Physics 7B Sp09 Freedman MT2

1. (20 pts total) True – False Questions – Place a T or an F for each question in the table below – 2 pts for each correct answer and a 1 pt reduction for each incorrect answer. Guessing is not necessarily a good idea, but you cannot get less than zero for the entire problem.

i	F	
ii	T	
iii	F	X Should be true, if it was not obvious
iv	T	
v	F	
vi	F	
vii	T	
viii	F	
ix	T	
x	F	

i) A 100-W incandescent light bulb has a higher resistance than a 75-W bulb.

ii) In a region of space with a constant electric potential the electric field must be zero.

iii) For a charged metal conductor shaped like an American football the electric charge density must be higher at the ends than it is on the flattened sides.

iv) It is possible to place an electric dipole consisting of opposite charges separated by a small distance in a constant electric field so it feels no net force and no net torque.

v) In a region of space where the electric field is constant the electric potential must be zero.

vi) A parallel plate capacitor can store more energy for a given stored charge if the dielectric constant of the material between the plates is increased.

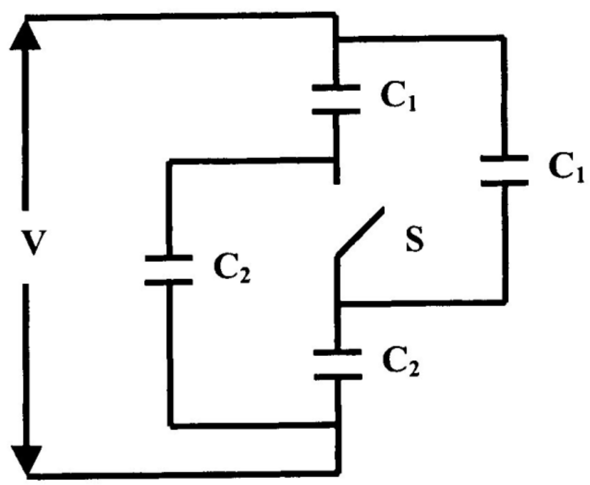
vii) Incandescent light bulbs are more likely to burn out when they are just turned on.

viii) A battery rated for 1 A-hr cannot deliver more than 1 A of electrical current.

ix) A point charge (+Q) sits at the center of a thin hollow conducting sphere of radius R. If the point charge is moved to $R/2$ from the center of the sphere, the electric field outside the sphere will not change.

x) The electric field lines on an equipotential surface must be parallel.

2.(20 pts total) A voltage V is applied to the capacitor network shown in the figure.



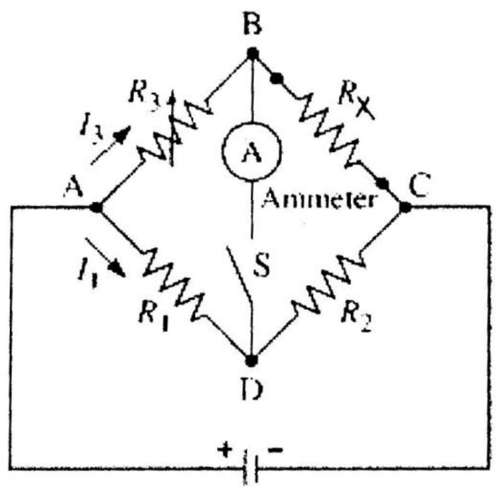
$C_1 = 5\ \mu F$ and $C_2 = 10\ \mu F$

(a)(6 pts) Calculate the equivalent capacitance of the circuit with the switch open.

(b)(6 pts) Calculate the equivalent capacitance of the circuit with the switch closed.

(c)(8 pts) What is the equivalent capacitance if the switch is replaced by a 50 μF capacitor?

3.(20 pts total) A "Wheatstone bridge" is a tool for measuring resistances. An adjustable and calibrated resistor R_3 is adjusted for a particular unknown resistor R_x until the circuit balances and the ammeter (the circled A in the figure) reads zero instantaneous current when the switch S is closed.

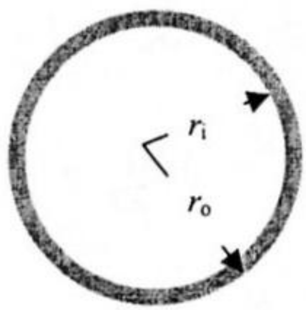


(a)(8 pts) Determine the relationship for R_x in terms of the known resistances R_1, R_2, and R_3 when the bridge is balanced.

(b)(6 pts) The resistance of an unknown length 2.3 mm in diameter Nichrome (Ni, Fe, Cr alloy, resistivity $\rho = 1 \times 10^{-6}$ Ω·m) is measured with a Wheatstone bridge (R_1 = 45.5 Ω and R_2 = 38.3 Ω). At balance R_3 = 4.72 Ω, how long is the wire?

(c)(6 pts) All real ammeters have some internal resistance. In general, to avoid disturbing the measurement, should the internal resistance be large or small? Explain how the internal resistance of the ammeter effects the measurement. Is there a problem with having R_{int} too large or too small?

4.(20 pts total) Your clever friend has invented a "warm marble" consisting of a spherical shell of a new plastic of inner radius $r_i = 4.00$ mm and outer radius $r_o = 4.01$ mm. The inner and outer surfaces are coated with a thin layer of a good conductor. A small hole and a thin wire provide a way for to provide an electrostatic potential between the inner and outer surface but you can neglect any other effect of the hole and wire. The new plastic is an excellent insulator ($\rho = 10^{12}\ \Omega\cdot$m) and it has an extremely large dielectric constant ($K = 1000$).



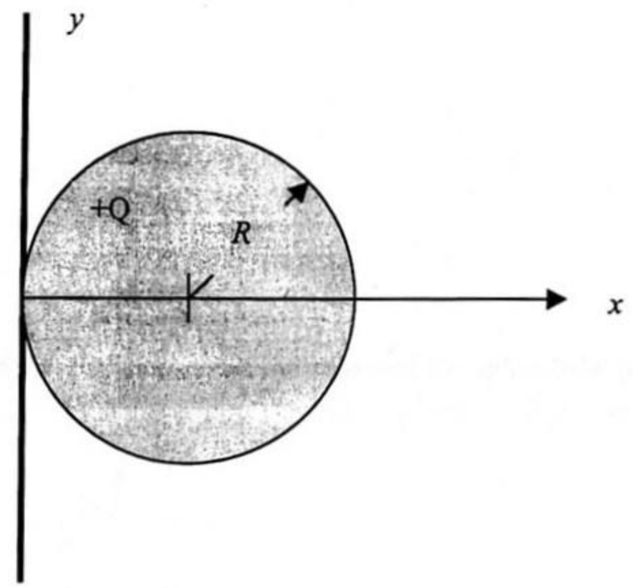
(a)(5 pts) Calculate the capacitance of the warm marble. (Remember. Obtain show both the formula and the numerical value for this type of question.)

(b) (5 pts) Calculate the resistance between the inside and the outside of the warm marble.

(c) (5 pts) How much energy is stored in the marble when a 5000V electric potential is applied between inner and outer surface?

(d)(5 pts) Describe the behavior of the marble when it is disconnected from the power supply. Draw the equivalent circuit and explain how the stored energy decays away in time. Where does the stored energy go?

5.(20 pts total) Consider an insulating sphere of radius R that is next to, and just touching, a very large (nearly infinite) conducting plane with zero net charge. The total charge +Q of the sphere is uniformly distributed within the volume. Take the point at which the sphere touches the conducting plane as the origin of a coordinate system with center of the sphere on the x-axis; the y-axis points up. Remember that the electric field is a vector quantity and you need to specify both its magnitude and direction. (Hint: On problems like this it often helps to replace the conduction plane with a fictitious charge distribution that gives the same electric field distribution as it would be at the surface of the conducting plane. The method is called the "method of image charges".)



(a)(2 pts) Is the charge density constant on the surface of the plane? Is the electrostatic potential constant on the surface of the plane?

(b)(2 pts) Is the charge density constant on the surface of the sphere? Is the electrostatic potential constant on the surface of the sphere?

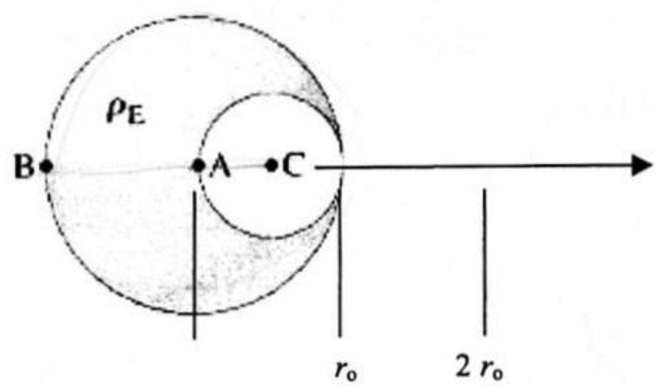
(c)(4 pts) Calculate the electric field at the point $(x, y) = (0, 0)$.

(d)(4 pts) Calculate the electric field at the center of the sphere, the point $(x, y) = (R,0)$.

(e)(4 pts) Calculate the electric field at the point $(x, y) = ((3/2)R,0)$.

(f)(4 pts) Calculate the electric field at the point $(x, y) = (R, R)$.

6.(20 pts total) A sphere of radius r_o carries a volume charge density ρ_E. A spherical cavity of radius $r_o/2$ is scooped out and left empty. There is a small hole at the thinnest point, just large enough to allow an electron to pass through. You may neglect any other consequence of the hole on the electric fields and potentials.



(a)(6 pts) What are the electric fields at A, B and C?

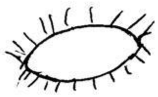
(b)(6 pts) Calculate the electrostatic potential at the points A and B. (Take the potential to be zero at infinity.)

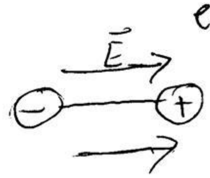
(c)(8 pts) Suppose the constant charge density ρ_E is negative and suppose and electron is initially placed at point A. The electron moves along the x-axis. What is the velocity of the electron when it reaches a point $2r_o$ from point A (see figure).

Problem 1

i) F V is fixed, so $P = \frac{V^2}{R}$

ii) T $\vec{E} = -\nabla V$

iii) T  field lines must be perpendicular to the surface therefore they diverge more at the ends, which requires more charge

iv) T  for example

v) F $\Delta V = -\int_a^b \vec{E} \cdot d\vec{s}$ so if $\vec{E} \neq 0$, $\nabla V \neq 0$ necessarily

vi) F $U = \frac{Q^2}{2C}$, and $C = K C_{vac}$

vii) T google it

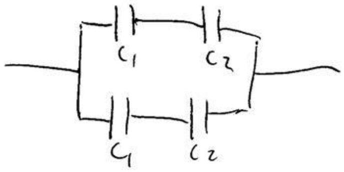
viii) F Ahr rating tells total charge

ix) T the field produced by the point charge cannot enter the conductor

x) F The field lines are perpendicular to the equipotential surface, but the surface does not have to be flat

Problem 2

a) The circuit can be redrawn as:



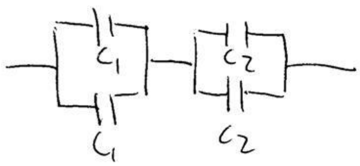
This circuit contains 2 parallel branches, each with C_1 and C_2 in series. Thus,

$$C_{eff} = \left(\frac{1}{C_1} + \frac{1}{C_2}\right)^{-1} + \left(\frac{1}{C_1} + \frac{1}{C_2}\right)^{-1}$$

$$= 2\left(\frac{C_1 + C_2}{C_1 C_2}\right)^{-1}$$

$$= \frac{2 C_1 C_2}{C_1 + C_2} = \frac{20}{3}\,\mu F$$

b) can be redrawn as:



This is a series of 2 C_1 capacitors in parallel and 2 C_2 capacitors in parallel. Thus

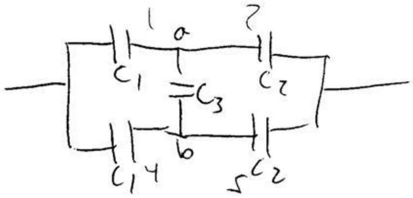
$$C_{eff} = \left(\frac{1}{C_1 + C_1} + \frac{1}{C_2 + C_2}\right)^{-1}$$

$$= \left(\frac{1}{2C_1} + \frac{1}{2C_2}\right)^{-1}$$

$$= \left(\frac{C_1 + C_2}{2 C_1 C_2}\right)^{-1}$$

$$= \frac{2 C_1 C_2}{C_1 + C_2} = \frac{20}{3}\,\mu F$$

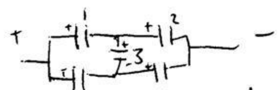
c) Looks like this:



There are no capacitors in series or parallel, so we cannot use those formulae.

However, by symmetry, we know that points a and b must be at the same potential, so the potential difference across C_3 is zero, thus it holds no charge, and does not effect the capacitance. So the answer is the same as in parts a and b: $C_{eff} = \frac{20}{3}\,\mu F = \frac{2C_1C_2}{C_1+C_2}$

To solve directly, label:



(we assume that C_3 has positive charge on top plate)

Conservation of charge tells us:

$$Q_1 = Q_2 + Q_3$$
$$Q_4 = Q_5 - Q_3$$
$$\longrightarrow Q_1 + Q_4 = Q_2 + Q_5$$

Calculating the potential drop, we get:

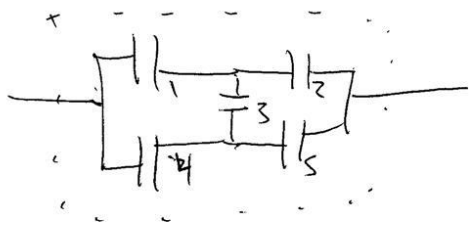
$$\frac{Q_1}{C_1} + \frac{Q_2}{C_2} = V \longrightarrow Q_1 = \left(V - \frac{Q_2}{C_2}\right)C_1$$
$$\frac{Q_4}{C_1} + \frac{Q_5}{C_2} = V \longrightarrow Q_4 = \left(V - \frac{Q_5}{C_2}\right)C_1$$

$$Q_1 + Q_4 = C_1V + C_1V - \frac{C_1}{C_2}Q_2 - \frac{C_1}{C_2}Q_5$$
$$Q_1 + Q_4 = 2C_1V - \frac{C_1}{C_2}(Q_2 + Q_5)$$
$$Q_1 + Q_4 = 2C_1V - \frac{C_1}{C_2}(Q_1 + Q_4)$$

$$\left(1+\frac{C_1}{C_2}\right)(Q_1+Q_4) = 2C_1V$$

$$Q_1+Q_4 = \frac{2C_1V}{1+\frac{C_1}{C_2}}$$

$$Q_1+Q_4 = \frac{2C_1C_2}{C_1+C_2}V$$



Capacitors 1 and 4 are the ones directly connected to the high potential. So

$$Q_1+Q_4 = Q_{total}\text{. Thus}$$

$$Q_{tot} = \frac{2C_1C_2}{C_1+C_2}V$$

so $\boxed{C_{eff} = \frac{2C_1C_2}{C_1+C_2}}$

Problem 3

Part a:

When the circuit is balanced there is no current through the ammeter, which means that $V_b = V_d$. It also means $I_3 = I_x$ and $I_1 = I_2$. We also know that the voltage drop across the $1-2$ part must be the same as the $3-x$ part because they begin and end at the same points.

$$V_b = V_d \Rightarrow I_1 \cdot R_1 = I_3 \cdot R_3 \Rightarrow \frac{I_1}{I_3} = \frac{R_3}{R_1}$$
$$I_1 \cdot (R_1 + R_2) = I_3 \cdot (R_3 + R_x) \Rightarrow I_1 \cdot R_2 = I_3 \cdot R_x$$
$$\Rightarrow R_x = \frac{I_1}{I_3} \cdot R_2 = \frac{R_3 R_2}{R_1}$$

■

Part b:

$$R = \rho \cdot \frac{l}{A} \Rightarrow l = \frac{R \cdot A}{\rho}$$
$$l_x = \frac{R_x \cdot A}{\rho} = \frac{R_3 R_2 \cdot A}{R_1 \cdot \rho} = 16.5\,m$$

■

Part c:

In general, ammeters are connected in series when measuring current. This means that it is good to have R_{int} be much less than R_{eq} of the circuit, since it then has a small effect on R_{eq} and thus the current being measured. In the case of the Wheatstone bridge, a small R_{int} means that the ammeter is drawing more current away from the rest of the circuit. Normally this would be bad, but this makes the Wheatstone bridge more sensitive to an unbalanced circuit, which increases the sensitivity of the measurement. ■

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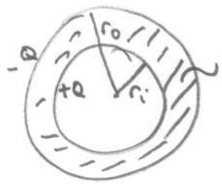
Freedman MT2 Spring '09 Problem 4

a)



Step 1) Put charges ± Q on the two surfaces.

Step 2) Find $\vec{E}$ in the dielectric:

$$\vec{E} = \frac{1}{4\pi\varepsilon_0 K}\frac{Q}{r^2}\hat{r} \quad r_i < r < r_o$$

You could have quoted this or used Gauss' Law.

Step 3): $\Delta V = -\int \vec{E}\cdot d\vec{\ell}$

$$|\Delta V| = \left|-\int_{r_i}^{r_o}\frac{Q}{4\pi\varepsilon_0 K r^2}\right| = \frac{Q}{4\pi\varepsilon_0 K}\left(\frac{1}{r_i} - \frac{1}{r_o}\right)$$

Take absolute value since capacitance must be positive.

Step 4):

$$C = Q/\Delta V = \frac{q}{\frac{q}{4\pi\varepsilon_0 K}\left(\frac{1}{r_i} - \frac{1}{r_o}\right)} = \boxed{4\pi\varepsilon_0 K\left(\frac{1}{r_i} - \frac{1}{r_o}\right)^{-1}}$$

or $\boxed{C = 4\pi\varepsilon_0 K\left(\frac{r_i r_o}{r_o - r_i}\right)}$

Step 5): Numerical:

$$C = 4\pi\cdot 8.85\cdot 10^{-12}\cdot 1000\cdot\frac{1}{\left(\frac{1}{4\cdot 10^{-3}} - \frac{1}{4.01\cdot 10^{-3}}\right)} =$$

$\boxed{1.78\cdot 10^{-7}\ \text{F}}$

Note: I also accepted answers if you quoted the result for a spherical capacitor

Common mistakes:

1) Wrong $\vec{E}$
2) Wrong sign
3) $\frac{1}{r_i} - \frac{1}{r_o} \neq \frac{1}{r_i - r_o}$
4) Trying to use $C = \varepsilon_0 A/d$ w/o any justification
5) Messing up $C = Q/V$ or $C = KC_0$

6) General: $R = \rho \, l/A$

Here the area changes so we must integrate:

$$dR = \frac{\rho\, dr}{4\pi r^2} \Rightarrow R = \frac{\rho}{4\pi}\int_{r_i}^{r_0} \frac{dr}{r^2} = \boxed{\frac{\rho}{4\pi}\left(\frac{1}{r_i} - 1/r_0\right)}$$

Numerical:

$$R = \frac{10^{12}}{4\pi}\left(\frac{1}{4\cdot 10^{-3}} - \frac{1}{4.01\cdot 10^{-3}}\right) = \boxed{4.96\cdot 10^{10}\,\Omega}$$

Common Mistakes:

1) Not integrating but providing no justification for this.
2) Messing up l or A in the integral
3) Again, $\frac{1}{r_i} - 1/r_0 \neq \frac{1}{r_i - r_0}$

c) Energy: $\boxed{U = \frac{1}{2}CV^2}$ ← use this form since potential is constant

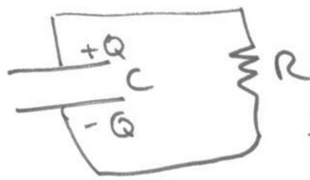
Numerical: $U = \frac{1}{2}\cdot 1.78\cdot 10^{-7}\cdot 5000^2 = \boxed{2.225\text{ J}}$

Common Mistakes:

1) Trying to use energy density w/o knowing $\vec{E}$

Note: ecf = error carried forward, if you got the wrong answer in a), you still got full credit in this part.

d) After the battery is disconnected, the circuit will look like an RC circuit due to the capacitance of the shells & the resistance of the dielectric:



Charge will flow between the two surfaces to equilibrate the potential between them.

Thus a current is flowing (according to $I = I_0 e^{-t/RC}$), and it will continue until the charge on each plate reaches zero. Since there is current going through the resistor, heat will be dissipated (hence the name "warm" marble).

Point Breakdown:

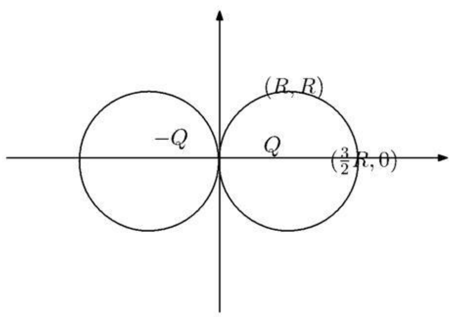
1 pt: drawing the circuit correctly
1 pt: Energy lost as heat/through the resistor
2 pts: Charge Dissipating/Current Flowing/or Potential Equilibrating
1 pt: capacitor becoming uncharged or equilibrium reached ($\Delta V = 0$)

Common Mistakes:

1) Wrong circuits
2) Saying charge goes into ~~the~~ air
3) Saying marble will roll
4) Energy going into kinetic energy of electrons or into ionizing the air.

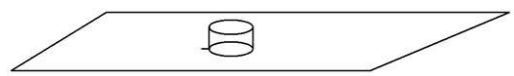
Note: Even if you said everything right, if you also put down wrong information, you lost points.

Problem 5 solution



1 part a

1.1 solution

Consider a pillbox on the surface of the conductor: 
If the surface charge density is locally $\sigma(\mathbf{x})$, then Gausss tells us

$$\oint \mathbf{E} \cdot \mathbf{dA} = \frac{Q_{enc}}{\epsilon}$$

$$\Longrightarrow E(\mathbf{x})_{top} - E(\mathbf{x})_{bottom} = \frac{sigma(\mathbf{x})}{\epsilon}$$

The method of images tells us the field $E(\mathbf{x})_{top}$ should look like the dipole field on the plane bisecting the dipole, which is, in cylindrical coordinates with z-axis along the x-axis, $\mathbf{E}(\rho, \theta, 0)_{top} = \frac{R\rho\hat{\mathbf{z}}}{2\pi\epsilon(\rho^2+R^2)^{\frac{3}{2}}}$, while $\mathbf{E}(\rho, \theta, 0)_{bottom} = 0$. So $\sigma(\rho, \theta) = \frac{R\rho}{2\pi(\rho^2+R^2)^{\frac{3}{2}}}$.

So, no, the charge density is not constant on the plane.

Noticee, however, that the field is everywhere normal to the plane. So $-\int \mathbf{E} \cdot \mathbf{dl} = 0$ for any path that lives on the plane.

So, yes, the potential is constant on the surface of the plane

1.2 rubric

1 for the no
1 for the yes

2 part b

The sphere is not a conductor: the charge is fixed.
So, yes.
However, because of the bending of the field lines so that they hit the conducting plane normal to its surface, the field lines no longer leave the sphere everywhere normal to it's surface. So paths on the surface of the sphere now pick up work.
So, no.

2.1 rubric

1 for the yes
1 for the no

3 part c

Just regard these sphere's now, as point charges Q at $(R, 0)$ and $-Q$ at $(0, R)$. So

$$\mathbf{r}_Q = -R\hat{\mathbf{x}}$$
$$\mathbf{r}_{-Q} = R\hat{\mathbf{x}}$$

and $E = -\frac{Q}{2\pi\epsilon R^2}\hat{\mathbf{x}}$

3.1 rubric

1 point if you calculated a correct field for Q at $(R, 0)$ but gave the plane no contribution
2 points if you calculated a correct field for Q at $(R, 0)$ but calculated the plane's correction incorrectly- i.e., regarded the plane as a plane of constant charge
3 points if you did both calculations correctly in spirit but miscomputed something along the way
4 points if you got it

4 part d

$$\mathbf{r}_Q = \mathbf{0}$$
$$\mathbf{r}_{-Q} = -2R\hat{\mathbf{x}}$$

Since we're at the center of the Q sphere, $\mathbf{E}_Q = 0$. So we have only to compute $\mathbf{E}_{-Q} = -\frac{Q}{16\pi\epsilon R^2}\hat{\mathbf{x}}$.

4.1 rubric

1 point if you calculated a correct field for Q at $(R, 0)$ but gave the plane no contribution
2 points if you calculated a correct field for Q at $(R, 0)$ but calculated the plane's correction incorrectly- i.e., regarded the plane as a plane of constant charge
3 points if you did both calculations correctly in spirit but miscomputed something along the way
4 points if you got it

5 part e

We're inside the Q sphere, so

$$\mathbf{r}_Q = -\frac{R}{2}\hat{\mathbf{x}}$$
$$\mathbf{r}_{-Q} = -\frac{5R}{2}\hat{\mathbf{x}}$$

so

$$\mathbf{E}_Q = \frac{Q\frac{\left(\frac{R}{2}\right)^3}{R^3}}{4\pi\left(\frac{R}{2}\right)^2\epsilon}\hat{\mathbf{y}}$$
$$= \frac{Q}{8\pi\epsilon R^2}\hat{\mathbf{x}}$$

We're outside the $-Q$ sphere at a distance of $\frac{5R}{2}$, so

$$\mathbf{E}_{-Q} = -\frac{Q}{25\pi\epsilon R^2}\hat{\mathbf{x}}$$
$$\Longrightarrow \mathbf{E} = \mathbf{E}_Q + \mathbf{E}_{-Q} = \frac{17Q}{200\pi\epsilon R^2}$$

5.1 rubric

1 point if you calculated a correct field for Q at $(R,0)$ but gave the plane no contribution
2 points if you calculated a correct field for Q at $(R,0)$ but calculated the plane's correction incorrectly- i.e., regarded the plane as a plane of constant charge
3 points if you did both calculations correctly in spirit but miscomputed something along the way
4 points if you got it

6 part f

We're outside both spheres, with

$$\mathbf{r}_Q = -R\hat{\mathbf{y}}$$
$$\mathbf{r}_{-Q} = 2R\hat{\mathbf{x}} + R\hat{\mathbf{y}} = 5R\left(\frac{2}{\sqrt{5}}\hat{\mathbf{x}} + \frac{1}{\sqrt{5}}\hat{\mathbf{y}}\right)$$

so

$$\mathbf{E} = -\frac{Q}{4\pi\epsilon R^2}\hat{\mathbf{y}} + \frac{Q}{120\pi\epsilon R^2}\left(\frac{2}{\sqrt{5}}\hat{\mathbf{x}} + \frac{1}{\sqrt{5}}\hat{\mathbf{y}}\right)$$
$$= \frac{Q}{120\pi\epsilon R^2}\left(\frac{2}{\sqrt{5}}\hat{\mathbf{x}} + \left(\frac{1}{\sqrt{5}} - 25\right)\hat{\mathbf{y}}\right)$$

6.1 rubric

1 point if you calculated a correct field for Q at $(R,0)$ but gave the plane no contribution
2 points if you calculated a correct field for Q at $(R,0)$ but calculated the plane's correction incorrectly- i.e., regarded the plane as a plane of constant charge
3 points if you did both calculations correctly in spirit but miscomputed something along the way
4 points if you got it

Solution 6

First consider a sphere with charge density ρ and radius R, it's electric field and potential can be calculated to be:

$$\mathbf{E} = \begin{cases} \frac{\rho}{3\epsilon_0} R^3 \frac{\hat{r}}{r^2} & (r > R) \\ \frac{\rho}{3\epsilon_0} r\hat{r} & (r < R) \end{cases} \tag{1}$$

$$\phi = \begin{cases} \frac{\rho}{3\epsilon_0} \frac{R^3}{r} & (r > R) \\ \frac{\rho}{3\epsilon_0} \frac{3R^2 - r^2}{2} & (r < R) \end{cases} \tag{2}$$

In this problem, the charge can be views as comprised of two parts, a big sphere (sphere1) with charge density ρ_E and radius r_0, and a small sphere (sphere 2) with charge density $-\rho_E$ and radius $r_0/2$. Use the principle of superposition we can find

(a) The field at A, B and C.

$$\begin{aligned} \mathbf{E}_A &= \mathbf{E}_{A1} + \mathbf{E}_{A2} \\ &= 0 + \frac{\rho_E}{3\epsilon_0} \frac{r_0}{2} \hat{x} \\ &= \frac{\rho_E}{3\epsilon_0} \frac{r_0}{2} \hat{x} \end{aligned} \tag{3}$$

$$\begin{aligned} \mathbf{E}_B &= \mathbf{E}_{B1} + \mathbf{E}_{B2} \\ &= \frac{\rho_E}{3\epsilon_0} r_0(-\hat{x}) + \frac{\rho_E}{3\epsilon_0} \frac{r_0}{18} \hat{x} \\ &= \frac{\rho_E}{3\epsilon_0} \frac{17r_0}{18} (-\hat{x}) \end{aligned} \tag{4}$$

$$\begin{aligned} \mathbf{E}_C &= \mathbf{E}_{C1} + \mathbf{E}_{C2} \\ &= \frac{\rho_E}{3\epsilon_0} \frac{r_0}{2} \hat{x} + 0 \\ &= \frac{\rho_E}{3\epsilon_0} \frac{r_0}{2} \hat{x} \end{aligned} \tag{5}$$

(b) The potential at point A and B.

$$\begin{aligned} \phi_A &= \phi_{A1} + \phi_{A2} \\ &= \frac{\rho_E}{3\epsilon_0} \frac{3r_0^2}{2} + \frac{\rho_E}{3\epsilon_0} \frac{-r_0^2}{4} \\ &= \frac{\rho_E}{3\epsilon_0} \frac{5r_0^2}{4} \end{aligned} \tag{6}$$

$$\begin{aligned}\phi_B &= \phi_{B1} + \phi_{B2} \\ &= \frac{\rho_E}{3\epsilon_0} r_0^2 + \frac{\rho_E}{3\epsilon_0}\frac{-r_0^2}{12} \\ &= \frac{\rho_E}{3\epsilon_0}\frac{11r_0^2}{12}\end{aligned} \tag{7}$$

(c) For a electron initially placed at point A, the electric force is to the positive $\hat{x}$ direction (since ρ_E is negtive). Mark the point $2r_0$ right from point A as point D, we can find

$$\begin{aligned}\phi_D &= \phi_{D1} + \phi_{D2} \\ &= \frac{\rho_E}{3\epsilon_0}\frac{r_0^2}{2} + \frac{\rho_E}{3\epsilon_0}\frac{-r_0^2}{12} \\ &= \frac{\rho_E}{3\epsilon_0}\frac{5r_0^2}{12}\end{aligned} \tag{8}$$

therefore we can use conservation of energy to find

$$-e\phi_A = -e\phi_D + \frac{1}{2}mv^2 \tag{9}$$

solve this equation we will get

$$v = \sqrt{\frac{-5e\rho_E r_0^2}{9m\epsilon_0}} \tag{10}$$

It's to the right and it won't come back.