A10288W1

FIRST PUBLIC EXAMINATION

Long Vacation

Preliminary Examination in Physics

Paper CP2: PHYSICS 2

06 September 2016, 9.30 am – 12.00 pm

Time allowed: 2$\frac{1}{2}$ hours

Answer **all** *of Section A and* **three** *questions from Section B.*

Start the answer to each question on a new page.

The use of approved calculators is permitted.

A list of physical constants, mathematical formulae and conversion factors accompanies this paper.

The numbers in the margin indicate the weight that the Moderators expect to assign to each part of the question.

Do NOT turn over until told that you may do so.

Section A

1. State Gauss' law in its integral form in a vacuum. Use this to obtain Coulomb's law for the **E**-field due to a point charge. [3]

Explain why **E** is normal to a conducting plate, and using Gauss' law, obtain an expression for the electric field just above a semi-infinite charged conducting plate with surface charge density σ. [3]

2. Two long concentric cylinders of thin conducting material have radii a and b ($b > a$). The inner cylinder carries a charge $+Q$ and the outer carries a charge $-Q$. Find expressions for the electric field and electric potential in the vacuum region between the cylinders ($a < r < b$). Calculate the capacitance per unit length of this system. [4]

3. Two charges, $+q$ and $-q$, are fixed at the ends of an insulating rod, and separated by displacement **d**. What is the dipole moment **p**? The dipole is inclined at angle θ to a uniform electric field **E**. What is the net force on the dipole? Derive the potential energy of dipole due to this uniform external electric field, and find an expression for the couple experienced by the dipole due to this electric field. [6]

4. State the laws of electromagnetic induction. [2]

A long air-cored solenoid of length D and radius a has n turns per unit length. Find an expression for its inductance. Justify any assumptions you make. [4]

5. A long straight wire has radius a and carries a current I distributed uniformly over the circular cross-section of the wire. As a function of perpendicular distance r from the centre of the wire, find expressions for the the **B**-field: (i) at $r < a$ and (ii) at $r > a$, and specify the direction of the **B**-field. In each case sketch the magnitude of **B** as a function of r. [6]

6. A cube is constructed by soldering one resistor of resistance R along each edge of the cube. Calculate the resistance between two adjacent corners. [7]

7. State Huygen's Principle, and use it to derive Snell's Law of refraction. [5]

Section B

8. Write down Maxwell's equations in their integral and differential forms. What would the equations be for free space? [4]

From these equations in a vacuum, show how a wave equation may be derived for the magnetic flux density B. What is the speed of propagation of the wave, in terms of the physical constants? [4]

If the electric field of an electromagnetic wave is polarized in the x-direction and is given by $\mathbf{E} = E_0 e^{i(\omega t - kz)}\hat{\mathbf{x}}$, find an expression for the magnetic flux density $\mathbf{B}$. State how these complex quantities, $\mathbf{E}$ and $\mathbf{B}$, related to the physical fields. [3]

Write down the expressions for the energy density per unit volume u in terms of the magnetic flux density B, and electric field, E. What is the ratio of the average energy density of the electric and magnetic fields for electromagnetic radiation in free space? [3]

Give an expression for the Poynting vector $\mathbf{S}$ in terms of the magnetic and electric field vectors, and explain the physical meaning of $\mathbf{S}$. Given that the average distance of the Moon from the Earth is 384,400 km, and the average distance of the Earth from the Sun is 1.496×10^{11} m, calculate the amplitudes of the $\mathbf{E}$-field and the $\mathbf{B}$-field of the light from the full Moon as seen from Earth if 12% of sunlight is reflected by the Moon's surface. [6]

9. Give the expression for the force on a charge q in the presence of both a magnetic flux density $\mathbf{B}$ and an electric field $\mathbf{E}$. [3]

Particles of mass m and charge q are initially travelling in a beam along the z-direction with speed v when they enter a long magnetic quadrupole lens, where there is no $\mathbf{E}$-field and the magnetic flux density is $\mathbf{B} = Ay\hat{\mathbf{x}} + Ax\hat{\mathbf{y}}$, and where A is a positive constant. Neglecting edge effects of the magnet, write down the equations of motion for one of the particles. Solve these equations under the assumption that the particle's path always makes a small angle with the z-direction, and that the particle had $x = x_0$ and $y = y_0$ before entering the magnetic field. [10]

Show that the lens has a focusing property in one plane, but is defocusing in the other. For the focussing plane, calculate the distance at which the particle beam is first focussed onto the z-axis. [7]

10. What is the meaning of "monochromatic light"? [1]

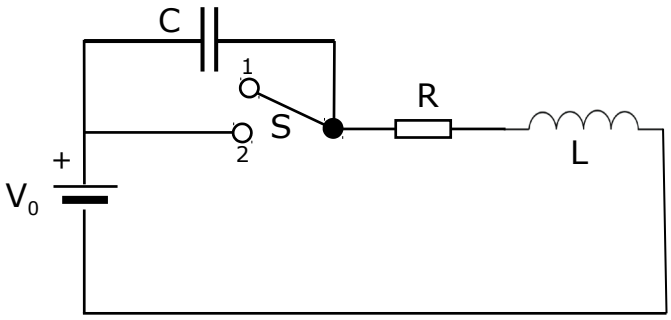
A Young's double-slit experiment is set up in a laboratory, with a parallel beam of monochromatic light incident on two long thin parallel slits which are separated by s. How might such an incident beam be produced from a lamp? [2]

The light emerging from the slits illuminates a screen parallel to the plane of the slits and distance D away. Assuming that $D \gg s^2/\lambda$, where λ is wavelength, derive an expression for the intensity of the light on the screen as a function of position. [6]

The slit separation is $s = 0.1\,\text{mm}$, and the distance to the screen is $D = 85\,\text{cm}$. If the separation of the central maximum of intensity and the 10^{th} maximum on the screen is measured to be $5\,\text{cm}$, calculate λ. [4]

One of the slits has a solid glass block placed between the light source and the slit. The block has a width of $0.1\,\text{mm}$ in the direction of propagation of the light. If the refractive index of the glass is $n_{\text{glass}} = 1.5$, and assuming $n_{\text{air}} \approx 1$, calculate the angle and the distance the central fringe moves relative to the set-up with no glass block. [7]

11. Consider the circuit shown below. The switch S is initially open (in position 1), and the components have the following values: $V_0 = 6\,\text{V}$, $R = 3\,\Omega$, $L = 8\,\text{mH}$ and $C = 0.4\,\mu\text{F}$.



(i) After a long time, the switch S is closed (moving it to position 2) at time $t = 0$, and instantaneously discharging the capacitor C. Calculate the current flowing through the coil L at a time $t = 0.005\,\text{s}$. [8]

(ii) If the switch S is opened at $t = 0.005\,\text{s}$ (moving it from position 2 to position 1), write down the boundary conditions and differential equations for the current flowing through the coil L. [4]

Show that the current flow is oscillatory, and calculate the frequency of oscillations. [5]

Calculate the time at which the amplitude of the current oscillation will fall to 5% of its initial value. [3]