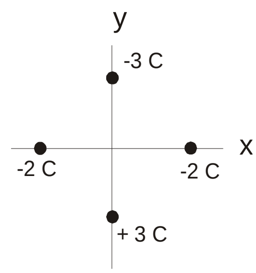
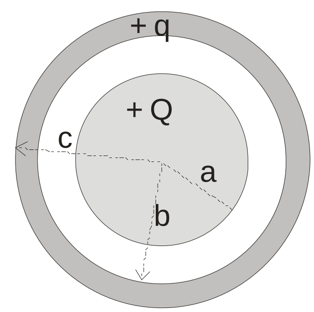
1. (*20 pts*) Four point charges are arranged on a 2-D *xy* coordinate system as shown in the figure. The top and bottom particles each have a charge of magnitude 3.0 C (*but of opposite sign, as shown*) while the left and right particles both have a charge of -2.0 C. The charges lie along the axes of the coordinate system and each charge is a distance 10 m from the origin.



   A. What is the electric field (*magnitude and direction*) at the origin?
   B. What is the electric potential at the origin?
   C. Calculate the of the force (*magnitude and direction*) on the -3 C charge due to the other three charges.
   D. How much work was required to assemble this system of charges, assuming that each charge was originally very far away from the origin of this co-ordinate system and from each other?

2. (*30 pts*) 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 q is placed on the conducting shell, distributing itself appropriately.



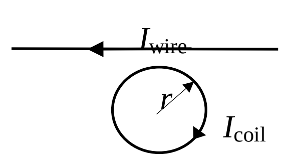
   A. How much charge resides on the inner and outer surfaces of the conducting shell, at $r = b$ & $r = c$?
   B. What is the electric field as a function of distance, *r*, in each of the regions listed below?

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

   C. What is the electrical potential *V* at each of the special points listed below, assuming that $V \equiv 0$ at infinity?

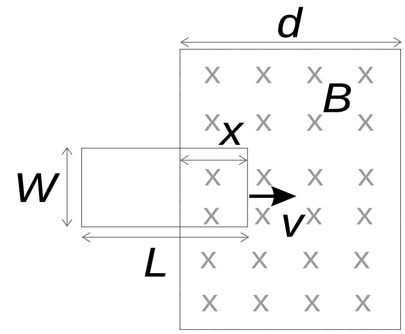
      $r = c$ $r = b$ $r = a$ $r = 0$

3. (*15 pts*) A coil of wire that has N turns and a radius $r = 0.22$ m is carrying a clockwise current $I_{coil} = 2.0$ A. A nearby long straight wire located in the plane of the coil and $l = 0.05$ m from its edge (*so the distance to the center of the coil is r +l*) carries a current $I_{wire} = 308.4$ A towards the left. When you measure the magnetic field at the center of the coil, you find it is zero.

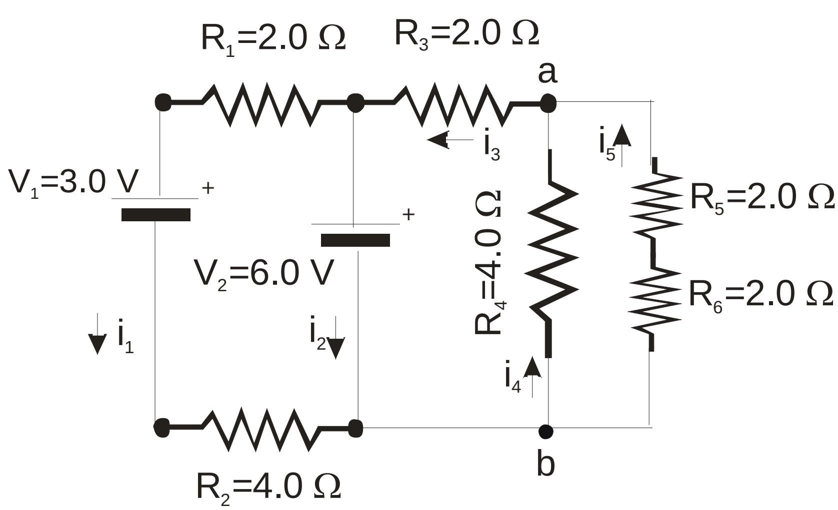


   A. What is the direction of the magnetic field due to I_{wire} at the center of the coil?
   B. What is the direction of the magnetic field due to I_{coil} at the center of the coil?
   C. Determine *N*, the number of turns of the coil.

4. (*20 pts*) A uniform magnetic field of magnitude B = 3.0 T pointing down into this page fills a strip of space of width d = 15 cm. A rectangular loop of wire lies in the plane of the paper and moves with a velocity v = 5.0 m/s through the region of magnetic field, from left to right. The loop has a width W = 8.0 cm and a length L = 10 cm. Plot the EMF, $\mathcal{E}$, induced in the loop as a function of the position of the leading edge of the loop, x (*defined as x = 0 when the loop first enters the strip of width d*), from x = -1 cm to x = + 30 cm. Be certain that your plot scales are labeled, *i.e.* you need to calculate and not just estimate the EMF as the loop of wire moves through the field. Assume that a clockwise EMF is defined as positive.

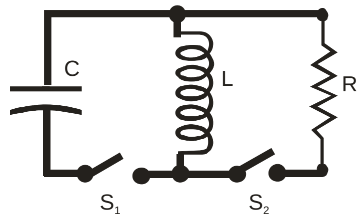


5. (*15 pts*) The figure below shows a DC circuit with two batteries and six resistors. Find the magnitude and sign of each of the five currents labeled in this figure as i_1 through i_5. Use the directions shown for these currents, reporting a negative value if a current in fact flows in the opposite direction. Also, find the potential of point *a* relative to point *b*.



6. (*10 pts*) C = ε_0A/d for a parallel plate capacitor, where A is the area of the plates and d is their separation. Show how to derive this formula using the definition of capacitance as C = Q/V plus Gauss's Law applied to an infinite sheet (*to find the electric field for sheets of charge*) and the relationship of electric potential differences to electric field.

7. (*25 pts*) Consider the circuit shown below with C = 1.7 μF,   L = 0.03 H, and R = 47 Ω. The capacitor is initially given a charge Q = 8.84 x 10^{-5} coulomb and switches S_1 and S_2 are both initially open.



A. What is the initial voltage across the capacitor?

B. At $t_1 = 0$ switch S_1 is closed. What is the current through this switch immediately afterwards?

C. At what time(s) does the current through the inductor reach a maximum (*in magnitude – don't worry about the sign*)?

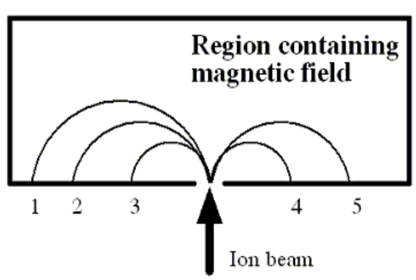
D. What is this maximum current i_{max} in the inductor?

E. What are the current through and the voltage across the capacitor when the current through the inductor is a maximum?

F. When the current through the inductor reaches its first maximum, switch S_2 is closed and an infinitesimal time later switch S_1 is opened. How long does it take the current through the inductor to fall to $(1/e)i_{max}$, where *e* is Euler's number = 2.718?

G. What total energy is eventually dissipated in the resistor?

8. (*15 pts*) A beam consisting of five types of ions labeled **A**, **B**, **C**, **D**, and **E** enters a chamber that contains a uniform magnetic field. 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 are traveling with the same speed v = 5x10^4 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. Is the direction of the magnetic field into or out of this page? (*Justify your response.*)

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

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

9. (*10 pts*) 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 magnesium fluoride layer have so as to give destructive interference for the perpendicular reflection of light of wavelength 550 nm that enters this lens from air?

   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)? *You need to provide a calculation that supports your response in order to earn much credit for it.*

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

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

   A. What is the wavelength λ of this wave?

   B. What is the frequency *f* (*in Hz*) of this wave?

   C. In what direction is this wave traveling?

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