ELECTROMAGNETIC WAVES

DEFINITION OF EM-WAVES

- The electric and magnetic field produced with an LC oscillator connected to an antenna in the z direction can be described with wave equations (at large distances):
  $E = E_m \sin(kx - \omega t)$ and $B = B_m \sin(kx - \omega t)$.
- The electric and magnetic fields are always perpendicular to the direction of travel. It is a transverse wave. The electric field is always perpendicular to the magnetic field.
- The cross product $\vec{E} \times \vec{B}$ always gives the direction of the wave. The electric and the magnetic field are in phase and vary with the same frequency.
- The speed of all electromagnetic waves is given by: $c = 1/\sqrt{\mu_0 \epsilon_0}$, $E_m/B_m = c$, $c = 299,792,458 m/s$.
- The rate of energy transport per unit area is called the pointing vector and is given by: $S = \vec{E} \times \vec{B}/\mu_0$, $S = E^2/(c\mu_0)$.
- The intensity of the wave is defined as $I = \bar{S} = E_{rms}^2/(c\mu_0)$, where E_{rms} is the root-mean-square value of the electric field: $E_{rms} = E_m/\sqrt{2}$. The intensity as a function of distance from the source is given by: $I = P_s/(4\pi r^2)$, where P_s is the power emitted by the source.
- The radiation pressure of a wave is defined as $P_r = I/c$ for total absorption and $P_r = 2I/c$ for total reflection.

POLARIZATION

- The electric field component of a wave parallel to the polarizing direction of a polarizer is passed (transmitted) by the polarizer, the component perpendicular to it is absorbed.
- The intensity of an unpolarized wave after a polarizer is reduced by a factor of 2: $I = I_0/2$.
- The intensity of a polarized wave going through a polarizer is given by $I = I_0 \cos^2\theta$, where θ is the angle between the polarization direction of the wave and the polarizer.

REFLECTION AND REFRACTION

- For electromagnetic waves reflected off surfaces the law of reflection is valid: $\theta_i = \theta_r$ where the incident i and reflected r ray (wave) is measured with respect to the normal of the surface.
- For transparent materials the wave is refracted: $n_1 \sin\theta_1 = n_2 \sin\theta_2$, where n is called the index of refraction for a given material, and 1 and 2 correspond to the incoming and refracted ray, respectively.
- When light (em-wave) travels from an optical denser medium into an optical less dens medium all of the light is reflected at the boundary between the two media when the incoming angle is larger than a critical angle θ_c: $\sin\theta_c = n_2/n_1$,($n_1 > n_2$).
- Reflected and refracted light is partially polarized. For a certain angle the reflected light is completely polarized (Brewster angle): $\tan\theta_B = n_2/n_1$.

GEOMETRIC OPTICS

MIRRORS

- The object distance p is located in front of the mirror. Plane mirrors form a *virtual* image behind the mirror at a distance i (= image distance). The mirror image is upright: $p = -i$.
- The magnification m is defined as the ratio of the image height h_i over the object height h_o: $|m| = h_i/h_o$ and is also given by $m = -i/p$. The magnification of a plane mirror is one.
- All spherical mirrors have focal points. The focal length is given by $f = r/2$, where r is the radius of curvature of the mirror.
- The mirror equation relates the focal length, object and image distances: $1/f = 1/p + 1/i$.
  Real images are always on the same side of the mirror as the object.

LENSES

- Symmetric spherical lenses have two symmetrically positioned focal points, one on each side. The distance between the center plane of the lens and the focal point is the focal length, f.
- The mirror equation is also valid for thin lenses: $1/f = 1/o + 1/i$,
  and the magnification is also $m = -i/o$.
  Real images are always formed on the other side of the lens as the object.
- For lenses with two different curvatures on both sides the focal length can be calculated with the lens makers equation: $1/f = (n-1)(1/r_1 - 1/r_2)$. When the object faces a convex refracting surface r is positive. When it faces a concave surface it r is negative.
- For a system of several lenses (or mirrors) the total magnification is given by the product of the individual magnifications: $M = m_1 m_2 m_3 ...$

MIRRORS AND SINGLE LENSES

Thin Lenses		diverging	converging			
Location	Object o (all +)	any value	o<f	2f>o>f	o=2f	o>2f
	Image i	$\lvert i \rvert < \lvert f \rvert$	any value	i > 2f	i=2f	2f>i>f
Image type	relative size	smaller	bigger	bigger	equal	smaller
	real/virtual	virtual	virtual	real	real	real
	erect/inverted	erect	erect	inverted	inverted	inverted
Signs	focal length f	−	+	+	+	+
	image position	−	−	+	+	+
	magnification	+	+	−	−	−
Spherical Mirrors		convex	concave			