UNIVERSITY OF KWAZULU-NATAL

SECOND SEMESTER EXAMINATION: NOVEMBER 2011

SUBJECT AND COURSE: PHYSICS 120/162/196

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

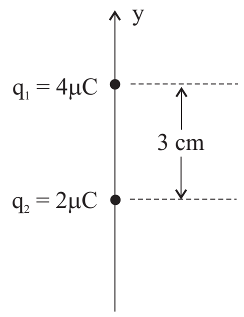
Internal Examiners: Dr N Chetty, Mr M Cavero, Mr N Dlamini & Mr S Mthembu
External Examiner: Dr J Govender (WESTVILLE CAMPUS)

GENERAL INSTRUCTIONS:

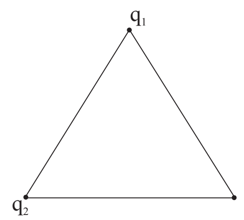
1. This question paper is in two parts. Section A–E (printed on blue paper) forms the first part: the second part is section F (printed on pink paper) and both are stapled separately.
2. Answer ALL Section A–E questions on the blue paper and Section F questions on the pink paper. Pencil may be used provided this is clearly visible. All answers must be in legible handwriting.
3. It is the candidate's responsibility to ensure that this paper has 23 pages. Rough work will not necessarily be marked. See instruction 7 below.
4. The last page of this exam is an information sheet and is printed separately on white paper.
5. No part of these exam papers 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. 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.
8. Where appropriate, candidates are advised to show working for their answers to all questions.

SECTION A SHORT QUESTIONS (15 × 3 marks) 45 MARKS

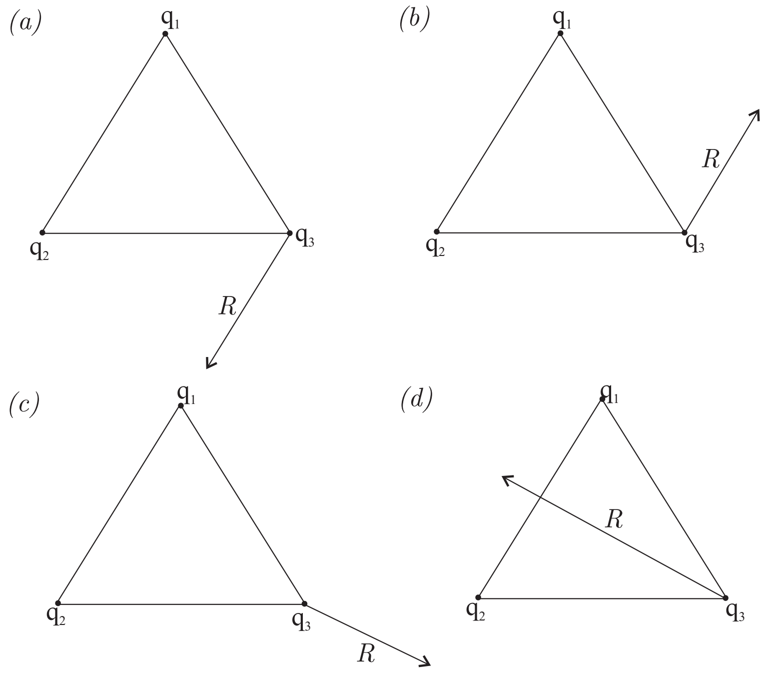
1. Two point charges 3 cm apart in vacuum are located on the y-axis as shown in the figure alongside. Calculate the force $\mathbf{F}_{12}$ exerted by q_1 on q_2.



2. Two positive charges q_1 and q_2, of equal magnitude, are placed at two corners of an equilateral triangle as shown.



Which diagrams below best represents the direction of the resultant force on a third positive charge q_3 placed at the third corner? (Circle the correct answer.)



3. Explain, with the aid of a resistance-temperature graph what is meant by the term "'superconductor"'.

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4. A conductor of length ℓ, resistivity ρ and cross-sectional area A has a resistance R. If the length of the conductor is increased by a factor of 3 and its cross-sectional area is reduced by a factor of 0.5, determine the new resistance of the conductor, in terms of R.

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5. The resistance of copper wire is $4\,\Omega$ at $0°$C. Given that $\alpha_{\text{Cu}} = 3.9\times10^{-3}\,°\text{C}^{-1}$, calculate the resistance of the wire at $80°$C.

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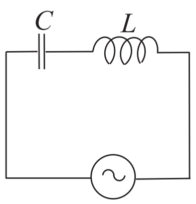
6. A capacitor C and an inductor L are connected as shown. The frequency of the supply source is then trebled. How, if at all, will the capacitative reactance of the circuit change?



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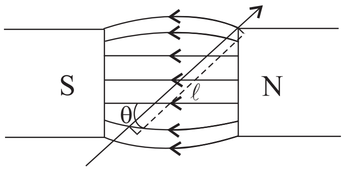
7. A wire carrying 30 A of current has a length $\ell = 12\,\text{cm}$. The wire is held between the faces of a magnet at an angle $\theta = 60°$ as shown. A uniform magnetic field of approximately 0.09 T exists between the magnet faces. Calculate the magnitude of the force on the length ℓ of the wire.



8. Two sources are emitting identical waves that have a wavelength of 0.44 m. Determine whether constructive or destructive interferance occurs at a point which is 3.33 m from the one source and 2.67 m from the other.

9. A certain diffraction grating gives a second order maximum at 25° from the central axis for normally incident monochromatic light. For the same light and grating, calculate the angle of the fourth-order maximum.

10. Two identical waves are described by the equation

$$y = 15\cos 2\pi(x/6 - t/5)$$

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

11. A string of length 25 cm and a mass per unit length of 2.0×10^{-2} kg m^{-1}is held fixed at one end and stretched at the other. If the string is vibrating at a resonant frequency of 300 Hz, which is 3 times the natural frequency of the string, what tension is the string under?

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12. Complete the following nuclear reactions

$$^{22}_{11}\mathrm{Na} \quad + \quad \ldots \quad \rightarrow \quad ^{6}_{3}\mathrm{Li} \quad + \quad ^{17}_{8}\mathrm{O}$$

$$^{9}_{4}\mathrm{Be} \quad + \quad \ldots \quad \rightarrow \quad ^{9}_{5}\mathrm{B} \quad + \quad ^{1}_{0}\mathrm{n}$$

$$^{35}_{17}\mathrm{Cl} \quad + \quad ^{1}_{1}\mathrm{H} \quad \rightarrow \quad ^{32}_{16}\mathrm{S} \quad + \quad \ldots$$

In each case assume that the initial kinetic energy and the energy released are negligible.

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13. Determine the energy in eV of a photon of the light of the wavelength 600 nm (in eV).

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14. A radioactive substance has a decay constant λ. How long will it take for 20% of the substance to decay? Express your answer in terms of λ.

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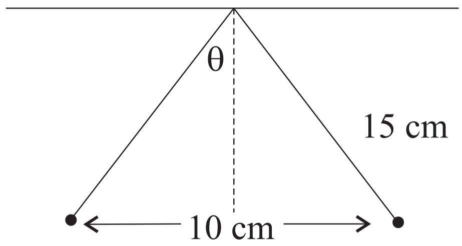
15. X-rays of wavelength 3.5×10^{-10} m are directed at a certain crystal and produce second order Bragg diffraction for an incident angle of 55°. Calculate the spacing of the planes responsible for this diffraction pattern.

/45

SECTION B ELECTRICITY AND MAGNETISM 55 MARKS

QUESTION B1

Two equally charged balls, each of mass 0.2 g, are suspended from the same point by non-conducting threads 15 cm long, as shown in the diagram. The balls come to rest 10 cm apart due to repulsion. Determine the magnitude of the charge q on each ball.



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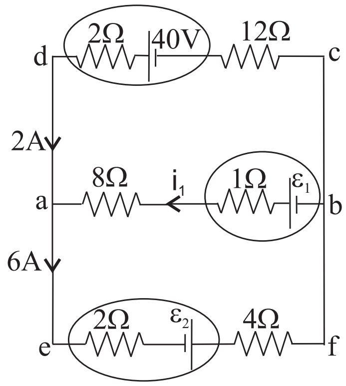
QUESTION B2

Calculate the emf ε_1 in the circuit alongside.



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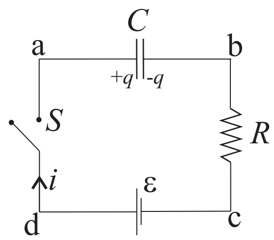
QUESTION B3

A circuit containing emf ε, resistance R, capacitance C, and a switch S in series is used to charge the capacitor.



The capacitor is initially uncharged. At time $t = 0$, the switch S is closed and a current i flows in the circuit.

(a) Show that the charge q on the capacitor varies with the time according to the equation:

$$q = \varepsilon C(1 - e^{-t/\tau})$$

where τ is the time constant. (7)

(b) Draw a graph (fully labelled) to show how q varies with time. (3)

(Continue answering Question B3 over the page...)

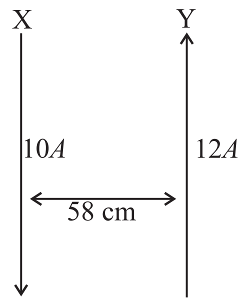
/10

QUESTION B4

(a) State Ampere's Law. (If you use symbols, define them.) (2)

(b) Use Ampere's Law to determine the magnetic field at a distance r from a long straight wire carrying current I. (6)

(c) Two long, fixed vertical wires X and Y are a distance 58 cm apart in a vacuum . They carry currents of 10 A and 12 A in opposite direction as shown alongside.



(i) Determine the magnitude of the force per length exerted by wire X on wire Y. (2)

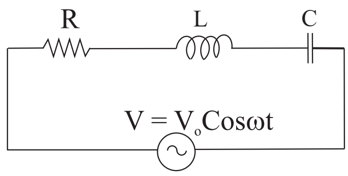
(ii) Calculate the position of any neutral point in a horizontal plane. (7)

(Continue answering Question B4 over the page...)

/17

QUESTION B5

Refer to the RLC series circuit shown alongside.



(a) (i) Write down an expression for the impedance Z in the circuit. (1)

(ii) Determine the resonance frequency ω_o for which this circuit resonates. (2)

(iii) Suppose a second capacitor with capacitance $C_1 = \dfrac{C}{2}$ is connected in series with the other components above. Express the new resonance frequency ω_o' in terms of ω_o. (4)

(b) At resonance in a series RLC circuit (R$= 100\,\Omega$), the RMS potential difference across the resistor and inductor are $40\,V$ and $30\,V$ respectively. If the resonance frequency f_0 is 1×10^5 Hz, determine the inductance L and capacitance C. (6)

/13

SECTION C **WAVES** **13 MARKS**

QUESTION C1

(a) In a factory, five identical machines operating simultaneously produce an average level of 80.000 dB. When additional identical machines are put in operation, the new intensity level is 83.802 dB. How many new machines were added? (4)

(b) A police car, whose siren has a natural frequency of 500 Hz, approaches a wall at 10 ms^{-1}. A stationary observer detects beats due to the waves approaching him directly and those reflected off the wall. Calculate the beat frequency, assuming the police car is between the observer and the wall. (4)

/8

QUESTION C2

An organ pipe which is open at one end and closed at the other, has a length of 26 cm. If the temperature of the air inside the pipe is $33\,^{\circ}\mathrm{C}$, determine the fundamental frequency and the second overtone.

/5

SECTION D — PHYSICAL OPTICS — 13 MARKS

QUESTION D1

Draw a suitable labelled diagram and prove the relationship

$$r_n^2 = Rn\lambda$$

used to describe the radii of the dark rings in a Newton's rings experiment with monochromatic light.

/6

QUESTION D2

A parallel beam of light containing only the wavelengths 490 nm and 588 nm falls normally on a pair of slits 0.300 mm apart. At what distance from the central bright fringe on a screen 50 cm away does a maximum of one wave length coincide with a maximum of the other?

/4

QUESTION D3

A mixture of yellow light of wavelength 580 nm and blue light of wavelength 450 nm is incident normally on an air film 0.00029 mm thick. Find the colour of the reflected light.

/3

SECTION E ATOMIC AND NUCLEAR PHYSICS 24 MARKS

QUESTION E1

(a) The mass of ${}^{92}_{36}$Kr nucleus is 91.907 u. Determine its binding energy per nucleon in MeV. (4)

(b) How many atoms of ${}^{235}_{92}$U are needed to produce the electric power of 800 MW in one day if the fission of one atom of ${}^{235}_{92}$U produces 185 MeV. (4)

/8

QUESTION E2

(a) Niels Bohr, developed a theory of hydrogen atom by trying to explain the structure of the line spectra emitted by the hydrogen atom and derived the expression $E_n = -\frac{E_1}{n^2}$ for its energy levels. List one assumption that Bohr made in his derivation. (1)

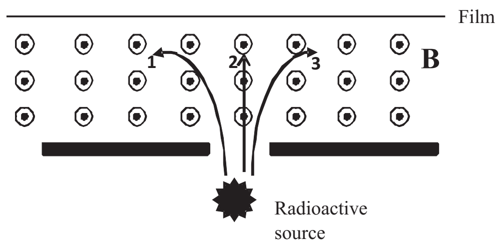
(b) Determine the wavelength of the photon emitted when an electron drops from $n = 6$ level to $n = 3$ level of the hydrogen atom. Assume that the ionization energy of the hydrogen atom is 13.6 eV. (5)

/6

QUESTION E3

(a) A radioactive isotope decays according to the formula $N = N_0 e^{-\lambda t}$ where λ is the decay constant. Show that the half-life ($t_{1/2}$) of the isotope is given by $t_{1/2} = \frac{0.693}{\lambda}$. (3)

(b) The radioactive material spontaneously disintegrates and produce three particles, α-particle, β-particle and γ-ray. In the presence of the magnetic field (coming out of the page) the particles are deflected as shown in the figure alongside. Identify the particles 1, 2, 3. (3)



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QUESTION E4

Photons of wavelength $\lambda = 360\,\text{nm}$ is incident on a metal surface which has a work function $\phi = 2.4\,\text{eV}$. Determine the stopping potential.

/4

PHYS120/162/196 – INFORMATION SHEET

PHYSICAL CONSTANTS

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

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

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

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

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

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

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

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

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

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

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

WAVES AND PHYSICAL OPTICS

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

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

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

ATOMIC PHYSICS

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

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

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

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