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Practice Midterm, Physics 1B, Winter 2020

- Please write your name and UID in the boxes on the front page, if you separate pages or use extra paper please write your name and UID on each one of them.
- Closed book, **one** 5x3in note card (both sides) allowed.
- Scientific Calculators allowed, no computers or smartphones, please put books and notebooks in your backpacks.
- If a problem is ambiguous, notify the instructor. Clarifications will be written on the blackboard. Check the board occasionally.
- Time for exam: 60 minutes
- There are 4 questions, check that your exam has all ... sheets.
- Useful quantities

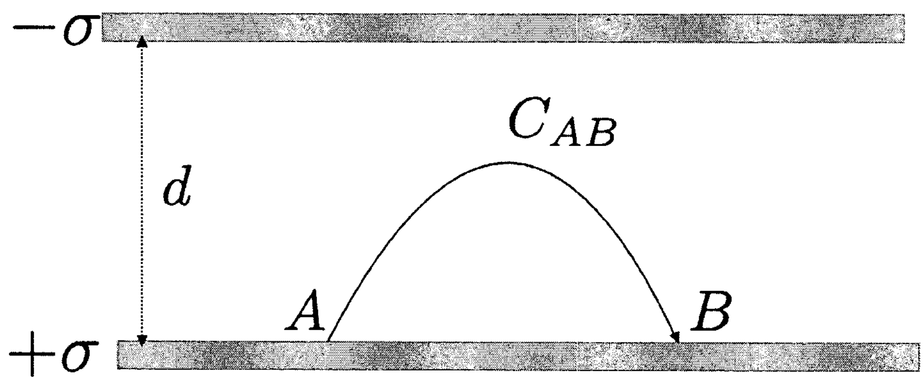
$$\begin{aligned}
\epsilon_0 &= 8.85 \times 10^{-12} C^2 m^{-2} N^{-1} \\
g &= 9.81 m/s^2 \\
m_{electron} &= 9.11 \times 10^{-31} kg \\
m_{proton} &= 1.67 \times 10^{-27} kg \\
q_e &= -1.602 \times 10^{-19} C
\end{aligned}$$

Problem 1: [15pts] Concept questions

a) **[5pts]** Two thin infinite conducting plates are charged with charge density σ and are a distance d apart. Consider a path C_{AB} from two points on the surface of one of the conductors. Consider the following quantity

$$\int_{C_{AB}} \vec{E} \cdot d\vec{x} \tag{1}$$

How does the result depend on σ, C_{AB} and d ?



(1) Only on σ and d

(2) Only on σ and the length of the path C_{AB}

(3) Only on the length of the path C_{AB}

(4) On σ, d and the length of the path C_{AB}

(5) On none of them

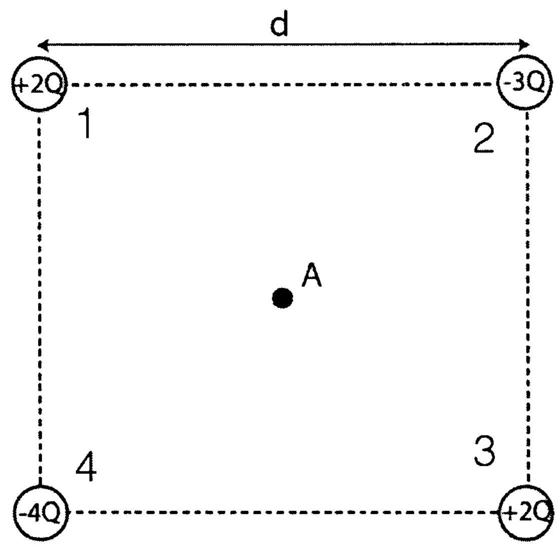
$\Delta V = -\int \vec{E} d\vec{r}$ is path independed

& $\vec{E} = 0$ on conductor

choose path $A \to B$

inside conductor

b) [**5pts**] In which direction does the electric field at A point ?



(**1**) to the left

(**2**) towards charge 2

(**3**) towards charge 3

(**4**) towards charge 4

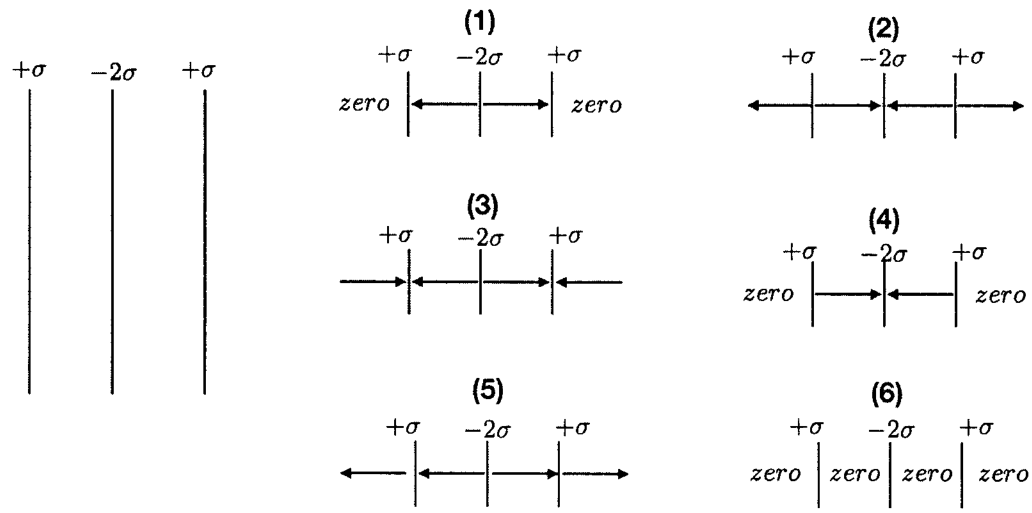
(**5**) to the right

(**6**) towards charge 1

(**7**) the electric field is zero

direction of $\vec{E}$ along
4-2 axis
by symmetry
$\vec{E}$ points towads lager
negative chage

c) **[5pts]** There are three parallel infinite sheets with constant charge density $+\sigma$, -2σ and $+\sigma$ (See figure). Which figure best represents the direction of the electric fields ?



(1)

(2)

(3)

(4)

(5)

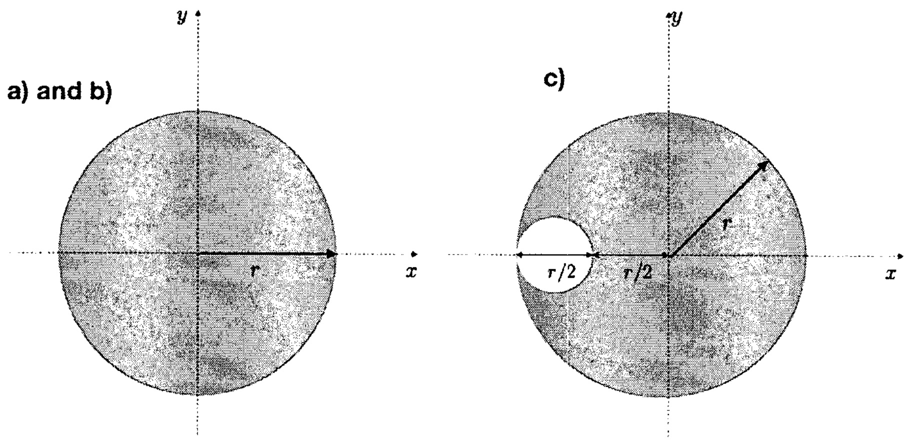
(6)

cancellation outside

$\vec{E}$ points towards negative charges

Problem 2: [30pts]

A spherical insulator has a constant charge density $\rho = -2.7 \times 10^{-4} C/m^3$. The sphere is centered at the origin and has a radius $r = 10cm$. [The figure depicts a cross section of the sphere in the x-y plane].



a) [10pts] Find the magnitude and direction of the electric field at $x = y = z = 0$ and at $x = 5cm, y = 0, z = 0$.

at $\vec{x} = 0$ $\quad \vec{E} = 0$ by symmetry

at $x = x_0 = 5m$ $\quad y = z = 0$

gaussian surface $\quad q_{encl} = \frac{4\pi}{3} \rho \, x_0^2 \quad$ Flux $= 4\pi x_0^2 E_x = \Phi$

sphere radius x_0 $\quad \Phi = \frac{q_{encl}}{\epsilon_0}$

Symmetry: $\quad E_x = \frac{1}{3} \frac{\rho x_0}{\epsilon_0}$

$E_x = 5.08 \cdot 10^5 \frac{N}{C}$

b) **[10pts]** Find the potential at $x = 20cm, y = 0, z = 0$ assuming that V is zero at infinity.

point is outside spherically symmetric charge distribution

$q_{encl} = \frac{4\pi}{3} R^3 \rho$

$V = \frac{1}{4\pi\varepsilon_0} \frac{q_{encl}}{x_1}$

$x_1 = 0.2m$

$R = 0.1m$

$q_{encl} = -1.13 \cdot 10^{-6} C$

$V = -5.08 \cdot 10^4 V$

c) **[10pts]** Out of the spherical insulator you remove a sphere of radius $\frac{r}{4}$ centered at $x = -\frac{3}{4}r, y = 0, z = 0$ [see the 2nd figure]. What is the magnitude and direction of the electric field at $x = y = z = 0$?

Original charge distribution $\vec{E} = 0$ at $x = 0$

removal of sphere corresponds to adding a sphere is radius $r' = \frac{r}{4}$ located $x = -\frac{3}{4}r$ $y = 0$ $z = 0$

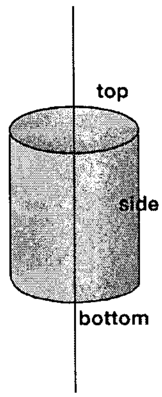
with $\rho' = -\rho$ $q'_{encl} = \frac{4\pi}{3} \rho' \left(\frac{r}{4}\right)^3$

electric field is that of a point charge $x' = \frac{3}{4}r$

$|E'| = \frac{1}{4\pi\varepsilon_0} \frac{q'_{encl}}{x'^2}$ direction positive x direction since $q'_{encl} > 0$

$q_{encl} = +1.76 \cdot 10^{-7} C$ $x' = 0.075$ $|\vec{E}| = 2.82 \cdot 10^4 \frac{N}{C}$

Problem 3: [20pts] An infinitely long line of charge has a linear charge density of $\mu = 4.5 \times 10^{-12} C/m$.



a) [10pts] Consider a cylindrical surface which is concentric to the line charge with height $20cm$ and radius $3cm$. Calculate the electric flux through the top and bottom base of the cylindrical surface as well as through the curved side.

electric field $\vec{E}$ points radially outward.

$\Phi_{\substack{top \\ bottom}} = 0$ since $\vec{E} \perp d\vec{A}$

then $\phi_{side} = \phi_{total} = \frac{q_{encl}}{\varepsilon_0} = \frac{1}{\varepsilon_0} \mu \cdot \ell$

$\mu = 4.5 \cdot 10^{-12} \frac{C}{m}$

$\ell = 0.2 m$

$\Phi = 0.101 \frac{Nm^2}{C}$

b) **[10pts]** A proton starts at a distance 15.0cm from the line and is moving directly toward the line with speed 2 km/s. How close does the proton get to the line of charge?

electrostatic potential for line charge

$$V_a - V_b = \frac{\mu}{2\pi\varepsilon_0} \ln \frac{r_b}{r_a}$$

potential energy $U = q_p V$

$$U_a + K_a = U_b + K_b$$

proton stops $K_a = 0$ $K_b = \frac{1}{2} m_p v^2$

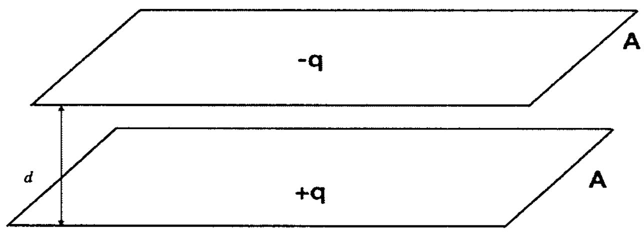
$$U_a - U_b = K_b \Rightarrow q_p \frac{\mu}{2\pi\varepsilon_0} \ln \frac{r_b}{r_a} = \frac{1}{2} m_p v^2$$

$$\frac{\pi \varepsilon_0 m_p v^2}{\mu q_p} = \ln \frac{r_b}{r_a}$$

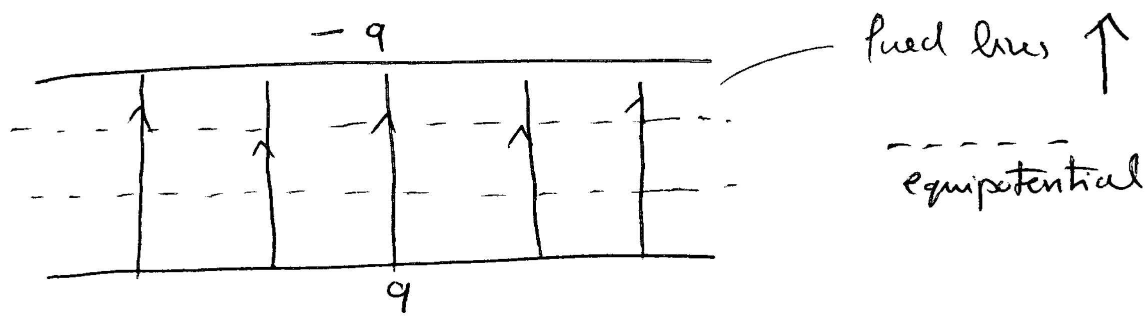
$$r_a = r_b \exp\left(-\frac{\pi \varepsilon_0 m_p v^2}{\mu q_p}\right)$$

$r_a = 0.116\,m$

Problem 4: [30pts] Two very thin sheets have an area of $A = 0.2m^2$ and are a distance $d = 1.2cm$ apart. On the top one a charge $+q$ is uniformly distributed and on the bottom sheet a charge of $-q$ is uniformly distributed. You can model the electric field between the sheets as if the sheets are infinite.



a) [10pts] For positive q sketch the field lines and the equipotential surfaces in between the charged sheets.



b) [**10pts**] You measure the potential difference between the top and the bottom sheet $V_{top} - V_{bottom} = -10$ Volts. Determine q.

$$V_{top} - V_{bottom} = -\frac{\sigma}{\varepsilon_0} d \qquad \sigma = \frac{q}{A}$$

$$q = -\frac{(V_{top} - V_{bottom}) A \varepsilon_0}{d}$$

$$q = 1.47 \cdot 10^{-9} C$$

c) [**10pts**] A tiny dust spec of mass $m = 1.5$ *milligramm* is charged with charge q_1 and brought between the two charged sheets. You observe that it is stationary and floating between the charged sheets. Determine q_1. [If you could not do b) assume $q = 2.12 \times 10^{-8} C$.]

$$E_z = \frac{\sigma}{\varepsilon_0} = \frac{q}{A \varepsilon_0}$$

$$F_E = q \frac{q}{A \varepsilon_0}$$

$$F_g = mg$$

$$\frac{q_1 q}{A \varepsilon_0} = mg$$

$$q_1 = \frac{A \varepsilon_0 mg}{q}$$

$$q_1 = 1.76 \; 10^{-6} C$$

-additional space for calculation-