

1994-1995 Physics Olympiad Preparation Program

– University of Toronto –

Problem Set 5: Electricity and Magnetism

Due March 6th, 1995

1. Okay, all you mental gymnasts – it’s time for the parallel conducting bar problem, an Olympian event designed to exercise your upper bodies. Consider two long parallel conductors, each carrying currents in the same direction, as shown in Figure 1. Conductor A carries a current of 100 A and is held firmly in position. Conductor B carries 147 A and is allowed to slide freely up and down (parallel to A) between a set of non-conducting guides. If the equilibrium distance between the two conductors is 2 cm, what is the linear mass density of conductor B?
2. Pretend for a moment that you’re an engineer working on the design of a resistor that is to have a temperature coefficient of expansion of zero at 20°C. The design is a composite of two bars having octagonal cross sections (each side of the octagon having a length $d = 0.25$ mm) as shown in Figure 2. The ratio of the resistivities of the two materials is $\rho_1/\rho_2 = 3.2$, and the ratio of the lengths is $l_1/l_2 = 2.6$. The cross sectional geometry and dimensions are uniform throughout the resistor. Assuming that the temperature of the two sections remains equal, calculate α_1/α_2 , the required ratio of the temperature coefficients of resistivity of the two materials.
3. It is the year 2236, and the Federation has just banned all telecommunication optical fibre in your sector for some unknown reason. The replacement configuration, consisting of two coaxial dielectrics, is depicted in Figure 3. The permittivities are ϵ_1 and ϵ_2 , respectively, the conductor has potential V_0 , and the outer shield is grounded.
 - (a) Derive an expression for the capacitance per unit length for the cable.
 - (b) Given that $V_0 = 1.2$ kV, $\epsilon_{r1} = (4.5/36\pi) \times 10^{-9}$ F/m, $\epsilon_{r2} = (3.0/36\pi) \times 10^{-9}$ F/m, and $r_3 = 2r_2 = 4r_1 = 40$ mm, determine the maximum electric field intensity in each dielectric.Note that, for an infinite single dielectric coaxial cable, the capacitance per unit length is $c = 2\pi\epsilon/\ln(b/a)$ where ϵ is the permittivity of the dielectric with outer radius b , and a is the radius of the conductor ($a < b$). By Gauss’ Law, the electric field intensity for such a coaxial cable is given by $E = q/2\pi r\epsilon$, where $a < r < b$ and q is the charge per unit length in the region enclosed by r .
4. Consider two conducting spheres, one of radius 6.0 cm and the other of radius 12 cm, where each has 3×10^{-8} C of charge and is positioned very far apart from the other. The spheres are then connected by a platinum wire maintained at a temperature of 312.5 K. Find:
 - (a) the direction of motion and magnitude of the charge transferred, and
 - (b) the final charge on and electric potential of each sphere.
5. As an accelerator physicist, you have been asked to design a fixed target machine to produce antiprotons, \bar{p} , the antimatter partner of protons, p . The reaction is $p + p \longrightarrow p + p + p + \bar{p}$, where one high energy proton hits another proton that is at rest (since it’s part of the target). In addition to the original two reactant particles, a proton-antiproton pair is created. What is the minimum energy required by the incident proton for this reaction to occur? Express your answer in terms of the proton mass m and the speed of light c . Hint: consider the centre of mass reference frame.
6. Imagine a long copper conductor with rhombic cross section having sides of length $\sqrt{5}$ mm and diagonal dimensions of 2 mm and 4 mm. The conductor is carrying a current of 10 A. Each second, what percentage of the conduction electrons must leave (to be replaced by others) a 100 mm length?