UNIVERSITY OF KWAZULU-NATAL

SECOND SEMESTER EXAMINATION: NOVEMBER 2008

SUBJECT AND COURSE: PHYSICS 120/162/196

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

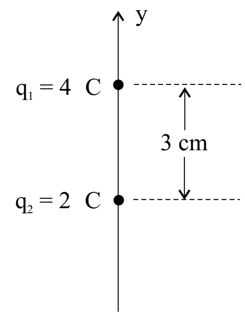
Internal Examiners: Mr N Chetty, Mr A Welter & Dr V Couling
External Examiner: Professor S R Pillay (WESTVILLE CAMPUS)

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 25 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.
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, and in particular those of Section A.
8. Take $g = 9.8\,\mathrm{m\,s^{-2}}$, $e = 1.6 \times 10^{-19}\,\mathrm{C}$, $c = 3.0 \times 10^{8}\,\mathrm{m\,s^{-1}}$, $\mu_0 = 4\pi \times 10^{-7}\,\mathrm{H\,m^{-1}}$, $h = 6.6 \times 10^{-34}\,\mathrm{J\,s}$, $\mathrm{N}_A = 6.02 \times 10^{23}\,\mathrm{mol^{-1}}$ where necessary.

SECTION A — SHORT QUESTIONS — 60 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.



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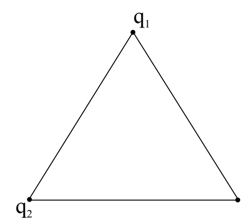
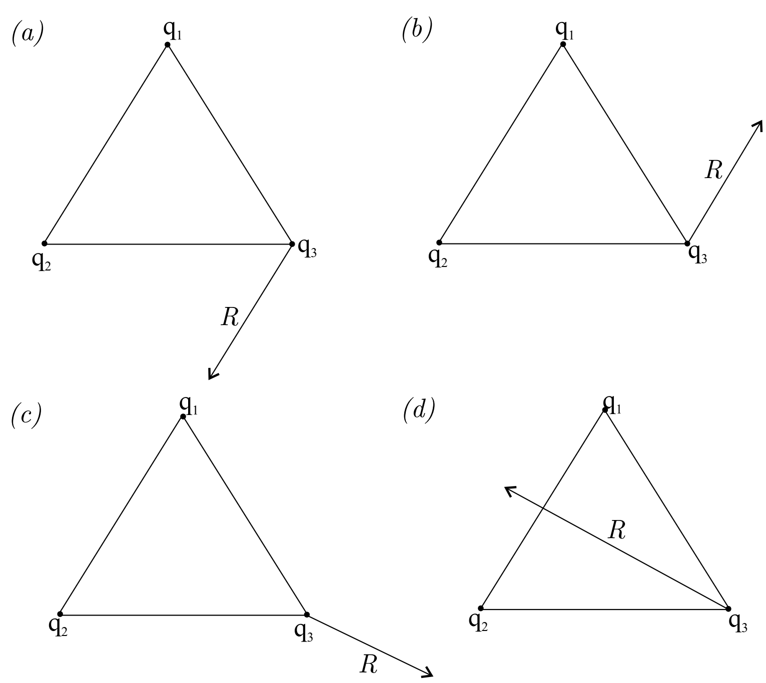
2. Two positive charges q_1 and q_2, of equal magnitude, are placed at two corners of an equilateral triangle as shown.



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



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3. The electric field at a point in vacuum is defined as

$$\boxed{\mathbf{E} = \frac{\mathbf{F}}{q_0}}$$

where the symbols have their usual meaning and q_0 is a stationary test charge. Why is it essential in this definition that the test charge $q_0 \rightarrow 0$?

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4. Draw a fully labeled graph to show how the resistance of a superconductor varies with a change in temperature.

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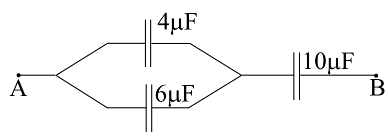
5. Consider the arrangement of capacitors as shown alongside. Determine the equivalent capacitance between points A and B.



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6. A wire carries a current of 5A. Calculate the number of electrons flowing past any point in this wire per minute.

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7. 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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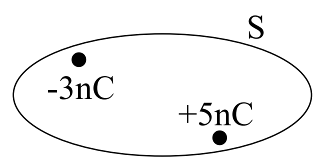
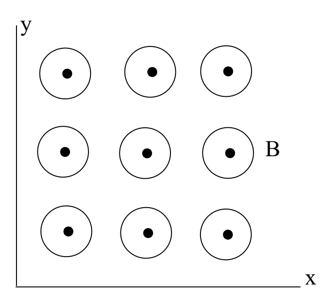
8. Calculate the cost of operating a 4.8 kW heater for 2 days, if electricity is billed for at R0.010 per kW-hr.

9. The resistance of copper wire is $4\,\Omega$ at $0°$C. Given that $\alpha_{\text{Cu}} = 3.9 \times 10^{-3}\,°\text{C}^{-1}$, calculate the resistance of the wire at $80°$C.

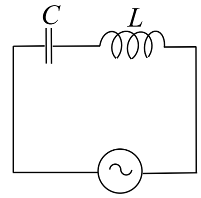
10. The diagram alongside shows two point charges in vacuum. Calculate the net outward electric flux through the closed surface S.



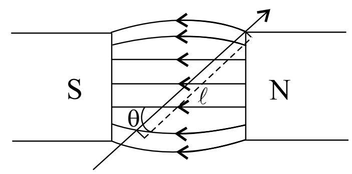
11. A uniform magnetic field **B** is normal to the plane of the page as shown in the figure alongside. Suppose $B = 3 \times 10^{-2}$ T. A particle (charge $q = -2\,\mu$C) travelling with velocity $\mathbf{v} = 2 \times 10^5\,\hat{\mathbf{x}}\,\text{m}\,\text{s}^{-1}$ enters the field. Calculate the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



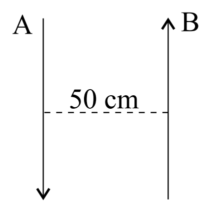
12. A capacitor C and an inductor L are connected as shown. The frequency of the supply source is then trebled. How, if at all, will the capacitative reactance of the circuit vary?



13. A wire carrying 30 A of current has a length $\ell = 12\,\text{cm}$ between the faces of a magnet at an angle $\theta = 60^\circ$ 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.



14. Two long fixed vertical wires A and B are a distance $r = 50\,\text{cm}$ apart in vacuum and carry currents of 100 A and 60 A respectively in opposite directions, as shown. Determine the magnitude of the force per unit length exerted by wire A on wire B.



15. A travelling wave propagating in the positive x direction has a frequency of 100 Hz and a velocity of $200\,\text{m}\,\text{s}^{-1}$. Calculate the wavenumber, k, and the angular frequency ω.

16. What is the mass per unit length of a piece of string whose fundamental frequency is 120 Hz if the length of the string is 0.50 m and the tension is 144 N ?

17. The frequency of the whistle of a train is 270 Hz . Calculate the frequency heard by a person standing at a station if the train is moving away from the station at a speed of $20\,\mathrm{m\,s^{-1}}$. (Take the speed of sound in air as $340\,\mathrm{m\,s^{-1}}$. You are reminded of the general formula

$$f'' = \frac{V + v_o}{V - v_s} \cdot f \,,$$

where the symbols have their usual meanings.)

18. Sketch the displacement curves of the fundamental mode of vibration of a sound wave in an open pipe, and the third harmonic of a sound wave in a closed pipe. Clearly mark the positions of the node(s) with an 'N' and the antinode(s) with an 'A' in each case.

19. What is the colour of light at the long wavelength end of the visible spectrum, and what is its approximate wavelength?

20. Circle the correct answer:

    Which physical phenomenon accounts for the blue colour of the sky, and the red colour of the setting sun?

    (a) polarization (b) light scattering (c) refraction (d) diffraction

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21. A diffraction grating has 2000 lines/cm ruled on it. What is the distance between slits (in units of metres)?

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22. The plane of polarization of a polarized beam of intensity I_0 is inclined at 25° to the plane of transmission of an analyzer. What is the intensity of the beam transmitted by the analyzer?

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23. Complete the following reaction equation (neglect energy terms).

$$^{6}_{3}\mathrm{Li} \quad + \quad \ldots \quad \rightarrow \quad ^{7}_{4}\mathrm{Be} \quad + \quad ^{1}_{0}\mathrm{n}$$

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24. The series limit of the Paschen series for hydrogen is 820 nm. Calculate the wavelength of the line of longest wavelength in this series.

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25. The ionisation energy of hydrogen is $13.6\,\mathrm{eV}$. Calculate the energy of the $n = 4$ level in a hydrogen atom.

26. X–rays of wavelength $2.0 \times 10^{-10}\,\mathrm{m}$ are directed at a certain crystal and produce second order Bragg diffraction for an incident angle of $60°$. Calculate the spacing of the planes responsible for this diffraction pattern.

27. What minimum voltage would be required across an X–ray tube in order to generate X–rays with a wavelength of $6.0\,\text{Å}$.

28. What is the speed of an ion which will emerge undeviated from the velocity selector of a Bainbridge mass spectrometer if the electric field is $3 \times 10^4\,\mathrm{V\,m^{-1}}$ and the magnetic field is $0.2\,\mathrm{T}$?

29. Calculate the number of excess electrons carried by an oil droplet of mass 9.6×10^{-16} kg if it remains stationary (in air) in an electric field of magnitude $1.96 \times 10^{4}\,\mathrm{V\,m^{-1}}$. (Neglect the upthrust of the air.)

30. Calculate the de Broglie wavelength of a cricket ball of mass 0.157 kg travelling at $80\,\mathrm{km\,h^{-1}}$.

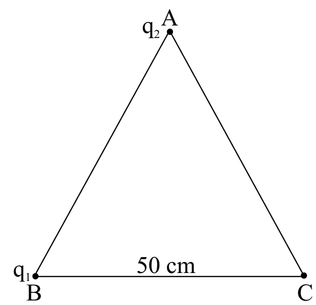
/60

SECTION B ELECTROMAGNETISM 60 MARKS

QUESTION B1

Two point charges $q_1 = 2 \times 10^{-9}$ C and $q_2 = \frac{1}{2} q_1$ are located in vacuum at two corners of an equilateral triangle ABC of side length 50 cm as shown. Determine the magnitude and direction of the electric field at the third corner C.

(You are reminded of the **cosine rule**: $a^2 = b^2 + c^2 - 2bc\cos\theta$ and **sine rule**: $\dfrac{\sin A}{A} = \dfrac{\sin B}{B}$)



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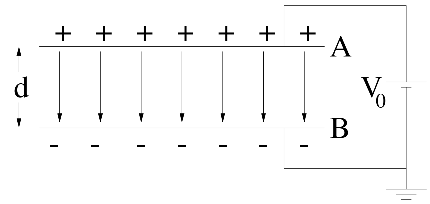
QUESTION B2

Consider the diagram alongside which shows two large oppositely charged parallel plates A and B separated by a distance d and connected to a battery which maintains a constant potential difference of V_0 between the plates. Assuming plate B is grounded, show that the magnitude of the electric field between the plates is given by



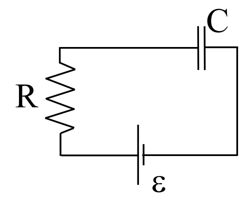
$$\boxed{E = \frac{V_0}{d}\ .}$$

(The relationship between the electric field **E** and electric potential V may be used without proof.) Be careful to show clear reasoning.

/6

QUESTION B3

Determine the number of time constants τ that must lapse before a capacitor in a series RC circuit, as shown, is charged to within 0.1 % of its equilibrium charge.



/3

QUESTION B4

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

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

(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

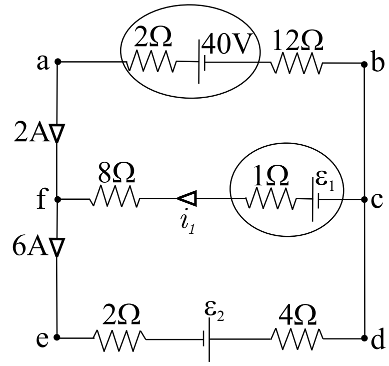
$$E = \frac{\sigma}{2\varepsilon_0} \ .$$

(Remember to include a sketch and show clear reasoning (not only equations) in your answer. (8)

/10

QUESTION B5

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



(a) Apply Kirchoff's 1st rule at a suitable point to obtain a value for the unknown current i_1. (1)

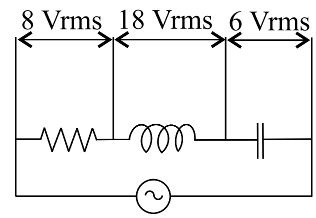
(b) Apply Kirchoff's second rule around suitable loops to determine the unknown emfs ε_1 and ε_2. (7)

(c) Find V_{cf}, the potential of point c relative to point f. (2)

/10

QUESTION B6

Consider the circuit shown alongside.



(a) Calculate

(i) the rms voltage across the oscillator terminals. $(1\frac{1}{2})$

(ii) the phase angle between the voltage and current, and $(1\frac{1}{2})$

(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 $C_1 = \dfrac{C}{3}$ is connected in series with the oscillator. Express the new resonance frequency ω_0' in terms of ω_0. (4)

/11

QUESTION B7

THIS QUESTION HAS TWO UNCONNECTED PARTS (a) AND (b).

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

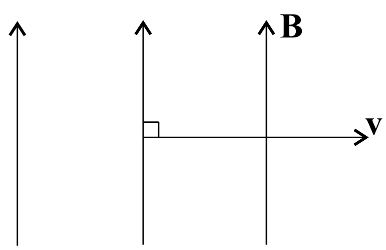
$$\phi = 5t^2 + 3t + 2$$

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



(9)

(You may continue answering this question on the next page.)

/12

SECTION C — WAVES AND PHYSICAL OPTICS — 30 MARKS

QUESTION C1

(a) A sound source radiates sound energy uniformly in all directions. If the intensity level at a point 50 cm from the source is 65 dB above the standard intensity, determine the power output of the sound source. (Take the standard intensity I_0 as $1.0 \times 10^{-12}\,\mathrm{W\,m^{-2}}$.) (4)

(b) In a factory, five identical machines operating simultaneously produce an average intensity level of 80 dB. If three additional such machines are put in operation, what is the new intensity level? (4)

/8

QUESTION C2

(a) A piano tuner uses overtones and beats as an aid in tuning a piano. The tuner has established that the first overtone (second harmonic) of the string whose fundamental frequency is 524 Hz is lower than the second overtone of the string he is tuning. If he hears a beat frequency of 2 Hz between these overtones, what is the frequency of the string he is tuning? (5)

(b) Should the piano tuner raise or lower the pitch of the string in part (a) above, and by how much? (2)

/7

QUESTION C3

Green light of wavelength 514 nm, from a point source, passes through two parallel and narrow slits which are 0.60 mm apart. Determine the distance between the central bright fringe and the seventh bright interference fringe formed on a screen parallel to the plane of the slits and 2.5 m away.

/3

QUESTION C4

An air film of thickness 0.00111 mm is formed between two parallel glass blocks. A mixture of red light of wavelength 633 nm and blue light of wavelength 444 nm is incident normally on the air film. What is the colour of the reflected light? (Show all workings.)

/4

QUESTION C5

(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 the plano–convex lens used in part (a) above is 5.0 m, what is the wavelength of the light being used? (2)

/6

QUESTION C6

Light is reflected from a glass coffee table. When the angle of incidence is 56.3°, the reflected light is fully polarized. Calculate the refractive index of the glass.

/2

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) For $^{235}_{92}\mathrm{U}$, calculate

(i) the mass defect (in u),

(ii) the binding energy in MeV, and

(iii) the binding energy per nucleon. (4)

(c) If the fission of one atom of $^{235}_{92}\mathrm{U}$ produces 174 MeV, how many fissions must occur per second to produce a power output of 500 MW? (2)

($^{1}_{0}\mathrm{n} = 1.0087$, $^{1}_{1}\mathrm{H} = 1.0078$ and $^{235}_{92}\mathrm{U} = 235.0439$)

/10

QUESTION D2

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 same pair of axes, draw 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, and

(ii) the mass of B remaining after a time $2.5T_B$, given that the atomic mass of B is 90 u. (6)

(1 curie $\equiv 3.7 \times 10^{10}$ Bq.)

/10

QUESTION D3

An 11.0 mW laser beam of wavelength 540 nm falls on a sodium surface. Calculate

(a) the number of photons striking the surface per second, and hence (4)

(b) the photoelectric current leaving the surface, assuming that 2.5% of the photons yield electrons. (3)

Given that the work function of sodium is 2.28 eV, determine also

(c) the maximum kinetic energy of the photoelectrons, and hence (2)

(d) the potential difference required to bring all ejected electrons to rest. (1)

/10