No. 262

NEW ZEALAND QUALIFICATIONS AUTHORITY
MANA TOHU MĀTAURANGA O AOTEAROA

University Entrance, Bursaries and Scholarships Examination

PHYSICS: 2000

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 Four	52 marks	62 minutes
Electricity and Electromagnetism	Questions Five to Eight	47 marks	56 minutes
Waves	Questions Nine and Ten	28 marks	33 minutes
Atomic and Nuclear Physics	Questions Eleven and Twelve	25 marks	29 minutes

Check that this question booklet has all of pages 2 – 15 in the correct order and that none of these pages is blank.

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.

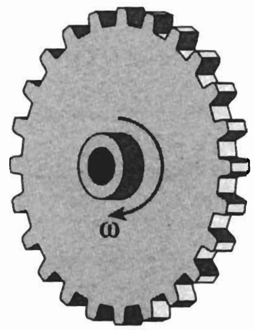
Some useful formulae are given on page 15 of the Answer Booklet. This page is detachable

MECHANICS

(52 marks; 62 minutes)

QUESTION ONE: ROTATIONAL MOTION (16 marks)

The flywheel in the engine of Petra's car is shown below. It is essentially a solid disc with a mass of 14 kg and a radius at the outer edge of the teeth of 0.23 m. It has a large rotational inertia and so resists rapid changes to rotational velocity. This helps the engine run more smoothly.



On one occasion the engine is running such that the flywheel is rotating at a constant 4100 revolutions per minute.

(a) Show that the angular velocity of the flywheel can be calculated to be 429.351 rad s^{-1}. (2 marks)

(b) Calculate the period of revolution of the flywheel. (2 marks)

(c) Calculate the linear velocity of a point on the outer edge of the teeth of the flywheel. (2 marks)

Petra applies the brakes and the flywheel takes 4.5 s to come to rest from an angular velocity of 430 rad s^{-1}.

(d) Calculate the angle the flywheel turns through. (2 marks)

The flywheel is built so that most of its mass is towards the outside of the disc.

(e) Explain how this affects the rotational inertia of the flywheel. (2 marks)

(f) The maximum torque that Petra's car can produce is fixed. Explain why having a large rotational inertia helps the flywheel resist rapid changes in rotational velocity. (2 marks)

Peter's car engine has a flywheel with a mass of 12 kg and radius of 0.21 m. On one occasion, as he accelerates away from a standing start, the flywheel is given an angular momentum of 120 kg $m^2 s^{-1}$ and reaches a constant angular velocity of 302 rad s^{-1}.

(g) Show that the rotational inertia of the flywheel is 0.40 kg m^2. (2 marks)

(h) Calculate the rotational kinetic energy of the flywheel. (2 marks)

QUESTION TWO: LINEAR AND ROTATIONAL FORCES (8 marks)

Acceleration due to gravity = 9.8 m s^{-2}

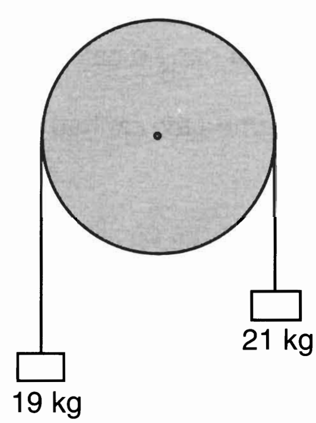
Part 1
Petra is driving a van on a dirt road. She has an 18 kg parcel in the back which is unrestrained, as shown below. The van is travelling at 4.2 m s^{-1} when it hits a large rock and stops suddenly. The total mass of the van, Petra and the parcel is 1850 kg.

(a) What is the **maximum** velocity of the parcel as it travels towards the front seat of the van during this unplanned stop? (1 mark)

Friction slows the parcel and it hits the stationary, soft front seat at a speed of 2.5 m s^{-1}. The stopping time of the parcel against the seat is 0.50 s.

(b) Calculate the average force on the parcel during this stopping time. (2 marks)

Part 2
In the apparatus shown below, known as an Atwood's machine, the two masses of 19 kg and 21 kg are suspended over a pulley. The pulley has negligible mass and a radius of 0.15 m. It is mounted on an essentially frictionless axle. The rope does not slip over the pulley, but rotates with it.



(c) Show that when the masses are released the acceleration of the 19 kg mass is 0.49 m s^{-2}. (2 marks)

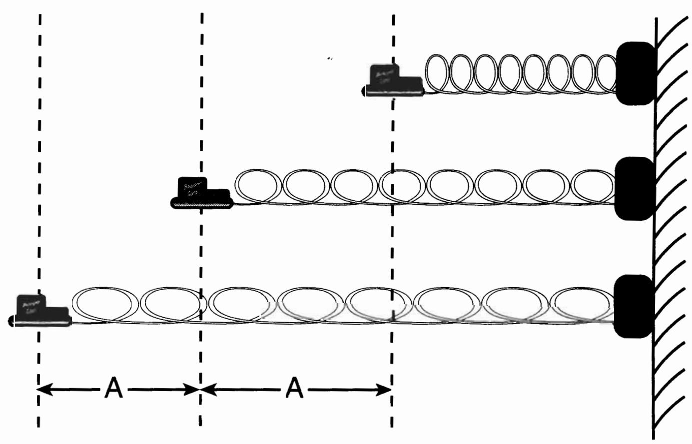
(d) How far has the 21 kg mass fallen after 1.5 seconds, if it starts from rest? (3 marks)

QUESTION THREE: SIMPLE HARMONIC MOTION (14 marks)

Acceleration due to gravity = 9.8 m s^{-2}

At a fun fair, the "bumper cars" have a spring between the car body and the front bumper and the cars float on a cushion of air, making them effectively frictionless. Petra's car, with her in it, has a mass of 145 kg and the spring constant of the front bumper spring is 1700 Nm^{-1}.

On one occasion Petra's car hits a rigid wall and the bumper becomes stuck fast to the wall. This leaves the car oscillating horizontally with simple harmonic motion (SHM) for several periods. Under these conditions the car can be modelled as a single point mass, at the centre of mass of the car, performing SHM on the end of a horizontal spring as shown below.



(a) Show that the period of oscillation of the car can be calculated to be 1.83501 s. (2 marks)

(b) Would this period be greater, less or the same if the car had got stuck when carrying a person of less mass than Petra? (1 mark)

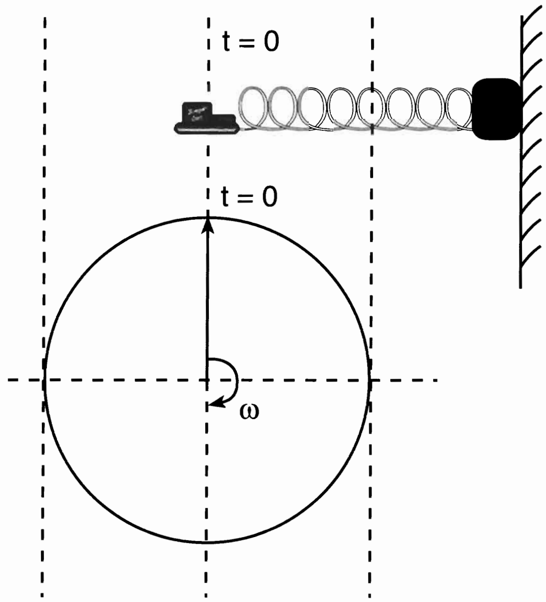
Immediately after becoming stuck the amplitude of the oscillations of the car is 0.11 m.

(c) On the axes provided in your Answer Booklet, **sketch** a graph of amplitude versus time for the damped SHM of this car if it takes about 5 s to come completely to rest. (2 marks)

(d) Calculate the energy stored in the spring when the car first comes to a halt against the wall (ignore damping effects). (2 marks)

(e) Calculate the velocity of the car as it passes through the equilibrium position after the first rebound (ignore damping effects). (2 marks)

Consider a complete oscillation of the car after it hits the wall. A reference circle for this motion is shown below. The motion starts at the instant the car bumper touches the wall, ie when the spring is in equilibrium with no compression. Assume no damping during the first one period.



(f) Use the reference circle in your Answer Booklet to find the position of the centre of mass of the car at t = 0.25 s. (3 marks)

One day Petra had a heavy text book on her bed and she attempted to demonstrate the concept of forced SHM to her brother. She repeatedly pushed down on the bed beside the book, causing the book to oscillate on the bed springs. She then showed what happens when the frequency of the repeated pushes is changed.

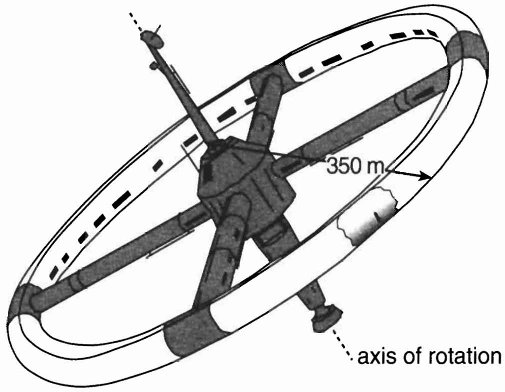
(g) On the axes provided in your Answer Booklet, sketch a graph of the amplitude of oscillations of the book versus Petra's pushing frequency for a range of frequencies. Centre the range around the resonant frequency of the bed springs and book system. No numerical values are required but you must label both axes. (2 marks)

QUESTION FOUR: GRAVITY AND CIRCULAR MOTION (14 marks)

Acceleration due to gravity at sea level on Earth = 9.8 m s^{-2}

Part 1

NASA is planning a manned space mission to the planet Mars. During the many months of travel the astronauts would be weightless, and so gravity is to be simulated. This can be done by rotating the entire spacecraft, which is shaped like a doughnut, around a central axis. The astronauts live around the outside edge of the spacecraft at a radius of 350 m. The diagram below illustrates the situation.



The astronauts are to be provided with a "gravity" of one half that felt on Earth.

(a) Calculate the size of the simulated gravitational force on an astronaut of mass 85 kg. (2 marks)

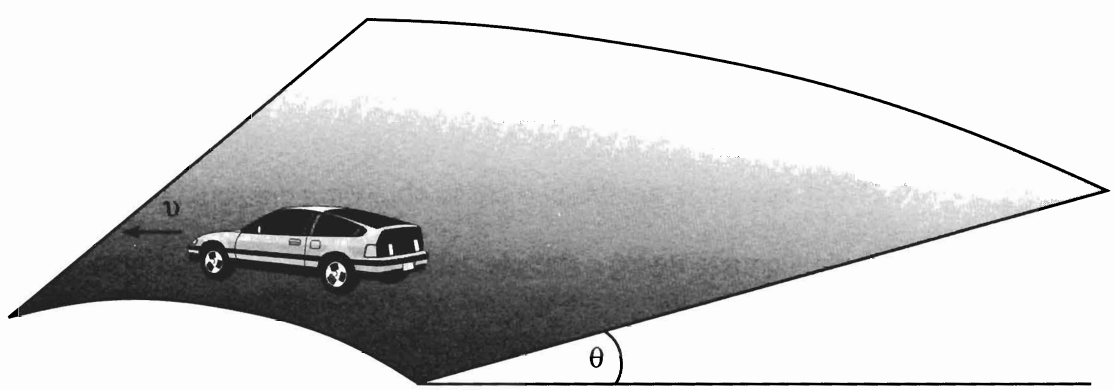
(b) Show that the speed of the astronauts relative to the central axis can be calculated to be 41.4126 m s^{-1}. (2 marks)

(c) Calculate the frequency of revolution of the spacecraft. (2 marks)

(d) Explain why the radius of the spacecraft has to be as large as it is. (2 marks)

Part 2

A motorway curve has a radius of 285 m. The curve is banked at angle, θ, as shown below, so that cars travelling at 105 km h^{-1} do not skid sideways in the absence of friction.



(e) Convert 105 km h^{-1} to m s^{-1}. (2 marks)

(f) On the diagram in your Answer Booklet, draw the forces acting on a car as it travels around the curve with a constant speed of 105 km h^{-1}. Assume there is no sideways friction between the tyres and the surface of the road. (2 marks)

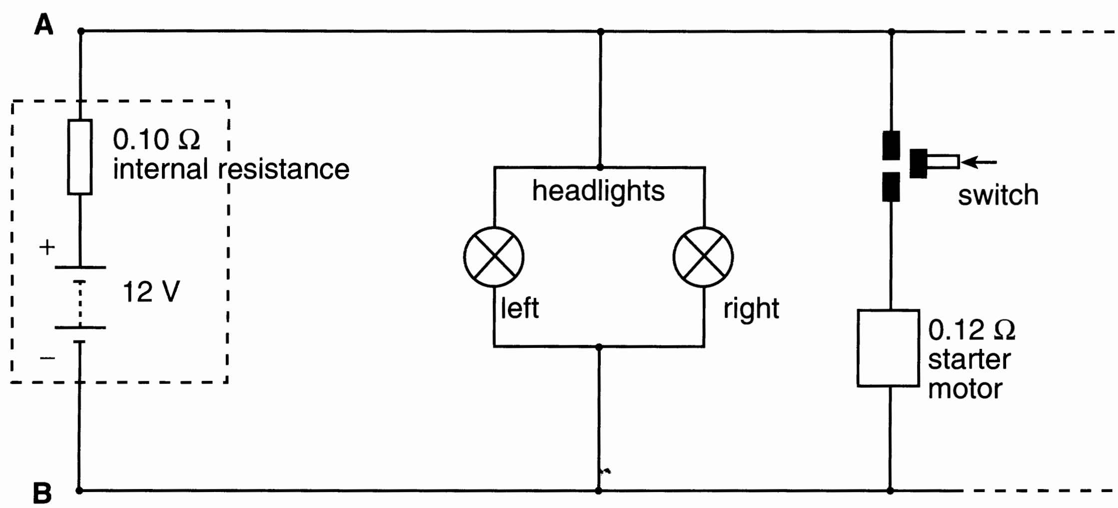
(g) At what angle, θ, should the curve be banked? (2 marks)

ELECTRICITY AND ELECTROMAGNETISM

(47 marks; 56 minutes)

QUESTION FIVE: DC ELECTRICITY (10 marks)

Part of the circuit for the electrical system of Peter's car is drawn below. The car battery has an internal resistance of 0.10 Ω and the two identical headlights in parallel have a combined resistance of 2.0 Ω. The starter-motor has a resistance of 0.12 Ω and is switched on by pushing the switch.



(a) Show that the **total** resistance of the circuit shown when the starter-motor switch is pushed can be calculated to be 0.213208 Ω. (3 marks)

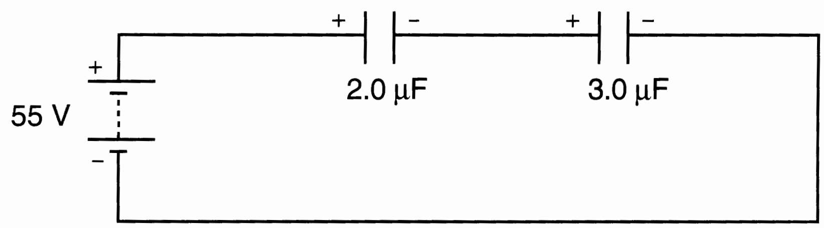
(b) What is the current flowing from the battery when the starter-motor switch is pushed? (2 marks)

(c) What is the voltage across each headlight when the starter-motor switch is pushed? (3 marks)

(d) If the headlights are on when the starter-motor switch is pushed, the headlights dim. Explain why this happens. (2 marks)

QUESTION SIX: CAPACITANCE (13 marks)

Once in a Physics class, Petra took a 2.0 μF capacitor and a 3.0 μF capacitor and connected them in series across a 55 volt DC supply, as shown below.

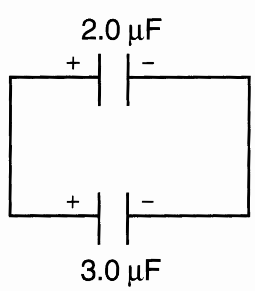


(a) Show that the total capacitance of the pair of capacitors in series is 1.2 μF. (2 marks)

(b) Calculate the charge on the positive plate of the 2.0 μF capacitor, when it is wired in this configuration. (2 marks)

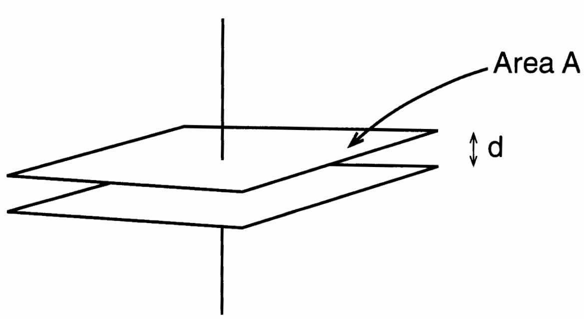
(c) Calculate the voltage across the 2.0 μF capacitor, when wired in this configuration. (2 marks)

Petra then disconnected the capacitors from the supply and from each other and immediately reconnected them, still charged, across each other, as shown below.



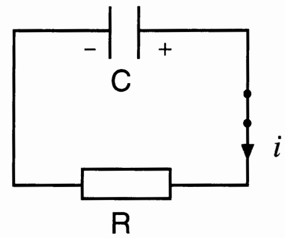
(d) Calculate the charge on the positive plate of the 2.0 μF capacitor, when equilibrium is reached. (2 marks)

The diagram below shows a parallel plate capacitor. With air between the plates it has a capacitance of 2.0×10^{-11} F.

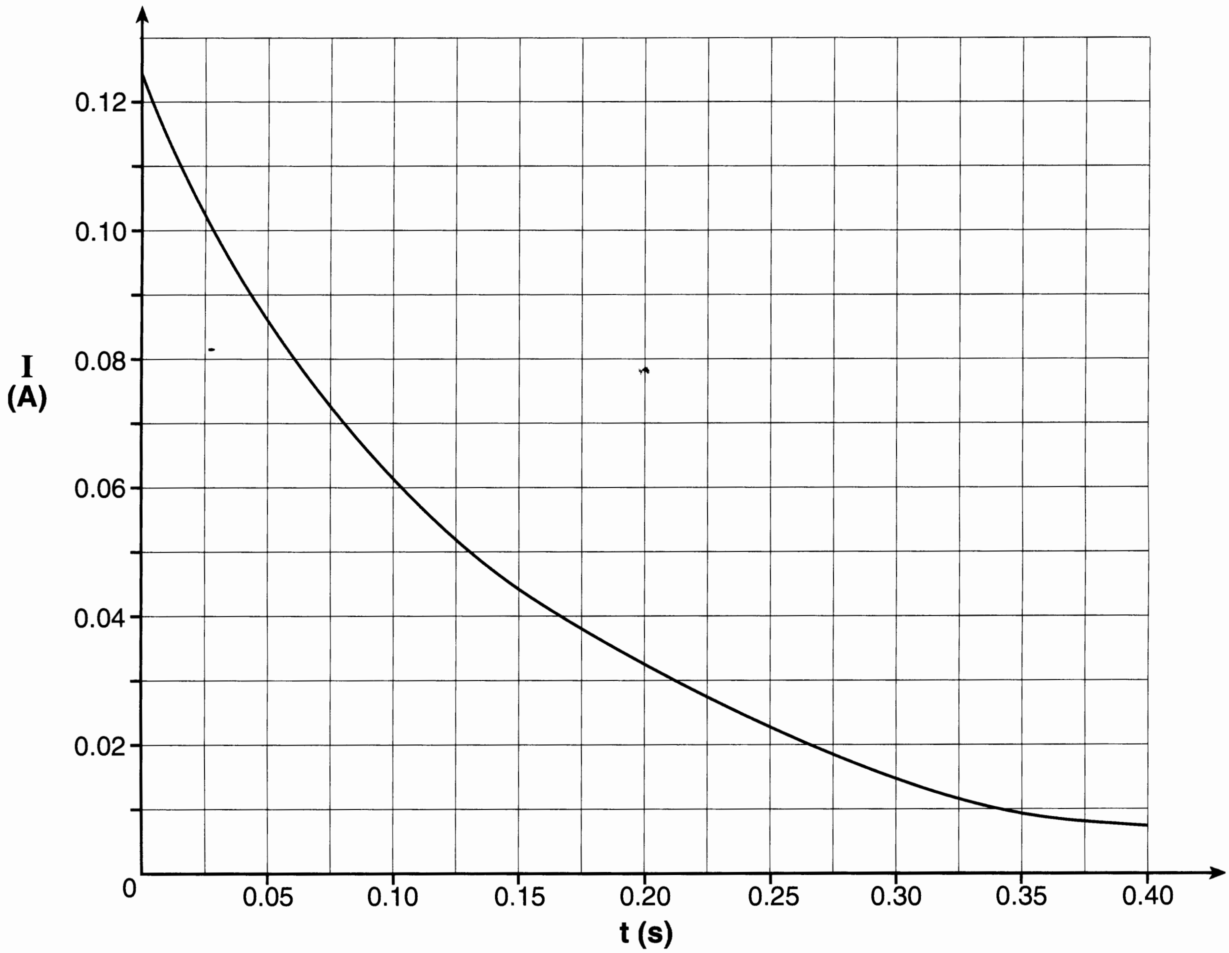


(e) Calculate the dielectric constant of the material that would have to be placed between the plates in order to increase the capacitance to 2.6×10^{-11} F. (1 mark)

A capacitor was charged to 55 V DC. The circuit below shows the capacitor being discharged through a resistor.



The graph below shows the current versus time curve for the discharge of the capacitor.



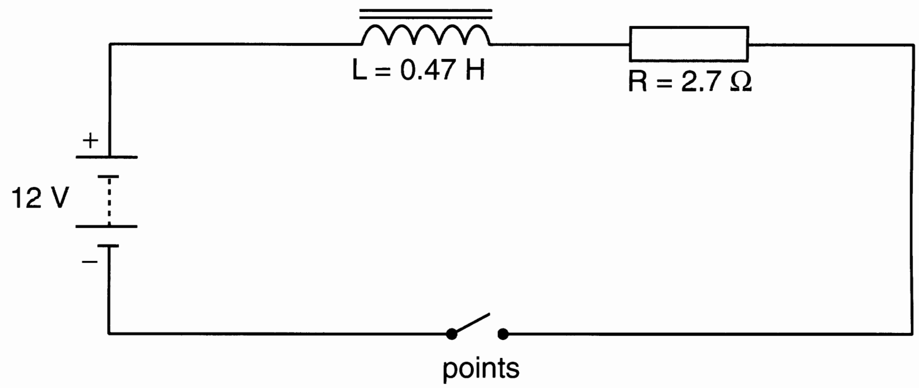
Use the graph to:

(f) Show that the resistance of the resistor is 440 Ω. (2 marks)

(g) Estimate the capacitance of the capacitor. (2 marks)

QUESTION SEVEN: INDUCTANCE (9 marks)

Part of the ignition circuit in Peter's old car is essentially an inductor and resistor connected across a 12 V battery via some contact points which act like a switch that opens and closes as the engine turns. A diagram of the circuit is shown below. The inductor has an inductance of 0.47 H and the resistor has a resistance of 2.7 Ω.



(a) Calculate the steady current in the circuit when the switch is closed. (2 marks)

(b) On the axes provided in your Answer Booklet, sketch a graph of voltage across the inductor against time for the first 1.0 s after the switch is closed. Numerical values are not required for this sketch. (2 marks)

(c) On the axes provided in your Answer Booklet, sketch a graph of the voltage across the **resistor** against time for the first 1.0 s after the switch is closed (and remains closed). Include numerical values for any asymptotes you use and indicate at least one time value. (3 marks)

(d) When the switch is closed and the current has reached a steady state value, how much energy is stored in the inductor? (2 marks)

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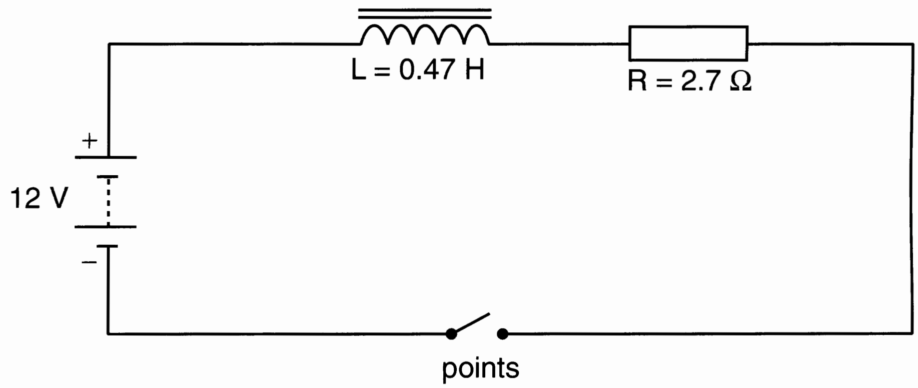

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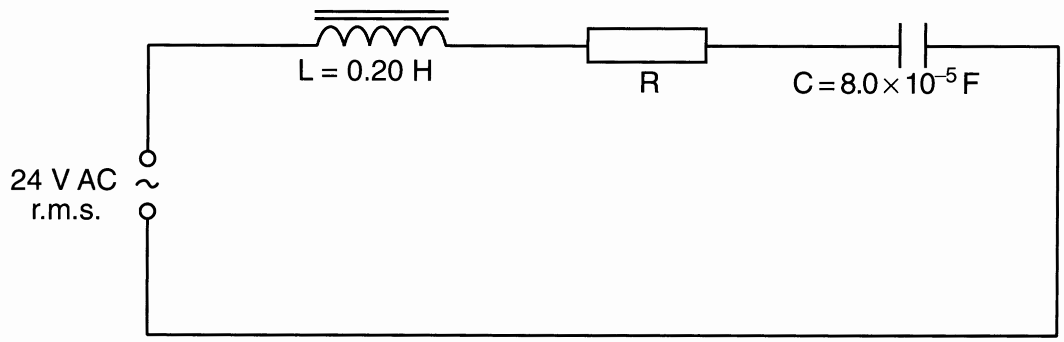
(d) When the switch is closed and the current has reached a steady state value, how much energy is stored in the inductor? (2 marks)

QUESTION EIGHT: AC ELECTRICITY (15 marks)

In a Physics class, Petra set up an LRC series circuit shown below where L = 0.20 H, C = 8.0×10^{-5} F and the variable frequency source voltage was 24 V AC r.m.s.



The frequency of the source is adjusted to the resonant frequency of the circuit.

(a) If the r.m.s. current is 0.060 A, calculate the impedance of the circuit. (2 marks)

(b) What is the resistance of the resistor? (1 mark)

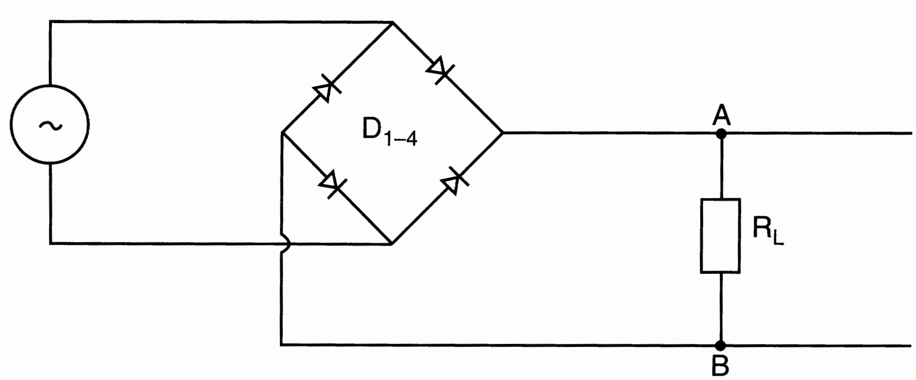
(c) Show that the resonant frequency of the circuit can be calculated to be 39.7887 Hz. (3 marks)

(d) Assuming it has negligible resistance, calculate the r.m.s. voltage across the inductor. (2 marks)

(e) In the space provided in your Answer Booklet, sketch the voltage phasor diagram for this circuit. Numerical values are not required but you must label each phasor. (3 marks)

(f) If the capacitance of the capacitor is increased, would the source voltage phasor then lead or lag the current phasor? Explain your answer. (2 marks)

In Peter's car, the generator produces AC electricity of 13 V peak amplitude which is then full-wave rectified, as shown below.



(g) At certain speeds of the car, the frequency of the AC electricity produced is 75 Hz. On the axes provided in your Answer Booklet, sketch a graph of the voltage across AB against time for two full cycles of the generator. Include numerical values for both voltage and time, but ignore any voltage drop across the diodes. (2 marks)

WAVES

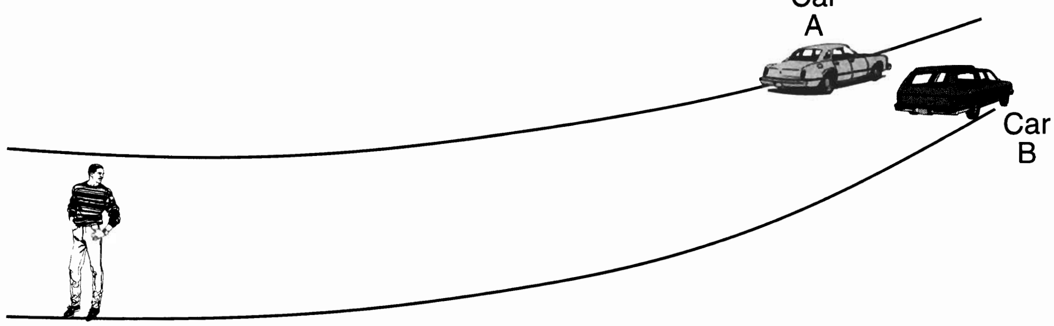
(28 marks; 33 minutes)

QUESTION NINE: SOUND (13 marks)

Part 1

Velocity of sound in dry air = 330 m s^{-1}

Peter could see and hear a stationary car, A, sounding its horn and producing a note of 600 Hz when he was 400 m away from the car, as indicated below.



(a) What is the wavelength of the sound waves being emitted by the horn? (2 marks)

(b) How long does it take the sound waves to travel from the car to Peter? (2 marks)

The other car B, also stationary, then sounded its horn for a few seconds. While both horns were sounding, Peter heard a 6.0 Hz beat.

(c) What possible frequencies could the horn of car B be emitting? (2 marks)

(d) Car A then drove away from Peter with its horn still sounding. He noticed that the pitch of the sound changed. Did it increase or decrease in frequency? Explain your answer. (2 marks)

Part 2

Petra visited an aquarium and saw porpoises playing in a large tank. Petra was told that they emit sounds of ultra-high frequencies and they sense the distance to a fish they are chasing by sending a short burst of sound waves and timing how long the echo takes to return.

(e) A particular burst of sound has a frequency of 100 kHz and takes 0.130 s to make the **round trip** from the porpoise to a fish 99 m away and back. What is the velocity of sound in this water? You may assume the speed of the porpoise and the fish are negligible compared with the speed of the sound wave. (3 marks)

(f) Porpoises have trouble sensing fish distances if there are regions of water of different density between them and the fish. Explain why such fluctuations in density might cause them problems. (2 marks)

QUESTION TEN: ELECTROMAGNETIC RADIATION (15 marks)

Velocity of light in air or a vacuum = 3.0×10^8 m s^{-1}

(a) Calculate the frequency of an electromagnetic wave of a wavelength of 1.0 mm travelling in air. (3 marks)

Two microwave sources, producing electromagnetic radiation with wavelength of 1.0 mm, are separated by a small distance, d, and radiate in phase, as shown below. At a distance of 280 m they produce an interference pattern in which the distance from the central intensity maximum to the first intensity maximum, x, is 2.6 m.

(b) What is the distance, d, between the two sources? (2 marks)

(c) On the diagram in your Answer Booklet, draw the intensity pattern which exists along the line AB. (4 marks)

(d) What happens to the position of the first intensity maximum if the sources are moved further apart? (1 mark)

As Petra was looking through a diffraction grating at a source of white light, she noticed that the third order blue line ($\lambda = 4.6 \times 10^{-7}$ m) and the second order red line ($\lambda = 6.9 \times 10^{-7}$ m) both showed constructive interference at an angle of 30°.

(e) Show that the distance between lines in the diffraction grating Petra was looking through can be calculated to be 2.76×10^{-6} m. (3 marks)

(f) How many lines per metre does the answer in (e) correspond to? (2 marks)

ATOMIC AND NUCLEAR PHYSICS

(25 marks; 29 minutes)

QUESTION ELEVEN: ATOMIC PHYSICS (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 particular photoelectric metal surface has a work function of 4.0 eV (6.4×10^{-19} J) and light of frequency 3.5×10^{15} Hz is incident upon it.

(a) Show that the maximum kinetic energy of an emitted photoelectron can be calculated to be 1.6805×10^{-18} J. (2 marks)

(b) What is the maximum speed of the photoelectron? (2 marks)

(c) If the electron in a hydrogen atom jumps from an excited energy state ($n \leq 6$) down to the n = 2 energy state, what type of photon will be emitted; infrared, visible or ultraviolet? (1 mark)

(d) Two hydrogen atom electrons exist in the same energy state. One jumps down to the n = 3 energy state, the other to the n = 5 energy state. Which of the two emitted photons will have the greater frequency? Explain your answer. (3 marks)

The electron of a hydrogen atom is initially in the ground energy state. It then absorbs a photon which excites it to the n = 4 energy state.

(e) Calculate the change in energy of the electron. (2 marks)

(f) Determine the frequency of the absorbed photon. (2 marks)

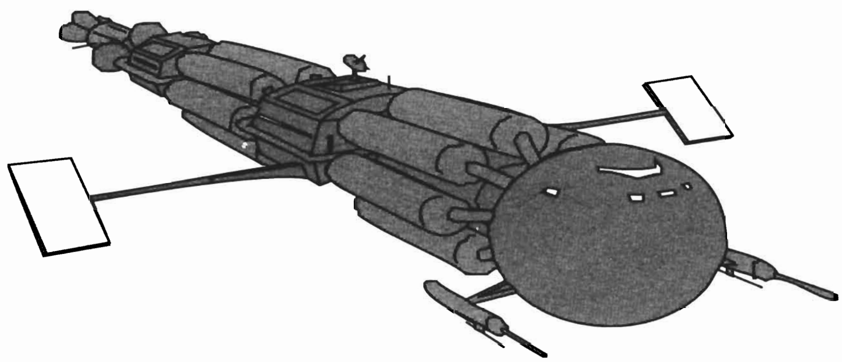
QUESTION TWELVE: NUCLEAR PHYSICS (13 marks)

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}

(a) Polonium $^{212}_{84}Po$ decays to an isotope of lead (Pb) by emitting an alpha particle. Write a full equation for the process including all atomic and mass numbers involved. (3 marks)

(b) The mass deficit for the decay in (a) above is 1.6×10^{-29} kg. Calculate the amount of energy released by the decay. (2 marks)

The nuclear power plant for a future interstellar spaceship must deliver 6.5×10^{8} W when the spaceship is cruising at full speed. Two hundred MeV of energy is produced per fission. On a particular journey the spaceship will be cruising at full speed for 75 days (6.48×10^{6} s).



(c) Convert 200 MeV to joules. (2 marks)

(d) Calculate the total energy required for the 75-day journey. (2 marks)

(e) Calculate the number of fissions that would produce the energy required for the 75-day journey. (2 marks)

(f) Does the total mass of the spacecraft change significantly as the fuel is used up? Explain your answer. (2 marks)