A10288W1

FIRST PUBLIC EXAMINATION

Trinity Term

Preliminary Examination in Physics

Paper CP2: PHYSICS 2

Tuesday 11 June 2019, 2.30 pm – 5.00 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

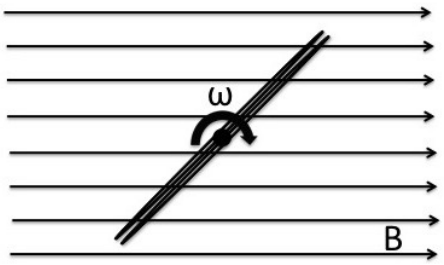
1. A long solenoid of length L and radius R is uniformly wound with N_1 closely spaced turns. It is tightly surrounded about the middle by a short coil closely wound with N_2 closely spaced turns on the same axis. What is the mutual inductance of the coils? [4]

2. Describe how the method of images can be used to evaluate the field configuration of a set of charges associated with conducting planes. Illustrate this by finding an expression for the force between the charge and the plane for a charge q a distance d above an infinite conducting plane. [5]

3. A hollow conducting sphere of radius R has an initial charge Q. By consideration of Gauss' law, find an expression for the electric field strength and for the potential inside and outside the sphere as a function of r, the distance from the centre of the sphere.

A second hollow conducting sphere of radius $2R$ and with no initial charge is brought into contact with the first sphere. Find expressions for the final charge on each sphere in this arrangement. [7]

4. A plane circular coil of radius r with N turns rotates at an angular velocity ω about an axis along a diameter and perpendicular to a uniform magnetic flux density B along the x-axis as shown in the figure.



Find an expression for the induced e.m.f. in the coil as a function of time t. What is the orientation of the coil with respect to the x-axis when the magnitude of the e.m.f. is a minimum? [6]

5. A transverse electromagnetic wave propagating in free space can be expressed as: $\mathbf{E}(x,t) = E_0 \cos(kx - \omega t)\, \hat{y}$. Explain all of the terms in this expression. Using the appropriate Maxwell's equation in differential form, find an expression for the **B** component and its direction of oscillation and hence find the speed of propagation of the wave. [5]

6. The most common forms of resistors used in electronic circuits are made out of carbon composite material. An alternative resistor composition uses resistive wire tightly wound around a small insulating substrate. Discuss the potential advantages and disadvantages of wire wound resistors compared to carbon composite devices. [3]

7. A thin equiconvex lens (a lens where the two convex surfaces have the same radius of curvature) is made of glass with refractive index n. Its spherical surfaces have radius of curvature R. Show that its focal length f is given by

$$f = \frac{R}{2(n-1)}\,.$$

[5]

An imaging system suffers from chromatic aberration so that an image in blue light is formed at a position 10 mm beyond an image in red light. A student wishes to correct for the aberration and form a corrected image on a screen 1 m from the red light image using a thin equiconvex lens placed between the aberrated images and the screen. Find expressions for the required focal lengths of the lens f_b and f_r at blue and red wavelengths. The lens has refractive indices $n_\mathrm{b} = 1.44$ and $n_\mathrm{r} = 1.40$ at blue and red wavelengths respectively. Calculate the radius of curvature of the lens surfaces and the focal lengths at blue and red wavelengths. [5]

Section B

8. A current I flows through a plane wire coil of radius a with N turns. Find an expression for the magnetic flux density at a distance x along the principal axis of the coil from the centre. [5]

A second identical coil is placed parallel to and coaxial with the first, and separated by a distance a. Identical currents I flow through the coils in the same direction. What is the magnetic flux density B on the axis midway between the pair of coils and at the centre of each coil? Sketch the total magnetic flux density and the contribution from each coil as a function of position on the axis between the coils. Describe briefly the properties of this coil arrangement. [9]

A stream of electrons is accelerated by a potential V and introduced into the region between the coils, perpendicular to the principal axis of the coils and close to the mid-point. An experimenter wants to deflect the electron stream so that it emerges from the region between the coils travelling parallel to but in the opposite direction to the input stream and separated by 2 cm. What is the value of the magnetic flux density between the coils required to achieve this, when the accelerating potential $V = 10$ kV? [6]

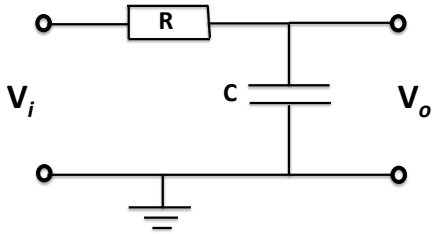
[You may neglect the effects of any B field external to the space between the two coils, and assume that the radius of the coils is $\gg 2$ cm.]

9. A charge $+q$ is located at the origin. What is the work required to bring (i) a charge $+q$ and (ii) a charge $-q$ from an initial position $(x, y) = (0, -2d)$ to a position $(0, +d)$ from the origin? [3]

A dipole consists of a positive charge $+q$ at position $(x, y) = (0, +a/2)$ and a negative charge $-q$ at position $(x, y) = (0, -a/2)$. Find expressions for the potential and electric field of the dipole at a distance r from the origin (where $r \gg a$). Sketch the dipole field lines. What are the radial and tangential components of the force acting on a point charge $+Q$ at a distance r from the origin? [9]

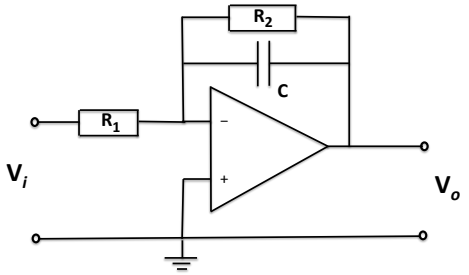
The dipole is fixed in space at the origin. Find the force acting on a point charge $+Q$ at positions $(x, y) = (-d, 0), (0, -d)$ and $(d, 0)$, where $d \gg a$. Describe the force that acts on a free charge initially located at $(x, y) = (-d, 0)$ and the resulting motion of the charge. [8]

10. A circuit consists of a resistor R and a capacitor C together with an input voltage V_i and is illustrated in the figure below. The input voltage V_i is a sinusoidal function of time. Find an expression for the magnitude and phase of the output voltage V_o. The resistor has a resistance of 5 kΩ and the capacitor has a capacitance of 3.2 nF. Determine the behaviour of the circuit as a function of frequency and find the output voltage at 100 Hz, 10^4 Hz and 5×10^4 Hz. Sketch a plot of the amplitude of V_o as a function of frequency. Give an application for such a circuit. [10]



An alternative design employs an operational amplifier and is illustrated below. The signal is transmitted to the inverting input of the op-amp through resistor R_1, while a capacitor C in parallel with a resistor R_2 connects the input and output of the op-amp. Again the input voltage V_i is a sinusoidal function of time. Find an expression for the output voltage V_o.

The resistor R_1 has a resistance of 1 kΩ, the resistor R_2 has a resistance of 5 kΩ, and the capacitor C has a capacitance of 3.2 nF. How does the output from this circuit compare with that from the circuit above? [7]



Comment on the advantages and disadvantages of the two circuits. [3]

11. A student plans an experiment to demonstrate double slit interference using a mercury discharge lamp as a light source. Discuss the advantages and disadvantages of using the classical double slit or a Lloyds Mirror arrangement. [4]

The student sets up a classical double slit experiment to measure fringes produced by a mercury discharge lamp using the green line at wavelength $\lambda = 546$ nm. Sketch and describe a practical arrangement for the experimental layout. Find an expression that relates the separation of the fringes measured on a screen to the slit separation, d and wavelength of the light, λ. [8]

When measuring the fringes, the student realises that the blue mercury line at wavelength $\lambda = 437$ nm is also transmitted through the slits. The slit separation used is $d = 100$ μm and the distance from the slits to the screen, $D = 0.5$ m. Calculate the fringe separations for each of the two wavelengths transmitted, and describe the fringe pattern and the overall appearance resulting from the two wavelengths of light. Sketch the central 30mm of the fringe pattern. [8]