EE119 Introduction to Optical Engineering

Spring 2010

Midterm Exam

Name: Solutions

Signature: ____________________

SID: ____________________

CLOSED BOOK. ONE 8 1/2" X 11" SHEET OF NOTES, AND SCIENTIFIC POCKET CALCULATOR PERMITTED.

TIME ALLOTTED: 80 MINUTES

Fundamental constants you might need:

Planck's constant, $h = 6.62 \times 10^{-34}$ J-s

Permittivity of free space, $\varepsilon_o = 8.85 \times 10^{-12}$ F/m

Permeability of free space, $\mu_o = 1.26 \times 10^{-6}$ H/m

Speed of light in vacuum, $c = 2.998 \times 10^{8}$ m/s

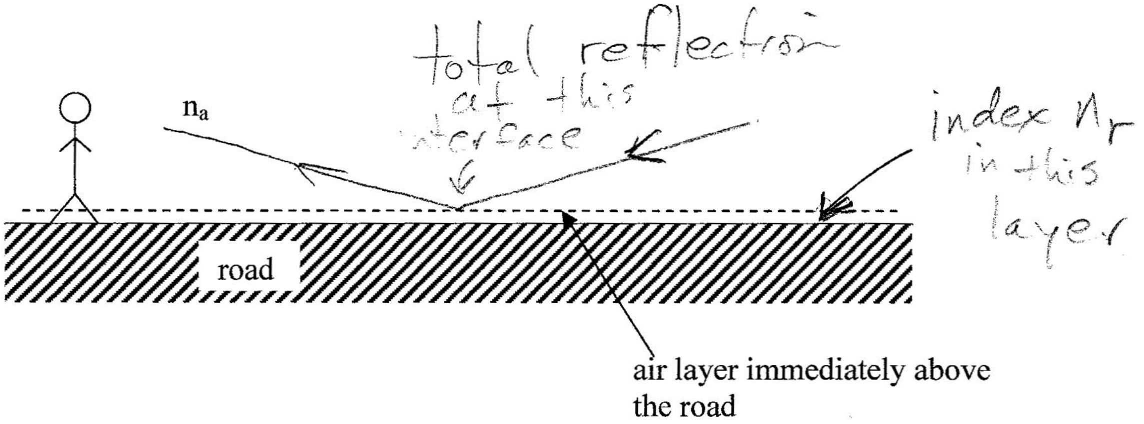
Electron charge, $e = 1.6 \times 10^{-19}$ C

Free electron mass, $m_o = 9.1 \times 10^{-31}$ kg

Electron volt, 1 eV $= 1.6 \times 10^{-19}$ J

1) **[20 points total]** Ray tracing

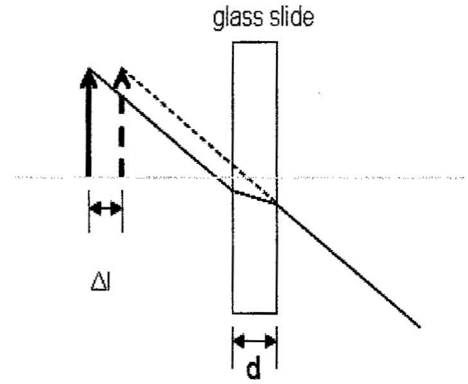
a) **[10 points]** Consider the common mirage associated with an inhomogeneous distribution of air situated above a warm roadway. Envision the bending of the rays as if it were instead a problem in total internal reflection. If an observer, at whose head the air index is n_a=1.00029, sees an apparent wet spot at $\theta_i \geq 88.7°$ down the road, find the index of the air layer (out to five decimal places) immediately above the road.

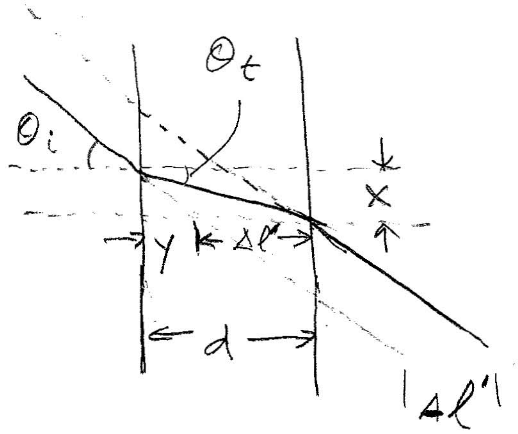


$$\sin\theta_i = \frac{n_r}{n_a}$$

$$n_r = n_a \sin\theta_i = \underline{1.000033}$$

b) **[10 points]** Using Snell's law of refraction, show that an object viewed through a glass slide of a certain thickness appears closer, and the shift in distance is $\Delta l' = d(1 - \frac{1}{n})$, in which d is the thickness of the glass slide and n is its refractive index. You can use a small angle approximation.





$\sin\theta_i = n \sin\theta_t$

$\theta_i = n\theta_t$ for small angles

$x = d\theta_t$

$y = x/\theta_i$

$\rightarrow y = \frac{d\theta_t}{\theta_i} = \frac{d}{n}$

$\Delta l' = d - y = d(1 - \frac{1}{n})$

2) **[15 points total]** A near-sighted person wears -2D lenses to correct her vision. It is known that at her age, the amount of accommodation of her eyes is 8D.

a) **[5 points]** What is the far point for her eyes before vision correction (without any glasses)?

b) **[5 points]** What is the near point for her eyes before vision correction (without any glasses)?

c) **[5 points]** If she wears -1D lenses which do not fully correct her vision, now what is the far point and near point?

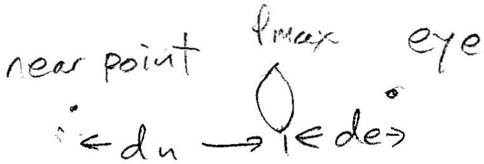
a) $d_1 = -\infty, \quad f = \frac{1}{-2}$

$$\frac{1}{d_2} = \frac{1}{f} + \frac{1}{d_1} = -2$$

$$d_2 = -\frac{1}{2} m = \underline{-0.5 m}$$

b)

$$\frac{1}{de} = \frac{1}{df} + P_{min}$$



$$\frac{1}{de} = \frac{1}{dn} + P_{max}$$

$$\frac{1}{df} - \frac{1}{dn} = P_{max} - P_{min}$$

$$-2 - \frac{1}{dn} = 8$$

$$dn = \underline{-0.1 m}$$

c) With -1D lens, she still needs -1D correction.

Similar to a) $d_f = -1 m$ (far point)

Similar to b) $\frac{1}{df} - \frac{1}{dn} = 8 \rightarrow \frac{1}{dn} = -1 - 8$

$$dn = -\frac{1}{9} m$$

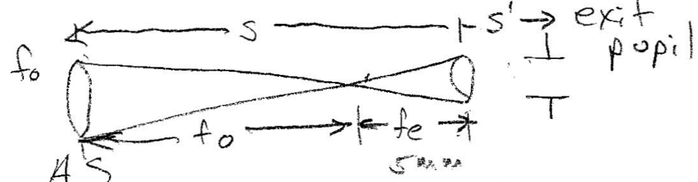
3) **[25 points total]** A set of binoculars has a total magnification of 20. The objective lenses have a clear aperture of 25 mm. The focal length of the eyepieces is 5 mm. These binoculars use a Newtonian telescope configuration.

a) **[5 points]** What is the distance from the objective lens to the eyepiece?

b) **[5 points]** Assuming that the objective lens itself is the aperture stop, give the location and diameter of the exit pupil.

c) **[5 points]** Make a sketch of the system (only one side of the binocular pair need be shown) clearly showing the locations of the objective lens, eyepiece lens, aperture stop, and exit pupil.

d) **[10 points]** The California Lottery has a very bright sign on the San Francisco waterfront near the Bay Bridge advertising the latest SuperLotto jackpot. The numbers on the sign are 10 feet high. From the Berkeley hills, the sign is 10 miles away (1 mile = 5280 feet). With your normal vision, using these binoculars can you read the sign from that distance? (Be sure to consider all relevant factors and thoroughly justify your answer.)



a) $M = f_o/f_e = 20 \rightarrow f_o = 100$ mm

total distance is $f_o + f_e = 105$ mm

b) $\frac{1}{s'} - \frac{1}{s} = \frac{1}{f_e}$ exit pupil is image of AS

$f_e = 5$ mm $s = -105$ mm

$\therefore s' = 5.25$ mm

$M = \frac{s'}{s} = -\frac{5.25}{105}$

exit pupil size is $M \cdot 25\text{mm} = 1.25$ mm

c) See above

d) the angular size of the letter (full height) is:

$\frac{10'}{52,800'} = 1.89 \times 10^{-4}$ rad

the diffraction limit is

$\alpha_T = 5.5/CA_o$ α_T in arcsec, CA_o in inches

CA_o is 1 inch, $\rightarrow \alpha_T = 5.5$ arcsec $= 2.67 \times 10^{-5}$ rad

→ diffraction is not a problem

The eye can resolve 60 arcsec $= 2.9 \times 10^{-4}$ rad

The binoculars have $M = 20$, so using them, the resolution of the eye is 1.45×10^{-5} rad, much smaller than the letters. You can read the sign.

4) Photographic camera **[10 points total]**

a) **[5 points]** The size of a standard 35 mm negative is actually 25×36 mm^2. If you use a 100 mm focal length lens, what would be the field of view at a distance of 10 m?

b) **[5 points]** Suppose you take a picture of a group of your friends standing at this distance of 10 m, with a lens opening of *f*/4 and shutter speed of 1/250 sec. Now you change the opening to *f*/8. What shutter speed should you use to keep the same exposure? What happens to the depth of focus in your picture?

a) Magnification is approximately $\frac{10\ m}{.1m} = 100$

field size is then 2500mm × 3600 mm

$= 2.5 m \times 3.6 m$

b) lens is stopped down by 2 stops.

Shutter needs to be slowed down 2 stops to

1/60

5) **[15 points total]** Intel just took delivery of a new wafer stepper. The system projects and demagnifies by a factor of 4 the circuit pattern from a mask to create an image on the photoresist coated silicon wafer. The system NA at the output (wafer) side is 0.8, and the wavelength of operation is 193 nm.

a) **[5 points]** What is the NA at the mask side?

b) **[5 points]** What is the smallest feature that the stepper can create on a chip according to Rayleigh's criterion?

c) **[5 points]** What is the corresponding resolution at the mask side?

a) $\frac{NA_{object}}{NA_{image}} = M = \frac{1}{4}$ $\quad NA_{object} = \frac{NA_{image}}{4} = \underline{0.2}$

b) $h = \frac{0.6\lambda}{NA_{image}} = 145\ nm$

c) $h_{mask} = 145nm \cdot 4 = 579\ nm$