GX764

COLÁISTE NA hOLLSCOILE
GAILLIMH

NATIONAL UNIVERSITY OF IRELAND
GALWAY

SUMMER EXAMINATIONS 1999

B.Sc. (Honours) Experimental Physics – Paper 2

EP433: EM and Relativity

Prof. J. Enderby
Prof. R.M. Redfern
Prof. G.F. Imbusch

Time Allowed: TWO hours	Answer THREE questions

Q.1 Write down a general formula for the electric field intensity (**E**(**r**)) at a point **r** due to, and outside of, a static charge distribution $\rho(\mathbf{r}')$.

Show that **E**(**r**) may be derived from a potential function, and derive a general formula for this potential function. Show that **E**(**r**) has the property that

$$\oint_L \vec{E}\cdot d\vec{l} = 0$$

where L is any closed loop.

The electrostatic potential $\varphi(\mathbf{r})$ due to a dipole of moment $\boldsymbol{p}$ at the origin is given by

$$\phi(\vec{r}) = \frac{\vec{p}\cdot\vec{r}}{4\pi\varepsilon_0|\vec{r}|^3}$$

where $|\mathbf{r}| \gg$ the dimension of the dipole. Derive an expression for the electric field intensity **E**(**r**) due to this dipole.

Q.2 Starting with the Biot-Savart law:

$$\mathbf{B}(\mathbf{r}) = \frac{\mu_0}{4\pi}\int_{V'} \frac{\vec{J}(\vec{r})\times(\vec{r}-\vec{r}')}{|\vec{r}-\vec{r}'|^3}dV',$$

show that **B** can be written as $\nabla\times\mathbf{A}$. Find the form of **A**. Show that $\nabla.\mathbf{B} = 0$.

Calculate the form of the **B**(**r**) field when $\mathbf{A}(\mathbf{r}) = -\frac{1}{2}(\mathbf{r}\times\mathbf{B}_o)$, where $\mathbf{B}_o$ is a constant vector.

p.t.o.

Q.3 Write down the four Maxwell equations governing the behaviour of the electric and magnetic fields in a linear isotropic material, when there are no free charges or true current in the material. Show that these have solutions in the form of travelling waves of electric and magnetic disturbance. Describe the nature of these waves, as well as the relationship between the electric and magnetic waves.

Write down an expression for the energy density in the electric and magnetic fields in terms of the **E** and **B** values. Show that $\mathbf{E} \times \mathbf{H}$ (or $\mathbf{E} \times \mathbf{B}/\mu_0$, if we are dealing with a non-magnetic material) gives the rate of energy flow per unit area of these electromagnetic waves.

If a 10 kW laser beam is directed onto a material, all of which is absorbed, what force is being exerted on the material by the beam?

Q.4 Answer both (a) and (b).

(a) As a model of a polarizable medium, we may consider a material in which each atom consists of an immovable fixed core and a movable particle of mass m and charge q bound by a restoring force, $-Kx$, to the core, x being the separation of the movable charge from the centre of the core. The equation of motion for such a charge, in the presence of an electric field, **E**, directed along the x axis is

$$m\ddot{x} + c\dot{x} + Kx = Eq$$

where $c\dot{x}$ is a damping force. Solve this equation for the case of an oscillating field, E, and show how it leads to the concept of a complex electrical susceptibility and a complex dielectric constant. Explain how a beam of electromagnetic radiation passing through this material will be attenuated.

(b) Define the electromagnetic four-vectors J_μ and A_μ. Show that, in the Lorentz gauge, these are related by

$$\Box^2 A_\mu = -\mu_o J_\mu$$

Q.5 Write down the Lorentz transformation between two coordinate frames moving relative to each other with constant velocity, v, in the x-direction. Use this to explain the phenomena of (a) time dilation, and (b) the Fitzgerald-Lorentz contraction.

Charged pions have an intrinsic half-life of 1.77×10^{-8} s. A collimated beam of such particles, produced in an accelerator, is found to drop to half of its original intensity after travelling 39 m. What is the velocity of the particles? Express it as a fraction of the velocity of light (3×10^8 m s^{-1}).

Special relativity requires that the laws of physics must be expressible in a form that is invariant under Lorentz transformation. Explain how the relativistic law of conservation of momentum is developed, and briefly discuss the implications of this conservation law.