1995-1996 Physics Olympiad Preparation Program

– University of Toronto –

Problem Set 5: Electricity and Magnetism

Due February 19^{th}*, 1996*

1. Pretend that you are an electrical engineer. You supervise the construction of an electric generating plant system at a rate of 1 GW and a voltage of 12,000 V.

   (a) It is desired to transmit the power at 756 kV. What must be the turns ratio of the step-up transformer?

   (b) What current would be sent out over the power lines if the transmission were at 12,000 V.

   (c) What is the actual current you expect?

2. Many environmentalists are disturbed by the radiation from power lines. They may not be concerned with the electric field because they can buy the argument that human body is almost a perfect conductor. (Will you buy it ... ?) Anyway, but they worry so much with the effect of magnetic field in the high voltage transmission lines like your design in the previous problem. As an engineer you try to convince them that the powerful plant like yours (1 GW and 756 kV transmission lines) is still safe because you already put the transmission line high enough. Otherwise, you will lose your job because they are very persuasive these days. What is the minimum height you have to put your lines so the effect of magnetic field on the ground is only 10% of the natural one? The magnetic field at Earth's surface is 0.5 gauss in contrast to the one in the lab which can go up to 1.0 T.

3. You are trapped in a dungeon to assist an old physicist of 1950's who still has his own ancient accelerator. It is a boring job but he pays you very well, better than your previous job as an electrical engineer. He asks you to accelerate a beam of electrons at a voltage of 10,000 V and this beam enters a uniform magnetic field of 0.50 T perpendicular to the motion of the electrons.

   (a) What is the force on each electron due to the magnetic field?

   (b) What will the speed of each electron be after it has been in the field for 10 seconds?

4. After working for years as a research assistant, sometimes you have nightmares. One day, you dreamt that you were an electron travelling parallel to a very long,thin wire at a distance of 20 cm. Suddenly, you felt you were pushed away from the wire by a strong force (well, you are very tiny now) because your boss turned on the electric current of 2.0 A on the wire. How much force did the magnetic field of the current exert on you and what was the direction of the force with respect to the current? After you woke up, you told your boss about your dream and he laughed, "Why didn't you tell me to place the wire between two large plates of a capacitor so I would not have bothered you?" You seemed puzzled. Now, after many years of enlightment, you know the reason why he said this. What was the voltage of the capacitor to keep you travelling happily along the wire and what was the direction of the electric field?

5. Nuclear fusion is like a long term commitment for a blind mouse couple. Sometimes you need to interfere by pushing one or both toward the other. But you can attract them by placing a piece of cheese between them so they will smell it. This kind of cheese is called a catalyst in the fusion reaction.

   To make the story simple, you would like to have fusion of two protons.

   (a) If the catalyst is an electron, what is the total kinetic energy of the system at its minimum potential energy where the electron sits collinearly between these two protons? Assume that all three are far apart from each other and the minimal distance between the protons is about 0.1 nm.

(b) Instead of an electron, you can also use a muon which is heavier by a factor of 207. This heaviness makes the distance between the protons smaller by a factor of 207, too. What is the total kinetic energy of the system now?

Of course, the story does not end here because the two protons will transform into a deuteron, and emit a positron and a neutrino.

NOTE: This minimal distance between the protons is determined by the Heisenberg uncertainty principle of quantum mechanics.

6. Here are a few questions that do not require any calculations.

   (a) You have been told that wave requires a medium to propagate like sound requires air. However, light, which is electromagnetic wave, can travel in vacuum. How do you explain this phenomenon?

   (b) Electromagnetic wave, like other waves, can transmit energy from one place to another, say E. How much momentum does it transmit if it can?

   (c) Why do we all have an AC-, instead of DC-, power in the houses and buildings?