PHY 202 Homework 5

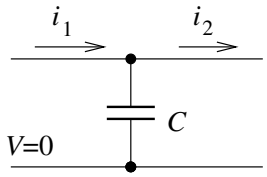
Due Friday, February 27 at 4:30 PM outside my office.

1. A parallel-plate capacitor has constant charges $+Q$ and $-Q$; each plate has area A and the plates have separation d. I pull the plates apart so that the separation is doubled.

   (a) By what factor does the energy in the capacitor change?

   (b) How much work did I do?

2. A capacitor, $C = 10\,\mu\text{F}$, is connected to two different current sources:



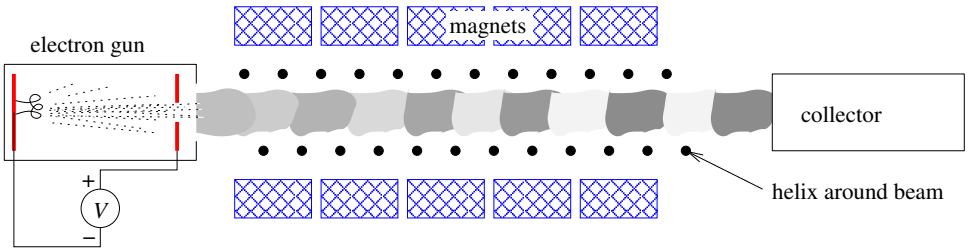
   where $i_1(t) = i_0 \sin(\omega t)$ and $i_2(t) = i_0 \cos(\omega t)$. The maximum current i_0 is 100 mA and the frequency of oscillation is 1000 Hz.

   (a) Find the charge on the capacitor as a function of time. Don't put in numbers yet. Use trig. relations to express your answer in $\sin(\omega t + \phi)$ form.

   (b) Find the difference between the maximum and minimum voltage across the capacitor. (Find the numerical value.)

   (c) Can you give a value for the voltage across the resistor at time $t = 0$? Explain briefly.

3. A travelling wave tube (TWT) is a vacuum tube device used to amplify microwave signals. Electrons are produced by a filament and are accelerated by an electric field. Then then enter a "delay line" region where an incoming signal causes the beam to bunch up.



   We can treat this as a one dimensional problem. Let us assume the current density of the beam behaves as

$$j(x,t) = j_0(1 + cx\sin(kx - \omega t))$$

(a) Find the charge density $\rho(x,t)$.

(b) Sketch a graph of j and ρ as a function of x .

(c) If the TWT is amplifying a 30 GHz signal and the accelerating voltage is $V = 13\,\text{kV}$, find the velocity of the electrons and numerical values for k and ω.

(d) In this case, how far apart are the bunches?

(e) If the electron gun uses 1100 W of energy, what is the current of the beam? (The total power of the TWT is somewhat less than this since some of the power is eventually recovered by the collector.)

4. Read about the "resistivity" of a material in your textbook. Find the resistance of a copper wire that is 100 m long and 1 mm in diameter.

5. An electric toaster has a heating element made of nichrome wire. When first connected to a 120 V power supply (constant voltage), the toaster has a current of 1.75 A. The current decreases as the toaster heats up. When the toaster has reached its maximum temperature, the current has dropped to 1.5 A.

   (a) What is the power consumed by the toaster when it first turns on?

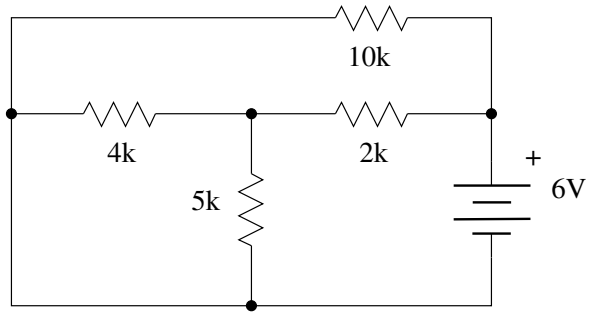
   (b) What is the final temperature of the heating element?

   (c) Do you smell something burning?

6. A potential difference of 1.0 V is applied between the ends of a copper wire that is 10 m long and has a diameter of 0.5 mm. Find the current density if the wire is kept at room temperature.

7. A material of resistivity ρ has a uniform current density J flowing through it. Show that the power per unit volume dissipated in the material is ρJ^2. This problem is not so hard if you define an "example" resistor with cross sectional area A and length l.

8. Find the equivalent resistance of the network of resistors and find the current produced by the battery. What is the voltage across the 5 k resistor?



9. In this circuit with two batteries, what is the voltage across the 1 k resistor?