2004-2005 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 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 7, 2005

Problem 1.

In a uniformly charged sphere with radius R there is a spherical cavity with radius r and its center at a distance a from the center of the sphere. A volume charge density of the sphere is ρ.

Find the electric field vector $\boldsymbol{E}(x, \theta)$ inside the sphere as a function of a distance x from the center of the sphere and an angle θ (fig.1).

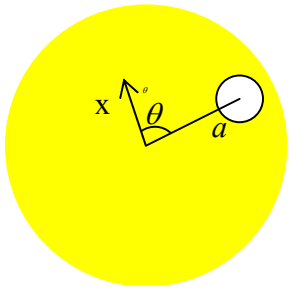

Fig.1

Problem 2.

Fig.2 shows a diagram for a hot-wire wattmeter (r_1 is much less than both r and R_L, where R_L is a resistance of a load). AB is a thin wire thrown over a pulley, which is pulled up by a spring. A needle is attached to a pulley and turns together with it. Amount of heat transferred from a wire into the surrounding air is directly proportional to their temperature difference. The change in the resistance of the wire AB due to its heating and mechanical elongation is negligible.

Prove that the angular displacement of a needle is directly proportional to the electric power consumption in the load with R_L.

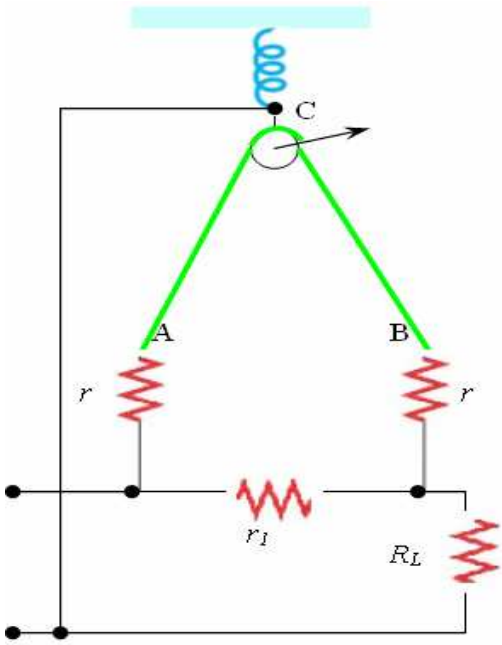

Fig.2

Problem 3.

The simplest magnetohydrodynamic generator consists of a parallel-plate capacitor immersed in a stream of a conductive liquid with conductivity σ. The surface area of a capacitor's plate is S, the distance between the plates is d. A liquid flows with the constant velocity v parallel to the plates. A capacitor is in a uniform magnetic field $\boldsymbol{B}$, which is perpendicular to the velocity and parallel to the plates.

What power is released in the external circuit that has a resistance R?

Problem 4.

A very thin dielectric ring with uniformly distributed electric charge Q and mass m lies on a frictionless horizontal plane. Magnetic field is perpendicular to the plane. Its induction changes from 0 to B_0.

What angular speed has a ring at the end of this process?

5. Imagine your experiment.

A "black box" with an unknown electric circuit inside has four terminals. A student wants to know the contents of the "black box". He has an ideal battery, two identical and not ideal voltmeters, and two identical and not ideal ammeters. The results of his measurements of current and voltage are shown in fig.3.

Determine the possible circuit in the "black box" and find its parameters numerically. Try to devise the simplest possible circuit.

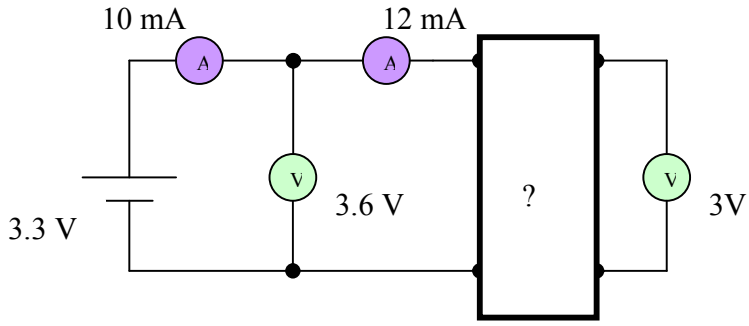

Fig.3