UNIVERSITY OF KWAZULU-NATAL

SECOND SEMESTER EXAMINATION: NOVEMBER 2012

SUBJECT AND COURSE: PHYSICS 120/196

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

Internal Examiners: Prof. D Wang and Mr A Welter
External Examiner: Dr J Govender (Westville Campus) & Dr N Chetty (PMBurg Campus)
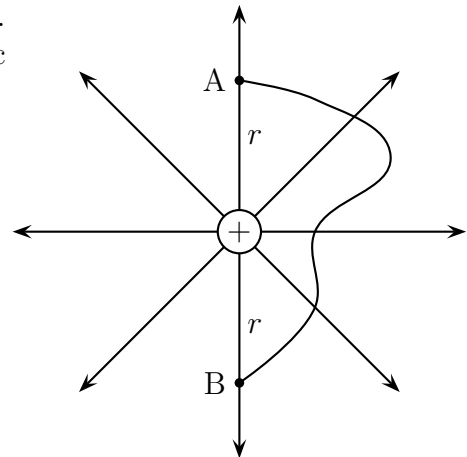

GENERAL INSTRUCTIONS:

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 **21** numbered pages including the information sheet which is separate. See instruction 8 below.

3. Do your rough work for a question on the back of the previous page. Rough work will not necessarily be marked. See instruction 4 below.

4. 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.

5. No part of this exam paper may be torn off.

6. 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.

7. Candidates must explain important physics steps in words and show appropriate working.

8. A separate information sheet is provided.

SECTION A   SHORT QUESTIONS $(20 \times 3\,\textbf{marks})$ 60 MARKS

1. Two identical conducting spheres carrying charges of -8 C and 12 C are brought into contact. Calculate the amount of charge transferred from one sphere to the other (remember to state +ve or −ve, and from which sphere to which).

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2. A point charge moves quasistatically from A to B in a radially symmetric electric field as shown alongside. Circle any statement(s) below concerning the electric field $\mathbf{E}$ and the electric potential V which are true.

   (a) $\mathbf{E}_\mathrm{A} = \mathbf{E}_\mathrm{B}$ and $V_\mathrm{A} = V_\mathrm{B}$

   (b) $\mathbf{E}_\mathrm{A} = \mathbf{E}_\mathrm{B}$ and $V_\mathrm{A} = -V_\mathrm{B}$

   (c) $\mathbf{E}_\mathrm{A} = -\mathbf{E}_\mathrm{B}$ and $V_\mathrm{A} = V_\mathrm{B}$

   (d) $\mathbf{E}_\mathrm{A} = -\mathbf{E}_\mathrm{B}$ and $V_\mathrm{A} = -V_\mathrm{B}$

   (e) $|\mathbf{E}_\mathrm{A}| = |\mathbf{E}_\mathrm{B}|$ and $V_\mathrm{A} = V_\mathrm{B}$

   (f) $|\mathbf{E}_\mathrm{A}| = |\mathbf{E}_\mathrm{B}|$ and $V_\mathrm{A} = -V_\mathrm{B}$

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3. Two charges, Q and $-2Q$, are located at points A and B as shown in the diagram below. Circle the point(s) on the line joining the two charges, which correspond most closely to the positions where the electric potential is zero.

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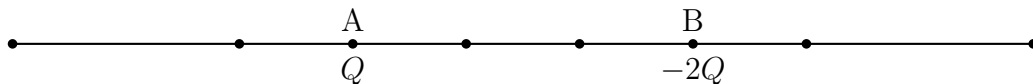
4. A charge of $2 \times 10^{-7}\,\mathrm{C}$ is between two oppositely charged parallel metal plates, separated by $50\,\mathrm{mm}$. The charge experiences a force of $4 \times 10^{-2}\,\mathrm{N}$ in the electric field. Determine the potential difference between the plates.

5. Starting with an expression for the single equivalent capacitance C_{eq} of a set of capacitors $C_1, C_2, C_3, \ldots C_S$ arranged in series, show that C_{eq} must be smaller than C_S, where C_S is the smallest capacitance in the set. (Do <u>not</u> use numerical values.)

6. A 3.7 V mobile telephone battery has an ampere-hour rating of 700 mA h. If a constant current of 200 mA is used during a normal conversation, determine how long it will take before the battery will start to run down.

7. A coil has a resistance of 20 . At a frequency of 100 Hz, the voltage across the coil leads the current in it by 30 . Determine the inductance of the coil.

8. At a certain frequency in a series RCL circuit $R = 16$, $X_C = 36$ and $X_L = 15$. Calculate the impedance Z in the circuit at twice this frequency.

9. (a) What property determines when an RCL circuit is at resonance?

    (b) Show that the resonance frequency ω_0 in an RCL circuit is given by $\omega_0 = \dfrac{1}{\sqrt{LC}}$, where the symbols have their usual meanings.

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10. The charge on a capacitor, in series with a resistor and a cell, varies with time t according to

$$q(t) = 10(1 - e^{-t/5}) \;\; \text{C},$$

with t in seconds. Calculate the current in the circuit at time $t = 1\,\text{s}$.

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11. The sound of a single violin playing is $60\,\text{dB}$ louder than the threshold of hearing. By how many decibels does the sound of 20 violins playing in the same way exceed the threshold of hearing?

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12. A closed pipe and an open pipe produce the same frequency of sound when they vibrate at their first harmonic or fundamental tone. What is the ratio of the length of the open pipe to that of the closed pipe?

13. In Young's double slit interference, the slits are 0.10 mm apart. The screen is 5.00 m from the slits, and the wavelength of the interfering light is 590 nm. Determine the spacing of the double slit interference fringes.

14. Sunlight reflected off a flat glass sheet is totally polarized. Determine the angle of incidence of the light on the sheet. The refractive index of the glass is 1.51.

15. Complete the following nuclear reaction:

$$ {}^{35}_{17}\text{Cl} + \quad \ldots \quad \longrightarrow {}^{32}_{16}\text{S} + {}^{4}_{2}\text{He} $$
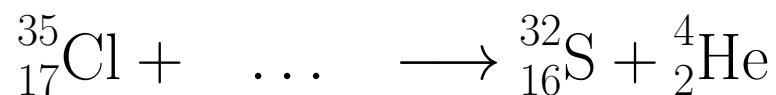
16. What is the energy of a photon of wavelength 660 nm?

17. What minimum voltage must be applied to an X-ray tube to generate X-rays with a wavelength of 4.0 Å?

18. The half life of a given isotope is $32\,\text{min}$. How long does it take for the number of atoms in a given sample to drop to a sixteenth of their original number?

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19. The atomic mass of copper is 64 and its density is $8930\,\text{kg}\,\text{m}^{-3}$. How many atoms of copper are there in a $100\,\text{g}$ sample?

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20. Calculate the de Broglie wavelength associated with a ball of mass $100\,\text{g}$ moving at $1.00\,\text{cm}\,\text{s}^{-1}$.

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SECTION B ELECTRICITY AND MAGNETISM 60 MARKS

QUESTION B1

A small, 3.00 g plastic sphere is suspended from a 13.0 cm insulating string of negligible mass. In the presence of a uniform electric field $\mathbf{E} = 4.90 \times 10^3 \, \hat{\mathbf{x}} \, \mathrm{N\,C^{-1}}$, the sphere comes to rest as shown in the diagram alongside.

(a) Is the charge on the sphere positive or negative? (1)

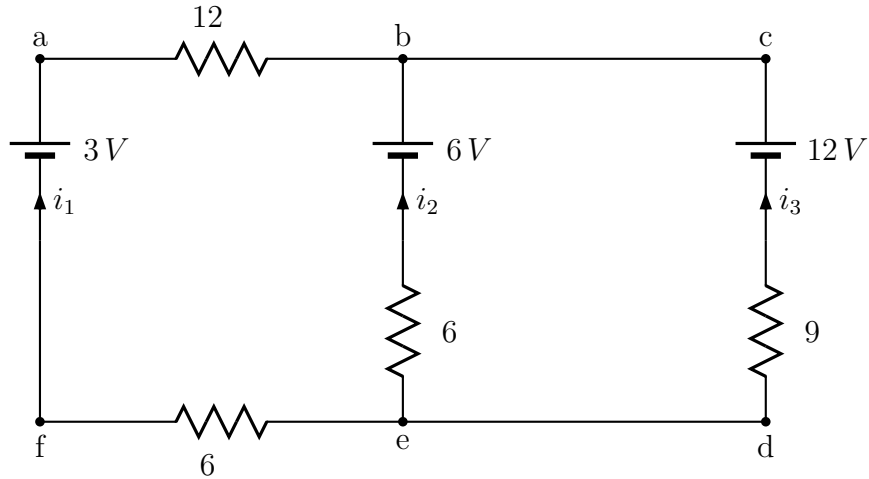(b) Determine the charge on the sphere. (9)

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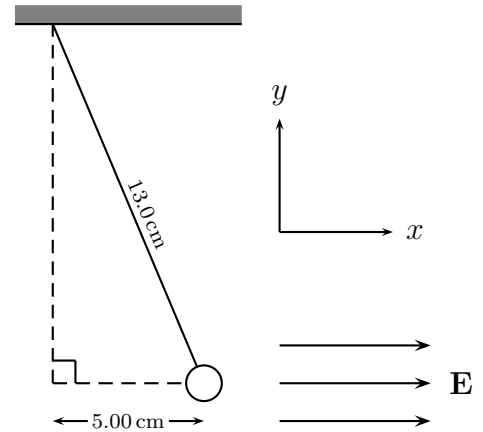
QUESTION B2

(a) (i) Write down Gauss' law of electromagnetism in mathematical form. (1)

    (ii) Define the symbols in your answer to (i) above. (3)

(b) Two concentric spherical shells of radius R and $2R$, carry charge Q and $-3Q$ respectively. Find the magnitude of the electric field for (i) $r < R$ and (ii) $r \geq 2R$. (6)

/10

QUESTION B3

(a) For the circuit shown above, with the directions of the currents chosen as shown, obtain three equations from which i_1, i_2 and i_3 can be determined. (DO NOT SOLVE FOR i_1, i_2, and i_3.) (5)

(b) If current i_2 were calculated to be $-0.25\,\text{A}$, calculate the potential difference between points b and e. Which point is at the higher potential? (3)

/8

QUESTION B4

The circuit shown alongside has been connected for a long time.

(a) Determine the voltage across the capacitor.   (6)
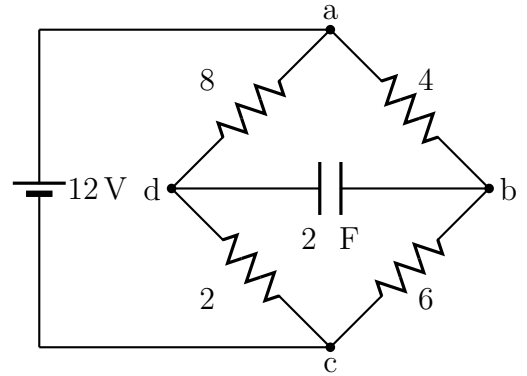
(b) If the battery is disconnected, how long does it take for the capacitor to discharge to 1% of its initial voltage? (8)

/14

QUESTION B5

Two long straight parallel wires, separated by $10\,\text{cm}$, carry currents $I_A = 2.0\,\text{A}$ and $I_B = 5.0\,\text{A}$ in opposite directions.

(a) Will the wires attract or repel each other? (1)

(b) With the aid of a sketch, explain your answer to (a). (4)

(c) Calculate the magnitude of the magnetic field at a point P in between the wires, $2.0\,\text{cm}$ from wire A, on the line joining the two wires. Indicate the direction of the magnetic field at P. (You may use your sketch in part (b) above.) (5)

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QUESTION B6

A solenoid of cross-sectional area $4.00\,\text{cm}^2$ and length $20.0\,\text{cm}$, has three layers of windings with 250 turns on each. The current in the solenoid is $5.00\,\text{A}$. A secondary winding of 2 turns encircles the solenoid. When the primary circuit is opened, the magnetic field of the solenoid becomes zero in $50.0\,\text{ms}$. What is the average induced emf in the secondary winding?

/8

SECTION C   <u>WAVES</u>   15 MARKS

QUESTION C1

A harmonic wave travelling along a string in the positive x-direction has a wavelength of $10\,\text{cm}$, a frequency of $500\,\text{Hz}$ and an amplitude of $5.0\,\text{cm}$.

(i) Calculate the speed c of the wave. (1)

(ii) Use the above information to write down an equation for the wave profile $y(x,t)$ assuming that $y(0,0) = 0$. (4)

(iii) Hence calculate the maximum speed of any point on the string. (3)

/8

QUESTION C2

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

(i) Show that the speed of propagation is $50 \, \text{m s}^{-1}$. (2)

(ii) Determine the wavelength of the wave. (1)

(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 the displacement curve for the string. (2)

(iv) Determine the length of the string. (1)

(v) How many antinodes are there? (1)

/7

SECTION D   PHYSICAL OPTICS   15 MARKS

QUESTION D1

An air film of thickness 6.8×10^{-4} 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 working.)

$$/5$$

QUESTION D2

(a) In a Newton's rings experiment the diameter of the 2nd dark ring is 2.48 mm. What is the diameter of the 9th dark ring? (4)

(b) If the radius of curvature of the plano-convex lens used in part (a) above is 5.00 m, what is the wavelength of the light being used? (2)

$$/6$$

QUESTION D3

Describe briefly what happens to the central maximum of a single slit diffraction pattern if

(a) the wavelength of the incident monochromatic light is increased and

(b) the width of the slit is increased.

Use suitable equations and explanations to justify your answer.

/4

SECTION E   ATOMIC AND NUCLEAR PHYSICS   30 MARKS

QUESTION E1

(a) Show that one atomic mass unit is equivalent to approximately 930MeV.   (4)

(b) For $^{235}_{92}$U, calculate

    (i) the mass defect (in u),

    (ii) the binding energy in MeV, and

   (iii) the binding energy per nucleon.   (6)

/10

QUESTION E2

Deduce the wavelength of the photon emitted when the electron in the hydrogen atom drops from the $n = 6$ level to the $n = 2$ level. (Take the ionization energy of the hydrogen atom as 13.6 eV.)

$$/6$$

QUESTION E3

Equal numbers (N_0) of atoms of two independent radioactive isotopes A and B are present initially in a certain mixture. The half-life of A (T_A) is twice that of B (T_B).

(a) On the axes below, sketch approximate decay curves for A and B up to a time $4T_B$. (4)
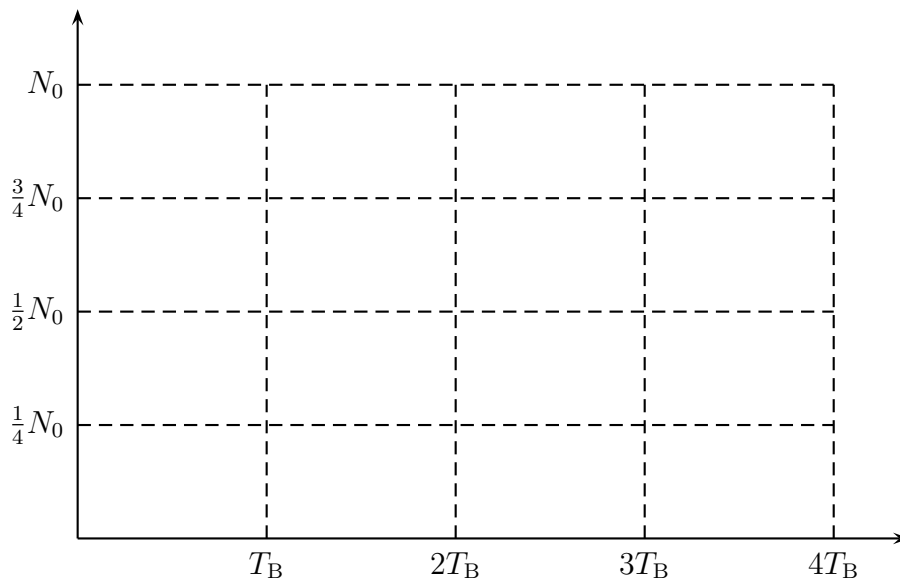
(b) If $N_0 = 2.4 \times 10^{13}$ atoms and the decay constant of A is $3.66 \times 10^{-7}\,\text{sec}^{-1}$, calculate

   (i) the initial activity of A in microcuries (1 curie $= 3.7 \times 10^{10}\,\text{Bq}$), and   (4)

   (ii) the mass of B remaining after a time $2.5\,\text{T}_\text{B}$, given that the atomic mass of B is 90 u.   (6)

$$/14$$

INFORMATION SHEET

PHYSICAL CONSTANTS

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

$m_e = 0.00055 \, \text{u}$ $m_p = 1.0073 \, \text{u}$ $m_n = 1.0087 \, \text{u}$ $m_e = 9.11 \times 10^{-31} \, \text{kg}$

$m_p \simeq m_n = 1.67 \times 10^{-27} \, \text{kg}$ $N_A = 6.02 \times 10^{23} \, \text{mol}^{-1}$ $h = 6.63 \times 10^{-34} \, \text{J s}$

$I_0 = 1.00 \times 10^{-12} \, \text{W m}^{-2}$ $\dfrac{1}{4\pi\varepsilon_0} = 9.00 \times 10^9 \, \text{N m}^2 \, \text{C}^{-2}$ $\dfrac{\mu_0}{2\pi} = 2.00 \times 10^{-7} \, \text{T m A}^{-1}$

ELECTRICITY AND MAGNETISM

$\mathbf{F} = q\mathbf{E}$ $j = \dfrac{i}{A} = nev$ $\psi = \dfrac{Q_{\text{net}}}{\varepsilon_0}$ $\psi = EA\cos\theta$ $\mathbf{F} = \dfrac{1}{4\pi\varepsilon_0}\dfrac{q_1 q_2}{r^2}\hat{\mathbf{r}}$

$E = \dfrac{V}{d}$ $\dfrac{1}{C_{\text{eq}}} = \sum_i \dfrac{1}{C_i}$ $V = \mathcal{E} - Ir$ $R = \rho\dfrac{\ell}{A}$ $\mathbf{E} = \dfrac{1}{4\pi\varepsilon_0}\dfrac{q}{r^2}\hat{\mathbf{r}}$

$R = \dfrac{V}{I}$ $C_{\text{eq}} = \sum_i C_i$ $V = L\dfrac{di}{dt}$ $W = \tfrac{1}{2}qV$ $V = \dfrac{1}{4\pi\varepsilon_0}\sum_n \dfrac{q_n}{r_n}$

$C = \dfrac{q}{V}$ $\dfrac{1}{R_{\text{eq}}} = \sum_i \dfrac{1}{R_i}$ $X_L = \omega L$ $X_C = \dfrac{1}{\omega C}$ $U = \dfrac{1}{4\pi\varepsilon_0}\dfrac{q_1 q_2}{r}$

$V = \dfrac{W}{q}$ $R_{\text{eq}} = \sum_i R_i$ $\omega_0 = \dfrac{1}{\sqrt{LC}}$ $\phi = BA\cos\theta$ $q = \mathcal{E}C\left(1 - e^{-t/\tau}\right)$

$\tau = RC$ $i = i_0 \cos\omega t$ $q = q_0 e^{-t/\tau}$ $B = \dfrac{\mu_0}{2\pi}\dfrac{I}{r}$ $\oint_C \mathbf{B}\cdot d\boldsymbol{\ell} = \mu_0 I_{\text{net}}$

$P = VI$ $\dfrac{V_s}{V_p} = \dfrac{n_s}{n_p}$ $\mathcal{E} = -\dfrac{d\phi}{dt}$ $F = BI\ell\sin\theta$ $R_T = R_0(1 + \alpha T)$

$i = \dfrac{dq}{dt}$ $F = qvB\sin\theta$ $B = \mu_0 nI$ $\dfrac{F}{\ell} = \dfrac{\mu_0}{2\pi}\dfrac{I_1 I_2}{L}$ $\tan\alpha = \dfrac{X_L - X_C}{R}$

$V_{AB} = V_B - V_A = -\displaystyle\int_A^B E\,dr$ $\langle P \rangle = V_{\text{rms}}I_{\text{rms}}\cos\alpha$ $Z = \sqrt{R^2 + (X_L - X_C)^2}$

PHYSICAL OPTICS AND WAVES

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

$2\mu t = n\lambda$ $d\sin\theta_n = n\lambda$ $f_n = \dfrac{nV}{2L} \;\; \text{or} \;\; \dfrac{nV}{4L}$ $I = I_0 \cos^2\theta$ $n = \tan\theta_B$

$r_n^2 = nR\lambda$ $f_b = f_1 - f_2$ $\beta = 10\log_{10}\dfrac{I}{I_0}\,dB$ $f'' = \dfrac{V + v_o}{V - v_s}\cdot f$

ATOMIC PHYSICS

$E = mc^2$ $E_k = \tfrac{1}{2}mv^2$ $\ell = \dfrac{nh}{2\pi}$ $E_n = -\dfrac{me^4}{8\varepsilon_0^2 h^2}\cdot\dfrac{1}{n^2}$ $F = \dfrac{mv^2}{r}$

$E = hf$ $eV = hf_{\text{MAX}}$ $N = N_0 e^{-\lambda t}$ $q = \dfrac{6\pi\eta r}{E}(v_G + v_E)$ $F = 6\pi\eta rv$

$A = \lambda N$ $n\lambda = 2d\sin\theta_n$ $T = \dfrac{\ln 2}{\lambda}$ $\tfrac{1}{2}mv_{\text{MAX}}^2 = hf - \phi$ $r_n = \dfrac{h^2\varepsilon_0}{\pi me^2}n^2$

$\lambda = \dfrac{h}{p}$ $A = A_0 e^{-\lambda t}$ $E_i - E_f = hf$ $\dfrac{1}{\lambda} = R\left(\dfrac{1}{n_f^2} - \dfrac{1}{n_i^2}\right)$