

# 2006-2007 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 along with 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 during the POPTOR Weekend.*

## Problem Set 5: Electricity and Magnetism

*Due March 5, 2007*

### Problem 1.

Two identical beads each have a mass  $m$  and charge  $q$ . When placed in a hemispherical bowl of radius  $R$  with frictionless, nonconductive walls, the beads move, and at equilibrium the distance between them is  $R$  (Fig. 1). Determine the charge on each bead.

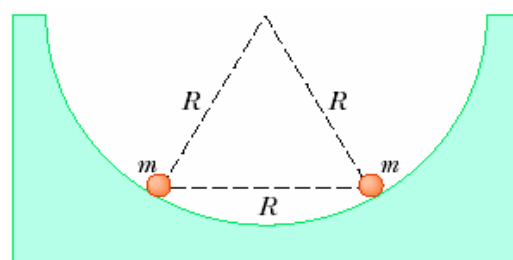
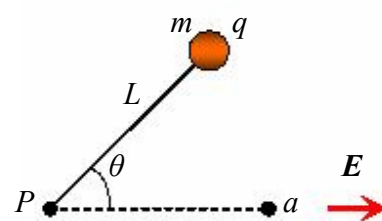


Fig.1

### Problem 2.

A particle having charge  $q = +2.00 \mu\text{C}$  and mass  $m = 0.0100 \text{ kg}$  is connected to a string that is  $L = 1.50 \text{ m}$  long and is tied to the pivot point  $P$  in Figure 2. The particle, string and pivot point all lie on a frictionless horizontal table. The particle is released from rest when the string makes an angle  $\theta = 60.0^\circ$  with a uniform electric field of magnitude  $E = 300 \text{ V/m}$ .



Top view

Fig.2

### Problem 3.

A plane capacitor is a pair of conductive plates charged with equal in magnitude charges of opposite signs. The capacitance  $C$  of a plane capacitor is given by:  $C = \epsilon_0 S / d$ , where  $\epsilon_0$  is called the permittivity of free space and is one of universal constants in the system of units SI;  $S$  is the surface area of the plates; and  $d$  is the distance between the plates.

A variable air capacitor used in a radio tuning circuit is made of  $N$  semicircular plates each of radius  $R$  and positioned a distance  $d$  from its neighbors, to which it is electrically connected. As shown in Figure 3, a second identical set of plates is enmeshed with its plates halfway between those of the first set. The second set can rotate as a unit.

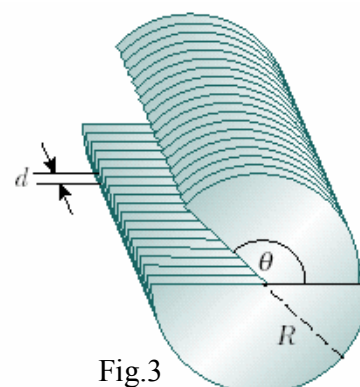


Fig.3

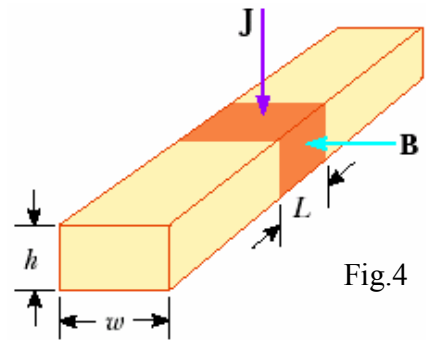
Determine the capacitance as a function of the angle of rotation  $\theta$ , where  $\theta = 0$  corresponds to the maximum capacitance.

**Problem 4.**

Sodium melts at  $99^{\circ}\text{C}$ . Liquid sodium, an excellent thermal conductor, is used in some nuclear reactors to cool the reactor core. The liquid sodium is moved through pipes by pumps that exploit the force on a moving charge in a magnetic field. The principle is as follows. Assume the liquid metal to be in an electrically insulating pipe having a rectangular cross section of width  $w$  and height  $h$ . A uniform magnetic field perpendicular to the pipe affects a section of length  $L$  (Fig. 4). An electric current directed perpendicular to the pipe and to the magnetic field produces a current density  $J$  in the liquid sodium.

(a) Explain why this arrangement produces on the liquid a force that is directed along the length of the pipe.

(b) Find a pressure increase on the highlighted section of liquid in the magnetic field.



**Problem 5 (experimental).**

Prepare an insulating stick and charge it (by rubbing, for example).

Use an elastic tube as a spraying device, directing a jet of a tap water at some angle to the horizontal. As a result, the water will fall down in a lot of droplets of different sizes like in a fountain. If now you approach a charged stick to this falling spray, you can observe how the droplets merge into a single continuous stream.

Try to perform this experiment and explain the result of using the charged stick.