2005-2006 Physics Olympiad Preparation Program

– University of Toronto –

We continue the competition for the best problems created by our POPTOR contestants. Name your self-made problem as "My Problem", and mail this problem and its solution on a separate sheet of paper as an attachment to the solutions of the POPTOR problems. You may send us any number of problems, but only self-made and unique will be considered. Authors of the best problems will be awarded regardless of their POPTOR results.

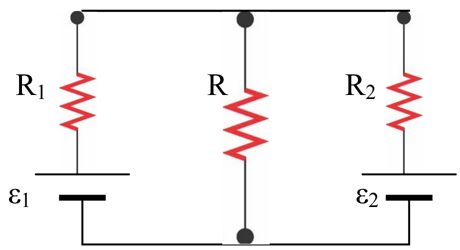
Problem Set 5: Electricity and Magnetism

Due March 6, 2006

Problem 1.
A little charged bead is inside the hollow frictionless sphere manufactured from the insulating material. Sphere has a diameter of 50 cm. The mass of the bead is 90 mg, its charge is 0.50 μC. What charge must carry an object at the bottom of the sphere to keep hold the charged bead at the vertex of the sphere?

Problem 2.
The diagram shows a circuit with given values for resistances R_1 and R_2 and electromotive forces of batteries ε_1 and ε_2. The internal resistances of the batteries can be neglected.

(a) Find the resistance R of the resistor when the maximum power is delivered to it.
(b) Find this maximum power.



Problem 3.
A cathode ray tube with the known applied voltage V is penetrated by the uniform magnetic field B, directed along the axis of the tube. There is a small diffuse spot on the screen of the operating tube. Varying B it is possible to obtain the focused electron trace on the screen when the magnetic field is equal to B_0, $2B_0$, $3B_0$, etc.
(a) Explain this phenomenon and the value of B_0.
(b) How is it possible to find the ratio of the electron charge and electron mass basing on the results of the described experiment?

Problem 4.
Brief theory.
When an electric current in a loop or coil is non-constant, it creates the variable magnetic field that, in turn, creates a changing flux through the coil. The changing flux induces the electromotive force (emf) of induction in the coil. This phenomenon is called a self-induction. As the origin of the self-induction is the changing current in the coil, the emf (ε) of self-induction is a function of the rate of change of the current, and is given by:

$$\varepsilon = -L\frac{\Delta I}{\Delta t}$$

where L is an inductance of the coil. The value of inductance depends on the geometry of the coil, number of its turns, and the core material. For a single loop L depends on its shape and size. The unit of inductance in the SI is 1 H (henry) = 1 V·s / A

A current-carrying circular loop of radius R = 50 mm manufactured from a very thin wire has an inductance of L = 0.26 μH and is inserted into the uniform magnetic field B = 0.50 mT. The plane of the loop is perpendicular to the magnetic field lines. The conductor of the loop was cooled down to the superconductive state with zero resistance. After it, the magnetic field has been turned off.
Find the current in the loop.

5. Drive experiment.

On a drive, you decide to demonstrate your family how powerful Physics is. You have a piece of wire and a compass.

(a) How to determine the electric charges on the terminals of the automobile storage battery using these tools and a bulb from the automobile kit?

(b) After the first success, you continue to demonstrate the power of Physics by determining the horizontal component of the magnetic field of the Earth using the same equipment. Explain the method in detail.