ELECTROMAGNETISM

Level 2 Physics problems – Foundations of physics 2

Question 6 Cycle 2 Version 1

Professor D P Hampshire – 2nd Year Physics Lecture Course

These problems are formatively self-assessed. Students who showed the chutzpah to volunteer for the peer-marking pilot scheme will also mark one of their peer's scripts.

Reading Material (Please note that questions may not be exclusively from these chapters): Please read chapters 7 and 8 of Griffiths.

1. The root mean square of the displacement current density in a linearly-polarised monochromatic plane wave in free space is 10^{-4} $\mathrm{Am^{-2}}$. The frequency is 10^{9} Hz. Obtain values for the amplitude of the electric and magnetic fields in the wave. [1 mark]

2. Find the conductivity of the medium if the magnitude of the conduction and displacement current densities in the medium, of relative permittivity equal to 5 and relative permeability equal to unity, are equal when a monochromatic plane wave of frequency 10^{9} Hz propagates through it. [1 mark]

3. A well-known Durham Physics student is hiding from the paparazzi behind the 'High Force Waterfall' in Co Durham and using their mobile phone. The water feature is such that the electromagnetic waves from their mobile phone must pass through 2 cm of water in order to reach the digital network receiver. By considering the dispersion relation for a conducting media;

$$k^2 = \omega^2 \mu \varepsilon + i\mu\sigma_N\omega$$

a) Show that at the frequency of an EE digital network mobile phone (i.e. ~ 1.8 GHz), the water cannot be considered either a very good or a very poor conductor. [1 mark]

Note: The dielectric constant for water is 50, the conductivity is 2 $\Omega^{-1}.\mathrm{m}^{-1}$

b) By what percentage does the mobile phone electric field signal reduce as a result of passing through the 2 cm of water? [1 mark]

4. In a high density plasma, such as a metal, collisions between electrons cannot be ignored and the average response of electrons to an applied $\underline{\boldsymbol{E}}$-field satisfies;

$$m\frac{d\underline{\boldsymbol{v}}}{dt} = -e\underline{\boldsymbol{E}} - \frac{m\underline{\boldsymbol{v}}}{\tau}$$

where τ is the mean time between collisions.

a) By considering the propagation of an $\underline{\boldsymbol{E}}$-field through the plasma and the propagation of the current (i.e. moving electrons) it produces (or otherwise), show that this leads to the expression; [1 mark]

$$\sigma_N = \frac{Ne^2}{m(\frac{1}{\tau} - i\omega)}$$

for σ_N for the electrical conductivity of the plasma.

b) Given that the electron concentration is $N = 10^{30}$ m^{-3}, use the low frequency value of σ_N (10^8 Ω^{-1} m^{-1}) to obtain an estimate for the value of τ. [1 mark]

c) At what frequency in Hz is the magnitude of the conductivity reduced to one third of its low frequency value? [2 marks]

5. A perfectly conducting spherical shell of radius a rotates about the z axis with an angular velocity ω, in a uniform magnetic field,

$$\underline{\boldsymbol{B}} = \mathrm{B}_0\hat{\boldsymbol{z}}$$

Find an expression for the EMF developed between:

a) The north pole and the equator. [1 mark]

b) The north pole and the south pole. [1 mark]

(c.f. Griffiths Problem 7.45)