VICTORIAN CURRICULUM AND ASSESSMENT AUTHORITY

Victorian Certificate of Education 2022

SUPERVISOR TO ATTACH PROCESSING LABEL HERE

Letter

STUDENT NUMBER

PHYSICS
Written examination

Wednesday 9 November 2022

Reading time: 9.00 am to 9.15 am (15 minutes)
Writing time: 9.15 am to 11.45 am (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	17	17	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 42 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.

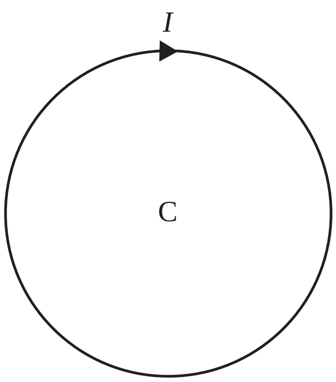
No marks will be given if more than one answer is completed for any question.

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

A single loop of wire carries a current, I, as shown in the diagram below.



Which one of the following best describes the direction of the magnetic field at the centre of the circle, C, which is produced by the current carrying wire?

A. to the left

B. to the right

C. into the page

D. out of the page

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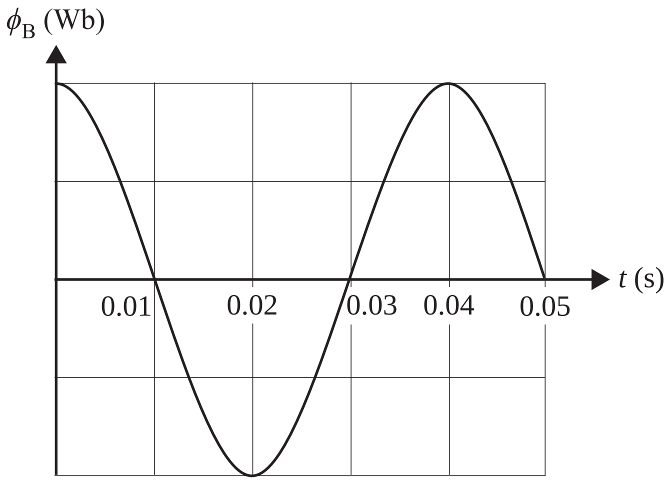
Question 2

The diagram below shows the magnetic flux variation through the coil of an AC generator.



Which one of the following is closest to the frequency of the magnetic flux variation through the coil of the AC generator?

A. 0.04 Hz

B. 10 Hz

C. 20 Hz

D. 25 Hz

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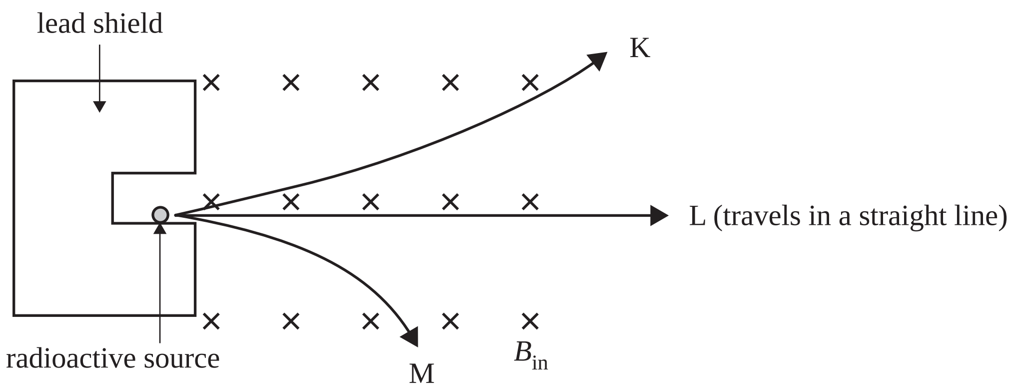
Question 3

Particles emitted from a radioactive source travel through a magnetic field, B_{in}, directed into the page, as shown schematically in the diagram below.

Three particles, K, L and M, follow the paths indicated by the arrows.

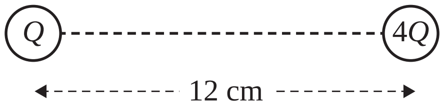


Which of the following correctly identifies the charges on particles K, L and M?

	K	L	M
A.	positive	no charge	negative
B.	positive	negative	negative
C.	negative	no charge	positive
D.	no charge	no charge	no charge

Question 4

Two point charges, Q and $4Q$, are placed 12 cm apart, as shown in the diagram below.



On the straight line between the charges Q and $4Q$, the electric field is

A. non-zero everywhere.

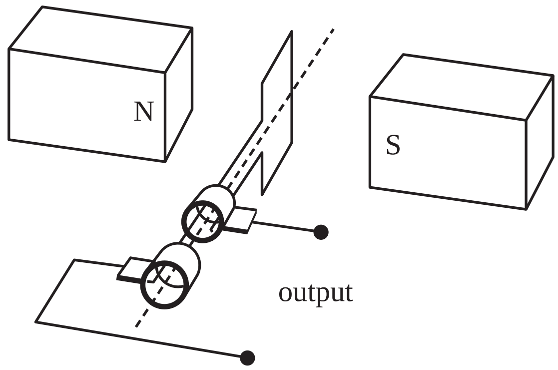
B. zero at a point 2.4 cm from Q.

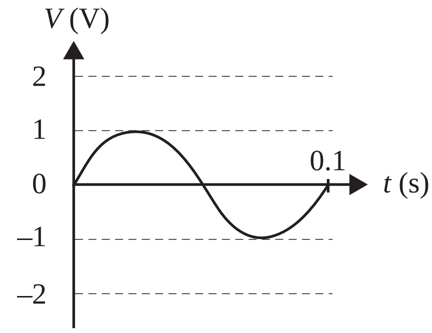
C. zero at a point 3 cm from Q.

D. zero at a point 4 cm from Q.

Question 5

A simple electricity generator is shown in the diagram below. When the coil is rotated, the output voltage across the slip rings is measured. The graph shows how the output voltage varies with time.

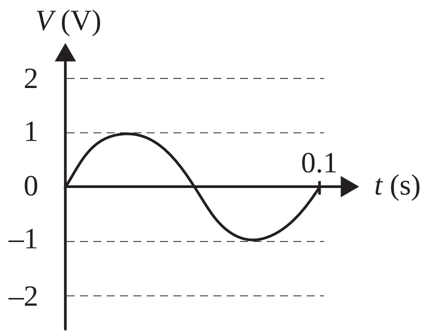




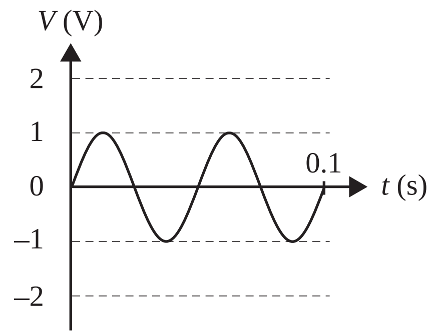
The frequency of rotation of the generator is now doubled.

Which one of the following graphs best represents the output voltage measured across the slip rings?

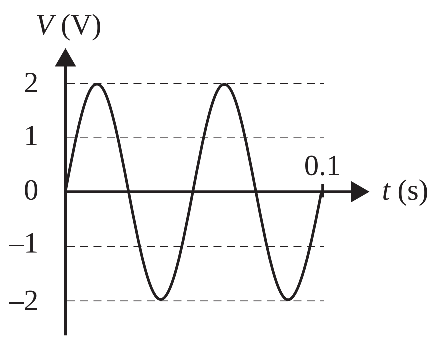
A.



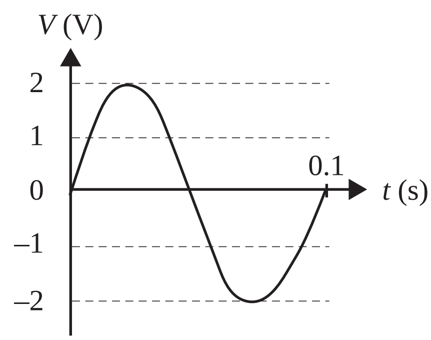
B.



C.



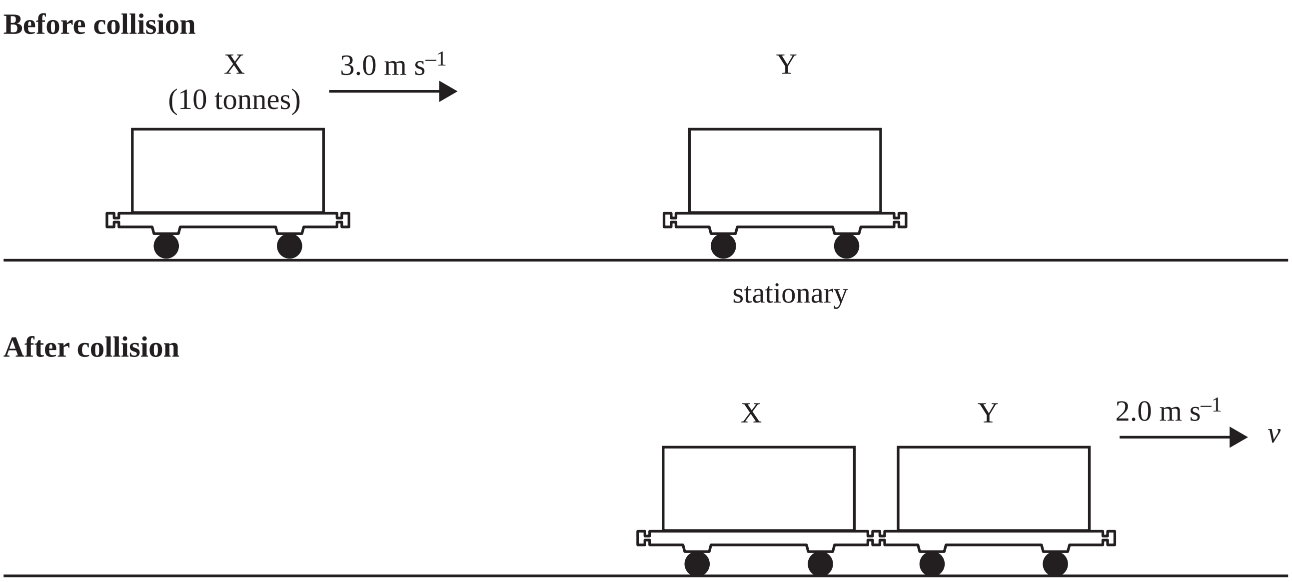
D.



Use the following information to answer Questions 6 and 7.

A railway truck (X) of mass 10 tonnes, moving at 3.0 m s^{-1}, collides with a stationary railway truck (Y), as shown in the diagram below.

After the collision, they are joined together and move off at speed $v = 2.0 \text{ m s}^{-1}$.



Question 6

Which one of the following is closest to the mass of railway truck Y?

A. 3 tonnes

B. 5 tonnes

C. 6.7 tonnes

D. 15 tonnes

Question 7

Which one of the following best describes the force exerted by the railway truck X on the railway truck Y ($F_{\text{X on Y}}$) and the force exerted by the railway truck Y on the railway truck X ($F_{\text{Y on X}}$) at the instant of collision?

A. $F_{\text{X on Y}} < F_{\text{Y on X}}$

B. $F_{\text{X on Y}} = F_{\text{Y on X}}$

C. $F_{\text{X on Y}} = -F_{\text{Y on X}}$

D. $F_{\text{X on Y}} > F_{\text{Y on X}}$

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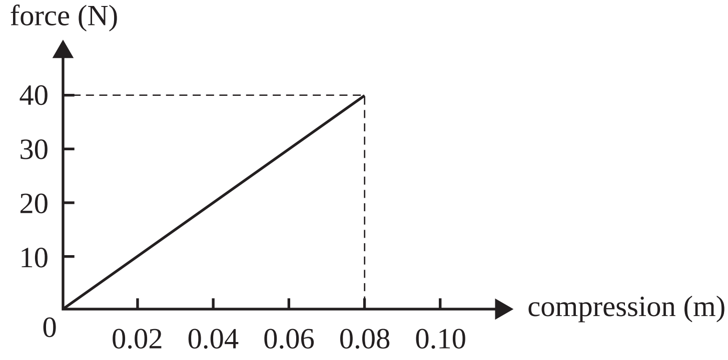
Question 8

The graph below shows force versus compression for a spring used in a Physics investigation.



Which one of the following is closest to the compression required to store 0.9 J of potential energy in the spring?

A. 0.05 m

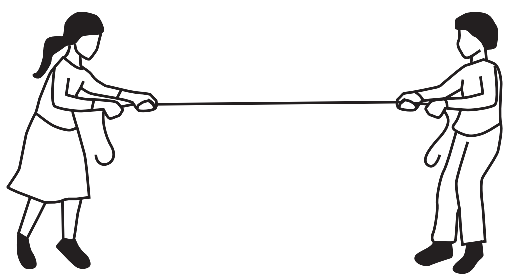
B. 0.06 m

C. 0.07 m

D. 0.08 m

Question 9

Two students pull on opposite ends of a rope, as shown in the diagram below. Each student pulls with a force of 400 N.



Which one of the following is closest to the magnitude of the force of the rope on each student?

A. 0 N

B. 400 N

C. 600 N

D. 800 N

Question 10

Which one of the following statements best describes an observation of the Doppler effect for sound?

A. a decrease in frequency received when a source of sound moves towards you

B. a decrease in frequency received when moving towards a stationary source of sound

C. an increase in frequency received when moving towards a stationary source of sound

D. a decrease in wavelength received when moving away from a stationary source of sound

Question 11

Which one of the following statements best describes transverse and longitudinal waves?

A. Both transverse waves and longitudinal waves travel in a direction parallel to their vibrations.

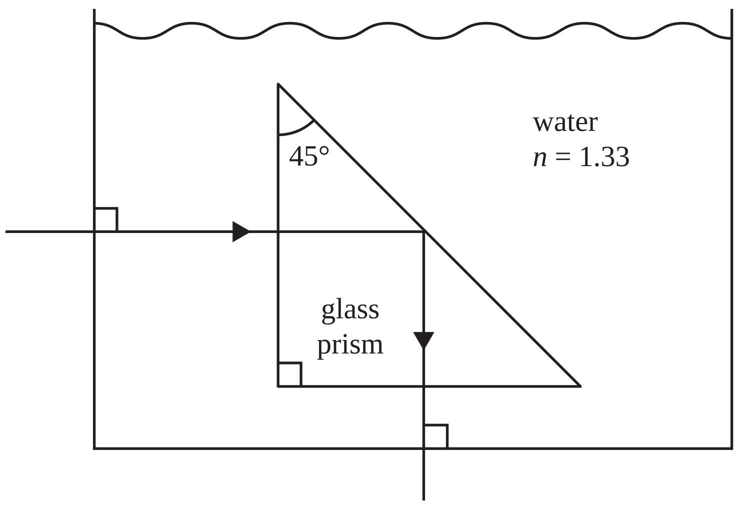
B. Both transverse waves and longitudinal waves travel in a direction perpendicular to their vibrations.

C. Transverse waves travel in a direction perpendicular to their vibrations; longitudinal waves travel parallel to their vibrations.

D. Transverse waves travel in a direction parallel to their vibrations; longitudinal waves travel perpendicular to their vibrations.

Question 12

A 45° glass prism is submerged in water and oriented as shown in the diagram below. It is used to reflect a light ray through 90°.



What is the lowest refractive index of the glass prism that will ensure that total internal reflection occurs inside the prism?

A. 1.00

B. 1.41

C. 1.61

D. 1.88

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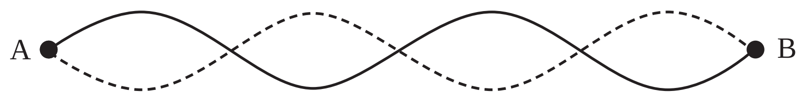
Question 13

A travelling wave produced at point A is reflected at point B to produce a standing wave on a rope, as represented in the diagram below.



The distance between points A and B is 2.4 m. The period of vibration of the standing wave is 1.6 s.

The speed of the travelling wave along the rope is closest to

A. 0.75 m s^{-1}

B. 1.0 m s^{-1}

C. 1.5 m s^{-1}

D. 2.0 m s^{-1}

Question 14

Which one of the following best provides evidence of electrons behaving as waves?

A. photoelectric effect

B. atomic emission spectra

C. atomic absorption spectra

D. diffraction of electrons through a crystal

Question 15

Which one of the following best provides evidence of light behaving as a particle?

A. photoelectric effect

B. white light passing through a prism

C. diffraction of light through a single slit

D. interference of light passing through a double slit

Question 16

Which one of the following phenomena best demonstrates that light waves are transverse?

A. polarisation

B. interference

C. dispersion

D. diffraction

Question 17

Gamma radiation is often used to treat cancerous tumours. The energy of a gamma photon emitted by radioactive cobalt-60 is 1.33 MeV.

Which one of the following is closest to the frequency of the gamma radiation?

A. 1.33×10^{6} Hz

B. 3.21×10^{20} Hz

C. 3.21×10^{21} Hz

D. 2.01×10^{39} Hz

Question 18

Which one of the following is an example of an inertial frame of reference?

A. a bus travelling at constant velocity

B. an express train that is accelerating

C. a car turning a corner at a constant speed

D. a roller-coaster speeding up while heading down a slope

Question 19

A particle produced in a linear particle accelerator is travelling at a speed of 2.99×10^8 m s^{-1}.

Take the speed of light to be 3.00×10^8 m s^{-1}.

Which one of the following is closest to the Lorentz factor (γ) of the particle?

A. 5.51

B. 7.86

C. 12.3

D. 15.1

Question 20

The experimental uncertainty of a measurement is best understood as

A. an estimate of the validity of the data.

B. a mistake in the experimental method used.

C. a mistake in the recording of a measurement.

D. an estimate of the maximum likely difference between the measurement and the true value.

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END OF SECTION A

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SECTION B

Instructions for Section B

Answer **all** questions in the spaces provided.
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 (5 marks)

Figure 1 shows four positions (1, 2, 3 and 4) of the coil of a single-turn, simple DC motor. The coil is turning in a uniform magnetic field that is parallel to the plane of the coil when the coil is in Position 1, as shown.

When the motor is operating, the coil rotates about the axis through the middle of sides *LM* and *NK* in the direction indicated. The coil is attached to a commutator. Current for the motor is passed to the commutator by brushes that are not shown in Figure 1.

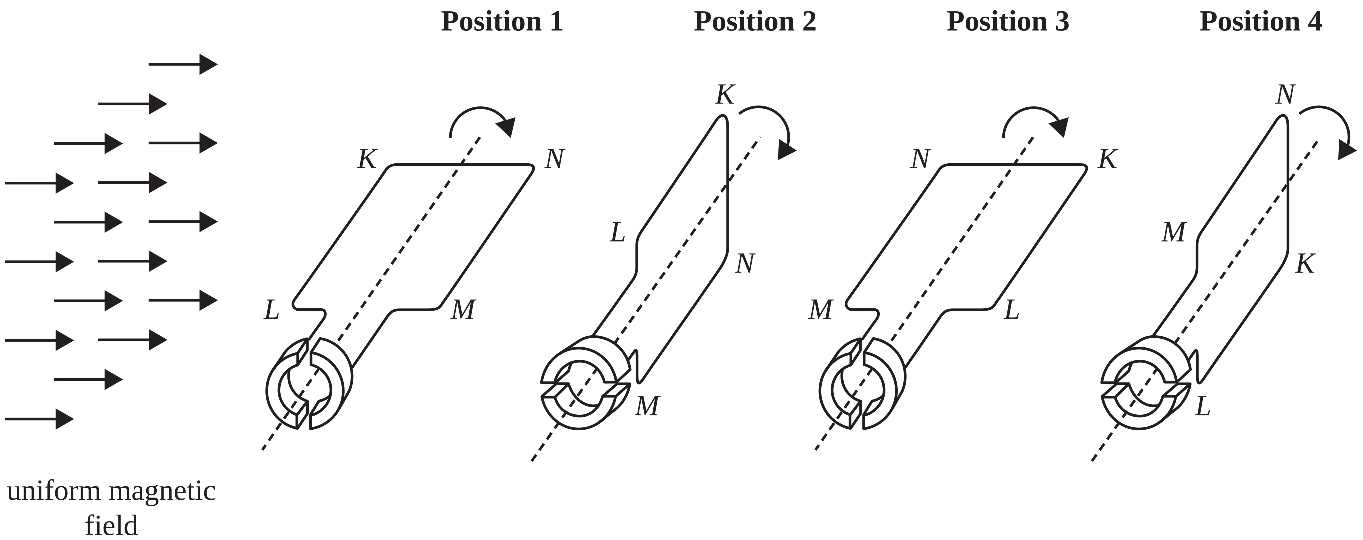

Figure 1

a. When the coil is in Position 1, in which direction is the current flowing in the side *KL* – from *K* to *L* or from *L* to *K*? Justify your answer. 2 marks

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b. When the coil is in Position 3, in which direction is the current flowing in the side *KL* – from *K* to *L* or from *L* to *K*? 1 mark

c. The side *KL* of the coil has a length of 0.10 m and experiences a magnetic force of 0.15 N due to the magnetic field, which has a magnitude of 0.5 T.

Calculate the magnitude of the current in the coil. 2 marks

A

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Question 2 (9 marks)

There are over 400 geostationary satellites above Earth in circular orbits. The period of orbit is one day (86 400 s). Each geostationary satellite remains stationary in relation to a fixed point on the equator. Figure 2 shows an example of a geostationary satellite that is in orbit relative to a fixed point, X, on the equator.

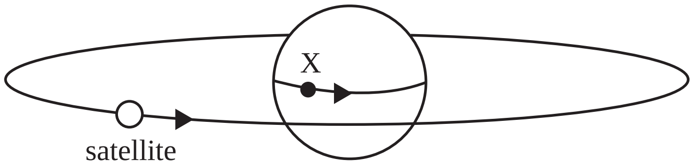

Figure 2

a. Explain why geostationary satellites must be vertically above the equator to remain stationary relative to Earth's surface. 2 marks

b. Using $G = 6.67 \times 10^{-11}$ N m^2 kg^{-2}, $M_E = 5.98 \times 10^{24}$ kg and $R_E = 6.37 \times 10^6$ m, show that the altitude of a geostationary satellite must be equal to 3.59×10^7 m. 4 marks

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c. Calculate the speed of an orbiting geostationary satellite. 3 marks

$\mathrm{m\ s^{-1}}$

Question 3 (7 marks)

A schematic diagram of a mass spectrometer that is used to deflect charged particles to determine their mass is shown in Figure 3. Positive singly charged ions (with a charge of $+1.6 \times 10^{-19}$ C) are produced at the ion source. These are accelerated between an anode and a cathode. The potential difference between the anode and the cathode is 1500 V. The ions pass into a region of uniform magnetic field, B, and are directed by the field into a semicircular path of diameter D.

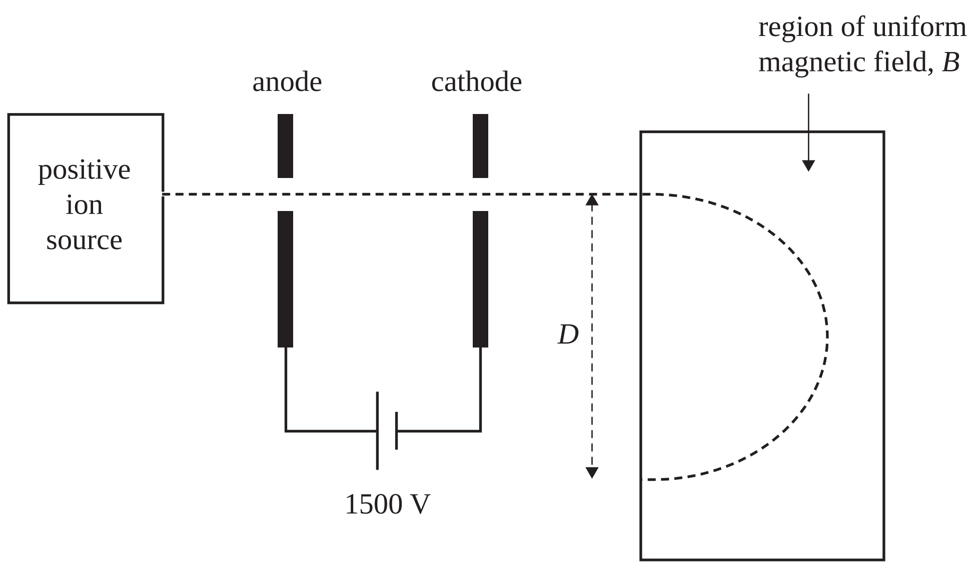

Figure 3

a. Calculate the increase in the kinetic energy of each ion as it passes between the anode and the cathode. Give your answer in joules. 2 marks

J

Each ion has a mass of 4.80×10^{-27} kg.

b. Show that each ion has a speed of 3.16×10^{5} m s^{-1} when it exits the cathode. Assume that the ion leaves the ion source with negligible speed. Show your working. 2 marks

c. The region of uniform magnetic field, *B*, in Figure 3 has a magnitude of 0.10 T.

Calculate the diameter, *D*, of the semicircular path followed by the ions within the magnetic field in Figure 3. 3 marks

m

Question 4 (6 marks)

A square loop of wire connected to a resistor, R, is placed close to a long wire carrying a constant current, I, in the direction shown in Figure 4.

The square loop is moved three times in the following order:

- Movement A – Starting at Position 1 in Figure 4, the square loop rotates one full rotation at a steady speed about the x-axis. The rotation causes the resistor, R, to first move out of the page.
- Movement B – The square loop is then moved at a constant speed, parallel to the current carrying wire, from Position 1 to Position 2 in Figure 4.
- Movement C – The square loop is moved at a constant speed, perpendicular to the current carrying wire, from Position 2 to Position 3 in Figure 4.

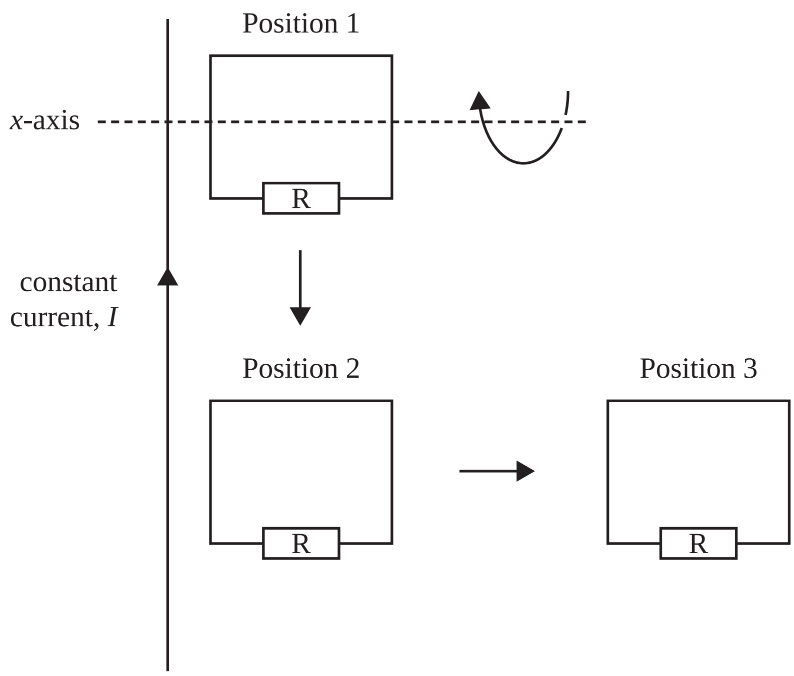

Figure 4

Complete the table below to show the effects of each of the three movements by:

- sketching any EMF generated in the square loop during the motion on the axes provided (scales and values are not required)
- stating whether any induced current in the square loop is ‘alternating’, ‘clockwise’, ‘anticlockwise’ or has ‘no current’.

Movement	Possible induced EMF	Direction of any induced current (alternating/clockwise/ anticlockwise/no current)
A rotation about x-axis		
B moving from Position 1 to Position 2		
C moving from Position 2 to Position 3		

Question 5 (7 marks)

A wind generator provides power to a factory located 2.00 km away, as shown in Figure 5.

When there is a moderate wind blowing steadily, the generator produces an RMS voltage of 415 V and an RMS current of 100 A.

The total resistance of the transmission wires between the wind generator and the factory is 2.00 Ω.

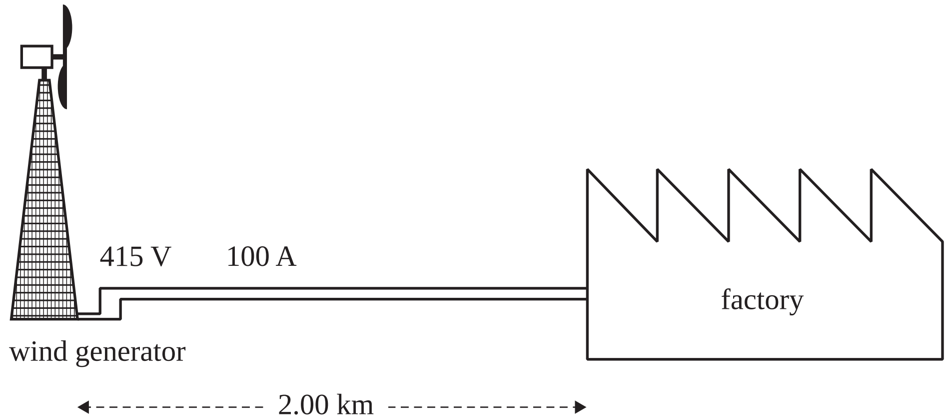

Figure 5

a. Calculate the power, in kilowatts, produced by the wind generator when there is a moderate wind blowing steadily. 1 mark

kW

To operate correctly, the factory's machinery requires a power supply of 40 kW.

b. Determine whether the energy supply system, as shown, will be able to supply power to the factory when the moderate wind is blowing steadily. Justify your answer with calculations. 3 marks

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c. The factory's owner decides to limit transmission energy loss by installing two transformers: a step-up transformer with a turns ratio of 1:10 at the wind generator and a step-down transformer with a turns ratio of 10:1 at the factory. Each transformer can be considered ideal.

With the installation of the transformers, determine the power, in kilowatts, now supplied to the factory. 3 marks

kW

Question 6 (5 marks)

Figure 6 shows a simple alternator consisting of a rectangular coil of area 0.060 m^2 and 200 turns, rotating in a uniform magnetic field. The magnetic flux through the coil in the vertical position shown in Figure 6 is 1.2×10^{-3} Wb.

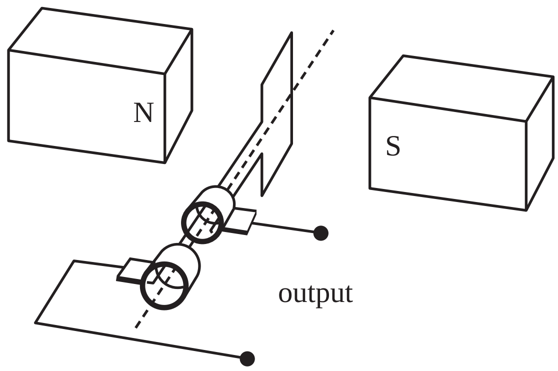

Figure 6

a. Calculate the strength of the magnetic field in Figure 6. Show your working. 2 marks

T

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b. The rectangular coil rotates at a frequency of 2.5 Hz.

Calculate the average induced EMF produced in the first quarter of a turn. Begin the quarter with the coil in the vertical position shown in Figure 6. 3 marks

V

Question 7 (10 marks)

Kym and Kelly are experimenting with trolleys on a ramp inclined at 25°, as shown in Figure 7. They release a trolley with a mass of 2.0 kg from the top of the ramp. The trolley moves down the ramp, through two light gates and onto a horizontal, frictionless surface. Kym and Kelly calculate the acceleration of the trolley to be 3.2 m s^{-2} using the information from the light gates.

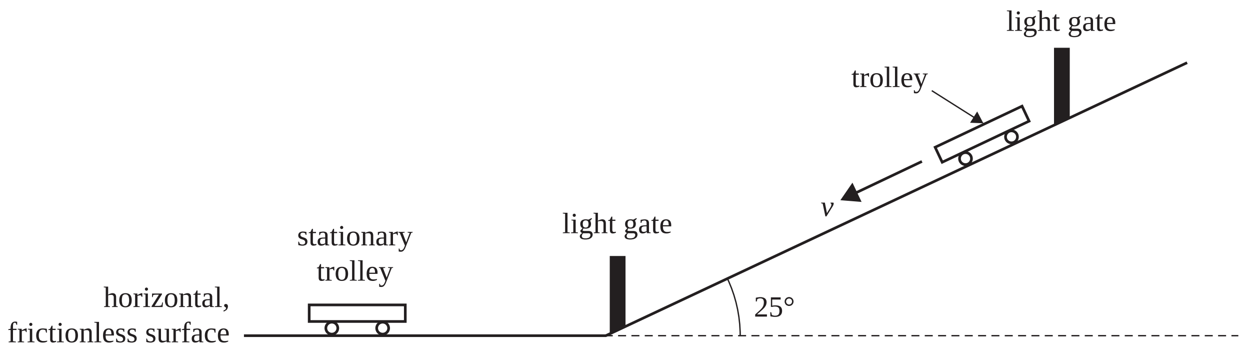

Figure 7

a. **i.** Show that the component of the gravitational force of the trolley down the slope is 8.3 N. Use $g = 9.8$ m s^{-2}. 2 marks

ii. Assume that on the ramp there is a constant frictional force acting on the trolley and opposing its motion.

Calculate the magnitude of the constant frictional force acting on the trolley. 2 marks

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b. When it reaches the bottom of the ramp, the trolley travels along the horizontal, frictionless surface at a speed of 4.0 m s^{-1} until it collides with a stationary identical trolley. The two trolleys stick together and continue in the same direction as the first trolley.

i. Calculate the speed of the two trolleys after the collision. Show your working and clearly state the physics principle that you have used. 3 marks

m s^{-1}

ii. Determine, with calculations, whether this collision is an elastic or inelastic collision. Show your working. 3 marks

Question 8 (5 marks)

A Formula 1 racing car is travelling at a constant speed of 144 km h^{-1} (40 m s^{-1}) around a horizontal corner of radius 80.0 m. The combined mass of the driver and the car is 800 kg. Figure 8a shows a front view and Figure 8b shows a top view.

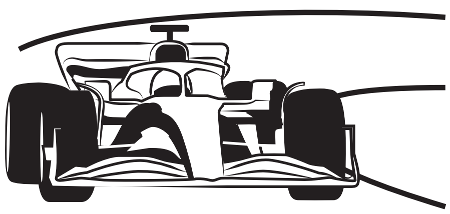

Figure 8a – Front view

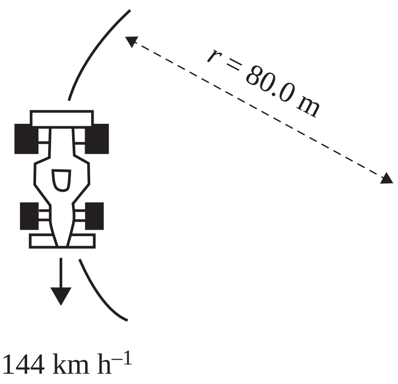

Figure 8b – Top view

a. Calculate the magnitude of the net force acting on the racing car and driver as they go around the corner. 2 marks

N

b. On Figure 8b, draw the direction of the net force acting on the racing car using an arrow. 1 mark

c. Explain why the racing car needs a net horizontal force to travel around the corner and state what exerts this horizontal force. 2 marks

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Question 9 (2 marks)

A star is transforming energy at a rate of 2.90×10^{25} W.

Explain the type of transformation involved and what effect, if any, the transformation would have on the mass of the star. No calculations are required.

Question 10 (16 marks)

Physics students use a tennis ball launcher on a level, outdoor oval on a windless day to investigate projectile motion, as shown in Figure 9. Assume that the tennis balls are launched from ground level.

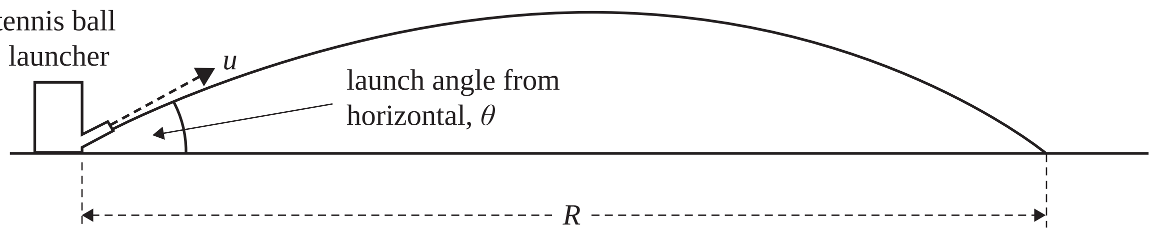

Figure 9

The tennis ball launcher can be set to project tennis balls at speeds, u, between 8 m s^{-1} and 30 m s^{-1} and at angles, θ, between 10° and 80°. Standard tennis balls of mass 56 g are used.

The students measure the range, R, of the projected tennis ball at a fixed speed for various angles.

a. The variables in this experiment can be classified as controlled, dependent or independent.

Complete the table below by providing one variable from the experiment for each classification. 3 marks

Classification	Variable
controlled	
dependent	
independent	

b. The students set the tennis ball launcher to project tennis balls at a speed of 25 m s^{-1}. They vary the angle between 10° and 80° and measure the range, R.

The students repeat each experiment at each angle three times and determine the average range. The results are shown in Table 1 below.

Table 1

Angle (°)	Average range (m)
10	17
20	30
30	37
40	40
50	40
60	36
70	29
80	15

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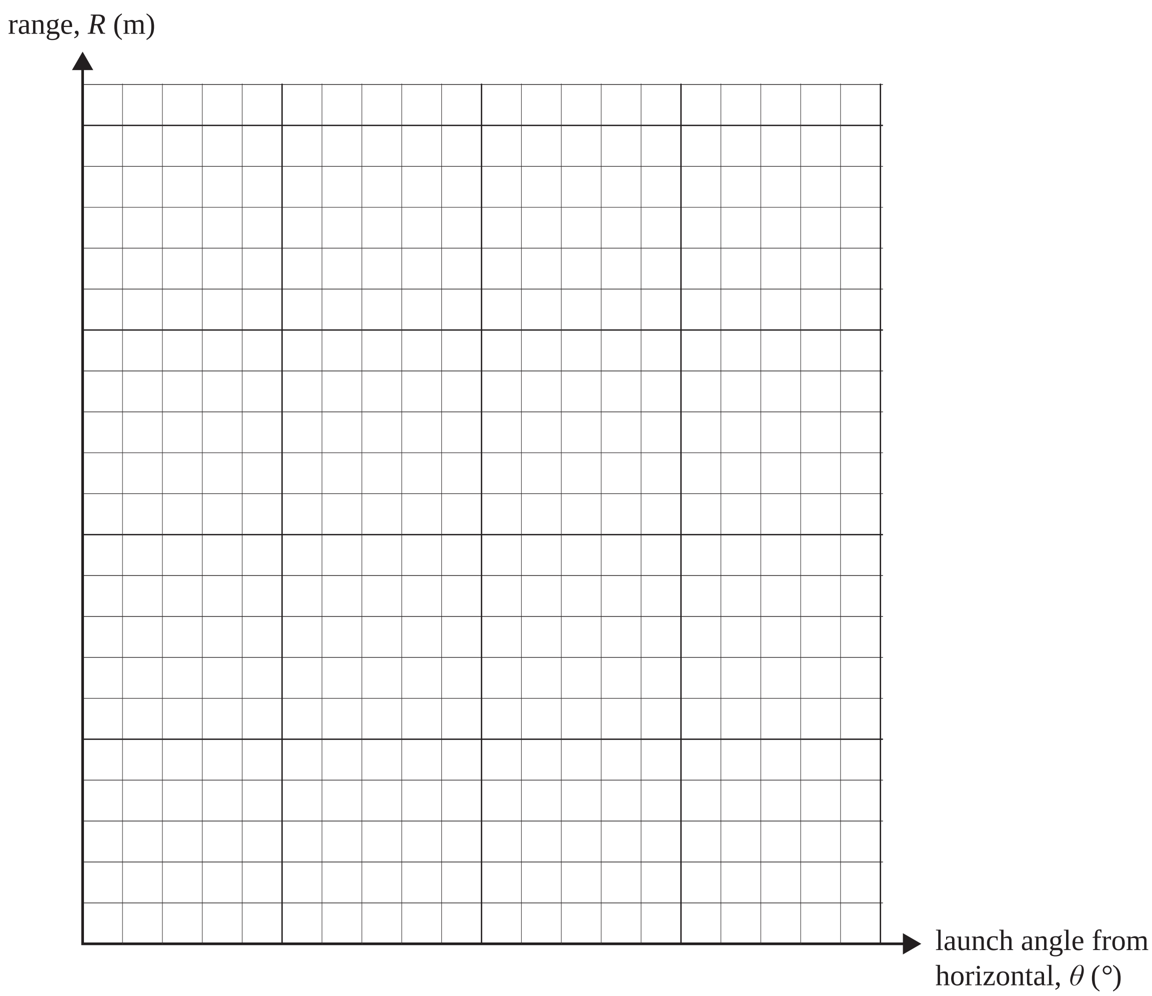
` The students determine that the uncertainty in the measurement of the range is ± 1 m.

On the grid provided below:

- plot the data from Table 1
- add a scale to each axis
- insert appropriate uncertainty bars for the range for at least three data points
- draw a smooth curve of best fit.

6 marks



c. From the graph in **part b.**, estimate the maximum range and the angle that gives the maximum range. 2 marks

Maximum range	m
Angle for maximum range	°

d. The students think that air resistance on the tennis ball may affect the maximum range. They decide to compare their data to the theoretical range achieved when air resistance is ignored.

i. Using the range formula $R = \dfrac{u^2 \sin 2\theta}{g}$, calculate the theoretical range of a projectile launched at an initial speed of 25 m s^{-1} and at an angle of 30°. Use g = 9.8 m s^{-2}. 2 marks

Theoretical range m

ii. Evaluate whether the effect of air resistance can be ignored by the students when analysing their data. Justify your answer. 3 marks

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Question 11 (2 marks)

Explain why muons formed in the outer atmosphere can reach the surface of Earth even though their half-lives indicate that they should decay well before reaching Earth's surface.

Question 12 (8 marks)

Students conduct an experiment in a Physics laboratory using a laser light source, two narrow slits and a screen, as shown in Figure 10.

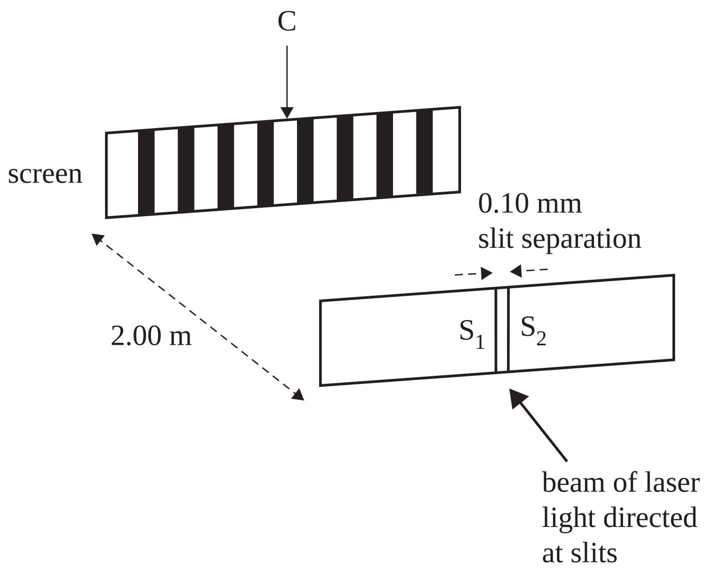

Figure 10

Point C is at the centre of the pattern of light and dark bands on the screen. The slit separation is 0.10 mm and the distance between the two slits and the screen is 2.00 m.

a. The band at point C is a bright band.

Explain why the band at point C is bright and why there is a dark band to the left of the centre. 2 marks

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The experiment performed by the students is often described as Young's double-slit experiment.

b. Explain how this experiment gave support to those who argued that light has a wave-like nature. 2 marks

The frequency of the laser light is 6.00×10^{14} Hz.

c. Calculate the spacing of the dark bands on the screen. Show your working. 2 marks

m

d. The students decide to safely immerse the entire apparatus in a liquid. The refractive index of the liquid is unknown but it is greater than the refractive index of air. Using the same laser light, they notice that the spacing of the bands changes.

Describe the change observed in the spacing of the bands and explain why this change occurred. 2 marks

Question 13 (7 marks)

A ray of green light from a light-emitting diode (LED) strikes the surface of a tank of water at an angle of 40.00° to the surface of the water, as shown in Figure 11. The ray arrives at the base of the tank at point X. The depth of the water in the tank is 80.00 cm. The refractive index of green LED light in water is 1.335

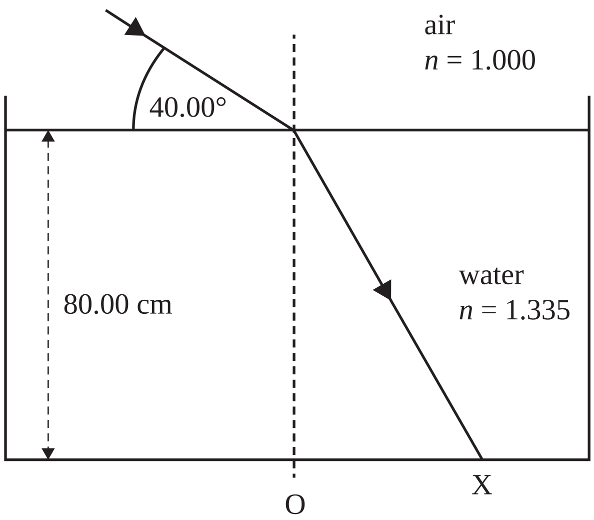

Figure 11

a. Calculate the distance OX. Outline your reasoning and show all your working. Give your answer in centimetres. 4 marks

cm

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b. The green LED light is replaced with a narrow beam of white sunlight.

Describe the colour of the light that arrives to the left of point X, at point X and to the right of point X. 3 marks

Light to the left of point X	**Light at point X**	**Light to the right of point X**

Question 14 (9 marks)

Sam undertakes a photoelectric effect experiment using the apparatus shown in Figure 12. She uses a green filter.

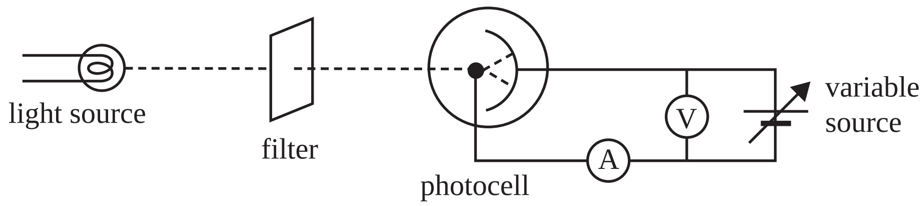

Figure 12

Sam produces a graph of photocurrent, *I*, in milliamperes, versus voltage, *V*, in volts, as shown in Figure 13.

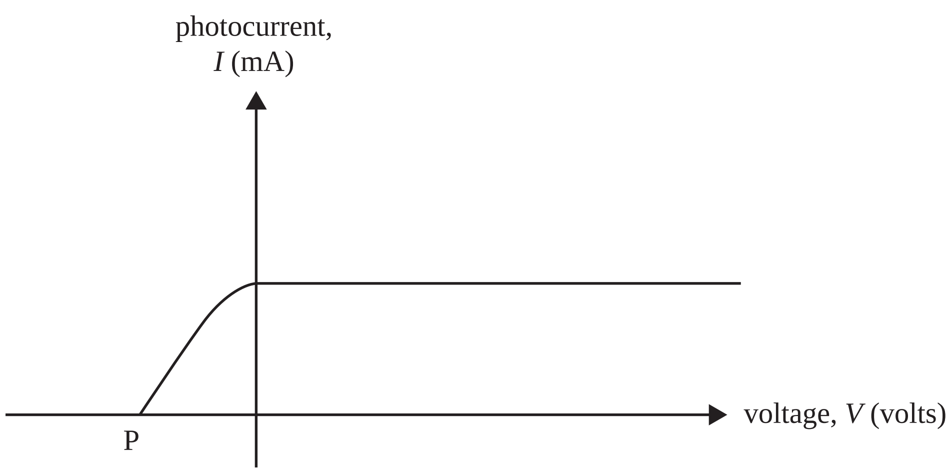

Figure 13

a. Identify what point P represents on the graph in Figure 13. 1 mark

D O N O T W R I T E I N T H I S A R E A

b. Sam then significantly increases the intensity of the light.

Sketch the resulting graph on Figure 14. The dashed line in Figure 14 represents the original data. 2 marks

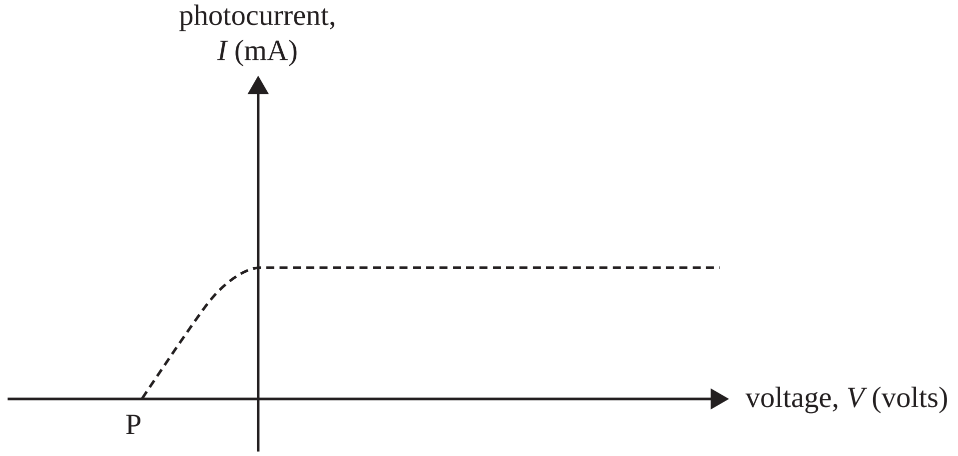

Figure 14

c. Sam replaces the green filter with a violet filter, keeping the light source at the increased intensity.

Sketch the resulting graph on Figure 15. The dashed line in Figure 15 represents the original data. 2 marks

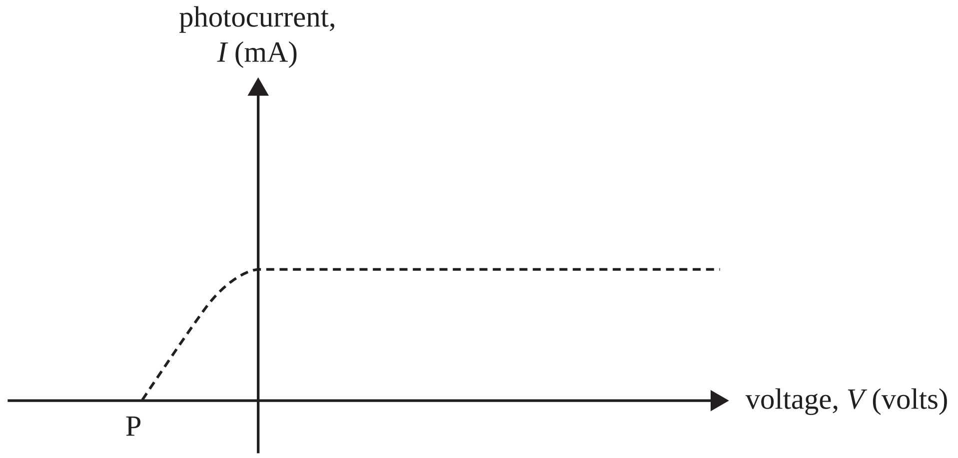

Figure 15

Further experiments produce Figure 16, a graph of maximum kinetic energy, $E_{k\ max}$, of emitted photoelectrons versus frequency, f, of light.

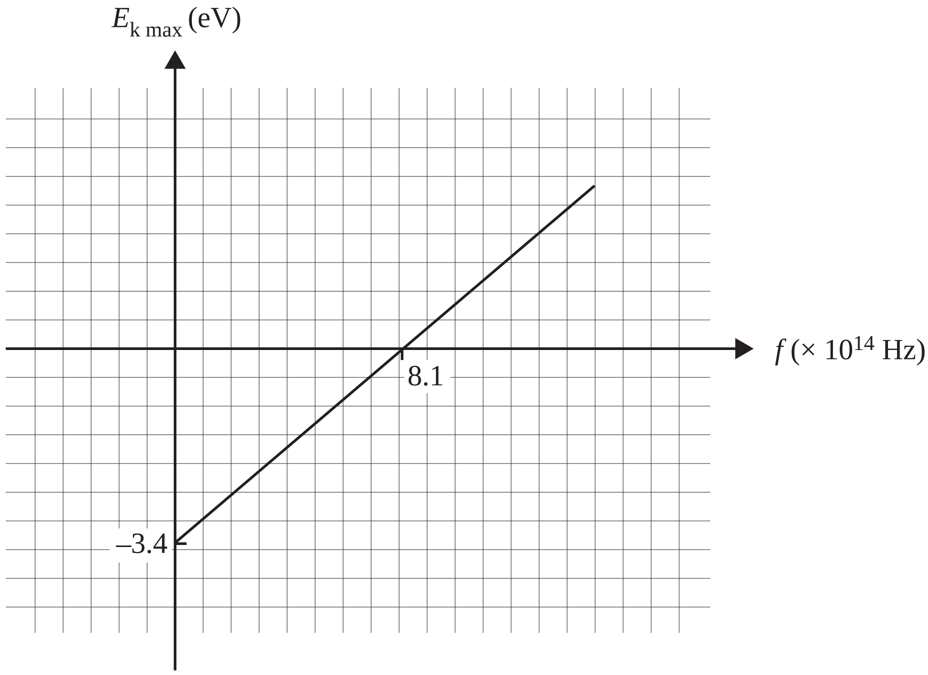

Figure 16

d. Determine the work function, in electron volts, of the metal surface used in the experiment that produced the data shown in Figure 16. 1 mark

eV

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e. From the graph shown in Figure 16, calculate, in joule-seconds, the value of Planck's constant. Show your working. 2 marks

J s

f. State **one** limitation of the wave model in explaining the results of the photoelectric effect. 1 mark

Question 15 (2 marks)

Figure 17 shows some of the energy levels of excited neon atoms. These energy levels are not drawn to scale.

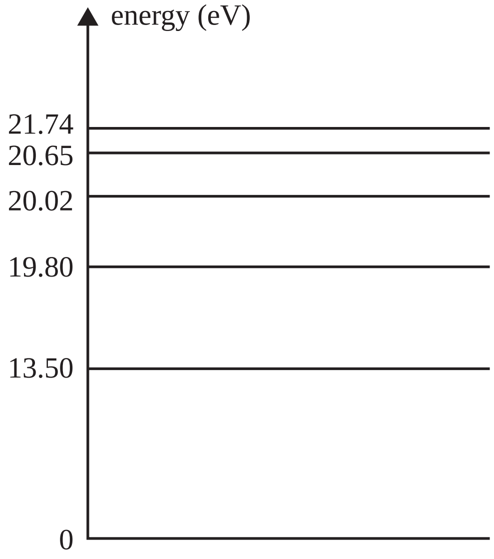

Figure 17

a. Show that the energy transition required for an emitted photon of wavelength 640 nm is 1.94 eV. 1 mark

b. On Figure 17, draw an arrow to show the transition that would emit the photon described in **part a.** 1 mark

Question 16 (3 marks)

A small sodium lamp, emitting light of wavelength 589 nm, is viewed at night through two windows from across a street. The glass of one window has a fine steel mesh covering it and the other window is open, as shown in Figure 18. Assume that the sodium lamp is a point source at a distance.

A Physics student is surprised to see a pattern formed by the light passing through the steel mesh but no pattern for the light passing through the open window. She takes a photograph of the observed pattern to show her teacher, who assures her that it is a diffraction pattern.

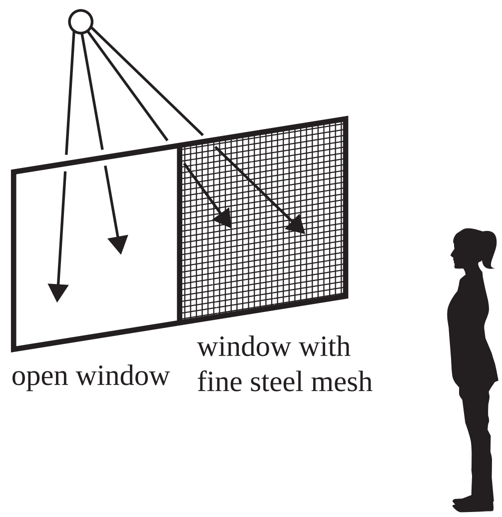

Figure 18

a. State the condition that the fine steel mesh must satisfy for a diffraction pattern to form. 1 mark

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____

b. Explain why the condition stated in **part a.** does not apply to the open window. 2 marks

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Question 17 (7 marks)

A materials scientist is studying the diffraction of electrons through a thin metal foil. She uses electrons with an energy of 10.0 keV. The resulting diffraction pattern is shown in Figure 19.

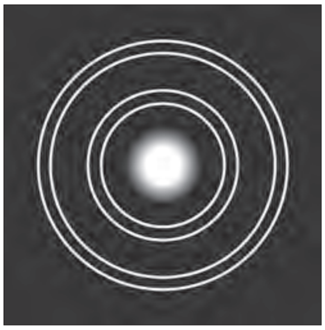

Figure 19

a. Calculate the de Broglie wavelength of the electrons in nanometres. 4 marks

nm

b. The materials scientist then increases the energy of the electrons by a small amount and hence their speed by a small amount.

Explain what effect this would have on the de Broglie wavelength of the electrons. Justify your answer. 3 marks

END OF QUESTION AND ANSWER BOOK

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VICTORIAN CURRICULUM AND ASSESSMENT AUTHORITY

Victorian Certificate of Education
2022

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	$E_{\mathrm{k\,max}} = hf - \phi$
photon energy	$E = hf$
photon momentum	$p = \dfrac{h}{\lambda}$
de Broglie wavelength	$\lambda = \dfrac{h}{p}$

Data

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