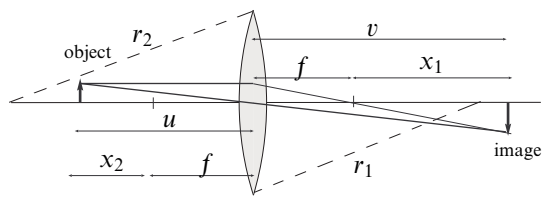
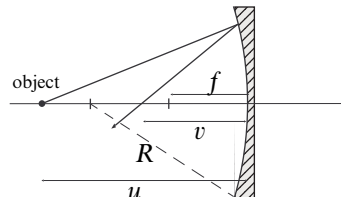


8.5 Geometrical optics

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	$L = \int \eta \, dl$ is stationary	(8.63)	L optical path length
			η refractive index
			dl 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	$x_1 x_2 = f^2$	(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	$D = \frac{1}{f} \quad \text{m}^{-1}$	(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

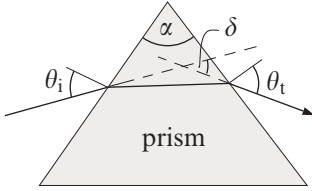
^aFormulas assume “Gaussian optics,” i.e., all lenses are thin and all angles small. Light enters from the left.

^bA stationary optical path length has, to first order, a length identical to that of adjacent paths.

^cThe mirror is concave if $R < 0$, convex if $R > 0$.

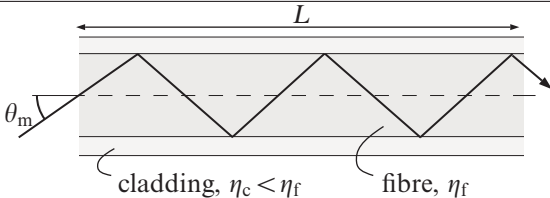
^dOr “ f -number,” written $f/2$ if $n = 2$ etc.

Prisms (dispersing)

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

^aAt minimum deviation.

Optical fibres

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

^aOf a pulse with a given wavelength, caused by the range of incident angles up to θ_m . Sometimes called “intermodal dispersion” or “modal dispersion.”