ANSWER KEY

name: ______________________

VS203B
Midterm Exam Version A
Dr. Roorda
Date: April 30, 2013
Permitted aids: pens/pencils, eraser, ruler, calculator
An equation sheet will be given out at the exam
This exam is out of **35** points

1. (1 point) Which one of the following statements about ARC thin film coatings ($n_{coating} < n_{glass}$) is **correct?**

d

a) An ARC works best when the amplitude of the first reflected wave is exactly one half of the amplitude of the second reflected wave.
b) Destructive interference occurs in the reflection when the thickness of the coating shifts the second reflected wave by one full wavelength relative to the first reflected wave.
c) If the amplitude condition is met, then the ARC will provide complete destructive interference for all wavelengths across the visible spectrum.
(d) The thinnest possible coating thickness is generally chosen because thicker coatings, even though they meet the condition for destructive interference, will be less effective because of the limited coherence length of typical light sources.

2. (1 point) (Choose the correct answer) When spectacles are fitted, their optic axes are tilted slightly downward from horizontal. This is referred to as the pantoscopic tilt. The purpose of this tilt is to…

c

a) … compensate for with-the-rule astigmatism, which is the dominant astigmatism in the human eye.
b) … compensate for the fact the fovea is not positioned along the best optical axis of the eye.
(c) … balance the radial astigmatism of spectacles between that which arises from looking forward to that which arises from looking downward (ie while reading).
d) … correct for angle kappa in the eye.

3. (1 point) A 1 inch diameter lens with a nominal power of 10 D has 10 mm of positive spherical aberration. What is the power in diopters at the edge of the lens?

c

a) 1.11 D
b) 9.09 D
(c) 11.11 D
d) 100 D

$f_{margin} = 90\text{ mm}$

$P_{margin} = \frac{1}{.09} = 11.11\text{ D}$

4. (1 point) A double-slit aperture has a slit separation of 0.1 mm. If the separation between two peaks in the interference pattern for 488 nm light is 1 cm, then what is the separation of two peaks for the same double slit aperture for 632 nm incident light?

c

a) 0.772 cm
b) 1.000 cm
(c) 1.295 cm
d) 3.389 cm

$x = \frac{m\lambda t}{h}$ since peak separation is directly proportional to λ, it follows that:

$(\text{peak separation}_{632}) = \frac{632}{488}(\text{peak separation}_{488}) = 1.295$

5. (1 point) What is the Abbe number for a refractive material with the following refractive indices?

Line	wavelength, λ	index, n
C-line	656 nm	1.55
D-line	589 nm	1.60
F-line	486 nm	1.67

a

(a) 5.00
b) 13.33
c) 22.14
d) 33.40

$\nu = \frac{1.60 - 1}{1.67 - 1.55} = 5$

6. (4 points total; 0.5 points each) Circle either T (True) or F (False) for each of the following statements

F a) T or (F): In the human eye, the blur caused chromatic aberration is too small to be detected.

T b) (T) or F: Distortion and curvature of field refer to aberrations that distort the images, but do not necessarily blur the image.

T c) (T) or F: In a biconvex lens, radial astigmatism arises whenever the chief ray of light from the object passes through a lens at an angle.

F d) T or (F): Lenses with spherical surfaces do not have spherical aberration.

T e) (T) or F: In optical systems that have spherical surfaces and where all elements are aligned (ie centers of curvature all fall along a single line) there is no coma for objects that are on-axis.

F f) T or (F): Astigmatism arises along the line of sight in the human eye primarily because light is passes obliquely through the eye's cornea and lens.

T g) (T) or F: Fraunhofer diffraction calculations can be used to describe the intensity distribution at the focal point of a lens.

F ~~h) T or (F): The dispersion (Abbe number) of a transparent material is directly related to its refractive index.~~ IGNORE

7. (5 points total) Two mutually coherent light waves of the same amplitude are traveling in water (n=1.33). Each has a frequency of 5×10^{14} Hz. The waves are out of phase by 75 degrees and their combined intensity is 113 (arbitrary units).

a) (4 points) Write the two wave equations (make sure your units are in radians):

$E_1 = \underline{6.7} \sin(\underline{1.39\times10^7}\, x - \underline{3.1416\times10^{15}}\, t + \underline{0});$

$E_2 = \underline{6.7} \sin(\underline{1.39\times10^7}\, x - \underline{3.1416\times10^{15}}\, t + \underline{1.309});$

$\omega = 2\pi f = 3.1416\times10^{15}$

$V = \frac{c}{n} = \frac{3\times10^8}{1.33} = 2.26\times10^8\ m/s$

~~$\lambda = \frac{V}{f}$~~ $k = \frac{\omega}{V} = 1.39\times10^7$

$75° = 1.309$ rad.

$I = 2A^2 + 2A^2\cos(1.309)$

$A^2 = \frac{I}{2(1+\cos(1.309))}$

$A^2 = 44.88$

$A = 6.7$

b) (1 point) What would the intensity be if the two waves were mutually incoherent?

$I = A^2 + A^2 = \underline{\underline{89.77}}$

8. (7 points total) A myope is corrected with -9 D spectacles of index n=1.5. She keeps her head pointing forward but directs her gaze 15 degrees to the left.

a) (1 point) What is the tangential power of the lens when viewing through it at this angle?

$$P_t = P\left(1 + \frac{4\phi^2}{3}\right) = -9\left(1 + \frac{4(0.262)^2}{3}\right) = -9.82$$

b) (1 point) What is the sagittal power of the lens when viewing through it at this angle?

$$P_s = P\left(1 + \frac{\phi^2}{3}\right) = -9\left(1 + \frac{(0.262)^2}{3}\right) = -9.2\,D$$

c) (1 point) What is the radial astigmatism of the lens when viewing through it at this angle?

$$RA = P\phi^2 = -9(0.262)^2 = -6.18\,D$$

d) (1 point) What is the orientation of the tangential axis in this situation?

horizontal

e) (3 points) What is the refractive error for this eye when viewing through the lens at this angle?

+.2 DS, +.618 DC, axis: 90 degrees

or

+.82 DS, -.618 DC, axis 180 deg

← this is the lens that will correct the residual refractive error

9. (3 points total) The ideal material for an ARC is one that has an index of refraction that is equal to the square root of the glass that it is coating. But consider a situation where all you had was a coating material with n = 1.9 and glass with n = 1.45.

(2 points) How thick would you make the coating to minimize the reflection for 550 nm light?

$$t_{dest} = \frac{m}{2}\frac{\lambda}{n_c} = \frac{550}{2(1.9)} = 144.74\,nm$$

(1 point) Why will choosing an antireflective coating with an index that is higher than the glass always be a worse choice?

* With this type of coating, you can never satisfy the amplitude condition, so you will never get total destructive interference.

also acceptable....

The thicker coating for this configuration will be less effective for low-coherent light

10. (11 points total) A magnesium fluoride (n=1.38) on glass (n=1.6) has a thickness of 100 nm.

a) (2 points) What visible wavelength is minimally reflected?

$t_{dest} = \frac{\lambda}{4n_c}$ $\lambda = (100)(4)(1.38) = 552\text{ nm}$

b) (4 points) What is the reflected intensity for 650 nm light?

$r_1 = \left|\frac{1.38-1}{1.38+1}\right| = 0.16$; $r_2 = \frac{1.6-1.38}{1.6+1.38} = .074$

phase

$2\pi \times \frac{200}{(650/1.38)} = 2.67$ radians.

$I = A_1^2 + A_2^2 + 2A_1A_2 \cos(P_1 - P_2) = (0.16)^2 + (0.074)^2 + 2(.16)(.074)\cos(2.67)$

$= .00998 \cong 1\%$

c) (1 point) What index of glass would be optimal for the magnesium fluoride antireflective coating?

$1.38^2 = 1.904$

d) (1 point) Answer part (a) for MgF_2 coated glass with the index you computed in part c.

552 ← same as above.

e) (3 points) Answer part (b) for MgF_2 coated glass with the index you computed in part c.

$r_1 = 0.16$; $r_2 = \left|\frac{1.904-1.38}{1.904+1.38}\right| = 0.16$

this is expected.

phase: same as before

$I = (0.16)^2 + (0.16)^2 + 2(0.16)(0.16)\cos(2.67)$

$= .0056$

$\Rightarrow .56\%$ ← this reflection is lower, as expected