MASENO UNIVERSITY

UNIVERSITY EXAMINATIONS 2016/2017

SECOND YEAR FIRST SEMESTER EXAMINATIONS FOR THE DEGREE OF BACHELOR OF SCIENCE AND BACHELOR OF EDUCATION SCIENCE WITH INFORMATION TECHNOLOGY

MAIN CAMPUS

SPH 202: ELECTRICITY AND MAGNETISM II

Date: 29th November, 2016 Time: 8.30 - 11.30 am

INSTRUCTIONS:

- Answer ALL questions in SECTION A and any TWO questions in SECTION B.

SPH 202: ELECTRICITY AND MAGNETISM II

Instruction to Candidates;

✓ Attempt **ALL** questions in **section A** and **ANY two** questions from section **B**.

Useful constants:

$\mu_o = 4\pi \times 10^{-7} TmA^{-1}$, $\varepsilon_o = 8.85 \times 10^{-12} Fm^{-1}$

SECTION A: COMPULSORY

Question 1: 30mrks

a. What is capacitance of a capacitor? [1mrk]
b. Write down the integral form of the Gauss electromagnetic theorem for a point charge. [2mrks]
c. Name two properties that affect the work function of dielectrics. [2mrks]
d. Distinguish between a charge and a saturation field. [2mrks]
e. State Lenz's law and write down the magnetic field equation inside a solenoid? [2mrks]
f. Define electromagnetic oscillations. [1mrk]
g. Name two examples of ferroelectrics. [1mrk]
h. Name any two divisions of magnetics. [2mrks]
i. What is an electric dipole moment? [1mrk]
j. State and explain two factors responsible for the origin of magnetic moments. [2mrks]
k. Oscillator circuits are used to produce electronic tones, for example in battery powered doorbells; they are used in timing devices and have many other useful applications. They are often made using capacitors and inductors. How is energy stored in an inductor? [2mrk]
l. A long solenoid with length l and a radius R consists of N turns of wire. A current I passes through the coil. Find the energy stored in the system. [2mrks]
m. Define Lorentz force. [1mrk]
n. Write down the torque equation on a current loop and define all the symbols used. [2mrks]
o. If a conducting molecular sphere field has a molecular radius of $a = 10^{-7} mm$, find the molecular/atomic dielectric susceptibility of the conducting molecular sphere. [2mrks]
p. You are given polarization, P for a dense gas as $P = \alpha \varepsilon_o N E^*$ with $E^* = E + \frac{P}{3\varepsilon_o}$. Use the definition of displacement vector $\vec{D}$ to derive the Clausius-Mosotti formula given by $\frac{3(\varepsilon_r - 1)}{\varepsilon_r + 2} = \alpha N$, where $\varepsilon_r = \frac{\varepsilon}{\varepsilon_o}$ is the relative permittivity and the other symbols having their usual meaning. [3mrks]
q. RLC circuits have many uses, for example they are used as the tuning circuit in radios, and as frequency generators to produce musical tones for doorbells. A mains powered RLC circuit is shown in Fig. 1 below.

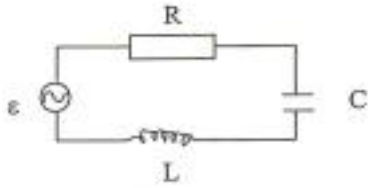

Fig. 1: RLC circuit

The power supply is $240V(RMS)$ with a frequency of $50Hz$. The resistor has a resistance of 50Ω, the capacitor has a capacitance of $50\mu F$ and the inductor has an inductance of $0.05H$. Calculate both the resonant frequency and the quality (Q) factor for the circuit. [2mrks]

SECTION B: ATTEMPT ANY TWO QUESTIONS ONLY

Question 2: 20mrks

a. State Gauss' law. [2mrks]

b. A second year University Physics student was investigating Gauss' law. He filled a metal can with polystyrene balls and placed it on the generator. He turned the generator on. Explain what happened. He later removed the metal can and replaced it with the plastic one and repeated the experiment. Explain what happened this time when he turned the generator on. [3mrks]

c. Under Kirchhoff's Loop rule modified for an inductor, we are given RL circuit described by the equation

$$\varepsilon - IR - L\frac{dI}{dt} = 0$$

Find the general expression for $I(t)$ from the above equation using the initial conditions $I = 0$ when $t = 0$. [10mrks]

d. Study the current resonance in **Fig. 2** below and answer the questions that follow;

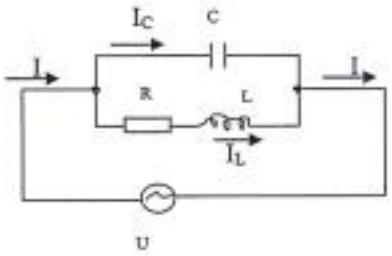

Fig. 2: LCR circuit with current resonance

If the current resonance flowing through the circuit in **Fig. 2** is given by

$$I = I_L + I_C = U\left(\frac{R - i\omega L}{R^2 + \omega^2 L^2} + i\omega C\right)$$

Show that the above equation can also be written as

$$I = I_L + I_C = \frac{UR}{R^2 + \omega^2 L^2} - i\frac{U}{R^2 + \omega^2 L^2}\Psi$$

Where $\Psi = \left\{\omega L - \omega C\left(R^2 + \omega^2 L^2\right)\right\}$ [5mrks]

Question 3: 20mrks

a. Name the three Gaussian surfaces. [3mrks]

b. Magnetic Resonance Imaging (MRI) is used to produce images of the interior of the body, especially the brain. The patient is strapped down tightly to a flat stretcher which is then slid into the MRI scanner. The scanner produces a strong magnetic field which is varied in time.

i. Why are patients asked to remove all jewellery and any clothing with zips or metal buttons or clips? [1mrk]

ii. The human body has been described as a bag of salt water, because it contains a great deal of fluid with dissolved ions. A woman is in an MRI scanner which can produce a field of $1.5T$. The largest surface area through which magnetic flux passes is $0.04m^2$ and has a normal which is parallel to the direction of the field. If the maximum average induced e.m.f is to be kept less than $0.01V$, how long must it take for the machine to be powered down from maximum field to zero? [2mrks]

c. In LC/RC circuits, the total energy of the system is given by $U = U_E + U_B = \frac{q^2}{2C} + \frac{Li^2}{2}$, where i is the current and other symbols have their usual meaning.

i. Differentiate the total energy equation above with respect to time (t) such that $\frac{dU}{dt} = 0$ [2mrks]

ii. Using the definition of current as $i = \frac{dq}{dt}$, re-write the differential equation in (i) above in simplified form in terms of q, C, L and t only. [3mrks]

iii. If the charge as a function of time is given by $q = q_{max}\cos(\omega_o t - \phi)$, where $\omega_o = \frac{1}{\sqrt{LC}}$, $i_{max} = \omega_o q_{max}$, show that the total energy of the system can be expressed as $U = U_E + U_B = \frac{q_{max}^2}{2C}$. [4mrks]

d. Consider an LCR circuit containing a source of extraneous e.m.f as shown in **Fig. 3** below.

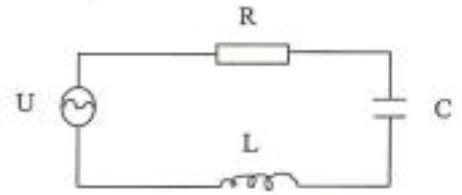

Fig. 3: An LCR circuit

The equation for the current in the circuit of **Fig. 3** has the form $IR = U - L\frac{dI}{dt} - \frac{Q}{C}$

i. Differentiate the above equation with respect to time (t). [1mrk]

ii. If U and I varies according to $U(t) = U_o e^{i\omega t}$, $I(t) = I_o e^{i\omega t}$ respectively, show that the differential equation in (i) above can be written as $IZ = U$, where $Z = R + i\left(\omega L - \frac{1}{\omega C}\right)$. [4mrks]

Question 4: 20mrks

a. Define the following terms [3mrks]
   i. Ferroelectrics
   ii. Magnetics
   iii. Magnetic flux

b. State Faraday's law. [2mrks]

c. Write down the equation for the magnitude of magnetic force on a current carrying conductor defining all the symbols in it. [2mrks]

d. State any three properties of a magnetic force. [3mrks]

e. Electric shock can injure and harm. However, it can also be used to revive people using a cardiac defibrillator which sends an electrical impulse to the heart to re-start it, for example after a heart attack. A certain cardiac defibrillator consists of a capacitor charged up to $1.0\times10^4 V$ with a total stored energy of $450J$.

   i. Calculate the charge on the capacitor in this defibrillator. [1mrk]

ii. If the internal resistance of the defibrillator is small, and the resistance across the skin of the patient's chest is $1.0k\Omega$, how long will it take the defibrillator to discharge 90% of its stored charge into the patient's chest? [4mrks]

f. A current I flows in a ring of radius r_o made of a very thin wire. The tensile strength of the wire is equal to f_o. The ring is placed in a magnetic field whose magnetic induction is perpendicular to the plane of the ring so that the forces tend to break the ring. Find the magnetic induction at which the ring will be broken assuming that $f_o = 1.5N, r_o = 15cm$ and $I = 10A$. [5mrks]

Question 5: 20mrks

a. Define the following terms. [2mrks]
   i. Magnetic dipole moment
   ii. Skin effect

b. Show that the relationship between magnetization $(\vec{M})$ and magnetic field strength $(\vec{H})$ yields magnetic susceptibility $\chi = \mu_r - 1$, where $\mu_r = \frac{\mu}{\mu_o}$ is the relative permeability of the medium. [5mrks]

c. State any three properties of ionic paramagnetic susceptibility. [3mrks]

d. If polarization is given by $P = \chi \varepsilon_o E$ in general for a dielectric susceptibility, χ show that relative permittivity for rarefied gases is given by $\varepsilon_r = 1 + \alpha N$, where α is the molecular/atomic susceptibility and N is the molecular concentration. [5mrks]

e. **Figure 4** shows n turns wound on a toroid of a rectangular cross-section, whose inner and outer radii are equal to r_1 and r_2 respectively, and the height is equal to a.

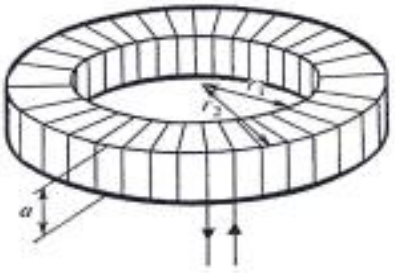

Fig. 4: A toroid with a rectangular cross-section.

Taking as the path of integration L_o, a circle of radius r, which is concentric with the symmetry axis of the toroid, and applying Ampere's circuital law such that

$$\oint \vec{H} . d\vec{l} = H_\varphi . 2\pi r = nI, \qquad r_1 < r < r_2$$

where I is the current flowing in the winding of the toroid, calculate the self-inductance of the system. [5mrks]