Electromagnetism and Optics: Class Exam I

19 September 2018

Name: ______________________________ **Total:** /70

Instructions

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

Physical constants and useful formulae

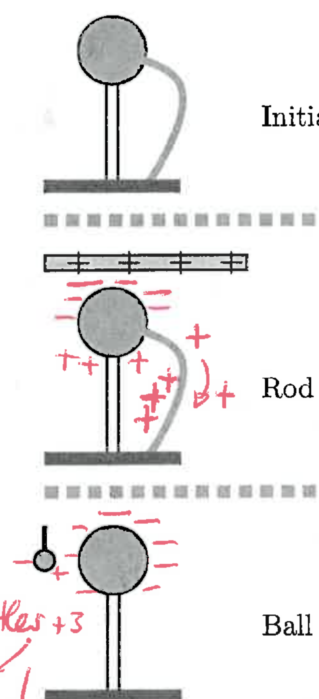
$$e = 1.61 \times 10^{-19}\,\mathrm{C} \qquad q_{\mathrm{electron}} = -e \qquad q_{\mathrm{proton}} = +e$$

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

$$k = 9.0 \times 10^{-9}\,\mathrm{Nm^2/C^2} \qquad \epsilon_0 = 8.85 \times 10^{-12}\,\mathrm{C^2/Nm^2}$$

Question 1

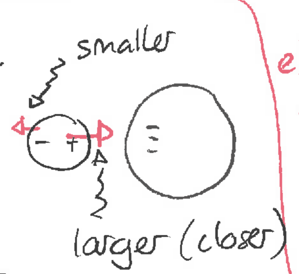
A metal ball on an insulating stand is initially neutral. The ball is connected to the earth by a wire. Then a positively charged rod is held above the ball but does not touch it. While the rod is in place, the wire is removed. After this the rod is removed. At this stage, a second metal ball suspended on a string and initially uncharged is brought into contact with the ball on the stand. Describe the charges on the two balls and whether they repel, attract or exert no force on each other. Explain your answer.



The rod polarizes the sphere effectively forcing positives into the earth. When the wire is removed the sphere has an excess negative charge.

+3

This polarizes the ball. The resulting forces on the suspended ball are illustrated. The net force is toward the ball on the stand. ⇒ attract



consistent with diagram. Different to "contact with ball on stand"

either +3

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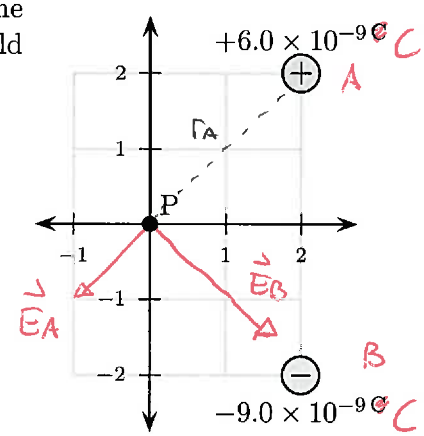
For to contact with ball on stand: Upon contact both balls are negative ~ after they repel

Question 2

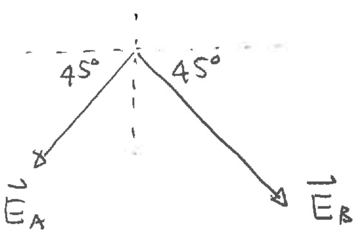
Two point charges are held fixed at the illustrated locations. The axis units are 1.0×10^{-3} m. Determine the **net** electric field produced by both of these at point P.



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

The two vectors are:

+2



+1 +1

Now $E_A = k \frac{q_A}{r_A^2}$ and $r_A^2 = (2.0 \times 10^{-3} m)^2 + (2.0 \times 10^{-3} m)^2$
$= 8.0 \times 10^{-6} m^2$

+2 $E_A = 8.99 \times 10^9 \frac{Nm^2}{C^2} \frac{6.0 \times 10^{-9} C}{8.0 \times 10^{-6} m^2} = 6.8 \times 10^6 N/C$

Then +2 $E_B = k \frac{q_B}{r_B^2} = 8.99 \times 10^9 \frac{Nm^2}{C^2} \frac{9.0 \times 10^{-9} C}{8.0 \times 10^{-6} m^2} = 10.1 \times 10^6 N/C$

To add vectors we need components

All four components? +4

$E_{Ax} = -E_A \cos 45°$
$= -6.8 \times 10^6 \cos 45° = -4.8 \times 10^6$ N/C

$E_{Ay} = E_{Ax}$ (45° triangle)

$E_{Bx} = E_B \cos 45°$
$= 10.1 \times 10^6$ N/C $\cos 45° = 7.2 \times 10^6$ N/C

	x	y
$\vec{E}_A$	-4.8×10^6 N/C	-4.8×10^6 N/C
$\vec{E}_B$	7.2×10^6 N/C	-7.2×10^6 N/C
	2.4×10^6 N/C	-12×10^6 N/C

So $\vec{E} = 2.4 \times 10^6 N/C\ \hat{i} - 12 \times 10^6 N/C\ \hat{j}$

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+2 addition

Question 3

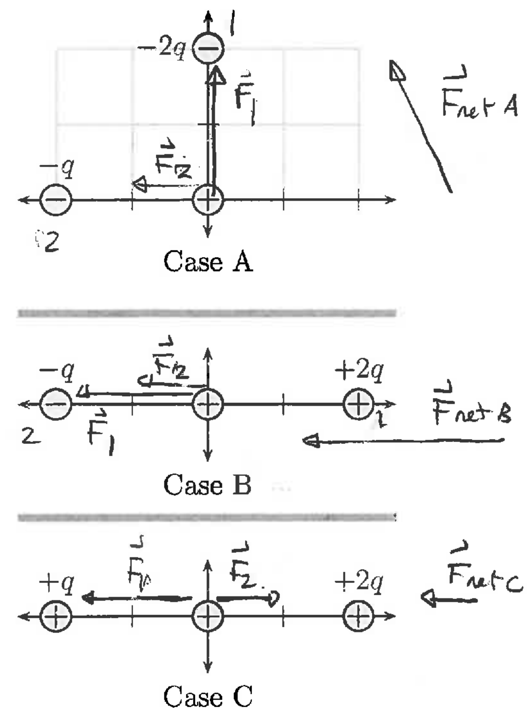
A +1.00 C particle is placed at the origin in the vicinity of other charge particles in various arrangements. Which of the following (choose one) is the correct rank of the *magnitudes* of the net force on the particle at the origin?

i) $F_{\text{case B}} < F_{\text{case A}} = F_{\text{case C}}$

ii) $F_{\text{case C}} < F_{\text{case A}} < F_{\text{case B}}$

iii) $F_{\text{case A}} < F_{\text{case C}} < F_{\text{case B}}$

iv) $F_{\text{case A}} < F_{\text{case B}} < F_{\text{case C}}$



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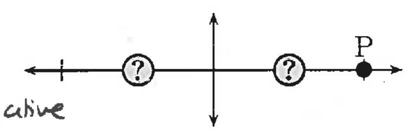
Question 4

Two mystery point charges are held fixed at the indicated locations. An electron is placed at point P and the net force on the electron is right (+î). The electron is removed and replaced by a proton.



negative

On electron → $\vec{F}$ and $\vec{F} = q\vec{E}$ means $\vec{E}$ is ←

a) Which of the following is true regarding the electric field produced by the two mystery charges at the proton's location?

i) $\vec{\mathbf{E}} = 0$.

ii) $\vec{\mathbf{E}} \neq 0$ and is →.

iii) $\vec{\mathbf{E}} \neq 0$ and is ←.

b) Which of the following is true regarding the force exerted by the two mystery charges on the proton?

i) $\vec{\mathbf{F}} = 0$.

ii) $\vec{\mathbf{F}} \neq 0$ and is →.

iii) $\vec{\mathbf{F}} \neq 0$ and is ←.

$\vec{F} = q\vec{E}$ ←

positive

mean $\vec{F}$ is ←

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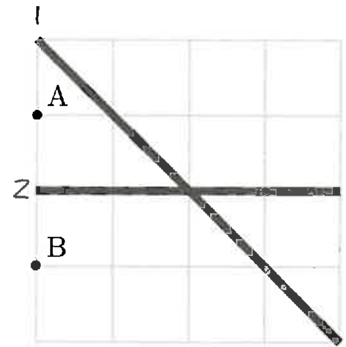
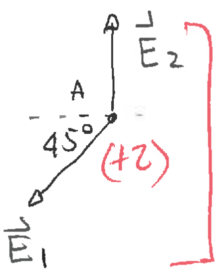
Question 5

Two uniformly charged infinite planes intersect at an angle of 45°, as illustrated. Each carries charge with charge density $+8.0 \times 10^{-6}\,\mathrm{C/m^2}$. The grid units are 0.010 m.



a) Determine the net electric field produced at point A.

$\vec{E} = \vec{E}_1 + \vec{E}_2$



The fields have the same magnitude

(+1)

$$E = \frac{\eta}{2\epsilon_0} = \frac{8.0\times10^{-6}\,C/m^2}{2\times 8.85\times10^{-12}\,C^2/Nm^2} = 4.5\times10^5\,N/C \quad (+2)$$

Then $\vec{E}_1 = E_{1x}\hat{i} + E_{1y}\hat{j}$

$E_{1x} = -E_1\cos 45° = -3.2\times10^5\,N/C$

$E_{1y} = -E_1\sin 45° = -3.2\times10^5\,N/C$ (+4)

$= -3.2\times10^5\hat{i} - 3.2\times10^5\hat{j}$ in N/C

(+1) $\vec{E}_2 = 4.5\times10^5\,N/C\,\hat{j}$

(+2) So $\vec{E} = -3.2\times10^5\,N/C\,\hat{i} - 3.2\times10^5\,N/C\,\hat{j} + 4.5\times10^5\,N/C\,\hat{j}$

$\vec{E} = -3.2\times10^5\,N/C\,\hat{i} + 1.3\times10^5\,N/C\,\hat{j}$

b) Two identical copies of this arrangement are created in one a proton is placed at point A and, in the other, an electron at point B. Which of the following (choose one) is true regarding the *magnitude* of the net force on the electron and proton? (+4)

i) The magnitudes of the net forces are the same.

(ii) The magnitude of the net force on the electron is larger than that on the proton.

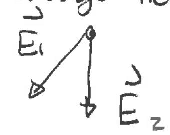
iii) The magnitude of the net force on the electron is smaller than that on the proton.

$\vec{F} = q\vec{E}$

$|\vec{F}| = |q||\vec{E}| = e|\vec{E}|$ — same

So larger $|\vec{E}|$ ⇒ larger $|\vec{F}|$ — larger at B

At B the two add to a larger field



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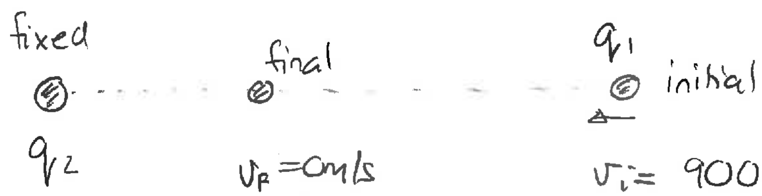
Question 6 0.080kg

A point particle with charge $+2.0 \times 10^{-6}$ C is held fixed. Another point particle with charge $+4.0 \times 10^{-3}$ C and mass ~~0.80~~ kg is fired directly toward the first from a distance of 0.40 m with a speed of 90~~0~~ m/s. Determine the distance between the two charges when they are nearest to each other.



$v_f = 0\,m/s$ $\quad$ $v_i = 900\,m/s$

$r_f = ??$ $\quad$ $r_i = 0.40\,m$

Energy conserved

$$\Delta K + q_1 \Delta V = 0$$] or equiv +1

$$K_f - K_i + q_1(V_f - V_i) = 0$$

Now the potential is $V = k\dfrac{q_2}{r}$] +1

$$\Rightarrow \quad -\frac{1}{2}mv_i^2 + q_1\left(k\frac{q_2}{r_f} - k\frac{q_2}{r_i}\right) = 0$$

+1 $\quad$ +3 (included in calculation)

$$\Rightarrow \quad -\frac{1}{2}mv_i^2 + kq_1q_2\left(\frac{1}{r_f} - \frac{1}{r_i}\right) = 0$$

$$\Rightarrow \quad kq_1q_2\left(\frac{1}{r_f} - \frac{1}{r_i}\right) = \frac{1}{2}mv_i^2$$

$$\Rightarrow \quad \frac{1}{r_f} - \frac{1}{r_i} = \frac{mv_i^2}{2kq_1q_2}$$

$$\Rightarrow \quad \frac{1}{r_f} = \frac{1}{r_i} + \frac{mv_i^2}{2kq_1q_2} = \frac{1}{0.40\,m} + 4.5\,m^{-1} = 7.0\,m$$

$$\Rightarrow \quad r_f = \frac{1}{7\,m} = 0.14\,m$$

+4

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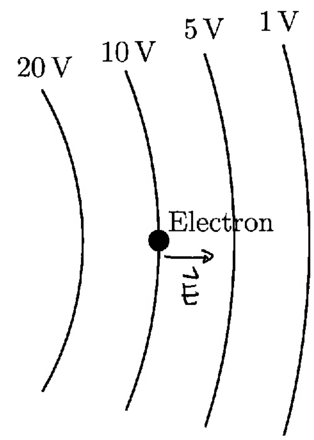
Question 7

A charge distribution produces equipotentials as illustrated. An electron is placed at the illustrated location. Which of the following best describes the direction of the force exerted on the electron?



i) $\hat{\mathbf{i}}$
ii) $-\hat{\mathbf{i}}$
iii) $\hat{\mathbf{j}}$
iv) $-\hat{\mathbf{j}}$

Briefly explain your answer.

$\vec{F} = q\vec{E} = -e\vec{E}$

So $\vec{F}$ is opposite $\vec{E}$.

$\vec{E}$ is perpendicular to equipotential in downhill direction $\rightarrow \hat{\imath}$

So $\vec{F}$ is $\leftarrow = -\hat{\imath}$

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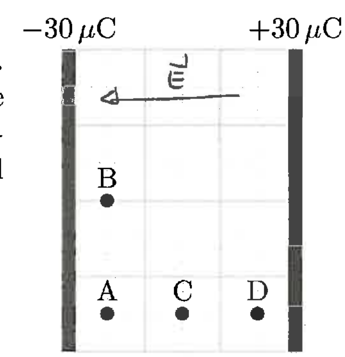
Question 8

Two parallel plates carry equal but opposite charges as illustrated. The plates are large enough that they can be assumed to be infinite and the charge is uniformly distributed on each. Which of the following (choose one) best ranks the electric potentials at the illustrated points?



i) $V_A = V_B < V_C < V_D$
ii) $V_A < V_B < V_C < V_D$
iii) $V_D < V_C < V_B < V_A$
iv) $V_D < V_C < V_B = V_A$

V decreases along field +
only depends on distance from + plate
$V_D > V_C > A_B = V_A$.

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