EE119 Introduction to Optical Engineering
Midterm Exam Spring 2004

Name: Solutions

SID: _____

CLOSED BOOK. ONE 8 1/2" X 11" SHEETS 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

Boltzmann's constant, $k = 1.38 \times 10^{-23}$ J/K

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. Multiple choice questions. Circle one answer for each question. Each question is worth 2 points.

A) At Brewster's angle, the reflected light is
   a) Brewsterized
   b) partially polarized
   c) completely polarized
   d) zero due to the full transmission at the interface

B) Which one of the following radiation beams will travel the faster than the others in a quartz block?
   a) $\lambda = 633$ nm
   b) E = 7 eV
   c) f = 428 THz $\quad -\lambda = 701\,nm$
   d) All of the above will have the same speed in a quartz block.

C) For light traveling from $n_1 = 1.45$ to $n_2 = 1.35$, the critical angle (for total reflection) at the interface is
   a) $\theta_C = 43.0°$
   b) $\theta_C = 47.0°$
   c) $\theta_C = 68.6°$
   d) does not exist

$$\theta_c = \sin^{-1}\left(\frac{n_2}{n_1}\right) = 68.6°$$

D) Light travels in a direction
   a) parallel to the wavefront
   b) perpendicular to the wavefront
   c) tangential to the wavefront
   d) opposite to the wavefront

E) For light traveling from $n_1 = 1.35$ to $n_2 = 1.45$, the polarizing (or Brewster) angle at the interface is
   a) $\theta_C = 43.0°$
   b) $\theta_C = 47.0°$
   c) $\theta_C = 68.6°$
   d) does not exist

$$\theta_B = \tan^{-1}\left(\frac{n_2}{n_1}\right) = 47°$$

F) Right-circularly polarized light passes through a half-wave plate. What is the polarization of the light emerging from the half-wave plate? (Hint: A half-wave plate introduces 180° phase difference between the two orthogonal polarization components, e-ray and o-ray.)
   a) Right-circularly polarized
   b) Left-circularly polarized
   c) Linearly polarized
   d) Elliptically polarized

G) Light traveling in air is incident on a glass surface (n=1.5) at near-normal incidence ($\theta_i = 1°$). Which of the following is true? 'R' stands for intensity-reflection coefficient.
   a) R(s-polarization) ~ 0% and R(p-polarization) ~ 0%
   b) R(s-polarization) ~ 4% and R(p-polarization) ~ 0%
   c) R(s-polarization) ~ 4% and R(p-polarization) ~ 4%
   d) R(s-polarization) ~ 25% and R(p-polarization) ~ 25%

H) Two perfect linear polarizers are placed one behind the other with the their transmission axes orthogonal to each other, such that there is zero transmission through the pair. Suppose that another polarizer is then inserted between these two with its transmission axis at 45°. If our light source is unpolarized with intensity I_0, the light emerging through all three polarizers has an intensity of
   a) 0
   b) $0.25 \cdot I_0$

c) $0.125 \cdot I_0$
d) $0.707 \cdot I_0$

I) How does a half-wave plate introduce a 180° phase delay between the two orthogonal polarization components (e-ray and o-ray) that travel through it?
a) The half-wave plate continuously rotates at 180 rpm (revolutions per minute).
b) e-ray and o-ray experience different refractive indices inside the half-wave plate.
c) The half-wave plate is cleaved at the Brewster's angle, making it hard for o-ray to pass through it.
d) The half-wave plate is a combination of two linearly polarizers overlapped at 45°, making it hard for e-ray to pass through it.

J) Which prism can separate the two orthogonal polarization components, e-ray and o-ray?
a) Porro prism
b) Schmidt prism
c) Nicol prism
d) Pellin-Broca prism

K) Which one of the following statements about thick-lens systems is correct?
a) Intersecting the optical axis at 90°, principal planes run through the points where the curved lens surfaces end.
b) Once the principal planes are defined, the Gaussian lens law can be applied.
c) The first principle point must be closer to the object than the second principle point .
d) Back-focal-length is measured from the second focal point to the second principal plane.

L) What is the correct definition of wavefront?
a) Surface of constant wavelength
b) Surface of constant phase
c) Surface of constant intensity
d) Surface of constant illumination

M) Which is the correct description of Rayleigh's criterion?
a) Two spots are resolved if the first minimum of the pattern from one point falls on the first minimum of the other.
b) Two spots are resolved if the maximum of the pattern from one point falls on the first minimum of the other.
c) Two spots are resolved if the maximum of the pattern from one point is at least 0.61λ away from the first minimum of the other.
d) Two spots are resolved if the first minimum of the pattern from one point is at least 0.61λ away from the first minimum of the other.

N) An imaging system has a numerical aperture (NA) of 0.2 at the object side. If the system's magnification M = -4, what is its numerical aperture at the image side?
a) 0.8
b) 0.05
c) 0.4
d) -0.05

O) Which one of the following statements is correct?
a) Rods are most sensitive to light, but they do not sense color.
b) Rods do not sense color, but they sense motion.
c) We have more cones than rods in our eyes.
d) Cones and rods are very similar to each other. They just differ in size.

P) For 20/20 vision, the minimum element that a person can resolve at 20 ft is

a) 1 mm
b) 75 μm
c) 1.8 mm
d) 10^{-3} ft.

Q) Which one of the following statements is correct?
a) Rods are highly concentrated in fovea.
b) The cornea is the only element that provides the focusing power.
c) The fovea becomes a blind spot in the dark because it has only cones.
d) Rods are much more sensitive to light than cones because rods are much bigger than cones, thereby accepting more photons.

R) Which one of the following patients needs to find a better doctor?
a) A patient with myopia who has received a pair of negative lenses
b) A patient with hyperopia who has received a pair of positive lenses
c) A patient with hyperopia who has received a pair of negative lenses
d) A patient with astigmatism who has received a pair of cylindrical lenses

S) In terms of photographic film exposure using a camera, which one is equivalent to (S=125, f/4)?
a) S=250, f/5.6
b) S=64, f/5.6
c) S=64, f/8
d) S=500, f/2.8

T) In order to increase the depth of focus, what do you do?
a) Increase the diameter of the aperture stop
b) Underexpose the film
c) Overexpose the film
d) Increase the F-number (or F-stop)

U) What does an "afocal" system mean?
a) Both object and image are at infinity
b) Only object is at infinity
c) Only image is at infinity
d) A system with no focal point

V) Which of the following is true?
a) For a positive lens forming a real image, if the object moves closer to the lens, the image moves closer to the lens.
b) For a positive lens forming a virtual image, if the object moves closer to the lens, the image moves closer to the lens.
c) For a negative lens forming a virtual image, if the object moves closer to the lens, the image moves farther from the lens.
d) For an imaging system with a magnification of -10, if the object moves closer to the lens by 1 mm, the image will move farther from the lens by 10 mm.

W) Consider a thin, spherical plano-convex lens having a radius of curvature of 50.0mm and an index of 1.5. What is it's focal length in air?
a) 75 mm
b) 50 mm
c) 25 mm
d) 100 mm

X) Rambo's aging mother has her far point at 2 m. Her eyeball is 2.5 cm long, but the overall power is not known. What lens power (in diopters) is needed to correct her vision?
a) 1.0 D

b) -1.5 D
c) -0.5D
d) 2.0 D

Y) A compound microscope has magnification of 400. The microscope has standardized tube-length, and a 100X objective lens with NA=0.75. What is the focal length of the objective lens?
a) 1.6 mm
b) 1.6 cm
c) 1 cm
d) 0.8 mm

2. Aberration [total 25 points].

A) A perfect spherical wavefront at the exit pupil of an imaging system is pictured in Figure 2A with a radius of curvature of 4cm. Sketch the rays and show the position of the focus. Be precise and show 5 rays: the chief ray, two marginal rays, and one ray one each side that is intermediate between the chief and the marginal ray. [5 points]

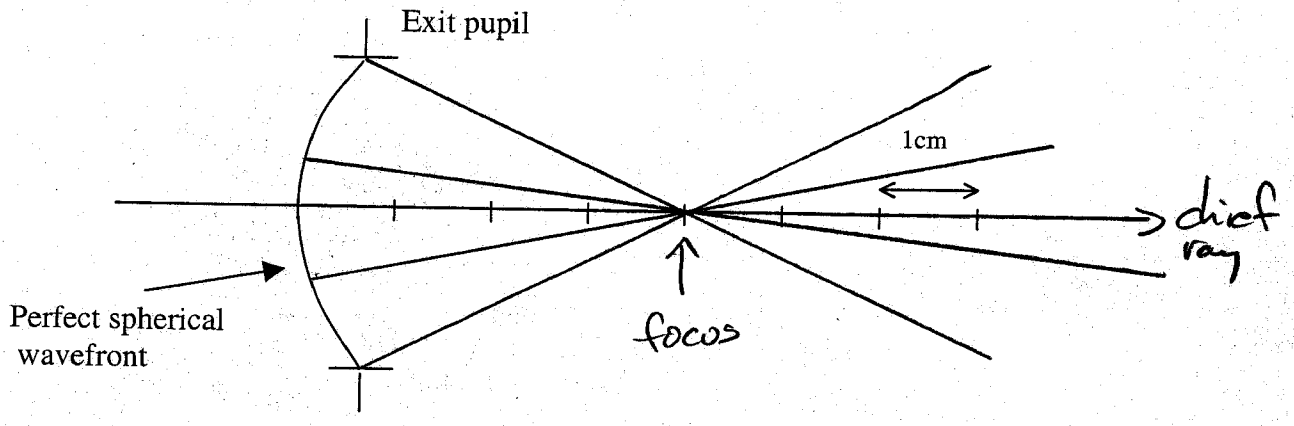

Figure 2A

B) Consider the dotted wavefront in Figure 2B, which is a tilted version of the perfect wavefront described in part A). Sketch the same 5 rays for the dotted line and show the position of the focus. Assume the tilt angle is 10degrees. [10 points]

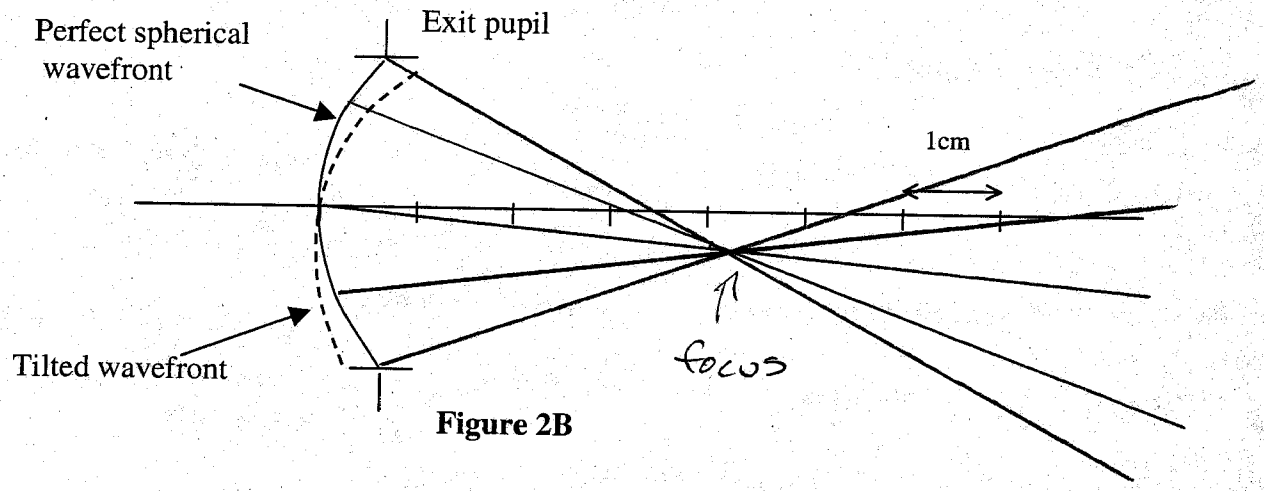

Figure 2B

C) The dotted wavefront in Figure 2C represents a spherically aberrated wavefront. Sketch the same 5 rays for the dotted wavefront and indicate the circle of least confusion. [10 points]

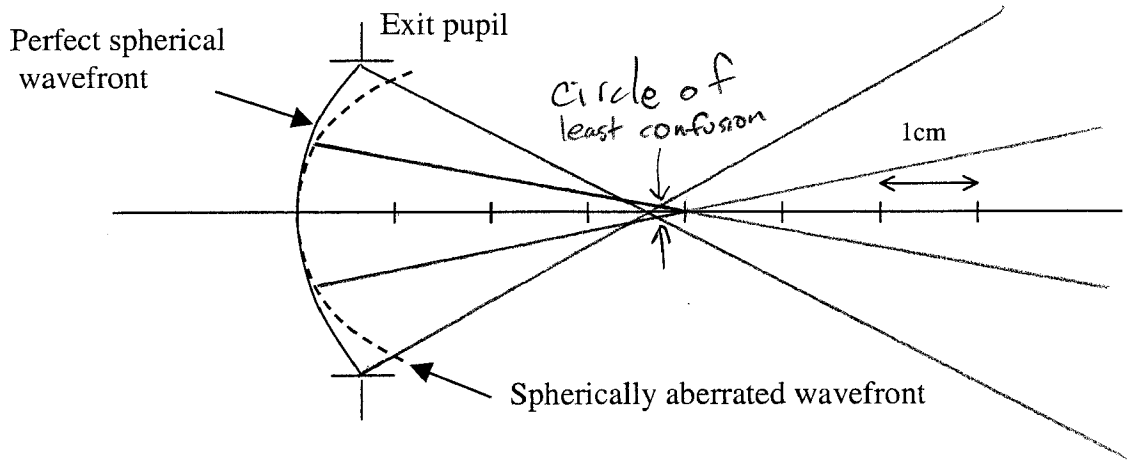

Figure 2C

3. An article appeared in the U.S.A. Today daily newspaper entitled, "Little can be kept from U.S. spy networks". In the article, the reporters mention the KH-12 spy satellite, which orbits at an altitude of 188-196 miles (i.e. roughly 1/3 X 10^6 meters) above the earth's surface. The reporters claimed that if KH-12 were to take a picture of a paperback book from approximately 1/3 X 10^6 meters, the title on the cover would be readable [25 points total].

A) A spy satellite contains an imaging system which forms a real image onto a detector array. Assume that the detector in the KH-12 is a charge-coupled device (CCD). The minimum resolvable separation between any two-image points in a CCD is about 20 μm. If the minimum feature that you wish to resolve on the book cover is 5 mm, what magnification would be required? [6 points]

B) Starting with the assumption that the focal length of the imaging system is much smaller than the distance from the Earth's surface to the satellite (i.e., 1/3 x 10^6 m), find the necessary focal length consistent with the above specification. [6 points]

C) What is the distance from the second principle plane of the imaging system to the image plane? [6 points]

D) Estimate the diameter of the primary mirror that is required to achieve this amazing feat. Is the reporter's claim reasonable? Why or why not? [Hint: The primary mirror on the Hubble Space Telescope is 2.4m in diameter.] [7 points]

A) $M = \frac{20\times10^{-6}\,m}{5\times10^{-3}\,m} = \boxed{4\times10^{-3}}$

B)

$$M = \frac{d_i}{d_o} = \frac{f d_i}{0.333\times10^{6}\,m} = -4\times10^{-3}$$

$$d_i = 1.333\times10^{3}\,m$$

$$\frac{1}{f} = \frac{1}{d_i} - \frac{1}{d_o} \rightarrow \boxed{f = 1.328\times10^{3}\,m}$$

C) $d_i = \boxed{1.333\times10^{3}\,m}$

D) Angular resolution is 5 mm at $1/3\times10^{6}$ m,

$$\gamma = 1.5\times10^{-8}\ rad$$

but $\gamma = 1.22\frac{\lambda}{D}$, so $D = 1.22\frac{\lambda}{\gamma} = \boxed{40.67\,m}$

Unreasonable. This could not fit in any launch vehicle, would be too heavy, and impossible to fabricate.