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NEW ZEALAND QUALIFICATIONS AUTHORITY
MANA TOHU MĀTAURANGA O AOTEAROA

University Entrance, Bursaries and Scholarships Examination

PHYSICS: 2002

QUESTION BOOKLET

9.30 am Tuesday 19 November, 2002
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.

Waves	Questions One and Two	28 marks	33 minutes
Mechanics	Questions Three to Six	57 marks	68 minutes
Electricity and Electromagnetism	Questions Seven to Ten	44 marks	52 minutes
Atomic and Nuclear Physics	Questions Eleven and Twelve	23 marks	27 minutes

Write your answers in the appropriate spaces in the printed Answer Booklet 262/1.

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

Some useful formulae are given on page 17 of this booklet. This page is detachable.

Check that this booklet has all of pages 2–17 in the correct order and that none of these pages is blank.

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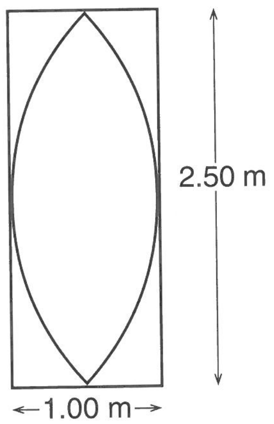
WAVES

(28 marks; 33 minutes)

QUESTION ONE: TOBIE AND THE SHOWER (14 marks)

Speed of sound in the shower = 3.35×10^2 m s^{-1}

Tobie is an excellent singer and practises in the shower every morning. The shower has the following dimensions: 2.50 m high, 1.00 m wide and 1.20 m deep. The shower can be modelled as a vertical pipe closed at each end, as shown below. The first harmonic (fundamental) standing wave produced by the singing is shown in the diagram.



(a) In your Answer Booklet, label all nodes (N) and antinodes (A) for the first harmonic shown. (2 marks)

(b) Show that the wavelength of the first harmonic is 5.00 m. (2 marks)

(c) Calculate the frequency of the first harmonic. (2 marks)

(d) In your Answer Booklet, sketch the third harmonic produced. (2 marks)

(e) Calculate the frequency of the third harmonic in this 2.50 m pipe. (2 marks)

Another resonance is heard at approximately 168 Hz.

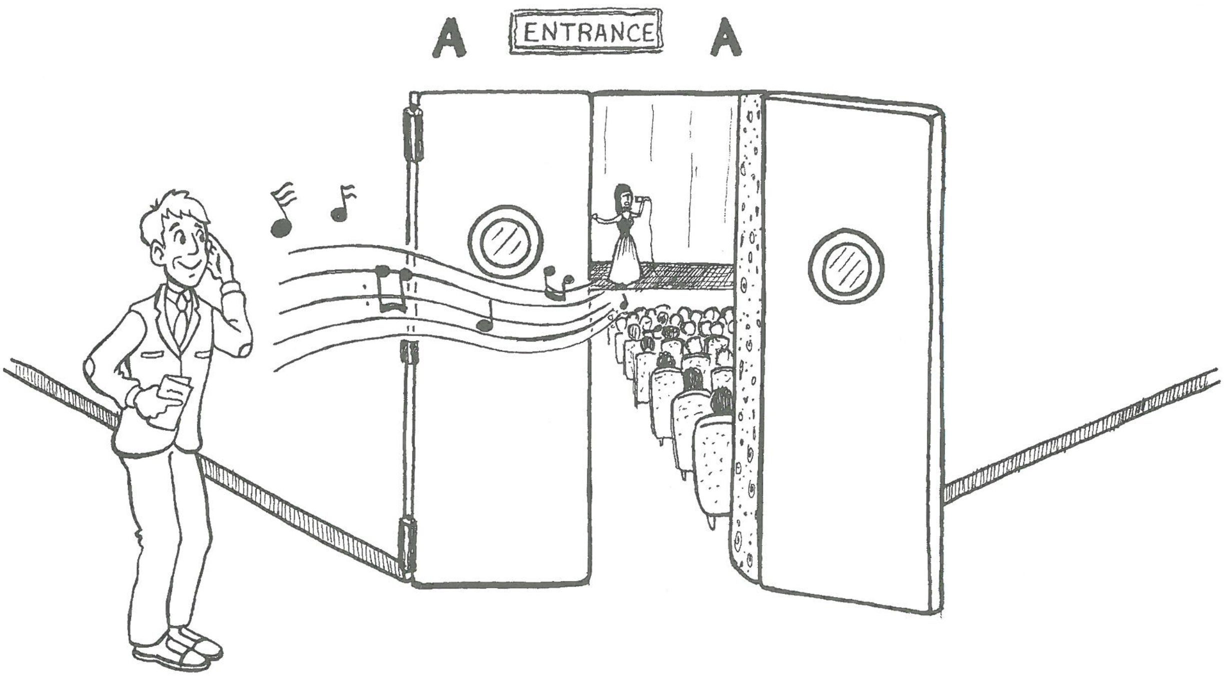
(f) Explain what is meant by the term **resonance**. (2 marks)

(g) Explain where the additional resonance comes from. (2 marks)

QUESTION TWO: THE CONCERT HALL (14 marks)

Speed of sound in the concert hall = 3.35×10^{2} m s^{-1}
Acceleration due to gravity = 9.80 m s^{-2}

Tobie is to perform in front of a large audience. Tobie sings a note of frequency 2.20×10^{2} Hz. Tobie's friend Lee decides to listen outside the open entrance to the concert hall so that Tobie doesn't know that he is there. The outside walls of the concert hall are very thick and do not allow sound to be transmitted through them.



(a) Show that the wavelength of the sound produced by Tobie is 1.52 m. (2 marks)

(b) Explain what is meant by the term **diffraction**. (2 marks)

(c) Using the concept of diffraction, explain why Lee can hear Tobie but cannot see her. (3 marks)

Lee walks away from the concert hall to the balcony at the back of the building. His cellphone emits a short beep of frequency 1.12×10^{3} Hz. As Lee reaches for the cellphone, he accidentally drops it over the balcony. A short time later, he hears a second beep with apparent frequency of 1.08×10^{3} Hz.

(d) Explain why Lee hears a lower frequency when the cellphone is falling. (2 marks)

(e) Calculate the speed of the cellphone at the time it emits the second beep. (3 marks)

(f) Calculate the distance the cellphone has travelled when it emits the second beep. (2 marks)

MECHANICS

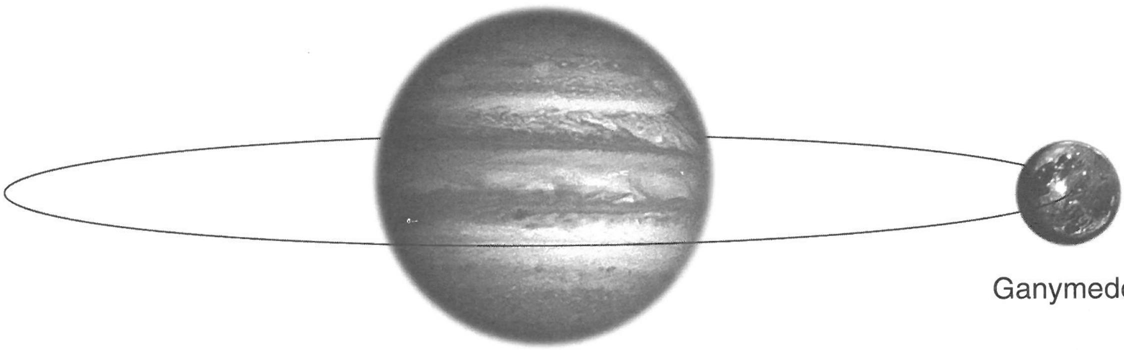
(57 marks; 68 minutes)

QUESTION THREE: GANYMEDE (11 marks)

Universal Gravitational Constant = 6.67×10^{-11} N m^2 kg^{-2}

During the last ten years, several unmanned missions to various parts of our solar system have taken place. One such mission was to investigate Jupiter and its moons.

One of Jupiter's moons is Ganymede. The orbit of Ganymede around Jupiter is circular, with a radius of 1.07×10^9 m and an orbital period of 7.15 days.



Jupiter
(Not to scale)

(a) Show that the orbital period is equal to 6.18×10^5 seconds. (1 mark)

(b) Calculate the linear speed of Ganymede. (2 marks)

(c) Explain why the velocity of Ganymede changes although its speed is constant. (1 mark)

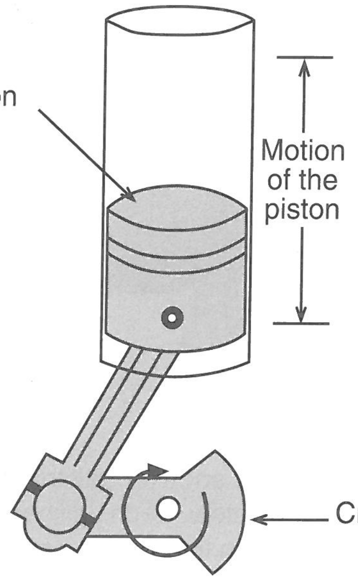
(d) Show that the centripetal acceleration of Ganymede is 0.111 m s^{-2}. (2 marks)

(e) By equating the gravitational force acting on Ganymede to the centripetal force needed for circular orbit, show that $\frac{R^3}{T^2} = \frac{GM}{4\pi^2}$ where M = mass of Jupiter, T = period of orbit and R = radius of orbit. (3 marks)

(f) Calculate the mass of Jupiter. (2 marks)

QUESTION FOUR: THE INTERNAL COMBUSTION ENGINE (16 marks)

One of the major components of the internal combustion engine in a car is the piston-crankshaft assembly, as shown in the diagram below.



The crankshaft rotates at 4.00×10^3 revolutions per minute. The rotation of the crankshaft causes the piston to move up and down. The amplitude of the piston's motion is 2.50×10^{-2} m. The mass of the piston is 0.310 kg.

(a) Show that the angular velocity of the crankshaft is 419 radians per second. (2 marks)

(b) Calculate the frequency of the motion of the piston. (2 marks)

The motion of the piston can be considered as simple harmonic motion.

(c) Calculate the maximum velocity of the piston. (2 marks)

(d) On the axes provided in your Answer Booklet, sketch a graph of the kinetic energy of the piston against time for one cycle of the piston's motion. At time t = 0, the velocity of the piston is zero. On the vertical axis, include an appropriate maximum value and, on the time axis, the period value. (4 marks)

(e) Calculate the maximum force acting on the piston. (2 marks)

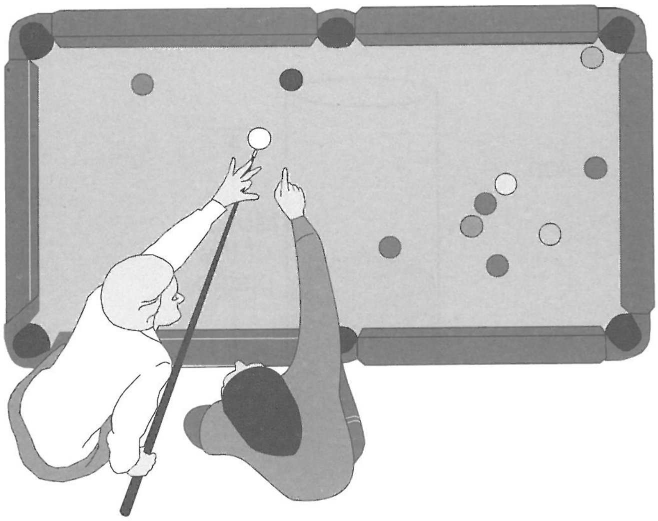
The car powered by this engine has a mass of 1.25×10^3 kg. The car is driven gently into a solid wall during a safety test. The front bumper of the car can be considered to behave like a spring, with a spring constant of 3.00×10^6 N m^{-1}. During the collision with the wall, the bumper compresses 2.16 cm and the car is brought to rest. Assume that no energy is lost to the wall during impact.

(f) Show that the speed, v, of the car before impact is given by the expression $v = \sqrt{\frac{kx^2}{m}}$ where m = mass, k = spring constant and x = compression. (2 marks)

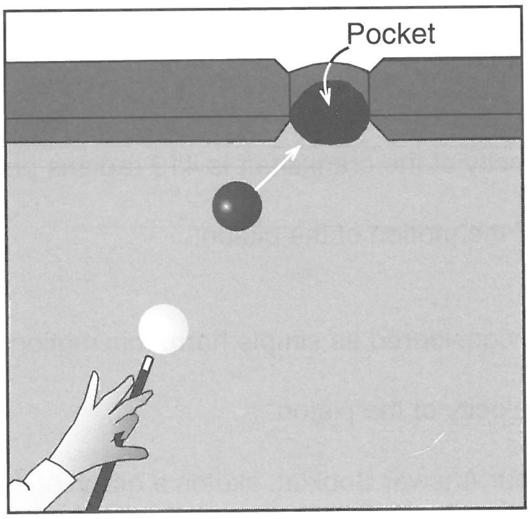
(g) Calculate the speed of the car before impact. (2 marks)

(Turn over

QUESTION FIVE: THE SNOOKER GAME (21 marks)



Using a cue (a thin rod), Lee hits a stationary white snooker ball that slides towards a stationary black ball with a velocity of 2.10 m s^{-1}, as shown in the diagram below. Each ball has a mass of 0.173 kg. Lee is trying to propel the black ball into the pocket along the path shown in the diagram below.

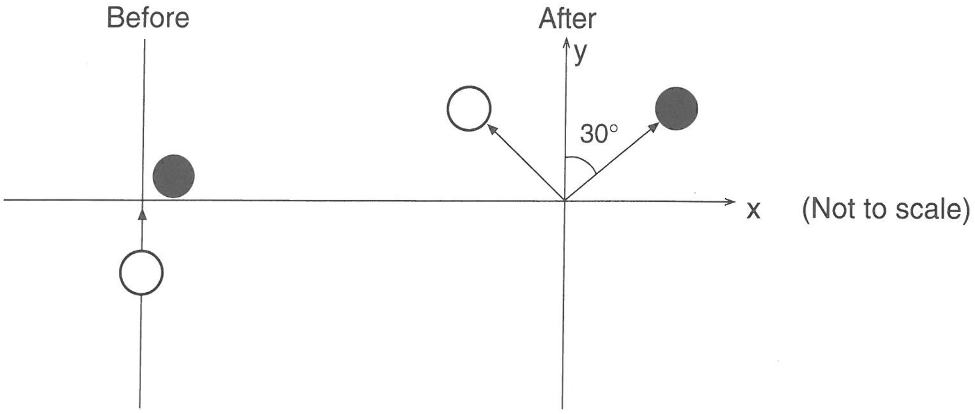


(a) Show that the kinetic energy of the white ball is 0.381 J. (2 marks)

(b) Calculate the magnitude of the change in momentum delivered by the cue on the white ball. (2 marks)

(c) If the cue was in contact with the white ball for 0.300 seconds, calculate the magnitude of the average force exerted by the cue on the ball. (2 marks)

Immediately after being hit by the white ball, the black ball slides towards the pocket with a velocity of 1.50 m s^{-1}. This is shown by the following diagram.



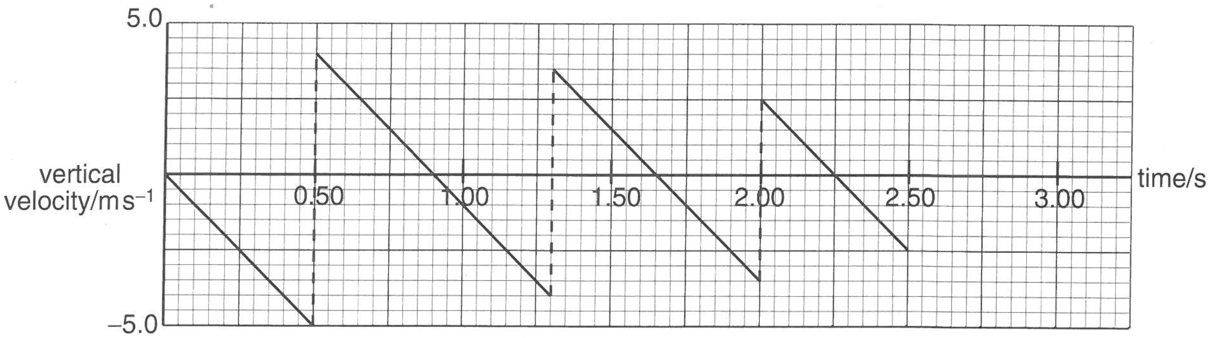
(d) Show that, after the collision, the component of the momentum of the black ball in the y direction is 0.225 kg m s^{-1}. (2 marks)

(e) Calculate the component of the momentum of the black ball in the x direction after the collision. (2 marks)

(f) Calculate the speed of the white ball after the collision. (3 marks)

(g) Before it reaches the pocket, the black ball has stopped sliding and is rolling. Explain. (2 marks)

The ball falls through a hole in the pocket directly onto a hard floor. Below is a plot of the velocity in the vertical direction against time for the ball's motion.



(h) At what time does the graph show the ball in contact with the ground for the first time? (1 mark)

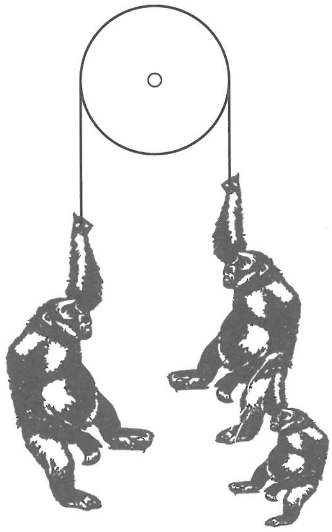
(i) Calculate the gradient of the parallel sloping lines. (1 mark)

(j) Explain why the time between vertical sections of the graph decreases. (2 marks)

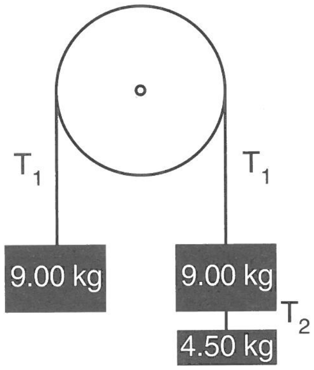
(k) Calculate the height from which the ball dropped. (2 marks)

QUESTION SIX: THE ZOO TRIP (9 marks)

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



One weekend, Tobie and Lee decide to visit the zoo. While they are there, they observe the chimpanzees playing with a new toy. One of the chimpanzees is holding a baby. This gives Tobie and Lee an idea for their own version of the toy. The toy is based on a simple pulley mechanism. Tobie and Lee decide to build their own version of the toy, as shown below.



The mass of the pulley and string is negligible and friction can be ignored. The tension in the string between the two 9.00 kg masses is T_1. The tension in the string between the 9.00 kg mass and the 4.50 kg mass is T_2.

(a) Show that the gravitational force acting on the left-hand mass is 88.2 N. (2 marks)

(b) State the direction of the tension force on the left-hand mass. (1 mark)

(c) Show that the magnitude of the linear acceleration of the three masses is 1.96 m s^{-2}. (3 marks)

(d) Calculate the magnitude of the tension T_2. (3 marks)

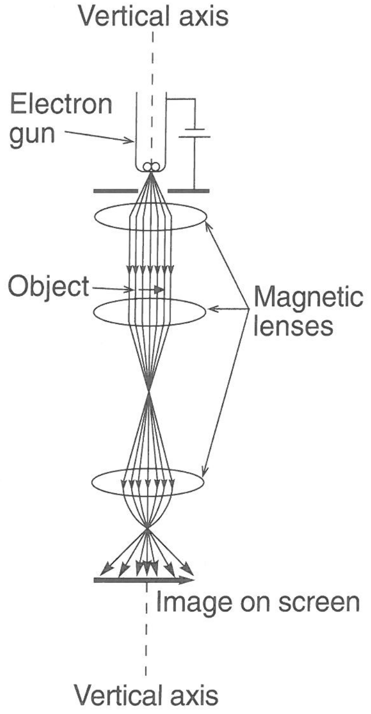
ELECTRICITY AND ELECTROMAGNETISM

(44 marks; 52 minutes)

QUESTION SEVEN: THE ELECTRON MICROSCOPE (7 marks)

Mass of electron = 9.11×10^{-31} kg
Charge on electron = 1.60×10^{-19} C

Diagram of an Electron Microscope



An electron microscope is an instrument that enables us to see images of objects at very high magnifications. One particular electron microscope achieves this by accelerating electrons through a potential difference of 5.00×10^3 V.

(a) Explain what is meant by the term **potential difference**. (2 marks)

The electron current flowing in this electron microscope is 1.20×10^{-8} A.

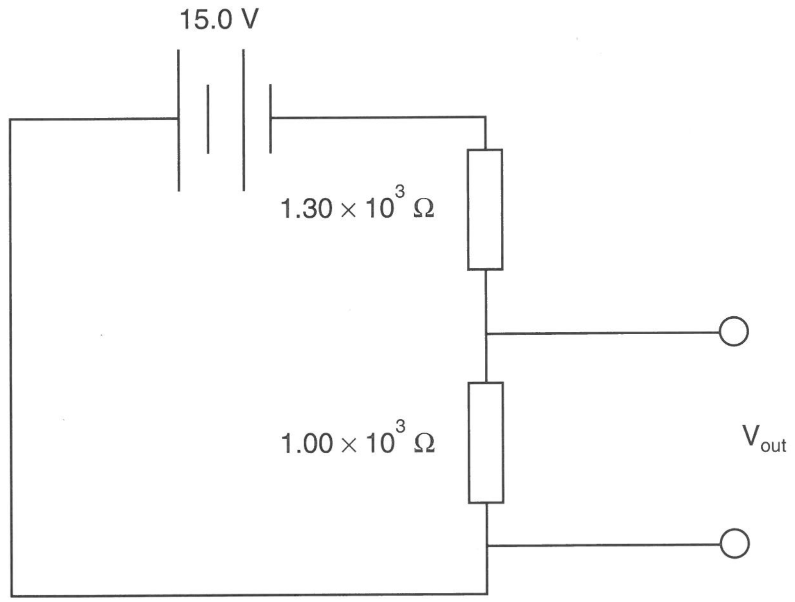
(b) Show that the number of electrons flowing past a point on the vertical axis of the electron microscope in one second is 7.50×10^{10}. (2 marks)

(c) Calculate the speed of the electrons when they have passed through the potential difference of 5.00×10^3 V. (3 marks)

QUESTION EIGHT: THE CONTACT TIMER (16 marks)

For an experiment on contact times, Lee needs a 10.0 V power supply but he only has a 15.0 V power supply. His friend Tobie said that he could use a voltage divider circuit to solve his problem.

Lee constructs the following circuit.



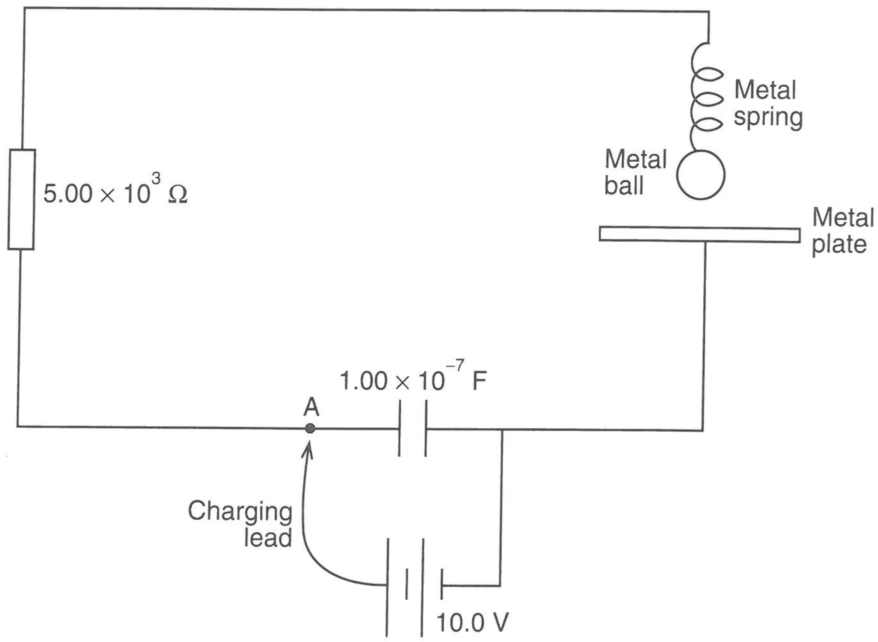
(a) Calculate the total resistance of the circuit. (1 mark)

(b) Show that the current, I, in the circuit is 6.52×10^{-3} A. (2 marks)

Lee measures V_{out} and finds it is not the 10.0 V that he needs. Lee changes the circuit by replacing the $1.00 \times 10^3\ \Omega$ resistor.

(c) Calculate the value of the replacement resistor that will enable Lee to produce the voltage of 10.0 V that he needs. (2 marks)

Lee wants to investigate the contact time that a small metal ball makes with a large metal plate. He sets up the following circuit.



To charge the capacitor, the charging lead is connected to point A for a short time.

(d) Assuming the 1.00×10^{-7} F capacitor is fully charged, show that the charge stored in the capacitor is 1.00×10^{-6} C. (2 marks)

The charging lead is disconnected again and Lee lets the small metal ball drop and contact the metal plate in order to complete the circuit.

(e) Calculate the time constant of the completed circuit. (2 marks)

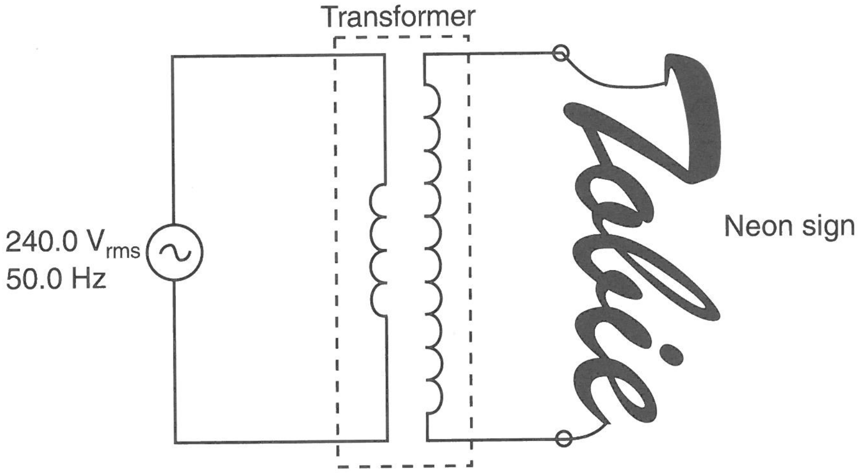
(f) Explain, using physical principles, why increasing the resistance in the circuit will increase the time for the capacitor to discharge. (2 marks)

(g) Calculate the voltage across the capacitor after one time constant. (2 marks)

(h) Calculate the contact time that would leave a voltage of 2.00 V across the capacitor. (3 marks)

QUESTION NINE: THE TRANSFORMER (9 marks)

Tobie required 1.20×10^4 V to light up her neon sign but only had a 240.0 V_{rms} AC input. Tobie set up the following circuit, using a transformer, to overcome the problem.



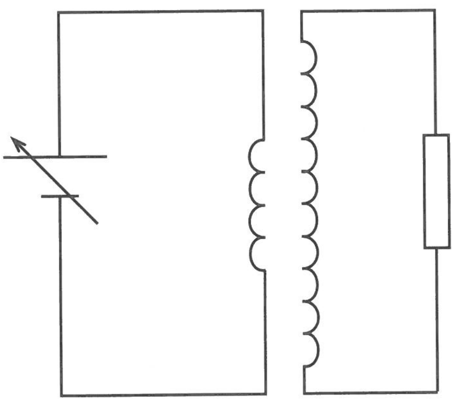
(a) State the name normally given to this kind of transformer. (1 mark)

(b) If there were 10 000 turns in the secondary windings, calculate the number of turns there must have been in the primary windings for the required voltage to have been produced. (2 marks)

Immediately after connection to the neon sign, the rms current in the secondary windings was 1.10×10^{-3} A.

(c) Assuming the transformer had negligible energy loss, calculate the rms current drawn in the primary windings. (2 marks)

Tobie disconnected the 240.0 V_{rms} AC supply and attached a DC supply instead, as shown in the diagram below. Tobie managed to increase the current in the primary windings from 0 to 1.00 A in 0.0210 s. The mutual inductance between the two windings was 0.215 H.

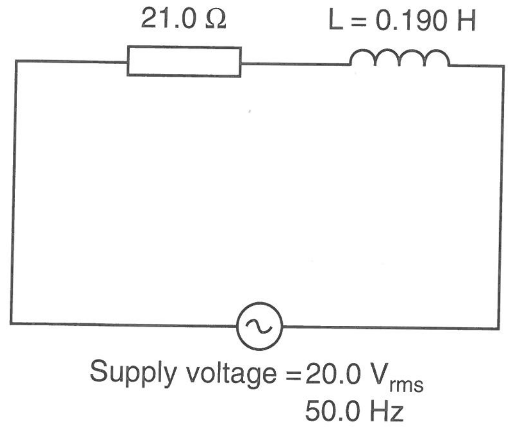


(d) Assuming the current increased at a constant rate, calculate the induced emf in the secondary windings. (2 marks)

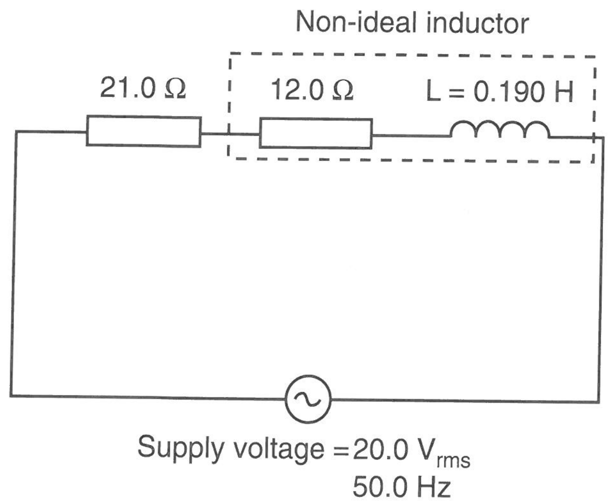
(e) Explain how the induced emf in the secondary windings of the transformer could have been increased. (2 marks)

QUESTION TEN: INDUCTORS (12 marks)

The following simple LR series circuit was constructed by Tobie. It was assumed that the inductor was ideal (ie had zero resistance).



After some investigation, it was found that the inductor, L, was non-ideal with a resistance of 12.0 Ω. The above circuit was redrawn by Tobie to include this resistance.

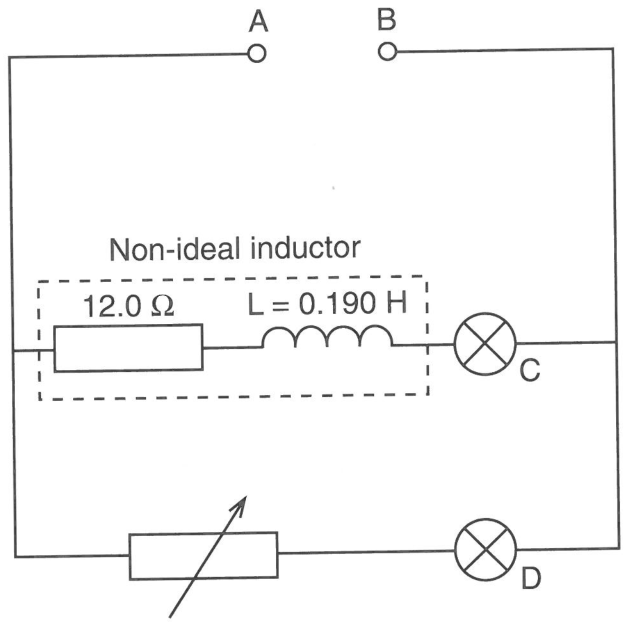


(a) Show that the angular frequency of the AC supply was 314 radians per second. (1 mark)

(b) Calculate the reactance of the inductor. (2 marks)

(c) Calculate the rms current that was flowing in the circuit. (3 marks)

Tobie decided that the inductor shown on page 13 needed further investigation. She constructed the following circuit.



Tobie connected points A and B to a 15.0 V **direct current** (DC) power supply and adjusted the variable resistor so that bulbs C and D (which were identical) shone with the same brightness.

(d) State the value of the variable resistance. (1 mark)

Tobie then disconnected the DC supply and replaced it with a 15.0 V_{rms}, 50.0 Hz, AC supply. Bulb D did not change brightness but bulb C changed considerably.

(e) Explain why bulb D showed no sign of changed brightness. (2 marks)

(f) (i) Would the brightness of bulb C have increased or decreased? (1 mark)

(ii) Explain your answer to (f)(i). (2 marks)

ATOMIC AND NUCLEAR PHYSICS

(23 marks; 27 minutes)

QUESTION ELEVEN: NUCLEAR PHYSICS (10 marks)

Speed of light = 3.00×10^{8} m s^{-1}

The nuclear reaction below gives one possible fusion reaction that can be used to generate power.

$$ {}^{2}_{1}H + {}^{2}_{1}H \rightarrow {}^{3}_{2}He + {}^{a}_{b}X + energy $$

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

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

The mass of the deuterium nucleus is 2.01411 amu.
The mass of the helium nucleus is 3.01603 amu.
The mass of the *X* nucleon is 1.00867 amu.
1 atomic mass unit (amu) = 1.66×10^{-27} kg.

(c) Calculate the energy released in this reaction. (3 marks)

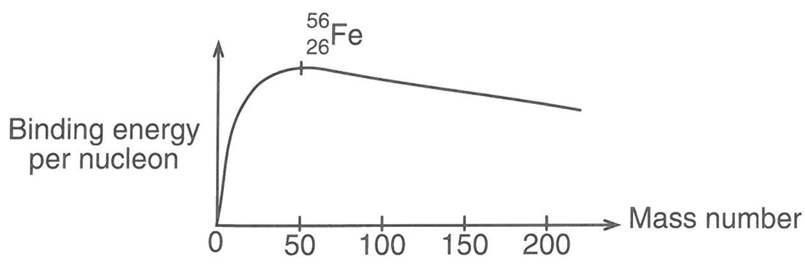
The following fission reaction can occur in a nuclear power plant.

$$ {}^{235}_{92}U + {}^{1}_{0}n \rightarrow {}^{92}_{36}Kr + {}^{141}_{56}Ba + k\,{}^{1}_{0}n + energy $$

(d) State the value of *k*. (1 mark)

(e) Explain why the above reaction can lead to a chain reaction. (1 mark)

The graph below shows how the binding energy per nucleon varies as the mass number increases.



(f) Using the above graph, explain how energy can be released in the above fission reaction. (2 marks)

QUESTION TWELVE: THE BOHR ATOM (13 marks)

Charge on electron = 1.60×10^{-19} C
Planck's Constant = 6.63×10^{-34} J s
Rydberg's Constant = 1.097×10^{7} m^{-1}
Speed of light = 3.00×10^{8} m s^{-1}

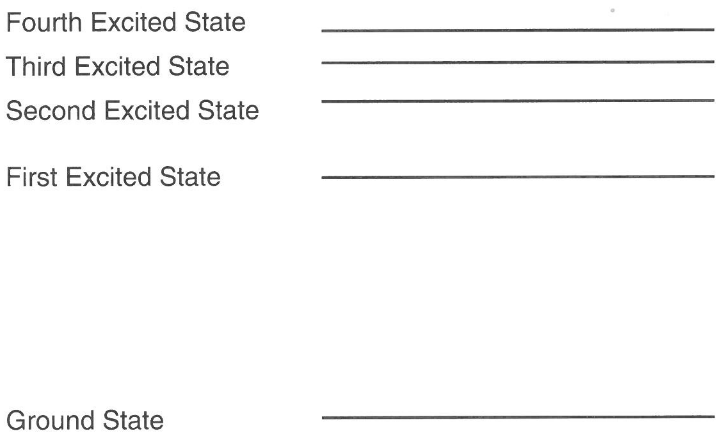
Niels Bohr, the famous Danish physicist, developed the Bohr model of the hydrogen atom. One of Bohr's postulates (assumptions) was that angular momentum, L, is quantised and can be calculated using the formula $L = \frac{nh}{2\pi}$.

(a) State the values that n can take. (1 mark)

(b) Explain what is meant by the term **quantised**. (1 mark)

(c) Calculate the angular momentum of an electron in its third excited state. (2 marks)

The diagram below shows some of the energy levels of the hydrogen atom. The energy of the ground state is -2.18×10^{-18} J.



(d) Convert the ground state energy from joules to electron-volts. (2 marks)

(e) The electron in a particular hydrogen atom is in the excited state for which n = 3. Show that the energy needed to ionise this atom is 2.42×10^{-19} J. (2 marks)

(f) In a hydrogen atom, the electron falls from an excited state directly to the ground state. Calculate the longest possible wavelength of the photon emitted by this process. (3 marks)

(g) Explain why the ground state energy is negative. (2 marks)

The following formulae may be of use to you:

$F_g = \frac{GMm}{r^2}$

$F_c = \frac{mv^2}{r}$

$\Delta p = Ft$

$\omega = 2\pi f$

$d = r\theta$

$v = r\omega$

$a = r\alpha$

$W = Fd$

$F = ma$

$p = mv$

$v = v_i + at$

$v^2 = v_i^2 + 2ad$

$d = \frac{(v_i + v)t}{2}$

$d = v_i t + \frac{1}{2}at^2$

$\omega = \frac{\Delta\theta}{\Delta t}$

$\alpha = \frac{\Delta\omega}{\Delta t}$

$L = I\omega$

$L = mvr_\perp$

$\tau = I\alpha$

$\tau = Fr$

$E_{K(ROT)} = \frac{1}{2}I\omega^2$

$E_{K(LIN)} = \frac{1}{2}mv^2$

$E_{GPE} = mgh$

$\omega = \omega_i + \alpha t$

$\omega^2 = \omega_i^2 + 2\alpha\theta$

$\theta = \frac{(\omega_i + \omega)t}{2}$

$\theta = \omega_i t + \frac{1}{2}\alpha t^2$

$T = 2\pi\sqrt{\frac{\ell}{g}}$

$T = 2\pi\sqrt{\frac{m}{k}}$

$E = \frac{1}{2}kA^2$

$F = -ky$

$a = -\omega^2 y$

$y = A\sin\omega t$

$v = A\omega\cos\omega t$

$a = -A\omega^2\sin\omega t$

$y = A\cos\omega t$

$v = -A\omega\sin\omega t$

$a = -A\omega^2\cos\omega t$

$\Delta E = Vq$

$P = VI$

$V = Ed$

$Q = CV$

$C_{TOT} = C_1 + C_2$

$\frac{1}{C_{TOT}} = \frac{1}{C_1} + \frac{1}{C_2}$

$E = \frac{1}{2}QV$

$C = \frac{\varepsilon_o\varepsilon_r A}{d}$

$\tau = RC$

$\frac{1}{R_{TOT}} = \frac{1}{R_1} + \frac{1}{R_2}$

$R_{TOT} = R_1 + R_2$

$\phi = BA$

$\varepsilon = BAN\omega\sin\omega t$

$\varepsilon = -\frac{\Delta\phi}{\Delta t}$

$\varepsilon = -L\frac{\Delta I}{\Delta t}$

$\varepsilon = -M\frac{\Delta I}{\Delta t}$

$\frac{N_p}{N_s} = \frac{V_p}{V_s}$

$E = \frac{1}{2}LI^2$

$\tau = \frac{L}{R}$

$I = I_{MAX}\sin\omega t$

$V = V_{MAX}\sin\omega t$

$I_{MAX} = \sqrt{2}\,I_{rms}$

$V_{MAX} = \sqrt{2}\,V_{rms}$

$X_C = \frac{1}{\omega C}$

$X_L = \omega L$

$V = IZ$

$n\lambda = \frac{dx}{L}$

$n\lambda = d\sin\theta$

$f = |f_1 - f_2|$

$f' = f\frac{V_W}{V_W \pm V_S}$

$E = hf$

$hf = \phi + E_K$

$E = mc^2$

$\frac{1}{\lambda} = R\left(\frac{1}{S^2} - \frac{1}{L^2}\right)$

$E_n = -\frac{hcR}{n^2}$

$\Delta E = |E_1 - E_2|$

$\upsilon = f\lambda$

$f = \frac{1}{T}$