97262

NEW ZEALAND QUALIFICATIONS AUTHORITY
MANA TOHU MĀTAURANGA O AOTEAROA

# University Entrance, Bursaries and Scholarships Examination

# PHYSICS: 2003

## QUESTION BOOKLET

9.30 am Thursday 20 November 2003
Time allowed: Three hours
(Total marks: 160)

This paper consists of 11 questions.

Answer **ALL** questions.

The total of 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 | 56 marks | 66 minutes |
| Electricity and Electromagnetism | Questions Seven to Nine | 44 marks | 52 minutes |
| Atomic and Nuclear Physics | Questions Ten and Eleven | 24 marks | 29 minutes |

Write your answers in the appropriate spaces in the printed Answer Booklet 97262/1.

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.

**YOU MAY KEEP THIS BOOKLET AT THE END OF THE EXAMINATION**

# WAVES

(28 marks; 33 minutes)

## QUESTION ONE: HENRY THE HARPSICHORD PLAYER (11 marks)

Henry is a member of an orchestra. In the orchestra, he plays an instrument called the harpsichord. The harpsichord is similar to a piano except that the strings are plucked instead of being struck by a small hammer. Henry creates a vibration in one of the strings as shown in the diagram below.

**A harpsichord**

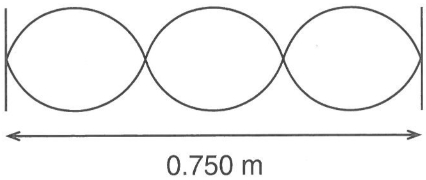



**Diagram of the vibration produced by the harpsichord**

(a) What is the name of this particular mode of vibration? (1 mark)

(b) The velocity of the wave on the string is 645 m $s^{-1}$. Calculate the frequency of this particular mode of vibration. (2 marks)

By playing another note on the harpsichord, Henry manages to cause another string of length 1.00 m to vibrate at its fundamental frequency of 326 Hz.

(c) Explain what is meant by the term **fundamental frequency**. (2 marks)

(d) Calculate the velocity of the wave on this particular string. (2 marks)

(e) State TWO reasons why the velocity on this string might be different from that in part (b). (2 marks)

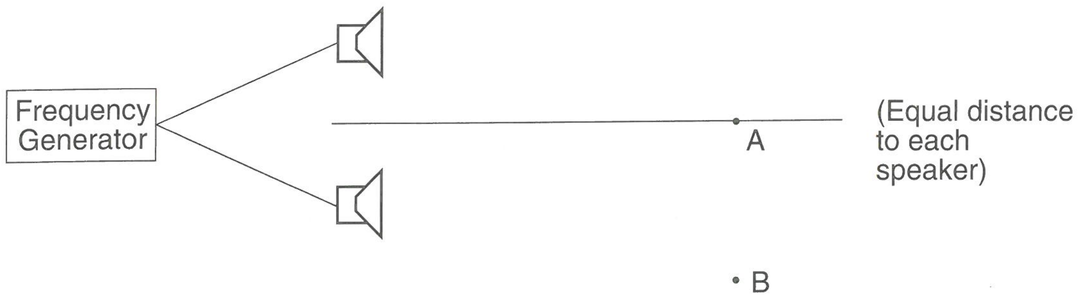
During his time in the orchestra, Henry finds that instruments change their frequencies as they warm up. He finds that woodwind instruments, such as flutes and clarinets, tend to increase their frequency as they warm up whereas the stringed instruments, such as violins and cellos, tend to decrease their frequency.

(f) Using physical principles, explain this phenomenon. (2 marks)

## QUESTION TWO: INTERFERENCE AND THE DOPPLER EFFECT (17 marks)

Speed of sound in air = 335 m $s^{-1}$

Jean and Henry are doing a physics project. They set up the speakers of their stereo outside in their garden. The arrangement is shown below.




Henry wires the speakers up so that they both emit sound waves of frequency 1250 Hz that are **in phase** with each other.

Sound waves are longitudinal waves.

(a) Explain what is meant by the term **longitudinal wave**. (2 marks)

Jean walks from A to B and finds that there are points of loudness and points of relative quietness.

(b) State the name of this phenomenon. Explain what causes it. (3 marks)

(c) Jean notices that the sound has maximum intensity at point A. Explain how a minimum rather than a maximum of sound intensity can be produced at A without moving the speakers or altering the frequency. (2 marks)

In a laboratory, a similar phenomenon can be produced with light. Two light sources, one of wavelength $577 \times 10^{-9}$ m and one of an unknown wavelength, are incident on two narrow slits. The second dark fringe away from the central maximum resulting from the known wavelength falls in the same place as the second bright fringe of the unknown wavelength.

(d) Calculate the unknown wavelength. (3 marks)

Jean hears a car sounding its horn. When the car approaches her, she finds that the frequency of the sound increases and when it goes away from her, the frequency decreases.

(e) Explain why the frequency decreases when the car goes away from Jean. (Include a diagram if necessary.) (2 marks)

(Turn over

Jean wants to calculate the difference between the frequencies when the car is approaching and when it is going away.

(f) Show that the difference between these frequencies is given by the formula:

$$\Delta f = f_{approaching} - f_{away} = \frac{2fv_s v_w}{v_w^2 - v_s^2}$$

(3 marks)

The frequency of the horn when the car is stationary is $4.00 \times 10^2$ Hz.

(g) Calculate the difference in frequency between the car approaching and the car going away if the car is travelling at 27.8 m $s^{-1}$. (2 marks)

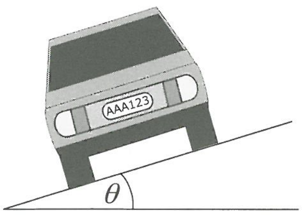
# MECHANICS

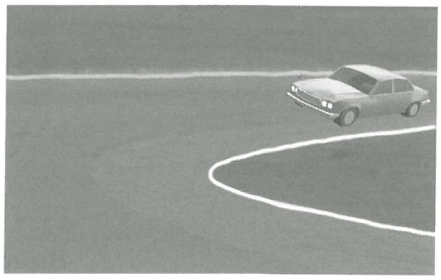
(56 marks; 66 minutes)

## QUESTION THREE: BANKED CURVES (11 marks)

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

Jean and Henry go on a car journey in the middle of winter. While travelling at a speed of 35.0 km $h^{-1}$, they come to an icy, banked corner on which there is no friction between the tyres and the road. The radius of the corner is 60.0 m.



(a) Convert 35.0 km $h^{-1}$ to metres per second. (2 marks)

(b) Explain why it is possible for the car to travel around a banked corner despite the fact that friction is not present. (2 marks)

It can be shown that the speed required to round a frictionless banked curve is $v = \sqrt{rg\tan\theta}$ where $r$ = radius of the curve, $g$ = acceleration due to gravity and $\theta$ is the angle of the banking.

(c) Show that the angle of the banking must be 9.13° if the car travelling at 35.0 km $h^{-1}$ is to travel around the curve safely. (2 marks)

(d) State what will happen to the car if it travels faster than 35.0 km $h^{-1}$. (1 mark)

(e) By resolving the forces acting on the car, prove the formula $v = \sqrt{rg\tan\theta}$. (4 marks)

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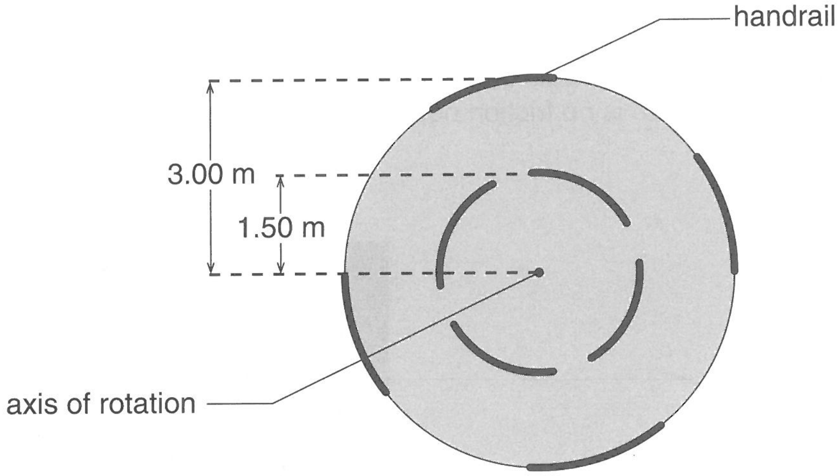
## QUESTION FOUR: THE ROUNDABOUT (15 marks)

Jean and Henry visit a playground roundabout with their daughter Jennifer. The roundabout is shown in the diagram below. The radius of the roundabout is 3.00 m. It has eight handrails as shown, each with a mass of 10.0 kg. The four inner handrails are 1.50 m from the centre. The other four handrails are at the edge of the roundabout.

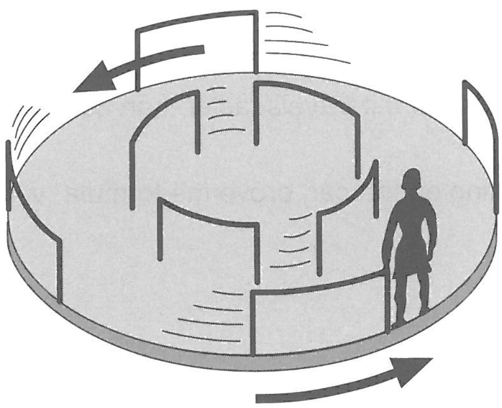



**Roundabout viewed from above**

The rotational inertia of each handrail can be calculated using the formula $I = mr^2$. The base of the roundabout has a rotational inertia of $6.00 \times 10^2$ kg m$^2$.

(a) Show that the rotational inertia of the entire roundabout is 1050 kg m$^2$. (2 marks)

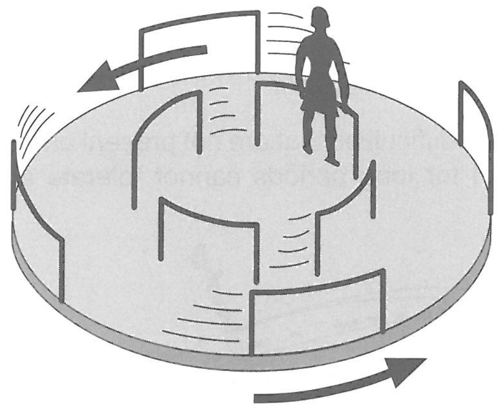
Jennifer, who has a mass of 40.0 kg, jumps onto the roundabout and holds onto one of the outside handrails. With Jennifer aboard, the roundabout takes 4.00 seconds to complete one revolution.



(b) Calculate the angular velocity of the roundabout. (2 marks)

(c) Calculate the angular momentum of the roundabout with Jennifer aboard, given that Jennifer adds a rotational inertia of $3.60 \times 10^2$ kg m$^2$ to the roundabout. (2 marks)

Jennifer now moves to one of the inner handrails.



(d) Explain why the angular velocity of the roundabout changes. (2 marks)

(e) Calculate the angular velocity of the roundabout when Jennifer is in this inner position. (3 marks)

(f) Show by calculation that the rotational kinetic energy has not been conserved. (2 marks)

(g) Explain this difference in energy. (2 marks)

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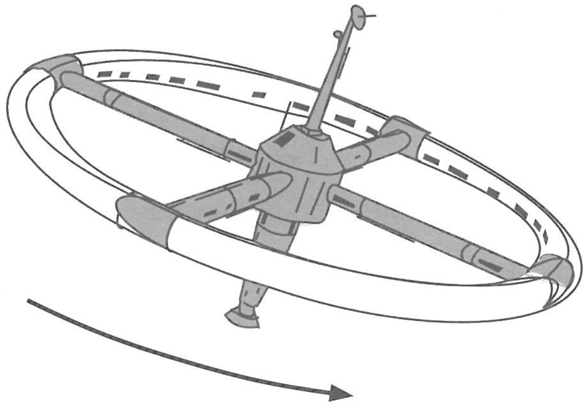
**QUESTION FIVE: A SPACE ODYSSEY** (14 marks)

Arthur C. Clarke's book, *2001: A Space Odyssey*, involves a space station in an orbit above the Earth. It uses a large rotating structure, as shown in the diagram below, to provide an artificial gravity.

Artificial gravity using rotation presents difficulties that are not present on Earth. For example, it has been found that people living in a rotating room for long periods cannot tolerate angular velocities greater than 2.00 revolutions per minute.

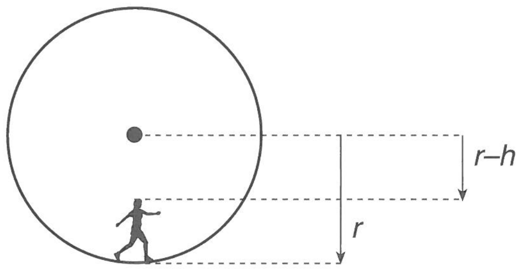


(a) Convert 2.00 revolutions per minute to radians per second. (2 marks)

The aim of the rotating structure is to produce an acceleration of 9.80 m $s^{-2}$.

(b) Show that the radius of the space station needed to produce this acceleration is 223 m, given that the station's angular velocity is 2.00 revolutions per minute. (2 marks)

(c) The top of the head of an astronaut (height = $h$) is closer to the centre of rotation than their feet, as shown in the diagram below. Show that the ratio of the 'head' acceleration to the 'foot' acceleration is given by $\frac{a_{head}}{a_{foot}} = \frac{r-h}{r}$ where $r$ = radius of the space station.

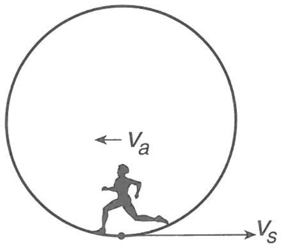



(Not to scale)

(2 marks)

(d) Calculate the ratio of the 'head' acceleration to the 'foot' acceleration if the height of the astronaut is 2.00 m. (2 marks)

Below is a diagram of an astronaut running with a velocity $v_a$ in the opposite direction to the velocity of the rim of the rotating space station $v_s$.




(Not to scale)

(e) Show that the velocity of the rim of the space station is 46.8 m s$^{-1}$. (2 marks)

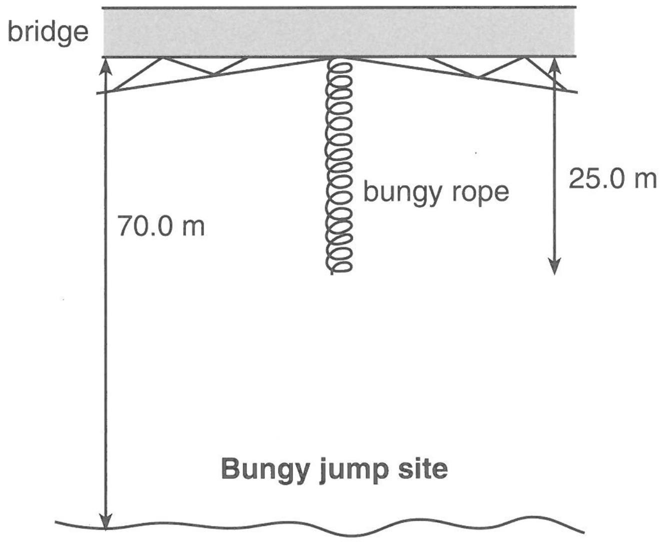
(f) Explain the effect on the artificial gravity experienced by the astronaut if $v_a$ is approximately a quarter of $v_s$. (2 marks)

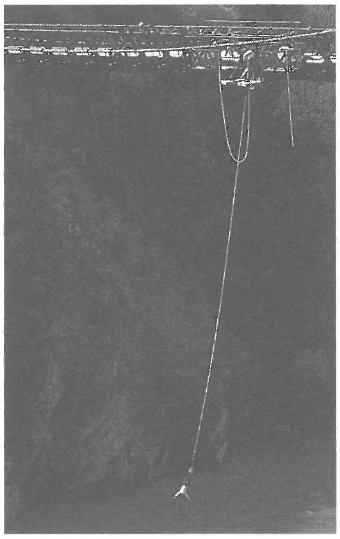
(g) Suggest ONE way in which the space station could be designed to minimise this effect. (2 marks)

**QUESTION SIX: BUNGY JUMPING** (16 marks)

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

In the South Island, there is a bungy jumping site on a bridge across a river. Henry is tied to one end of a rubber rope (the bungy) and the other end is fixed firmly to the bridge. The length of the bungy is adjusted so that Henry stops his downward motion at the surface of the river. The unstretched length of the bungy is 25.0 m. Henry's mass is 85.0 kg. The bridge is 70.0 m above the river.



*Source: The Queenstown Experience by David Wall, New Holland Kowhai, 1999*

(a) Show that at the surface of the river, where Henry is no longer falling, his loss of gravitational potential energy is 58 300 J. (2 marks)

(b) Explain where this energy has gone. (1 mark)

(c) Using conservation of energy, calculate the spring constant of the bungy, neglecting Henry's height and assuming that the bungy behaves like a spring. (3 marks)

At some point on the jump, Henry reaches a maximum speed.

(d) By considering the forces acting on Henry, explain why the acceleration is zero at this point. (2 marks)

The distance below the bridge at which Henry reaches his maximum speed is 39.5 m.

(e) Using conservation of energy, calculate Henry's maximum speed. (4 marks)

(f) At what point in the jump will Henry experience the maximum upward acceleration? Explain your answer. (2 marks)

(g) Explain what will happen to the spring constant of the bungy when its length is reduced by 50%. (2 marks)

# ELECTRICITY AND ELECTROMAGNETISM

(44 marks; 52 minutes)

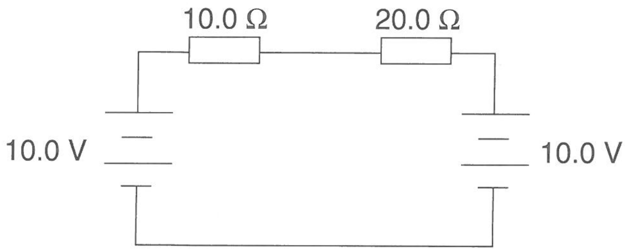
## QUESTION SEVEN: KIRCHHOFF'S LAWS (12 marks)

In the middle of the nineteenth century, Gustav Kirchhoff devised two laws for solving electrical circuits.

(a) State (in words) **each** of Kirchhoff's laws. (2 marks)

(b) For each law, state the basic physical principle upon which it is based. (2 marks)

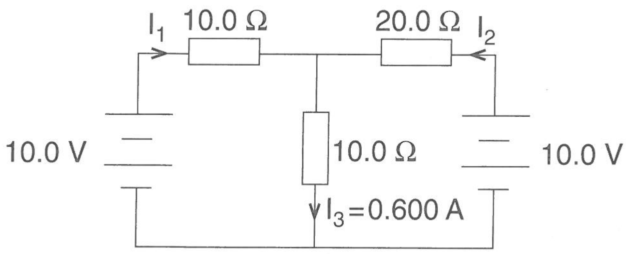
A simple circuit is constructed.




(c) State what is meant by the term **current**. (2 marks)

(d) Explain why the current in this circuit is zero. (2 marks)

A 10.0 Ω resistor is added to the above circuit, as shown below.

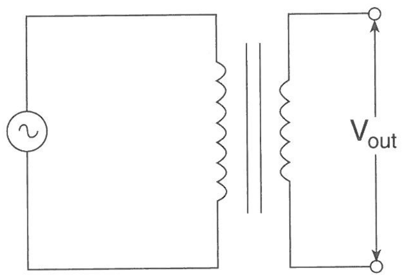



(e) Using Kirchhoff's laws, calculate $I_1$ and $I_2$ given that $I_3 = 0.600$ A. (4 marks)

## QUESTION EIGHT: RECTIFICATION (14 marks)

Electrical devices often require small DC voltages in order to operate. Jean wishes to design a 12.0 V DC supply to charge up her cellphone.

She initially constructs the following circuit.

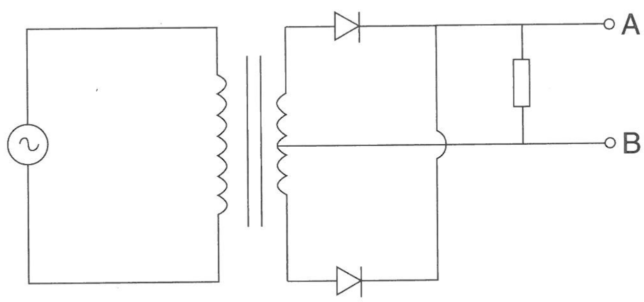



The supply voltage is 235 $V_{rms}$ and the operating frequency is 50.0 Hz. The number of turns in the transformer primary is 8000.

(a) Show that the peak value of the input voltage is 332 V. (2 marks)

(b) Calculate the number of turns required to produce a peak value of 12.0 V across the secondary turns of the transformer. (2 marks)

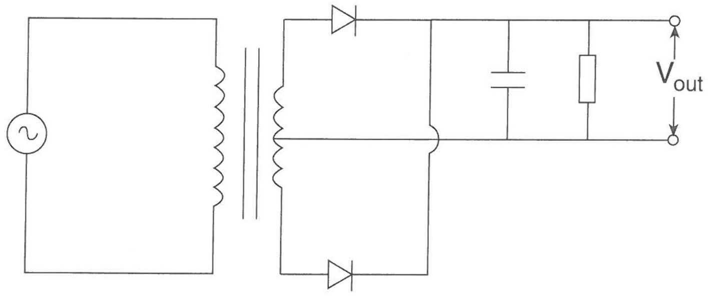
Jean now places two diodes and a resistor in the circuit to make a full wave rectifier, as shown in the diagram below. (The supply voltage and frequency are unchanged.)




(c) Jean measures the voltage between A and B with an oscilloscope and finds that A is always at a higher potential than B. Explain why. (2 marks)

(d) Assuming there is no voltage drop across the diodes, on the axes provided in your Answer Booklet sketch a graph of voltage between points A and B against time. Include a maximum voltage value and a period value. (4 marks)

To improve the circuit, Jean places a capacitor into the circuit as shown in the diagram below.




(e) Explain, using physical principles, the effect of the capacitor on the output voltage. (2 marks)

(f) On the axes provided in your Answer Booklet, sketch a graph of $V_{out}$ against time. No numerical values need to be included. (2 marks)

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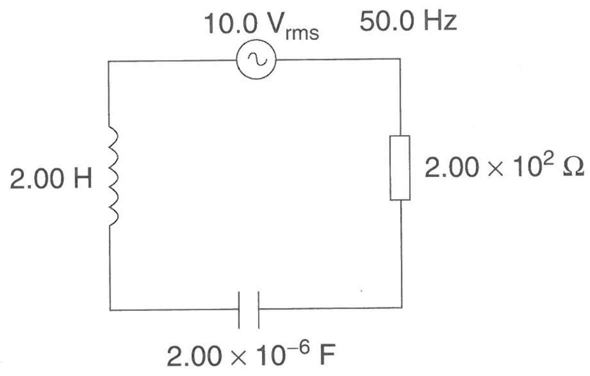
## QUESTION NINE: AC RESONANCE (18 marks)

Jean decides to investigate the role of inductors and capacitors in AC circuits. She sets up the following circuit.




(a) Show that the angular frequency of the AC supply is 314 radians per second. (2 marks)

(b) Show that the reactance of the capacitor is 1590 Ω. (2 marks)

(c) Show that the impedance of this circuit is 984 Ω. (3 marks)

(d) Calculate the current in this circuit. (2 marks)

Jean is able to alter the frequency of the AC supply. At a particular frequency, the current reaches a maximum value. At this point the circuit is said to be in resonance.

(e) On the axes provided in your Answer Booklet, sketch a graph of current versus frequency. (2 marks)

(f) Calculate the current at the resonant frequency. (2 marks)

(g) Explain, using physical principles, why the current is maximum at the resonant frequency. (2 marks)

(h) Calculate the resonant frequency for the above circuit. (3 marks)

# ATOMIC AND NUCLEAR PHYSICS

(24 marks; 29 minutes)

**QUESTION TEN: THE PHOTOELECTRIC EFFECT** (14 marks)

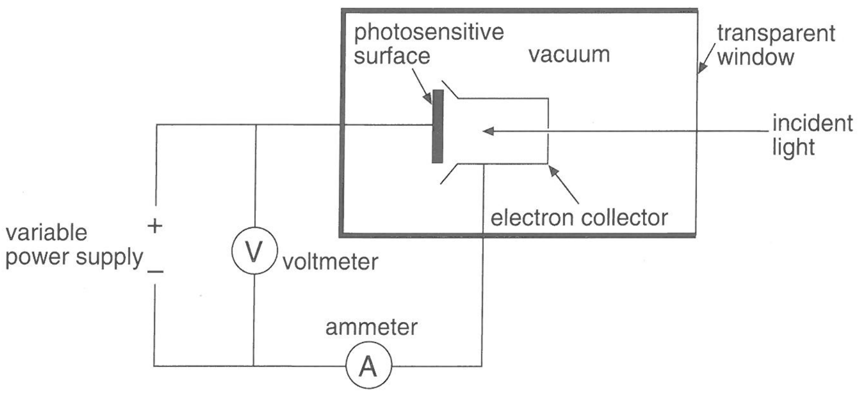
Speed of light = $3.00 \times 10^8$ m s$^{-1}$
Planck's constant = $6.63 \times 10^{-34}$ J s

Albert Einstein was awarded the Nobel Prize for correctly predicting the photoelectric effect. His famous equation states that $hf = \phi + E_k$.

(a) State the conservation law on which Einstein's equation is based. (1 mark)

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

The diagram below shows an experimental set-up to study the photoelectric effect. Monochromatic light is incident on the photosensitive surface and electrons are emitted.




(c) Explain how the above apparatus can be used to determine the maximum kinetic energy of the ejected electrons. (2 marks)

(d) The photoelectric effect provides evidence for a particular model of light. Name this model and give one piece of supporting evidence from the photoelectric effect. (2 marks)

In another experiment, one particular wavelength of light, $4.75 \times 10^{-7}$ m, falls onto the photosensitive surface with a work function of $3.10 \times 10^{-19}$ J.

(e) Show that the energy of the incident photon is $4.19 \times 10^{-19}$ J. (2 marks)

(f) Calculate the maximum kinetic energy of a released electron. (2 marks)

The light which is incident on the photosensitive surface has an intensity of $5.10 \times 10^{-6}$ W m$^{-2}$.

(g) Calculate the number of photons per square metre incident on the photosensitive surface in one second. (2 marks)

The photosensitive surface has an area of $4.00 \times 10^{-4}$ m$^2$. An incident photon has only a 1 in 2000 chance of ejecting an electron.

(h) Calculate the number of electrons emitted per second. (2 marks)

**(Turn over**

## QUESTION ELEVEN: NUCLEAR PHYSICS (10 marks)

Mass of the electron = $9.10 \times 10^{-31}$ kg

Radioactive carbon-14, produced in the upper atmosphere, decays by the following method.

$$^{14}_{6}C \rightarrow \, ^{0}_{-1}e + \, ^{a}_{b}N + \, ^{0}_{0}\overline{\nu}$$

$\overline{\nu}$ is an antineutrino.

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

(b) State the common name for this form of decay. (1 mark)

Before the decay, the carbon nucleus is stationary. After the decay, the electron and antineutrino are emitted at 90° to each other while the nitrogen nucleus recoils. The magnitude of the momentum of the antineutrino is $4.55 \times 10^{-24}$ kg m s$^{-1}$. The mass of the nitrogen nucleus is $2.32 \times 10^{-26}$ kg. The speed of the electron is $5.00 \times 10^{6}$ m s$^{-1}$.

(c) Show that the magnitude of the momentum of the electron is $4.55 \times 10^{-24}$ kg m s$^{-1}$. (2 marks)

(d) Explain why the nitrogen nucleus recoils. (2 marks)

(e) Calculate the magnitude of the recoil velocity of the nitrogen nucleus. (3 marks)