Physics 122, Summer 2005
Midterm Examination (Set A)
July 22nd, 2005

Exam policy for students and proctors:

- Write your name, SB ID number and Lab section (A/B) on each blue book you use.
- Solve any four of the five problems.
- Start a new problem solution on a new page.
- You can use one A4 size formula sheet.
- Use any non programmable calculator.

1.) A uniform electric field exists in the region between two oppositely charged parallel plates 1.68 cm apart. A proton is released from rest at the surface of the positively charged plate and strikes the surface of the negatively charged plate in a time interval $1.60 \times 10^{-6}$ s. (Mass of proton is $1.67 \times 10^{-27}$ kg, Charge on the proton is $1.60 \times 10^{-19}$ C)

a ) Find the magnitude of the electric field between the plates. (15 points)
b ) Obtain the speed of the proton at the moment it strikes the negatively charged plate. (5 points)

SOLN: The acceleration is given from the Equation of motion as

$$a = \frac{2x}{t^2} = \frac{2 \times 0.0168}{(1.6 \times 10^{-6})^2} = 1.3125 \times 10^{10} \ m/s^2$$

The Electric Field is then obtained as

$$E = \frac{ma}{q} = \frac{1.67 \times 10^{-27} \times 1.3125 \times 10^{10}}{1.60 \times 10^{-19}} = 137 \ N/C$$

The speed of the proton is then

$$v = \sqrt{2ax} = \sqrt{2 \times 1.3125 \times 10^{10} \times 0.0168} = 2.1 \times 10^4 \ m/s$$

2.) A 1.0 $\mu C$ charge feels a force due to two other charges. The first is a -2.0 $\mu C$ charge 1.0 m directly to the left of the 1.0 $\mu C$ charge. The second is a +3.0 $\mu C$ charge 1.0 m directly below the 1.0 $\mu C$ charge.

a ) Find the magnitude & direction (w.r.t North) of net electric force on the 1.0 $\mu C$ charge. (10 points)
b ) Where should a third charge of 4.0 $\mu C$ be placed so that there is no net force on the 1.0 $\mu C$ charge? (10 points)

SOLN: The force($F_{31}$) due to the +3.0 $\mu C$ is repulsive directed north with magnitude

$$F_{31} = \frac{kq_1q_3}{r_{13}^2} = \frac{9 \times 10^9 \times 10^{-6} \times 3 \times 10^{-6}}{1^2} = 27 \times 10^{-3} N$$
The force $F_{21}$ due to the -2.0 $\mu$C is attractive directed west with magnitude

$$F_{21} = \frac{kq_1 q_2}{r_{12}^2} = \frac{9 \times 10^9 \times 10^{-6} \times 2 \times 10^{-6}}{1^2} = 18 \times 10^{-3} N$$

The net force has magnitude.

$$F_N = \sqrt{F_{21}^2 + F_{31}^2} = \sqrt{(18 \times 10^{-3})^2 + (27 \times 10^{-3})^2} = 32.45 \times 10^{-3} N$$

Direction of the force

$$\theta = \tan^{-1} \left( \frac{18}{27} \right) = 33.69^\circ \text{ West of North}$$

To make the force equal and opposite on the 1.0 $\mu$C charge, keep the 4.0 $\mu$C at the same angle (West of North) and at a distance $r_{14}$ from the 1.0 $\mu$C charge.

$$r_{14} = \sqrt{\frac{kq_1 q_4}{F_N}} = \sqrt{\frac{9 \times 10^9 \times 10^{-6} \times 4 \times 10^{-6}}{32.45 \times 10^{-3}}} = 1.053 \text{ m}$$

3.) A particle of mass $m = 2.0 \times 10^{-12}$ kg, velocity $v = 10^6$ m/s and charge $q = 10^{-6}$ C enters Region 1 between the parallel plates which has an electric field $E = 10^6$ N/C. After passing Region 1 undeflected it enters Region 2 where there is no electric field, but a magnetic field $B = 2.0$ T perpendicular to $v = 10^6$ m/s.

a ) If the particle is undeflected Region 1, then find the magnitude & direction of the B. (5 points)

b ) What is the direction of B in Region 2 to make the particle go in a counterclockwise circular path? (3 points)

c ) Determine the area of the semi circle in Region 2. (7 points)

d ) In Region 1, if $v$ changes to $10^5$ m/s & $10^7$ m/s, then in both cases find the direction of deflection. (5 points)

**SOLN:**

a.) The magnetic field in Region 1 is directed out of the plane of the paper with magnitude,

$$B = \frac{E}{v} = \frac{10^6}{10^6} = 1 \text{ T}$$

b.) The magnetic field in Region 2 is directed into the plane of the paper.

c ) Radius is given as

$$r = \frac{mv}{qB} = \frac{2.0 \times 10^{-12} \times 10^6}{10^{-6} \times 2} = 1 \text{ m}$$

Area of semi circle $A = \pi r^2 / 2 = 1.57 m^2$

d ) **CASE 1.)** If $v = 10^5$ m/s then the force due to magnetic field is less than force due to Electric field and hence the charge will be deflected towards the negative plate.

case 2.) If $v = 10^7$ m/s then the force due to magnetic field is greater than force due to Electric field and hence the charge will be deflected towards the positive plate.
4.) The parallel plates of a capacitor have an area of 0.2 m$^2$ and are 10$^{-2}$ m apart. The original potential difference between them is 3000 V and it decreases by 60% when a sheet of dielectric is inserted between the plates. (The permittivity in free space is $\epsilon_0 = 8.85 \times 10^{-12}$ V/m)

a) Find the capacitance ($C_0$) before and capacitance ($C$) after insertion of dielectric. (10 points)

b) Dielectric constant $k$ and the permittivity ($\epsilon$) of the dielectric (10 points)

**SOLN:**

The capacitance ($C_0$) of the plate is given as

$$C_0 = \frac{\epsilon_0 A}{d} = \frac{8.85 \times 10^{-12} \times 0.2}{0.01} = 177 \text{ pF}$$

1 pico Farad (pF) is $10^{-12}$ Farad.

The voltage reduces by 60%, hence final $V = 1200$ V. The charge in the plate stays the same when you introduce the dielectric hence

$$C = \frac{C_0 V_0}{V} = \frac{177 \times 3000}{1200} = 442.5 \text{ pF}$$

The dielectric constant and permittivity

$$k = \frac{C}{C_0} = 2.5$$

$$\epsilon = k \epsilon_0 = 2.2125 \times 10^{-13} \text{ C}^2/\text{Nm}^2$$

5.) Consider the following DC circuit:

![DC Circuit Diagram](image)

a) What is the current in the 900 $\Omega$ resistor? (10 points)

b) Determine the power dissipated by both the 2 k$\Omega$ resistors together. (10 points)

**SOLN:** This problem can be done two ways.

1.) **By using the Kirchoff’s Laws.** If $I_1$, $I_2$ and $I_3$ are the current through 1.5 k$\Omega$, 900 $\Omega$, both the 2k$\Omega$, then from the junction and the loop rule we get

$$I_1 - I_2 - I_3 = 0$$

$$E - 1500 I_1 - 900 I_2 = 0$$

$$E - 1500 I_1 - 1000 I_3 = 0$$

$$900 I_2 - 1000 I_3 = 0$$
Solving the above we get $I_1 = 0.0506 \ A$, $I_2 = 0.0267 \ A$, $I_3 = 0.0241 \ A$. Part (a) asks for value of $I_2$.

b) Power dissipated by both the 2 kΩ resistor is

$$P = 2I^2R = 2 \times (0.012)^2 \times 2000 = 0.0241^2 \times 1000 = 0.580 \text{ Watt}$$

2.) **Using equivalent resistance.** For the combination we get

$$R_{eq} = 1500 + \frac{900 \times 1000}{1900} = 1973.68 \ \Omega$$

Then current the circuit is

$$I_1 = \frac{V}{R_{eq}} = \frac{100}{1973.68} = 0.0506 \ A$$

$$I_2 = \frac{100 - 1500 \times 0.0506}{900} = 0.0267 \ A$$

$$I_3 = I_1 - I_2 = 0.0241 \ A$$