Name SOLUTIONS

Midterm
Due 10/15/09

BioE 164
Optics & Microscopy

(1) A student is trying to complete a midterm when all of the overhead lights, except one, go out. The remaining bulb has a 100W filament behind a 3 mm thick glass casing with an index of refraction $n = 1.50 - i\ 7.85 \times 10^{-6}$ at a wavelength of 550 nm. Accounting for absorption from the glass casing, calculate the amplitude of the electric field illuminating the student's exam 3 meters below (neglect reflection from the glass casing and assume one wavelength). [15 points]

(2) The sun is shining vertically on the bay. A passing ship carrying oil has a small leak that causes a thin film of oil (n=1.5) to spread on the water (n=1.3).

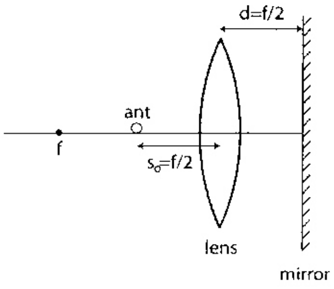
- (a) What fraction of light is reflected from the water alone? [5 points]
- (b) Calculate how the intensity and reflected spectrum would appear different with the thin oil film, assuming the film is 0.15 um in thickness? [10 points]
- (c) What changes will occur to the reflected sunlight as the oil film gets thicker? [5 points]

(3) You are given seven positive lenses to construct an infinity-corrected microscope with Kohler illumination (recall that infinity-corrected imaging systems use pairs of lenses to form images).

- (a) Sketch a microscope design that uses all lenses, assuming you are illuminating the sample with an emitting filament, forming an intermediate image, and capturing the final image with a CCD. Label planes conjugate to the aperture diaphragm. [15 points]
- (b) You are given a flat piece of glass to use as a semi-transparent reflector and asked to image a sample mounted on an opaque table that prevents having the illumination lenses behind the sample. Preserving Kohler illumination and the entire imaging path, how would you rebuild the microscope, and how many lenses do you need? (Hint: use the objective as the condenser) [10 points]

(4) An ant being chased by an anteater scurries in front of a thin lens having a focal length, f, which itself is directly in front of a plane mirror. The ant sits on the central axis a distance, $s_0 = f/2$, in front of the lens, which is a distance d=f/2 from the mirror.

- (a) Use ray tracing to locate the three images of the ant. (It may be useful to draw three separate diagrams, one for each image.) [10 points]
- (b) Calculate the location, size and type of the three images. The anteater is rather lazy, and is searching for the biggest, closest meal. What does he do? [15 points]



(5) Look at the images on the back of this page.

- (a) What is the aberration shown in Image (a)? [5 points]
- (b) What is wrong with the diagram in Image (b)? [5 points]
- (c) What is wrong with the diagram in Image (c)? [5 points]

Image (a)

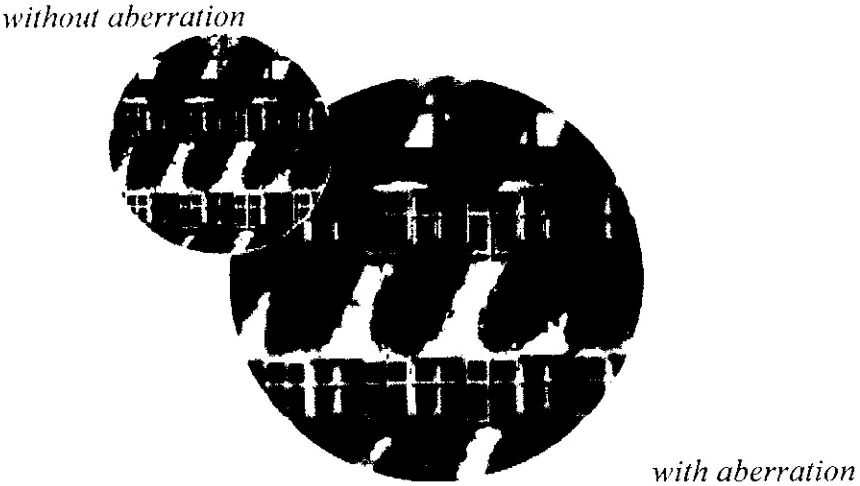


Image (b)

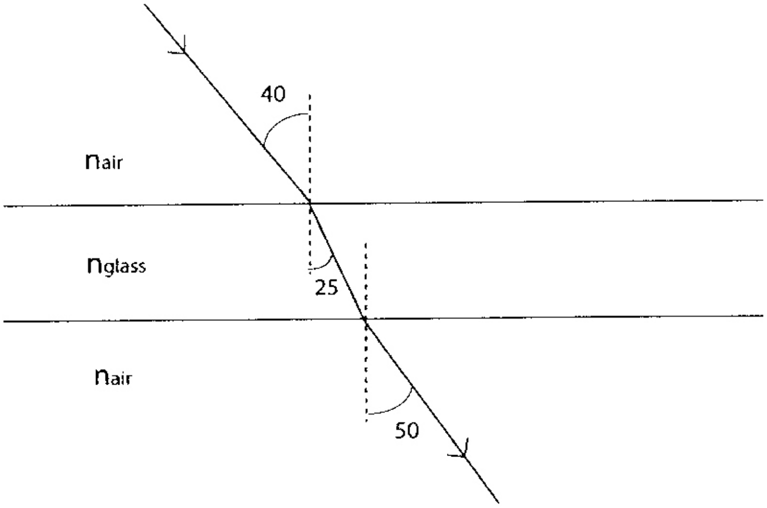
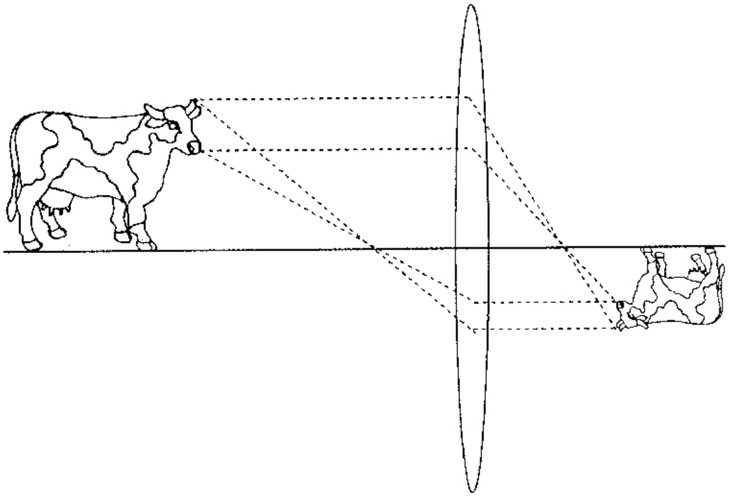


Image (c)



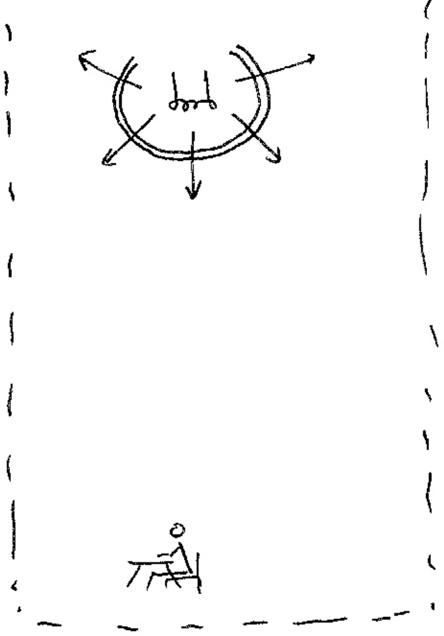
BONUS [5 points]: Come up with your own combination of optics words from class (like "reflaction") and define it.

①

absorption

$$I = \frac{I_0 e^{-\alpha y}}{4\pi r^2}, \quad y = 3mm, \quad r = 3m$$

divergence



$$\alpha = \frac{4\pi}{\lambda_0} n_I = \frac{4\pi}{550nm}\left(7.85\times10^{-6}\right)$$

$$\alpha = 0.18 \ mm^{-1}$$

$$I = \frac{\cancel{(100W)\,e^{-(0.18\times3)}}}{\cancel{4\pi(3m)^2}} = \frac{100W \ e^{-(0.18\times3)}}{4\pi(3m)^2} = \frac{58 \, W}{36\pi \ m^2}$$

$$I = 0.51 \ W/m^2$$

$$E_0 = \sqrt{\frac{2I}{c\,\varepsilon_0}} = 19.7 \ N/C$$

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2. a) $R = \left(\frac{n_t - n_i}{n_t + n_i}\right)^2 = \left(\frac{1.3 - 1}{1.3 + 1}\right)^2 = 0.017$ or 1.7% reflected off water

b) Intensity: $R = \left(\frac{1.5 - 1}{1.5 + 1}\right) = 0.04$ or 4% reflected off oil

Reflected Spectrum:

2 (oil film thickness) = 0.3 μm < coherence length ~1.5λ
therefore interference can occur

Phase shift at air-oil interface
($n_t > n_i$ and normal incidence)

Constructive: $\delta = \frac{4\pi n_f d}{\lambda_0} + \pi = 2\pi m$

$m=1 \rightarrow \lambda_0 = 900nm$
$m=2 \rightarrow \lambda_0 = 300nm$
} Both outside visible spectrum

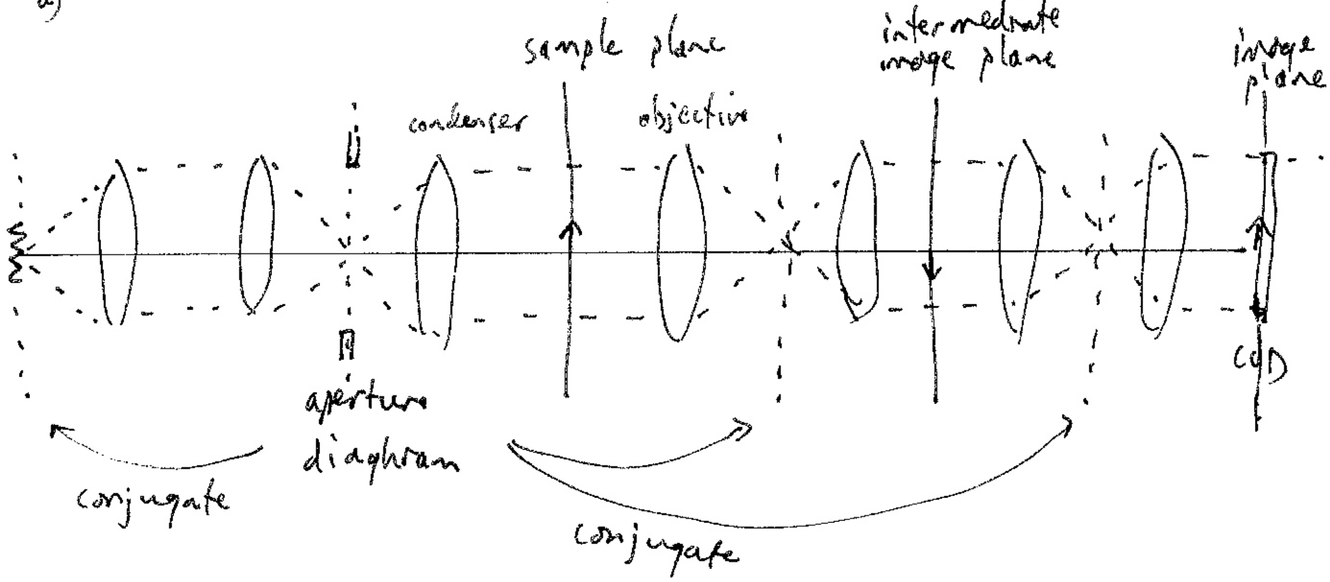
Destructive: $\delta = \frac{4\pi n_f d}{\lambda_0} + \pi = (2m+1)\pi$

$m=1 \rightarrow \lambda_0 = 450nm$

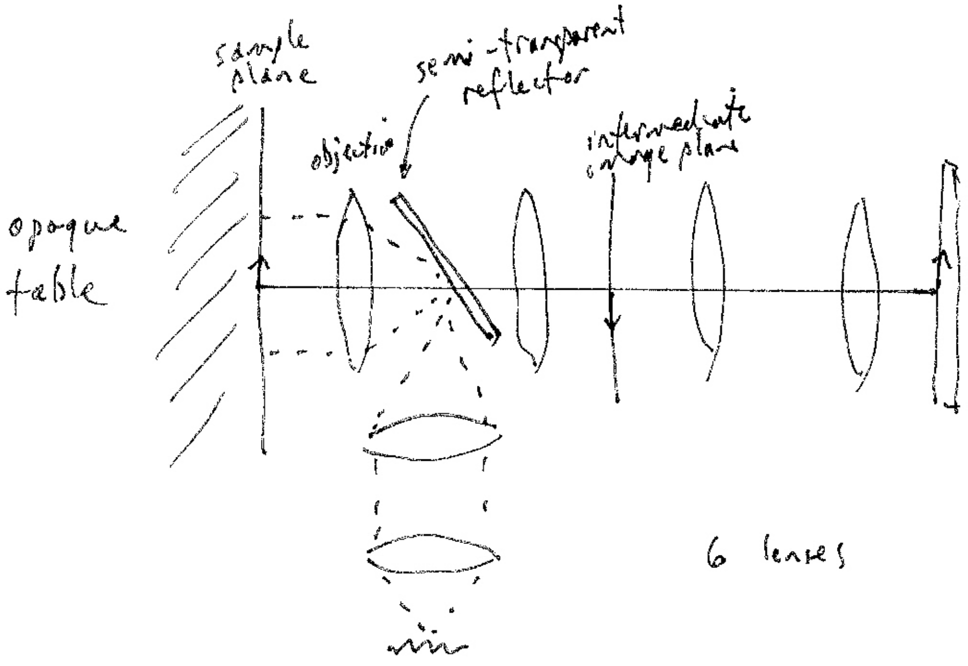
Therefore the reflected spectrum will be missing blue.

c) As d increases, longer wavelengths will interfere and beyond the coherence length, no interference will be observed.

③ a)


sample plane
intermediate image plane
image plane
condenser
objective
CCD
aperture diaghram
conjugate
conjugate

b)


sample plane
semi-transparent reflector
objective
intermediate image plane
opaque table

6 lenses

④ a) image 1.

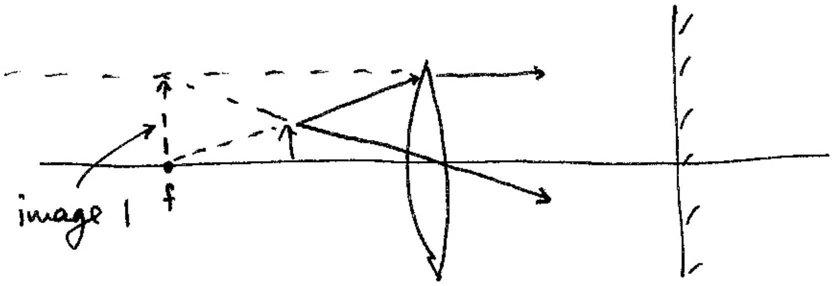


image 2

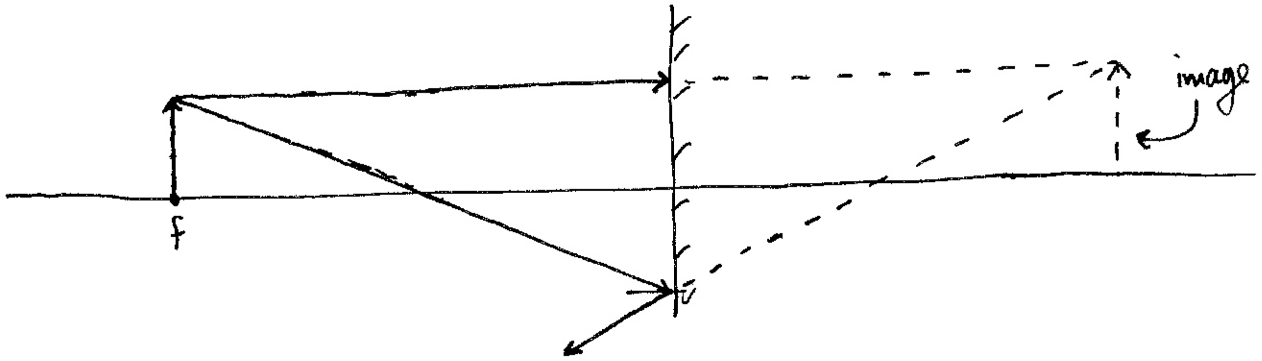
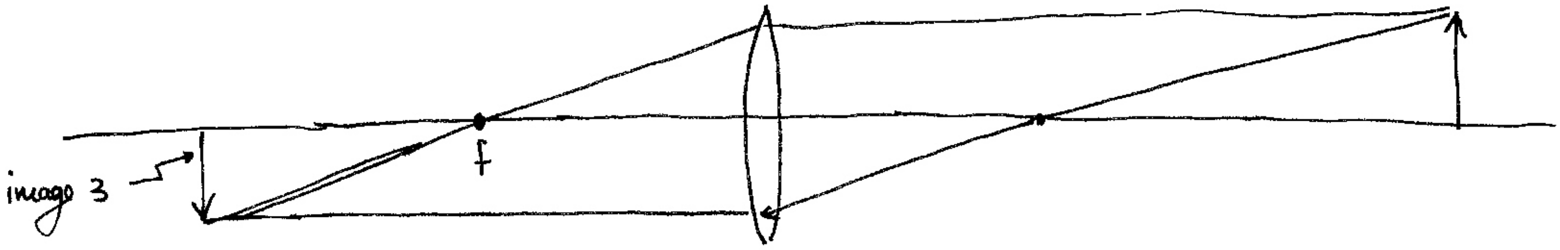


image 3



b) <u>image 1</u> - formed from lens

$$\frac{1}{s_o} + \frac{1}{s_i} = \frac{1}{f} \rightarrow \frac{1}{s_i} = \cancel{\frac{2}{s_o}} \frac{1}{f} - \frac{1}{s_o} = \frac{1}{f} - \frac{2}{f} = -\frac{1}{f}$$

$$\therefore \; s_i = -f$$

$$m_T = -\frac{s_i}{s_o} = \frac{-(-f)}{f/2} = 2 \quad \text{(upright)} \; , \quad Y_i = 2Y_o$$

$s_i < 0$ $\therefore$ virtual image.

image 2 - from ~~mirror~~ planar mirror

$$\frac{1}{s_o} + \frac{1}{s_i} = \frac{1}{f} = \frac{1}{\infty} = 0 \qquad \therefore \; s_i = -s_o$$

from part (a), $s_o = f + d = f + f/2 = \frac{3}{2} f$

$\therefore$ $s_i = -\frac{3}{2} f$ which is $\frac{3}{2} f$ to the right of the mirror.

$s_i < 0$ $\therefore$ virtual image.

$$M_T = -\frac{s_i}{s_o} = \frac{-\left(-\frac{3}{2} f\right)}{\frac{3}{2} f} = 1 \; , \quad Y_i = Y_o$$

(which is twice the size of original ant)

image 3

$$\frac{1}{s_o} + \frac{1}{s_i} = \frac{1}{f} \rightarrow \frac{1}{s_i} = \frac{1}{f} - \frac{1}{s_o}$$

now from part (a), $s_o = \frac{3}{2} f + d = \frac{3}{2} f + \frac{f}{2} = 2f.$

$$\frac{1}{s_i} = \frac{1}{f} - \frac{1}{2f} = \frac{1}{2f} \qquad \therefore \; s_i = 2f. \qquad M_T = -\frac{s_i}{s_o} = \frac{-2f}{2f} = -1$$

$s_i > 0$ $\therefore$ real image. ~~Note image 3 is~~

The final image is 2x the size of the real ant, and a distance $\frac{3f}{2}$ closer to the ant eater.

It is also real.

$\therefore$ the anteater chases after image 3.

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5. a) Almost any aberration accepted due to bad quality of image. Chromatic aberration hard to justify given black & white image.

b) Incident and transmitted angles in air should be the same.

c) The cow is facing the wrong direction. The Image horns should be farther from the lens.