P123 University of Rochester NAME Soln key - SLM
S. Manly Spring 2013

Exam 2 (April 11, 2013)

Please read the problems carefully and answer them in the space provided. Write on the back of the page, if necessary. Show all your work. Partial credit will be given unless specified otherwise.

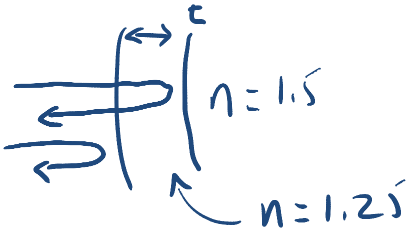
Problem 1 (14 pts):

(4 pts) Which of the following can be observed for electromagnetic waves but not sound waves?

- a) Interference
- b) Diffraction
- [✓ c)] polarization
- d) Refraction
- e) Absorption
- f) Scattering

(6 pts, *show work*) Fast forward … after graduation you get a job with Al's Muffler Repair and Lens Design shop. On your first day on the job, Al hands you a lens and asks you to apply a material with n=1.25 to the surface of the lens in order to make the lens nonreflective at a wavelength of 555 nm. Al's a cheapskate, so he adds, "and make that layer as thin as possible because that stuff is expensive." The lens is made of glass with n=1.5. What is the approximate minimum thickness of the coating that you need to put on the lens? (*show your work here)*

- a) 56 nm
- [✓ b)] 110 nm
- c) 220 nm
- d) 280 nm
- e) 140 nm



180° phase change at Both surfaces

so, No reflection means

$$2t = \frac{\lambda_n}{2} = \frac{\lambda}{1.25}\frac{1}{2}$$

$$t = \frac{\lambda}{(1.25)(4)} \cong 110$$

(4 pts) When a plane wave from infinity is diffracted by a single slit,

- a) the shadow is always sharp.
- b) the narrower the slit, the narrower the central diffraction maximum.
- [✓ c)] the narrower the slit, the wider the central diffraction maximum.
- d) the width of the central diffraction maximum is independent of the width of the slit.
- e) None of these is correct.

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1)	/14
2)	/12
3)	/10
4)	/15
5)	/16
6)	/14
7)	/19
tot	/100

Problem 2 (12 pts, 4 pts for each part):

Green light of wavelength 500 nm is incident normal on a diffraction grating that has 5300 lines/cm. The second-order image is diffracted at an angle from the normal of

- a) 10 degrees.
- b) 16 degrees.
- [✓ c) 32 degrees.]
- d) 48 degrees.
- e) 57 degrees.

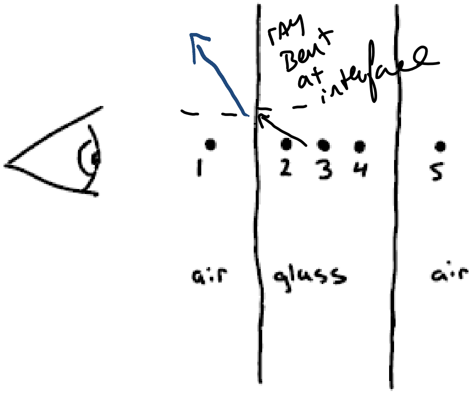
$d\sin\theta = m\lambda$

$5300\,\frac{\text{lines}}{\text{cm}} \rightarrow 5.3\times10^{5}\ \text{lines}/ \rightarrow 1.9\times10^{-6}\ \text{m} = d$

$\sin\theta = \frac{(2)\,5\times10^{-7}}{1.9\times10^{-6}}$ $\quad\theta \sim 32^{\circ}$

Your eye looks into a thick glass slab at an air bubble located at point 3. The bubble appears to be at point

- a) 1.
- [✓ b) 2.]
- c) 3.
- d) 4.
- e) 5.

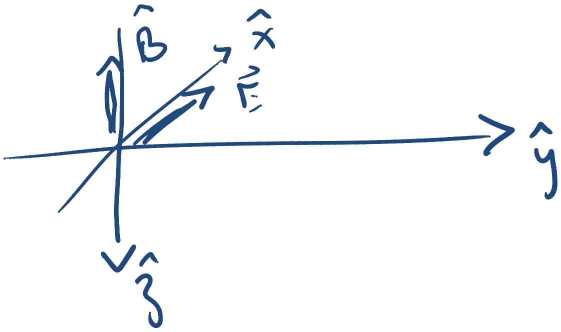


If you consider the earth to be a perfect blackbody and the average temperature of earth's surface is 288 K, at what wavelength will earth radiate energy (glow) with the highest intensity?

$\lambda_p T = 2.9\times10^{-3}\ \text{m}\cdot\text{K}$ $\qquad \frac{2.9\times10^{-3}}{288} = 1\times10^{-5}\ \text{m}$

Problem 3 (10 pts):

An electromagnetic plane wave is moving in a vacuum in the +y-direction. It is linearly polarized along the x-axis and has a wavelength λ, wavenumber k, and frequency ω. Assume the electric field has maximum amplitude E_o. Write down an equation that describes the B field for this wave as a function of y and t.

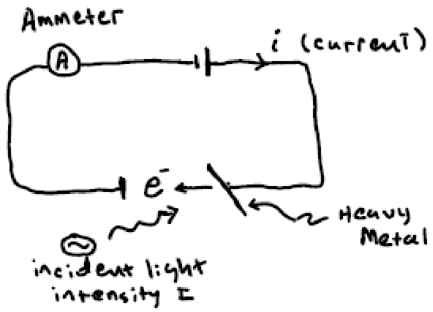


$\vec{B}(y,t) = \frac{E_0}{c}\sin(ky-\omega t)\,\hat{z}$

-or-

$\vec{B}(y,t) = \frac{E_0}{c}e^{i(ky-\omega t)}\,\hat{z}$

Problem 4 (15 pts):



Suppose light with intensity I shines on a plate of clean metal in a vacuum. For this particular metal, it is determined that red light of wavelength λ=700 nm (and photon energy 1.76 eV) is the threshold wavelength at which electrons are freed from the metal. In terms of the classic photoelectric effect experiment shown in the sketch, this means that when the metal is placed under a voltage and light is shown on it, a current is not observed for light with λ>700 nm, but that a current is observed for λ≤700 nm.

(a) (7 pts) If blue light of wavelength λ=450 nm (and photon energy 2.7 eV) is shown on this metal, what is the maximum kinetic energy of the ejected electrons?

$KE = h\nu - W$ $KE = 2.7 - 1.76$ eV

$= 0.94$ eV

(b) (4 pts) How will this maximal kinetic energy change if the intensity of the blue light is doubled?

It will remain unchanged

(c) (4 pts) How will the current observed change if the intensity of the blue light is doubled?

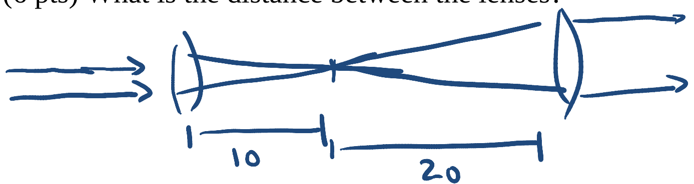
It will double

Problem 5 (16 pts):

A beam of parallel light, 1.0 mm in diameter passes through a lens with a focal length of 10.0 cm. Another lens, this one of focal length 20.0 cm, is located behind the first lens so that the light traveling out from it is again parallel.

a) (6 pts) What is the distance between the lenses?

Focal points overlap



b) (5 pts) How wide is the outgoing beam?

2.0 mm due to same angles + lever arm scaling

$\theta_1 = \theta_2$ $f_1 = \frac{f_2}{2}$

c) (5 pts) Assuming no losses due to diffraction or interference, how does the intensity of the outgoing beam compare to the intensity of the incoming beam?

Intensity $\propto 1/\text{area}$

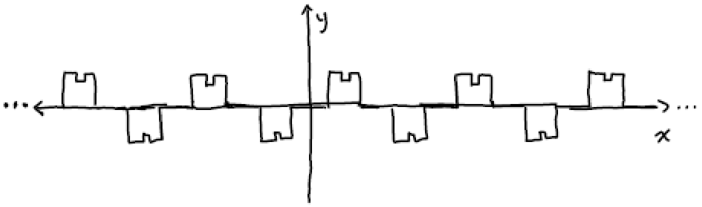
area $\sim r^2$

$\frac{r_{in}}{r_{out}} = \frac{1}{2}$ So $I_{out} = \frac{1}{4} I_{in}$

Problem 6 (14 pts):

Consider the function pictured below (and forgive my imperfect hand in the drawing). It is periodic with spatial frequency k. Through Fourier analysis, this function can be described in terms of a series of harmonic functions of increasing frequency.

$$F(x) = A_o + \sum_{m=1}^{\infty} A_m \cos(mkx) + \sum_{m=1}^{\infty} B_m Sin(mkx)$$



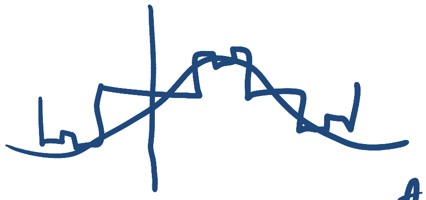
(a) (7 pts) Make an argument as to why each of the constants, A_n (n=0, 1, 2 …), is zero. (Note: I am not asking you to make a calculation.)

$\int_0^\lambda F(x)\,dx = A_0 = 0$ Since $\int F(x) = 0$ over one λ

Function is odd
So all A_m, m=1… is 0 too

(b) (7 pts) If you were to solve for all coefficients, B_n (n=1, 2 …) in this series, for which n would you expect the coefficient magnitude to be the largest? (Note: don't solve for the B_n. I'm asking for conceptual/qualitative answer.)

n=1
will
be
largest



Higher n give the contributions of higher frequency components that give the smaller "structural" corrections to the basic n=1 Sin waveform.

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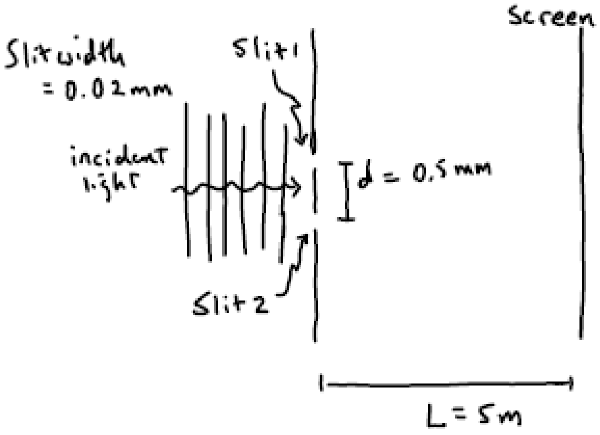
Problem 7 (19 pts):

Consider light of wavelength λ=700 nm incident on two thin slits as shown in the sketch. The slits are 0.02 mm in width and separated by 0.5 mm. Light passing through the slits is observed on a screen 5 m behind the slits.

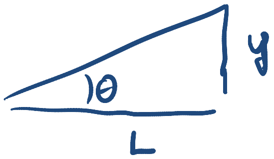


(a) (5 pts) If both slits are uncovered, what is the distance between the interference fringes in the central diffraction maximum of the pattern on the screen?

$d \sin\theta = m\lambda$

$0.0005 \sin\theta = 7\times10^{-7}\,m$

$\theta = 0.08$



$\tan\theta = \frac{y}{L}$

$y = 5\,m \tan\theta$

$y = 0.007$

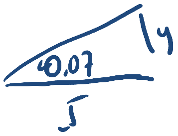
7 mm

(b) (5 pts) How wide is the central diffraction maximum on the screen?

1st Min $\sin\theta = \frac{\lambda}{D} = \frac{7\times10^{-7}}{0.00002}$

$\theta \sim 2°$

width = 0.35 m



4° = .07 rad

y = (.07)5

(c) (9 pts) Now suppose white light is incident on the two slits and one slit is covered with a red filter allowing light of wavelength λ=700 nm to pass through, while the other slit is covered with a blue filter allowing light of wavelength λ=450 nm. Qualitatively describe the pattern on the screen.

No interference because sources (each slit) are no longer coherent

Each slit individually will project a single slit diffraction pattern on the screen.