TE WHARE WĀNANGA O TE ŪPOKO O TE IKA A MĀUI

VICTORIA

UNIVERSITY OF WELLINGTON

EXAMINATIONS - 2018

TRIMESTER 2

PHYS 115

PHYSICS 1B

Time allowed: THREE HOURS

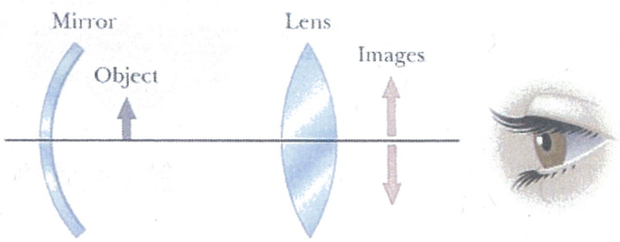
CLOSED BOOK

Instructions: Answer **ALL** questions
All questions are of equal value (10 marks each).
Give full explanations and draw diagrams where appropriate.

Permitted material: Only silent non-programmable calculators or silent programmable calculators with their memories cleared are permitted in this examination.
Printed foreign language-English dictionaries are permitted.

Useful data:
Permittivity of free space, $\varepsilon_0 = 8.85 \times 10^{-12}\ \mathrm{C^2\ N^{-1}\ m^{-2}}$
Permeability of free space, $\mu_0 = 4\pi \times 10^{-7}\ \mathrm{T\ m\ A^{-1}}$
Elementary charge, $e = 1.60 \times 10^{-19}$ C
Electron mass, $m_e = 9.11 \times 10^{-31}$ kg
Atomic mass unit, (amu) = 1.67×10^{-27} kg
Stefan-Boltzmann constant, $\sigma = 5.67 \times 10^{-8}\ \mathrm{W\ m^{-2}\ K^{-4}}$
Boltzmann constant, $k_B = 1.38 \times 10^{-23}\ \mathrm{JK^{-1}}$

1. An observer to the right of the mirror-lens combination shown in the figure (not to scale) sees two real images that are the same size and in the same location. One image is upright and the other is inverted. Both images are 1.50 times the size of the object. The lens has a focal length of 10.0 cm. The lens and mirror are separated by 40.0 cm. Determine the focal length of the mirror.



[10 marks]

2. (a) Give equations for

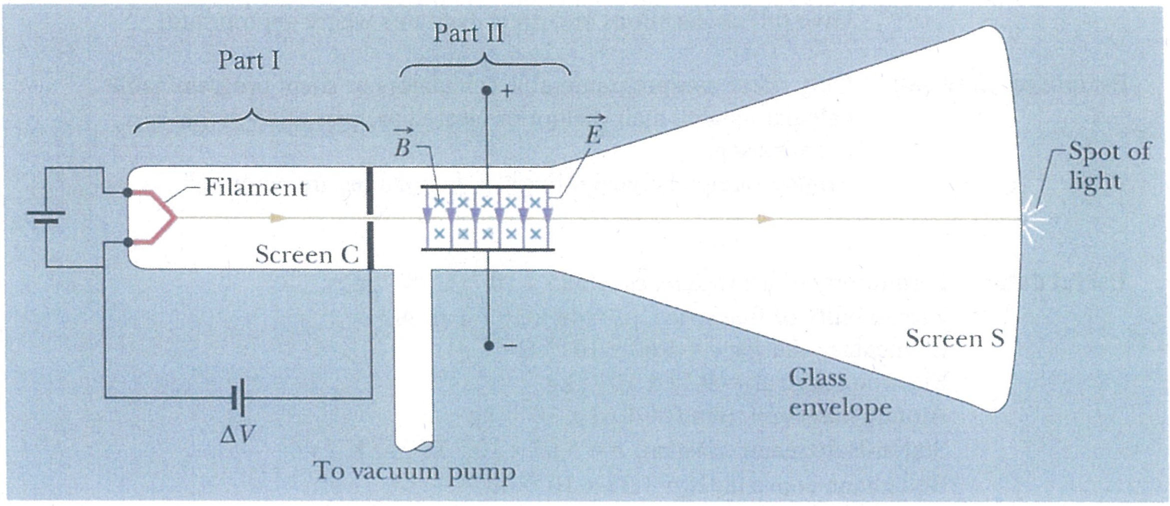
(i) the force on a charge q_1 in an electric field $\underline{E}$; and

(ii) the force on a charge q_2 moving with velocity $\underline{v}$ in a magnetic field, $\underline{B}$.

In each case explain fully the symbols you use.

[2 marks]

The diagram below shows a modern version of the apparatus used by J.J. Thomson in 1897 to measure the mass/charge ratio of the electron.



(b) Describe fully the forces on the electrons as they pass through part I and part II of the apparatus, and their effects on the motion of the electrons.

[3 marks]

(c) In part II of the apparatus the plates are 5 cm long, and the electric field E is 2000 V/m (N/C). In the absence of a magnetic field (i.e. $B = 0$), the electrons undergo a vertical deflection of 0.5 mm between entering and leaving the plates. Calculate the horizontal speed of the electrons.

[3 marks]

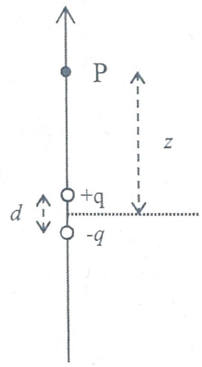
(d) What magnetic field must now be applied to cancel out this deflection, and restore the electron beam to horizontal?

[2 marks]

3. (a) (i) Sketch the electric field lines of an electric dipole (equal and opposite charges separated by a distance d).
Sketch the magnetic field lines of (ii) a bar magnet and (iii) a single current-loop;

[2 marks]

(b) An electric dipole consists of charges $+q$ and $-q$, separated by a distance d, lying along the z-axis as shown.



(i) Obtain an expression for the electric field at the point P on the z axis, at a distance z from the centre of the dipole

(ii) Show that if $z >> d$ then your expression simplifies to

$$E = \frac{1}{4\pi\varepsilon_0}\frac{2p}{z^3}$$; where $p = qd$ is the dipole moment.

[3 marks]

(c) The magnetic field on the axis of a magnetic dipole of moment m, is similarly given by

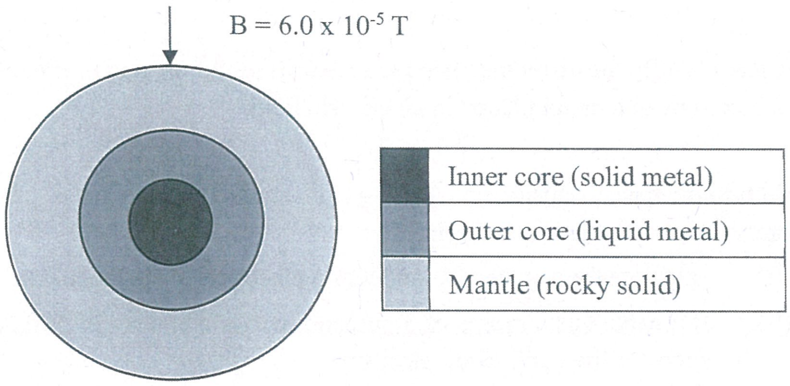
$$B = \frac{\mu_0}{4\pi}\frac{2m}{z^3}$$

The magnetic field at Earth's North Pole is vertically downwards, and has an intensity of 6.0 x 10^{-5} T.

(i) Calculate the moment of the magnetic dipole, placed at the centre of Earth and aligned with the rotation axis, that would produce this field.

A current I in a conducting loop of area A produces a magnetic field similar to that of a dipole of moment m, where $m = IA$.

(ii) Calculate the current flowing around the equator of Earth's outer core that would produce the observed field at the North Pole.



[3 marks]

(d) Which do you consider the more likely source of the geomagnetic field: a permanent dipole moment in the solid inner core or electric current in the liquid outer core? Explain your answer.

[2 marks]

[Radius of Earth = 6370 km; radius of Earth's outer core = 3480km]

4. Gauss's Law was given in lectures in the form

$$\oint_{\substack{closed\\surface}} \underline{E}.d\underline{A} = \frac{\sum_{enclosed} q}{\varepsilon_0}.$$

(a) Explain the meaning of each of the terms in this equation.

[2 marks]

(b) In 1911 Rutherford modelled the nucleus of an atom as a point positive charge $+Ze$, and the electrons as a negative charge of $-Ze$ uniformly distributed throughout a concentric sphere of radius R. Show that within such an atom the electric field varies with radius r as

$$E = \frac{Ze}{4\pi\varepsilon_0}\left(\frac{1}{r^2} - \frac{r}{R^3}\right)$$

[4 marks]

(c) In another classical model of the atom the electrons orbit the much more massive nucleus in circular orbits.

(i) If a hydrogen atom consists of a single electron of mass m_e orbiting a single proton at radius R, under the action of the electrostatic Coulomb force, show that the speed, v, of the electron is given by $v = \dfrac{e}{(4\pi\varepsilon_0 m_e R)^{1/2}}$.

(ii) By considering the electron as a current loop, obtain expressions for the current and the magnetic dipole moment, μ, of the current loop. Evaluate μ if R is equal to the Bohr radius, 5.3×10^{-11} m.

[4 marks]

5. (a) Explain briefly the difference between the drift speed, v_d, and thermal speed, v_{th}, of conduction electrons in a metal placed in an electric field.

[2 marks]

(b) Aluminium has a density of 2700 kg·m^{-3} and an atomic mass of 27.0. If each atom contributes one conduction electron,

(i) calculate the number of conduction electrons per cubic metre.

(ii) If a cable has a radius of 5 cm, and carries a current of 500 A, calculate the drift speed of the conduction electrons.

[4 marks]

(c) The electric resistivity of aluminium is 28.2×10^{-9} Ω·m. Calculate

(i) the resistance per kilometre of the cables described above;

(ii) the power loss per kilometre, when carrying 500 A; and

(iii) if the NZ distribution network comprises 12,000 km of such cables carrying an average of 500 A, calculate the total energy lost due to resistance in a year.

[4 marks]

6. The mass of a hot-air balloon and its cargo (not including the air inside) is 200 kg. The air outside is at 10.0 °C and 101 kPa. The volume of the balloon is 400 m^3, which is assumed to be *constant* in the following because of the strong stiffness of the balloon material. The air density at 10.0 °C is 1.24 kg m^{-3}.

   (a) Heating the air in the balloon will cause it to expand under the constant atmospheric pressure maintained at the opening at the bottom of balloon. Air will therefore be expelled through this opening while the balloon volume stays constant. Eventually, the balloon and its cargo will start lifting off. Draw a free-body force diagram that applies to the situation when the balloon is just starting to lift off and write down expressions for the acting forces in terms of relevant quantities. Derive a relation involving the inside-air ρ_{in} and outside-air density ρ_{out} for this situation.

   [4 marks]

   (b) Based on your knowledge of ideal-gas thermodynamics, obtain a relation between the inside and outside-air densities in terms of the inside and outside-air temperatures.

   [4 marks]

   (c) Use your results from (a) and (b) above to determine the temperature that the air in the balloon must be warmed to such that the balloon will start lifting off.

   [2 marks]

7. A glass window pane in a home is 0.62 cm thick and has dimensions 1.00 m × 2.00 m. On a certain day, the temperature of the interior surface of the glass is 25.0 °C and the exterior surface is at 0 °C.

   (a) Find the rate at which energy is transferred as heat through the glass via thermal *conduction*. (The thermal conductivity of glass is 0.8 W m^{-1} K^{-1}.)

   [3 marks]

   (b) Find the rate at which energy is transferred as heat through the glass via thermal *radiation*. Assume emissivities of all objects to be equal to 1.

   [3 marks]

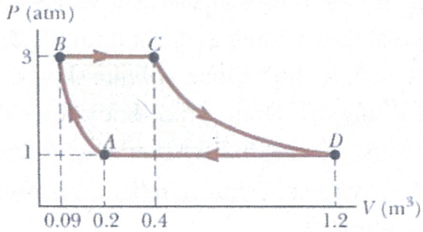
   (c) Determine how much energy in total (ie, via conduction and radiation combined) is transferred through the window in one day. (Assume the temperatures on the surfaces to remain constant during the day.)

   [2 marks]

   (d) Discuss by how much the daily energy loss through the window could be reduced by double-glazing it.

   [2 marks]

8. A sample of an ideal gas goes through the process shown in the figure below. From A to B, the process is adiabatic; from B to C, it is isobaric with 100 kJ of energy entering the system by heating; from C to D, the process is isothermal; and from D to A, it is isobaric with 150 kJ of energy leaving the system through cooling.



(a) What is the total change in internal energy experienced by the gas when undergoing the cycle *ABCDA*?

[2 marks]

(b) How is the total change in internal energy for the cycle *ABCDA* related to the changes in internal energy for the sub-processes *AB*, *BC*, *CD*, and *DA*?

[1 mark]

(c) Explain why the change in internal energy for this system is zero for sub-process *CD*.

[2 marks]

(d) Use the first law of thermodynamics to determine the changes in internal energy associated with sub-processes *BC* and *DA*. (Remember: 1 atm = 101 kPa.)

[3 marks]

(e) Use your results to find the change in internal energy experienced by the gas for the sub-process *AB*.

[2 marks]

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