Physics 202 Exam 3 (Hokin)
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TA: SOLUTIONS

Problem 1 (circular capacitor)

Problem 2 (solar radiation)

Problem 3 (converging lens)

Problem 4 (Lloyd's mirror)

Problem 5 (single slit)

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TOTAL  _____ / 100
1. A capacitor is made of circular plates 10.0 cm in radius, separated by 4.00 mm. It is being charged by a constant 0.200 A current.

(a, 5 pts) Calculate the time rate of increase of the electric field between the plates, \( \frac{dE}{dt} \).

\[ \text{Need } E \rightarrow \text{ need } V \rightarrow \text{ need } C = \varepsilon_0 \frac{A}{d} = \varepsilon_0 \frac{\pi R^2}{d} \]

\[ \Rightarrow V = \frac{Q}{C} \] and \( E = \frac{V}{d} = \frac{Q}{C d} = \frac{Q}{\varepsilon_0 A} \) (Gauss' Law) \[ +2 \]

\[ \frac{dE}{dt} = \frac{1}{\varepsilon_0 A} \frac{dQ}{dt} = \frac{I}{\varepsilon_0 A} = \frac{7.19 \times 10^3 \text{ V/s}}{\left( \pi \left( 10 \text{ cm} \right)^2 \right)} \] \[ +3 \]

(b, 15 pts) Calculate the magnetic field \( B \) between the plates 5.00 cm from the center.

\[ I_{	ext{displ.}} = \varepsilon_0 \frac{dE}{dt} = \varepsilon_0 A \frac{dE}{dt} = \varepsilon_0 \frac{\pi R^2 I}{4} \]

\[ B = \frac{\mu_0 I_{	ext{displ.}}}{2 \pi R} = 2.00 \times 10^{-7} \text{ T} \]

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- Using \( I_{	ext{displ.}} \) in Ampere's Law \[ +5 \]
- Correct Ampere Loop \( \int B \cdot ds = 2\pi R B \) \[ +5 \]
- Correct value for \( B \) \[ +5 \]
2. The intensity of solar radiation incident on Earth's atmosphere is $1370 \text{ W/m}^2$. The average Earth-Sun distance is $1.496 \times 10^{11} \text{ m}$ and the radius of the Earth is $6.37 \times 10^6 \text{ m}$.

(a, 5 pts) Calculate the total power $P_{\text{sun}}$ radiated by the sun.

$$P_{\text{sun}} = S_{\text{sun}} \frac{4 \pi R^2}{\mu_0} = 1370 \text{ W/m}^2 \frac{4 \pi (1.496 \times 10^{11} \text{ m})^2}{\mu_0} = 3.85 \times 10^{26} \text{ W}$$

(b, 10 pts) Determine the RMS values of the electric field, $E_{\text{rms}}$, and the magnetic field, $B_{\text{rms}}$, in the sunlight incident on the Earth.

$$S = \frac{1}{\mu_0} \frac{E_{\text{rms}} B_{\text{rms}}}{c} \Rightarrow E_{\text{rms}} = \sqrt{\frac{\mu_0 c S}{c}} = 720 \text{ V/m}$$

$$E_{\text{rms}} = c \Rightarrow B_{\text{rms}} = \frac{E_{\text{rms}}}{c} = 2.4 \times 10^{-6} \text{ T}$$

If RMS value is not considered $\Rightarrow -4$

(c, 5 pts) Calculate the total power $P_{\text{earth}}$ incident on the Earth.

$$P_{\text{earth}} = S \frac{\pi R^2}{\mu_0} = 1370 \text{ W/m}^2 \frac{\pi (6.37 \times 10^6 \text{ m})^2}{\mu_0} = 1.75 \times 10^{17} \text{ W}$$
3. An object’s distance from a converging lens is 4.00 times the focal length.

(a, 10 pts) Draw a ray diagram for this situation showing the position of the image. You are free to choose the object height and focal length, but the diagram must be drawn to scale given the stated information.

\[ f = 20 \text{ mm} \]
\[ h = 30 \text{ mm} \]
\[ h' = -10 \text{ mm} \]

(b, 5 pts) Determine the position \( q \) of the image as a fraction of the focal length.

\[
\frac{1}{p} + \frac{1}{q} = \frac{1}{f} \quad p = 4f \quad \Rightarrow \quad \frac{1}{q} = \frac{1}{f} - \frac{1}{4f} = \frac{3}{4f}
\]

\[ q = \frac{4}{3} f \leftarrow 5 \text{ if correct} \]

(c, 5 pts) Determine the magnification \( M \) of the image and state whether it is real or virtual.

\[ M = -\frac{2}{p} = -\frac{4/3f}{4f} = -\frac{1}{3} \quad \text{real, inverted} \]

\[ \uparrow \quad 2 \]
\[ \downarrow \quad 2 \quad 1 \]
4. Interference fringes are produced using Lloyd's mirror and a source $S$ of wavelength $\lambda = 623$ nm as shown. Fringes separated by $\Delta y = 1.35$ mm are formed on a screen a distance $L = 2.20$ m from the source. (The drawing is very much not to scale.)

(20 pts) Determine the vertical distance $h$ of the source above the reflecting surface.

Looks like double-source interference with $d = 2h$ plus $\pi$ shift from reflection

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

$$s = d \sin \theta = d (m + \frac{1}{2}) \lambda$$

$$\theta = (m + \frac{1}{2}) \frac{\lambda}{d}$$

$$d \theta = \frac{\lambda}{d} \left( \text{diff between } m \text{ and } m+1 \right)$$

Correct expr. wrong answer

Wrong expr. answer 17

Wrong expr. answer 10

Answer nothing

$$\frac{\lambda}{d} = \frac{\Delta y}{L} \Rightarrow d = 2h = \frac{\lambda}{\Delta y}$$

$$h = \frac{\lambda L}{2 \Delta y} = 5.08 \times 10^{-4} \text{ cm} = 508 \mu\text{m}$$
5. Light from an unknown monochromatic source is sent through a single slit of width 0.650 mm. A diffraction pattern is observed on a screen 1.65 m beyond the slit. The distance between the positions of zero intensity on both sides of the central maximum is measured to be 2.73 mm.

(a, 10 pts) Calculate the wavelength $\lambda$ of the light.

\[ \lambda = 0.650 \text{ mm} \]

Minimum when

\[ b = \frac{na \sin \theta}{2} = m\pi \]

\[ \sin \theta = \frac{by}{L} \]

\[ \Rightarrow \frac{na}{2} \frac{dy}{L} = \pi \]

\[ dy = \frac{2.73 \text{ mm}}{2} \]

- Wrote $\sin \theta = m\lambda$, $m = 1$ (4)
- Low angle approximation $\theta \approx \sin \theta = \frac{y}{L}$ (1)
- Width $= 2 \cdot \frac{dy}{m+1} = 2.73$ (1)
- $\lambda = \frac{a}{2} \cdot \frac{dy}{L} = 538 \text{ nm}$

- Ended with a correct value (4)

(b, 10 pts) Calculate the intensity $I_1$ of the light at the first maximum away from the center, as a fraction of the central intensity, $I_0$.

First maximum

\[ \beta = \frac{\pi}{2} = \frac{na \sin \theta}{2} \]

\[ \Rightarrow \left( \frac{\sin \beta}{\beta} \right)^2 = \left( \frac{1}{\pi/2} \right)^2 = 0.405 \]

\[ I_1/I_0 = 0.405 \]

- Correct single slit formula $I = \left[ \frac{\sin \beta}{\beta} \right]^2$, $\beta = \frac{na \sin \theta}{2}$ - (5)
- Find $\beta$ correctly $\beta = \frac{\pi}{2}$ - (2)
- $\frac{I_1}{I_0} = 0.405$ Number Correct - (3)