

Final Exam (2014 Summer)

PHYS 203B: College Physics

Date: 2014 Jul 31

Solution

(Name)

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Instructions

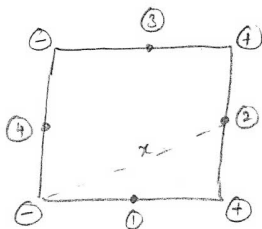
1. Total time = 110 minutes.
2. There are 15 questions in this exam, worth a total of 150 points.
3. Equation sheet is provided.
4. To obtain partial credit for your work you need to show your work in detail and organize it clearly.

1. (10 points.) A spherical surface completely surrounds a collection of charges. Find the electric flux through the surface if the collection consists of five protons, four electrons, and nine neutrons.

$$\begin{aligned}\phi_E &= \frac{Q_{\text{inside}}}{\epsilon_0} \\&= \frac{(5 - 4 + 0) \times 1.6 \times 10^{-19}}{8.85 \times 10^{-12}} \\&= 1.8 \times 10^{-8} \frac{\text{Nm}^2}{\text{C}}\end{aligned}$$

2. (10 points.) Two electrons and two protons are placed at the corners of a square of side 5 cm, such that diagonally opposite corners have unlike charges.

- (a) What is the electric potential at the center of the square?
 (b) What is the electric potential at the midpoint of each of the four sides of the square?



$$\text{diagonal} = d = \sqrt{2} L$$

$$\begin{aligned} (a) \quad V_{\text{center}} &= + \frac{ke}{(d/2)} + \frac{ke}{(d/2)} - \frac{ke}{(d/2)} - \frac{ke}{(d/2)} \\ &= 0 \end{aligned}$$

$$(b) \quad V_{\text{①}} = 0$$

$$V_{\text{③}} = 0$$

$$\begin{aligned} V_{\text{②}} &= \frac{ke}{(L/2)} + \frac{ke}{L/2} - \frac{ke}{x} - \frac{ke}{x} \\ &= \frac{2ke}{L} - \frac{2ke}{\sqrt{2} L/2} = \frac{2ke}{L} \left(1 - \frac{2}{\sqrt{2}}\right) \\ &= \frac{2 \times 8.9 \times 10^9 \times 1.6 \times 10^{-19}}{5 \times 10^{-2}} = 5.8 \times 10^{-8} \text{ V} \end{aligned}$$

$$\begin{aligned} x &= \sqrt{\left(\frac{L}{2}\right)^2 + L^2} \\ &= \sqrt{5} \frac{L}{2} \end{aligned}$$

$$\begin{aligned} V_{\text{④}} &= \frac{ke}{x} + \frac{ke}{x} - \frac{ke}{L/2} - \frac{ke}{L/2} \\ &= -V_{\text{②}} \\ &= -5.8 \times 10^{-8} \text{ V} \end{aligned}$$

3. (10 points.) An electron and a proton, starting from rest, are accelerated through an electric potential difference of the same magnitude. In the process, the electron acquires a speed v_e , while the proton acquires a speed v_p . Find the ratio of their velocities,

$$\frac{v_e}{v_p}, \quad (1)$$

where m_e is the mass of the electron and $m_p = 1836m_e$ is the mass of the proton.

$$K_e = K_p$$

$$\frac{1}{2} m_e v_e^2 = \frac{1}{2} m_p v_p^2$$

$$\frac{v_e^2}{v_p^2} = \frac{m_p}{m_e} = 1836$$

$$\frac{v_e}{v_p} = \sqrt{1836} = 42.9$$

4. (10 points.) A charge particle enters a uniform magnetic field and follows the path shown in Fig. 1. What can you conclude about the charge of the particle, that is, is it positive, negative, or neutral?

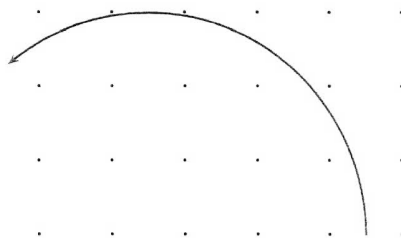


Figure 1: Problem 4

Negative

5. (10 points.) A wire carries a current of 1.5 A. This wire makes an angle of 60° with respect to a magnetic field of magnitude $6.00 \times 10^{-5} \text{ T}$. The wire experiences a magnetic force of magnitude $4.50 \times 10^{-5} \text{ N}$. What is the length of the wire?



$$\theta = 60^\circ$$

$$F = ILB \sin \theta$$

$$4.5 \times 10^{-5} = 1.5 \times L \times 6.00 \times 10^{-5} \sin 60$$

$$L = \frac{4.5 \times 10^{-5}}{1.5 \times 6.00 \times 10^{-5} \sin 60}$$

$$= 0.58 \text{ m}$$

6. (10 points.) Figure 2 shows a conducting rod being pulled along horizontal, frictionless, conducting rails at a constant speed v . A uniform magnetic field $\mathbf{B}$ fills the region in which the rod moves. Assume $L = 10 \text{ cm}$, $v = 5.0 \text{ m/s}$, $B = 1.5 \text{ T}$, and $R = 0.50 \Omega$.
- Is the magnetic flux in the loop increasing or decreasing?
 - What is the direction of the induced current in the loop?
 - Determine the magnitude of the induced current in the loop.

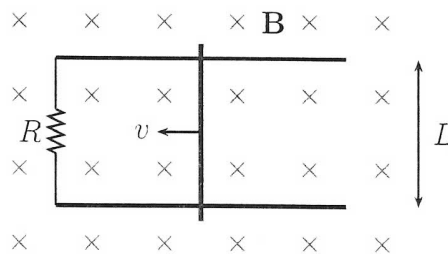


Figure 2: Problem 6

(a) Decreasing

(b) clockwise.

$$\begin{aligned}
 \text{(c)} \quad I &= \frac{BvL}{R} \\
 &= \frac{1.5 \times 5.0 \times 10 \times 10^{-2}}{0.50} \\
 &= 1.5 \text{ A}
 \end{aligned}$$

7. (10 points.) Figure 3 shows five snapshots of a rectangular coil being pushed across the dotted region where there is a uniform magnetic field directed into the page. Outside of this region the magnetic field is zero. Determine the direction of induced current in the loop at each of the five instances in the figure.

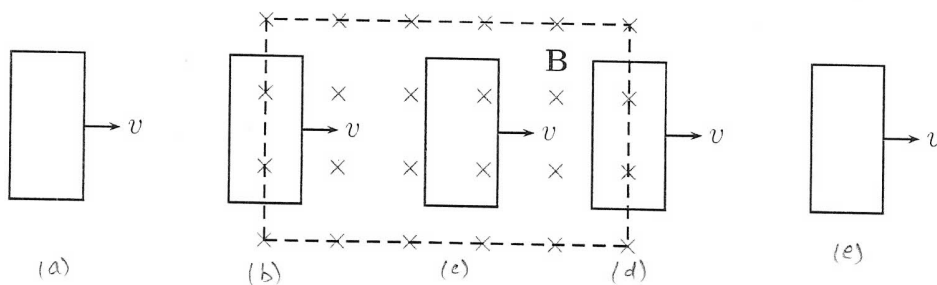


Figure 3: Problem 7

(a) $I = 0$

(b) Flux increasing
 I is anticlockwise.

(c) $I = 0$

(d) Flux decreasing
 I is clockwise.

(e) $I = 0$

8. (10 points.) Galaxy *A* is moving to the East with respect to an observer at 320 km/s. Galaxy *B* is moving to the West with respect to the same observer at 420 km/s. Light of frequency 690 MHz is emitted by galaxy *A*. What will be the frequency of this light as measured by an observer in galaxy *B*?

$$\begin{aligned} u_{\text{rel}} &= 420 + 320 \\ &= 740 \frac{\text{km}}{\text{s}} \\ &= 7.4 \times 10^5 \frac{\text{m}}{\text{s}} \end{aligned}$$

$$\begin{aligned} f' &= f \left(1 - \frac{u_{\text{rel}}}{c} \right) \\ &= 690 \text{ MHz} \left(1 - \frac{7.4 \times 10^5}{3 \times 10^8} \right) \\ &= 688 \text{ MHz} \end{aligned}$$

9. (10 points.) Figure 4 shows three polarizers in series. The angles θ_A , θ_B , and θ_C , represent the angles the respective transmission axis of the polarizers A , B , and C , makes with the vertical. Consider a beam of unpolarized light of intensity I_0 incident on the polarizer A . (Express your answers in terms of I_0 .)

- What is the intensity of the transmitted beam after it passes the polarizer A and before it passes polarizer B ?
- What is the intensity of the transmitted beam after it passes the polarizer B and before it passes polarizer C ?
- What is the intensity of the transmitted beam after it passes the polarizer C ?
- In the absence of polarizer B , what is the intensity of the transmitted beam after it passes the polarizer C ?

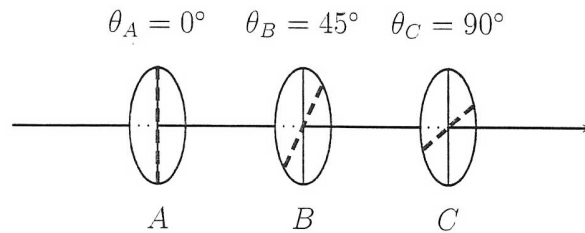


Figure 4: Problem 9

$$(a) \quad I_A = \frac{I_0}{2}$$

$$(b) \quad I_B = I_A \cos^2(\theta_B - \theta_A) \\ = \frac{I_0}{2} \cos^2(45^\circ - 0^\circ) = \frac{I_0}{2} \cdot \frac{1}{2} = \frac{I_0}{4}$$

$$(c) \quad I_C = I_B \cos^2(\theta_C - \theta_B) \\ = \frac{I_0}{4} \cdot \frac{1}{2} = \frac{I_0}{8}$$

10. (10 points.) A 2.0 cm object is placed upright at a distance 4.0 cm from a concave mirror. The mirror's radius of curvature is 10.0 cm.

- Calculate the image distance.
- What is the magnification?
- Is the image real or virtual?
- Is the image inverted or upright?
- What is height of the image?
- Confirm your above results by drawing a ray diagram for the above case. Points will be awarded for precision.

$$(a) \quad \frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$$

$$\frac{1}{4} + \frac{1}{d_i} = \frac{1}{5}$$

$$\frac{1}{d_i} = \frac{1}{5} - \frac{1}{4} = -\frac{1}{20} \Rightarrow d_i = -20 \text{ cm}$$

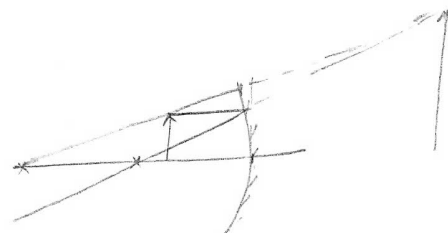
$$(b) \quad m = -\frac{d_i}{d_o} = -\frac{(-20 \text{ cm})}{4 \text{ cm}} = 5$$

(c) virtual

(d) upright

$$(e) \quad m = \frac{h_i}{h_o}$$

$$\begin{aligned} h_i &= m h_o \\ &= 5 \times 2.0 \text{ cm} \\ &= 10 \text{ cm} \end{aligned}$$



11. (10 points.) A 2.0 cm object is placed upright at a distance 4.0 cm from the center of a convex lens (converging lens). The lens' focal length is 6.0 cm.

- Calculate the image distance.
- What is the magnification?
- Is the image real or virtual?
- Is the image inverted or upright?
- What is height of the image?
- Confirm your above results by drawing a ray diagram for the above case. Points will be awarded for precision.

$$(a) \quad \frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$$

$$\frac{1}{4} + \frac{1}{d_i} = \frac{1}{6}$$

$$\frac{1}{d_i} = \frac{1}{6} - \frac{1}{4} = -\frac{2}{24} \Rightarrow d_i = -12 \text{ cm}$$

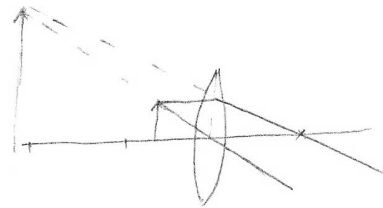
$$(b) \quad m = -\frac{d_i}{d_o} = -\frac{(-12 \text{ cm})}{(4 \text{ cm})} = 3$$

(c) virtual

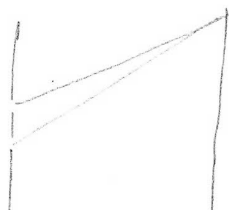
(d) upright

$$(e) \quad m = \frac{h_i}{h_o}$$

$$\begin{aligned} h_i &= m h_o \\ &= 3 \times 2 \text{ cm} \\ &= 6 \text{ cm} \end{aligned}$$



12. (10 points.) Two slits in the Young's double slit experiment have a separation of 0.300 mm. The first-order minimum occurs at an angle of 0.100° from the central maximum. Determine the wavelength of light (in nm).

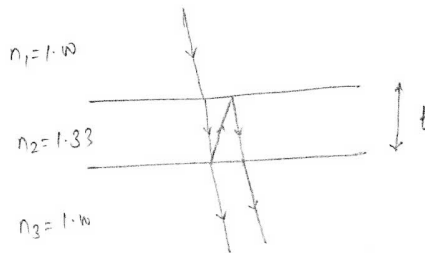


$$\frac{d \sin \theta}{\lambda} = \begin{cases} m & \text{max} \\ m + \frac{1}{2} & \text{min} \end{cases}$$

$$\frac{d \sin \theta}{\lambda} = 0 + \frac{1}{2} \quad (m=0, \text{ minimum})$$

$$\begin{aligned} \lambda &= 2 d \sin \theta \\ &= 2 \times 0.300 \times 10^{-3} \text{ m} \times \sin(0.100) \\ &= 1047 \text{ nm} \end{aligned} \quad (\text{not in visible spectrum!})$$

13. (10 points.) Light of wavelength 636 nm is incident perpendicularly on a soap film ($n = 1.33$) suspended in air ($n = 1.00$). What is the smallest nonzero thickness (in nm) of the film for which the transmitted light from the film undergoes fully destructive interference? (Caution: The observer is viewing transmitted light.)



$$n \frac{x_2 - x_1}{\lambda} = n_2 \frac{2t}{\lambda}$$

$$m' = 0$$

$$n \frac{x_2 - x_1}{\lambda} + m' \frac{\lambda}{2} = \begin{cases} m & \text{max} \\ m + \frac{1}{2} & \text{min} \end{cases}$$

$$n_2 \frac{2t}{\lambda} = (m + \frac{1}{2})$$

$$t = (m + \frac{1}{2}) \frac{\lambda}{2n_2}$$

$$= \frac{\lambda}{4n_2} \quad (m=0)$$

$$= \frac{636 \text{ nm}}{4 \times 1.33}$$

$$= 119.6 \text{ nm}$$

14. (10 points.) A man on the moon observes two spaceships coming toward him from the same direction at speeds of $0.8c$ and $0.9c$ respectively. What is the relative speed of the two spaceships as measured by an observer on either one?

$$\begin{array}{ccc} \longrightarrow & & \longrightarrow \\ V_{AG} = 0.8c & & V_{BG} = 0.9c. \end{array} \quad (10)$$

$$\begin{aligned} V_{AB} &= \frac{V_{AG} - V_{BG}}{1 - \frac{V_{AG}}{c} \frac{V_{BG}}{c}} \\ &= \frac{0.8c - 0.9c}{1 - 0.8 \times 0.9} \\ &= - \frac{0.1c}{0.28} = -0.357c. \end{aligned}$$

$$V_{BA} = 0.357c.$$

15. (10 points.) A stick is projected into space at so great a speed that its length appears contracted by three-fifth. How fast is the stick going in m/s?

$$L' = \frac{L}{\gamma}$$

$$L' = \frac{3}{5} L$$

$$\frac{3}{5} = \frac{1}{\gamma}$$

$$\frac{9}{25} = 1 - \frac{v^2}{c^2}$$

$$\frac{v}{c} = \sqrt{1 - \frac{9}{25}}$$

$$v = \frac{4}{5} c$$

$$= 2.98 \times 10^8 \text{ m/s.}$$