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EE214000 Electromagnetics, Fall 2020

Your name: _____ ID: _____ Nov. 23rd, 2020

EE214000 Electromagnetics, Fall, 2020
Quiz #11-1, Open books, notes (22 points), due 11 pm, Wednesday, Nov. 25th, 2020
(email solutions to 劉峰麒 alex851225@gmail.com)

Late submission won't be accepted!

1. An electron moves under the force of an electric field. In Newton's mechanics, the electron is accelerated under the electric force. Explain why the Ohmic law, valid for a Ohmic material, gives a linear relationship between *I* and *V*. In other words, what is an Ohmic material? (5 points)

Ans: In an Ohmic material, electrons collide with the material matrix in a short distance and move with an average speed *u* proportional to the electric field driving it, ie. $\vec{u} = \mu\vec{E}$. Therefore, $\vec{J} = \rho\vec{u} = \rho\mu\vec{E} = \sigma\vec{E}$, which gives a linear relationship between *I* and *V*.

2. The I-V relationship in an Ohmic material is I ∝ V; whereas that in a space-charge limited vacuum diode is $I \propto V^{3/2}$. What could be the I-V relationship in a vacuum diode with negligible space charge field? (4 points)

Ans: In a vacuum diode with a very low electron density, an electron does not see the electric field from nearby electrons. For a single electron, from energy conservation, the final speed of the electron is

$\frac{1}{2}mu^2 = eV \Rightarrow u = \sqrt{\frac{2eV}{m}}$, which is the same as that for all other electrons. This means in such a vacuum diode COULD follow the following I-V relationship.

$J = \rho u \Rightarrow I \propto V^{1/2}$.

For this problem, it is OK for you to come up with different IV relationships, if you state your assumption an logic clearly.

3. An electron is accelerated between two electrode plates of voltage *V* to gain a kinetic energy of *e*×*V*, where *e* is the electron charge. Therefore, *eV* is a common energy unit for an electron beam from an accelerator. Suppose, in vacuum, an electron beam of current *I* = 0.1 Ampere has energy of 1 GeV (values comparable to those in the Taiwan Synchrotron facility). What is the total power carried by this electron beam? (5 points)

Ans: The number of electrons in the current I is $\frac{I \times \Delta t}{e}$

The total energy in the electron beam in an arbitrary time period Δt is

$$\Delta W = \frac{I \times \Delta t}{e} \times 1\,\text{GeV} = I \times 1GV \times \Delta t$$

The power carried by the electron beam is therefore

$$\frac{\Delta W}{\Delta t} = I \times 1MV = 0.1A \times 1GeV = 100MW$$

In fact, this is just what we have derived from the Joule's law

$$P = I \times V$$

4. State the assumption and physical meaning of the equation of continuity. (5 points)

Ans: The basic assumption of the equation of continuity is charge conservation in space. Therefore, the change of the charges per unit time in closed volume is equal to the current flowing out from the surface of the volume.

5. What is Joule's law? Does it apply to both Ohmic and non-Ohmic materials? (3 points)

Ans: The Joules law states $P = \int_V \vec{E} \cdot \vec{J} dv$. This law, derived from Newton's mechanics without any assumption, is very fundamental and is applicable to both Ohmic and non-Ohmic materials.