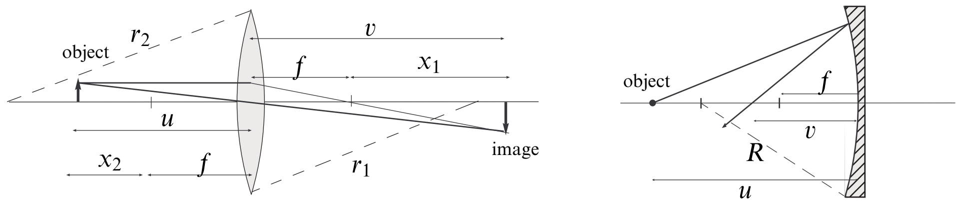
8.5 Geometrical optics

Lenses and mirrors[a]



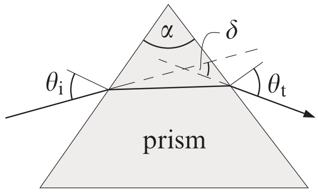
lens mirror

	sign convention	
	+	−
r	centred to right	centred to left
u	real object	virtual object
v	real image	virtual image
f	converging lens/ concave mirror	diverging lens/ convex mirror
M_T	erect image	inverted image

Fermat's principle[b]	$L=\int \eta\,\mathrm{d}l$ is stationary	(8.63)	L optical path length; η refractive index; $\mathrm{d}l$ ray path element
Gauss's lens formula	$\frac{1}{u}+\frac{1}{v}=\frac{1}{f}$	(8.64)	u object distance; v image distance; f focal length
Newton's lens formula	$x_1x_2=f^2$	(8.65)	x_1 $=v-f$; x_2 $=u-f$
Lensmaker's formula	$\frac{1}{u}+\frac{1}{v}=(\eta-1)\left(\frac{1}{r_1}-\frac{1}{r_2}\right)$	(8.66)	r_i radii of curvature of lens surfaces
Mirror formula[c]	$\frac{1}{u}+\frac{1}{v}=-\frac{2}{R}=\frac{1}{f}$	(8.67)	R mirror radius of curvature
Dioptre number	$D=\frac{1}{f}$ m^{-1}	(8.68)	D dioptre number (f in metres)
Focal ratio[d]	$n=\frac{f}{d}$	(8.69)	n focal ratio; d lens or mirror diameter
Transverse linear magnification	$M_T=-\frac{v}{u}$	(8.70)	M_T transverse magnification
Longitudinal linear magnification	$M_L=-M_T^2$	(8.71)	M_L longitudinal magnification

[a] Formulas assume "Gaussian optics," i.e., all lenses are thin and all angles small. Light enters from the left.
[b] A stationary optical path length has, to first order, a length identical to that of adjacent paths.
[c] The mirror is concave if $R<0$, convex if $R>0$.
[d] Or "f-number," written $f/2$ if $n=2$ etc.

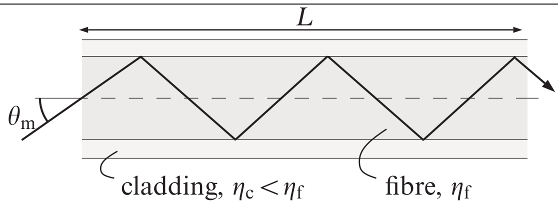
Prisms (dispersing)



Transmission angle	$\sin\theta_t = (\eta^2 - \sin^2\theta_i)^{1/2}\sin\alpha - \sin\theta_i\cos\alpha$	(8.72)	θ_i angle of incidence θ_t angle of transmission α apex angle η refractive index
Deviation	$\delta = \theta_i + \theta_t - \alpha$	(8.73)	δ angle of deviation
Minimum deviation condition	$\sin\theta_i = \sin\theta_t = \eta\sin\frac{\alpha}{2}$	(8.74)	
Refractive index	$\eta = \frac{\sin[(\delta_m + \alpha)/2]}{\sin(\alpha/2)}$	(8.75)	δ_m minimum deviation
Angular dispersion[a]	$D = \frac{d\delta}{d\lambda} = \frac{2\sin(\alpha/2)}{\cos[(\delta_m+\alpha)/2]}\frac{d\eta}{d\lambda}$	(8.76)	D dispersion λ wavelength

[a] At minimum deviation.

Optical fibres



Acceptance angle	$\sin\theta_m = \frac{1}{\eta_0}(\eta_f^2 - \eta_c^2)^{1/2}$	(8.77)	θ_m maximum angle of incidence η_0 exterior refractive index η_f fibre refractive index η_c cladding refractive index
Numerical aperture	$N = \eta_0 \sin\theta_m$	(8.78)	N numerical aperture
Multimode dispersion[a]	$\frac{\Delta t}{L} = \frac{\eta_f}{c}\left(\frac{\eta_f}{\eta_c} - 1\right)$	(8.79)	Δt temporal dispersion L fibre length c speed of light

[a] Of a pulse with a given wavelength, caused by the range of incident angles up to θ_m. Sometimes called "intermodal dispersion" or "modal dispersion."