VS203B
Midterm Exam Solutions
(versions A and B are the same except for the ordering of multiple choice answers)
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Permitted aids: pens/pencils, eraser, ruler, calculator
This exam is out of 38 points

1. (1 point) Consider an optical system where all optics have spherical surfaces and all optics and apertures are centered on the optical axis. **Choose the one statement that is <u>not</u> correct**:

a) <u>Pincushion distortion is observed if the lens is positive and barrel-shaped distortion is observed if the lens is negative.</u>
b) Astigmatism does not occur for on-axis objects.
c) Spherical aberration is the only monochromatic aberration for on-axis objects.
d) Blur due to coma is only observed in images of objects that are off the optical axis.

2. (1 point) If the material available for use as an antireflection coating for a lens has an index of refraction of 1.4, what would be the index of refraction of the lens that would provide a most suitable match?

a) 0.714
b) 1.18
c) 1.5
d) <u>1.96</u>

$$n_c = \sqrt{n_g} \Rightarrow n_g = n_c^{\,2} = 1.96$$

3. (1 point) When a -6D myope looks through his spectacle lens (index = 1.5) downward at an angle of 10 degrees, what is the spherical equivalent power?

a) -0.18D
b) -6.06D
<u>c) -6.15D</u>
d) -6.24D

$$SE = 0.5\times\left(P_t + P_s\right) = 0.5\times\left(-6\left(1+\frac{4\phi^2}{3}\right)+-6\left(1+\frac{\phi^2}{3}\right)\right) = 0.5\times\left((-6.24)+(-6.06)\right) = -6.15D$$

4. (1 point) Which of the following correctly describes the effective power of this lens when looked through in the manner described above?

<u>a)</u>	**<u>-6.06 DS,</u>**	**<u>-0.18 DC,</u>**	**<u>axis 180</u>**
b)	-6.15 DS,	-0.18 DC,	axis 90
c)	-6.24 DS,	-0.18 DC,	axis 180
d)	-6.06 DS,	-0.18 DC,	axis 90

5. (1 point) In the situation described above, which axis is the tangential axis?

<u>a) Vertical</u>
b) Horizontal
c) Both
d) Neither

6. (1 point) An emmetrope observes a blue and a red spot through a small pinhole held in front of the pupil (like in the lab). Which of the following statements best describes how the two spots appear?

<u>a) The blue spot moves (relative to the red spot) in a direction that is the same as the direction of motion of the pinhole.</u>
b) The blue spot moves (relative to the red spot) in a direction that is opposite to the direction of motion of the pinhole.
c) The blue spot appears blurrier than the red spot, and does not move relative to the red spot when the pinhole is moved.
d) The red spot appears blurrier than the blue spot, and does not move relative to the blue spot when the pinhole is moved.

7. (1 point) Light is modeled as a transverse wave and not a longitudinal wave..

a) because a transverse wave does not require a physical medium to propagate through.
b) to better explain how light can refract around corners.
<u>c) to better explain phenomena related to polarization.</u>
d) because a transverse wave can travel in all directions, whereas longitidunal waves can only travel in one direction.

8. (8 points total) The silicone polymer used by Advanced Medical Optics for their IOLs have the following optical properties (n_C=1.4675, n_D = 1.4700, n_F = 1.4760). For a single refractive surface of this material in air, where the radius of curvature of the silicon surface is 0.008 **m** (convex), answer the following questions.

a) (2 points) What are the powers for the C, D and F wavelengths?

$$P_C = \frac{1.4675-1}{0.008} = 58.4375D; \quad P_D = \frac{1.47-1}{0.008} = 58.75D; \quad P_C = \frac{1.476-1}{0.008} = 59.5D$$

b) (2 points) What are the focal lengths (in the silicone medium) for the C, D and F wavelengths?

$$f_C = \frac{1.4675}{58.4375} = 0.0251m; \quad f_D = \frac{1.47}{58.75} = 0.02502m; \quad f_C = \frac{1.476}{59.5} = 0.0248m$$

c) (1 point) What is the longitudinal chromatic aberration in mm (in the silicone medium)?

$$0.0251 - 0.0248 = 0.0003m = 0.3mm$$

d) (1 point) What is the longitudinal chromatic aberration in diopters?

$$59.5 - 58.4375 = 1.0625D$$

e) (1 point) Is the LCA positive, or negative?

Positive (blue has higher power than red)

f) (1 point) What is the refractive efficiency of the material?

$$\upsilon = \frac{1.47-1}{1.4760-1.4675} = 55.29$$

9. (6 points total) For the following two mutually coherent light waves:

$$E_1 = 0.2 \times \sin\left(15,707,963 \times x - 3.543 \times 10^{15} t + 0\right)$$
$$E_2 = 0.5 \times \sin\left(15,707,963 \times x - 3.543 \times 10^{15} t + \pi/2\right)$$

a) (1 point) What is the wavelength of light in the media?

$$k = \frac{2\pi}{\lambda}; \Rightarrow \lambda = \frac{2\pi}{k} = 400nm$$

b) (1 point) What is the frequency of light in the media?

$$\omega = 2\pi f; \quad \Rightarrow \quad f = \frac{\omega}{2\pi} = 5.63886 \times 10^{14}$$

c) (1 point) What is the speed of the wave?

$$V = \frac{\omega}{k} = 225,544,389 \ m/s$$

d) (1 point) What is the index of refraction of the material they are traveling through?

$$V = \frac{c}{n}; \quad \Rightarrow \quad n = \frac{c}{V} = 1.33$$

e) (1 point) What would the wavelength be if the light were in a vacuum?

$$\lambda_m = \frac{\lambda}{n}; \quad \Rightarrow \quad \lambda = n \times \lambda_m = 1.33 \times 400 = 532nm$$

f) (1 point) What is the coherent intensity of the two waves?

$$I = 0.2^2 + 0.5^2 + 2 \times (0.2) \times (0.5) \times \cos\left(\pi/2\right)$$
$$= 0.04 + 0.25 + 0 = 0.29$$

10. (12 points total) Your boss has given you the specs for an antireflection coating and has specified the materials; acrylic (index of refraction = 1.28) and flint glass (index = 1.64), and the thickness (97.66 nm), but he forgot to tell you which material was for the lens and which material was for the coating. So, the only way to be sure is to do the calculations.

a) (5 points) What is the percentage reflectance of 500 nm light for a flint glass surface with a 97.66 nm thick acrylic coating?

$$r_1 = \left|\frac{n_{ac} - n_{air}}{n_{ac} + n_{air}}\right| = \left|\frac{1.28-1}{1.28+1}\right| = \frac{0.28}{2.28} = 0.123 \qquad r_2 = \left|\frac{n_{fg} - n_{ac}}{n_{fg} + n_g}\right| = \left|\frac{1.64-1.28}{1.64+1.28}\right| = \frac{0.36}{2.92} = 0.123$$

$$\Delta waves_{1,2} = \frac{2\times 97.66}{500/1.28} = 0.500 \Rightarrow \text{convert to radians} \Rightarrow 0.500\times 2\pi = 3.1416 radians$$

$$I_{coherent} = A_1^2 + A_2^2 + 2A_1A_2\times\cos(p_1 - p_2) = 0.123^2 + 0.123^2 + 2\times 0.123\times 0.123\times\cos(3.1416)$$
$$= 0.00 = 0\%$$

b) (5 points) What is the percentage reflectance of 500 nm light for an acrylic surface with a 97.66 nm thick coating of flint glass?

$$r_1 = \left|\frac{n_{ac} - n_{air}}{n_{ac} + n_{air}}\right| = \left|\frac{1.64-1}{1.64+1}\right| = \frac{0.64}{2.64} = 0.242 \qquad r_2 = \left|\frac{n_{fg} - n_{ac}}{n_{fg} + n_g}\right| = \left|\frac{1.28-1.64}{1.64+1.28}\right| = \frac{0.36}{2.92} = 0.123$$

$$\Delta waves_{1,2} = \frac{2\times 97.66}{500/1.64} = .6406 \Rightarrow \text{convert to radians} \Rightarrow .6406\times 2\pi = 4.025 radians$$

but you need to add an additional π phase shift due to the reflections

$$I_{coherent} = A_1^2 + A_2^2 + 2A_1A_2\times\cos(p_1 - p_2) = 0.242^2 + 0.123^2 + 2\times 0.242\times 0.123\times\cos(4.025+\pi)$$
$$= 0.1115 = 11.15\%$$

c) (1 point) Was the thickness condition for total destructive interference met for either of these situations? If yes then which one?

Yes, situation #a (acrylic on glass)

d) (1 point) Was the amplitude condition for total destructive interference met for either of these conditions? If yes, then which one?

Yes, situation #a (acrylic on glass)

11. (5 points) Design an achromatic prism comprised of CR39 Hard Resin Plastic (refractive efficiency = 58.0) and polycarbonate (refractive efficiency = 30.0) that has prism diopter power of 7^{Δ}. (ie Z = 7)

$$Z = Z_1 + Z_2 = 7^{\Delta} \qquad (1)$$

$$CA = \frac{Z_1}{30} + \frac{Z_2}{58} = 0 \qquad (2)$$

from (2),

$$Z_2 = \frac{-58}{30} Z_1 \qquad (3)$$

sub (3) into (1)

$$Z_1 \times \left(1 - \frac{58}{30}\right) = 7$$

$$Z_1 = -7.5^{\Delta} \qquad (4)$$

sub (4) into (1)

$$-7.5 + Z_2 = 7$$

$$Z_2 = 14.5^{\Delta}$$

$Z_1 = -7.5^{\Delta}$ (polycarbonate)

$Z_2 = 14.5^{\Delta}$ (CR39)