No. 262

New Zealand Qualifications Authority

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

PHYSICS: 1996

QUESTION BOOKLET

Time allowed: Three hours
(Total marks: 160)

This paper consists of eight questions.

ALL questions should be answered.

The total marks assigned to the 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:

Linear and Rotational Mechanics	Questions One and Two	36 marks	43 minutes
Oscillations and Wave Motion	Questions Three to Five	44 marks	52 minutes
Electromagnetism	Questions Six and Seven	48 marks	57 minutes
Photons, Atoms and Nuclei	Question Eight	24 marks	28 minutes

Check that this Question Booklet contains pages 2 – 18 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

LINEAR AND ROTATIONAL MECHANICS

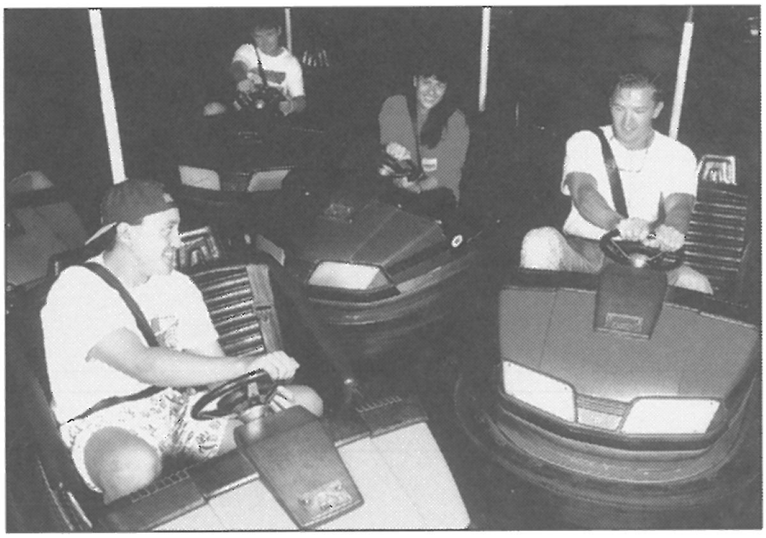
(36 marks; 43 minutes)

Use the value g = 9.80 m s^{-2}.

FUN PARKS

QUESTION ONE: DODGEMS AND THE LOG FLUME (18 marks)

Dodgems are electrically powered steerable vehicles. The fun comes from creating collisions.



One dodgem has a mass of 170 kg and the driver has a mass of 85 kg. The dodgem is travelling at its maximum speed of 3.0 m s^{-1}.

(a) Calculate the value of the momentum of this dodgem, including the driver, when it is travelling at its maximum speed. (2 marks)

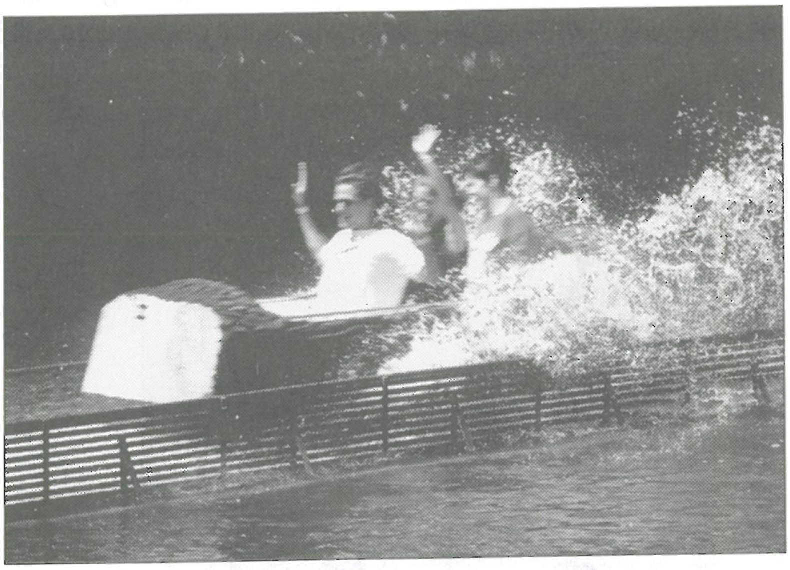
The driver makes a head-on collision with a second dodgem which is travelling at constant speed directly towards the first one. The size of the momentum of the second dodgem is the same as that of the first.

(b) Assuming that the first dodgem and its driver stops immediately on impact, describe and explain what happens to the motion of the second dodgem the instant after the collision has occurred. (2 marks)

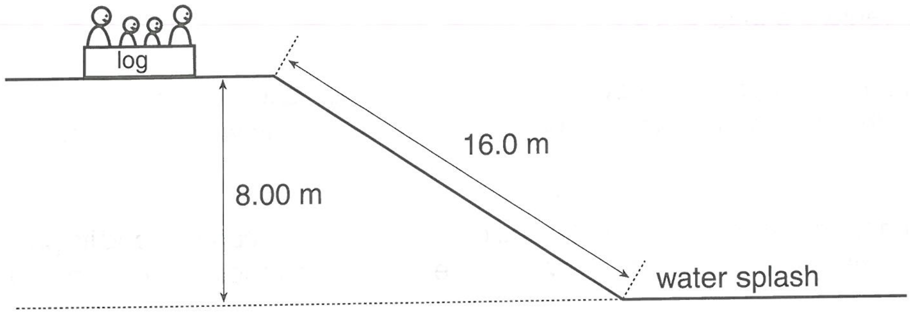
(c) Calculate the kinetic energy of the first dodgem, including the driver, before it collides with the second dodgem. (2 marks)

(d) State what happens to the energy of the dodgems in this collision. (1 mark)

In a log flume ride, passengers sit in a hollowed-out plastic "log" and are carried around a series of curves and falls in a channel of flowing water.



The main fun feature is a water splash as shown in the following diagram.



The log accelerates over the whole length of the slide shown.
A log is stationary at the top of the slide. The total mass of the log and its passengers is 311 kg.

(e) (i) Use energy considerations to calculate the maximum velocity that the log and passengers **could** have when they reach the bottom of the slide. (3 marks)

(ii) Explain why the **actual** velocity would be less than this. (1 mark)

The diagrams for questions (f) and (g) in your Answer Booklet show the log (plus passengers) when it is halfway down the ride.

(f) Draw clear arrows naming and showing the direction of the three main forces acting on the log. (3 marks)

(g) Draw one arrow to show the direction of the resultant force on the log at this point. (1 mark)

(h) The actual velocity of the log (plus passengers) is 11.5 $m\,s^{-1}$ at the bottom of the slide. Calculate the average value of the force exerted on the log by the water to bring the log and its passengers to a stop in 1.50 s. (3 marks)

(Turn over

QUESTION TWO: THE ROLLER COASTER AND BUMPER BOATS (18 marks)

A roller coaster is a carriage which runs at high speeds on rails. The track is built into a series of steep slopes and sharp curves as well as complete vertical loops where the passengers will be travelling upside down.

The mass of a roller coaster carriage is 1.00×10^3 kg.
It carries 20 passengers who have a total mass of 1.50×10^3 kg.
The radius of the vertical loop is 4.77 m.

Suppose the carriage is "looping the loop" (ie. travelling in a vertical circle). The reaction force of the rail on the carriage when the carriage is at the bottom of the loop is R_B, and when the carriage is at the top of the loop is R_T.

(a) On the diagrams in your Answer Booklet, the gravity force of the carriage and its passengers, F_g, has been drawn in. Draw labelled arrows to show the direction of the reaction force when the carriage is at the

(i) bottom of the loop (R_B),

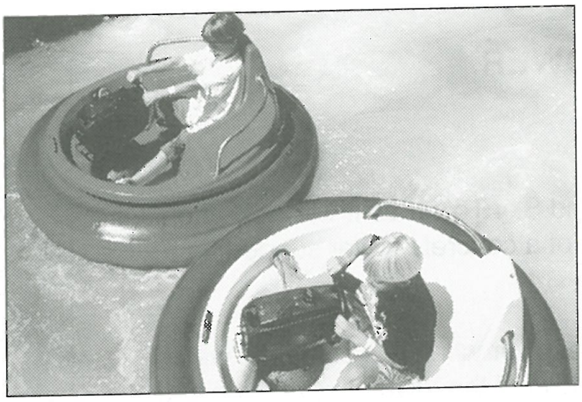
(ii) top of the loop (R_T). (2 marks)

(b) Write down the equation relating the resultant force, F, at the **top** of the loop to F_g and R_T. (1 mark)

(c) Use the equation from (b) and the data given above to calculate the **minimum** speed at the top of the loop which would ensure that safety devices are not needed to prevent the carriage from leaving the track or the passengers from falling out.

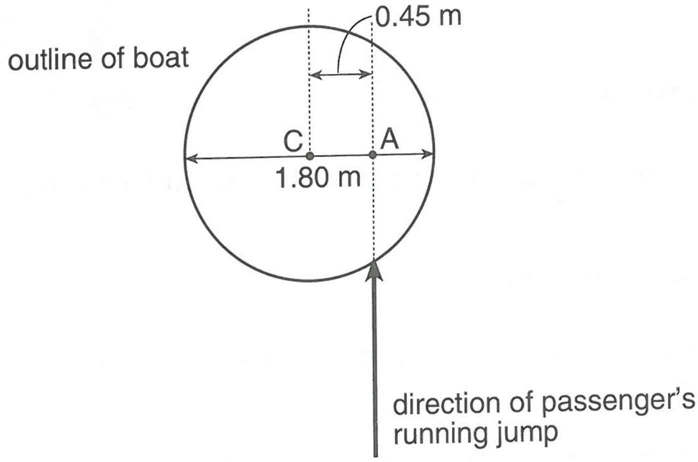
(3 marks)

Bumper boats are circular inflatable boats which are driven by a low power unit. The main attraction is to collide with other boats to create spin.



One empty bumper boat has a mass of 52 kg and a diameter of 1.80 m and is floating freely in a stationary position.

An intending passenger, of mass 58 kg, takes a run in the direction shown by the arrow in the diagram below and jumps into the boat, landing at point A. Assume that the centre of mass of the boat is at its centre C.



(d) Show that the distance of the centre of mass of the system of boat and passenger from the centre of the boat has an unrounded value of 0.237272 m. (2 marks)

(e) Describe fully the motion of the boat and passenger immediately after the passenger has landed at point A. (3 marks)

The passenger was travelling in a straight line with a horizontal speed of 2.0 m s^{-1} when he landed in the boat. The angular velocity of the boat immediately after the passenger has landed in it is 3.16 rad s^{-1}.

(f) Calculate the angular momentum of the passenger about the **centre of mass** of the system at the instant he lands in the boat. (3 marks)

The boat spins for 6.0 seconds before coming to rest.

(g) Calculate the value of the angular deceleration of the boat, assuming that it is uniform. (2 marks)

(h) The average frictional torque that the water exerts on the boat to stop it is 4.11 N m. Calculate the rotational inertia of the system of boat and passenger. (2 marks)

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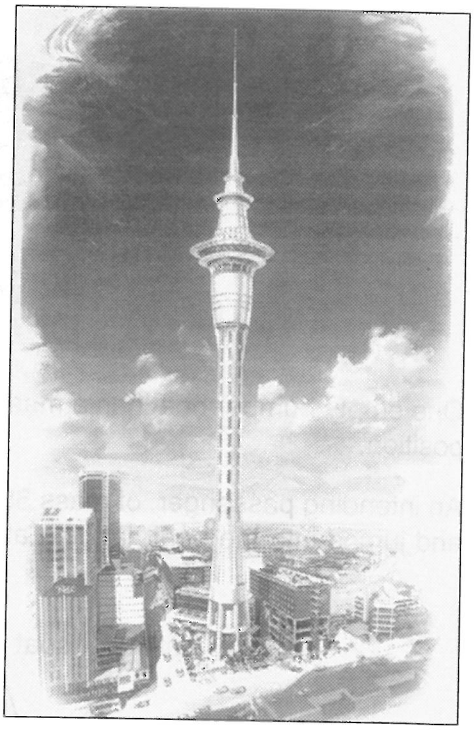
OSCILLATIONS AND WAVE MOTION

(44 marks; 52 minutes)

THE AUCKLAND SKY TOWER



The illustration shows the Auckland Sky Tower as it will look when it is finished. Its construction consists of a concrete tower supporting a flexible mast.

The top of the concrete part of the tower when it is complete will be 217 m above street level. In a high wind the tower sways back and forth in simple harmonic motion.

QUESTION THREE: OSCILLATIONS (14 marks)

In a particular wind the amplitude of oscillation at the top of the **concrete** part of the tower is 0.80 m. The natural period of oscillation is 7.5 s.

(a) Calculate the angular frequency of the oscillations. (2 marks)

(b) Show that the maximum acceleration of a person standing on top of the tower is 0.56 m s^{-2}. (2 marks)

(c) On the axes in your Answer Booklet sketch **one cycle** of graphs of

(i) displacement against time

(ii) acceleration against time

for the motion of the top of the tower. Assume that at $t = 0$ the tower is at its zero displacement position. (6 marks)

The top of the tower is reached by a lift which travels up the centre of the tower.

(d) Why does the maximum acceleration of the person, due to the oscillations, decrease as they descend in the lift? (1 mark)

Oscillations of the top of the tower which exceed an amplitude of 1.0 m are monitored.

(e) If the amplitude of oscillation of the top of the tower is 1.1 m, using a reference circle or otherwise, calculate for how long during each oscillation the displacement of the top of the tower from its equilibrium position is greater than 1.0 m.

(3 marks)

QUESTION FOUR: WAVES (16 marks)

A gusting wind will set the top of the Sky Tower oscillating and a standing wave will be established in the length of the tower. A standing wave occurs when two waves of the same frequency travel through each other in opposite directions.

(a) Explain how these **two** waves can occur in the tower. (1 mark)

(b) Is the wave longitudinal or transverse? (1 mark)

(c) State two factors which might affect the amplitude of the standing wave. (2 marks)

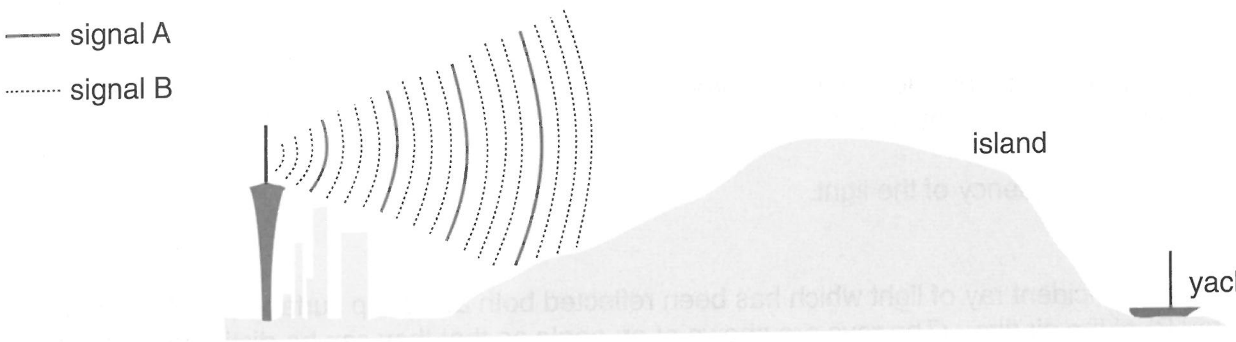
One of the most important aspects in the design of the Sky Tower was earthquake proofing. In many high rise buildings two types of earthquake proofing are used. The first allows the surface of the ground to slide horizontally beneath the building (base isolation). The second consists of thick compressible buffers which the building sits on.

(d) What characteristics of earthquake waves makes it necessary to have both types of proofing? (1 mark)

(e) Explain how each type of proofing might help. (2 marks)

(f) Because the main period of oscillation of earthquake waves is about one second, the Sky Tower, in fact, needs neither of these types of proofing. Explain why this is so. (2 marks)

The mast on the top of the Sky Tower will be used to broadcast waves (signals) of different frequencies. The diagram shows the wave crests of two broadcast signals.



(g) Explain which of the two signals is in the microwave range of frequencies and which is in the short wave radio range. (2 marks)

(h) Explain which of the two signals, A or B, would be more likely to be picked up by a receiver on a yacht anchored behind an island. (2 marks)

One of the conditions for two waves to interfere with each other is that they must be travelling through each other. The two signals fulfil this condition.

(i) Explain why neither signal would be distorted by interference with the other signal. (1 mark)

The diagram in your Answer Booklet shows a displacement / position graph for one complete wave of signal A.

(j) On the same set of axes, sketch the displacement position graph for **signal B** for the same instant in time. The amplitude of the wave has been marked on the displacement axis. (2 marks)

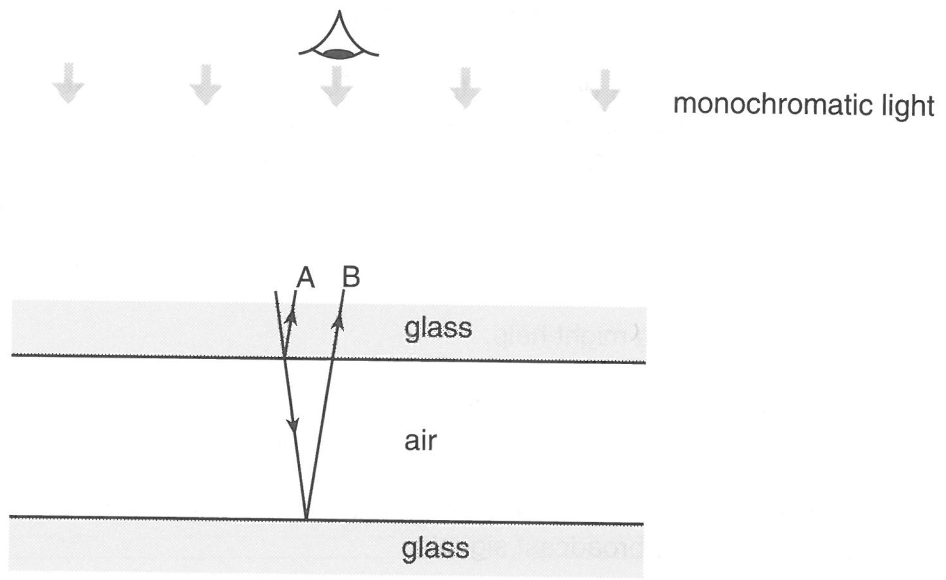
(Turn over

THE HUBBLE TELESCOPE

QUESTION FIVE: INTERFERENCE (14 marks)

Speed of light, $c = 3.0 \times 10^8$ m s^{-1}

If two microscope slides are placed one on top of the other, a thin film of air will be trapped between them. If the surfaces of the slides are perfectly plane, the air film will have exactly parallel sides as shown in the diagram below.



The only light shining on to the slides is monochromatic yellow (of wavelength 6.0×10^{-7} m) and it is directed normally (at right angles) to the surfaces.

(a) Calculate the frequency of the light. (2 marks)

Also shown is an incident ray of light which has been reflected both at the top surface (ray A) and the bottom surface (ray B) of the air film. (The rays are shown at an angle so that they can be distinguished from each other. In fact, the rays are all at right angles to the surfaces. Also, the thickness of the air film has been grossly exaggerated so that the rays can be seen.)

The diagram is a side view of the air film being observed from above.

Two waves can interfere only if they are travelling through each other. Rays A and B fulfil this condition.

(b) State what **other** condition must apply for the two rays to interfere **destructively.** (1 mark)

The total phase difference between the two reflected rays, A and B, as they enter the eye, is exactly $5\frac{1}{2}$ cycles.

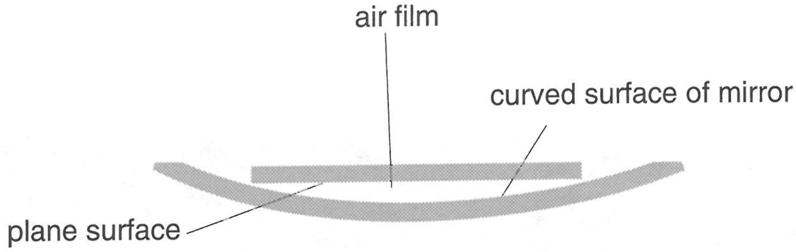
(c) Calculate how much further ray B will have travelled compared with ray A when they come together again. (2 marks)

(d) Calculate the thickness of the air film. (1 mark)

(e) Describe what colour would be observed when the air film has this thickness. (1 mark)

When it was first established in orbit, the Hubble Space Telescope did not work as well as it should have because the curvature of the giant mirror was inaccurate by a very small amount.

One way of testing the accuracy of the curvature of a mirror is illustrated in the diagram below.



An air film is created between the curved surface of the mirror and a perfectly plane surface. The diagram in your Answer Booklet shows the pattern of circular bright and dark interference fringes which will be seen from above if monochromatic light is incident, normally, on a film of this shape.

(f) What characteristic of the film causes a **pattern** of fringes to be created? (1 mark)

(g) Explain why the fringes are not **evenly** spaced. (1 mark)

(h) In what way would the pattern change if:

(i) the curvature of the mirror decreased? (1 mark)

(ii) the mirror was not smoothly curved, but its surface was distorted? (1 mark)

One of the research projects for which the telescope is providing data is the improvement in the accuracy of the value for the rate at which the galaxies are moving away from us. This rate is measured from the observed change in the colour of the light emitted by galaxies. A moving galaxy provides a moving source of light.

(i) What property of light determines its colour? (1 mark)

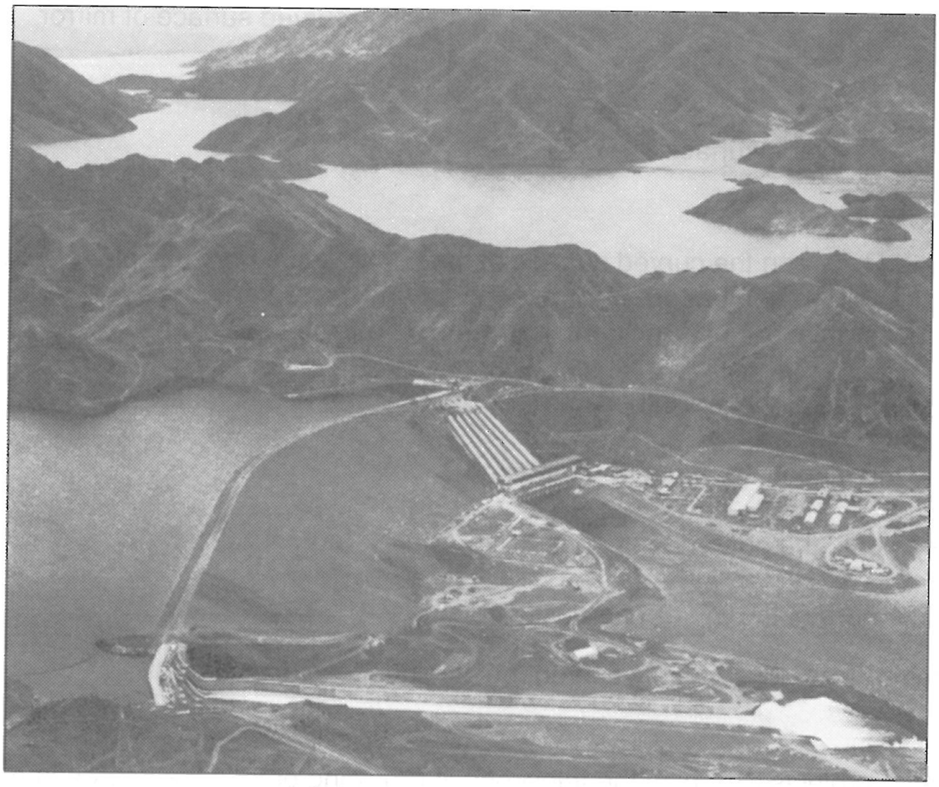
(j) Towards which end of the spectrum will the change in colour occur? Explain your answer. (2 marks)

ELECTROMAGNETISM

(48 marks, 57 minutes)

QUESTION SIX: ELECTRICITY SUPPLY IN NEW ZEALAND (34 marks)

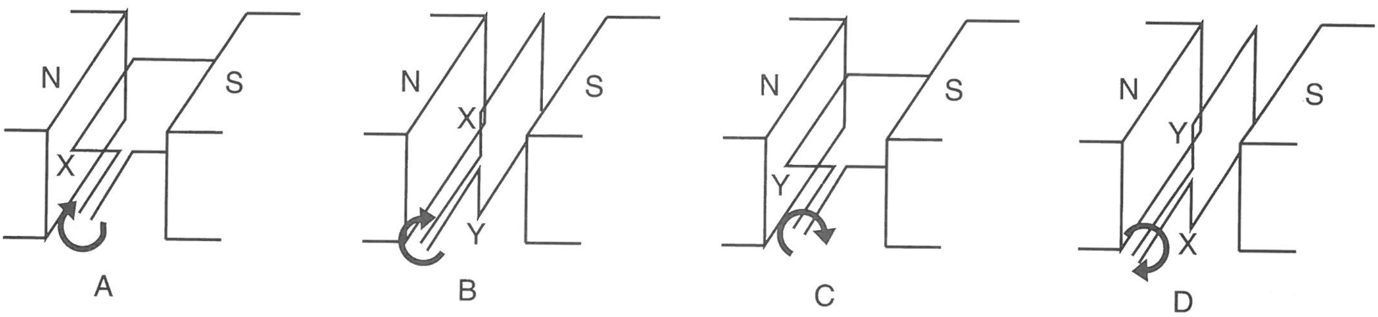
Generation (12 marks)



The Benmore Power Station generates 540 MW of electricity for supply around New Zealand. The power station operates by water rushing down the penstocks from the top of a hydro-electric dam to the power station at the bottom. This water then turns a turbine which is connected to a generator causing it to rotate.

(a) What energy **change** has occurred to the water before it hits the turbine? (1 mark)

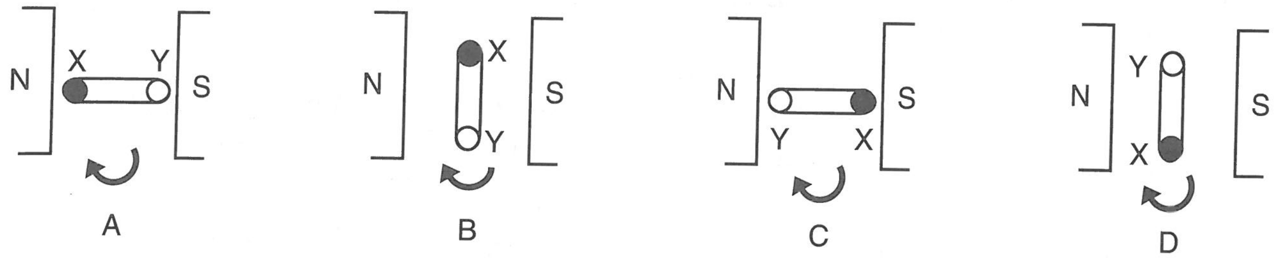
A generator can be modelled as a **square** loop of wire rotating at a frequency of 50 Hz between two magnets. (An actual generator has rotating magnets and a stationary coil but the principle is the same.) A generator produces alternating current.



The diagram above shows a reduced scale model generator in which the side length of the loop is 50 cm and the magnets produce a uniform field of strength 1.2 T between them.

(b) Calculate the area of the loop. (1 mark)

The diagrams below show the loop, end on, at four different positions (A, B, C and D) in one complete cycle.



(c) At which two positions is the **magnitude** of magnetic flux in the loop maximum? Explain why the flux is **maximum** at those positions. (2 marks)

(d) Calculate the value of the maximum magnetic flux that occurs in the loop. (3 marks)

The maximum voltage that is induced in the loop is 95 V.

(e) On the graph paper in your Answer Booklet carefully sketch a graph of **voltage** against time for one complete cycle. The labels on the time axis correspond to the positions A, B, C and D in the diagrams above. (3 marks)

(f) The maximum voltage produced by the Benmore Power Station generator is 2.5×10^3 V. Calculate the rms voltage of the generator. (2 marks)

Distribution (11 marks)

Electrical energy is distributed around New Zealand by cables carried on large pylons. The cables are generally made from aluminium.

Material	**Resistivity (Ω m)**	**Density (kg m^{-3})**	**Melting Point (°C)**
Aluminium	2.55×10^{-8}	2700	660
Copper	1.67×10^{-8}	8900	1083
Iron	9.85×10^{-8}	7900	1539

Some information about iron, copper and aluminium is given in the table above. Use this information to answer questions (g) and (h).

(g) Which of these materials is the best conductor? Explain your answer. (2 marks)

(h) Explain why aluminium is used in power cables even though it is not the best conductor. (1 mark)

An aluminium power cable is being constructed to carry electrical energy from Benmore to Christchurch, a distance of 220 km ± 5%. The cable has a radius of (49.0 ± 0.5) mm.

The formula for calculating the resistance of a length of cable is $R = \frac{\rho L}{A}$.

(i) Calculate the percentage uncertainty in the radius. (1 mark)

(j) Calculate the percentage uncertainty in the resistance. (2 marks)

An engineer uses a calculator to calculate the resistance of the complete length of power cable. Her calculator reads 0.7437394.

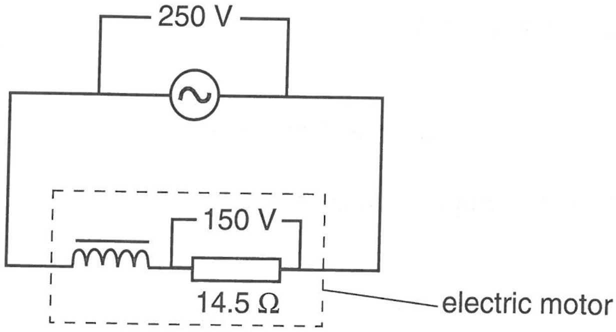
(k) State the value of the resistance of the power cable with its absolute uncertainty. (3 marks)

(l) The power cable carries electricity at 220 000 V. Explain the advantage of using this high voltage rather than a lower 240 V. (2 marks)

Use (11 marks)

A large amount of electrical energy is used in industry to drive electric motors. An electric motor has a large coil of wire and hence acts as a high value inductor. The coil of wire also has resistance, so an electric motor can be thought of as an inductor and a resistor in series.

An electric motor is connected to a fixed frequency 250 V AC supply. The circuit diagram below shows the electric motor as an inductor in series with a resistor.



(m) The phasor diagram in your Answer Booklet shows the supply voltage and the voltage across the resistor. Draw the phasor for the inductor voltage. (2 marks)

(n) Show that the value of the inductor voltage is 200 V. (1 mark)

The resistance of the electric motor is 14.5 Ω.

(o) Calculate the current in the electric motor. (2 marks)

(p) For the situation shown in the diagram, calculate the reactance of the inductor. (2 marks)

It is more energy efficient to run an AC circuit with the supply voltage in phase with the supply current.

(q) **Explain** what you could add to the electric motor circuit to make the current and voltage of the supply run in phase. (2 marks)

The fixed frequency supply is now replaced with a variable frequency supply set to the frequency of the original supply.

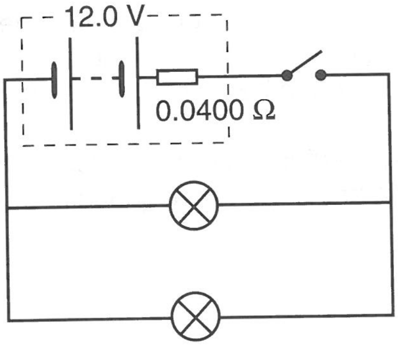
(r) If the frequency of the AC supply is **increased**, state what will happen to

(i) the reactance of the inductor, (1 mark)

(ii) the voltage across the resistor. (1 mark)

QUESTION SEVEN: THE ELECTRICAL SYSTEM OF A CAR (14 marks)

The starter motor (10 marks)

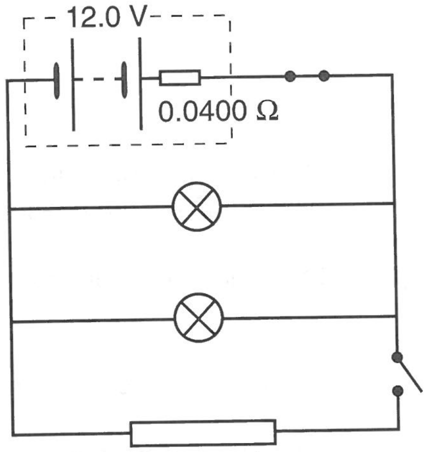


The driver of a car turns on the car headlights before the engine is started. The car headlight circuit can be considered to be the same as the circuit shown in the diagram alongside.

The battery has an emf of 12.0 V and an internal resistance of 0.0400 Ω. Each light bulb has a working resistance of 4.22 Ω.

(a) Show that the total resistance of the complete circuit is 2.15 Ω. (2 marks)

(b) Calculate the current flowing through each light bulb. (2 marks)



The driver of the car then uses the starter motor to start the engine while the headlights are still on. In the circuit diagram shown alongside, the starter motor has been shown as a resistor.

The starter motor of the car needs about 50 A to work effectively.

(c) Explain why the starter motor must have a low resistance. (1 mark)

(d) Explain why the starter motor is connected in **parallel** with the headlights rather than in series. (1 mark)

The current drawn from the battery when the lights and starter motor are all connected is 61.5 A.

(e) Show that the voltage across the terminals of the battery, while the starter motor and lights are all drawing current, is 9.54 V. (2 marks)

(f) Use the information given in part (e) to explain why the headlights go dim when the driver starts the starter motor. (2 marks)

The distributor (4 marks)

The distributor in a car makes the spark plug in the engine create a spark when a switch (called the contact breaker) in the circuit is opened. One part of the distributor is a capacitor (often called a condenser) which is connected across the contact breaker. The purpose of the capacitor is to store charge and hence reduce the possibility of a spark occurring across the open contact breaker while the induced voltage in the circuit is very high.

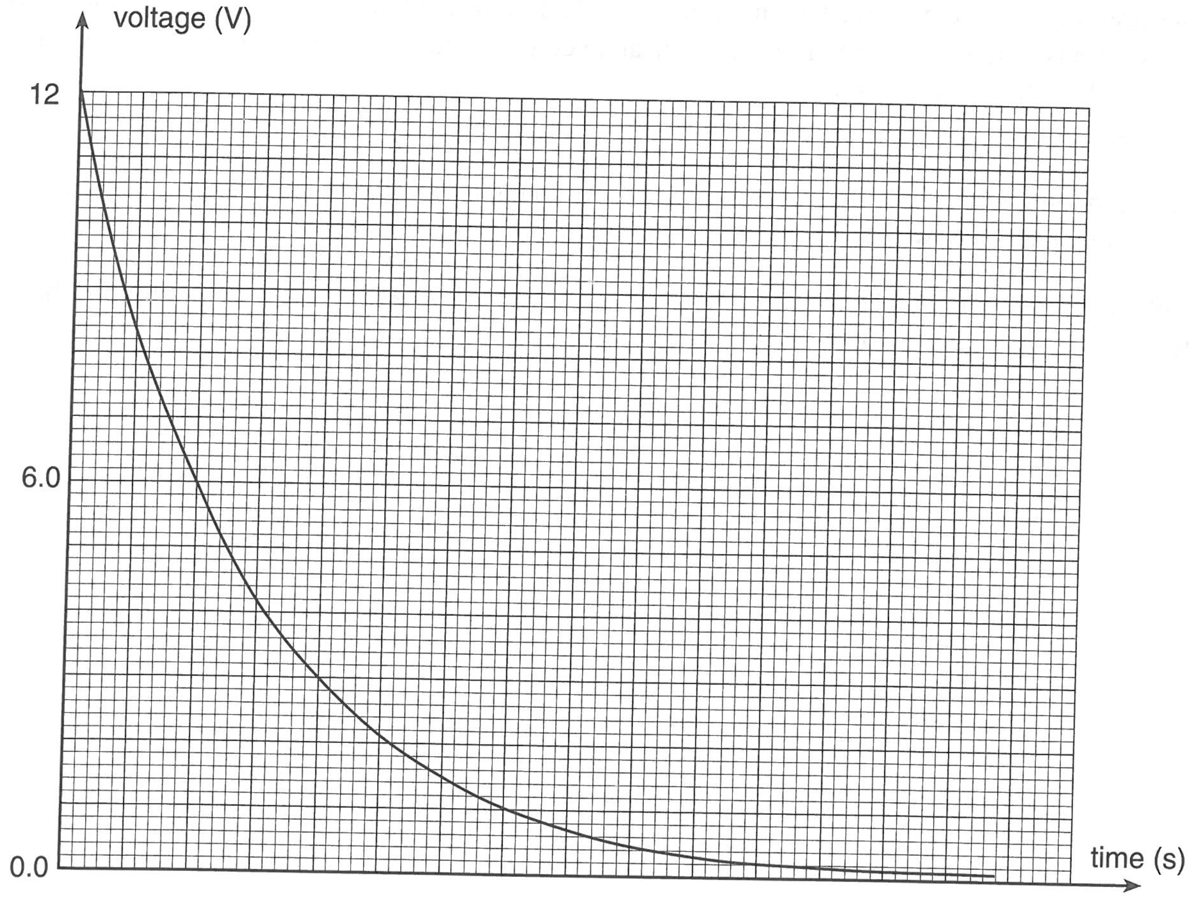
A typical capacitor in a distributor is 0.20 μF.

(g) Calculate the charge stored on the capacitor when it is charged up to 12 V. (2 marks)

Once the spark plug has sparked, the capacitor must discharge ready for the next spark.

The greater the capacitance of the capacitor, the greater the amount of charge which can be stored and so the more effective the capacitor is in reducing the possibility of an unwanted spark.

The voltage across the capacitor is measured with an oscilloscope. The contact breaker is closed to discharge the capacitor and the following graph of voltage against time is obtained.



(h) On the axes of the graph in your Answer Booklet, **sketch** what the graph would look like if the capacitor had a capacitance of 0.40 μF. (2 marks)

PHOTONS, ATOMS AND NUCLEI

(24 marks; 28 minutes)

QUESTION EIGHT: COSMIC RAYS (24 marks)

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

Read the following information about cosmic rays.

> Cosmic rays include electrically charged particles (mainly protons) which originate from the sun and other sources in space. When such cosmic radiation is absorbed in the earth's upper atmosphere, unstable high speed elementary particles called muons can be produced.
>
> The lifetime of a muon before it decays into something else is 2.20 μs. (1 μs = 10^{-6} s).
>
> A muon travelling vertically down towards the surface of the earth at 2.97×10^{8} m s^{-1} would cover a distance of 650 m before it decayed.
>
> Muons are known to be produced at an altitude of 4.60 km (4.60 km above the surface of the earth). This distance is **much** greater than the distance an average muon travels before it decays, yet muons are detected on the surface of the earth.

(a) Calculate the time it would take the muons to travel a distance of 4.60 km, assuming that they are travelling vertically downwards at a constant speed of 2.97×10^{8} m s^{-1}. (2 marks)

(b) Explain carefully why the lifetime of a muon travelling at this speed is many times greater than the lifetime of a stationary muon. (2 marks)

Cosmic rays penetrate the earth's atmosphere most deeply at the North and South Pole. They often collide with, and transfer their energy to, atoms of nitrogen or oxygen, causing the emission of visible light. These dramatic effects are the *Aurora Borealis* (Northern Lights) or *Aurora Australis.*

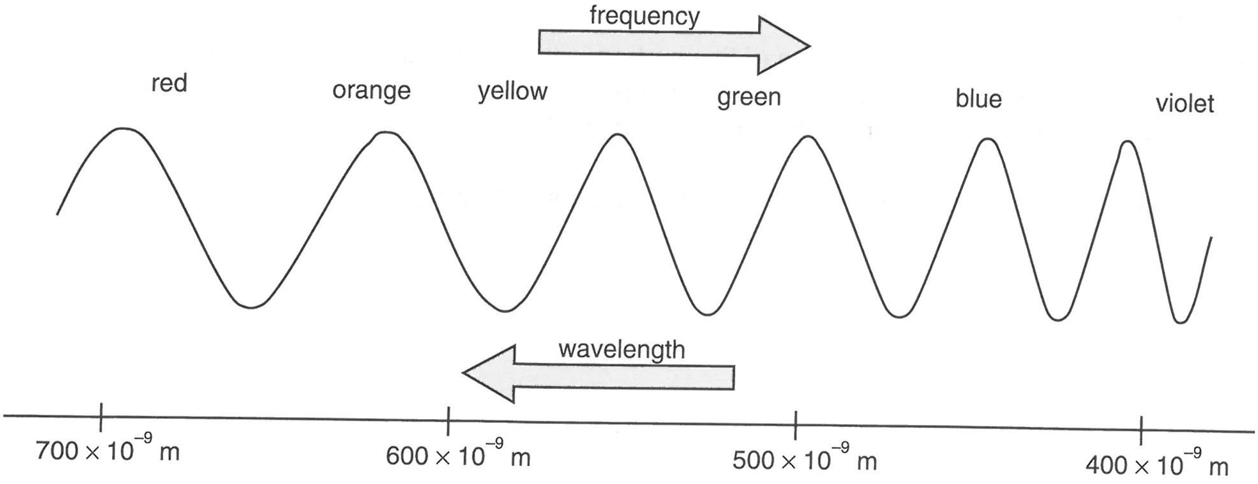
The energy transferred to the nitrogen or oxygen atoms raises their electrons to higher energy levels. When these electrons return to lower energy levels they emit electromagnetic radiation. One of the common colours of auroras is greenish-yellow. It is emitted by oxygen atoms and has a frequency of 5.379×10^{14} Hz.

(c) Calculate the wavelength of this colour. (2 marks)

(d) Show that 3.57×10^{-19} J of energy are emitted from an oxygen atom undergoing the electron energy change which produces this colour. (2 marks)

A different colour is emitted when the electrons of oxygen atoms in a particular excited state return to their ground state energy. These electrons lose 3.16×10^{-19} J of energy.

(e) Use the diagram below to find out what this colour is. Show your reasoning. (3 marks)



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The energies of the two emissions mentioned in parts (d) and (e) are the outcome of a single electron dropping **in two stages** to the ground state.

(f) The diagram in your Answer Booklet shows three lines which represent the three energy levels involved. The energy value of the ground state is shown. Label the other two lines with their energy values. (3 marks)

Another component of an aurora is photons emitted from excited hydrogen atoms where the electron drops from the first excited state.

The Rydberg formula can be used to calculate the wavelength of these emitted photons:

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

where $S = 1$
and $R = 1.097 \times 10^7 \text{ m}^{-1}$.

(g) If the emitted photons are the result of the electrons returning to their ground state, what is the value of L? (1 mark)

(h) Use the Rydberg formula to calculate the wavelength of the emitted photon. (2 marks)

(i) In what part of the electromagnetic spectrum is this radiation? (1 mark)

Since these hydrogen atoms are neutral and energetic, they move at high speeds in straight lines, unaffected by the earth's magnetic field.

(j) What effect would this high speed have on the wavelength of the emitted radiation as measured by a stationary detector on earth? (Assume the atoms are moving straight down towards the detector.) (1 mark)

Wherever cosmic rays strike matter, nuclear collisions produce substantial amounts of radioactive isotopes. An important example of an atmospheric nuclear reaction is when neutrons in cosmic rays are captured by atmospheric nitrogen to produce the radioactive isotope carbon-14.

$$^{14}_{7}N + ^{1}_{0}n \rightarrow ^{14}_{6}C + ^{a}_{b}X$$

(k) Identify each of the unknowns, a, b and X in the above equation. (3 marks)

All living things contain carbon. A proportion of this carbon is the radioactive isotope carbon-14. While the organism is living this proportion is fixed. After death, the proportion of carbon-14 reduces as it undergoes radioactive decay. Carbon-14 has a half-life of 5,600 years.

(l) Use the above facts about carbon-14 to explain a use for this isotope. (2 marks)

Whatever your future holds, we want to be there for you.

(And for today... good luck.)

Peering into the future can be a bit scary. Who knows where you'll be in five or ten years..?

OK, so knowledge gives you power - and qualifications can help pave your way on the ROAD OF LIFE, but what else do you really want?

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The National Bank of New Zealand Limited's current disclosure statement may be obtained from the Bank's Finance Division, 170-186 Featherston Street, Wellington. The Bank's normal lending criteria apply.

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