Course Code and Title: **P 14B Introductory Physics B**

Date: **Wednesday May 14, 2008**

Duration: Three (3) **Hours**.

Materials required:

- **Answer booklet**: Normal [ ] Special [ ] Not required [ ]
- **Calculator**: Programmable [ ] Non Programmable [ ]

Multiple choice answer sheets: numerical [ ] alphabetical [ ] 1-20 [ ] 1-100 [ ]

Auxiliary/Other material(s) - Please specify:

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Candidates are permitted to bring the following items to their desks:

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**Instructions to Candidates**: This paper has 7 pages & 10 questions.

Candidates are reminded that the examiners shall take into account the proper use of the English Language in determining the mark for each response.

Attempt SIX (6) questions, THREE (3) from each Section

Assume where necessary:

- Permittivity of free space, \( \varepsilon_0 = 8.85 \times 10^{-12} \text{ F m}^{-1} \)
- Permeability constant, \( \mu_0 = 4\pi \times 10^{-7} \text{ H m}^{-1} \)
- Speed of light, \( c = 2.99792458 \times 10^8 \text{ m s}^{-1} \)
- Mass of electron = \( 9.109 \times 10^{-31} \text{ kg} \)
- Planck's constant = \( 6.6260755 \times 10^{-34} \text{ J s} \)
  \[ = 4.1356692 \times 10^{-15} \text{ eV s} \]
SECTION A
ELECTRICITY & MAGNETISM & A. C. THEORY
(Questions 1-5)

1. (a) State Gauss’ Law of electrostatics. [2 marks]

(b) Apply Gauss’ Law to show that the electric field strength at a point outside a metal sphere carrying a free charge $Q$ at a distance $R$ from the centre is given by

$$E = \frac{Q}{4\pi\epsilon_0 R^2}$$  [4 marks]

(c) A metal sphere of radius 0.2 m carries a free charge of +5 $\mu$C and is enclosed by a charged concentric metal shell of inner radius 0.5 m and outer radius 0.9 m. The free charge on the metal shell is -3 $\mu$C.

(i) Deduce the free charge on the surfaces of the sphere and shell.
(ii) Find the electric flux through a concentric spherical surface of radius 1.0 m.
(iii) Find the electric flux through of $E$ at a point where $R = 1.0$ m
(iv) Find also the magnitude and direction of $E$ at a point where $R = 0.4$ m.  [11 marks]

(d) Sketch a graph showing the variation of $E$ from $R = 0$ to $R = 1.0$ m. [3 marks]

2. A series circuit consists of a source of emf $\epsilon$, a capacitor $C$ and a resistor $R$. If the capacitor is originally uncharged, its charge at a time $t$ after the circuit is completed is given by:

$$q = Ce\left[1 - \exp\left(-\frac{t}{RC}\right)\right]$$

(a) A 2 M$\Omega$ resistor is connected in series with a 1.5 $\mu$F capacitor and a 6.0 V battery of negligible internal resistance. The capacitor is initially uncharged. After a time $t = \tau = RC$, find

(i) the charge on the capacitor
(ii) the rate at which the charge is increasing
(iii) the current
(iv) the power supplied by the battery
(v) the power dissipated in the resistor
(vi) the rate at which the energy stored in the capacitor is increasing [12 marks]

(b) (i) What is the Hall effect? [2 marks]

Contd........................
(ii) Show that the Hall voltage set up across a metal strip of width d and thickness t carrying a current I in a direction perpendicular to a uniform magnetic field of flux density B is \( \frac{IB}{net} \) where n is the number of conduction electrons per unit volume. [6 marks]

3. (a) Use Ampere's Law to show that the magnetic flux B at a distance R from a straight wire carrying a current I is given by:

\[ B = \frac{\mu_0 I}{2\pi R} \] [5 marks]

(b) In the figure below, the long straight wire carries a current of 30 A and the rectangular loop carries a current of 20 A.

Determine:
(i) for sides WX and YZ of the rectangular loop, the value of B due to the 30 A current in the long wire,
(ii) for sides WX and YZ of the rectangular loop, the magnitude and direction of the force experienced because of the 30 A current,
(iii) for the sides XY and WZ, the direction of the force experienced because of the 30 A current. What can be noted about their net force?
(iv) the magnitude and direction of the resultant force acting on the loop. [15 marks]

4. (a) State Faraday's and Lenz's laws of electromagnetic induction. [2 marks]

(b) (i) Show that the e.m.f. induced in a coil of cross-sectional area A and N turns which is rotating with angular frequency \( \omega \) about an axis perpendicular to a uniform magnetic field of strength B is given by

\[ e = BAN\omega \sin \omega t \]

where \( t \) is time in seconds. [5 marks]

Contd........................................
(ii) A coil of area 0.75 m² and 50 turns is rotated at a frequency of 50 Hz about an axis perpendicular to a uniform field of strength $2 \times 10^2$ T. Determine:
- the maximum induced e.m.f.
- the position of the coil (relative to the field) where the induced e.m.f. is 100V
- the flux through the coil when the e.m.f. is 100V

[7 marks]

(c) A square wire loop with 2.00 m side is perpendicular to a uniform magnetic field, with half of the area of the loop in the field as shown below. The magnitude of the field varies with time according to $B = 0.0420 - 0.870t$, with B in tesla and t in seconds.

(i) Determine the induced e.m.f.
(ii) Briefly explain, with the aid of a suitable diagram, the direction in which the induced current would flow.

[6 marks]

5. (a) Given an AC transformer, 2 diodes, resistor R, inductor L, capacitors C1 and C2. Draw a full-wave rectifier using at output (i) a RC filter, and (ii) a LC filter.

[6 marks]

(b) Given the following circuit with the values:
$V = 100 \, V_{rms}$; $R = 500\Omega$, $X_C = -j2\, K\Omega$, $X_L = j1.5\, K\Omega$ calculate:
(i) Impedance $Z_{total}$ in polar form;
(ii) Total current $I_t$ in polar form;
(iii) Find $V_r$, $V_c$ and $V_L$ in polar form and calculate power factor $\cos \Phi$.
(iv) If $f = 10$KHz find the values for L and C.

[4 marks]

[2 marks]

[4 marks]

[4 marks]

Contd........................
SECTION B
ELECTRONICS & MODERN PHYSICS
(Questions 6-10)
SECTION B

6. a) Convert decimal number 5624 to octal number;

b) Convert decimal number 5624 to hexadecimal number;

c) Convert hexadecimal number B2F8 to decimal number using two methods of conversion. [5 + 5 + 10 marks]

7. a) For the logic circuit drawn below deduce the logic expression. [5 marks]

Contd.........................
b) Simplify the logic expression found above to the expression ABC using Boolean algebra and DeMorgan's theorems. (Hints: \( AA=A \), \( A+A=A \), \( A''=A \), \( 1+A=1 \) and \( A+B=A'B' \), \( AB=A'+B' \)) [10 marks]

c) Draw the new logic circuit for the simplified logic expression found at b) and give the truth table. [5 marks]

8. A hydrogen atom can jump between quantized energy levels by emitting or absorbing light with specific wavelengths (called absorption or emission lines), grouped into series.

(a) What are the home-base levels of the quantum number \( n \) for the Lyman, Balmer and Paschen series.

<table>
<thead>
<tr>
<th>Series</th>
<th>Home-base level of ( n )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lyman</td>
<td></td>
</tr>
<tr>
<td>Balmer</td>
<td></td>
</tr>
<tr>
<td>Paschen</td>
<td></td>
</tr>
</tbody>
</table>

Contd.........................
(b) Plot the energy levels of the first line and the series limit lines corresponding to Lyman, Balmer and Paschen series of the hydrogen atom.

(c) The energy of a state of the hydrogen atom with quantum number \( n \) is \( E_n = -13.6/n^2 \). What is the energy difference (\( \Delta E \) in eV) between the first three transition levels involved in emission of the Lyman spectral lines?

(d) Calculate the wavelengths (in nm) corresponding to the transition levels in (c)?

\[ 3 + 3 + 8 + 6 \text{ marks} \]

9. (a) The scattering of photons from charged particles is called Compton effect.

(i) Write down the Compton scattering equation and define the parameters used;
(ii) Draw a schematic diagram of the Compton scattering geometry showing the incident and scattered photon, and the scattering angle.

\[ 3 + 3 \text{ marks} \]

(b) X-rays of wavelength \( \lambda = 0.2250 \text{ nm} \) undergo Compton scattering from a carbon block. If the scattered radiation is detected at \( 75^\circ \) to the incident beam, find:

(i) the Compton shift \( \Delta \lambda \) (in nm); (ii) the wavelength \( \lambda' \) of the scattered x-rays at this angle (in nm); (iii) the kinetic energy of the recoiling electron (in keV),

(iv) the de Broglie wavelength (in nm) of an electron recoiling with a speed of \( 6.5 \times 10^6 \text{ m/s} \).

\[ 4 + 3 + 3 + 4 \text{ marks} \]

10. (a) Write down the expressions defining the symbols that relate:
(i) Dilated time and proper time;
(ii) Contracted length and the proper length.

\[ 4 + 4 \text{ marks} \]

(b) Spaceship of proper (rest) length \( L = 100 \text{ m} \) move in direction along its length with a speed \( v \) relative to an observer on the Earth. The length of the spaceship measured by the Earth observer is 65 m.

(i) What is the speed of the spaceship?

(ii) If the astronaut in the spaceship decide to get a nap for 1 hour, how long does his nap last as measured on the earth?

(iii) How old is the astronaut when he returns to the earth from a 75 years round trip on the spaceship if he was 20 years old at departure.

\[ 5 + 5 + 2 \text{ marks} \]