No. 262

New Zealand Qualifications Authority

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

PHYSICS: 1997

QUESTION BOOKLET

Time allowed: Three hours
(Total marks: 160)

This paper consists of 13 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.

Sport and Fitness Mechanics	Questions One to Five	56 marks	66 minutes
Shopping Electromagnetism Wave Motion Atoms, Photons and Nuclei	Questions Six to Ten	62 marks	74 minutes
The Stars Wave Motion Atoms, Photons and Nuclei	Questions Eleven to Thirteen	34 marks	40 minutes

Check that this Question Booklet contains pages 2 — 17 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

SPORT AND FITNESS

(56 marks; 66 minutes)

PLAYING CRICKET

QUESTION ONE: LINEAR MOTION (11 marks)

Jane is a keen cricket player and is using her knowledge of physics to investigate the size of the forces involved when a cricket bat hits the ball. Super slow video techniques enable the time that the bat and ball are in contact with each other to be measured and radar techniques enable the speed of the ball to be measured.

On one occasion the velocity of the ball is 25 m s^{-1} at the instant it hits the bat and –17 m s^{-1} (ie. travelling in exactly the opposite direction) when it leaves the bat. The time during which the ball is in contact with the bat is 5.6×10^{-5} s. The ball has a mass of 0.160 kg.

(a) Calculate the size of the momentum of the ball as it hits the bat. (2 marks)

(b) Calculate the size of the **change** in momentum of the ball while it is in contact with the bat. (2 marks)

(c) Calculate the size of the average force which is applied to the ball while it is in contact with the bat. (2 marks)

On a different occasion, when the ball had different velocities from above, the size of the average acceleration of the ball while in contact with the bat was calculated to be 512 349 m s^{-2}.
The equation which was used for the calculation was:

$$a = \frac{\Delta v}{t} = \frac{v_{final} - v_{initial}}{t}$$

The absolute uncertainty in the initial velocity of the ball is $\pm$ 2 m s^{-1} and in the final velocity of the ball is $\pm$ 1 m s^{-1}.

(d) Calculate the **absolute** uncertainty in Δv. (1 mark)

The absolute uncertainty in Δv gives a **percentage** uncertainty of $\pm$ 4%. The percentage uncertainty in the time of contact is $\pm$ 2%.

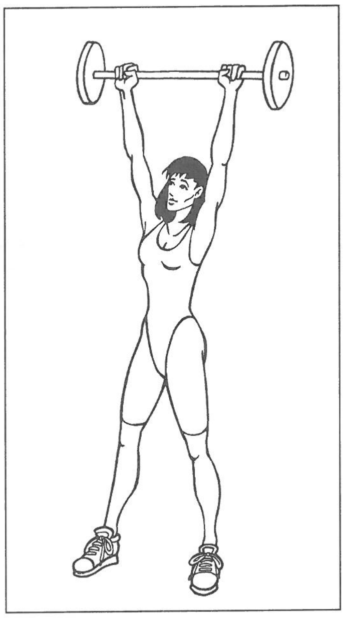
(e) Calculate the **percentage** uncertainty in the acceleration of the ball. (1 mark)

(f) State the acceleration of the ball with its **absolute** uncertainty. (3 marks)

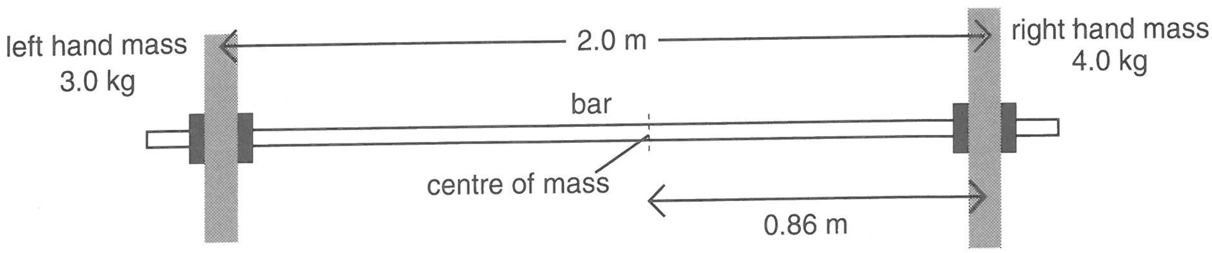
QUESTION TWO: LINEAR MOTION (9 marks)

Jane is also a bowler, and to improve the strength of her arms she regularly uses the fitness equipment in the school gymnasium.

The picture shows a barbell being used to strengthen the muscles of the arm.



Normally the same mass is put on each end of the bar, but Jane decides that she could strengthen her right (bowling) arm if a greater mass is put on the right-hand end of the bar. The diagram below shows the set-up she uses. Assume the mass of the bar is negligible compared with the right and left-hand masses.



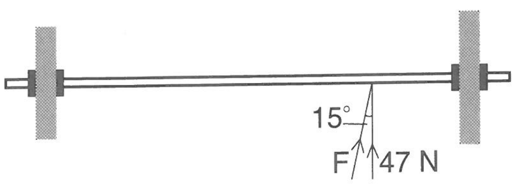
(a) The centre of mass of the barbell is drawn in the diagram at a position which is 0.86 m from the right-hand mass. Show by calculation that this is the correct distance. (2 marks)

(b) On the diagram in your Answer Booklet draw a single vector to show the position and direction of the total gravity force on the barbell. Label the vector with its size. (2 marks)

Jane places her hands symmetrically on either side of the centre of the bar, lifts it, and holds it stationary for a moment before lowering it to the floor. The size of the vertical force her **right** hand exerts on the bar is 47 N.

(c) What is the size of the vertical force exerted by Jane's **left** hand? (1 mark)

(d) While she is holding the barbell stationary, Jane's **right** arm makes an angle of 15° with the vertical direction (see diagram below). Calculate the size of the force, *F*, in Jane's right arm. (2 marks)



To lift the barbell off the floor, Jane has to accelerate it from zero speed. The initial acceleration of the barbell is 8.8 m s^{-2}.

(e) Calculate the **total** vertical force which Jane has to apply to the barbell to give it this initial acceleration. (2 marks)

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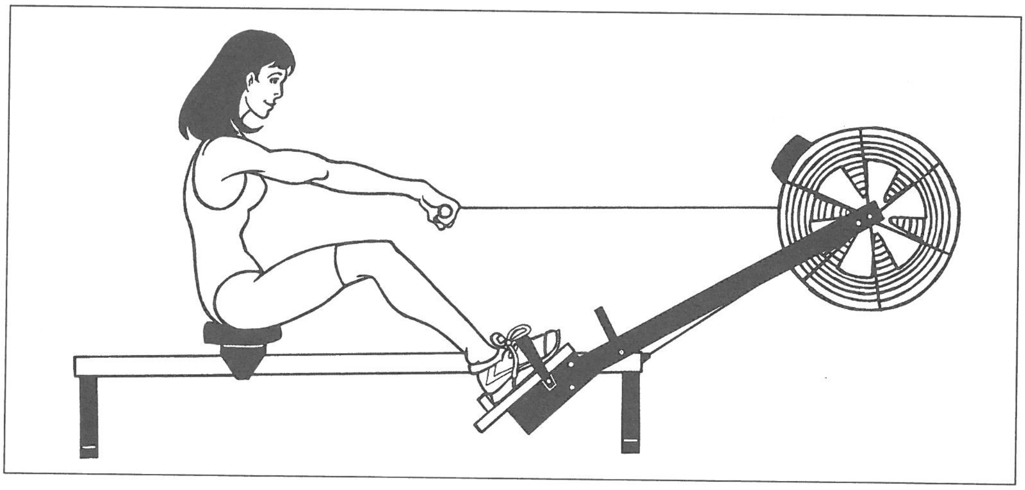
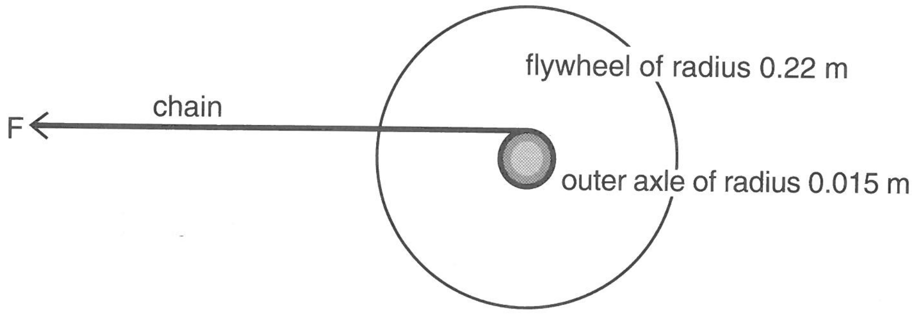
QUESTION THREE: ROTATIONAL MOTION (9 marks)

To keep up her general fitness in the off-season, Jane works out on the rowing machine.



The diagram below shows the physics principle on which the rowing machine is based.



Pulling on the chain causes the flywheel to rotate without any slipping occurring between the axle and the chain.

During the first part of the rower's first "stroke" the flywheel and axle are constantly accelerated from rest.

(a) If this acceleration takes place over a distance of 0.55 m in a time of 0.88 s

(i) show that the angle through which the axle turns is 37 radians. (1 mark)

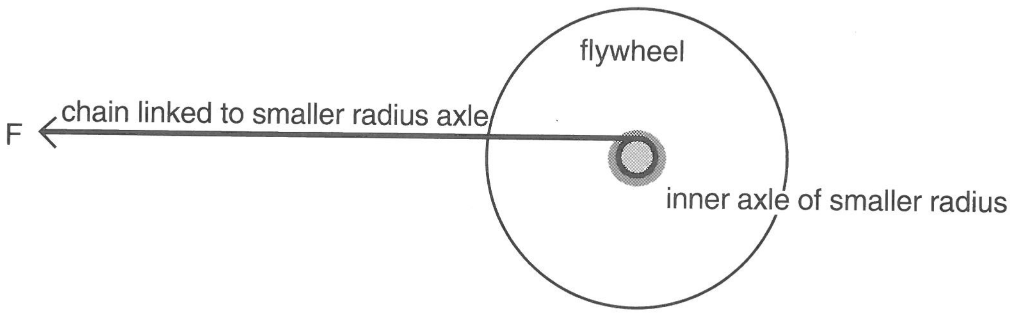
(ii) calculate the angular acceleration of the axle. (2 marks)

(b) If the average force which Jane applies to the handle is 192 N, calculate:

(i) the torque applied to the axle. (2 marks)

(ii) the rotational inertia of the system of flywheel and axle. (2 marks)

(c) The rowing machine has two axles to which the chain can link. The diagram shows the chain now linked to the axle with a **smaller** radius. Will Jane find it harder or easier to achieve the same angular acceleration as before? Explain your answer. (2 marks)



TRAMPOLINING

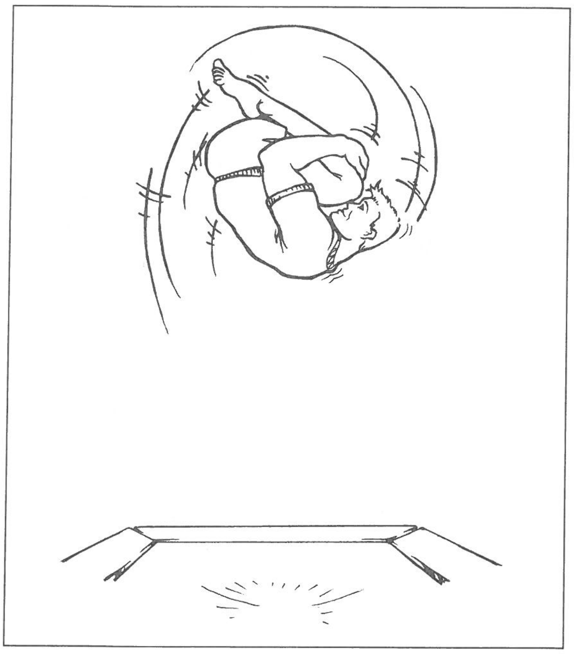
QUESTION FOUR: ROTATIONAL MOTION (11 marks)

John's sport is trampolining. John warms up by working his arms and legs until he is jumping high and vertically above the trampoline mat. John has a mass of 75 kg.

(a) State the change in John's energy between the instant he leaves the mat on the way up, to the instant he reaches his highest point. (1 mark)

(b) As he leaves the mat, John's linear kinetic energy is calculated to be 2100 J. Calculate his linear speed at the instant he leaves the mat. (2 marks)

One of the common moves in trampolining is to turn a complete somersault while in the air. To do this John must jump in such a way that his body has rotational motion as well as linear motion when it leaves the mat.



On one occasion, as he leaves the mat, John's total kinetic energy (both linear and rotational) is 2200 J. At the top of the jump his **linear** speed is momentarily zero and he has gained 1400 J of gravitational potential energy.

(c) At the top of the jump, assuming mechanical energy is conserved, calculate:

(i) John's height above the mat. (2 marks)

(ii) John's rotational kinetic energy. (1 mark)

(d) At the top of the jump the angular speed of John's somersault is 18 rad s^{-1}. Calculate his rotational inertia about his centre of mass. (2 marks)

To complete the somersault while in the air, John folds his body into the tucked position shown in the picture, causing it to rotate at a faster rate. At the end of the rotation he straightens his body and lands back on the mat in as upright a position as possible.

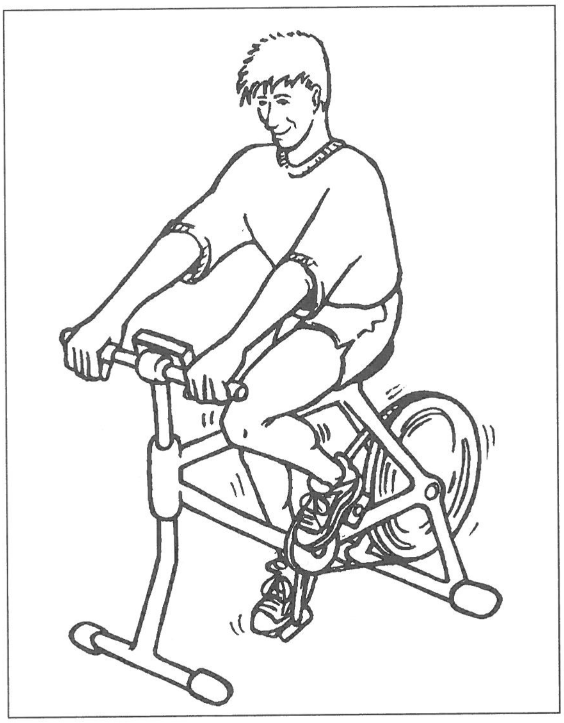
(e) Explain what effect the action of tucking has on John's rotational inertia. (2 marks)

(f) Explain why this tucking action causes John's body to rotate faster than if he remains in the untucked position. (1 mark)

(Turn over

QUESTION FIVE: SIMPLE HARMONIC MOTION (16 marks)

John notices that when he pedals on the exercycle (a bicycle which can be pedalled without it moving forward) each knee moves up and down in (approximate) simple harmonic motion while each foot (on the pedal) moves in a circle.



(a) Describe what type of motion the pedal must have to make John's knee move in (approximate) simple harmonic motion. (1 mark)

(b) The first diagram in your Answer Booklet shows the direction of the displacement phasor for the simple harmonic motion of John's knee when it is at its top position. On the second and third diagrams draw the velocity and acceleration phasors for the same position of John's knee. (2 marks)

(c) Using the terms maximum or zero, describe the **size** of the velocity and acceleration of John's knee when it is at its top position. (2 marks)

(d) In which direction is the acceleration of John's knee at this top position? (1 mark)

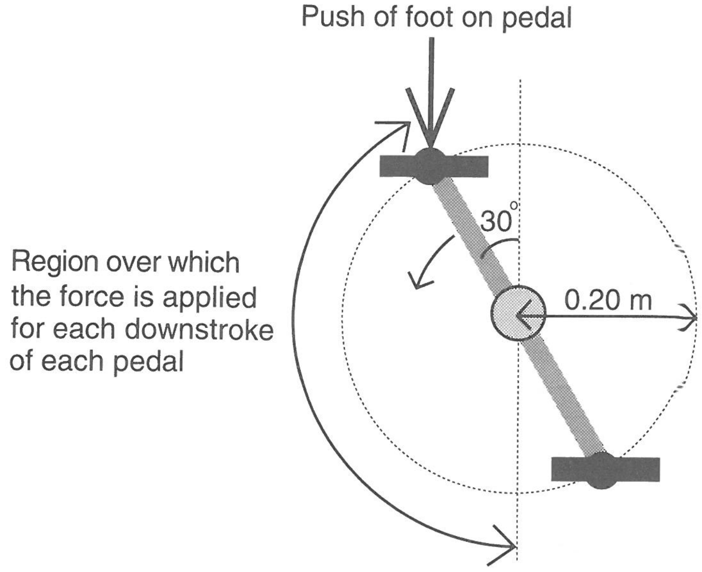
To pass the time away, John works out the frequency of his pedalling. He counts 89 revolutions in 60 s. He estimates that the radius of the circular path of the pedal is 0.20 m. Assuming the conditions for simple harmonic motion are being met, calculate:

(e) the frequency of John's pedalling. (2 marks)

(f) the angular frequency of the simple harmonic motion of John's knee. (2 marks)

(g) the linear speed at which John's foot is moving. (2 marks)

Each pedal is pushed only on its downward stroke. By judging when each foot is actually pushing its pedal, John estimates that he is applying a force for only 5/6 of each push. The diagram below shows a side view of the rotating pedals and the region in which a force is being applied to the downwards moving pedal.



(h) What is the amplitude of the simple harmonic motion of John's knee? (1 mark)

(i) By using the reference circle in your Answer Booklet, or otherwise, calculate how far John's knee has moved vertically down from its highest position before his foot starts to push the pedal. (3 marks)

(Turn over

SHOPPING

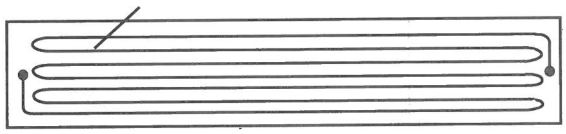
(62 marks; 74 minutes)

Sarah is visiting her local shopping centre.

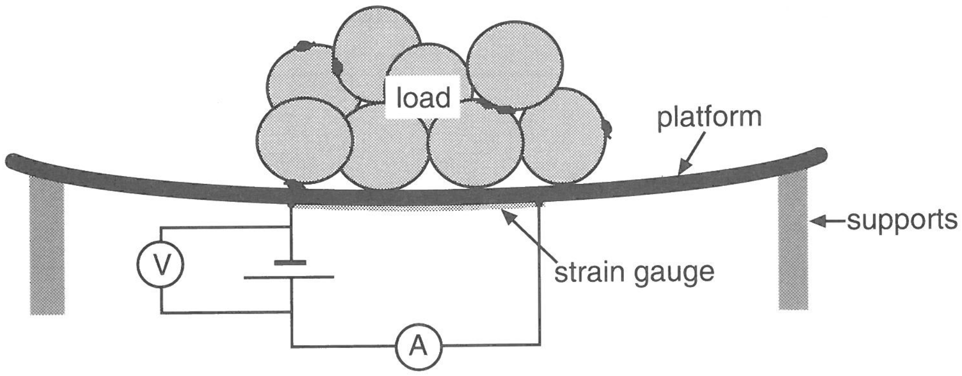
FRUIT SHOP

QUESTION SIX: DC ELECTRICITY (7 marks)

Sarah goes to a fruit shop and asks for 2½ kg of oranges. The shopkeeper weighs the oranges on an electronic scale that uses a strain gauge. A strain gauge is constructed as shown in the diagram below.



The scale works by having a platform which is held by two supports. The strain gauge is attached to the underside of the platform. When something is placed on the platform it will bend slightly. The strain gauge will bend with the platform.
The diagram below shows a strain gauge connected into an electric circuit.



(a) Jane knows that the resistance of a wire depends in some way on both its length and thickness.

(i) State what will happen to the resistance of a wire if its radius increases. (1 mark)

(ii) State what will happen to the resistance of a wire if its length increases. (1 mark)

(b) When the strain gauge bends its resistance increases. Assume the cell in the circuit above has **negligible** internal resistance.

(i) State what will happen to the reading on the ammeter as the strain gauge bends. (1 mark)

(ii) State what will happen to the reading on the voltmeter as the strain gauge bends. (1 mark)

The voltage of the cell is 1.5 V and the current in the circuit when there is no load on the platform is 0.018 A.

(c) Calculate the power consumed by the strain gauge. (2 marks)

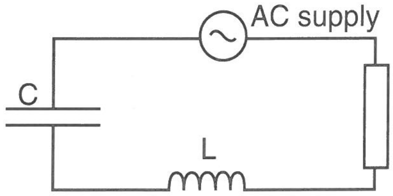
(d) Explain why it is necessary for this power to be low. (1 mark)

DRESS SHOP

QUESTION SEVEN: AC ELECTRICITY (13 marks)

At the dress shop there is a security system which has two large metal loops that shoppers must walk between as they enter and leave the shop. When Sarah buys a blouse, the shop assistant forgets to remove the security tag and the security alarm goes off when she leaves the shop.

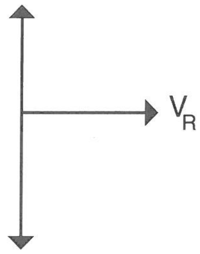
The circuit which operates the security alarm is like that in the diagram below.



The inductor in the circuit is the two large metal loops at the entrance to the shop. The capacitor in the circuit has a reactance of 24 Ω.

The phasors representing the voltages across the inductor, the resistor and the capacitor are shown in the diagram.

The same phasor diagram is shown in your Answer Booklet.



(a) Label the diagram in your Answer Booklet with the voltage, V_L, across the inductor, and the voltage, V_C, across the capacitor. (1 mark)

(b) On the same diagram draw **accurately** the phasor for the voltage of the supply. (2 marks)

The security tag attached to the blouse consists of a small magnet which, when it passes through the loops, increases the inductance of the inductor in the circuit until the sizes of the voltages across the inductor and the capacitor are approximately the same.

(c) Explain the effect that this increased inductance will have on the AC current flowing in the circuit. (2 marks)

(d) Suggest a reason why the security alarm goes off when the security tag passes through the large metal loops. (1 mark)

Assume that the sizes of the voltages across the inductor and the capacitor are **exactly** the same.

(e) When this occurs state the value of the reactance of the inductor. (1 mark)

(f) When the alarm goes off, the value of the current in the resistor is 300 mA. The resistor, R, has a resistance of 200 Ω. Calculate the voltage across:

(i) the resistor. (3 marks)

(ii) the capacitor. (2 marks)

(iii) the AC supply. (1 mark)

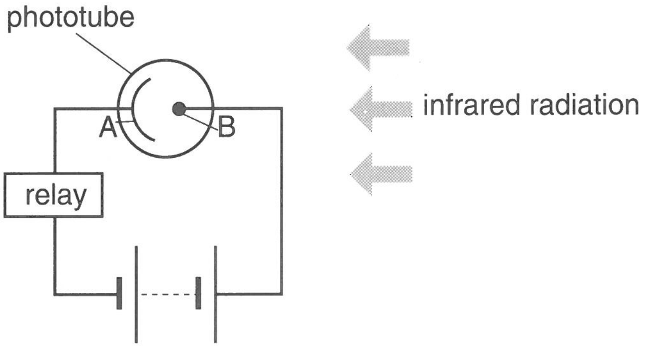
(Turn over

MUSIC SHOP

Planck's constant, $h = 6.626 \times 10^{-34}$ J s

QUESTION EIGHT: ATOMIC PHYSICS AND ELECTROMAGNETISM (14 marks)

Sarah goes to a music shop which has an automatic door opener. The door is operated by a phototube. The diagram below shows a phototube circuit.

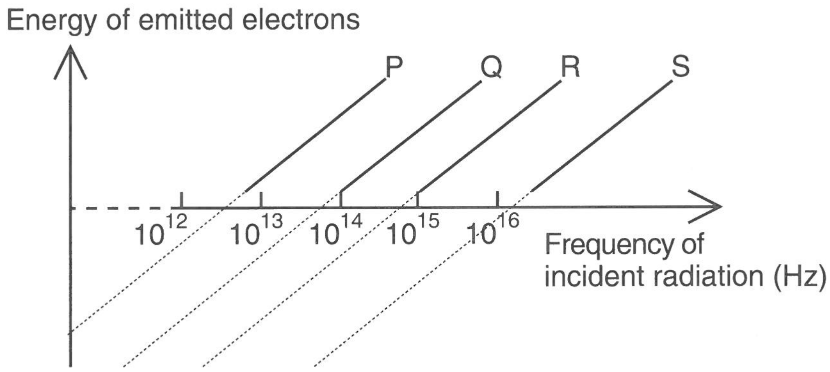


When infrared radiation shines on plate A, electrons flow in the circuit.

(a) Which way will the electrons flow in the phototube, from A to B or B to A? (1 mark)

(b) Explain why the battery is in the circuit. (2 marks)

The choice of material for plate A is important. The graph below shows how the energy of the emitted electrons varies with the frequency of the incident radiation for each of four different materials P, Q, R, S.



(c) Explain why the lines:

(i) are parallel to each other. (2 marks)

(ii) cut the frequency axis at different positions. (1 mark)

In a particular phototube the material from which plate A is made has a work function energy of 2.41×10^{-19} J and the frequency of the infrared radiation is 3.82×10^{14} Hz.

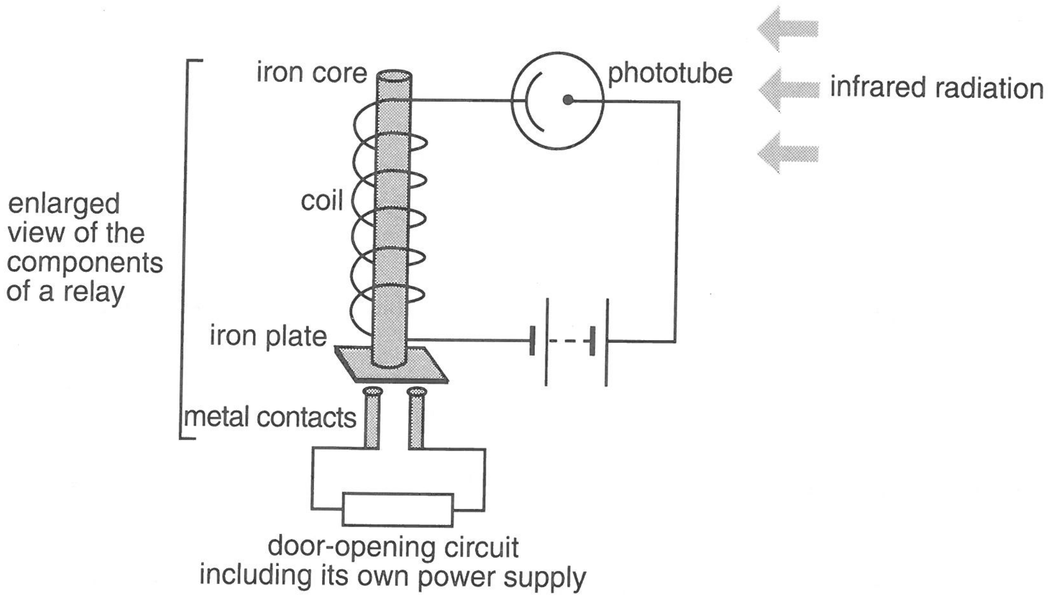
(d) Calculate the energy of the photons of infrared radiation. (2 marks)

(e) Calculate the maximum kinetic energy of electrons as they are released. (1 mark)

(f) Use the graph on page 10 to decide which material(s) (P, Q, R or S) could **not** be used for plate A. Explain your answer. (2 marks)

The circuit that operates the motor which opens the door, requires a much larger current than that which flows in the phototube circuit. The relay in the phototube circuit acts as a switch in the door-opening circuit.

A diagram which demonstrates the action of a relay is given below. The iron plate is **not** attached to the iron core and is free to move under gravity.



When a current flows in the phototube circuit there is a magnetic field in the coil in the relay.

(g) What effect does the iron core have on the magnetic field in the coil? (1 mark)

(h) Explain how the relay is able to switch on the current in the door-opening circuit. (2 marks)

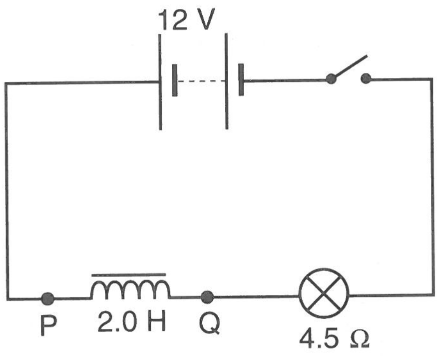
NOVELTY SHOP

QUESTION NINE: ELECTRO-MAGNETISM AND WAVES (18 marks)

Sarah visits a novelty shop to get a birthday present for her older sister. She is fascinated by a robot which will lift up small objects with a pick-up device when a switch is closed.

She notices that the light which signals that the "pick up" is operating does not glow immediately the switch is closed.

The circuit which operates the "pick-up" device is shown below. The resistance of the inductor is sufficiently low that it can be assumed to be a pure inductor.



(a) When the switch is closed, explain why the lamp does not immediately reach maximum brightness. (1 mark)

(b) Calculate the maximum current that will flow in the circuit. (2 marks)

(c) Calculate the energy that is stored in the inductor when the maximum current is flowing. (2 marks)

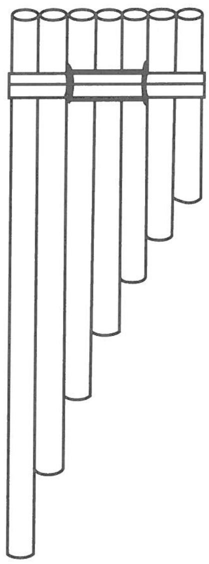
When the switch is closed it takes 0.20 s for the current and the voltage between the points P and Q to reach their steady values.

(d) Calculate the **average** voltage induced between the points P and Q while the current is changing. (2 marks)

(e) While the voltage induced between the points P and Q is changing, which is the high potential end of the inductor? Explain your answer. (2 marks)

(f) On the axes in your Answer Booklet sketch a graph of voltage induced across the inductor against time. (3 marks)

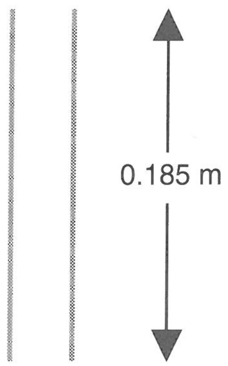
Sarah finds a set of pan-pipes as an appropriate gift for her sister.



A set of pan-pipes consists of a number of hollow vertical pipes. The pipes are of differing lengths and are **open at both ends**. A pipe is "played" by the player blowing across the top opening. This makes it emit a musical note.

(g) Is the wave created in the air inside the pipe **transverse** or **longitudinal**? (1 mark)

One of the pipes has a working length of 0.185 m. When played, it sounds its fundamental frequency (first harmonic).



(h) On the diagram in your Answer Booklet, show clearly the position(s) of the displacement anti-node(s) in the tube when it is sounding its fundamental frequency. (1 mark)

(i) What is the wavelength of this fundamental frequency? (1 mark)

The speed of sound in air is 3.30×10^2 m s^{-1}.

(j) Calculate the frequency of the fundamental. (2 marks)

The first overtone (second harmonic) is also present when this pipe is sounding.

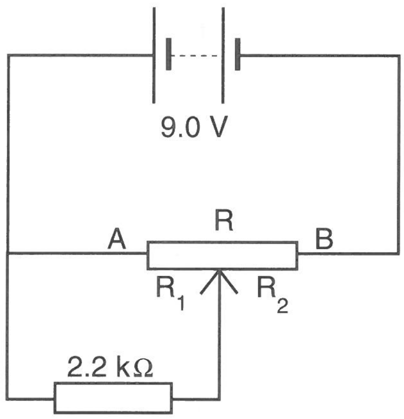
(k) In the diagram in your Answer Booklet, show the new arrangement of displacement anti-node(s) in the pipe for the first overtone. (1 mark)

(Turn over

THE STEREO SHOP

QUESTION TEN: DC ELECTRICITY (10 marks)

Sarah's final stop is at a stereo shop where she looks at various stereo systems. One of the differences she notices is the way in which the volume is controlled. The main component in one type of volume control device is a potentiometer (or "pot" for short). To illustrate the effect of a potentiometer as a volume control device consider the circuit shown below.



The potentiometer consists of a single resistor of resistance R which can be divided into two resistors of resistances R_1 and R_2 in series, by changing the position of a sliding connector. The total resistance R stays constant and is always the sum $R_1 + R_2$, of the values of the two resistances.
The total resistance R of the pot is 4.7 kΩ (4700 Ω).

(a) When the sliding connector is at the end B of the resistor, the resistance R_2 is zero.

(i) What is the value of the voltage across the 2.2 kΩ resistor? (1 mark)

(ii) Calculate the current in the 2.2 kΩ resistor. (2 marks)

(b) When the sliding connector is at the end A of the resistor, the resistance R_1 is zero. What is the value of the voltage across the 2.2 kΩ resistor? (1 mark)

(c) When the sliding connector moves gradually from A to B, state what effect this will have on:

(i) the total resistance of the circuit. (1 mark)

(ii) the current in the 2.2 kΩ resistor. (1 mark)

(d) If the sliding connector is moved to a position at which the resistance R_1 is 2.9 kΩ, calculate:

(i) the total resistance of the circuit. (2 marks)

(ii) the voltage across the 2.2 kΩ resistor. (2 marks)

THE STARS

(34 marks; 40 minutes)

Speed of light, $c = 2.9979 \times 10^{8}$ m s^{-1}

QUESTION ELEVEN: THE DOPPLER EFFECT (9 marks)

When the light received from a star is examined, each line in the spectrum of a particular element in the star is seen at a wavelength different from that in the spectrum of the same element when viewed in the laboratory.

Most stars and galaxies are "red-shifted", that is, their spectral lines appear to be at longer wavelengths. A few of the nearer galaxies are "violet-shifted" so that their spectral lines appear to be at shorter wavelengths.

(a) State what "violet-shifted" tells us about the motion of galaxies. (1 mark)

The mean frequency of a sodium line as measured in the laboratory is 5.091×10^{14} Hz. The same line in the light from a particular star has a frequency of 5.089×10^{14} Hz when viewed from earth.

(b) State whether the star is moving towards or away from earth. (1 mark)

(c) Calculate the velocity of the star with respect to the earth. (Ignore relativistic effects.) (3 marks)

(d) Calculate the wavelength of sodium light which has a frequency of 5.091×10^{14} Hz. (2 marks)

A double star consists of two stars which are so close together that they appear as a single star. The two stars orbit about their common centre of mass. The overall movement of a particular double star in our galaxy is such that when one of the pair is moving towards an observer on earth, the other is moving away.

In this particular double star one star is "dead" and is no longer producing light, though it still has significant mass.

(e) Describe and explain the effect of the movement of the still visible star on the appearance of its spectrum assuming the speed of rotation is sufficiently slow for individual frequencies to be distinguished. (2 marks)

(Turn over

QUESTION TWELVE: DIFFRACTION AND INTERFERENCE (14 marks)

A diffraction grating may be used to study the spectra of light from distant stars. Yellow sodium light of wavelength 5.895×10^{-7} m was viewed using a diffraction grating which had 250 lines per mm.

(a) Calculate the diffraction angle of this line in the first order spectrum. (3 marks)

The diffraction grating is replaced with one having only half the number of lines per mm.

(b) Describe and explain the effect that this will have on the observed position of the diffracted spectral line. (2 marks)

The same yellow light ($\lambda = 5.895 \times 10^{-7}$ m) is now shone onto just two narrow slits which are separated by a distance of 1.000×10^{-3} m. An interference pattern is formed on a screen 2.00 m beyond the slits.

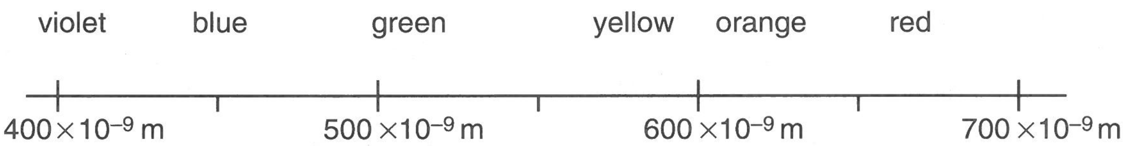
(c) Describe carefully and precisely the appearance of the interference pattern on the screen, stating

(i) what is seen in the central position. (1 mark)

(ii) what is seen on either side of the central position. (2 marks)

(d) Calculate the distance between the two third order maxima observed on the screen. (3 marks)

The diagram below shows the spectrum of visible light with the approximate wavelengths for different colours.



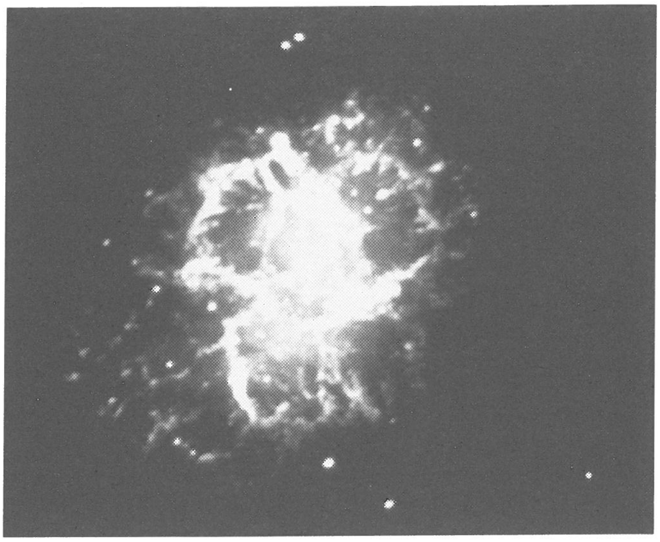
(e) What is the maximum angle, measured from the straight through direction, through which light can be diffracted by a diffraction grating? (1 mark)

(f) When sunlight is viewed through a particular diffraction grating, the complete first and partial second order spectra can be seen. The colour green in the second order spectrum is diffracted at the maximum angle. What other colours would be seen in that second order spectrum? Explain your answer. (2 marks)

QUESTION THIRTEEN: ATOMS AND NUCLEI (11 marks)

Speed of light, c = 2.9979×10^{8} m s^{-1}

The Crab nebula is the remnant of a supernova seen in AD 1054. A supernova is the violent explosion of a star.



A possible energy-releasing process in a supernova is represented by the following equation:

$$^{13}_{6}C + ^{4}_{2}He \rightarrow ^{a}_{b}X + ^{1}_{0}Y + 3.5488 \times 10^{-13} J$$

(a) Name this type of nuclear reaction. (1 mark)

(b) Identify the numbers a and b. (2 marks)

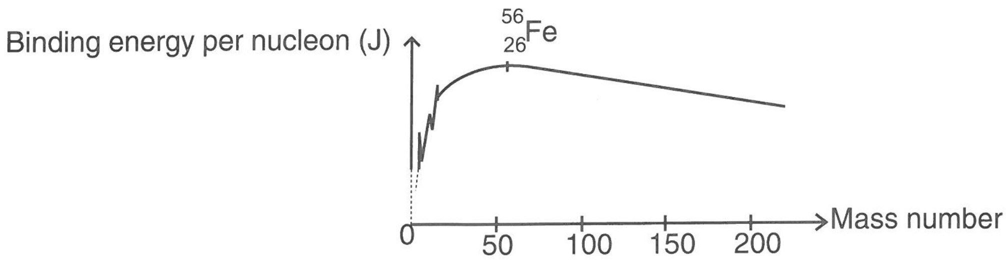
(c) Name particle Y. (1 mark)

(d) Show that the mass equivalent of the energy released in the reaction is 3.9486×10^{-30} kg. (2 marks)

(e) Use the data listed below and the value given in part (d) to calculate the rest mass of X. (2 marks)

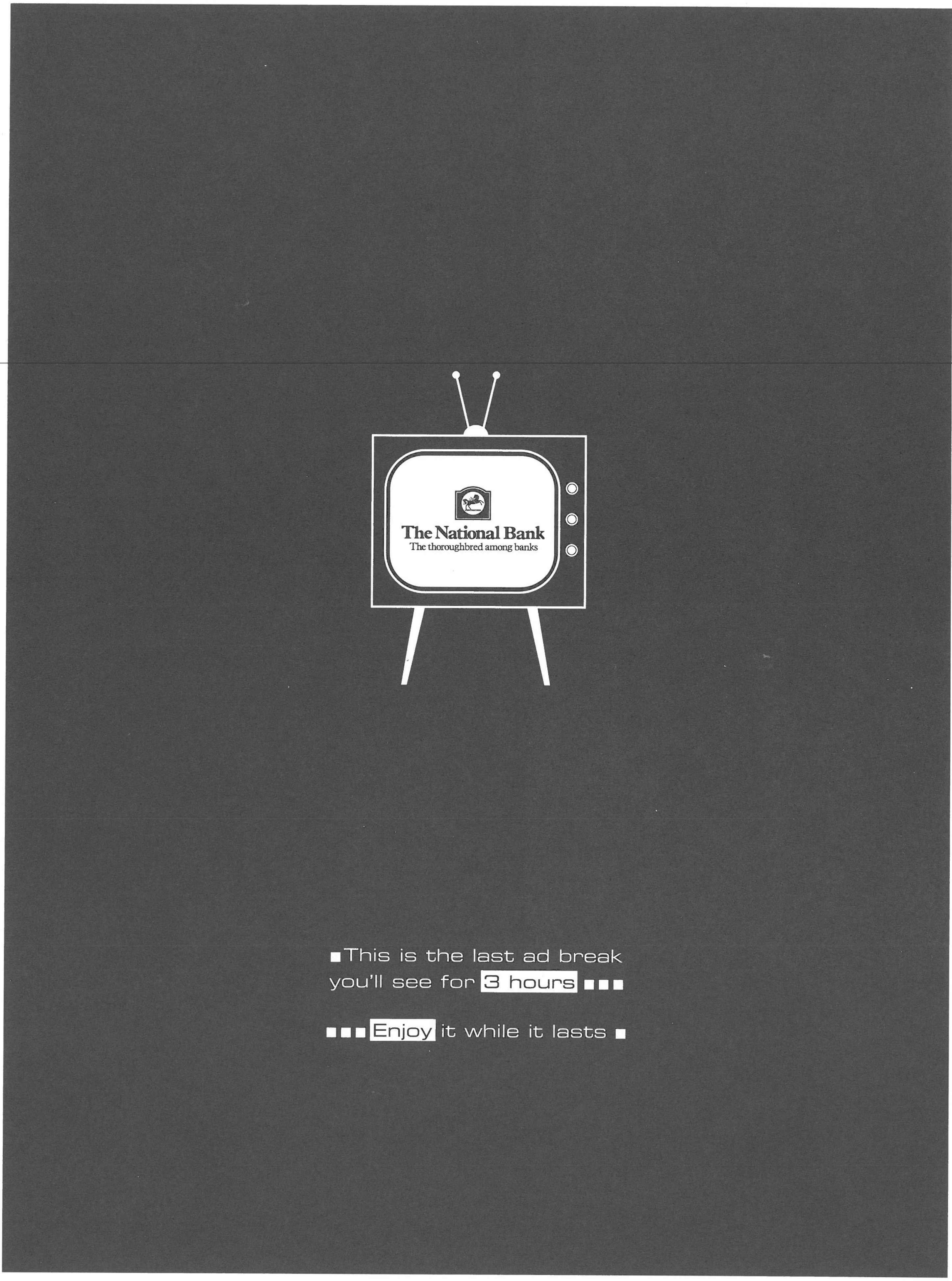
Rest mass of $^{13}_{6}C$ = 21.5912×10^{-27} kg
Rest mass of $^{4}_{2}He$ = 6.6460×10^{-27} kg
Rest mass of $^{1}_{0}Y$ = 1.6748×10^{-27} kg

Within a nucleus, the relationship between the binding energy per nucleon and the mass number is of the form shown in the graph below.



(f) The graph shows that iron-56 has the most binding energy per nucleon. What does this indicate about the nuclear properties of iron compared with other elements? (1 mark)

(g) Explain why the rest mass of a nucleus is always **less** than the combined rest mass of its constituent particles. (2 marks)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