Electromagnetism and Optics: Class Exam I

20 February 2026

Name: SOLUTION **Total:** /80

Instructions

- There are 8 questions on 6 pages.
- Show your reasoning and calculations and always explain your answers.

Physical constants and useful formulae

$$e = 1.60 \times 10^{-19}\,\mathrm{C} \qquad q_{\text{electron}} = -e \qquad q_{\text{proton}} = +e$$

$$m_{\text{electron}} = 9.11 \times 10^{-31}\,\mathrm{kg} \qquad m_{\text{proton}} = 1.67 \times 10^{-27}\,\mathrm{kg}$$

$$k = 8.99 \times 10^{9}\,\mathrm{Nm^2/C^2} \qquad \epsilon_0 = 8.85 \times 10^{-12}\,\mathrm{C^2/Nm^2}$$

Question 1

A minute sphere with radius 2.34×10^{-8} m contains exactly 3.80×10^{17} protons and 3.95×10^{17} electrons. Both are uniformly distributed in fixed positions on the sphere. A single proton is to the right of the sphere 7.0×10^{-6} m from the center of the sphere. Determine the force exerted by the sphere on the proton. ✓

$\underbrace{F = k\dfrac{q_1 q_2}{r^2}}_{+1}$

$\vec{F} \leftarrow$ $q_2 = e$ $\bullet +$

charge $= \underbrace{0.15 \times 10^{17}}_{+1}$ electrons $\times \underbrace{1.6 \times 10^{-19}\,C}_{+1} = 2.4 \times 10^{-3}\,C$

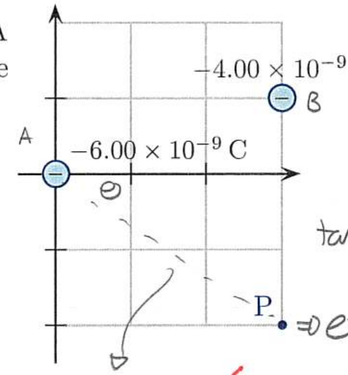
$\underbrace{F = 8.99 \times 10^{9}\,\dfrac{Nm^2}{C^2}\,\dfrac{2.4 \times 10^{-3}\,C \times 1.6 \times 10^{-19}\,C}{(7.0 \times 10^{-6}\,m)^2}}_{+2}$

$\vec{F} = 0.072N \underbrace{\leftarrow}_{+1}$

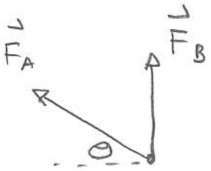
/6

Question 2

Two point particles are held fixed at the illustrated locations. A third particle with charge 3.50×10^{-6} C is placed at location P. The axis units are 1.00×10^{-3} m.



a) Determine the net force on the particle at location P.



+1

$$\vec{F} = \vec{F}_A + \vec{F}_B$$

$\tan\theta = \frac{2}{3}$

$\Rightarrow \theta = \arctan\frac{2}{3}$

+1 $\Rightarrow \theta = 33.7°$

magnitudes

$$F_A = \underbrace{k\frac{q_A q}{r_A^2}}_{+1} = 8.99\times10^9 \frac{Nm^2}{C^2}\frac{6.0\times10^{-9}C \times 3.5\times10^{-6}C}{(3.61\times10^{-3}m)^2}$$

+1

$$= 14.5N$$

$r_A = \sqrt{(3\times10^{-3}m)^2 + (2\times10^{-3}m)^2}$

+1 $= 3.61\times10^{-3}m$

$$F_B = \frac{kq_Bq}{r^2} = 8.99\times10^9\frac{Nm^2}{C^2}\frac{4.0\times10^{-9}C \times 3.5\times10^{-6}C}{(0.003m)^2} = 14.0N$$

+1

Components formula +1

$F_{Ax} = -F_A\cos 33.7° = -14.5N\cos 33.7° = -12.1N$

$F_{Ay} = F_A\sin 33.7° = 14.5N\sin 33.7°$ +3

$F_{Bx} = 0$

$F_{By} = 14.0N$

	x	y
$\vec{F}_A$	$-12.1N$	$8.04N$
$\vec{F}_B$	0	$14.0N$

+3

$\Rightarrow F_x = -12.1N$

$F_y = 22.0N$

$$\vec{F} = -12.1N\,\hat{i} + 22.0N\,\hat{j}$$

b) Suppose that the -4.00×10^{-9} C particle was replaced with a $+4.00 \times 10^{-9}$ C particle. Which of the following (choose one) is true regarding, F, the magnitude of the force exerted on the particle at P?

i) F would stay the same as before.

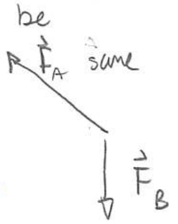
ii) F would be larger than what it was before.

iii) F would be smaller than what it was before.

/16

+3

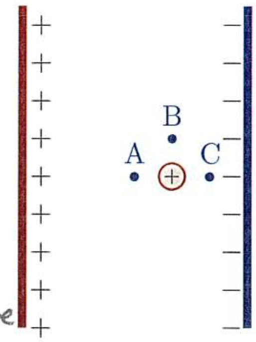
The forces would be



y component would be smaller.

Question 3

An infinite parallel plate capacitor hold charges that are equal in magnitude but opposite in sign on its plates. A positive point charge is placed between the plates, closer to the negatively charged plate. Consider the electric field at the three illustrated locations, which are all the same distance from the point charge. Which of the following (choose one) is true regarding the *magnitudes* of the total electric field (produced by *all the charges*) at the illustrated locations?



i) $E_A = E_B = E_C$

ii) $E_A < E_B < E_C$

iii) $E_A > E_B > E_C$

iv) $E_A = E_C > E_B$

v) $E_A = E_C < E_B$

$\vec{E}_{plate}$ is $\rightarrow$ same everywhere

at A $\vec{E}_{point}$ $\vec{E}_{plate}$ $\rightsquigarrow$ $\vec{E}$

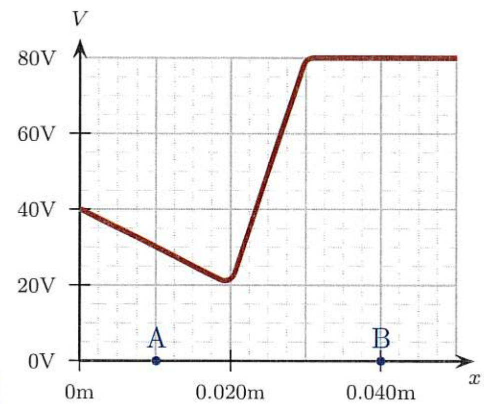
at B

at C

/5

Question 4

Various hidden sources produce an electric potential that depends on horizontal location as illustrated. The horizontal axis units are meters and the vertical axis units are Volts. ~~Determine the electric field at points A,B,C and D.~~



a) Determine the electric field at location A.

$$\underbrace{E_x = -\frac{dV}{dx}}_{(+2)} = -\text{slope } V \text{ vs } x$$

$$= -\frac{\Delta V}{\Delta x} = -\frac{-20V}{0.020m} \quad \cancel{+3}\ +2$$

$$= 1000V/m$$

must have correct direction.

$$\Rightarrow \vec{E} = 1000\ V/m\ \hat{\imath} \quad +1$$

b) Explain whether the *magnitude* of the electric field at location B is the same as, larger than or smaller than that at location A.

$$\underbrace{E_x = -\frac{\Delta V}{\Delta x} = 0}_{+2} \Rightarrow \underbrace{\text{smaller}}_{+2}$$

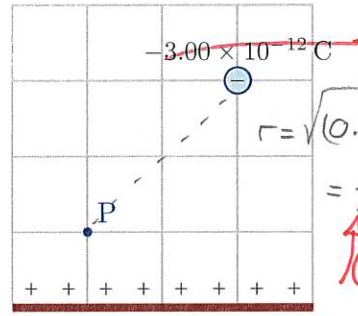
/9

-1.2×10^{-12}

Question 5

A uniformly charged infinite plane carries charge with charge density $+8.00 \times 10^{-8}\,\mathrm{C/m^2}$. A particle with charge $-\cancel{3.00}$ 1.20 $\times 10^{-12}\,\mathrm{C}$ is fixed as illustrated. The grid units are $1.00 \times 10^{-3}\,\mathrm{m}$.

$-1.20 \times 10^{-12}\,C$

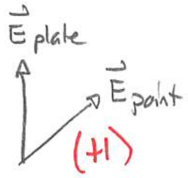


$r = \sqrt{(0.002)^2 + (0.002)^2}$

$= 2.8 \times 10^{-3}\,m$

(+1)

a) Determine the electric field, produced by all illustrated charges at location P.



$$\vec{E} = \vec{E}_{plate} + \vec{E}_{point}$$

magnitudes

$$E_{plate} = \underset{(+1)}{\frac{\eta}{2\epsilon_0}} = \frac{8 \times 10^{-8}\,C/m^2}{2 \times 8.85 \times 10^{-12}\,C^2/Nm^2} = \underset{(+1)}{4.52 \times 10^3\,N/C}$$

$$E_{point} = \underset{(+1)}{k\frac{q}{r^2}} = 8.99 \times 10^9\,\frac{Nm^2}{C^2}\,\frac{1.2 \times 10^{-12}\,C}{(2.83 \times 10^{-3}\,m)^2} = \overset{(+1)}{1.35 \times 10^3\,N/C}$$

components

$$\left.\begin{aligned} E_{point\,x} &= E_{point}\cos 45^\circ = 0.953 \times 10^3\,N/C \\ E_{point\,y} &= E_{point}\sin 45^\circ = 0.953 \times 10^3\,N/C \end{aligned}\right]\ (+3)$$

	x	y
plate	0.953×10^3 N/C	0.953×10^3 N/C
point	0	4.52×10^3 N/C

(+3)

$$\vec{E} = 0.953 \times 10^3\,N/C\,\hat{i} + 5.47 \times 10^3\,N/C\,\hat{j}$$

b) Determine the acceleration of a proton at location P.

$$(+1)\left[\vec{F} = q\vec{E}\right. \Rightarrow \vec{F} = 1.6 \times 10^{-19}\,C\,\vec{E} =$$

$$(+1)\left[\vec{a} = \vec{F}/m\right. \Rightarrow \vec{a} = \frac{q}{m}\vec{E} = \frac{1.6 \times 10^{-19}\,C}{1.67 \times 10^{-27}\,kg}\vec{E}$$

// $9.13 \times 10^{10}\,m/s^2\,\hat{i} + 5.24 \times 10^{11}\,m/s^2\,\hat{j}$

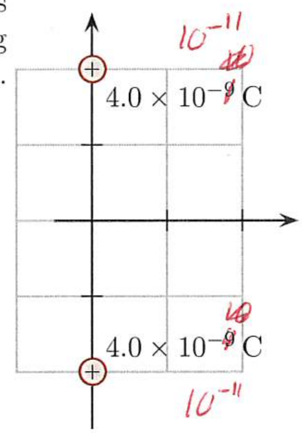
magnitude 5.32×10^{11}

(+2) must have direction otherwise (−1)

/16

Question 6

Two identical point charges are held fixed at the illustrated locations (grid units are 1.00×10^{-2} m). An electron is released from rest along the horizontal axis at a distance approaching infinity from the origin. Determine the speed of the electron when it reaches the origin.



$$\Delta K + q\Delta V = 0$$

$$K_f - K_i + q(V_f - \cancel{V_i}) = 0$$

$V_i = k\frac{q_{upper}}{r_i}$ ∞

need this

$$\frac{1}{2}mv_f^2 - \cancel{\frac{1}{2}mv_i^2} + qV_f = 0$$

$$\frac{1}{2}mv_f^2 = -qV_f$$

$$v_f = \sqrt{\frac{-2qV_f}{m}}$$

only use one charge (-3)

$$V_f = V_{upper} + V_{lower} = k\frac{q_{upper}}{r} + k\frac{q_{lower}}{r} = 2 \times 8.99\times10^9 \frac{Nm^2}{C^2}\,\frac{4.0\times10^{-11}C}{2.00\times10^{-2}m}$$

$$= 36V$$

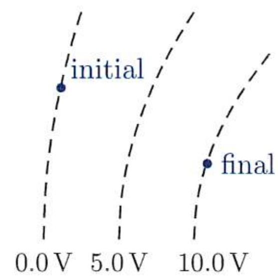
$$v_f = \sqrt{\frac{-2(-1.6\times10^{-19}C)\,36}{9.11\times10^{-31}kg}}$$

$$= 3.6\times10^6 \, m/s$$

/14

Question 7

Various hidden sources produce a potential with the illustrated equipotential lines. A particle with charge $-8.0\,\mathrm{nC}$ passes through the initial location at speed $60\,\mathrm{m/s}$.



a) Determine the change in electric potential energy as the particle moves from the initial to final point.

$\Delta U_{elec} = \underbrace{q\,\Delta V}_{+1}$

$= -8\times10^{-9}\,C \times \underbrace{10\,V}_{+1} = \underbrace{-8\times10^{-8}\,J}_{+3 \text{ negative}}$

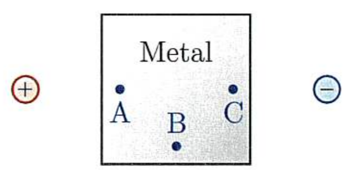
b) Does the particle speed up or slow down as it moves from initial to final location? Explain your answer.

$\underbrace{\Delta K + \Delta U_{elec} = 0}_{+2 \text{ or equiv}} \Rightarrow \Delta K > 0$ $\underbrace{\text{speeds up}}_{+2}$

/9

Question 8

Two point particles with opposite charges are on either side of a cube of perfectly conducting metal. Which of the following (choose one) is true regarding the electric potential at the illustrated points inside the cube?



i) $V_A = V_B = V_C$ conductor

ii) $V_A < V_B < V_C$

iii) $V_A > V_B > V_C$

iv) $V_A = V_C > V_B$

v) $V_A = V_C < V_B$

/5