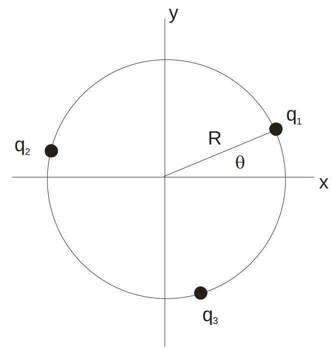
1. (25 pts) Three point charges, q_1, q_2 and q_3 that have the same +2 Coulomb charge are fixed to a circle of radius R = 5 m centered on the origin of an *xy* coordinate system. The charges can each be positioned at arbitrary angles θ_1, θ_2, θ_3 with respect to the positive *x*-axis.



   a. If the charges produce an electric field at the center of the circle that points upward along the vertical axis with a magnitude $E = 4\text{x}10^8$ N/C, where are the charges positioned?

   b. What is the electric potential at the center of the circle with the charges in these positions?

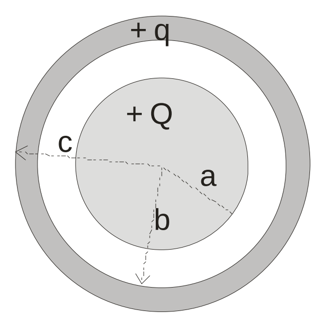
   The charges are rearranged so that the electric field at the center of the circle is 0.

   c. Describe the positions of the charges. (*There may be several options; you need only describe one.*)

   d. What is the electric potential at the center of the circle now?

   e. What is the electric potential energy of this system of charges?

2. (25) Consider a spherical charge distribution of radius *a* that contains a total, uniformly distributed charge Q (*a cross-sectional view is shown to the right*). This sphere is surrounded by a concentric spherical conducting shell of inner radius *b* and outer radius *c*. A total charge of q is placed on the conducting shell, distributing itself appropriately.



   a. How much charge resides on the outer surface of the conducting shell, at $r = c$?

   b. What is the electric field as a function of distance, *r*, in each of the regions

      $r < a$ $a < r < b$ $b < r < c$ and $c < r$?

   c. What is the electrical potential *V* at $r = b$, assuming that V = 0 at infinity?

   d. What would change about your answers if, instead of Q being uniformly distributed throughout the sphere of radius *a*, it has a distribution which varies with *r* as described by $\rho = \alpha r$, where α is a constant that is determined by the requirement that the total charge still adds up to Q.

3. (20) A parallel-plate capacitor with a capacitance of 6.0 nF and a plate area of $5.0\times10^{-2}\ \text{m}^2$ is connected to a 12 V battery.

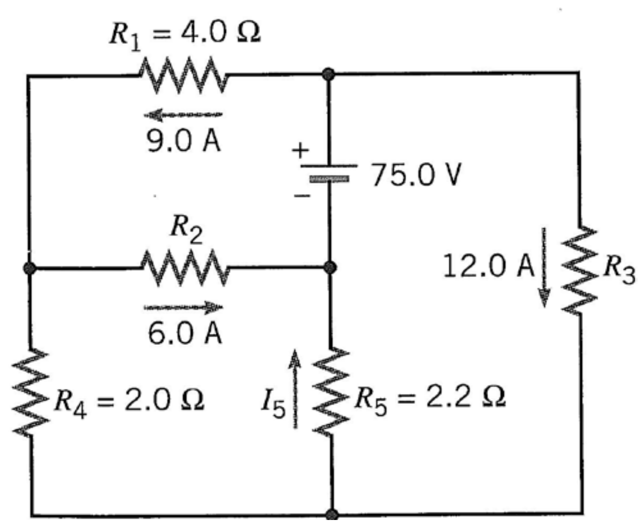
   a. What is the electric field between the plates?

   b. What is the separation between the plates?

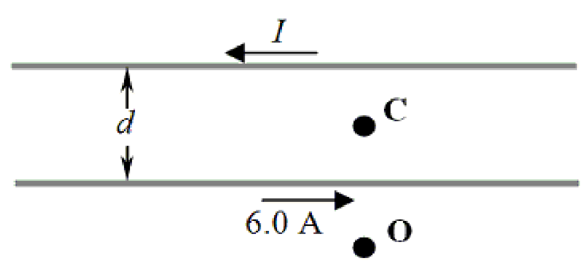
   c. An electron released from rest at the negative plate of the capacitor accelerates to the positive plate. What is the acceleration of the electron?

   d. What is the kinetic energy of the electron when it reaches the positive plate?

4. (15) In the DC circuit drawn below, you are given the values for three of the five resistors plus three of the currents that flow through various branches of the circuit. You need to solve for I_5, R_2 and R_3.



5. (20) Two long, straight, parallel wires separated by a distance *d* carry currents in opposite directions as shown in the figure below. The bottom wire carries a current of 6.0 A toward the right. Point **C** is at the midpoint between the wires. Point **O** is a distance 0.50*d* below the 6 A wire and the magnetic field at point **O** is zero tesla.

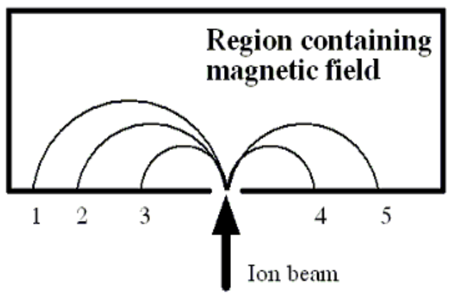


a. Determine the value of the current, *I*, in the top wire.

b. If *d* = 0.10 m, what is the magnitude and direction (*into or out of the page*) of the magnetic field at point **C**.

c. With what force (*per length of wire*) are the wires attracted to or repelled from each other (*and are they attracted or repelled*)?

6. (15) A beam consisting of five types of ions labeled **A**, **B**, **C**, **D**, and **E** enters a chamber that contains a uniform magnetic field as shown in the figure below. The table below gives the masses and charges of the ions. (*1 mass unit = 1.67 × 10^{-27} kg and e = 1.6 × 10^{-19} C.*) The magnetic field is perpendicular to the plane of the paper, but you are not told whether it points into or out of the page. All five types of ions in the beam travel with the same speed v = $5\text{x}10^4$ m/s when they enter the chamber.



Ion	*Mass*	*Charge*
A	2 units	+*e*
B	4 units	+*e*
C	6 units	+*e*
D	2 units	−*e*
E	4 units	−*e*

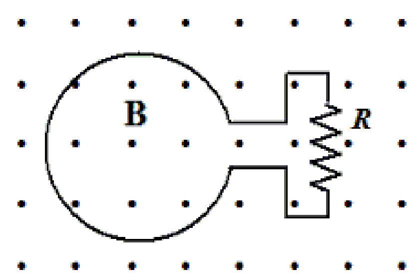
a. Which type of ion hits the wall of the chamber at position **2**? Explain your answer.

b. What is the direction of the magnetic field, into or out of this page? (*Justify your response.*)

c. What speed does each ion have when it strikes the wall of the chamber?

d. If position 2 is a distance d = 0.2 m from the ion beam entry point, what is the magnitude of the magnetic field?

7. (20) The figure below shows a uniform magnetic field that is normal to the plane of a circular conducting loop that has negligible resistance but is connected to a resistor *R*. (***Note***: *this drawing is not to scale: the area of the non-circular portion of the circuit is negligible compared to that of the loop.*)



a. What is the direction (*up or down*) of the current through R if the radius of the loop increases? Explain your answer.

b. Suppose that the radius of the loop is fixed at 0.500 m. At what *rate* must **B** change with time if the emf induced in the loop is 3π volts?

c. Now, suppose that the area of the loop and the magnetic field are constant. What is the direction of the current induced in the loop if the loop is moved to the right *within* the magnetic field? Explain.

d. The area of the loop and the magnetic field are again fixed at 0.500 m but the loop spins about at axis that is perpendicular to B at an angular frequency $\omega = 4\pi\ \text{sec}^{-1}$. Describe the emf as a function of time, providing as much detail as possible. (*You don't need to worry about the sign of the emf since you aren't told the direction of the spin.*)

8. (10) A lens made of flint glass with an index of refraction of 1.61 is to be coated with a thin layer of magnesium fluoride with an index of refraction of 1.38 in order to reduce reflection.

   a. What minimum thickness should the layer have so as to give destructive interference for the perpendicular reflection of light of wavelength 550 nm that enters this lens from air? You must provide a diagram with clearly labeled phase changes in order to earn full credit.

   b. Does your choice of thickness permit constructive interference for the reflection of light of some other wavelength in the visible spectrum (380 nm – 750 nm)? *To earn full credit for this part, you need to provide a calculation that supports your response.*

9. (10) An electromagnetic wave traveling in vacuum is described by the formula

   $\vec{E} = A\sin(ky - \omega t)\,\hat{x}$ with $A = 100\ V/m$ and $k = 1.2\text{x}10^7\ m^{-1}$.

   a. What is the frequency f of this wave?

   b. What is the wavelength λ of this wave?

   c. In what direction is this wave traveling?

   d. What is the direction of polarization of this wave?