SEMESTER 1 EXAMINATION 2014-2015

ELECTRICITY AND MAGNETISM

Duration: 120 MINS (2 hours)

This paper contains 8 questions.

Answers to Section A and Section B must be in separate answer books

Answer **all** questions in **Section A** and **only two** questions in **Section B**.

Section A carries 1/3 of the total marks for the exam paper and you should aim to spend about 40 mins on it.

Section B carries 2/3 of the total marks for the exam paper and you should aim to spend about 80 mins on it.

An outline marking scheme is shown in brackets to the right of each question.

A Sheet of Physical Constants is provided with this examination paper.

Only university approved calculators may be used.

A foreign language translation dictionary (paper version) is permitted provided it contains no notes, additions or annotations.

Maxwell's Equations:

The Maxwell equations for electric field $\underline{E}$ and magnetic field $\underline{B}$ are given by

$$\int \underline{E}.d\underline{A} = \frac{Q_{\text{enc}}}{\epsilon_0}$$

$$\int \underline{B}.d\underline{A} = 0$$

where these two equations are area integrals over closed surfaces and Q_{enc} is the charge enclosed by the surface,

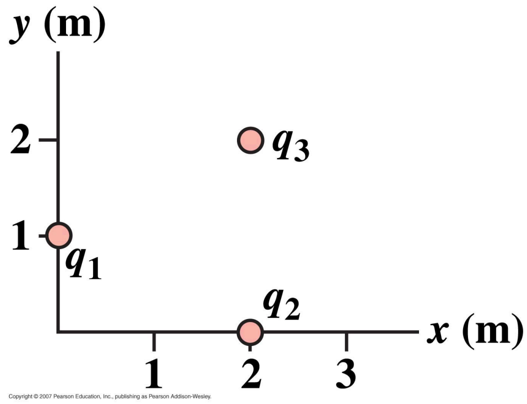
$$\int \underline{E}.d\underline{l} = -\frac{d\Phi_B}{dt}, \qquad \Phi_B = \int \underline{B}.d\underline{A}$$

$$\int \underline{B}.d\underline{l} = \mu_0 I + \mu_0\epsilon_0\frac{d\Phi_E}{dt}, \qquad \Phi_E = \int \underline{E}.d\underline{A}$$

where the two integrals on the left are line integrals round closed loops, Φ_E and Φ_B are the electric and magnetic fluxes through the areas enclosed by the loops, and I is the current passing through the closed loop.

Section A

A1. Three charged particles are held at the positions shown in the figure.



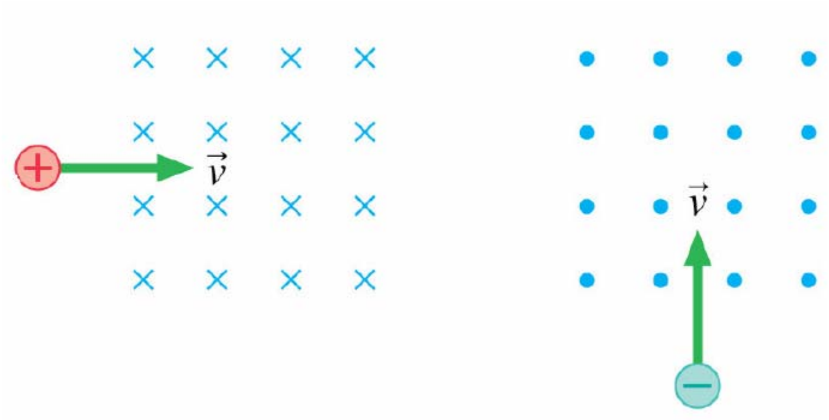
Take $q_1 = 57\mu$C, $q_2 = -23\mu$C, and $q_3 = 17\mu$C. Find the electric force on q_3. [3]

A2. The charge density in a sphere of radius a varies with radial distance, r, from the centre as $\rho = kr^2$. k is a constant of units Cm^{-5}. Compute the total charge on the sphere. [4]

A3. An electron close to a large, flat sheet of charge is repelled from the sheet with a force of magnitude 2.8×10^{-12}N. Find the surface charge density on the sheet. You should compute the electric field using Gauss' Law, explaining your steps, as part of your answer. [5]

TURN OVER

A4. What is the initial direction of deflection for the charged particles entering the magnetic fields shown in the figure? A cross means the magnetic field is directed into the page, a dot that it is directed out of the page.



If the particle on the left is a proton with speed 2.0×10^{7} m s^{-1}, and the magnetic field strength is B = 0.70 T, what is the magnitude of the magnetic force on the proton? [4]

A5. Use Ampere's law to determine the magnetic field around an infinitely long, current carrying wire. Explain all the steps that you take. [4]

Section B

B1. (a) A point charge is located a fixed distance from a spherical shell with charge uniformly distributed on its surface. If the shell shrinks in size without losing any charge, what happens to the force on the point charge? Explain your reasoning using the appropriate law of physics. [5]

(b) In (a), work must be done in order to shrink the spherical shell as described. This energy becomes stored in the electric field. The general expression for the energy density, $\mathcal{E}$, stored in an electric field, $\mathbf{E}$, is

$$\mathcal{E} = \frac{1}{2}\epsilon_0|\mathbf{E}|^2$$

Compute the extra energy in the electric field if the sphere shrinks from an initial radius R to a smaller radius L. [5]

(c) A long, thin wire carrying 4.7 nC m^{-1} runs down the centre of a long, thin-walled, hollow pipe with radius 1.0 cm carrying -6.2 nC m^{-1} spread uniformly over its surface. Use Gauss' Law to find expressions for the electric field strength moving radially away from the wire. Then determine the magnitude of the electric field (i) 0.50 cm from the wire and (ii) 1.5 cm from the wire. [10]

TURN OVER

B2. (a) Define in words what is meant by the potential difference between two points in an electric field. [3]

(b) If an electron is released into a region containing an electric field, will it move toward higher or lower potential? Explain your answer using both a diagram and the formula relating potential to electric field. [5]

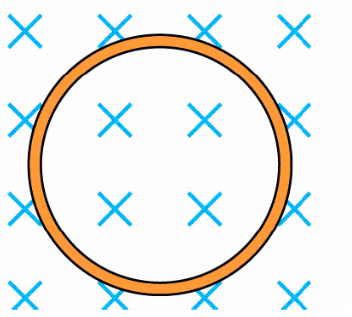
(c) The electric potential difference between the ground and a cloud in a particular thunderstorm is 1.2×10^9 V. What is the magnitude of the change in potential energy of an electron that moves between the ground and the cloud? [3]

(d) Derive an expression for the potential at a distance r from an isolated solid metal sphere of radius R and carrying a charge Q. Draw a well-labelled graph of potential as a function of r from the centre of the sphere to values of r far from the sphere. [7]

(e) Two solid metal spheres each 1.0 cm in radius are far apart. Sphere A carries 38 nC of charge, sphere B carries -10 nC. If the spheres are connected by a thin wire, what will be the potential on each once equilibrium is reached? State the assumptions you have made. [2]

B3. (a) State Faraday's Law and Lenz' Law using words as well as formulae. [6]

(b) The figure below shows a conducting loop in a uniform magnetic field directed into the page.



Taking care to explain your reasoning, give the direction of current flow in the loop in the figure if

(i) the magnetic field strength is increasing

(ii) the radius of the loop is shrinking.

[4]

(c) A physicist's gold ring moves from an area with a magnetic field of 0.80T to a location with no magnetic field in 45ms. The 2cm diameter ring has a resistance of 50$\mu\Omega$ and a mass of 15g.

Estimate the thermal energy produced in the ring due to the induced current. [7]

Find the resulting temperature rise of the ring. The specific heat capacity of gold is 129 Jkg^{-1}K^{-1}. [3]

END OF PAPER