UCA Department of Physics and Astronomy

PHYS 3345: OPTICS

Exam 03: Chapters 06–08 Solution

Spring 2008

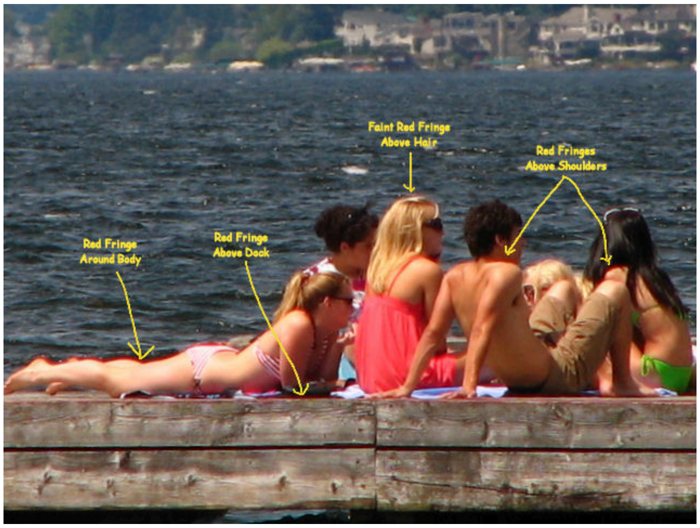
1. Describe longitudinal spherical aberration, and distinguish it from transverse spherical aberration.

SEE FIGURE 6.14 (P 254). RAYS PARALLEL TO THE OPTIC AXIS AND VERY CLOSE TO THE CENTER OF THE LENS WILL FOCUS FURTHER THAN PARALLEL RAYS ENTERING THE LENS NEAR ITS EDGES. THE RANGE OF FOCAL POINTS ON THE OPTIC AXIS IS THE LONGITUDINAL SA.

TRANSVERSE SA IS MEASURED IN A PLANE PERPENDICULAR TO THE OPTIC AXIS, AS THE DISTANCE FROM THE AXIS WHICH A RAY STRIKES THE PLANE. AN INCIDENT RAY CLOSE TO THE OPTIC AXIS WILL STRIKE THE SCREEN CLOSER TO THE AXIS THAN A RAY INCIDENT NEARER THE EDGE OF THE LENS (AGAIN, AS PER FIG 6.14).

2. How is coma a separate effect from spherical aberration?

SEE FIGURES 6.14 (P 254) AND 6.21 (P 259).



3. Explain why the sunbathers in the photo seem to have red fringes.

SEE FIGURE 6.37 (P 268). FOR THE PHOTOGRAPH SHOWN, THE FILM WAS APPARENTLY LOCATED IN THE PLANE OF FOCUS FOR BLUE LIGHT. THUS, BLUE OBJECTS ARE CRISP AND SHARP. ANY OBJECT WITH A STRONG RED COLOR COMPONENT WILL HAVE THE HALO YOU SEE, BECAUSE THE PLANE OF FOCUS FOR RED LIGHT WILL BE BEHIND THE PLANE FOR BLUE. NOTICE THAT THE HOT PINK TANK TOP FRINGES VERY STRONGLY, BUT THE GREEN BIKINI NOT REALLY AT ALL.

4. Show how phasor addition can be used to illustrate the stationary nature of a standing wave.

SEE FIGURE 7.12 (P 291). THE FACT THAT THE RESULTANT PHASOR DOES NOT ROTATE IS WHAT DEMONSTRATES THE FACT THAT THE WAVE IS STATIONARY (DOES NOT PROPAGATE THROUGH SPACE).

5. Is natural light actually unpolarized? Explain.

NOT UNPOLARIZED, RANDOMLY POLARIZED. NATURAL LIGHT CONSISTS OF MULTIPLE INDEPENDENT EMITTERS (THINK E^- OSCILLATION MODEL) THAT EMIT MULTIPLE PHOTONS. INITIAL PHASE IS RANDOM FOR ANY GIVEN EMISSION.

6. Explain why a vertical wire-grid polarizer allows a horizontal **E** field to pass.

THE VERTICAL COMPONENT WILL CREATE CURRENT IN THE VERTICAL GRID WIRES. EASIER FOR THE VERTICAL OSCILLATIONS TO INDUCE VERTICAL OSCILLATIONS IN VERTICAL WIRE THAN FOR HORIZONTAL OSCILLATIONS TO ESTABLISH HORIZONTAL OSCILLATIONS IN VERTICAL WIRES. VERTICAL OSCILLATIONS MOSTLY ABSORBED, HORIZONTAL MOSTLY IGNORED.

7. If two polaroids are held so that their transmission axes are 90° apart, no light is transmitted. Explain why a third polaroid, inserted between the two sheets at an angle of 45°, allows transmission. A sketch may be very helpful here.

VERTICALLY POLARIZED LIGHT EMERGING FROM THE FIRST POLAROID WILL HAVE COMPONENTS PARALLEL AND PERPENDICULAR TO THE TRANSMISSION AXIS OF THE SECOND. A BEAM POLARIZED AT 45° EMERGES FROM POLAROID 2, AND THIS WILL HAVE A HORIZONTAL COMPONENT PARALLEL TO THE TRANSMISSION AXIS OF POLAROID 3.

ALTERNATIVELY, USE MALUS' LAW TO SHOW THE THE INTENSITY OF THE FINAL EMERGENT BEAM ≠ ZERO:

$$I_1 = \tfrac{1}{2} I_o \qquad I_3 = I_2 \cos^2 45°$$

$$I_2 = I_1 \cos^2 45° \qquad I_3 = \tfrac{1}{2} I_o \cos^4 45°$$

8. Define birefringence, relating it back to the idea of crystallographic anisotropy.

SEE P 337: "AN ANISOTROPY IN THE BINDING FORCE WILL BE MANIFEST IN AN ANISOTROPY IN THE REFRACTIVE INDEX."

THE BINDING FORCE CAN BE DIFFERENT IN DIFFERENT DIRECTIONS OR MULTIPLE REASONS: DIFFERENT ATOMIC NEIGHBORS IN DIFFERENT DIRECTIONS, DIFFERENT ATOMIC DISTANCES IN DIFFERENT DIRECTIONS, SOME COMBINATION OF BOTH. SO THE CRYSTAL IS NOT SYMMETRIC IN ALL DIRECTIONS.

IF RANDOMLY POLARIZED LIGHT ENTERS A BIREFRINGENT CRYSTAL (LET'S ASSUME Z-AXIS PROPAGATION, AND AXES PARALLEL TO THE THE CRYSTALLOGRAPHIC AXES), ITS COMPONENTS WILL NOT ALL BE TRANSMITTED IDENTICALLY. SEE FIGURE 8.15 (P 337): THE ABSORPTION BAND IN

Exam 03: Chapters 06–08 Spring 2008
Solution

THE Y-DIRECTION DOES NOT CORRESPOND THE THE BAND IN THE X-DIRECTION. IF THE INCOMING FREQUENCY IS IN THE ABSORPTION BAND FOR ONE, IT'S NOT FOR THE OTHER. AS SHOWN IN THE FIGURE, LIGHT OSCILLATING PARALLEL TO THE Y-DIRECTION WILL BE STRONGLY ABSORBED, WHILE THE SAME FREQUENCY OSCILLATING IN THE X-DIRECTION IS TRANSMITTED.

9. Explain briefly how a retarder works. How would you design a retarder to transform an incident linearly polarized beam into circularly polarized output?

SEE FIGURE 8.38 (P 353). A RETARDER IS A POLARIZER. IF THE MATERIAL IS ANISOTROPIC SO THAT THE SPEED OF THE WAVE WILL BE DIFFERENT IN THE X AND Y DIRECTIONS, THEN THE COMPONENTS OF AN INCOMING WAVE WILL BE TRAVELING AT DIFFERENT SPEEDS. THIS WILL CREATE A RELATIVE PHASE DIFFERENCE AS THE WAVE PASSES THROUGH A RETARDER OF THICKNESS D. ADJUSTING THE THICKNESS WILL ADJUST THE AMOUNT OF PHASE SHIFT (ALSO DEPENDS ON WAVELENGTH AND THE MATERIAL OF THE POLARIZER).

SEE FIGURE 8.40 (P 355). IF THE INCOMING BEAM IS UNPOLARIZED NATURAL LIGHT, FIRST PASS IT THROUGH A POLARIZER WITH TRANSMISSION AXIS AT 45° TO LINEARLY POLARIZE. A RELATIVE PHASE SHIFT OF $\pi/2$ CHANGES LINEAR TO CIRCULAR, SO YOUR RETARDER SHOULD BE DESIGNED (CHOOSE MATERIAL AND THICKNESS) TO INTRODUCE A QUARTER-WAVELENGTH RELATIVE SHIFT (HENCE THE TERM QUARTER-WAVE PLATE).

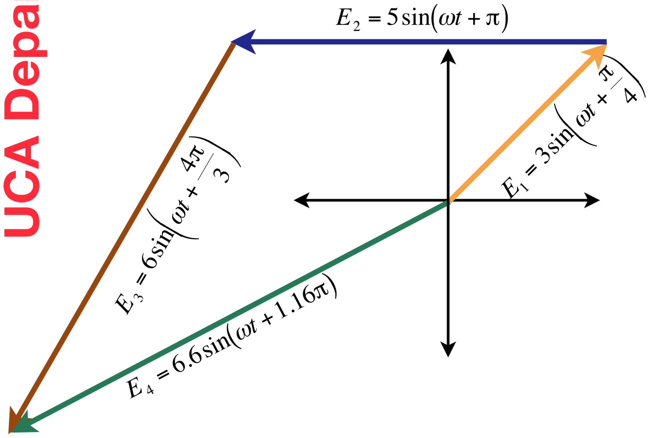
1. Design a Fraunhofer cemented achromat with a focal length of 50 cm. Use Table 6.2 (page 270), and select a crown and a flint with $V_{1D} - V_{2D} \approx 40$. Do not copy the example in the textbook.

EACH SOLUTION WILL BE UNIQUE, ASSUMING YOU DID NOT COMMUNICATE TELEPATHICALLY AND ALL CHOOSE THE SAME CROWN AND FLINT.

2. Use phasor addition to add the following e·m waves:

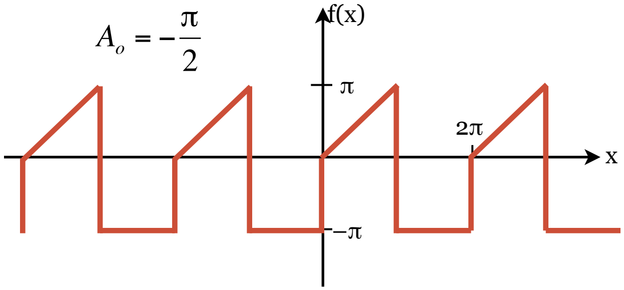
$$E_1 = 3\sin\left(\omega t + \frac{\pi}{4}\right)$$
$$E_2 = 5\sin(\omega t + \pi)$$
$$E_3 = 6\sin\left(\omega t + \frac{4\pi}{3}\right)$$

$$E_4 = E_1 + E_2 + E_3$$
$$E_4 = 6.6\sin(\omega t + 1.16\pi)$$



3. For the function shown below, derive the first term of the Fourier series, A_o. Do not construct the entire series.

$$A_o = \frac{2}{\lambda}\int_0^{\lambda} f(x)\,dx$$
$$A_o = \frac{2}{2\pi}\int_0^{\pi} x\,dx + \frac{2}{2\pi}\int_{\pi}^{2\pi}(-\pi)\,dx$$
$$A_o = \tfrac{1}{\pi}\left[\tfrac{1}{2}x^2\right]_0^{\pi} + \tfrac{1}{\pi}\left[-\pi x\right]_{\pi}^{2\pi}$$
$$A_o = \tfrac{1}{\pi}\left[\tfrac{1}{2}\pi^2 - 0\right] + \tfrac{1}{\pi}\left[-2\pi^2 + \pi^2\right]$$
$$A_o = -\frac{\pi}{2}$$



4. Write the equation of a right-handed $\mathcal{E}$–state propagating in the z–direction that makes an angle of 120° to the x–axis.

SEE FIGURE 8.7 (P 329).

$$120° = \tfrac{2\pi}{3}$$

E_y leads E_x: $\varepsilon = -\frac{2\pi}{3}$	E_x leads E_y: $\varepsilon = +\frac{4\pi}{3}$
$E_x = E_{ox}\cos(kz - \omega t)$	$E_x = E_{ox}\cos(kz - \omega t)$
$E_y = E_{oy}\cos\left(kz - \omega t - \frac{2\pi}{3}\right)$	$E_y = E_{oy}\cos\left(kz - \omega t + \frac{4\pi}{3}\right)$

5. Two ideal linear polarizers are positioned one behind the other. What angle should the transmission axes make if an incident unpolarized beam (150 W/m²) is to be reduced to an emergent 50 W/m²?

$$I_1 = \tfrac{1}{2}I_o$$
$$I_2 = I_1\cos^2\theta$$
$$I_2 = \tfrac{1}{2}I_o\cos^2\theta$$

$$50\,\tfrac{\text{W}}{\text{m}^2} = \tfrac{1}{2}\left(150\,\tfrac{\text{W}}{\text{m}^2}\right)\cos^2\theta$$
$$\tfrac{2}{3} = \cos^2\theta$$
$$\theta = 35.3°$$