No. 262

NEW ZEALAND QUALIFICATIONS AUTHORITY
MANA TOHU MĀTAURANGA O AOTEAROA

University Entrance, Bursaries and Scholarships Examination

PHYSICS: 2001

QUESTION BOOKLET

Time allowed: Three hours
(Total marks: 160)

This paper consists of 12 questions.

Answer **ALL** questions.

The total marks assigned to questions is 152. In addition to this, four marks will be awarded for correct use of significant figures and a further four marks will be awarded for correct use of units of measurement.

The questions are organised under the headings below, with allocations of marks and suggested times indicated.

Mechanics	Questions One to Three	52 marks	62 minutes
Waves	Questions Four to Six	29 marks	34 minutes
Electricity and Electromagnetism	Questions Seven to Ten	51 marks	60 minutes
Atomic and Nuclear Physics	Questions Eleven and Twelve	20 marks	24 minutes

Write your answers in the appropriate spaces in the printed Answer Booklet No. 262/1 (purple cover).

The front cover of the Answer Booklet has instructions for answering the questions.

Some useful formulae are given on page 17 of the Answer Booklet. This page is detachable.

Check that this booklet has all of pages 2 – 14 in the correct order and that none of these pages is blank.

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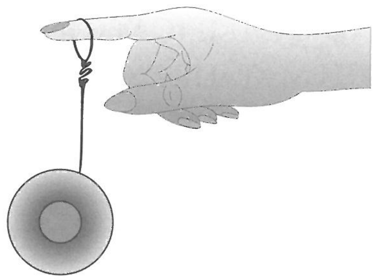
MECHANICS

(52 marks; 62 minutes)

QUESTION ONE: THE SPINNING YO-YO (14 marks)

Acceleration due to gravity = 9.80 m s^{-2}



Side view of the yo-yo

Helen is playing with a yo-yo that has a mass of 3.20×10^{-2} kg. The centre of the yo-yo, around which the string is wound, has a radius of 4.00×10^{-3} m. With one end of the string wrapped around her finger, which she keeps still, Helen allows the yo-yo to fall. The yo-yo drops with constant linear acceleration. After 1.40 seconds it has fallen 1.20 m and reached an angular velocity of 4090 revolutions per minute.

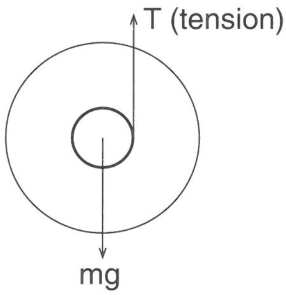
(a) How many radians per second is 4090 revolutions per minute? (2 marks)

(b) Show that during the fall of 1.20 m, the angle through which the yo-yo turns is 300 radians. (2 marks)

(c) Calculate the angular acceleration of the yo-yo during the fall. (2 marks)

(d) Show that the linear acceleration of the yo-yo during the fall of 1.20 m is 1.22 m s^{-2}. (2 marks)

The forces on the yo-yo are shown on the following diagram.



(e) Given that the tension T on the string is 0.274 N, show that the torque on the yo-yo is 1.10×10^{-3} N m. (2 marks)

(f) Calculate the rotational inertia of the yo-yo. (2 marks)

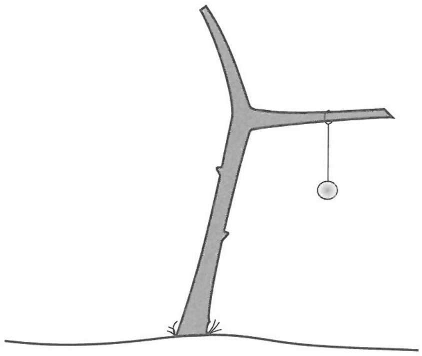
Helen has another yo-yo which is lighter but otherwise is identical.

(g) Will the rotational inertia of the lighter yo-yo be the same, more, or less than the original yo-yo? Explain your answer. (2 marks)

QUESTION TWO: LINEAR AND ROTATIONAL MOTION (21 marks)

Part 1: Collision Time

Helen went into the garden and hung her yo-yo from a tree as shown below.



Her little sister, Julie, was playing nearby with her toy pram. Julie lost control of the pram on a steep section of the lawn and it banged into the tree that had the yo-yo attached. Helen wondered about the physics of this situation.

The pram has a mass of 5.00 kg and just prior to impact it had a velocity of 7.30 m s^{-1}. After colliding with the tree it rebounded with a velocity of 2.10 m s^{-1} (in a direction opposite to the initial direction).

(a) Show that the initial momentum of the pram before impact was 36.5 kg m s^{-1}. (1 mark)

(b) Calculate the size of the change in momentum of the pram during this collision. (2 marks)

(c) Helen estimated the time the pram was in contact with the tree was 0.2 seconds. Based on Helen's estimate, calculate the average force exerted on the pram due to this collision. (2 marks)

(d) If the pram had been made of softer material, would the average force have been greater or less? Explain. (2 marks)

(e) Show, using calculations of the kinetic energy, that the pram lost energy in the collision. (2 marks)

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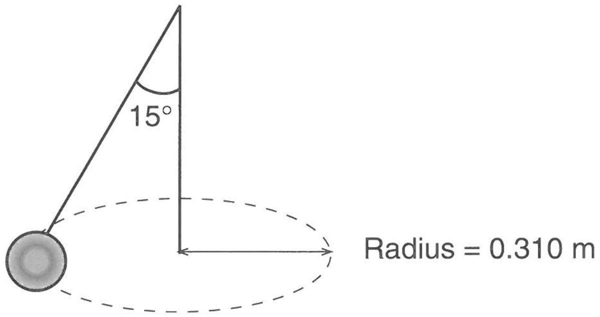
Part 2: The Conical Pendulum

Acceleration due to gravity = 9.80 m s^{-2}

After the collision with the tree, Helen observed that her yo-yo made a horizontal circular path of radius 0.310 m as in the diagram below.

Mass of yo-yo = 3.20×10^{-2} kg.



(a) On the diagram in your Answer Booklet, draw labelled vectors to show the tension and weight forces acting on the yo-yo. (2 marks)

(b) On the diagram in your Answer Booklet, show the direction of the centripetal force acting on the yo-yo. (1 mark)

Helen times the motion and finds that the period of this motion is 2.16 seconds.

(c) Show that the frequency of revolution is 0.463 Hz. (2 marks)

(d) Calculate the linear speed of the yo-yo as it goes round the circle. (2 marks)

(e) Show that the centripetal force on the yo-yo is 0.0839 N. (2 marks)

(f) Calculate the tension in the string. (3 marks)

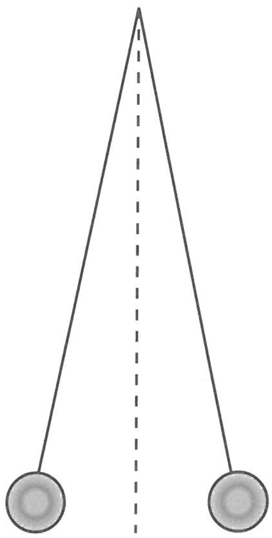
QUESTION THREE: SIMPLE HARMONIC MOTION (17 marks)

Helen took the yo-yo and set it swinging like a simple pendulum. She measured the amplitude in the horizontal direction and found it to be 0.100 m. She then measured the period and found it to be 2.20 seconds.

Mass of yo-yo = 3.20×10^{-2} kg

(a) Show that the angular frequency of this pendulum was 2.86 rad s^{-1}. (2 marks)

Helen released the pendulum from position **A** at time t = 0 seconds.



(b) Whereabouts in the motion does the pendulum have maximum acceleration? (1 mark)

(c) Show that the maximum velocity of the pendulum is 0.286 m s^{-1}. (2 marks)

(d) By considering conservation of energy, calculate the potential energy of the pendulum at position **C**, one of the points of maximum displacement. (3 marks)

(e) The reference circle in your Answer Booklet shows the position **P** of the pendulum after 1.00 seconds. Calculate the horizontal distance of the pendulum from the centre of its swing at this time using the reference circle. (3 marks)

(f) On the axes provided in your Answer Booklet, sketch, for the first complete cycle following release of the pendulum (from position **A** at time t = 0 seconds), the graphs of:

(i) velocity against time

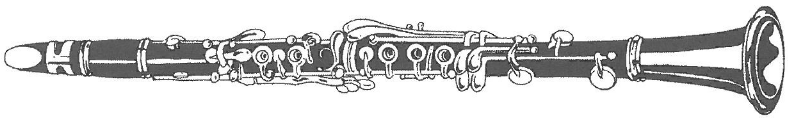
(ii) acceleration against time.

On the vertical axes, include appropriate maximum values and, on the time axis, the period value. (6 marks)

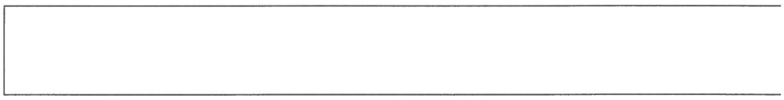
WAVES

(29 marks; 34 minutes)

QUESTION FOUR: THE ORCHESTRA (14 marks)



A clarinet can be modelled as a pipe closed at one end, as shown below.



Helen plays the clarinet and is a member of a local orchestra. The clarinet can be considered as a closed pipe in which standing waves are produced. Helen's clarinet is 0.660 m long. The speed of sound in air is 3.30×10^2 m s^{-1}.

(a) In your Answer Booklet, sketch the fundamental standing wave (showing particle displacement) produced when the clarinet is played. Label all nodes (N) and antinodes (A). (3 marks)

(b) Calculate the wavelength of this wave. (2 marks)

(c) State whether the sound heard by members of the audience is a transverse or longitudinal wave. (1 mark)

Helen can produce the 3rd harmonic without changing the length of the air column.

(d) (i) In your Answer Booklet, sketch this standing wave. (1 mark)

(ii) Calculate the frequency of the 3rd harmonic. (3 marks)

Helen's friend David also plays the clarinet in the orchestra. When they both played the same note on their clarinets, they heard beats. After some investigating they found that the note heard from Helen's clarinet had a frequency of 440 Hz, while the note heard from David's clarinet had a frequency of 430 Hz.

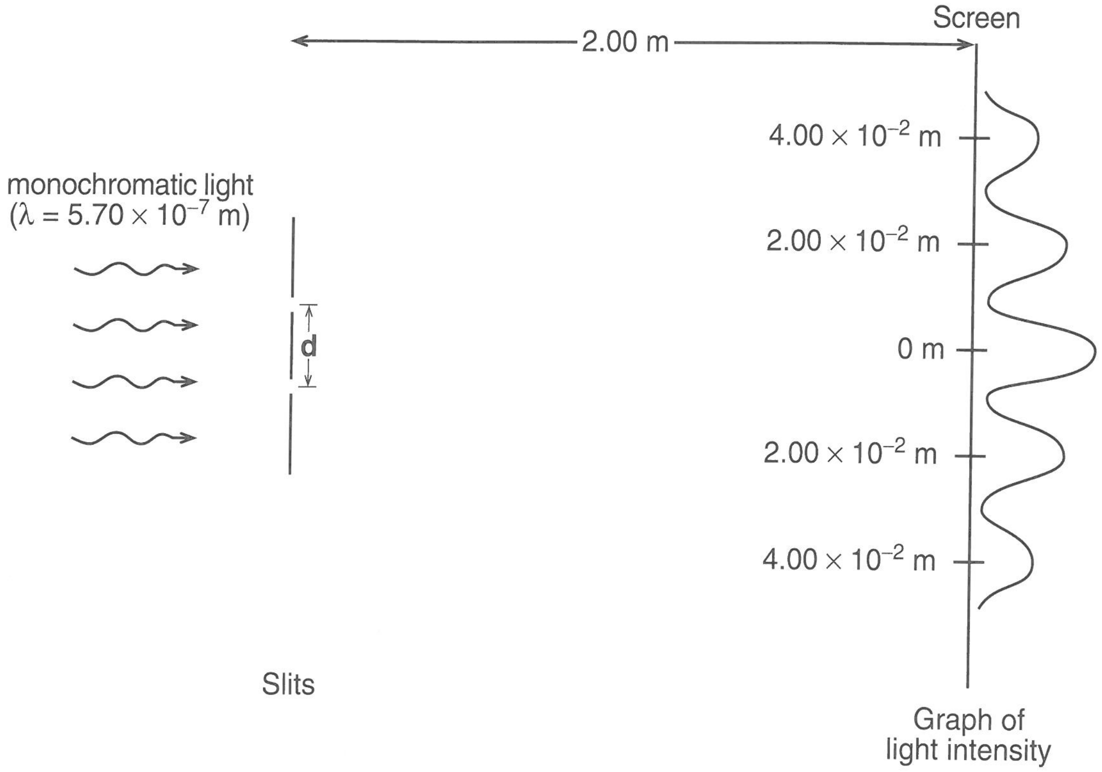
(e) Which clarinet is the shorter? Explain. (3 marks)

(f) Calculate the frequency of the beats. (1 mark)

QUESTION FIVE: INTERFERENCE (9 marks)

Speed of light = 3.00×10^{8} m s^{-1}

The diagram below shows the light intensity pattern produced when monochromatic light is incident on two slits separated by a distance, **d**. The incident light has a wavelength of 5.70×10^{-7} m. The distance from the slits to the screen is 2.00 m. The distance between adjacent maxima seen on the screen is 2.00×10^{-2} m.



(a) What is meant by the term **monochromatic**? (1 mark)

(b) Show that the frequency of the incident light is 5.26×10^{14} Hz. (2 marks)

(c) Show that **d**, the separation of the slits, is 5.70×10^{-5} m. (3 marks)

(d) The wavelength of light is now increased to 6.33×10^{-7} m. Calculate the distance between two adjacent maxima using this new wavelength. (2 marks)

(e) What would be the effect on the distance between adjacent maxima if the distance between the screen and the slits was decreased? (1 mark)

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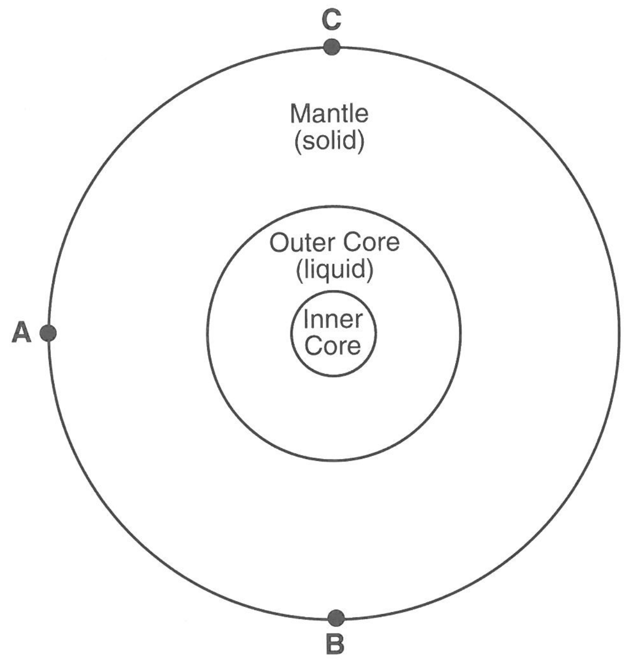
QUESTION SIX: EARTHQUAKES (6 marks)

The diagram below (not drawn to scale) represents a simple model of the Earth. It is known that the mantle is solid and that the outer core is liquid.

An earthquake occurs at **C** and is recorded at points **A** and **B** on the Earth's surface. (All points **A**, **B** and **C** lie on a plane through the centre of the Earth).

The distance in a straight line between **C** and **A** is 8.10×10^6 m.



Earthquakes generate p (longitudinal) and s (transverse) waves. It is known that s waves travel only through solids, whereas p waves travel through solids, liquids and gases.

(a) Describe the difference between these two types of waves. (Include diagrams if necessary).
(2 marks)

(b) Assuming that the waves travel in straight lines from **C** towards **A** and from **C** towards **B**, what types of waves (s and/or p) are recorded at:

(i) **A**?

(ii) **B**?
(2 marks)

(c) Assuming the p wave travels at 11.0×10^3 m s^{-1}, calculate the time taken for this wave to go from **C** to **A**.
(2 marks)

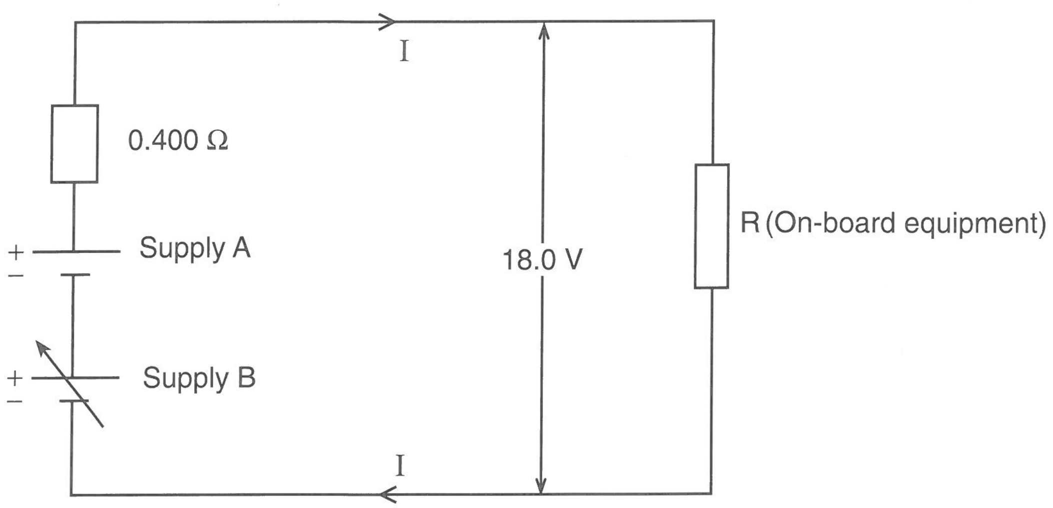
ELECTRICITY AND ELECTROMAGNETISM

(51 marks; 60 minutes)

QUESTION SEVEN: DC ELECTRICITY (13 marks)

Part of the power system of an aircraft has to provide a constant 18.0 V for the on-board equipment. This is independent of the current drawn by that equipment.

One way to achieve this is to use two separate power supplies, A and B, connected in series as shown.



Power Supply A is set at 20.0 V. In series with it there is a resistance of 0.400 ohms.

Power Supply B varies automatically to maintain the constant 18.0 V supplied to the on-board equipment.

The on-board equipment has a total resistance R. With this resistance connected across the power supplies, the current drawn, I, is 11.0 A.

(a) Calculate the voltage across the resistance of 0.400 ohms. (2 marks)

(b) Show that the total resistance, R, of the on-board equipment is 1.64 ohms. (2 marks)

(c) Calculate the power supplied to the on-board equipment. (2 marks)

(d) Calculate the power used in heating the resistance of 0.400 ohms. (2 marks)

(e) Show that the voltage output required of Supply B is 2.40 V. (3 marks)

(f) Explain why the voltage output of Supply B must increase if the current supplied to the on-board equipment increases. (2 marks)

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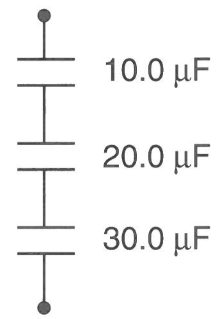
QUESTION EIGHT: CAPACITORS (10 marks)

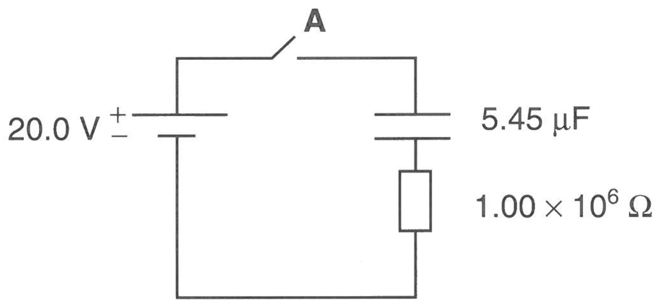
In her physics class, Helen wired three capacitors in series, as shown below.

$1\ \mu F = 1 \times 10^{-6}$ F



(a) Show that the above combination of capacitors is equivalent to one capacitor of value 5.45 μF. (2 marks)

Helen decided to connect this combined capacitor with a 20.0 V power supply and a $1.00 \times 10^6\ \Omega$ resistor as shown in the diagram below.



Helen closed switch **A** at time t = 0 seconds.

(b) Calculate the time constant for this circuit. (2 marks)

(c) On the axes provided in your Answer Booklet, sketch graphs of:

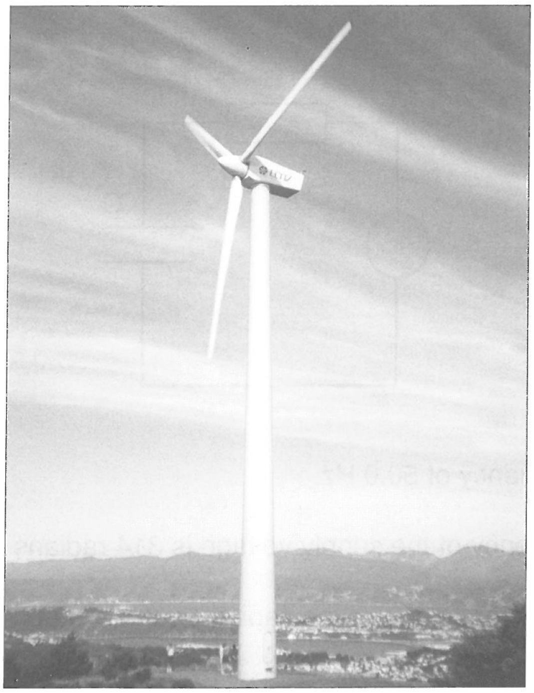
(i) current through the **resistor** against time after the switch is closed (2 marks)

(ii) voltage across the 5.45 μF **capacitor** against time after the switch is closed. (2 marks)

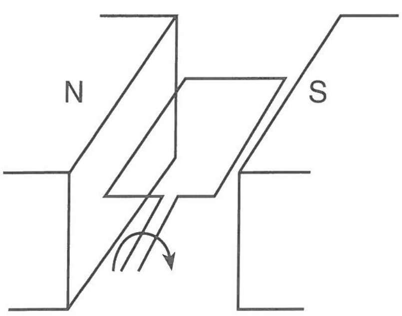
Indicate the values of any intercepts and asymptotes.

(d) Calculate the energy stored in the combined capacitor when it is fully charged. (2 marks)

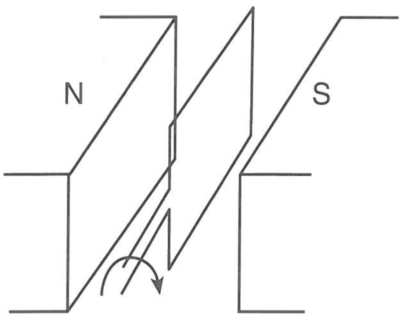
QUESTION NINE: THE WIND TURBINE (10 marks)



Wind turbine generators are used in various places in New Zealand to generate electricity. A model of a simple generator is shown below. (Only one loop of wire is shown for simplification.)



Position **A**



Position **B**

The magnets produce a uniform magnetic field of 0.250 T. The area of the loop in the magnetic field is $1.00 \times 10^{-2}\,m^2$.

(a) At which position, **A** or **B**, is the magnetic flux through the coil maximum? (1 mark)

(b) Calculate the maximum magnetic flux through the coil. (2 marks)

The actual generator coil used has 500 turns of wire and is rotating at a frequency of 1.00×10^2 Hz.

(c) Calculate the angular frequency of the coil. (2 marks)

(d) Show that the maximum voltage (ie peak voltage) produced by the coil is 785 V. (3 marks)

(e) Calculate the rms voltage produced. (2 marks)

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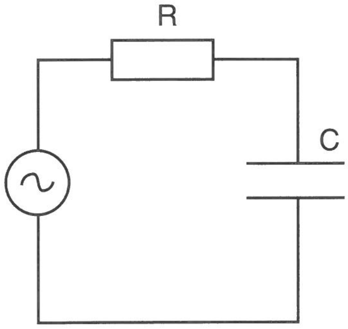
QUESTION TEN: AC THEORY (18 marks)

Helen constructed the following RC series circuit.



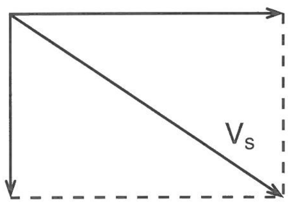
R = 12.0 ohms
C = 1.20×10^{-4} F
Supply voltage = 16.0 V rms

The AC supply operated at a frequency of 50.0 Hz.

(a) Show that the angular frequency of the supply voltage is 314 radians per second. (2 marks)

(b) Show that the capacitive reactance, X_C, of the capacitor at the supply frequency of 50.0 Hz is 26.5 Ω. (2 marks)

The phasors indicating the voltage across the resistor, capacitor and supply (V_s) are shown in the diagram below.



(Not drawn to scale.)

The same diagram is in your Answer Booklet.

(c) Clearly label the diagram in your Answer Booklet to show which phasor is the voltage across the resistor, V_R, and which phasor is the voltage across the capacitor, V_C. (1 mark)

(d) Calculate the impedance, Z, of the above RC series circuit. (2 marks)

(e) Show that the rms current flowing in the series circuit is 0.550 A. (2 marks)

(f) Calculate the rms voltage across the:

(i) resistor (2 marks)

(ii) capacitor. (2 marks)

(g) If the frequency of the AC supply is decreased, explain what will happen to the:

(i) reactance of the capacitor (1 mark)

(ii) voltage across the resistor. (2 marks)

(h) What is the phase angle (in degrees) between the voltage across the capacitor and the supply voltage (at 50.0 Hz)? (2 marks)

ATOMIC AND NUCLEAR PHYSICS

(20 marks; 24 minutes)

QUESTION ELEVEN: ATOMIC PHYSICS (10 marks)

Planck's constant = 6.63×10^{-34} J s

X-rays are used widely in hospitals to help in diagnosing illnesses. The main method of absorption of X-rays is the photoelectric effect.

X-rays of a frequency 1.05×10^{19} Hz can be used to form an image of a bone.

(a) Show that the X-ray photon energy is 6.96×10^{-15} J. (2 marks)

The energy required to free a tightly-bound electron from a calcium atom (found in the bone) is 9.61×10^{-16} J.

(b) Calculate the maximum kinetic energy with which one of these electrons is emitted from a calcium atom. (2 marks)

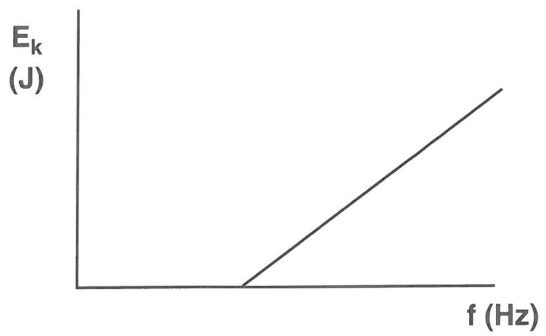
Photoelectrons can also be released when light falls on a metal surface.
Experiments show that light that has a frequency below a certain threshold frequency will not release photoelectrons.

(c) Explain, with the aid of an equation, why photoelectrons are not released unless the frequency of the light is above a threshold frequency. (2 marks)

Experiments also show that the kinetic energy of the released photoelectrons only depends on the frequency of the incident light, not on the intensity of the light.

(d) Explain how this result supports a particle model of light. (2 marks)

The graph below shows how the kinetic energy, E_k, of released photoelectrons changes with the frequency, f, of the light incident on one particular metal.



(e) By adding a second line to the graph in your Answer Booklet, show how the kinetic energy of another metal with a smaller work function changes with the frequency of the incident light. (2 marks)

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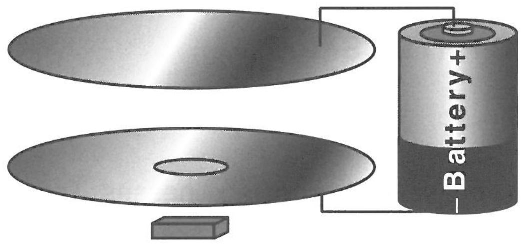
QUESTION TWELVE: NUCLEAR PHYSICS (10 marks)

Speed of light = 3.00×10^{8} m s^{-1}



Americium-241

Simplified diagram of a smoke detector

Part 1: The Smoke Detector

The main component of a household smoke detector is a very tiny amount of Americium-241. This element was discovered about 50 years ago during the Manhattan Project. Americium-241 can be formed from the decay of Plutonium-241.

This decay is shown below.

$$^{241}_{94}\text{Pu} \rightarrow {}^{241}_{95}\text{Am} + {}^{b}_{a}\text{X} + \text{energy}$$

(a) State the values of a and b. (2 marks)

(b) Name the particle X. (1 mark)

Americium-241 found in smoke detectors undergoes alpha decay. The following equation represents this decay process.

$$^{241}_{95}\text{Am} \rightarrow {}^{237}_{93}\text{Np} + {}^{4}_{2}\text{He} + \gamma$$

Use the following data to answer questions (c) and (d) below.

Rest mass of $^{237}_{93}\text{Np} = 3.9360161 \times 10^{-25}$ kg.

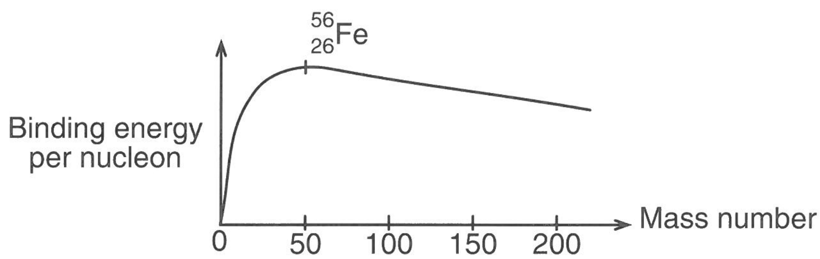
Rest mass of $^{241}_{95}\text{Am} = 4.0025778 \times 10^{-25}$ kg.

Rest mass of $^{4}_{2}\text{He} = 0.0664604 \times 10^{-25}$ kg.

(c) Show that the mass deficit in this reaction is 1.013×10^{-29} kg. (2 marks)

(d) Calculate the energy released in joules. (2 marks)

Part 2: Binding Energy



(e) Explain, using the above graph, why large mass nuclei (mass numbers around 200) are less stable than nuclei of mass numbers around 50. (3 marks)