No. 262

New Zealand Qualifications Authority

University Entrance and Bursaries Examination, incorporating The National Bank of New Zealand Ltd Scholarships

PHYSICS: 1995

QUESTION BOOKLET

Time allowed: Three hours
(Total marks: 160)

This paper consists of eleven questions.

ALL questions should be answered.

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

Mechanics	Questions One to Four	56 marks	63 minutes
Wave Motion	Questions Five and Six	32 marks	36 minutes
Electromagnetism	Questions Seven to Nine	48 marks	54 minutes
Photons, Atoms and Nuclei	Questions Ten and Eleven	24 marks	27 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 on page two of the Answer Booklet.

YOU MAY KEEP THIS BOOKLET AT THE END OF THE EXAMINATION

(Turn over

MECHANICS

(56 marks; 63 minutes)

SAFETY ON THE ROAD

QUESTION ONE: A HEAD-ON COLLISION (13 marks)

One of the safety features which have proved successful in cars is the use of seat belts for adults and safety seats for children. Another is having car panels that crumple on impact.

Consider an accident in which a car, travelling at 25 km h^{-1} (6.9 m s^{-1}), runs head-on into a tree. The mass of the car is 950 kg, the mass of the driver is 85 kg and the mass of the front passenger is 65 kg. The average deceleration of the car as it comes to a halt is 55 m s^{-2}. Both passenger and driver have their seat belts tightly fastened.

During the impact:

(a) Calculate the size, and state the direction, of the **change in momentum** of the car and its occupants. (3 marks)

(b) Calculate the total average force exerted on the tree by the car and its occupants. (2 marks)

(c) Calculate the time it took for the car to stop. (2 marks)

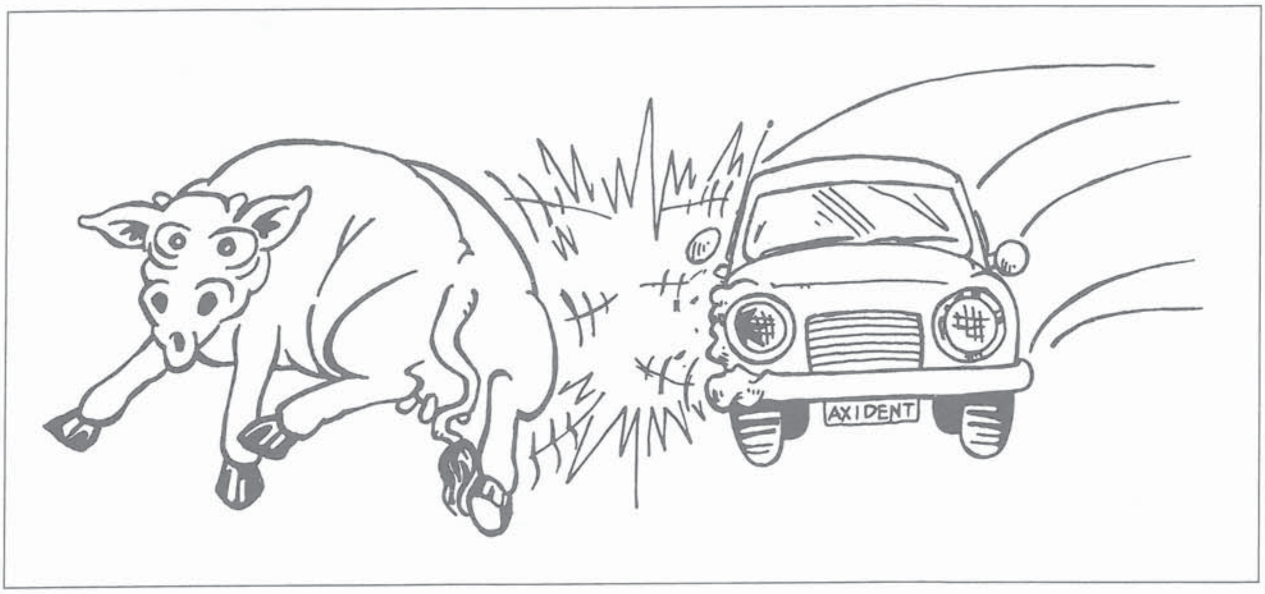
(d) Explain how the **initial** force on the tree might have been different if either of the occupants had **not** been belted in. (2 marks)

The front passenger was holding a small child on her lap. The mass of the child was 13 kg.

(e) During the collision, the passenger tries to prevent the child from flying off her lap. Calculate the size of the force that the passenger would have to apply to the child to do this. (2 marks)

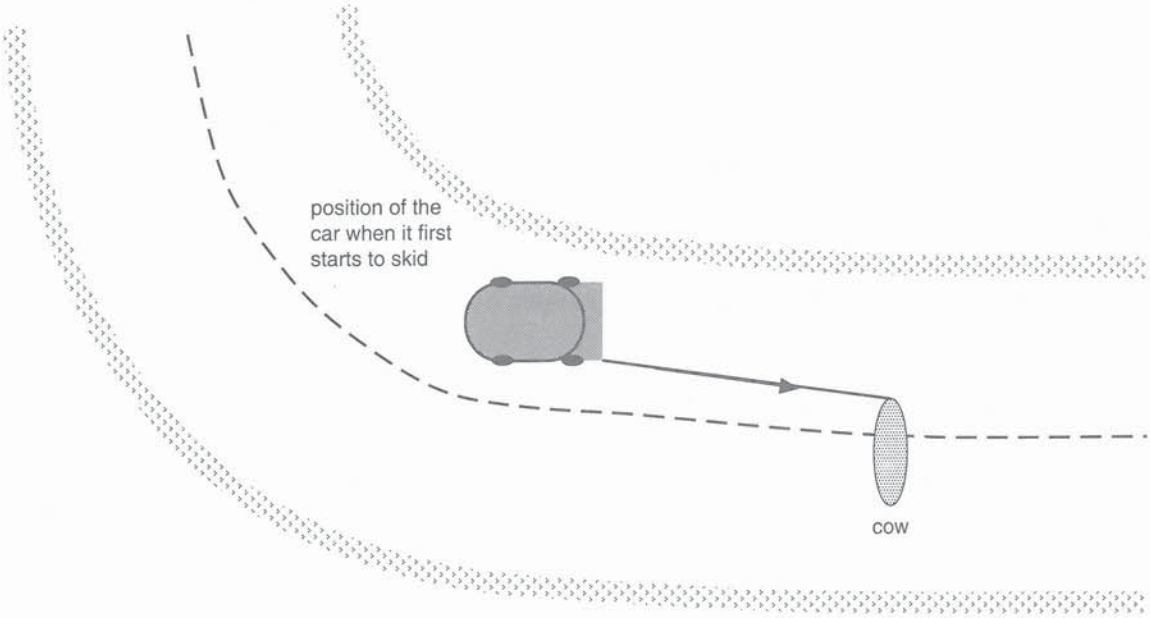
(f) By relating the size of this force to your own **weight** explain whether you think it would be likely that the passenger would be able to keep hold of the child. (2 marks)

QUESTION TWO: A GLANCING COLLISION (19 marks)



One of the potentially dangerous aspects of many New Zealand roads is the presence of stock and other animals on the roads.

A car, of total mass 860 kg, goes round a bend in the road. As the car comes out of the bend the driver sees a cow standing in the middle of the road and slams on the brakes, causing them to lock almost immediately. The car skids out of control straight towards the cow, hits it a glancing blow, and then goes into a spin. The diagram below illustrates the situation.



The Collision:

In your Answer Booklet there is an unlabelled vector diagram that shows the motion of the cow and car **immediately** after the collision.

(a) Label each vector with a description that clearly indicates what it represents. (4 marks)

(b) Because it was a glancing blow, after the impact the car starts to **spin**. Explain why a **glancing** blow causes the car to spin. (2 marks)

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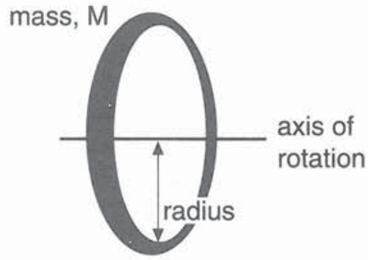
The Wheel:

For the purpose of estimating the rotational inertia, a freely rotating wheel (assumed to include the hub assembly) can be modelled by a hollow cylinder in which all the mass is concentrated at the rim.



The mass, M, of the wheel is 25 kg and its radius is 29 cm.
The radius of the model is 25 cm.

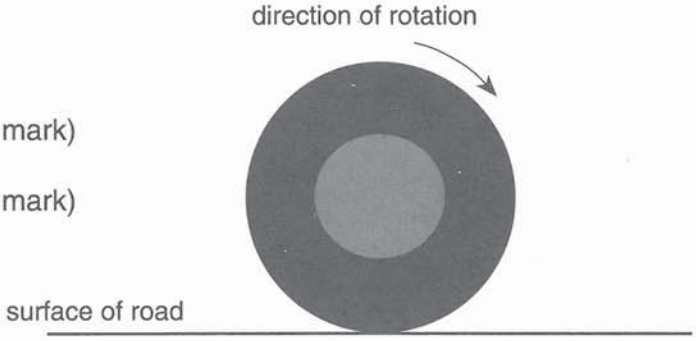
(c) Explain why the radius of the model is **less** than the true radius of the wheel. (2 marks)

(d) Use the formula $I = MR^2$ to calculate the rotational inertia of the wheel. (2 marks)

The diagram shows the wheel as it rolls along the surface of the road.

(e) (i) On the diagram in your Answer Booklet, draw a vector showing the horizontal force of the road acting on the rolling **tyre** as the brakes are applied. (1 mark)

(ii) State what causes this horizontal force. (1 mark)



The Skid:

The speed of the car at the moment the brakes are first applied is 90 km h^{-1} (25 m s^{-1}). For the first 0.85 s after the brakes are applied the car decelerates without skidding. During this time the angular speed of the wheels decreases from 86 rad s^{-1} to 72 rad s^{-1}. After this time the wheels stop rotating (i.e. they lock and stay locked) and skidding starts to occur.

(f) Calculate the average angular deceleration of the wheels during the first 0.85 s after the brakes are applied. (3 marks)

(g) Show that the speed of the car when it first starts to skid is 21 m s^{-1}. (2 marks)

(h) The speed of the car when it first starts to skid is greater than its speed when it hits the cow. Explain what happens to the lost linear kinetic energy. (2 marks)

QUESTION THREE: STOPPING DISTANCES (10 marks)

The road code states that when following another vehicle you must drive at a speed that enables you to stop in the length of clear lane you can see in front of you. It suggests that there is a proportional relationship between the stopping distance and the speed of travel.

Some enthusiastic senior physics students (all of whom have a full driving licence) decide to investigate this relationship by finding out if the stopping distance really is proportional to the speed value.

One of the students has a very obliging mother who allows the use of her car for the investigation and they all go off to a local air strip where there are long straight strips of sealed roadway.

The first thing they do is to write a plan for an experiment that they could carry out, using the car they have available to them, to test the hypothesis that:

> *When the driver has to bring a car safely to a halt in as short a distance as possible, the distance it takes* ***while braking*** *is proportional to the speed of the car before the brakes are applied.*

Answer the following questions which relate to their plan.

(a) What are the independent and dependent variables that relate to the hypothesis? (2 marks)

(b) It is important that the experiment is a fair test. The students must identify other possible variables. Write down **two** of these and for each one state what they could do to ensure the experiment is a fair test. (4 marks)

Establishing the exact position of the car at the instant the brakes are applied is one of the challenging aspects of the experimental plan.

One suggestion is that a line is drawn across the roadway and one of the students should raise his arm at the instant the front tyres cross the line. The driver should brake as soon as she sees the arm signal and stopping distances would then be measured from this line.

(c) If this method were to be adopted, explain the main inaccuracy in the measured stopping distance. (2 marks)

(d) Explain how data obtained from the investigation would be used to test the hypothesis. (2 marks)

(Turn over

OSCILLATIONS

QUESTION FOUR: SIMPLE HARMONIC MOTION OF AN ELECTRON (14 marks)

When alternating current flows in a conductor the movement of an electron in the wire can be modelled by simple harmonic motion. Consider an electron for which the angular frequency, ω, of its simple harmonic motion is 314 rad s^{-1}.

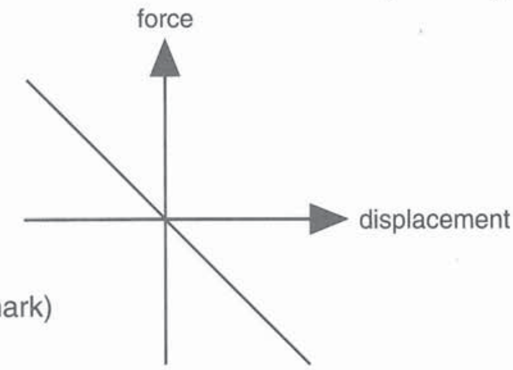
(a) If the maximum speed of the electron is 2.4×10^{-4} m s^{-1}, calculate the amplitude of the motion of the electron. (2 marks)

(b) If the percentage uncertainty in the amplitude is 3%, calculate its absolute uncertainty. (2 marks)

The maximum acceleration of an electron is given by $a = -\omega^2 A$.

(c) If the percentage uncertainty in the frequency of the alternating current is 1%, calculate the percentage uncertainty in the maximum acceleration. (2 marks)

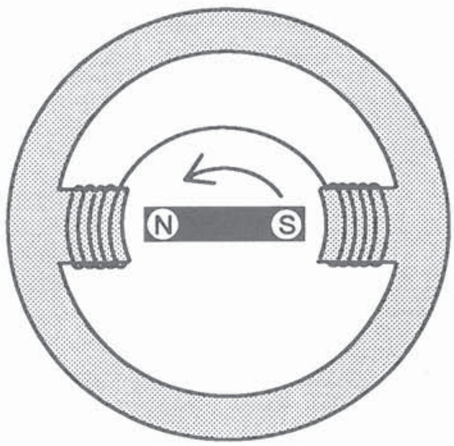
(d) The diagram in your Answer Booklet shows the path along which an electron travels. Mark on the diagram the position(s) where the acceleration of the electron has its maximum numerical value. (2 marks)



The diagram shows a theoretical graph of the induced force on an electron against the displacement from its equilibrium position.

(e) Give a physical explanation for why the slope is **negative**. (1 mark)

(f) Explain why the graph line is **straight**. (1 mark)



In electric generating stations alternating electric current is produced when a magnet spins within a coil of wire.

Each complete revolution of the magnet causes the electrons to execute one cycle of their simple harmonic motion.

(g) State the formula relating the angular frequency of the electrons with the frequency of rotation (cyclic frequency) of the magnet. (1 mark)

(h) The diagram in your Answer Booklet again shows the path along which an electron travels. A position is marked at which the electron's displacement, y, from its equilibrium position is half the amplitude, A, of its motion. Calculate the angle through which the magnet will turn while the electron is travelling from its equilibrium position to the position marked. (3 marks)

WAVE MOTION

(32 marks; 36 minutes)

QUESTION FIVE: THE DIDGERIDOO (17 marks)

The didgeridoo is a wind instrument used by Australian Aboriginals.

It is a hollow pipe open at both ends, about one and a half metres long and usually made of bamboo or a eucalyptus branch.

(a) The diagram in the Answer Booklet models the instrument by drawing it as a uniform tube 1.50 m long. Sketch the fundamental standing wave (showing particle displacement) which is set up when the pipe is blown. Label any nodes, N. (2 marks)

(b) State whether this standing wave is transverse or longitudinal. (1 mark)

(c) Find the wavelength of the wave. (2 marks)

The didgeridoo has no holes, keys or valves like orchestral wind instruments have, but overtones or harmonics may be sounded by overblowing (blowing more strongly).

(d) Use the diagram in your Answer Booklet to show the standing wave when the instrument is blown in such a way that the first overtone (second harmonic) can be heard. (1 mark)

(e) Given that the speed of sound in air is 335 m s^{-1}, calculate the frequency of the first overtone (second harmonic) produced from a 1.50 m long didgeridoo. (3 marks)

A second didgeridoo sounds its fundamental note of frequency at 106 Hz. The fundamental frequency of the original instrument is 110 Hz.

(f) Which is the longer of the two instruments? Explain your answer. (2 marks)

(g) If the original instrument and the second instrument are both sounded together at the same loudness, describe the sound that would be heard. (Note that a full response to this question will include a numerical answer.) (2 marks)

The original instrument, being sounded at its fundamental frequency of 110 Hz, is transported on a truck as part of a parade. The truck, moving at 5.0 m s^{-1}, drives past a stationary tourist. She notices that there is a distinct difference in the note heard just before and just after the truck passes her.

(h) What characteristic of the note is different and in what way does it change? (2 marks)

(i) The apparent frequency, f', of the note heard from the didgeridoo as the truck approaches can be calculated using the relationship: $f' = \frac{vf}{v'}$. State what each of the speeds v and v' represents.

(2 marks)

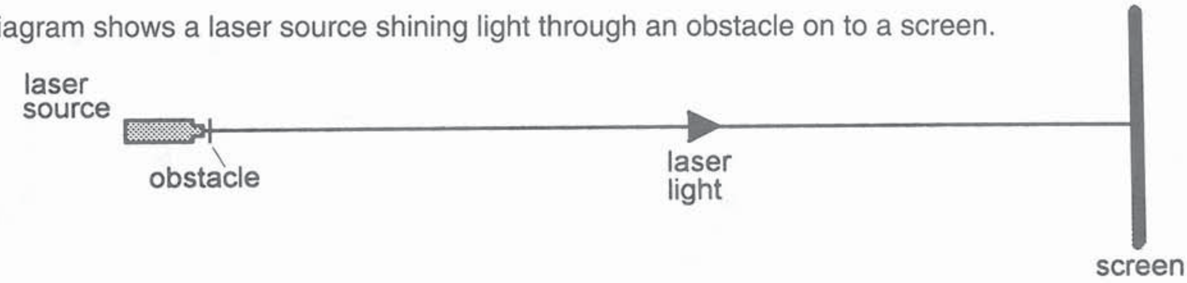
(Turn over

QUESTION SIX: DIFFRACTION (15 marks)

In experiments using light, laser light is often used because it is almost monochromatic, is coherent and can be focused sharply.

(a) Explain what is meant by monochromatic. (2 marks)

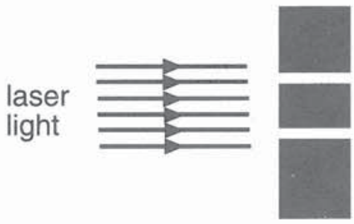
The diagram shows a laser source shining light through an obstacle on to a screen.



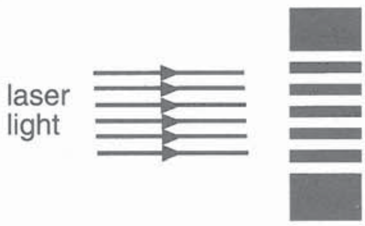
Two different obstacles are used in turn. The diagrams (i) and (ii) below show a magnified view of these obstacles.

(b) In the spaces provided in your Answer Booklet draw what you should expect to **see** on the screen in each case, clearly indicating both the similarities and differences between the two situations.

(i) Double narrow slits

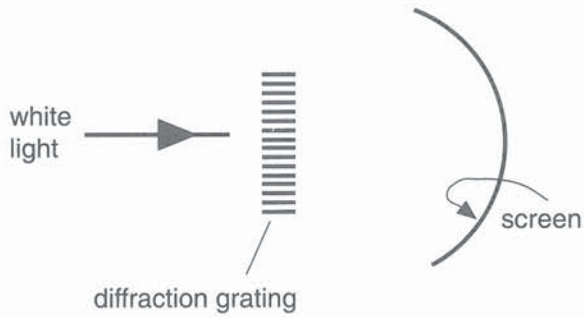


(ii) Multiple slits



(4 marks)

(c) White light consists of a range of wavelengths, the wavelength of red light being longer than the wavelength of blue. The diagram shows white light being shone through a diffraction grating on to a curved screen.



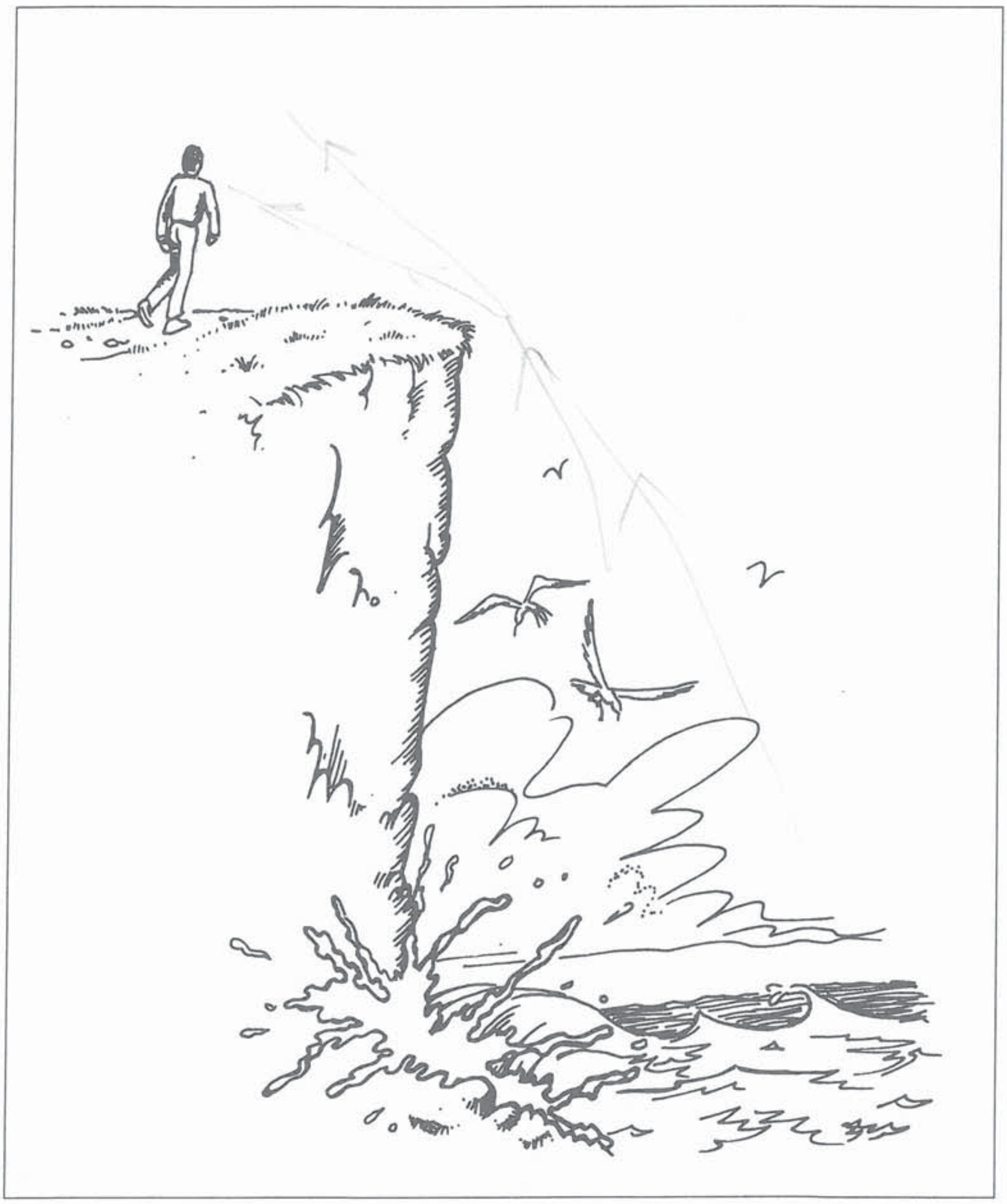
(i) In the space provided in your Answer Booklet draw and label what you should expect to **see** on the screen. (Note that a front view of the screen shows it as being flat, not curved.) (3 marks)

(ii) State **two** essential features of a diffraction grating. (2 marks)

(iii) A particular frequency of red light has a wavelength of 700 nm ($1\ nm = 10^{-9}\ m$). Calculate the angle through which it is diffracted in the first order after passing through a diffraction grating that has 6000 lines per centimetre. (2 marks)

You are walking along a path on a cliff above a surf beach. The path is not quite on the cliff edge, so you cannot actually see the surf, nor can you see seagulls that are flying below the cliff.

(d) Explain why you **can** hear the pounding of the surf, but you **cannot** hear the cries of the gulls.
(2 marks)

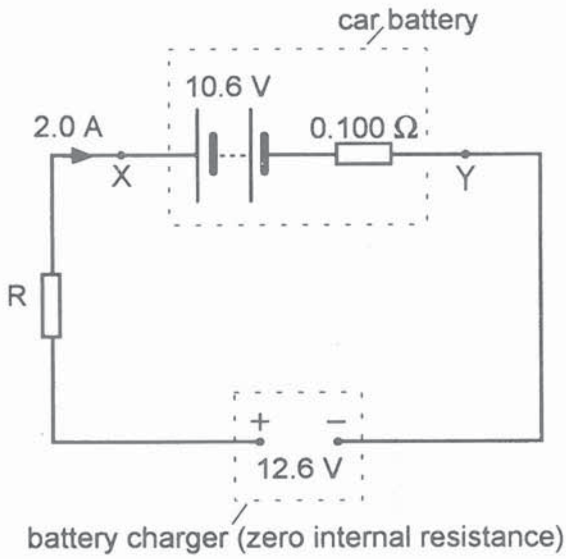


ELECTROMAGNETISM

(48 marks, 54 minutes)

QUESTION SEVEN: RECHARGING A CAR BATTERY (15 marks)

A car battery has become discharged (flat). In its discharged state it has an e.m.f. of 10.6 V and a total internal resistance of 0.100 Ω. A battery charger that delivers 12.6 V between its terminals is used to recharge the car battery, using an initial current of 2.0 A. The diagram below shows a circuit diagram of the charging arrangement including the external resistor, *R*, used to limit the initial charging current to 2.0 A.



The voltage across the terminals, XY, of the car battery when the circuit in the diagram is first connected is 10.8 V.

(a) Explain why the voltage across the battery terminals is **greater** than the battery e.m.f. (2 marks)

(b) Show that the value of the resistance, *R*, that is needed to limit the initial charging current to 2.0 A is 0.90 Ω. (2 marks)

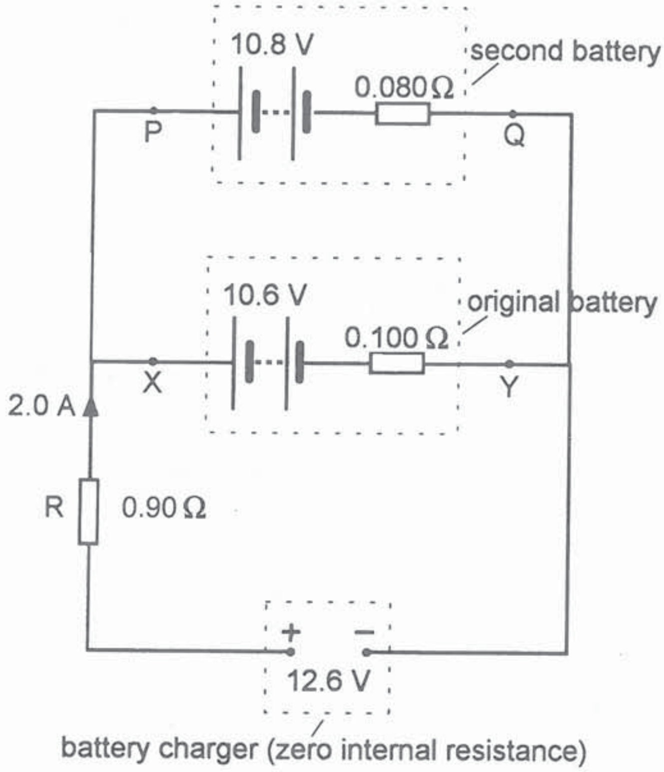
Electrical energy is being stored in the car battery while it is being recharged.

(c) Calculate the amount of electrical energy being stored per second as the battery initially recharges. (3 marks)

As the car battery recharges, its e.m.f. increases to 12.6 V and its internal resistance reduces to an insignificant value.

(d) Explain what happens to the size of the charging current as the charging progresses. (2 marks)

A second discharged car battery with e.m.f. 10.8 V and internal resistance 0.080 Ω is connected in parallel with the original battery, which is also in its **discharged** state. The same current limiting resistor as determined in (b) is used. The new arrangement is shown in the diagram below.



When the connections are **first made** the current supplied by the battery charger is still 2.0 A.

(e) (i) Calculate the voltage across the resistor, *R*. (1 mark)

(ii) Hence show that the voltage across PQ is 10.8 V. (1 mark)

(iii) Explain why the current in the second battery is zero. (1 mark)

As soon as the current through the original battery starts the recharging process, current also starts to flow through the second battery and it too starts to recharge. After a while the voltage across XY rises to 10.9 V. However, neither the e.m.f. of the second battery nor the internal resistances of either battery have changed significantly.

(f) By considering the voltages around the loop PQYXP, or otherwise, calculate the current which now flows through the second battery. (3 marks)

QUESTION EIGHT: "HIGH TECH" CAPACITORS (12 marks)

The technology of making capacitors is now well developed. Certain types can be used to provide a supply voltage in portable electronic equipment for a short period while the equipment's batteries are being replaced. The photograph shows one such "high tech" capacitor. The markings on its side state:

5.5 V, 0.47 F

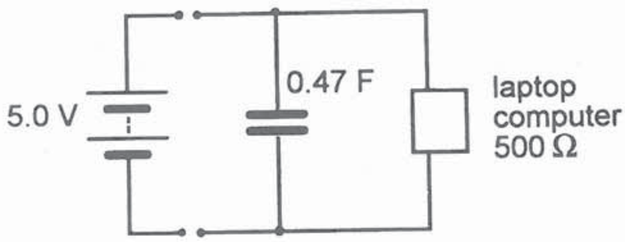
(a) (i) State what the symbol F stands for on the side of the capacitor. (1 mark)

(ii) What physical quantity is measured in this unit? (1 mark)

The stated value 5.5 V is the maximum voltage that can be safely applied across the capacitor. Many computer circuits, however, operate from a supply voltage of 5.0 V.

(b) Calculate the electrical energy stored in this capacitor when charged to a voltage of 5.0 V. (3 marks)

The circuit below shows the above capacitor used with a laptop computer.



While the 5.0 V batteries are removed and are being replaced, the computer has an effective resistance of 500 Ω (5.0×10^2 Ω). 10 minutes (600 s) after the batteries have been disconnected the voltage across the capacitor is about 0.4 V.

(c) On the axes provided in your Answer Booklet plot the two points whose co-ordinates you know from information already given. Sketch a graph to show how the voltage across the capacitor varies with time after the batteries have been removed. (3 marks)

(d) The computer will continue to work properly while the voltage supplied by the capacitor is above 3.0 V. Use your graph to estimate the time the person changing the batteries has before the capacitor voltage falls below 3.0 V. (1 mark)

The capacitance in the circuit is doubled by connecting a second identical capacitor.

(e) Explain whether this will give the person more or less time to change the batteries. (2 marks)

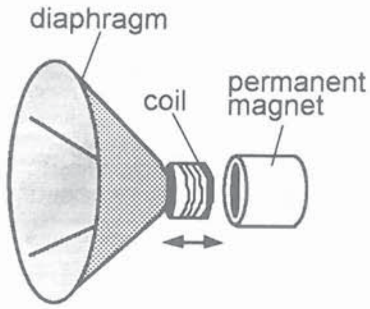
(f) In the box in your Answer Booklet draw the two capacitors connected in such a way that the capacitance in the circuit has been doubled. (1 mark)

QUESTION NINE: A LOUDSPEAKER CIRCUIT (21 marks)

The diagram alongside shows the parts of a moving coil loudspeaker.

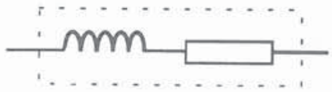
The coil is connected to a variable voltage AC supply.

When a current passes through the coil a magnetic field is produced and the coil is either attracted to, or repelled from, the permanent magnet depending on which way the current flows.



(a) The diagram in your Answer Booklet shows the coil with the direction of the current marked. Draw on the diagram the direction of the magnetic field in the coil. (2 marks)

The coil of a particular loudspeaker is made from a long length of fine copper wire, the resistance of which is 7.0 Ω. The coil can therefore be modelled as a pure inductor and pure resistor in series.



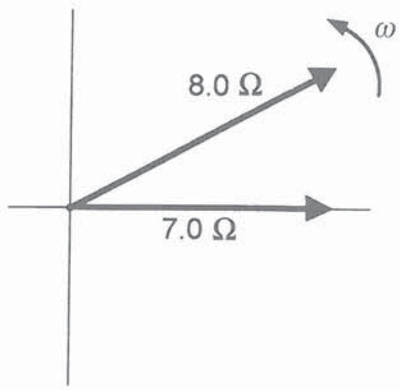
(b) If the current in the coil changes, explain why a voltage will be induced across the inductive component of the model. (2 marks)

(c) If the current in the coil is decreasing, state the direction (with respect to the supply voltage) of the induced voltage. (1 mark)

The coil has an impedance of 8.0 Ω when the supply voltage has a frequency of 1 000 Hz (1.00×10^3 Hz).

(d) Calculate the angular frequency, ω, for a frequency of 1.00×10^3 Hz. (2 marks)

The vector diagram alongside shows the impedance and resistance of the loudspeaker for a frequency of 1.00×10^3 Hz.



(e) A copy of the vector diagram is printed in your Answer Booklet. Draw on it a vector that represents the inductive reactance, X_L, of the coil. (2 marks)

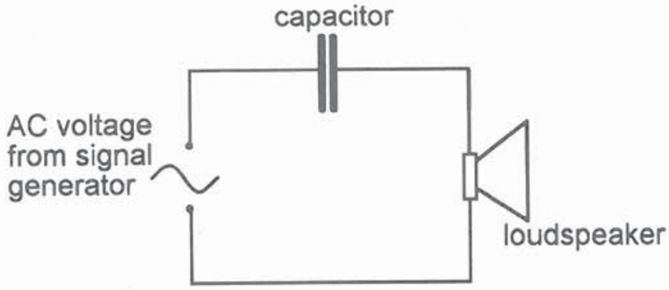
It can be shown that the magnitude of X_L is 3.9 Ω.

(f) Show that the numerical value of the self inductance, L, of the coil is 6.2×10^{-4}. (2 marks)

(g) State the unit for inductance. (1 mark)

In normal operation the variable voltage supply would be an amplifier. The amplifier can be modelled by a variable frequency signal generator and a capacitor.

The diagram alongside shows a circuit diagram of the signal generator and capacitor connected in series with the loudspeaker.



Since the loudspeaker is a combination of both inductance and resistance, the circuit shown is actually a combination of inductance, capacitance and resistance (i.e. a series LCR circuit).

(h) State a condition necessary for resonance to occur in a series LCR circuit. (1 mark)

(i) State the phase relationship between current and supply voltage at resonance. (1 mark)

(j) When the frequency of the AC voltage from the signal generator approaches the resonant frequency, explain what happens to the current in the circuit. (2 marks)

(k) If the capacitor in the circuit has a value of 100 μF (1.0×10^{-4} F), use the relationship $\omega L = \frac{1}{\omega C}$ as a starting point to show that the resonant frequency of the circuit is 640 Hz. (3 marks)

An alternating current in the loudspeaker coil causes the diaphragm to vibrate. This produces sound waves which travel through the air. At resonance the loudness of the sound from the loudspeaker increases. Ideally, the system should ensure that **all** audible frequencies (20 Hz to 20 000 Hz) from the loudspeaker have the **same** loudness.

(l) Explain how the capacitance in the circuit would need to be changed in order to achieve this. (2 marks)

PHOTONS, ATOMS AND NUCLEI

(24 marks; 27 minutes)

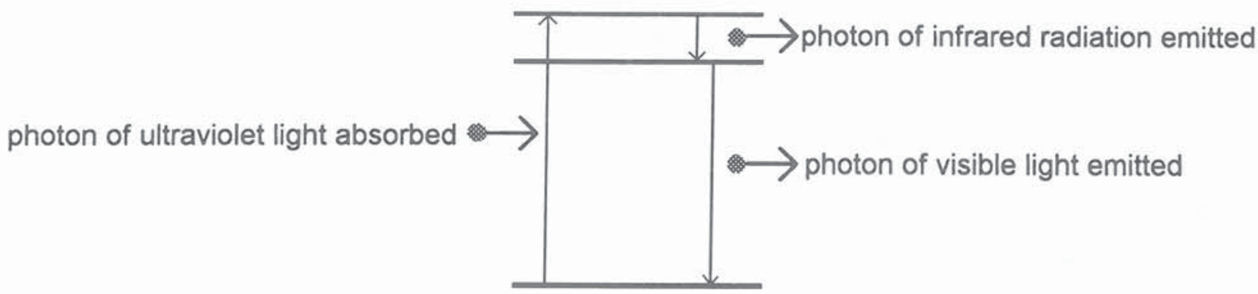
QUESTION TEN: SPECTRA: FLUORESCENT LIGHTS (9 marks)

Planck's constant, $h = 6.63 \times 10^{-34}$ J s
Speed of light, $c = 3.00 \times 10^{8}$ m s^{-1}

In a fluorescent light, a filament at one end is heated to a high temperature so that the filament emits electrons. These electrons are then accelerated by an applied voltage, causing them to collide with atoms of mercury vapour contained within the tube. As a result of these collisions, the energy levels of the mercury atoms are raised. When they return to their normal energy levels, the mercury atoms emit photons of ultraviolet light of wavelength 220 nm (*1 nm = 10^{-9} m*).

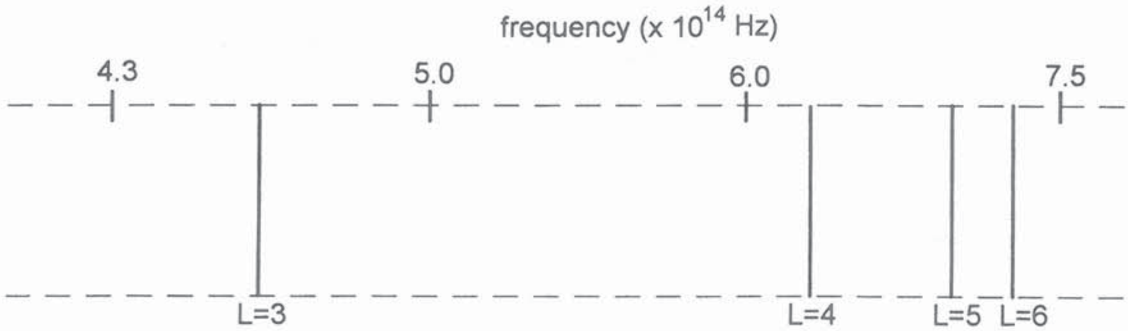
(a) Calculate the energy of the photons of ultraviolet radiation within the tube. (3 marks)

The UV photons emitted by the mercury atoms strike the phosphor coating on the inside of the fluorescent tube. The phosphor absorbs the photons and emits visible light by "fluorescence". The following diagram illustrates a possible fluorescence of an atom of phosphor.



(b) What do the horizontal lines in the above diagram represent? (1 mark)

The spectrum from a high quality fluorescent lamp is mainly continuous, similar to sunlight. However, the visible spectrum from a glowing low pressure hydrogen discharge tube consists of four lines as shown in the diagram below.



(c) Explain carefully why light of only certain frequencies (colours) is emitted by hydrogen. (3 marks)

(d) Using the information given in the diagrams above, explain which of the lines L = 3, 4, 5 or 6 is the red line. (2 marks)

(Turn over

QUESTION ELEVEN: THE SUN (15 marks)

Speed of light, $c = 3.00 \times 10^8 \text{ m s}^{-1}$

The sun's energy comes from the conversion of hydrogen into helium at a temperature of 1.5×10^7 °C deep within the core of the sun.

(a) (i) Name this process. (1 mark)

(ii) Explain why the process will only happen at very high temperatures. (2 marks)

When two light nuclei (e.g. hydrogen) combine to form a heavier nucleus (e.g. helium), the **rest** mass of the final nucleus is less than the combined **rest** mass of the original nuclei.

(b) (i) Use the appropriate conservation law to explain this loss of mass. (2 marks)

(ii) Explain why the nuclear masses are referred to as rest masses. (2 marks)

Every second, inside the sun, 564 million tonnes of hydrogen are converted into 560 million tonnes of helium (plus a negligible mass of other particles). *(1 tonne = 10^3 kg)*

(c) Calculate the sun's power in megawatts *(1 MW = 10^6 W).* (4 marks)

A process similar to the nuclear reaction within the sun can be performed artificially.

This process uses two isotopes of hydrogen. These isotopes, deuterium $^{2}_{1}H$ and tritium $^{3}_{1}H$, react together at very high temperatures — a thermonuclear reaction.

Such a process can be described by the following equation:

$$^{2}_{1}H + ^{3}_{1}H \rightarrow ^{4}_{2}He + ? + \text{energy}$$

(d) (i) State the atomic number and mass number of the unknown particle required to balance the equation. (2 marks)

(ii) What is the name of this particle? (1 mark)

(iii) Both the isotopes deuterium and tritium can be extracted either directly or indirectly from sea water. Why is sea water a useful source of the isotopes? (1 mark)