Foundations in Quantum Optics – Modern Optics
PHY485/1485F
University of Toronto
Problem Set #3

4 November 2008 — due: 18 November 2008

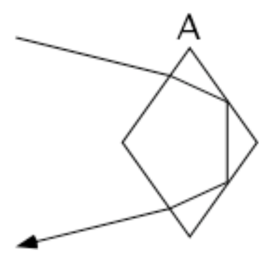
1. *Polarization changers*
   a) Hecht Q 8.48
   b) Hecht Q 8.65

2. *Reflections*
   a) Hecht Q 4.55
   b) Hecht Q 4.56
   c) Hecht Q 4.61

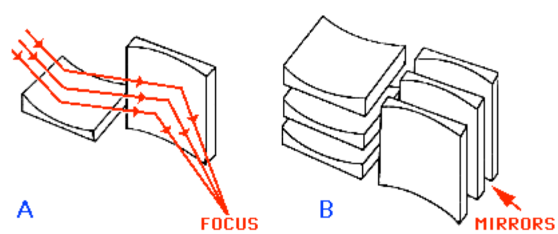
3. *Mooney rhomb*

   At right is a diagram of a Mooney rhomb, which is used to produce circularly polarized light, following relative phase changes produced by total internal reflection. Take an index of refraction n=1.65 for the glass of this rhomb. Show that the apex angle A of should be designed to be about 60 degrees. You may find some interest (this is not a hint) in this paper:

   http://www.iop.org/EJ/article/1464-4258/6/4/020/joa4_4_020.pdf



4. *X-ray mirrors*— Certain kinds of microscope work in the x-ray range by using grazing-incidence mirrors. The figure at right shows a basic Kirkpatrick-Baez microscope together with a variant that increases collection efficiency.



   These depend on the dielectric function of a metal:

$$\frac{\varepsilon(\omega)}{\varepsilon_0} = 1 - \frac{\omega_p^2}{\omega^2 + i\omega\nu}$$

   where ω is the frequency of light or x-rays, ω_p is the plasma frequency:

$$\omega_p = \sqrt{\frac{N_e e^2}{m\varepsilon_o}}$$

   and ν is the collision frequency of electrons in the metal. N_e is the electron density, e is the charge of an electron, and m is the mass of an electron. Typical plasma frequencies in a metal are roughly 10^{15} s^{-1}, around the frequency of visible and near-ultraviolet; typical collision frequencies are on the order of 10^{15} s^{-1}, about the same as infrared light.

   The Fresnel formulae we derived in class still applies, although the index of refraction and transmitted angles become complex-valued (Ref: Fowles § 6.6).

[question continues on next page…]

a) Show that for electromagnetic radiation above a certain frequency, it becomes possible to produce something approximating *total internal reflection* on going from vacuum into a metal, *i.e.*, that though the metal is more dense physically, it is less dense optically. Note that absorption makes this imperfect (how imperfect?).

b) For x-rays of energy 10 keV, what angle of incidence is necessary to make a good reflector of the type above?

c) At what angle should a flat metal mirror be set in order to reflect only extreme-ultraviolet radiation of energy below 50eV? This can be used to make a sort of low-pass filter.

Formation of Optical Images by X-rays, Journal of the Optic Society of America, 38 (1948) 766, P. Kirkpatrick and A. V. Baez

[NB: be prepared to approximate equations appropriately, using series expansions, or to solve by computer-plotting.]

5. *Thick lens formula*

In class, we determined the focal length of a very thin lens, assuming its thickness was essentially zero. Show using ray matrix methods that the focal length of a lens of thickness d is:

$$\frac{1}{f} = (n-1)\left\{\frac{1}{R_1} - \frac{1}{R_2} + \frac{(n-1)d}{nR_1R_2}\right\}$$

Show that the A, B, and D elements of the ray matrix are also not their ideal values of 1, 0, and 1.