No. 262

NEW ZEALAND QUALIFICATIONS AUTHORITY
Mana Tohu Matauranga o Aotearoa

University Entrance, Bursaries and Scholarships Examination

PHYSICS: 1998

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 measurements.

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

Mechanics	Questions One to Four	52 marks	62 minutes
Electromagnetism	Questions Five to Eight	47 marks	56 minutes
Waves	Questions Nine and Ten	30 marks	36 minutes
Atomic and Nuclear	Questions Eleven and Twelve	23 marks	26 minutes

Check that this Question Booklet contains pages 2 – 16 in the correct order.

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

Page one 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.

YOU MAY KEEP THIS BOOKLET AT THE END OF THE EXAMINATION

(Turn over

MECHANICS

(52 marks; 62 minutes)

THE RECORD PLAYER

QUESTION ONE: ROTATIONAL MOTION (11 marks)

People used to listen to music played from vinyl records on turntables. John found a turntable in a second-hand shop and turned it on. He watched very carefully and saw that from a standing start it accelerated uniformly at 0.94 rad s^{-2} for the first 5.0 seconds until it was finally rotating clockwise at a constant 45 revolutions per minute.

(a) Show that 45 revolutions per minute is an angular velocity of 4.7 radians per second. (2 marks)

(b) Calculate the angle turned through during the start up period of 5.0 s. (2 marks)

The turntable had a radius of 0.15 m and there was a dead fly resting on the surface at the edge.

(c) Calculate the linear speed of the fly on the turntable when the constant rotational speed had been reached. (2 marks)

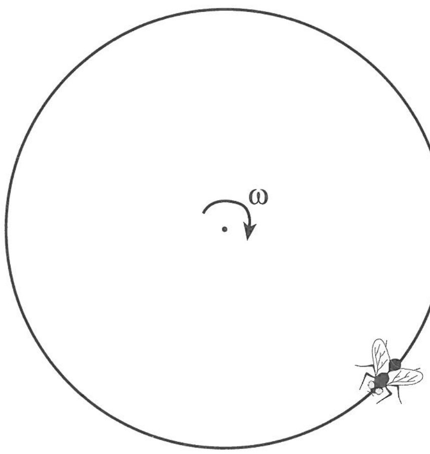
(d) Describe the direction of motion of the fly, if the rotational speed causes it to slip off the turntable. (1 mark)

(e) (i) On the diagram in your Answer Booklet, draw the direction of the horizontal force acting on the fly during the period of constant speed. (1 mark)

(ii) What name is usually given to this force? (1 mark)

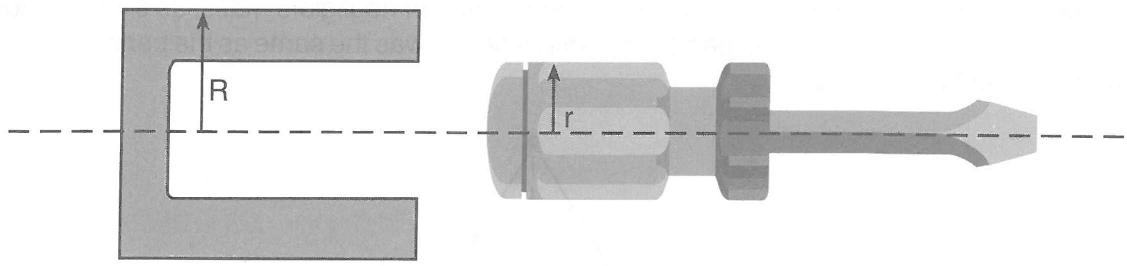
John then turned the power off and calculated from the stopping time that the angular deceleration was 3.0 rad s^{-2}.

(f) Calculate the time it took for the turntable to stop. (2 marks)



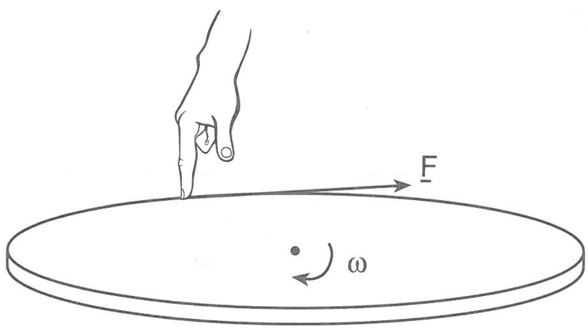
QUESTION TWO: TORQUES AND ANGULAR MOMENTUM (12 marks)

John purchased the old turntable and took it home. He wanted to unscrew the back to see how it worked but the screws were old and stuck fast. His father suggested that John borrow his **torque amplifier**, a plastic cylinder which fitted over the screwdriver handle. The cylinder was slotted onto the screwdriver handle so that the two objects rotated together without any slippage.



(a) Explain, with the help of an equation, how such a device might work to help free the screws. (2 marks)

John then wanted to measure the rotational inertia of the turntable. He assumed that the turntable was a frictionless rotating table of radius 0.15 m. He pushed with his finger at the edge of the turntable in a tangential way, as shown below, and watched the turntable begin to rotate (it was not connected to its motor at this stage). He was able to move his arm around with the turntable as he applied a constant 0.60 N tangential force for 2.0 s. The turntable accelerated constantly for those 2.0 s, finally reaching a constant angular velocity of 4.0 rad s^{-1}.



(b) Calculate the angular acceleration of the system during that 2.0 s period. (2 marks)

(c) Show that the torque acting on the turntable during that 2.0 s period was 0.090 N m. (2 marks)

(d) What was the rotational inertia of the turntable? (2 marks)

(e) When the turntable was rotating at a constant 45 revolutions per minute (4.7 rad s^{-1}), what angular momentum did it have? (2 marks)

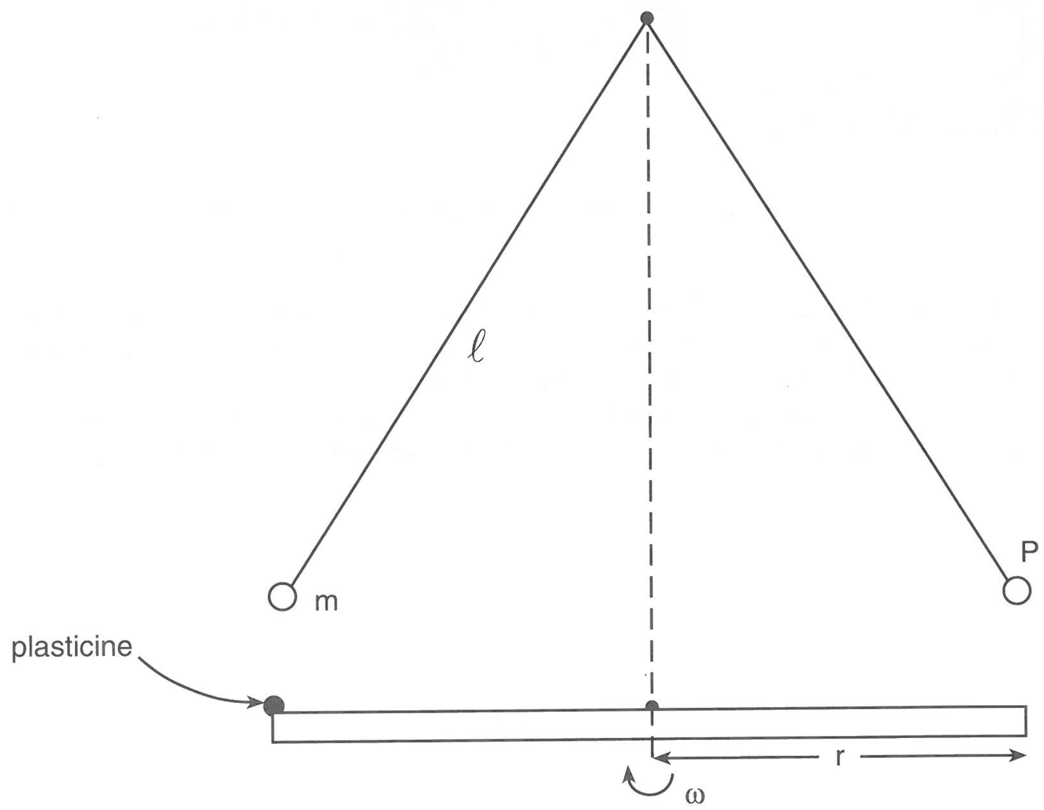
(f) (i) If the turntable was truly frictionless, rotating at constant angular velocity, and an extra mass, such as a record (not rotating), was dropped onto it, what quantity would be conserved? (Note, it is still not connected to a motor.) (1 mark)

(ii) What effect would the extra mass have on the angular velocity (ie an increase, decrease or no change)? (1 mark)

QUESTION THREE: SIMPLE HARMONIC MOTION (14 marks)

Acceleration due to gravity, $g = 9.8 \text{ m s}^{-2}$

When John was watching the turntable rotating with constant angular velocity, it occurred to him that any particular point at the rim would be (approximately) describing simple harmonic motion (SHM), if viewed from the side. To check this he attached a small lump of plasticine to the edge of the turntable (at the radius of 0.15 m), and hung a simple pendulum (small mass of 100 g, string of negligible mass, as shown below) above the turntable. He adjusted the length of the pendulum until its period was the same as the period of the turntable. He measured the period to be 1.3 s.



(a) Calculate the length of string he used. (3 marks)

(b) Show that for a period of 1.3 s the angular velocity of the turntable was 4.8 rad s^{-1}. (2 marks)

(c) Calculate the maximum velocity of the pendulum mass. (2 marks)

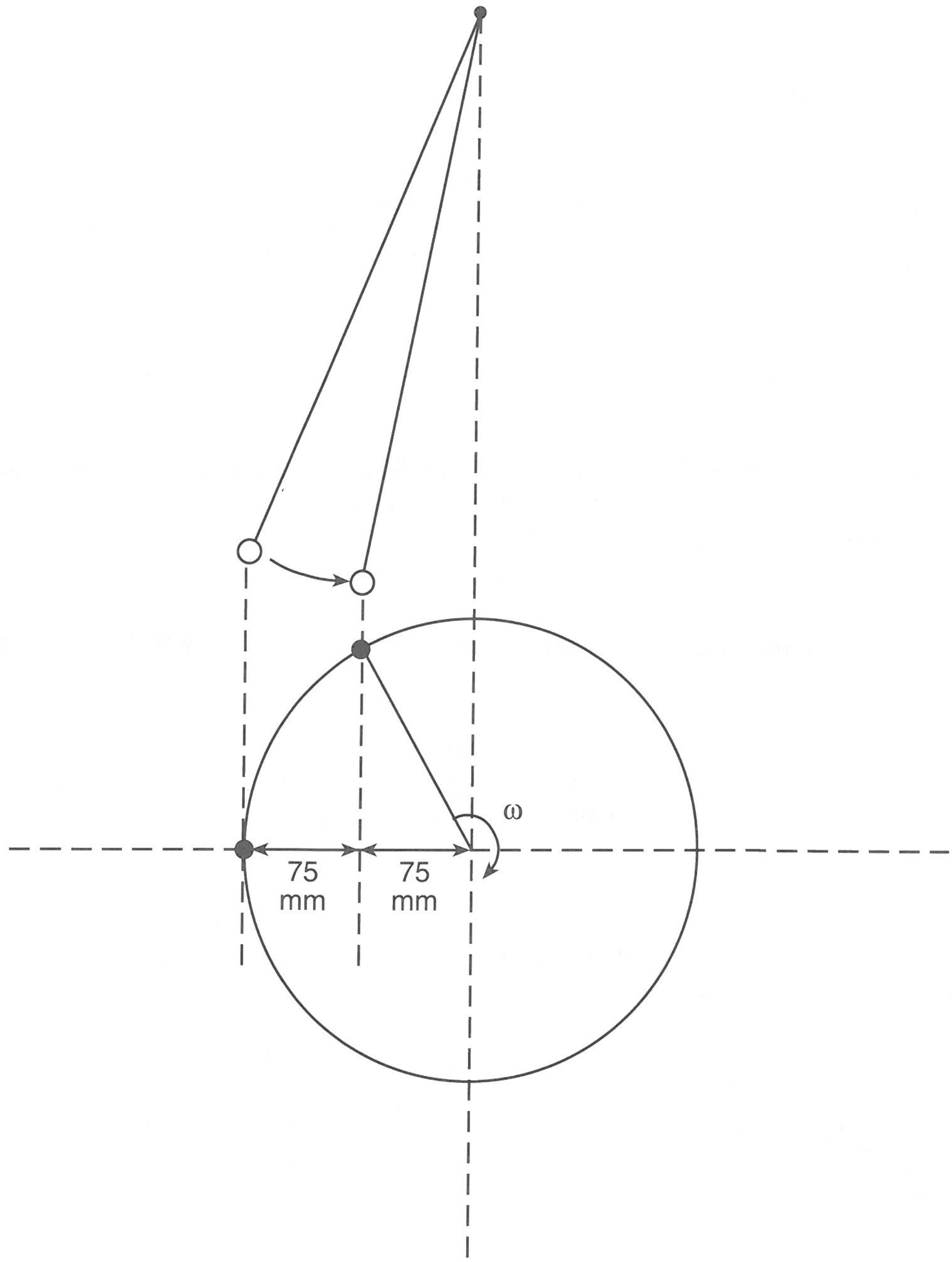
(d) At what point in the motion of the pendulum did maximum velocity occur? (1 mark)

(e) Indicate on the diagram in your Answer Booklet, the direction of the acceleration of the mass at the point marked P (the point of maximum displacement from equilibrium). (1 mark)

(f) Assuming no friction, is there a point in the motion of the pendulum where the total energy is a maximum (ie yes or no)? (1 mark)

(g) While the pendulum swings, its energy is interchanging between two major forms. What are they? (1 mark)

(h) John said he could use the reference circle technique to answer any SHM problem. Janet challenged him to find out how long the pendulum took to travel from its position of maximum displacement to half way in toward the centre position (ie 0.075 m inward), as in the diagram below. Use the reference circle in your Answer Booklet to show how John calculated that time interval. (3 marks)



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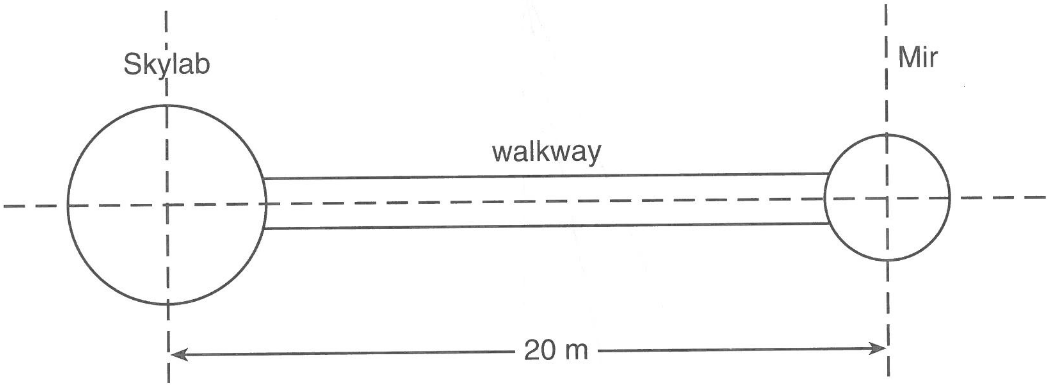
QUESTION FOUR: GRAVITY (15 marks)

Mass of Earth = 6.0×10^{24} kg
Radius of Earth = 6.4×10^{6} m
Mass of moon = 7.3×10^{22} kg
Universal gravitational constant = 6.7×10^{-11} N m^2 kg^{-2}
Acceleration due to gravity at sea level on Earth = 9.8 m s^{-2}



If the Russian space station **Mir** and the US space station **Skylab** were to dock in **deep space**, they could be considered as two small spheres with their centres of mass separated by 20 m (as in the diagram above). Assume the walkway connecting the two has negligible mass.
(Mass of Mir = 2.0×10^4 kg and mass of Skylab = 7.0×10^4 kg.)

(a) (i) Calculate the force of attraction between Mir and Skylab due **only** to their gravitational attraction to each other. (2 marks)

(ii) Thruster rockets are used to separate Mir and the Skylab at the end of the mission. Is the force due to their gravitational attraction large enough to affect the power the thruster rockets must have in order to separate them? Explain your answer by comparing this force of attraction with some common force you know. (2 marks)

It is 3.8×10^8 m from the centre of the Earth to the centre of our moon, if we assume that the moon is in a circular orbit around the Earth. With that radius the linear orbital speed of the moon is 1016 m s^{-1}.

(b) (i) Calculate the centripetal acceleration of the moon about the Earth. (2 marks)

(ii) Calculate the acceleration due to the Earth's gravity of an object 60 Earth radii away from the Earth (380,000 km is ~ 60 Earth radii). Explain any connection between this acceleration value and your answer to (b) (i). (3 marks)

A new satellite is placed in a geostationary orbit above the equator, meaning that it rotates with the Earth so as to have the same period (T = 24 hours = 86,400 s). The radius of the orbit of the satellite is R.

(c) (i) By considering the distance the satellite travels each orbit, write an expression for the speed of the satellite in terms of R. (2 marks)

(ii) By equating the gravitational attraction between Earth and the satellite to the centripetal force which keeps the satellite in orbit, write another expression for the speed of the satellite in terms of R. (2 marks)

(iii) By equating the two expressions from (i) and (ii) calculate the radius of the orbit of the satellite. (2 marks)

ELECTROMAGNETISM

(47 marks; 56 minutes)

THE TELEVISION SET

QUESTION FIVE: ELECTRONS (12 marks)

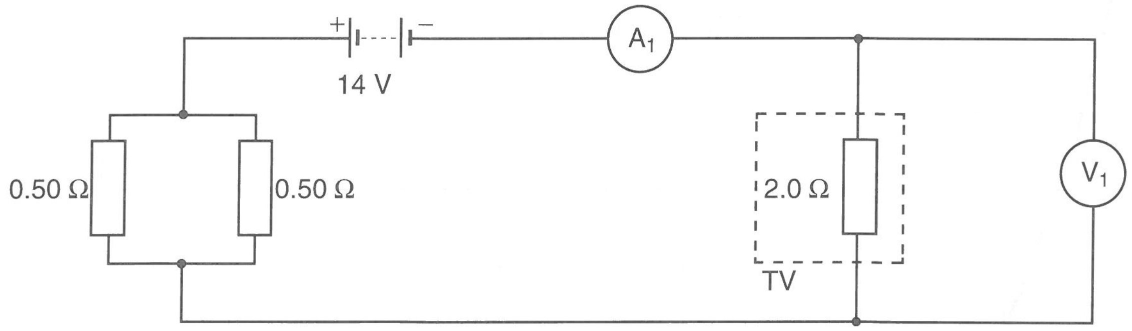
Mass of an electron = 9.1×10^{-31} kg
Charge on an electron = 1.6×10^{-19} C
Speed of light = 3.0×10^{8} m s^{-1}

John had a portable TV which had a label indicating that it would operate from a 12 V DC supply and consume 72 W of power.

(a) (i) What current did it draw? (1 mark)

(ii) Show that the effective total resistance of the set was 2.0 Ω. (2 marks)

John wired it up as in the circuit below (since he only had a 14 V DC supply).

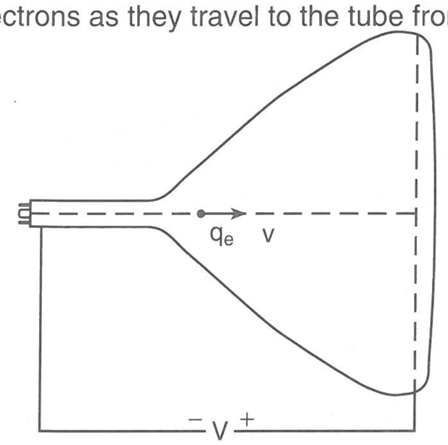


(b) (i) Determine the effective total resistance of the circuit. (2 marks)

(ii) What current will ammeter A_1 read? (2 marks)

(iii) What voltage will voltmeter V_1 read? (2 marks)

In the tube of a television, electrons are generated at the neck and accelerated towards a large positive voltage at the tube front, as shown below. In some colour televisions the accelerating voltage for the electrons is V = 27,000 volts. The work done on electrons as they travel to the tube front is $V \times q_e$.



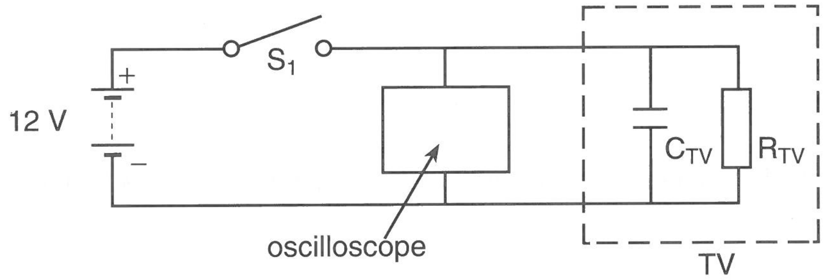
(c) (i) By equating the work done on the electrons to the kinetic energy they gain, derive an equation for the velocity of the electrons at the front of the tube. (2 marks)

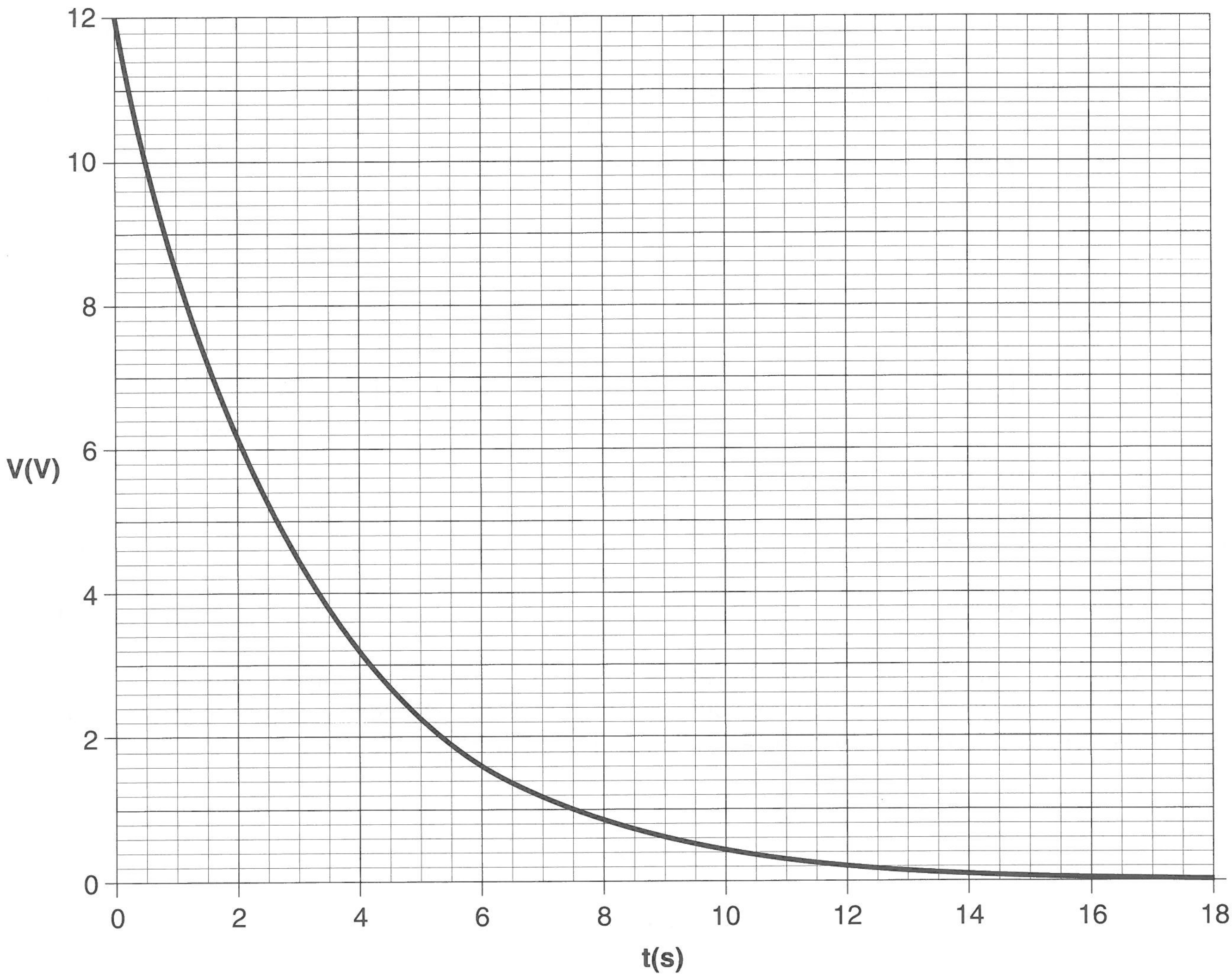
(ii) Calculate the velocity of the electrons. (1 mark)

(Turn over

QUESTION SIX: CAPACITORS (14 marks)

One day Janet turned off the 12 V DC electricity supplying **her** portable TV and she noticed that the screen took some time to finally go dark and the sound some time to go off. She assumed there must be a large capacitor in the TV power supply somewhere. She connected an oscilloscope across the 12 V supply at the TV, as in the diagram below. When she disconnected the battery she watched as the voltage decreased with time, as in the graph below.



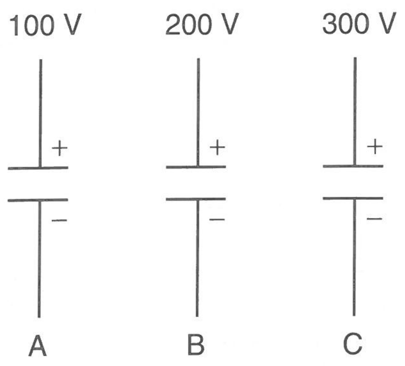


(a) Using the graph, explain why the time constant of this capacitive system is 3.0 seconds. (2 marks)

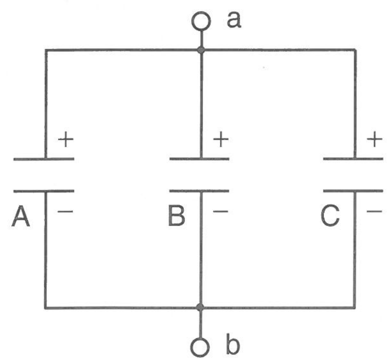
(b) If the resistance of Janet's TV was 22 Ω, what was the capacitance value for Janet's TV? (2 marks)

(c) Explain, in terms of charge (electrons), why increasing the value of the capacitor in Janet's TV would make the time it takes for the TV to go off even longer. (2 marks)

As shown in the left figure below, three 1.0 μF (1.0×10^{-6} F) capacitors are separately charged to 100, 200 and 300 volts, respectively.



1.0×10^{-6} F each



(d) Calculate the charge stored in capacitor A. (2 marks)

When the capacitors are then connected in parallel, as shown above on the right, the **total** charge stored is 600 μC (6.0×10^{-4} C).

(e) Calculate the total capacitance of the three capacitors when connected in parallel. (2 marks)

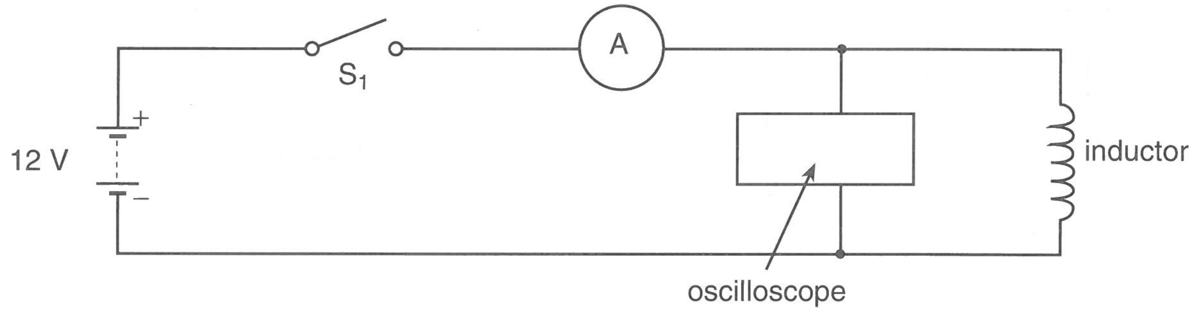
(f) Calculate the voltage, V_{ab}, across the combination. (2 marks)

(g) Calculate the total energy stored by the capacitor combination. (2 marks)

(Turn over

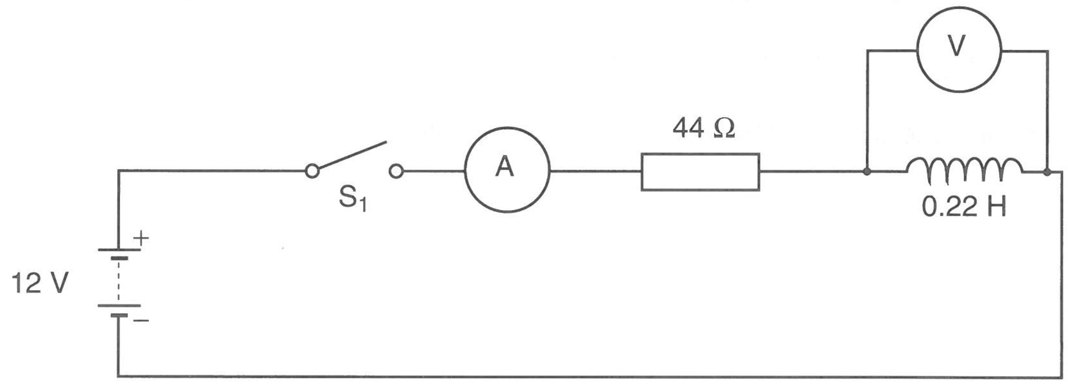
QUESTION SEVEN: INDUCTANCE (10 marks)

John's friend gave him a large coil (inductor) which had unknown inductance, L, and he asked John to determine the value of the inductance for him. Using an oscilloscope and an ammeter, John found that when connected to a 12 V DC supply, the steady state current drawn by the coil was 5.0 A. When the inductor was switched off the current dropped to approximately zero in 0.012 s. During this time an e.m.f. (voltage) of 410 V was induced across the inductor.



(a) Calculate the inductance of the inductor. (2 marks)

(b) Calculate the energy stored in the inductor when the steady state current was flowing. (2 marks)



(c) Sketch the current and voltage curves in your Answer Booklet for the **different** (ideal) inductor of 0.22 H shown in the circuit above after the switch is closed, ie at turn-on. Indicate the values of any intercepts and asymptotes you assign. You do **not** need to calculate any values for the time axes. (5 marks)

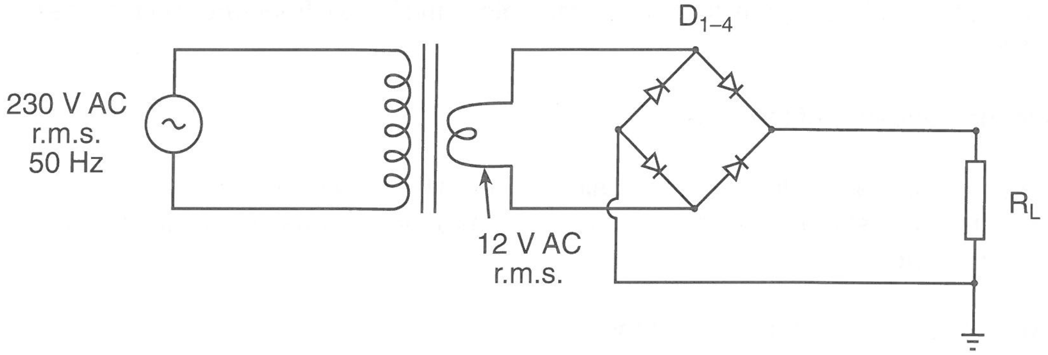
(d) What will be the approximate voltage across the inductor after 0.5 s? (Assume zero internal resistance.) (1 mark)

QUESTION EIGHT: AC ELECTRICITY (11 marks)

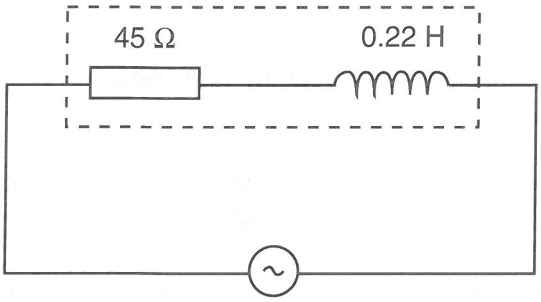
Janet's portable TV could also run off 230 V AC electricity. Her teacher had said there must be a transformer inside that outputs a lower voltage AC, which is then rectified to produce DC electricity.

(a) The primary windings of a similar transformer have 500 turns and run off 230 V AC r.m.s. and the secondary windings produce 12 V AC r.m.s. How many turns do the secondary windings have? (2 marks)

(b) Consider the full-wave bridge rectification circuit below. On the diagram in your Answer Booklet, sketch a graph of voltage across the resistor against time. Indicate the maximum voltage value on your graph and at least one time value. (3 marks)



In the LR series circuit shown below, the inductor has an inductance of 0.22 H and a resistance of 45 Ω. The voltage source is 230 $V_{r.m.s.}$ AC at 50 Hz.



$V_{r.m.s.}$ = 230 V, 50 Hz

(c) (i) Calculate the inductive reactance, X_L, of the inductor, at 50 Hz. (2 marks)

(ii) Calculate the impedance, Z, of the resistor-inductor combination. (2 marks)

(iii) Calculate the r.m.s. current which flows in this circuit. (2 marks)

(Turn over

WAVES

(30 marks; 36 minutes)

QUESTION NINE: SOUND (14 marks)

Velocity of sound in dry air = 331 m s^{-1}.

One day in his physics class, John pulled his pen to bits. What he was left with was a hollow plastic cylinder, open at the top end and closed at the bottom. It was 0.120 m long and had a 0.0050 m internal diameter. He blew across the top end and made a note of a certain frequency.

(a) Show, with the aid of a diagram, that the wavelength of the lowest frequency note made by the pen-whistle was 0.480 m. (2 marks)

(b) Calculate the frequency of the note. (2 marks)

Janet, who was in the same class, made a similar pen-whistle with a different length, which produced a 1000 Hz note. After class she blew it while running towards John, who was standing still. What John heard was actually a 1010 Hz note.

(c) With what velocity did Janet run towards John? (3 marks)

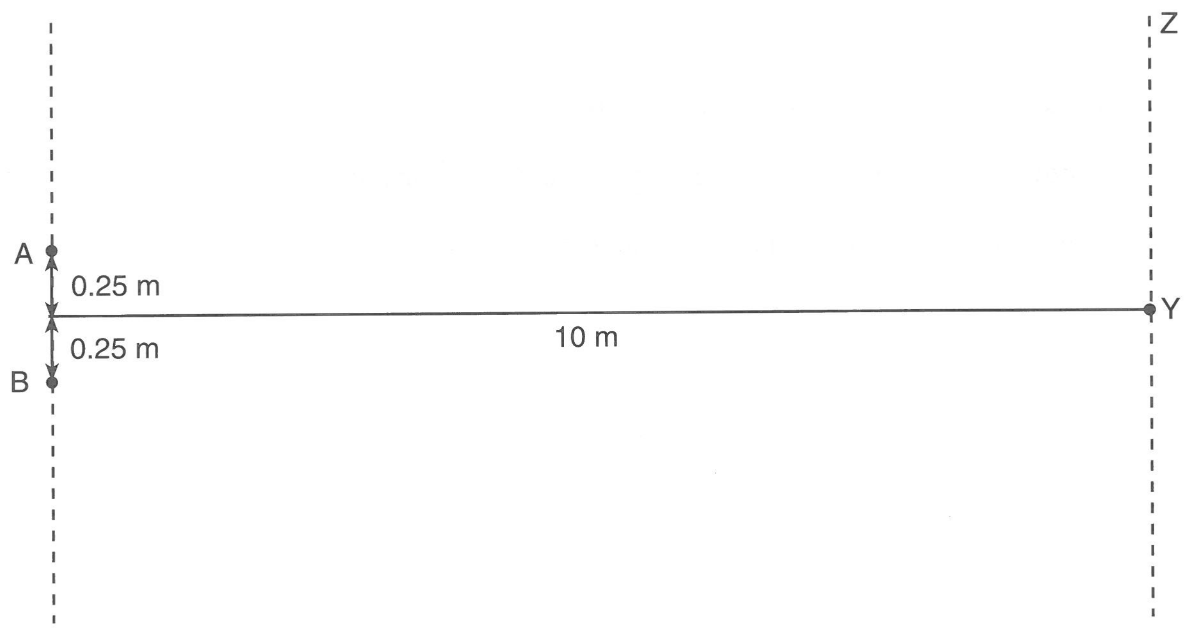
(d) How long was Janet's pen-whistle? (3 marks)

When Janet blew across the top of her pen-whistle with more force, it made a sound called an overtone or harmonic, of much higher frequency than its 1000 Hz natural note.

(e) On the diagram in your Answer Booklet show clearly the position(s) of the displacement antinode(s) in the cylinder when it is sounding its first overtone. (1 mark)

Two 120 mm pen-whistles at A and B are blown in the middle of a hockey field, simultaneously and roughly **in phase**, as shown in the diagram below (which is not to scale).

(f) What will the teacher hear as she walks from Y towards Z? Explain your answer. (2 marks)



(g) If the two whistles were blown together in the laboratory, explain why the teacher would not hear the same sound(s) as in (f). (1 mark)

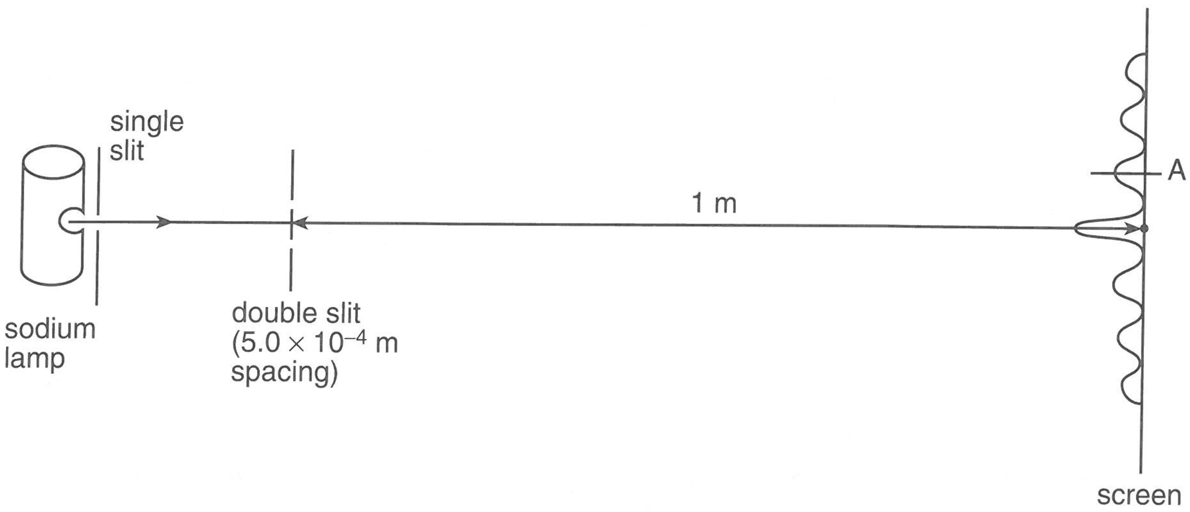
QUESTION TEN: RADIO AND LIGHT (16 marks)

Velocity of light = 3.0×10^{8} m s^{-1}.

(a) John's favourite AM radio station has a frequency of 1.2×10^{6} Hz. What is the wavelength of the electromagnetic waves it transmits? (2 marks)

(b) Television antennae often have lengths equal to half the signal wavelength. The one on the roof at John's house is 0.90 m long. What signal frequency was the antenna designed to detect? (2 marks)

Yellow light from a sodium lamp ($\lambda = 5.893 \times 10^{-7}$ m) is directed at two slits 5.0×10^{-4} m apart. When a screen is placed 1.0 m away, a series of fringes (bands of yellow and dark) are seen. The setup is indicated in the diagram below.



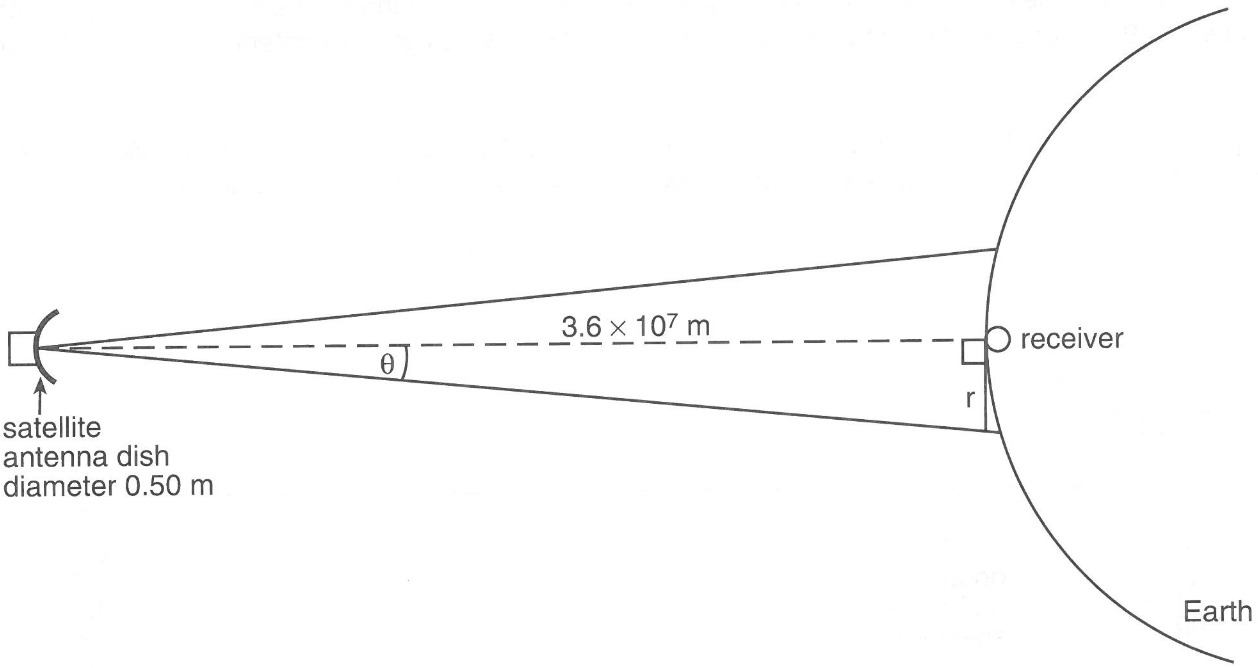
(c) What two optical phenomena are responsible for causing such fringes? (2 marks)

(d) Find the distance from the centre line to the first bright fringe (marked at point A). (3 marks)

(e) What would be the effect on the spacing between the fringes if the double slits were further apart than 0.5 mm? (1 mark)

Satellites transmitting electromagnetic waves back to a single receiver on Earth would ideally have the transmitted beam narrow and parallel so that the signal collected by the receiving antenna is as strong as possible. However, diffraction is a problem and the beam is spread out over an area, as shown in the diagram below. The greater the spread the weaker the signal picked up by the receiving antenna.

The angle, θ, in radians, is given by $\theta = \frac{1.22\lambda}{d}$ where λ is the wavelength of the transmitted wave and d is the diameter of the transmitting antenna dish.



(f) The distance above the Earth's surface of the satellite is 3.6×10^7 m, the wavelength of the transmitted wave is 1.0×10^{-3} m and the diameter of the antenna dish is 0.50 m.

(i) Calculate the angle, θ, in radians. (2 marks)

(ii) Calculate the spread radius, r, of the illuminated spot. (2 marks)

A satellite at the edge of our solar system would be at a distance far greater than the distance shown in the diagram above. The spread then makes it difficult for a receiver on Earth to pick up a strong enough signal.

(g) Suggest two ways of improving the satellite design (transmitter and/or antenna) so that the strength of the signal picked up by the receiver is increased. (2 marks)

ATOMIC AND NUCLEAR

(23 marks; 26 minutes)

QUESTION ELEVEN: ATOMS (12 marks)

Planck's constant = 6.626×10^{-34} J s
Speed of light = 3.0×10^{8} m s^{-1}
Rydberg's constant = 1.097×10^{7} m^{-1}
Mass of an electron = 9.1×10^{-31} kg

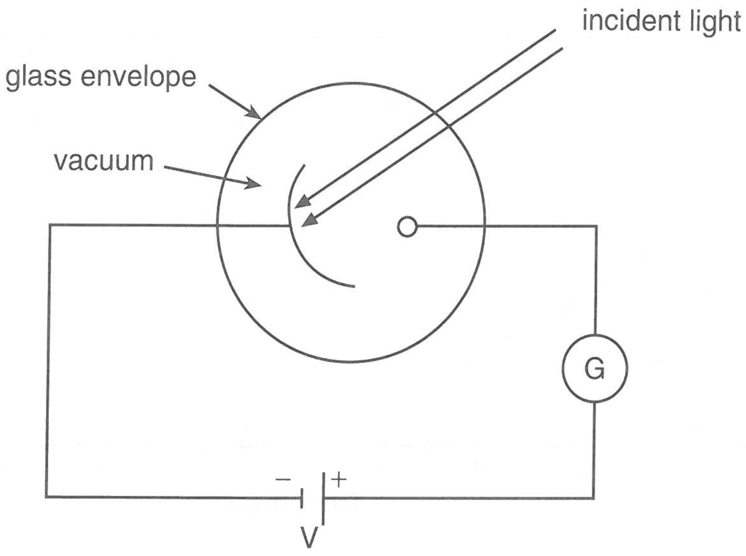
(a) A laser, which produces a beam of parallel, coherent light with wavelength $\lambda = 5.5 \times 10^{-7}$ m, has an optical power output of 1.0×10^{-3} W.

(i) Show that the energy of each photon produced by the laser is 3.6×10^{-19} J. (3 marks)

(ii) Given that a watt is a joule per second, how many photons does the laser emit each second? (2 marks)

(b) In the Bohr model for the hydrogen atom the angular momentum of the electron is given as $L = \frac{nh}{2\pi}$

What do the symbols n and h stand for ? (2 marks)



The diagram above shows a simplified arrangement to demonstrate the photoelectric effect. The equation usually associated with this phenomenon is $E_K = hf - \Phi$, where E_K is the kinetic energy of any released electrons and Φ is the work function of the metal being used.

(c) Explain why, with some metals, blue light will release electrons whereas intense red light will not. (3 marks)

(d) Why is the small voltage from the cell helpful in the arrangement shown above? (2 marks)

(Turn over

QUESTION TWELVE: NUCLEAR (11 marks)

Speed of light = 3.0×10^{8} m s^{-1}.

A typical fission reaction might be

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{141}_{56}Ba + ^{92}_{\mathbf{a}}Kr + 3^{1}_{0}n + 2^{0}_{0}\gamma.$$

(a) What number does **a** represent in the above reaction? (1 mark)

(b) What does the γ symbol represent in the above reaction? (1 mark)

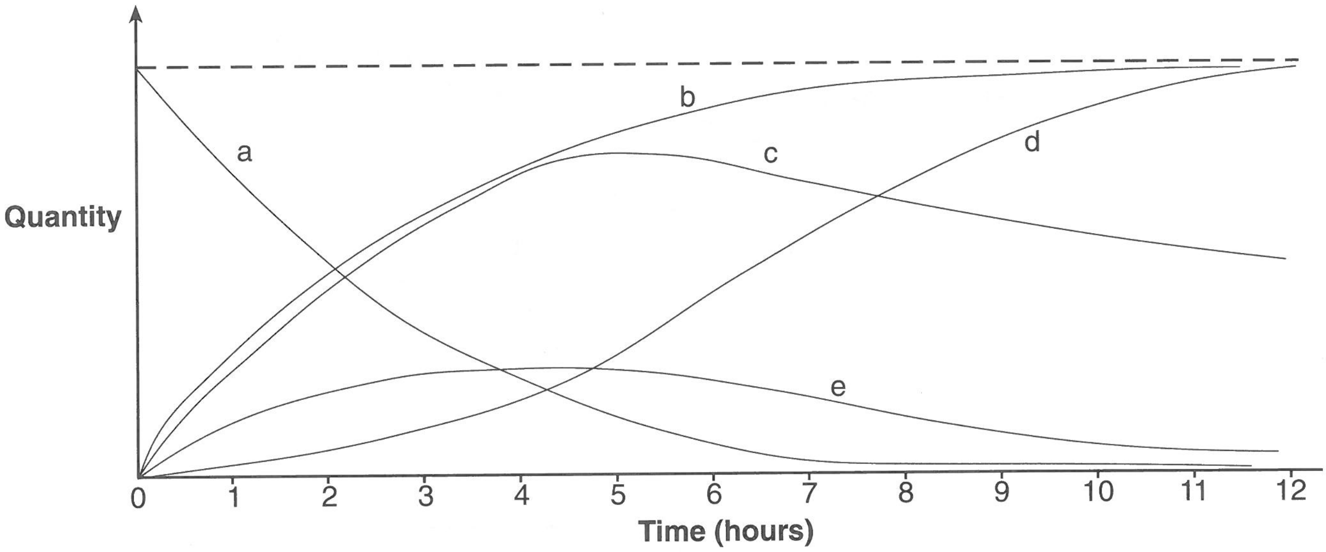
On their own, neutrons are unstable and decay as follows: $^{1}_{0}n \rightarrow ^{1}_{1}p + ^{0}_{\mathbf{b}}\mathbf{X} + ^{0}_{0}\bar{\nu}$

(c) What number does **b** represent in the above reaction? (1 mark)

(d) What does the **X** symbol represent in the above reaction? (1 mark)

A quantity of radioactive **Substance A** is given to a patient for radiography testing. **Substance A** decays, with a half-life of two hours, to a second **Substance B**, which is also radioactive with a half-life of about 10 hours.

(e) Which of the curves below best represents the time variation of the quantity of **Substance B** in the patient? (1 mark)



In a nuclear fission reactor (power station) each ^{235}U fission event releases 2×10^{8} eV of thermal energy and requires only one neutron to initiate the process. The fission event results in the release of, on average, 2.6 neutrons. Steady power output means that, on average, only one of the released neutrons results in another fission event.

(f) Express 2×10^{8} eV as joules. (1 mark)

(g) Explain what would happen if there was a change in the system which meant that **slightly** more than one released neutron (on average) resulted in a fission event. (1 mark)

(h) What would happen if **all** 2.6 neutrons (on average) resulted in a fission event? (2 marks)

(i) If the energy released by the atomic bomb dropped on Hiroshima was 2.0×10^{14} J, how much mass must have been transformed into energy? (2 marks)