UNIVERSITY OF KWAZULU-NATAL

SECOND SEMESTER EXAMINATION: NOVEMBER 2009

SUBJECT AND COURSE: PHYSICS 120/162/196

TIME: 3 hours **TOTAL MARKS:** 180

Internal Examiners: Dr N Chetty, Dr V Couling & Mr A Welter
External Examiner: Professor S R Pillay (WESTVILLE CAMPUS)

GENERAL INSTRUCTIONS:

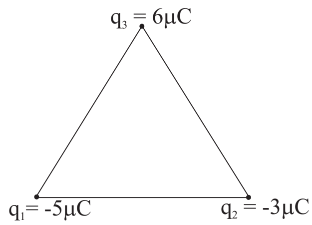
1. Answer ALL questions on the question paper. Pencil may be used provided this is **clearly** visible. All answers must be in **legible** handwriting.
2. **It is the candidate's responsibility to ensure that this paper has 27 numbered pages.**
3. Do your rough work for a question on the back of the previous page. Rough work will not necessarily be marked. See instruction 6 below.
4. No part of this exam paper may be torn off, except for the data sheet at the end. It may be removed and retained by the candidate.
5. Marks have been allocated in such a way that 1 mark corresponds approximately to one minute of time. Candidates are advised not to spend a **disproportionate amount of time** on any question.
6. Should a candidate require more space to answer a question than has been provided, this must be indicated **clearly**, by, for example, 'PTO' or 'See back of page 7', etc.
7. Where appropriate, candidates are advised to **show working** for their answers to all questions.

SECTION A ELECTRICTY & MAGNETISM 90 MARKS

Question A1

(a) Two small charged objects q_1 and q_2 each experience a force of magnitude F when separated by a distance d. If the charge on each is reduced to one quarter of its original value and the separation distance is reduced to $\frac{d}{2}$, determine the force that now acts on these two charged objects. (3)

(b) Three charges $q_1 = -5\mu\text{C}, \quad q_2 = -3\mu\text{C} \;\; and \;\; q_3 = 6\mu\text{C}$ are fixed at the vertices of an equilateral triangle of side length 12 cm, as shown alongside.



(You are reminded of the cosine rule:

$$r^2 = x^2 + y^2 - 2xy\cos\theta$$

and sine rule:

$$\frac{\sin A}{A} = \frac{\sin B}{B}\text{).}$$

(a) Determine the magnitude of the force acting on the charge q_2. (Be sure to fully explain your answer.) (6)

(Question A1(b)... continues over the page)

(b) Calculate the electrical potential energy of the system. (You may assume that charge q_1 was assembled first.) (4)

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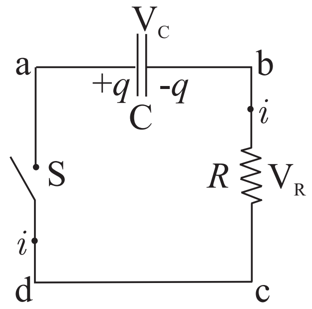
Question A2

(a) A stationary point charge q is located in a vacuum. Derive an expression for the electric potential V at a point P a distance r away from the charge q. The relationship between the electric field $\mathbf{E}$ and electric potential V, may be used without proof. (5)

(Question A2(b)... continues over the page)

(b) A circuit comprises resistance R, capacitance C and a switch S in series, as shown alongside. When the switch is open the capacitor carries the initial charge q_o. At time $t = 0$ the switch is closed.



(i) Show that the charge q on the capacitor at a later time t is $q = q_o e^{-t/\tau}$. (7)

(ii) Draw a labelled digram to show how the charge varies with time. (3)

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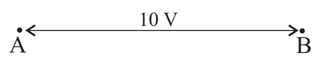
Question A3

(a) Calculate the energy stored by a 90 pF capacitor when it is charged to 220 V. (2)

(b) A conductor of length ℓ, resistivity ρ and cross-sectional area A has a resistance R. If the length of the conductor is halved and its cross-sectional area is decreased by a factor of 2, determine the new resistance of the conductor, in terms of R. (2)

(c) The potential difference between points A and B in the diagram is 10 volts. An electron of charge e and mass m is released from A and accelerates across to B. Determine the electron's speed when it reaches B. (4)



(d) A $6\,\mu$C charge is placed at the centre of a cube of side a. Calculate the outward flux through any one of the cube faces. (2)

(Question A3(e)... continues over the page)

(e) An electron moves with a speed of $1 \times 10^6\,\mathrm{m\,s^{-1}}$ at an angle of 30° to a magnetic field of strength 0.5 T. Determine the magnitude of the force on the electron. (2)

(f) State what is meant by a superconductor. Draw a fully labelled diagram to show how the resistance of superconductor varies with temperature. (4)

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Question A4

(a) State Gauss's law in words. (2)

(b) Consider an "infinite" uniform rod of linear charge density (i.e charge per unit length.) λ. Use Gauss's law to show that the electric field close to the rod is given by:

$$\boxed{E = \frac{1}{2\pi\varepsilon_0}\frac{\lambda}{r}\ .}$$

(Remember to include a sketch and show clear reasoning (not only equations) in your answer.) (7)

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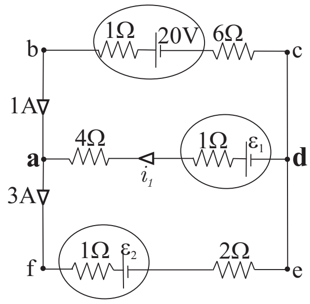
Question A5

Consider the circuit shown alongside. The current i_1 has the direction as shown.



(a) Apply Kirchoofs 1st rule at a suitable point to obtain a value for the unknown current i. (1)

(b) Apply Kirchoff's second rule around suitable loops to determine the unknown emfs ε_1 and ε_1. (6)

(c) Find V_{ab}, the potential of point **a** relative to point **b**. (2)

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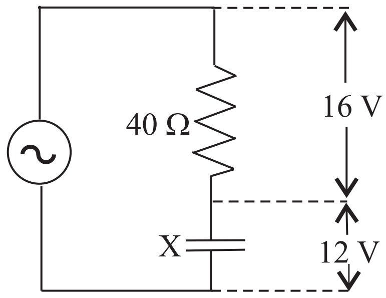
Question A6

The voltages shown in the circuit opposite are rms quantities. Calculate



(a) the peak voltage across the terminals of the oscillator

(b) the reactance X of the capacitor

(c) the impedance in the circuit.

(d) the peak current in the circuit.

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Question A7

(a) The magnetic flux through a loop of a coil varies according to the relation

$$\phi = 8t^2 + 7t + 6$$

where ϕ is in milliwebers and t in seconds.

(i) State Faraday's Law mathematically defining all the symbols you use. (1)

(ii) Determine the magnitude of the emf induced in the loop when $t = 5\,\text{s}$. (2)

(b) A transformer raises a 19 V AC source to 190 V AC in order to operate a cutting machine. The primary coil is wound from 25 turns of wire and draws 360 mA of current.

(i) Determine the number of turns in the secondary coil. (2)

(ii) Calculate the output current. (2)

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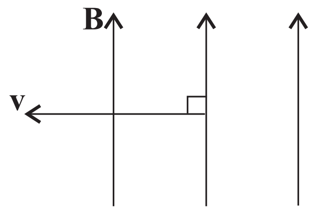
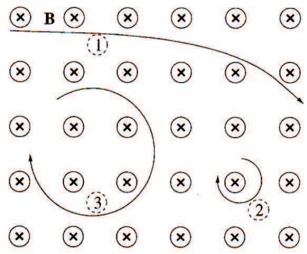
Question A8

(a) Consider a charge q that enters a uniform magnetic field **B** with a velocity **v** that is perpendicular to **B** as shown alongside. (**B** is up the page and **v** moves to the left in the plane of the page.) Derive an equation for the radius r of the circular path followed by the particle. (6)



(Question A8(b)... continues over the page)

(b) Three particles with identical charges q and masses m enter a uniform magnetic field and follow the paths shown in the diagram alongside. Which particle is moving the fastest. Justify your answer. (2)



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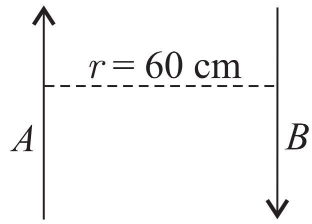
Question A9

Two long fixed vertical wires A and B are a distance $r = 60\,\text{cm}$ apart in a vacuum and carries currents of 50 A and 110 A respectively in opposite directions, as shown alongside.
Determine:

(i) the <u>force</u> per unit length exerted by wire A on wire B.

(ii) the position of any neutral point in a horizontal plane.



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SECTION B **Waves and Physical Optics** **45 MARKS**

QUESTION B1

(a) A travelling transverse wave is moving in the positive x–direction with an amplitude of 0.200 m, a frequency of 400 Hz and a propagation velocity of $300\,\mathrm{m\,s^{-1}}$. Write down the travelling wave equation in the form

$$y = A\sin(kx - \omega t)$$

inserting numerical values where appropriate. (6)

(b) If the speed of sound in air at 0°C is $331\,\mathrm{m\,s^{-1}}$, calculate its value in air at 35°C. (2)

(c) What can be said about the resultant displacement at the nodes of a stationary wave system, and how far apart are the adjacent nodes (in terms of wavelength)? (2)

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QUESTION B2

A transverse wave of frequency 300 Hz is applied to a string which has a mass per unit length of $2.00 \times 10^{-2}\,\mathrm{kg\,m^{-1}}$ and is under tension of 50.0 N. Show that

(i) the speed of propagation is $50\,\mathrm{m\,s^{-1}}$, and

(ii) calculate the wavelength of the wave.

(iii) If the string is fixed at both ends, and is displaying a standing wave vibrating at the third harmonic (second overtone), draw a sketch of what is seen.

(iv) Calculate the length of the string.

(v) How many antinodes are there?

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QUESTION B3

A speeding motorcyclist passes a stationary police car. The car siren is started (the car still being stationary) and the motorcyclist hears a frequency of 630 Hz. If the true frequency is 690 Hz and the speed of sound in air is $340\,\mathrm{m\,s^{-1}}$,

(i) Calculate the speed of the motorcyclist.

The police car starts up in pursuit and soon reaches a speed of $40.0\,\mathrm{m\,s^{-1}}$, still sounding its siren.

(ii) What frequency does the motorcyclist now hear?

/5

QUESTION B4

(a) What is the colour of light at the short–wavelength end of the visible spectrum, and what is its approximate wavelength? (2)

(b) An air film of thickness 0.00068 mm is formed between two parallel glass blocks. A mixture of green light of wavelength 544 nm and red light of wavelength 680 nm is incident normally on the air film. What is the colour of the reflected light? (Show all workings.) (5)

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QUESTION B5

Monochromatic light of wavelength $\lambda = 600.0\,\text{nm}$ is incident normally on a diffraction grating containing 6400 lines/cm. Find the angular positions of the 1st–order and 2nd–order maxima, and show that higher–order maxima do not exist.

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QUESTION B6

Draw a labelled diagram showing what happens when white light passes through a diffraction grating at normal incidence.

/5

QUESTION B7

In a Newton's rings experiment, the reading of the first dark ring is 0.500 mm. What is the diameter of the sixth dark ring?

/3

SECTION C — Atomic and Nuclear Physics — 45 MARKS

QUESTION C1

(a) A pure gold ring has a mass of 7.3 g. Assuming gold has an atomic mass of 197 u, estimate the number of atoms in the ring. (2)

(b) Ignoring net energy released, complete the following

$$^{35}_{17}\mathrm{Cl} \quad + \quad \ldots \quad \rightarrow \quad ^{32}_{16}\mathrm{S} \quad + \quad ^{4}_{..}\mathrm{He}$$ (2)

(c) A nucleus with 54 protons and 54 neutrons is formed in a collision of two heavy nuclei.

(i) Would you expect this nucleus to be stable? Give a brief explanation of your answer. (2)

(ii) Explain whether electron or positron emission is more likely to occur. (2)

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QUESTION C2

A rock is found to contain ^{238}U and ^{206}Pb atoms in the ratio 5:1. If all the ^{206}Pb present is from the decay of ^{238}U, determine the age of the rock. (Take the half-life of ^{238}U as 4.5×10^9 years and assume that the half-lives of the daughter products in the ^{238}U series are negligible.)

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QUESTION C3

(a) State the values which the quantum numbers, corresponding to the initial and final orbits of an electron in the Bohr model of the hydrogen atom, can take for the Lyman, Balmer and Paschen series. (3)

Taking the series limit of the Lyman series as 91.3 nm, calculate

(b) a value for the Rydberg constant in m^{-1}, (2)

(c) the series limit for the Paschen series, and (2)

(d) the longest wavelength in the Balmer series in nm. (2)

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QUESTION C4

A charged oil drop is observed in air between two horizontal, parallel, metal plates 6.00 mm apart. When a potential difference of 120 V is applied to the metal plates, the drop moves upward at a constant speed of $0.0335\,\mathrm{mm\,s^{-1}}$. The drop falls freely under gravity at a constant speed of $0.0500\,\mathrm{mm\,s^{-1}}$. The coefficient of viscosity of air is 1.80×10^{-5} SI units and the density of the drop is $900\,\mathrm{kg\,m^{-3}}$. Neglecting the buoyancy of the air,

(a) show that the charge on the oil drop is given by

$$q = \frac{6\pi\eta r}{E}\left(v_G + v_E\right) , \qquad (3)$$

(b) the radius of the oil drop is given by

$$r = \left(\frac{9\eta v_G}{2\rho g}\right)^{\frac{1}{2}} , \qquad (3)$$

(c) hence determine the number of excess electronic charges carried by the drop. (6)

(You may continue with the answer to Question C4(c) over the page....)

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QUESTION C5

The work function of tungsten is 4.49 eV.

(a) Determine the threshold wavelength for photo-emission. (3)

(b) If ultraviolet light of wavelength 250 nm falls on the surface, calculate the maximum energy of the emitted electrons in eV. (3)

(c) What potential difference is required to bring all the ejected electrons in (b) above to rest? (1)

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QUESTION C6

List the fundamental forces by which

(a) hadrons and

(b) leptons

can interact.

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INFORMATION SHEET

PHYSICAL CONSTANTS

$g = 9.80\,\mathrm{m\,s^{-2}}$ $\quad n_{\text{air}} = 1.00$ $\quad c = 3.00 \times 10^{8}\,\mathrm{m\,s^{-1}}$ $\quad e = 1.60 \times 10^{-19}\,\mathrm{C}$

$m_e = 9.11 \times 10^{-31}\,\mathrm{kg}$ $\quad m_p = 1.67 \times 10^{-27}\,\mathrm{kg}$ $\quad h = 6.63 \times 10^{-34}\,\mathrm{J\,s}$

$\dfrac{1}{4\pi\varepsilon_0} = 9.00 \times 10^{9}\,\mathrm{N\,m^2\,C^{-2}}$ $\quad \dfrac{\mu_0}{2\pi} = 2.00 \times 10^{-7}\,\mathrm{T\,m\,A^{-1}}$ $\quad N_{\text{A}} = 6.02 \times 10^{23}\,\mathrm{mol^{-1}}$

ELECTRICITY AND MAGNETISM

$V_{\text{AB}} = V_{\text{B}} - V_{\text{A}} = -\int_{\text{A}}^{\text{B}} E dr$ $\quad V = \dfrac{1}{4\pi\varepsilon_0}\sum_n \dfrac{q_n}{r_n}$ $\quad U = \dfrac{1}{4\pi\varepsilon_0}\dfrac{q_1 q_2}{r}$

$E = \dfrac{V}{d}$ $\quad V = IR$ $\quad \text{Energy} = \dfrac{1}{2}qV$ $\quad R_T = R_0(1 + \alpha T)$

$R = \rho\dfrac{\ell}{A}$ $\quad P = VI$ $\quad V = \mathcal{E} - Ir$ $\quad i = i_0 \sin\omega t$

$F = BI\ell\sin\theta$ $\quad F = qvB\sin\theta$ $\quad B = \dfrac{\mu_0}{2\pi}\dfrac{I}{r}$ $\quad \dfrac{F}{\ell} = \dfrac{\mu_0}{2\pi}\dfrac{I_1 I_2}{L}$

$\psi = EA\cos\theta$ $\quad q = \mathcal{E}C\left(1 - e^{-t/RC}\right)$ $\quad j = \dfrac{i}{A} = nev$ $\quad q = q_0 e^{-t/\tau}$

$\phi = BA\cos\theta$ $\quad \oint B d\ell\cos\theta = \mu_0 I_{\text{net}}$ $\quad P = V_{\text{rms}} I_{\text{rms}}\cos\alpha$ $\quad \dfrac{V_{\text{s}}}{V_{\text{p}}} = \dfrac{n_{\text{s}}}{n_{\text{p}}}$

PHYSICAL OPTICS AND WAVES

$y_n = \dfrac{n\lambda x}{d}$ $\quad 2\mu t = n\lambda$ $\quad r_n^2 = nR\lambda$ $\quad n = \tan\theta_{\text{B}}$ $\quad I = I_0\cos^2\theta$

$a\sin\theta_n = n\lambda$ $\quad d\sin\theta_n = n\lambda$ $\quad V = \sqrt{\dfrac{T}{\mu}}$ $\quad y = A\sin(kx - \omega t)$

$V \propto \sqrt{T}$ $\quad f'' = \dfrac{V + v_{\text{o}}}{V - v_{\text{s}}}\cdot f$ $\quad f_{\text{b}} = f_1 - f_2$ $\quad f_n = \dfrac{nV}{2L}$ or $\dfrac{nV}{4L}$

ATOMIC PHYSICS

$E = mc^2$ $\quad E = hf$ $\quad E_k = \frac{1}{2}mv^2$ $\quad \ell = \dfrac{nh}{2\pi}$ $\quad F = \dfrac{mv^2}{r}$

$\dfrac{1}{\lambda} = R\left(\dfrac{1}{n_f^2} - \dfrac{1}{n_i^2}\right)$ $\quad r_n = \dfrac{h^2\varepsilon_0}{\pi m e^2}n^2$ $\quad E_n = -\dfrac{me^4}{8\varepsilon_0^2 h^2}\cdot\dfrac{1}{n^2}$ $\quad eV = hf_{\text{MAX}}$

$n\lambda = 2d\sin\theta_n$ $\quad N = N_0 e^{-\lambda t}$ $\quad T = \dfrac{\ln 2}{\lambda}$ $\quad A = A_0 e^{-\lambda t}$ $\quad A = \lambda N$

$q = \dfrac{6\pi\eta r}{E}(v_{\text{G}} + v_{\text{E}})$ $\quad F = 6\pi\eta r v$ $\quad E_i - E_f = hf$ $\quad \frac{1}{2}mv_{\text{MAX}}^2 = hf - \phi$ $\quad \lambda = \dfrac{h}{p}$