VICTORIAN CURRICULUM AND ASSESSMENT AUTHORITY

Victorian Certificate of Education 2019

SUPERVISOR TO ATTACH PROCESSING LABEL HERE

STUDENT NUMBER									Letter

PHYSICS
Written examination

Wednesday 29 May 2019

Reading time: 10.00 am to 10.15 am (15 minutes)
Writing time: 10.15 am to 12.45 pm (2 hours 30 minutes)

QUESTION AND ANSWER BOOK

Structure of book

Section	*Number of questions*	*Number of questions to be answered*	*Number of marks*
A	20	20	20
B	19	19	110
			Total 130

- Students are permitted to bring into the examination room: pens, pencils, highlighters, erasers, sharpeners, rulers, pre-written notes (one folded A3 sheet or two A4 sheets bound together by tape) and one scientific calculator.
- Students are NOT permitted to bring into the examination room: blank sheets of paper and/or correction fluid/tape.

Materials supplied
- Question and answer book of 36 pages
- Formula sheet
- Answer sheet for multiple-choice questions

Instructions
- Write your student number in the space provided above on this page.
- Check that your **name** and **student number** as printed on your answer sheet for multiple-choice questions are correct, **and** sign your name in the space provided to verify this.
- Unless otherwise indicated, the diagrams in this book are **not** drawn to scale.
- All written responses must be in English.

At the end of the examination
- Place the answer sheet for multiple-choice questions inside the front cover of this book.
- You may keep the formula sheet.

Students are NOT permitted to bring mobile phones and/or any other unauthorised electronic devices into the examination room.

SECTION A – Multiple-choice questions

Instructions for Section A

Answer **all** questions in pencil on the answer sheet provided for multiple-choice questions.

Choose the response that is **correct** or that **best answers** the question.

A correct answer scores 1; an incorrect answer scores 0.

Marks will **not** be deducted for incorrect answers.

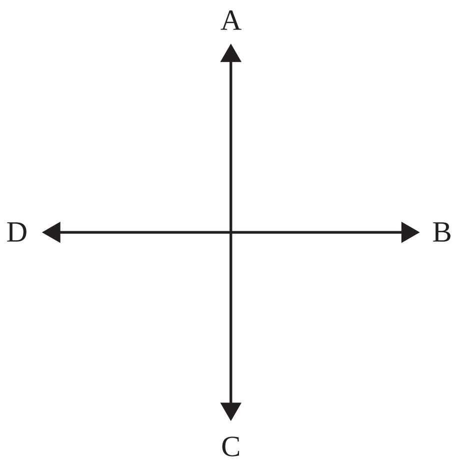
No marks will be given if more than one answer is completed for any question.

Unless otherwise indicated, the diagrams in this book are **not** drawn to scale.

Take the value of g to be 9.8 m s^{-2}.

Question 1

Two identical bar magnets are placed end to end, as shown below. Point X is midway between the bar magnets.



Which direction best shows the direction of the magnetic field at point X?

A. A

B. B

C. C

D. D

Use the following information to answer Questions 2 and 3.

A powerline carries a current of 1000 A DC in the direction east to west. At the point of measurement, Earth's magnetic field is horizontally north and its strength is 5.0×10^{-5} T.

Question 2

Which one of the following best gives the direction of the electromagnetic force on the powerline?

A. horizontally west
B. horizontally north
C. vertically upwards
D. vertically downwards

Question 3

The magnitude of the force on **each metre** of the powerline is best given by

A. 5.0×10^{3} N
B. 5.0×10^{2} N
C. 5.0×10^{-2} N
D. 5.0×10^{-5} N

Question 4

The gravitational field strength at the surface of Mars is 3.7 N kg^{-1}.

Which one of the following is closest to the change in gravitational potential energy when a 10 kg mass falls from 2.0 m above Mars's surface to Mars's surface?

A. 3.7 J
B. 7.4 J
C. 37 J
D. 74 J

Use the following information to answer Questions 5 and 6.

A light globe operates at 12 V_{RMS} AC that is supplied by a 240 V to 12 V transformer connected to a 240 V_{RMS} mains supply.

Question 5

In the transformer, the ratio of turns in the primary (input) to turns in the secondary (output) is

A. 20:1
B. 1:20
C. 28:1
D. 1:28

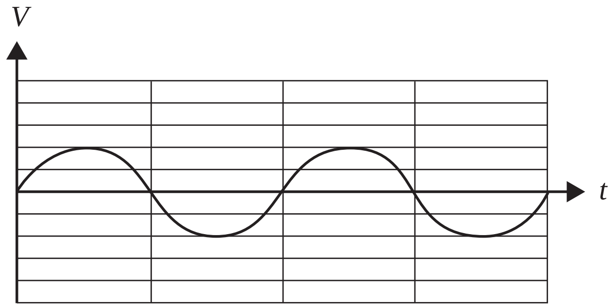
Question 6

If the light globe is to be operated using a battery instead of the mains supply, what voltage should the battery have for the light globe to operate correctly?

A. 12 V
B. 17 V
C. 8.5 V
D. 6.0 V

Question 7

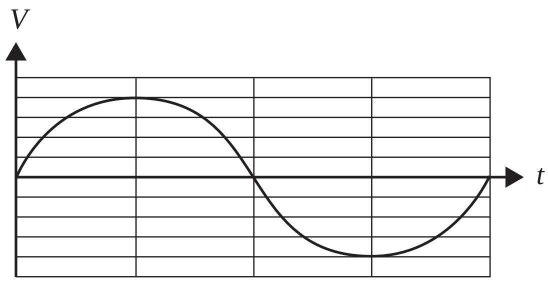
An alternator is rotating at 10 revolutions per second. Its output is measured by an oscilloscope. The signal produced is shown below.



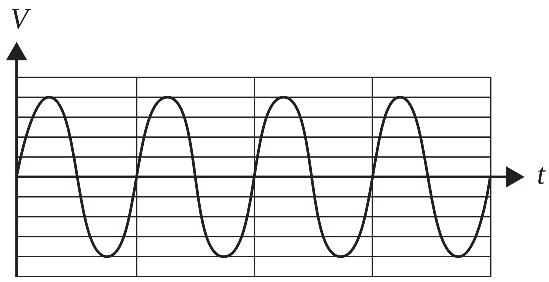
The alternator is then slowed so that it rotates at five revolutions per second.

Which one of the following best shows the display observed on the oscilloscope?

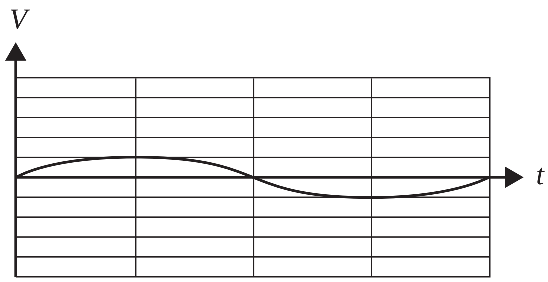
A.



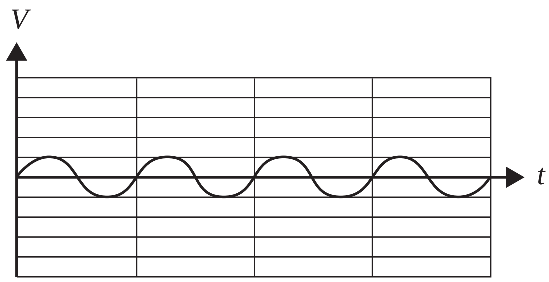
B.



C.

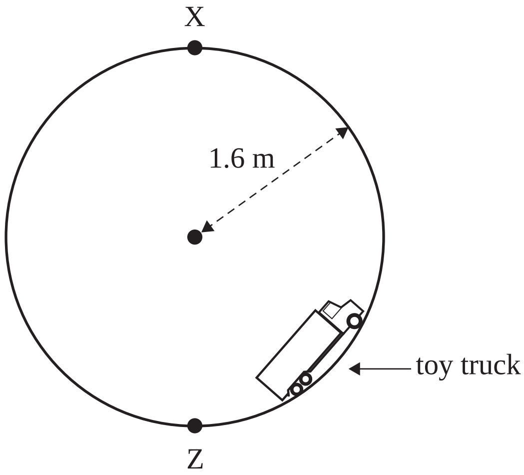


D.



Use the following information to answer Questions 8 and 9.

A toy truck travels on a track around a vertical loop of radius 1.6 m, as shown below. Assume that the toy truck is a point mass.

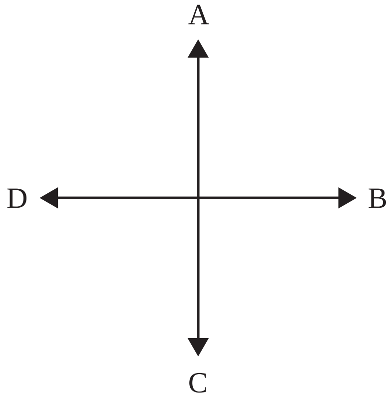


Question 8

The minimum speed at which the toy truck must be moving at point X for it to stay on the track is closest to

A. 1.6 m s^{-1}
B. 3.2 m s^{-1}
C. 4.0 m s^{-1}
D. 16 m s^{-1}

Question 9



Which direction best shows the direction of the resultant force on the toy truck at point Z?

A. A
B. B
C. C
D. D

Question 10

When light refracts as it passes from one medium to another, which one of the following will change?

A. colour

B. period

C. frequency

D. wavelength

Question 11

Which one of the following best supports the statement that light is a transverse wave rather than a longitudinal wave?

A. Light can be polarised.

B. Light has different colours.

C. Light can travel through a vacuum.

D. Energy in light oscillates in a direction parallel to its propagation direction.

Question 12

Which one of the following statements about electromagnetic radiation is correct?

A. Electromagnetic radiation cannot be produced by atomic-energy-level transitions.

B. Electromagnetic radiation is only produced by atomic-energy-level transitions.

C. Electromagnetic radiation can be produced by accelerating charges.

D. All electromagnetic radiation is produced by accelerating charges.

Question 13

When a mechanical wave moves through a medium, there is a net transfer of

A. mass.

B. energy.

C. particles.

D. mass and energy.

Question 14

Which one of the following statements about sound waves and electromagnetic waves is correct?

A. Both sound waves and electromagnetic waves can travel through a vacuum.

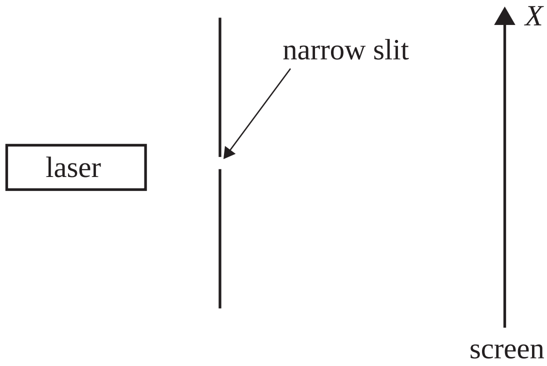
B. Neither sound waves nor electromagnetic waves can travel through a vacuum.

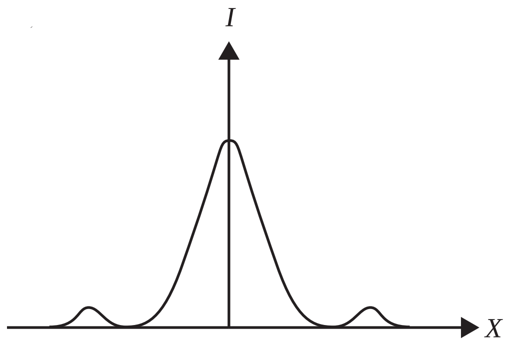
C. Sound waves can travel through a vacuum but electromagnetic waves cannot travel through a vacuum.

D. Sound waves cannot travel through a vacuum but electromagnetic waves can travel through a vacuum.

Question 15

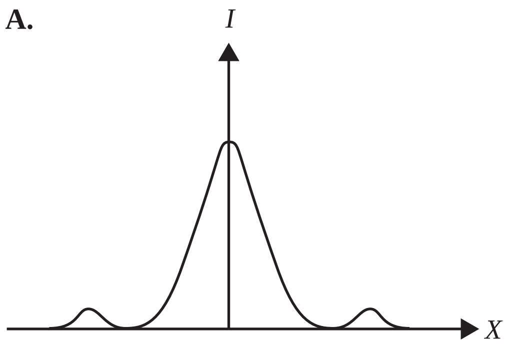
Monochromatic laser light of wavelength 600 nm shines through a narrow slit. The intensity of the transmitted light is recorded on a screen some distance away, as shown below in the diagram on the left. The intensity graph of the pattern seen on the screen is shown below on the right.



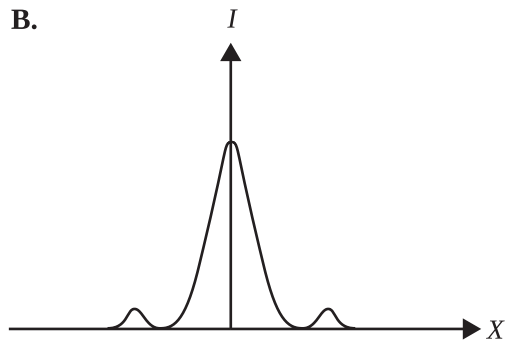


Which one of the following intensity graphs best represents the pattern that would be seen if a slightly wider slit were used?

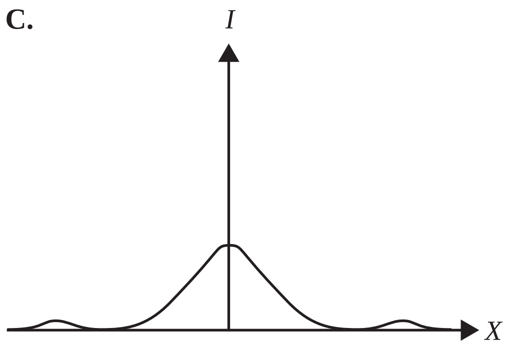
A.



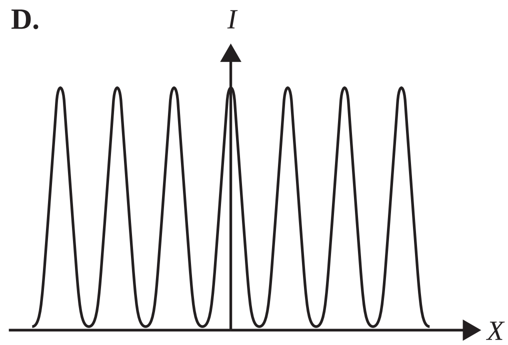
B.



C.



D.



Question 16

In a particle accelerator, magnesium ions are accelerated to 20.0% of the speed of light.

Which one of the following is closest to the Lorentz factor, γ, for the magnesium ions at this speed?

A. 1.02

B. 1.12

C. 1.20

D. 2.24

Question 17

The lifetime of stationary muons is measured in a laboratory to be 2.2 μs. The lifetime of relativistic muons produced in Earth's upper atmosphere, as measured by ground-based scientists, is 16 μs.

The resulting time dilation observed by the scientists gives a Lorentz factor, γ, of

A. 0.14

B. 1.4

C. 3.5

D. 7.3

Question 18

If a particle's kinetic energy is 10 times its rest energy, E_{rest}, then the Lorentz factor, γ, would be closest to

A. 9

B. 10

C. 11

D. 12

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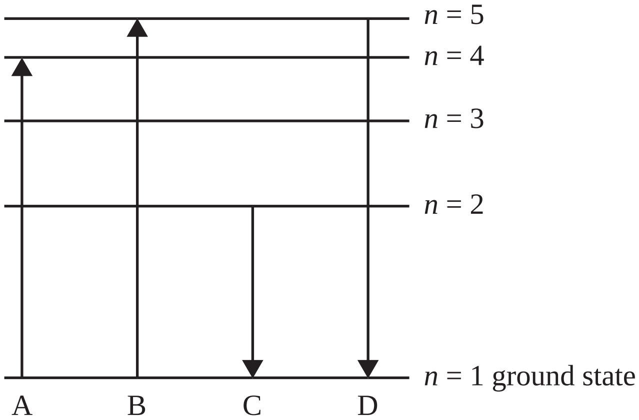
Question 19

Part of the energy-level diagram for an unknown atom is shown below.



Which one of the arrows shows a change of energy level corresponding to the absorption of a photon of highest frequency?

A. A

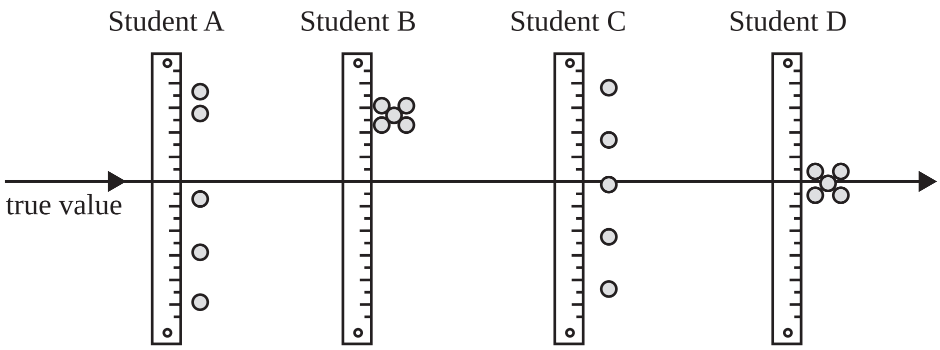
B. B

C. C

D. D

Question 20

Four students measure the length of a piece of string. Each student takes five measurements and displays the results as five dots, as shown in the diagram below. The true value is also shown in the diagram.



Which student produced a set of precise but inaccurate results?

A. Student A

B. Student B

C. Student C

D. Student D

END OF SECTION A
TURN OVER

SECTION B

Instructions for Section B

Answer **all** questions in the spaces provided. Write using blue or black pen.
Where an answer box is provided, write your final answer in the box.
If an answer box has a unit printed in it, give your answer in that unit.
In questions where more than one mark is available, appropriate working **must** be shown.
Unless otherwise indicated, the diagrams in this book are **not** drawn to scale.
Take the value of g to be 9.8 m s^{-2}.

Question 1 (7 marks)

Electrons are accelerated from rest between two plates that are 50 cm apart, as shown in Figure 1.
The electrons emerge from the second plate at a speed, v, of 4.2×10^7 m s^{-1}.

Ignore relativistic effects.

Data

mass of electron	9.1×10^{-31} kg
charge on electron	-1.6×10^{-19} C

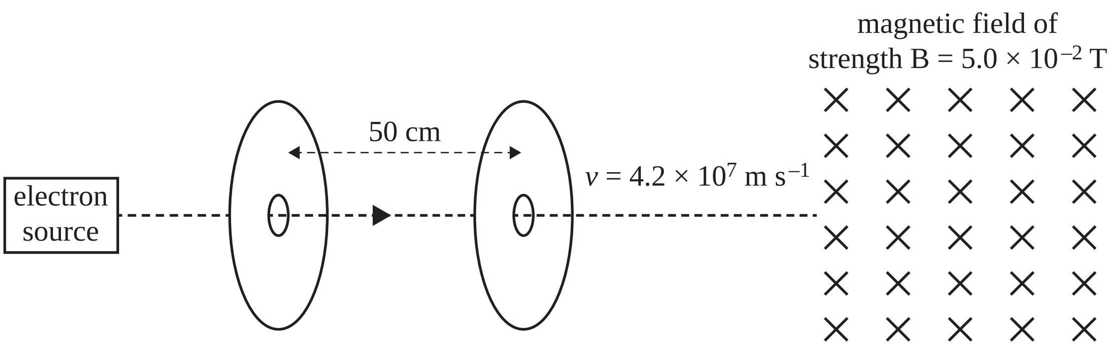


Figure 1

a. Calculate the voltage between the two plates. Show your working. 3 marks

V

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The electrons enter a region of uniform magnetic field of strength $B = 5.0 \times 10^{-2}$ T that is at right angles to their path.

b. Calculate the magnitude of the force on each electron. Show your working. 2 marks

N

c. Will the path of the electrons in this region of uniform magnetic field be a straight line, part of a parabola or part of a circle? Give a reason for your answer. 2 marks

Question 2 (5 marks)

A square loop of wire with a cross-sectional area of 0.010 m^2 and 20 turns rotates in a magnetic field of strength 4.0×10^{-2} T. The wires of the loop are connected to two slip rings and an oscilloscope, as shown in Figure 2.

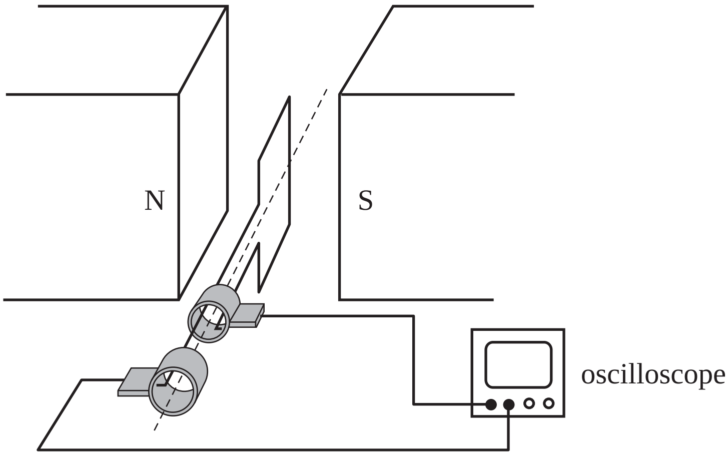


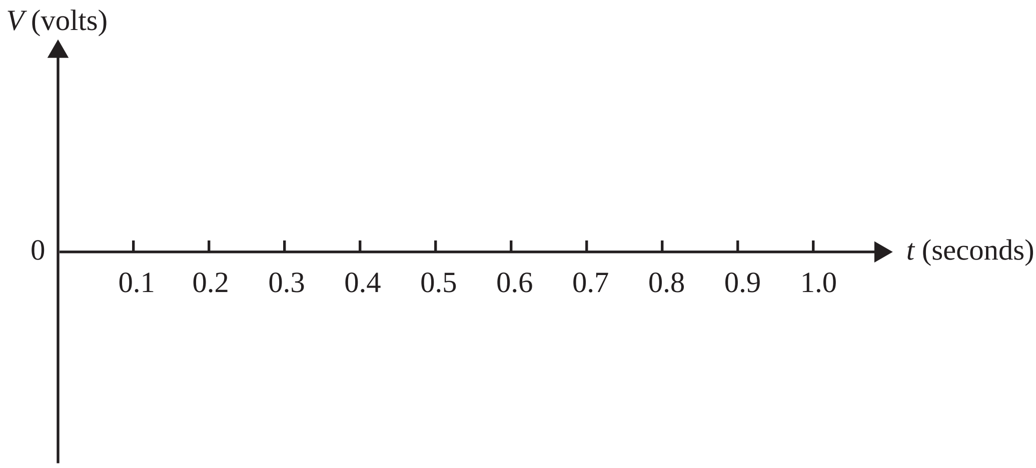
Figure 2

The loop takes 0.10 s to make a quarter rotation (from a position at right angles to the field to a position parallel to the field).

a. Calculate the average magnitude of the induced EMF in the loop as it makes this quarter rotation. Show your working. 3 marks

V

b. On the axes provided below, sketch the output signal that would be displayed on the oscilloscope over 1.0 s. A value or scale on the *y*-axis is not necessary. Take the position of the loop at $t = 0$ to be that shown in Figure 2. 2 marks



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Question 3 (5 marks)

Figure 3 shows a simple DC motor consisting of a square loop of wire of side 10 cm and 10 turns, a magnetic field of strength 2.0×10^{-3} T, and a commutator connected to a 12 V battery. The current in the loop is 2.0 A.

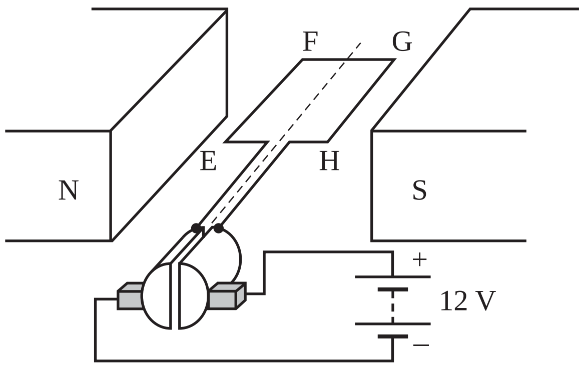

Figure 3

a. Calculate the magnitude of the total force acting on the side EF when the loop is in the position shown in Figure 3. Show your working. 2 marks

N

b. Explain the role of the commutator in a DC motor. 3 marks

Question 4 (8 marks)

An electrician is installing a power supply to a yard located 500 m from a farmhouse in order to operate a 240 V_{RMS}, 480 W light globe, as shown in Figure 4.

The connecting wires have a total resistance, R_T, of 40 Ω.

At the farmhouse, the electrician provides the required input voltage, V_{in}, to the connecting wires for the light globe to operate at 240 V_{RMS} and 480 W.

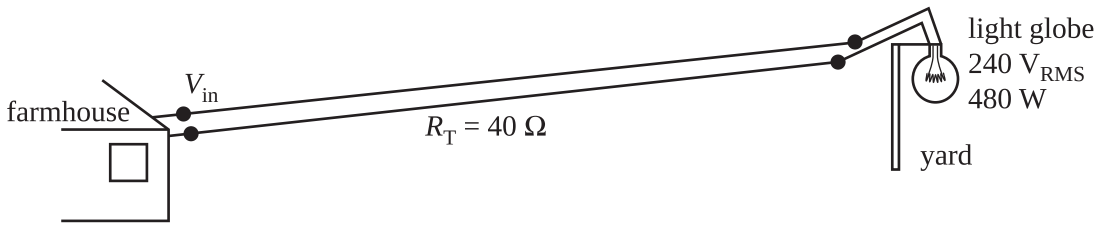

Figure 4

a. When the light globe is operating at 240 V_{RMS} and 480 W, what is the power loss in the connecting wires? Show your working. 2 marks

W

b. Calculate the RMS voltage of V_{in}. Show your working. 3 marks

V_{RMS}

SECTION B – Question 4 – continued

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c. To reduce the power loss in the connecting wires, the electrician changes the input voltage, V_{in}, and installs an 8:1 step-down transformer at the yard. After these changes, the light globe still operates at 240 V_{RMS} and 480 W, as shown in Figure 5.

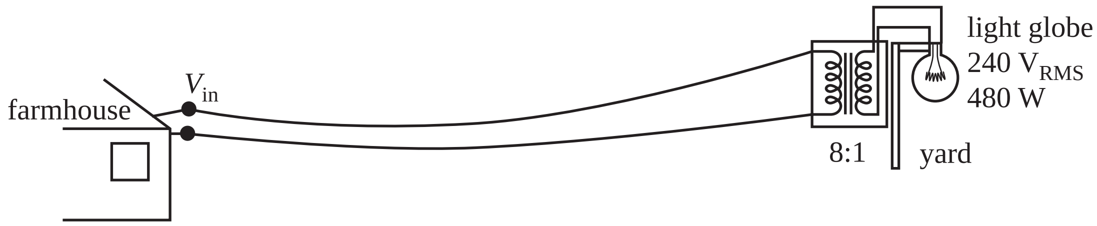

Figure 5

Calculate the RMS power loss in the connecting wires for this new situation. Show your working. 3 marks

W

Question 5 (8 marks)

Students conduct an experiment in which a mass of 2.0 kg is suspended from a spring with spring constant $k = 100 \text{ N m}^{-1}$.

Ignore the mass of the spring.

Take the gravitational field, g, to be 10 N kg^{-1}.

Take the zero of gravitational potential energy when the mass is at its lowest point.

The experimental arrangement is shown in Figure 6.

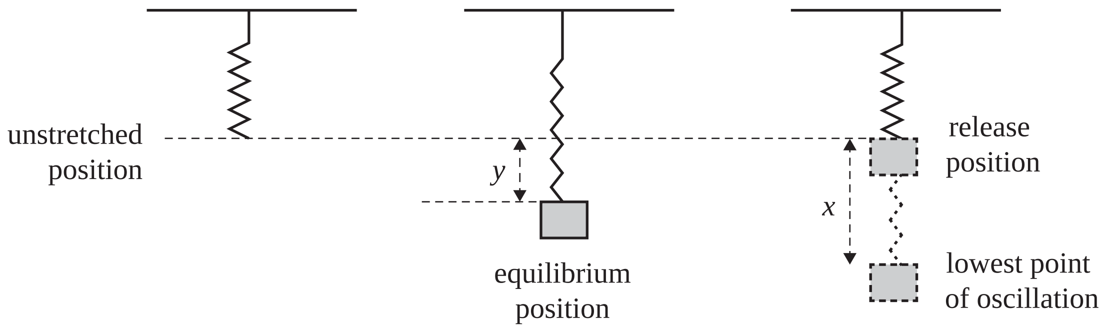

Figure 6

a. The mass is attached to the spring and slowly lowered to its equilibrium position.

Calculate the extension, y, of the spring from its unstretched position to its equilibrium position. Show your working. 2 marks

m

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b. The mass is now raised to the unstretched length of the spring and released so that it oscillates vertically.

i. Determine the distance, x, from the release position to the point at which the mass momentarily comes to rest at the lowest point of oscillation. Ignore frictional losses. Show your working. 2 marks

m

ii. Calculate the maximum speed of the mass. Show your working. 4 marks

m s^{-1}

Question 6 (6 marks)

A golfer hits a ball so that it leaves the ground at a speed of 40 m s^{-1} at an angle of 30° to the horizontal, as shown in Figure 7.

Take g = 9.8 m s^{-2}.

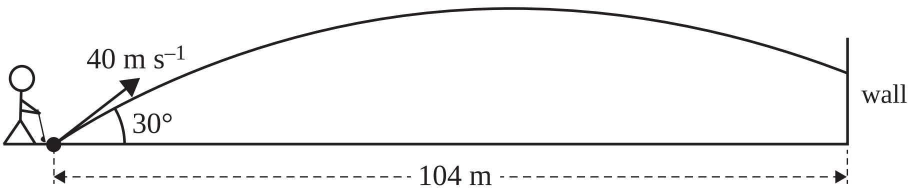

Figure 7

a. Calculate the maximum height that the ball rises above the ground. Show your working. 2 marks

m

b. Instead of landing on the ground, the ball hits a wall that is 104 m away from the point at which the golfer hits the ball.

At what height up the wall does the ball hit the wall? Show your working. 4 marks

m

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Question 7 (7 marks)

Students are using high-speed photography to analyse the collision between a bat and a ball. The experiment is arranged so that the bat and the ball are both moving horizontally just before and just after the collision, as shown in Figure 8.

Assume that the bat and the ball are point masses.

The students record the following measurements.

mass of bat	2.0 kg
mass of ball	0.20 kg
speed of bat immediately before collision	10 m s^{-1} (bat is stationary after collision)
speed of ball immediately before collision	60 m s^{-1} (towards bat)
speed of ball immediately after collision	40 m s^{-1} (away from bat)
time ball is in contact with bat	0.010 s

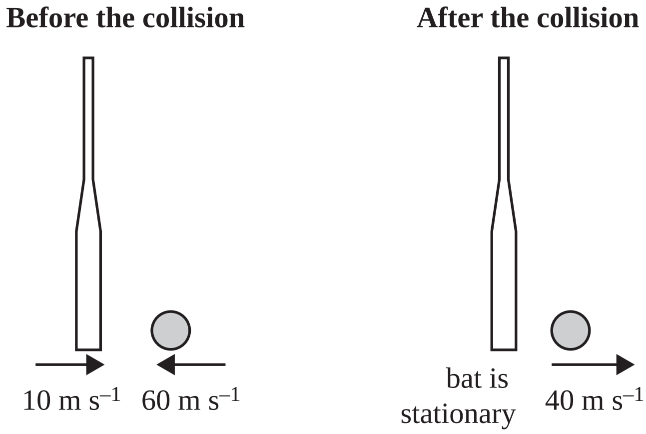

Figure 8

a. Calculate the magnitude of the impulse given by the bat to the ball. Include an appropriate unit. Show your working. 3 marks

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b. Calculate the average force of the bat on the ball during the collision. Show your working. 2 marks

N

c. Use calculations to determine whether the collision between the bat and the ball is elastic or inelastic. Show your working. 2 marks

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Question 8 (15 marks)

Students are investigating the forces involved in horizontal circular motion. Their apparatus consists of a model car that travels in a circle at constant speed. The speed of the model car can be set at different values. The car is connected by a string of length 1.0 m to the centre of the circle. Incorporated in the string is a sensor that measures the tension (force) of the string. There is no radial friction force between the car's tyres and the surface that the car moves on.

Figure 9 shows the experimental arrangement viewed from above.

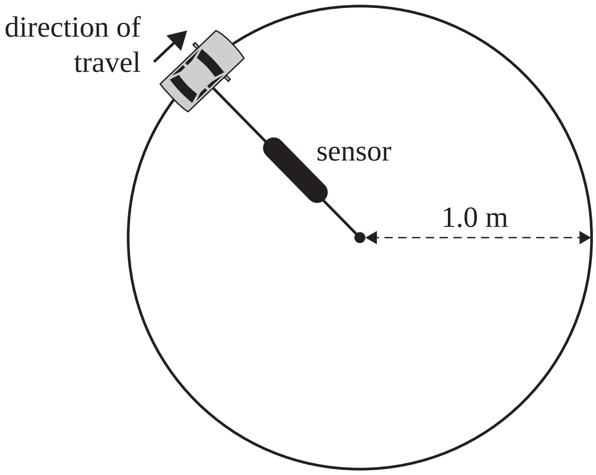


Figure 9

The students obtain a number of measurements by varying the setting for the period of rotation, T, and then recording the force, F_T, in the string. They know T with great accuracy but the sensor has an experimental uncertainty of ± 0.4 N.

a. What is experimental uncertainty and how can it be reduced? 2 marks

____

____

____

____

____

b. Identify the independent variable, the dependent variable and two controlled variables involved in this experiment. 3 marks

Independent variable ______________________________

Dependent variable ______________________________

Controlled variable 1 ______________________________

Controlled variable 2 ______________________________

c. **i.** The students have recorded the data for the period of rotation, T, and the force, F_T, in the table below. The radius of the circle is 1.0 m.

Calculate the values of $1/T^2$ and write them in the table below. 1 mark

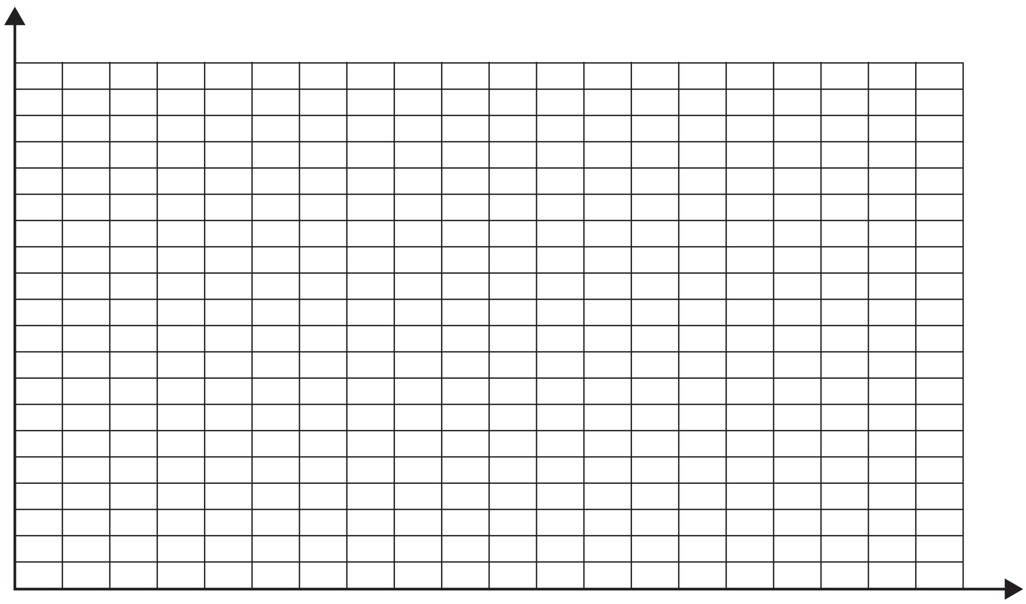
Period T (s)	**$1/T^2$ (s^{-2})**	**Force F_T (N)**
5.00		8
10.0		2
15.0		0.9
20.0		0.5

ii. The relationship between F_T and T is given by the formula

$$F_T = \frac{4\pi^2 mr}{T^2}$$

On the axes provided below:

- plot a graph of F_T versus $1/T^2$ using the data in the table in **part c.i.**
- include the correct uncertainty bars for the F_T values
- label each of the axes correctly
- draw a line of best fit. 6 marks



d. Using the line of best fit and the formula from **part c.ii.**, determine the value of m, the mass of the car. Show your working. 3 marks

____

____

____

	kg

Question 9 (2 marks)

Figure 10 shows two masses. Mass A has a mass of 10 kg. It rests on top of Mass B, which has a mass of 20 kg.

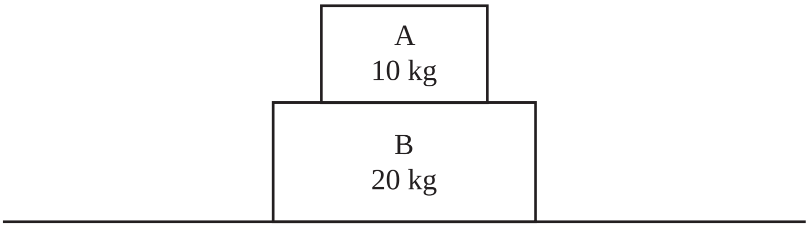


Figure 10

Calculate the magnitude and direction of the force on Mass A by Mass B. Take $g = 9.8\ \text{N kg}^{-1}$.

N	

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Question 10 (6 marks)

A spacecraft with astronauts on board is in orbit around Mars at an altitude of 1.6×10^6 m above the surface of Mars.

The mass of Mars is 6.4×10^{23} kg and its radius is 3.4×10^6 m.

Take the universal gravitational constant, G, to be 6.7×10^{-11} N m^2 kg^{-2}.

The mass of the spacecraft is 2.0×10^4 kg.

a. Calculate the period of orbit of the spacecraft around Mars. Show your working. 4 marks

s

b. The altitude of the spacecraft above the surface of Mars is doubled so that the spacecraft is now in a new stable orbit.

Will the speed of the spacecraft be greater, the same or lower in this new orbit? Explain your reasoning. 2 marks

Question 11 (6 marks)

Kym and Roger conduct an experiment to observe an electron diffraction pattern. 5000 eV electrons are projected through a diffracting grid and the resulting pattern is observed on a screen.

Kym and Roger want to calculate the wavelength of X-rays that would produce a similarly spaced diffraction pattern.

Kym says that they will need X-rays of 5000 eV.

Roger says that X-rays of a different energy will be needed.

a. Explain why Roger is correct. 2 marks

b. Showing each of the steps involved in your working, calculate the energy of X-rays that would be required to produce the similarly spaced diffraction pattern. 4 marks

eV

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Question 12 (3 marks)

Optical fibres are constructed using transparent materials with differing refractive indices. A laser light beam of wavelength 590 nm is shone into the fibre and travels along the arrowed path shown in Figure 11.

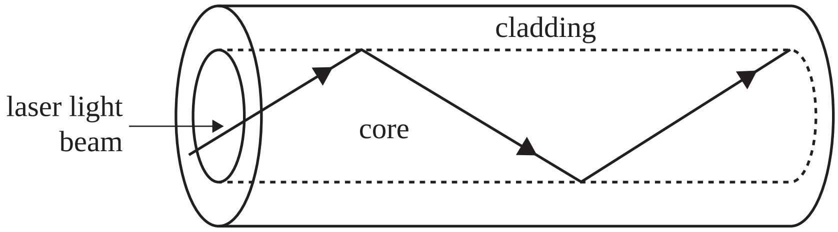

Figure 11

a. For the fibre to operate as designed, which must have the greater refractive index – the cladding or the core? 1 mark

b. The refractive index of the cladding is 1.42. The critical angle for light striking the core–cladding boundary is 66.0°.

Calculate the refractive index of the core material. Show your working. 2 marks

Question 13 (4 marks)

A seawall that is aligned north–south protects a harbour of constant depth from large ocean waves, as shown in Figure 12.

The seawall has two small gaps, S_1 and S_2, which are 60 m apart. Inside the harbour, a small boat sails north parallel to the seawall at a distance of 420 m from the seawall. At point C sits a beacon, equidistant from the two gaps in the seawall.

The boat's captain notices that, at about every 42 m, there is calm water, while there are large waves between those calm points.

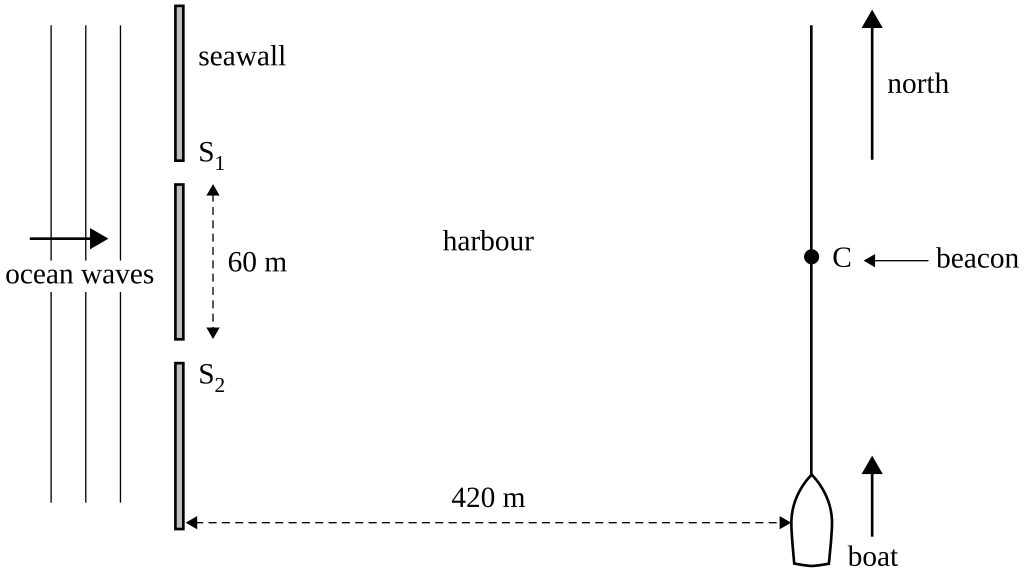

Figure 12

a. Will the beacon at point C be in calm water or large waves? Give a reason for your answer. 2 marks

b. Calculate the wavelength of the ocean waves. Show your working. 2 marks

m

DO NOT WRITE IN THIS AREA

Question 14 (6 marks)

Figure 13 shows a simple apparatus that can be used to determine the frequency of a tuning fork.

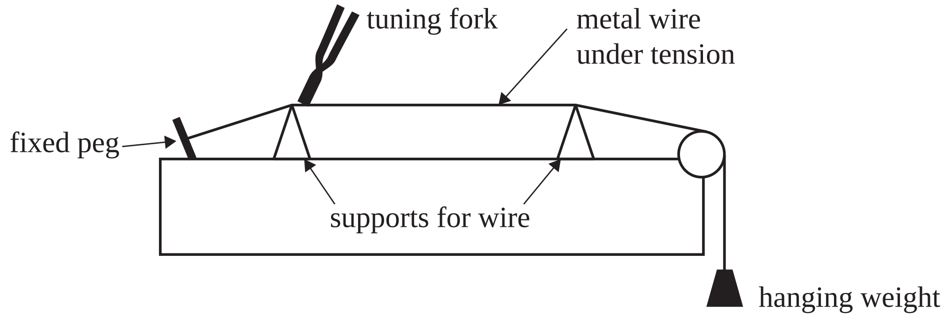

Figure 13

The apparatus consists of two supports and a metal wire that is stretched between a fixed peg and a hanging weight. The wire is under tension.

The tuning fork is set vibrating and is then touched onto the wire close to the left-hand support, which makes the wire vibrate at the same frequency as the tuning fork.

a. Draw a diagram of the simplest standing wave pattern that can exist on the vibrating section of the wire (the fundamental) between the two supports. 2 marks

b. When the distance between the supports is 0.92 m, the fundamental frequency resonates in the wire.

Calculate the wavelength of the fundamental. Show your working. 2 marks

m

c. Calculate the frequency of the tuning fork if the speed of the waves in the wire is 224 m s^{-1}. Show your working. 2 marks

Hz

Question 15 (6 marks)

Figure 14 shows the energy-level diagram for a hydrogen atom.

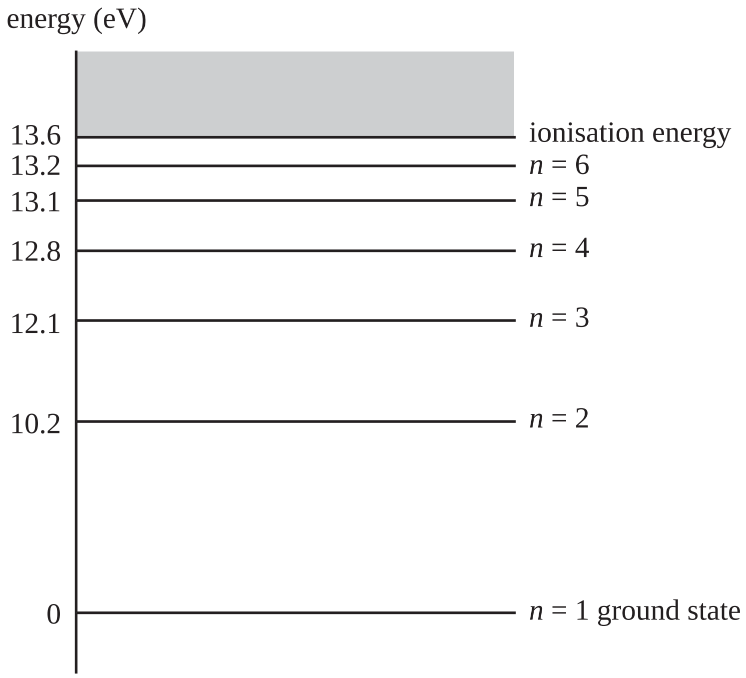

Figure 14

a. The hydrogen atom is excited from the ground state to a higher energy level. Subsequently, it makes a transition from this higher energy level to the $n = 3$ energy level, emitting a photon of wavelength 1242 nm.

What was the number, n, of the energy level before the photon was emitted? Show your working. 3 marks

$n =$

b. The quantised states of the electron of the hydrogen atom provide evidence of the wave–particle duality of the electron.

Describe how an electron in an allowed state is modelled to provide this evidence. You may include a diagram. 3 marks

Question 16 (8 marks)

April sets up the apparatus shown in Figure 15 to investigate the photoelectric effect. She can change the frequency of the light incident on the metal plate by changing the filter and she can change the type of metal of which the plate is made.

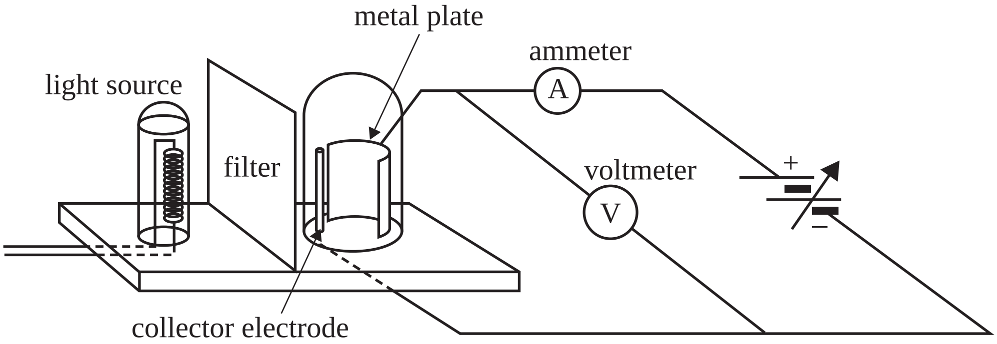

Figure 15

a. For her first experiment, April chooses a filter that gives light of frequency 7.13×10^{14} Hz and a metal plate made of caesium with a work function of 1.95 eV.

April adjusts the voltage of the collector electrode so that the current becomes smaller and smaller.

When the ammeter, A, reaches zero, April records the voltage shown on the voltmeter, V.

Use calculations to determine this voltage. 3 marks

V

b. For her second experiment, April uses a metal plate made of zinc. Zinc has a threshold frequency for emission of photoelectrons of 1.04×10^{15} Hz. Photoelectrons are emitted.

Calculate the maximum wavelength, in nanometres, of the light for photoelectrons to be emitted from the zinc plate. Show your working. 2 marks

nm

SECTION B – Question 16 – continued

c. For her third experiment, April changes the metal plate from the zinc plate used in the second experiment to a plate made of platinum. Platinum has a threshold frequency of 1.53×10^{15} Hz. April uses light of frequency 7.13×10^{14} Hz but does not make any other changes. Photoelectrons are not emitted.

April observes for a longer time and then increases the intensity of the light beam but still finds that photoelectrons are not emitted.

Explain how April's observations support the particle model of light but do not support the wave model of light in explaining the photoelectric effect. 3 marks

Question 17 (3 marks)

A spaceship is travelling from Earth to the star system Epsilon Eridani, which is located 10.5 light-years from Earth as measured by Earth-based instruments.

If the spaceship travels at $0.85c$ ($\gamma = 1.90$), determine the duration of the flight as measured by the astronauts on the spaceship travelling to Epsilon Eridani. Take one light-year to be 9.46×10^{15} m. Show your working.

years

Question 18 (3 marks)

Alien astronauts are travelling between star systems aboard a cube-shaped spaceship, as shown in Figure 16. The sides of the cube along the *x*-axis, *y*-axis and *z*-axis measure 3.20×10^3 m in the spaceship's frame of reference.

The spaceship passes Bob, who is on a space station, at speed $v = 0.990c$ ($\gamma = 7.09$).

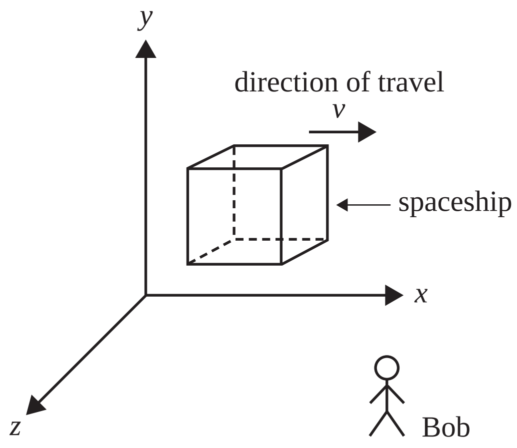

Figure 16

In the table below, determine the dimensions of the cube-shaped spaceship as measured from Bob's frame of reference and explain your reasoning.

length of side along *x*-axis	m
length of side along *y*-axis	m
length of side along *z*-axis	m

Reasoning ____

____

____

Question 19 (2 marks)

In a nuclear fusion reaction in the sun's core, two deuterium nuclei, each with a mass of 3.3436×10^{-27} kg, fuse to produce one helium-4 nucleus with a mass of 6.6465×10^{-27} kg.

Ignore the kinetic energy of the nuclei before the reaction.

Calculate the energy released. Show your working.

J

END OF QUESTION AND ANSWER BOOK

VICTORIAN CURRICULUM
AND ASSESSMENT AUTHORITY

Victorian Certificate of Education
2019

PHYSICS

Written examination

FORMULA SHEET

Instructions

This formula sheet is provided for your reference.
A question and answer book is provided with this formula sheet.

Students are NOT permitted to bring mobile phones and/or any other unauthorised electronic devices into the examination room.

Physics formulas

Motion and related energy transformations

velocity; acceleration	$v = \frac{\Delta s}{\Delta t}; \quad a = \frac{\Delta v}{\Delta t}$
equations for constant acceleration	$v = u + at$ $s = ut + \frac{1}{2}at^2$ $s = vt - \frac{1}{2}at^2$ $v^2 = u^2 + 2as$ $s = \frac{1}{2}(v + u)t$
Newton's second law	$\Sigma F = ma$
circular motion	$a = \frac{v^2}{r} = \frac{4\pi^2 r}{T^2}$
Hooke's law	$F = -k\Delta x$
elastic potential energy	$\frac{1}{2}k(\Delta x)^2$
gravitational potential energy near the surface of Earth	$mg\Delta h$
kinetic energy	$\frac{1}{2}mv^2$
Newton's law of universal gravitation	$F = G\frac{M_1 M_2}{r^2}$
gravitational field	$g = G\frac{M}{r^2}$
impulse	$F\Delta t$
momentum	mv
Lorentz factor	$\gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}$
time dilation	$t = t_o\gamma$
length contraction	$L = \frac{L_o}{\gamma}$
rest energy	$E_{rest} = mc^2$
relativistic total energy	$E_{total} = \gamma mc^2$
relativistic kinetic energy	$E_k = (\gamma - 1)mc^2$

Fields and application of field concepts

electric field between charged plates	$E = \frac{V}{d}$
energy transformations of charges in an electric field	$\frac{1}{2}mv^2 = qV$
field of a point charge	$E = \frac{kq}{r^2}$
force on an electric charge	$F = qE$
Coulomb's law	$F = \frac{kq_1q_2}{r^2}$
magnetic force on a moving charge	$F = qvB$
magnetic force on a current carrying conductor	$F = nIlB$
radius of a charged particle in a magnetic field	$r = \frac{mv}{qB}$

Generation and transmission of electricity

voltage; power	$V = RI$; $P = VI = I^2R$
resistors in series	$R_T = R_1 + R_2$
resistors in parallel	$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2}$
ideal transformer action	$\frac{V_1}{V_2} = \frac{N_1}{N_2} = \frac{I_2}{I_1}$
AC voltage and current	$V_{RMS} = \frac{1}{\sqrt{2}}V_{peak}$ $I_{RMS} = \frac{1}{\sqrt{2}}I_{peak}$
electromagnetic induction	EMF: $\varepsilon = -N\frac{\Delta\Phi_B}{\Delta t}$ flux: $\Phi_B = B_\perp A$
transmission losses	$V_{drop} = I_{line}R_{line}$ $P_{loss} = I^2_{line}R_{line}$

Wave concepts

wave equation	$v = f\lambda$
constructive interference	path difference = $n\lambda$
destructive interference	path difference = $\left(n - \frac{1}{2}\right)\lambda$
fringe spacing	$\Delta x = \frac{\lambda L}{d}$
Snell's law	$n_1 \sin\theta_1 = n_2 \sin\theta_2$
refractive index and wave speed	$n_1 v_1 = n_2 v_2$

The nature of light and matter

photoelectric effect	$E_{\text{k max}} = hf - \phi$
photon energy	$E = hf$
photon momentum	$p = \frac{h}{\lambda}$
de Broglie wavelength	$\lambda = \frac{h}{p}$

Data

acceleration due to gravity at Earth's surface	$g = 9.8\ \text{m s}^{-2}$
mass of the electron	$m_e = 9.1 \times 10^{-31}\ \text{kg}$
magnitude of the charge of the electron	$e = 1.6 \times 10^{-19}\ \text{C}$
Planck's constant	$h = 6.63 \times 10^{-34}\ \text{J s}$ $h = 4.14 \times 10^{-15}\ \text{eV s}$
speed of light in a vacuum	$c = 3.0 \times 10^{8}\ \text{m s}^{-1}$
gravitational constant	$G = 6.67 \times 10^{-11}\ \text{N m}^2\ \text{kg}^{-2}$
mass of Earth	$M_E = 5.98 \times 10^{24}\ \text{kg}$
radius of Earth	$R_E = 6.37 \times 10^{6}\ \text{m}$
Coulomb constant	$k = 8.99 \times 10^{9}\ \text{N m}^2\ \text{C}^{-2}$

Prefixes/Units

p = pico = 10^{-12}	n = nano = 10^{-9}	μ = micro = 10^{-6}	m = milli = 10^{-3}
k = kilo = 10^{3}	M = mega = 10^{6}	G = giga = 10^{9}	t = tonne = 10^{3} kg

END OF FORMULA SHEET