UNIVERSITY OF KWAZULU-NATAL

SECOND SEMESTER EXAMINATION: NOVEMBER 2010

SUBJECT AND COURSE: PHYSICS 120/162/196

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

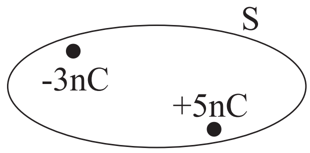
Internal Examiners: Dr N Chetty, Dr J Pierrus, Mr E Obaga & Mr A Welter
External Examiner: Dr J Govender (WESTVILLE CAMPUS)

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 **23** 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 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** (20×3 **marks**) **60 MARKS**

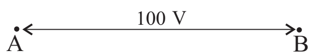
(1) The diagram alongside shows two point charges in vacuum. Calculate the net outward electric flux through the closed surface S.



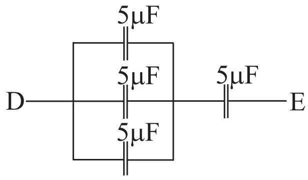
(2) In the hydrogen atom, the electron and proton are a distance $d = 5 \times 10^{-11}$ m apart. Calculate the electric potential due to the electron, at the position of the proton.

(3) 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.

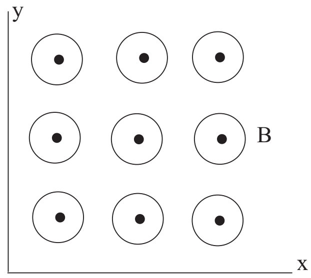
(4) The potential difference between points A and B in the diagram is 100 volts. An electron of charge e and mass m is released from A and accelerates across to B. Determine the electron's speed when it reaches B.



(5) Calculate the equivalent capacitance between points D and E for the arrangement of capacitors shown in the diagram alongside.



(6) A uniform magnetic field **B** is normal to the plane of the page as shown in the figure alongside. Suppose $\mathrm{B} = 3 \times 10^{-2}\,\mathrm{T}$. A particle (charge $q = -2\,\mu\,\mathrm{C}$) travelling with velocity $\mathbf{v} = 4 \times 10^5\,\hat{\mathbf{x}}\,\mathrm{ms}^{-1}$ enters the field. Calculate the force $\mathbf{F}$ on the particle.



(7) An electric field has magnitude 400 NC^{-1} and is in the positive x direction. Determine the acceleration of an electron in this field.

(8) A coil has a resistance of $20\,\Omega$. At a frequency of 100 Hz the voltage across the coil leads the current in it by 30°. Determine the inductance of the coil.

(9) A transformer has 1500 primary turns and 120 secondary turns. The input voltage to the transformer is 240 V.

(a) Is this a step up or step down transformer? Justify your answer.

(b) What is the output voltage?

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(10) State, in words, Lenz's law.

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(11) At a certain point on the ground, the sound intensity level produced by a jet engine is 140 db. What is the sound intensity at the point?

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(12) Two identical waves are described by the equation

$$y = 10 \sin 2\pi(x/5 - t/4)$$

where x and y are in metres and t is in seconds. Suppose these waves interfere constructively. What is the amplitude A, period T and wavelength λ of the resultant wave?

$A =$ ....

$T =$ ....

$\lambda =$ ....

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(13) Name

(a) the phenomenon which gives rise to the color effects seen in a soap bubble, and

(b) the phenomenon which gives rise to light bending around a sharp edge:

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(14) Explain the meaning of the symbols y_n, x and d in Young's double-slit equation

$$y_n = \frac{n\lambda x}{d}\,.$$

y_n : ....

x : ....

d : ....

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(15) Complete the following nuclear reaction equation. (Neglect energy released.)

$$^{64}_{29}\mathrm{Cu} \quad \rightarrow \quad ^{64}_{28}\mathrm{Ni} \quad + \quad \ldots \quad + \quad \ldots$$

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(16) If rubidium-86 has a half-life of 18.6 days, how long will it take for 7/8 of a given sample to decay?

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(17) What is the threshold frequency of a photoelectric surface if its work function is 2.0 eV?

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(18) Calculate the number of excess electrons carried by an oil droplet of mass 3.2×10^{-15} kg if it remains stationary (in air) in an electric field of magnitude $4.9 \times 10^{4}\,\mathrm{V\,m^{-1}}$. (Neglect the upthrust of the air.)

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(19) Calculate the wavelength associated with a proton travelling at a speed of $1.5 \times 10^{7}\,\mathrm{m\,s^{-1}}$.

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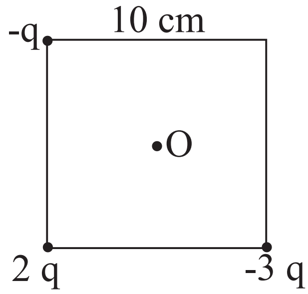
(20) What quarks make up a proton? Give the charge of these quarks.

SECTION B ELECTROMAGNETISM 60 MARKS

QUESTION B1

In the figure alongside ABCD is a square of side 10 cm and centre O. Charges are placed in vacuum as shown with $q = 1 \times 10^{-6}$ C. (You are reminded of the cosine rule $r^2 = x^2 + y^2 - 2xy\cos\theta$, where all the symbols have their usual meaning.)



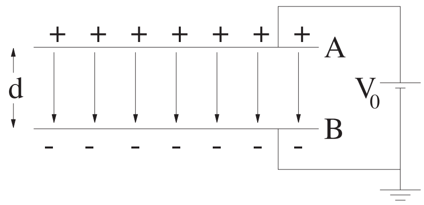
(a) On the diagram alongside indicate the directions of all the forces acting on the $-3\,q$ charge. (2)

(b) Calculate the magnitude of the resultant force acting on the $-3\,q$ charge. (6)

/8

QUESTION B2

Consider the diagram alongside which shows two large parallel plates A and B separated by a distance d and connected to a battery which maintains a constant potential difference of V_o between the plates. Assuming plate B is grounded, show that the magnitude of the electric field between the plates is given by



$$E = \frac{V_o}{d} .$$

(The relationship between the electric field $\mathbf{E}$ and electric potential V may be used without proof.)

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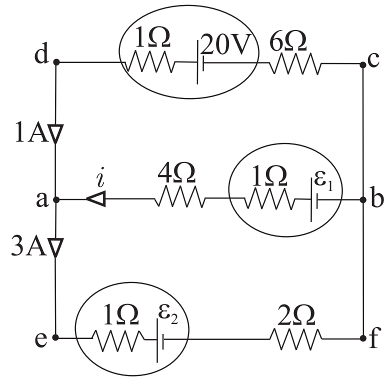
QUESTION B3

Consider the circuit shown alongside.



(a) Use Kirchhoffs' laws to calculate the emf's ε_1 and ε_2. (6)

(b) Determine the potential of point to relative to point a (i.e. Find V_{ab}) (2)

/8

QUESTION B4

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

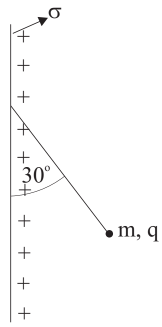
(b) Use Gauss's law to show that the magnitude of the electric field close to an "infinite" plane sheet of charge with charge per unit area σ is given by

$$E = \frac{\sigma}{2\varepsilon_0} \, .$$

Include a sketch and show clear reasoning (not only equations) in your answer. (5)

(Question B4(c)... continues over the page.)

(c) A small sphere of mass $m = 2\,\text{mg}$ carries a charge q of $0.03\,\mu\text{C}$. It hangs from a silk thread which makes an angle of 30° with a large charged conducting sheet as shown alongside. Calculate the charge density of the sheet. (5)



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QUESTION B5

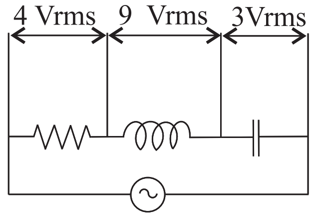
(a) Define a superconductor. (2)

(b) A closely–wound rectangular coil of 50 turns has dimensions of 12 cm × 25 cm. The plane of the coil is rotated in time $t = 0.1\,\text{s}$ from a position where it makes an angle of 60° with a uniform magnetic field of strength $2.0\,T$ to a position perpendicular to the field. What is the average emf $\mathcal{E}$ induced in the coil? (6)

/8

QUESTION B6

Consider the circuit shown alongside.



(a) Calculate

(i) the rms voltage across the oscillator terminals. (2)

(ii) the phase angle between the voltage and current, and (2)

(iii) the power factor. (1)

(b) Determine the impedance in the above circuit, given that the rms current is 0.48 A. (2)

(Question B6(c)..... continues over the page)

(c) Write down the resonance frequency ω_0 for the above circuit. (1)

(d) Suppose a second capacitor with capacitance $C_1 = \frac{C}{3}$ is connected in series with the oscillator. Express the new resonance frequency ω_0' in terms of ω_0. (4)

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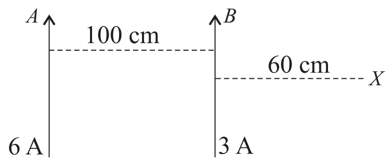
Question B7

Two long, fixed vertical wires A and B are a distance 100 cm apart in a vacuum and carry currents of 6 A and 3 A respectively in the same direction as shown.



(a) Determine the force per unit length exerted by wire A on wire B. (2)

(b) Determine the magnetic field at a point X, 60 cm away from wire B. (Remember to explain all your steps.) (5)

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SECTION C **WAVES AND PHYSICAL OPTICS** **30 MARKS**

QUESTION C1

A harmonic wave travelling along a string in the positive x-direction has a wavelength of 20 cm, a frequency of 500 Hz and an amplitude of 5.0 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 $y(0,0) = 0$. (5)

(iii) Hence calculate the maximum speed of any point on the string. (2)

(iv) Calculate the phase difference between two displacements $y(x,t)$ at a certain point x at times 250 μs apart. (2)

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QUESTION C2

A bat is flying around in a large cave, navigating via ultrasonic squeaks. Assume that the sound emission frequency of the bat is 35.7 kHz. Suppose the bat is flying directly **away** from a flat wall surface at a speed $c/9$ (c is the speed of sound in air). Calculate the frequency of the sound reflected off the wall, received by the bat. (Do not assume a numerical value for c.)

/6

QUESTION C3

Monochromatic light of wavelength $\lambda = 400.0\,\text{nm}$ is incident normally on a diffraction grating containing 5000 lines/cm.

(a) Find the angular positions of the 1st order and 3rd order maxima.

(b) Are sixth order diffraction maxima possible? Explain.

/8

QUESTION C4

An air film of thickness 0.00065 mm is formed between two parallel glass blocks. A mixture of green light of wavelength 520 nm and red light of wavelength 650 nm is incident normally on the air film. What is the colour of the reflected light? (Show all workings.)

/6

SECTION D **ATOMIC AND NUCLEAR PHYSICS** **30 MARKS**

QUESTION D1

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

(b) Determine the binding energy per nucleon for $^{120}_{50}\text{Sn}$ in MeV. (Take the mass of $^{120}_{50}\text{Sn}$ as 119.9 u.) (4)

/8

QUESTION D2

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

/6

QUESTION D3

(a) What is the least voltage that must be applied across an X-ray tube in order to produce an X-ray beam of wavelength 4.0×10^{-11} m? (3)

(b) What is the spacing of the atomic planes in a crystal which produce a second-order diffracted beam for an angle of incidence of 60° with the above beam? (3)

/6

QUESTION D4

A sample of wood from an ancient barge discovered at an archeological dig is found to contain 8.0 g of carbon and has an activity of 1.18 decays per second. Determine the age of the sample, given that the ratio of ^{12}C to ^{14}C atoms in living organisms is 8.3×10^{11}. (Take the half-life of ^{14}C as 5730 years.)

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PHYS120/162/196 – INFORMATION SHEET

PHYSICAL CONSTANTS

$m_e = 9.11 \times 10^{-31}\,\mathrm{kg}$ $\quad m_p = 1.67 \times 10^{-27}\,\mathrm{kg}$ $\quad m_n = 1.67 \times 10^{-27}\,\mathrm{kg}$

$m_e = 0.00055\,\mathrm{u}$ $\quad m_p = 1.0073\,\mathrm{u}$ $\quad m_n = 1.0087\,\mathrm{u}$

$e = 1.60 \times 10^{-19}\,\mathrm{C}$ $\quad \frac{1}{4\pi\varepsilon_0} = 9.00 \times 10^{9}\,\mathrm{N\,m^2\,C^{-2}}$ $\quad \frac{\mu_0}{2\pi} = 2.00 \times 10^{-7}\,\mathrm{T\,m\,A^{-1}}$

$N_{\mathrm{A}} = 6.02 \times 10^{23}\,\mathrm{mol^{-1}}$ $\quad h = 6.63 \times 10^{-34}\,\mathrm{J\,s}$ $\quad g = 9.80\,\mathrm{m\,s^{-2}}$

c for em waves $= 3.00 \times 10^{8}\,\mathrm{m\,s^{-1}}$

c for sound waves in air at $0\,^\circ\mathrm{C}$ is $332\,\mathrm{m\,s^{-1}}$

$I_0 = 1.00 \times 10^{-12}\,\mathrm{W\,m^{-2}}$ $\quad n_{\mathrm{air}} = 1.00$

ELECTRICITY AND MAGNETISM

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

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

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

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

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

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

WAVES AND PHYSICAL OPTICS

$c = \sqrt{\frac{\tau}{\mu}}$ $\quad c = \sqrt{\frac{\gamma RT}{M}}$ $\quad \beta = 10\log_{10}\frac{I}{I_0}$ $\quad f_{\mathrm{O}} = f_{\mathrm{S}}\left(\frac{c \pm v_{\mathrm{O}}}{c \mp v_{\mathrm{S}}}\right)$

$f_{\mathrm{b}} = f_1 - f_2$ $\quad f_n = \frac{nc}{2L}$ or $\frac{(2n-1)c}{4L}$ $\quad y_n = \frac{n\lambda x}{d}$ $\quad 2\mu t = n\lambda$

$r_n^2 = nR\lambda$ $\quad n = \tan\theta_{\mathrm{B}}$ $\quad I = I_0\cos^2\theta$ $\quad a\sin\theta_n = n\lambda$ $\quad d\sin\theta_n = n\lambda$

ATOMIC PHYSICS

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

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

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

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