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EE214000 Electromagnetics, Fall 2020

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Quiz #11-1, Open books, notes (22 points), due 11 pm, Wednesday, Nov. 25th, 2020
(請上傳到 iLMS)

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)

In the Ohmic materials, collision will limit an electron to move at an average speed under an electric field $\vec{u} = -\mu_e \vec{E}$ (m/s), where μ_e is the mobility of an electron.

The volume current density becomes linearly proportional to the electric field $J = \rho\vec{u} = -\rho\mu_e\vec{E} = \sigma\vec{E}$, where σ is the conductivity

Ohm's Law:

$$\left.\begin{array}{l} I = JS = \sigma E S \\ V = E\ell \end{array}\right\} \frac{V}{I} = \frac{\ell}{\sigma S} = R \Rightarrow V = IR$$

Ohmic Loss

$$P = \int_v \vec{E}\cdot\vec{J}\,dv = \int_\ell \vec{E}\cdot d\vec{\ell} \int_s \vec{J}\cdot d\vec{s} = V\cdot I$$

$$\Rightarrow P = I\cdot V = I^2R = \frac{V^2}{R}$$

From the equations above, we can find the Ohmic material has three characteristics:

(1) Speed of electrons is linearly proportional to the applied electric field. $\Rightarrow \vec{u} = -\mu_e\vec{E}$

(2) Current is linearly proportional to the applied voltage. $\Rightarrow V = IR$

(3) Collision will induce the energy loss $\Rightarrow P = I\cdot V = I^2R = \frac{V^2}{R}$

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2. The I-V relationship in an Ohmic material is I $\propto$ 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)

$\nabla \cdot \vec{J} = \frac{\partial \rho_v}{\partial t} \Rightarrow$ steady , $\frac{\partial \rho_v}{\partial t} = 0$

$\Rightarrow \nabla \cdot \vec{J} = 0$, for ρ_v is constant.

$\Rightarrow J = \rho u = \rho\sqrt{\frac{2eV}{m}} \Rightarrow J \propto V^{\frac{1}{2}}$

$\Rightarrow I \propto V^{\frac{1}{2}}$

3. An electron is accelerated between two electrode plates of voltage V to gain a kinetic energy of $e\times V$, 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)

$P = N \cdot \frac{E}{t}$, P: power , N: number of electrons E: energy t: period

$\Rightarrow P = \frac{0.1}{1.6 \cdot 10^{-19}} \cdot \frac{1.6 \cdot 10^{-19} \cdot 10^9}{1s} = 0.1 \cdot 10^9 = 10^8 = 100\,MW$

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

Equation of continuity : $\nabla \cdot \vec{J} + \frac{\partial \rho}{\partial t} = 0$

By charge conservation , in the close volume :

positive (negative) time-rate change of charges

= current flowing outward (inward)

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

Joule's Law : consider a group of charges pulled by an electric field.

$\vec{F} = q\vec{E}$

$dP = d(\vec{F} \cdot \vec{u}) = (\vec{E}\,dq) \cdot \vec{u} = (\vec{E}\rho\,dv) \cdot \vec{u} = \vec{E} \cdot (\rho\vec{u}\,dv) = \vec{E} \cdot \vec{J}\,dv$

$\Rightarrow P = \int_V \vec{E} \cdot \vec{J}\,dv$, for $\vec{E} \cdot \vec{J}$ is the volume power density

$\Rightarrow$ It applies to both Ohmic and non-Ohmic materials.