Physics 485/1485F
Modern Optics
Department of Physics
University of Toronto

Midterm Test, 22 October 2007

STUDENT-SUPPLIED AID SHEET
(hand-prepared, one side 8 1/2" x 11")
NON-PROGRAMMABLE CALCULATOR
DO ALL FOUR QUESTIONS
DURATION OF TEST: 2 HOURS

[20] 1) Define these terms, and explain as succinctly as possible (usually three sentences or less) the meaning *and* significance of each of the following, in an optics context:

- i) electric susceptibility
- ii) optical activity and birefringence
- iii) frequency-chirped pulse
- iv) Jones calculus

[30] 2) *Origin of the index of refraction*

In essay format, no more than 3 pages, describe how the index of refraction is a natural expression of the effect of matter on a propagating lightwave. You should make use of the Lorentz model, and include the effect of the lightwave that a driven charge-oscillation must radiate. In terms of this model, describe the connection between the real and imaginary parts of the index of refraction, and also the change of the real index around an absorption frequency.

[30] 3) *Dispersion in a plasma*

An ionized gas or plasma is a dispersive medium for EM-waves. The dispersion relation is

$$\omega^2 = \omega_p^2 + c^2 k^2$$

a) Find expressions for the phase and group velocity. Show that the product of these two velocities is c^2.

Consider a uniform plasma having a density such that the plasma frequency is the frequency of green light with vacuum wavelength λ_0 = 500 nm.

b) For light with wavelength λ_0 = 250 nm, solve for the propagation constant. What is the nature of propagation for such light? Explain, giving wavelength in the plasma or other useful scalelengths.

c) Repeat (b) above, for light of wavelength λ_0 = 500 nm.

d) Repeat (b) above, for light of wavelength λ_0 = 750 nm.

e) A transform-limited pulse of centre-wavelength λ_0 = 400 nm and duration 50 fs (1 femtosecond = 10^{-15} s) is incident on a 2cm-thick layer of this plasma. Ignoring intensity changes from reflection, what effect does this plasma have on the transmitted pulse? Describe qualitatively, and give quantitative estimates (at least) of the changes.

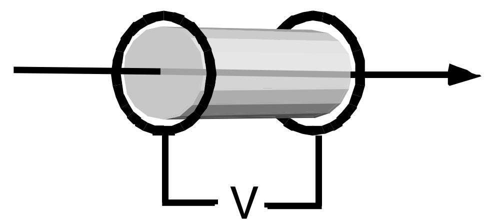
(Question 4 follows on next page…)

[30] 4) *Birefringence*

We discussed in class how a birefringent waveplate works, and gave specific examples of the quarter-wave plate, and the half-wave plate.

a) Describe in words the quarter-wave plate and the half-wave plate: the construction or principles of each, and how to rotate the plane of linearly polarized light through an arbitrary angle θ. Repeat your description of how to rotate the polarization, this time using the Jones calculus.

In the *Pockels effect*, a crystal can be made birefringent by the application of a strong electric field. The index of refraction associated with polarization along one direction increases by an amount proportional to the applied field. For one kind of crystal the electric field is applied longitudinally (*i.e.,* along the direction of propagation), and the index for one transverse direction changes as:



$$\Delta n = n_0^3 r_{63} E$$

where n_0 is the unperturbed index of refraction of the crystal, and r_{63} is the *electro-optic constant* (for the crystal KD*P this value is $r_{63} = 23.3 \times 10^{-12}$ m/V, and $n_0 = 1.52$).

b) Find a formula for the relative phase-change $\Delta\phi$ as a function of voltage V applied along a crystal of length L. Describe how to set up two polarizers and a waveplate in such a way that an optical shutter is created. What length and voltage must be used to create a fully transmitting shutter?

[110] TOTAL