South Australian
Certificate of Education

1

Physics
2023

Question booklet 1

- Questions 1 to 12 (60 marks)
- Answer ***all*** questions
- Write your answers in this question booklet
- You may write on page 16 if you need more space
- Allow approximately 65 minutes

Examination information

Materials
- Question booklet 1
- Question booklet 2
- Formula sheet
- SACE registration number label

Instructions
- Use black or blue pen
- You may use a sharp dark pencil for diagrams and other representations
- Approved calculators may be used

Total time: 130 minutes
Total marks: 120

Attach your SACE registration number label here

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1. A charger for a laptop computer contains a transformer which converts 220 V to 11 V.

Source: © Darkhriss | Dreamstime.com

(a) State whether the charger is a step-up transformer or a step-down transformer.

____ (1 mark)

(b) The input coil of the charger has 3000 turns.

Determine the number of turns in the output coil.

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____ (2 marks)

2. Two different types of vehicles are shown in the photographs below.

Delivery van

Source: © Maria Wachala | Dreamstime.com

Formula One racing car

Source: © randomwinner | Pixabay.com

(a) Explain whether the van or the racing car would experience a smaller drag force when both vehicles are travelling at the same speed.

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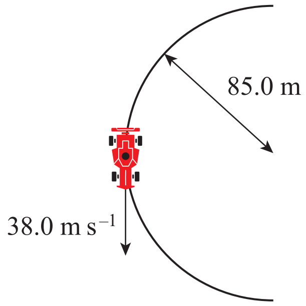
____ (2 marks)

(b) The racing car travels along a section of a circular path that has a radius of $85.0\ \text{m}$. The car moves at a constant speed of $38.0\ \text{m}\,\text{s}^{-1}$, as shown in the diagram below.



[This diagram is not drawn to scale.]

The force due to friction between the tyres and the road causes the car to move in a circular path. The force due to friction has a magnitude of $1.35 \times 10^{4}\ \text{N}$.

Determine the mass of the car.

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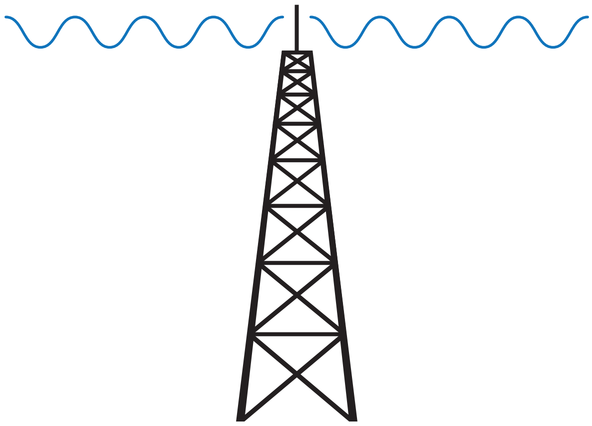
____ (3 marks)

3. A vertically oriented transmitting antenna, as shown in the diagram below, produces an electromagnetic wave.



[This diagram is not drawn to scale.]

(a) State whether the plane of polarisation of the electromagnetic wave is vertical or horizontal.

____ (1 mark)

(b) The electromagnetic wave produced by the antenna has a wavelength of $3.10\ \text{m}$.

Calculate the frequency of the electromagnetic wave.

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____ (2 marks)

4. Titan is the largest of Saturn's many moons. Both are shown in the image below.

This image cannot be reproduced here for copyright reasons.

Source: adapted from Francesco Fiori, Radio Science and Planetary Exploration Lab n.d. 'Artwork of Saturn, Titan, and the Cassini spacecraft,' viewed 9 August 2023, www.pma.caltech.edu

Titan has a mass of 1.35×10^{23} kg and Saturn has a mass of 5.68×10^{26} kg.

(a) Calculate the magnitude of the gravitational *forces* between Titan and Saturn when their centres are separated by 1.24×10^{9} m.

(2 marks)

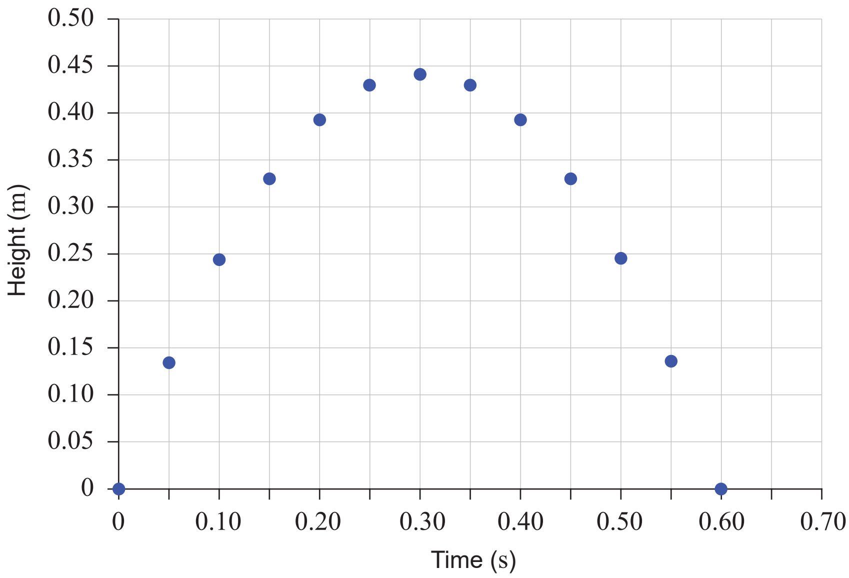
(b) Explain how gravitational forces are consistent with Newton's Third Law of Motion.

(2 marks)

5. A group of students used a projectile launcher, similar to the one shown below, to investigate the parabolic path of a ball. The students launched the ball and recorded the height of the ball every $0.050\ \mathrm{s}$ after it was launched.

Source: PASCO n.d. 'Mini Launcher,' viewed 9 August 2023, www.pasco.com

Their results are shown in the graph below.



The range of the ball was $3.6\ \mathrm{m}$.

Assume that air resistance is negligible.

(a) Show that the horizontal speed of the ball was $6.0\ \mathrm{m\,s^{-1}}$.

(1 mark)

(b) The ball reached its maximum height after 0.30 s.

Determine the initial vertical speed of the ball.

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____ (3 marks)

(c) (i) State *one* adjustment to the projectile launcher that would increase the maximum height reached by the ball.

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____ (1 mark)

(ii) Explain your answer to part (c)(i).

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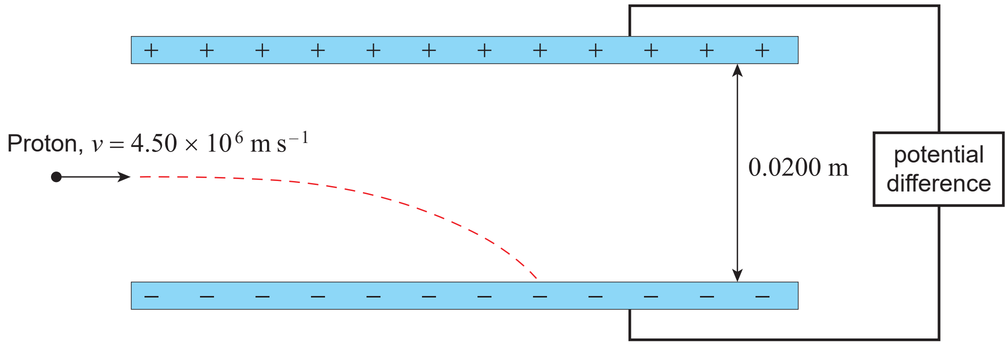
____ (2 marks)

6. A potential difference between two parallel plates produced a uniform electric field. The two plates were separated by 0.0200 m. A proton entered the field between the two plates, perpendicular to the field, at a point midway between the plates. The proton had an initial speed of $4.50 \times 10^6 \text{ m s}^{-1}$.

The path of the proton between the plates is shown below.



[This diagram is not drawn to scale.]

(a) The potential difference between the plates was 204 V.

(i) Show that the magnitude of the electric field between the plates was $1.02 \times 10^4 \text{ V m}^{-1}$.

(1 mark)

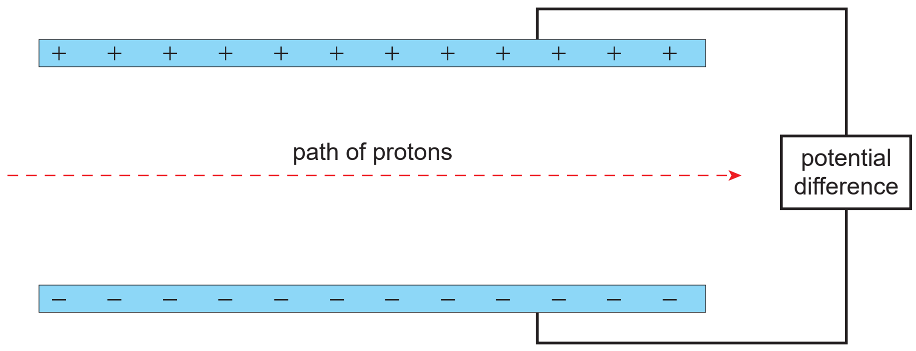
(ii) Show that the magnitude of the proton's acceleration in the electric field was $9.77 \times 10^{11} \text{ m s}^{-2}$.

(1 mark)

(iii) Determine the time taken for the proton to strike the lower plate.

(3 marks)

(b) The plates were then positioned so that the electric field between the plates was perpendicular to a uniform magnetic field. Protons entered the electric field between the two plates, perpendicular to the field, at a point midway between the plates. The potential difference was adjusted so that the protons passed through the region between the plates in a straight line, as shown below.



[This diagram is not drawn to scale.]

(i) State the direction of the force acting on the protons due to the magnetic field.

____ (1 mark)

(ii) State the direction of the magnetic field.

____ (1 mark)

7. Skykraft is an Australian company that is developing a network of many satellites to monitor global air traffic. Some of Skykraft's satellites are in low-altitude orbits around the Earth.

This image cannot be reproduced here for copyright reasons.

Source: adapted from Canberra Times 2023 'An artist's impression of a Skykraft satellite,' viewed 9 August 2023, canberratimes.com.au

The Skykraft satellites orbit at an altitude of 5.30×10^5 m.

Assume that the satellites move in a circular orbit.

(a) Calculate the orbital period of a Skykraft satellite.

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____ (3 marks)

(b) Global Positioning System (GPS) satellites move in circular orbits, but with a much larger orbital radius than a Skykraft satellite.

Explain whether a GPS satellite will have a higher or lower orbital speed than a Skykraft satellite.

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____ (2 marks)

(c) State *one* advantage of satellites orbiting at a low altitude.

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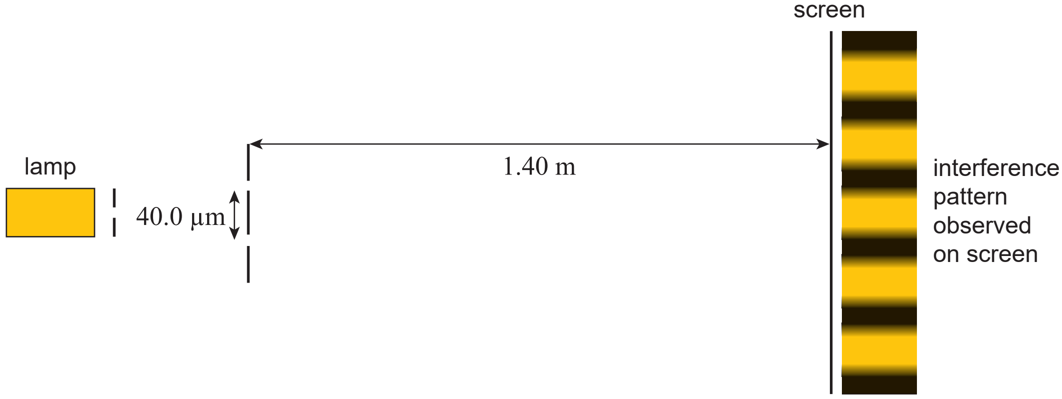
____ (1 mark)

8. A sodium vapour lamp was used in a two-slit experiment. The light from the lamp passed through a single slit that was positioned equidistant from two slits to produce coherent light. A pattern of dark and light fringes was observed on a screen, as represented in the diagram below.



[This diagram is not drawn to scale.]

(a) Explain the production of the dark fringes observed on the screen.

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____ (3 marks)

(b) The slit-to-screen distance was $1.40\ \text{m}$ and the two slits were separated by $40.0\ \mu\text{m}$. The sodium vapour lamp emitted light with a wavelength of $589\ \text{nm}$.

Determine the distance between adjacent bright fringes.

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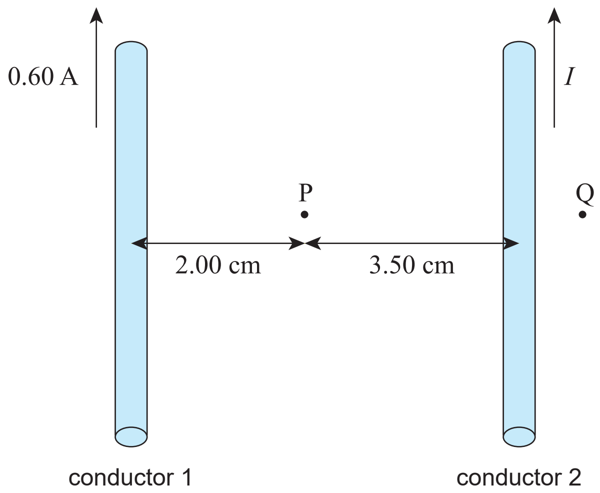
____ (3 marks)

9. Two parallel conductors carry currents flowing in the same direction. Conductor 1 carries a current of $0.60\ \text{A}$ and conductor 2 carries a current I. Point P is $2.00\ \text{cm}$ from the centre of conductor 1 and $3.50\ \text{cm}$ from the centre of conductor 2. Point Q is to the right of conductor 2, as shown in the diagram below.



[This diagram is not drawn to scale.]

(a) Show that the magnitude of the magnetic field at point P due to the current flowing in conductor 1 is $6.0 \times 10^{-6}\ \text{T}$.

(1 mark)

(b) The net magnetic field due to the current in conductor 1 and the current in conductor 2 is zero at point P.

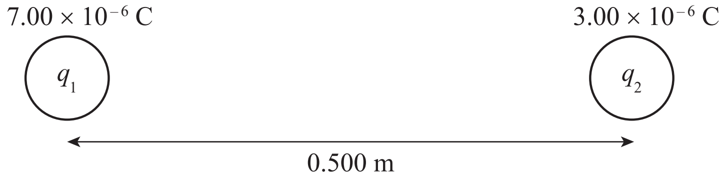
Determine the current in conductor 2.

(3 marks)

(c) State the *direction* of the net magnetic field at point Q due to the current in conductor 1 and the current in conductor 2. Justify your answer.

(2 marks)

10. Two charged particles, q_1 and q_2, are positioned so that the centre of q_1 is 0.500 m from the centre of q_2. The charge of q_1 has a magnitude of 7.00×10^{-6} C and the charge of q_2 has a magnitude of 3.00×10^{-6} C.



[This diagram is not drawn to scale.]

(a) Calculate the magnitude of the electric force acting on q_1 due to q_2.

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____ (2 marks)

(b) The diagram below shows the electric field of q_2 in the region immediately around q_2.
A vector representing the electric force acting on q_1 due to the charge of q_2 is also shown.

[This diagram is not drawn to scale.]

State whether q_1 is positively charged or negatively charged. Justify your answer.

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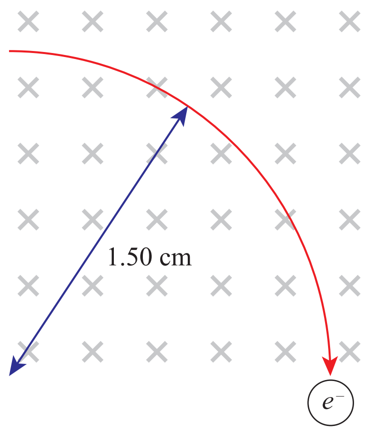
____ (2 marks)

11. An electron enters a uniform magnetic field. The velocity of the electron is perpendicular to the magnetic field. The electron undergoes uniform circular motion when it is within the magnetic field, as shown in the diagram below.



[This diagram is not drawn to scale.]

The magnitude of the magnetic field is 0.0230 T and the radius of the circular path of the electron is 1.50 cm.

Determine the speed of the electron.

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______________________________________ (3 marks)

12. A group of students undertook an experiment using a transmission diffraction grating. The students directed monochromatic light through a diffraction grating that has 500 lines per mm. The first-order maxima were observed at an angle of $18°$.

(a) Show that the monochromatic light has a wavelength of 6.2×10^{-7} m.

(3 marks)

(b) Determine the maximum number of orders that would be observed in this experiment.

(3 marks)

You may write on this page if you need more space to finish your answers to any of the questions in this question booklet. Make sure to label each answer carefully (e.g. 6(a)(ii) continued).

South Australian
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Physics
2023

Question booklet 2

- Questions 13 to 22 (60 marks)
- Answer ***all*** questions
- Write your answers in this question booklet
- You may write on page 18 if you need more space
- Allow approximately 65 minutes

2

Copy the information from your SACE label here

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13. Some of the emission lines for the line emission spectrum for hydrogen are shown below.

(a) Explain how the presence of discrete frequencies in the line emission spectrum of hydrogen provides evidence for the existence of states with discrete electron energy-levels in hydrogen.

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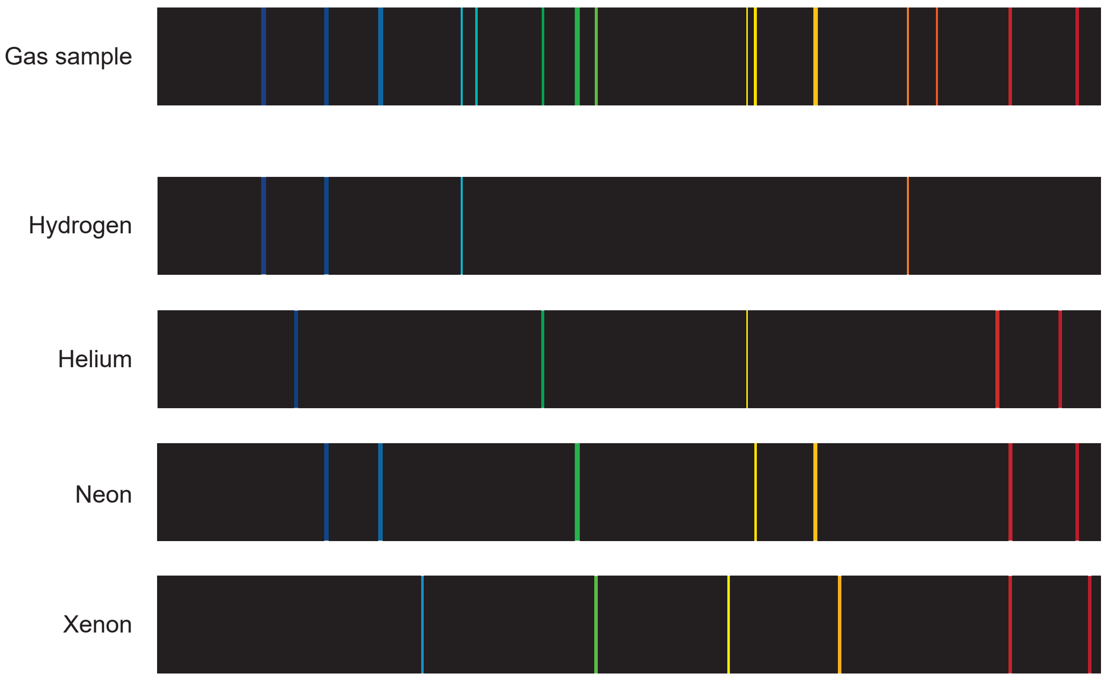
____ (2 marks)

(b) The diagrams below show the line emission spectra of different elements and the line emission spectrum of a gas sample containing a mixture of elements.



(i) Explain whether or not hydrogen is contained in the gas sample.

____

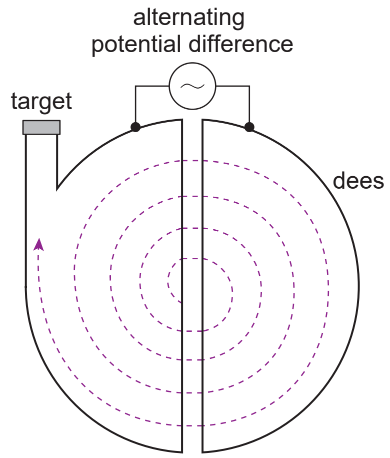
____ (1 mark)

(ii) For each element listed below, indicate whether the element is present in the gas sample by ticking the appropriate box.

	Present	*Not present*
Helium	☐	☐
Neon	☐	☐
Xenon	☐	☐

(2 marks)

14. A cyclotron accelerates a positive ion. The path of the ion is shown in the diagram below.



[This diagram is not drawn to scale.]

(a) Explain why the potential difference across the gap in the cyclotron needs to alternate in direction.

(2 marks)

(b) The frequency of the alternating potential difference is 1.75×10^{7} Hz.

Show that the period of the circular motion of the ion is 5.71×10^{-8} s.

(1 mark)

(c) The ion has a charge of magnitude 1.60×10^{-19} C and a mass of 3.34×10^{-27} kg.

Show that the magnitude of the magnetic field inside the cyclotron is 2.30 T.

(3 marks)

(d) The radius of the cyclotron is 0.550 m.

Calculate the kinetic energy of the ion as it exits the cyclotron.

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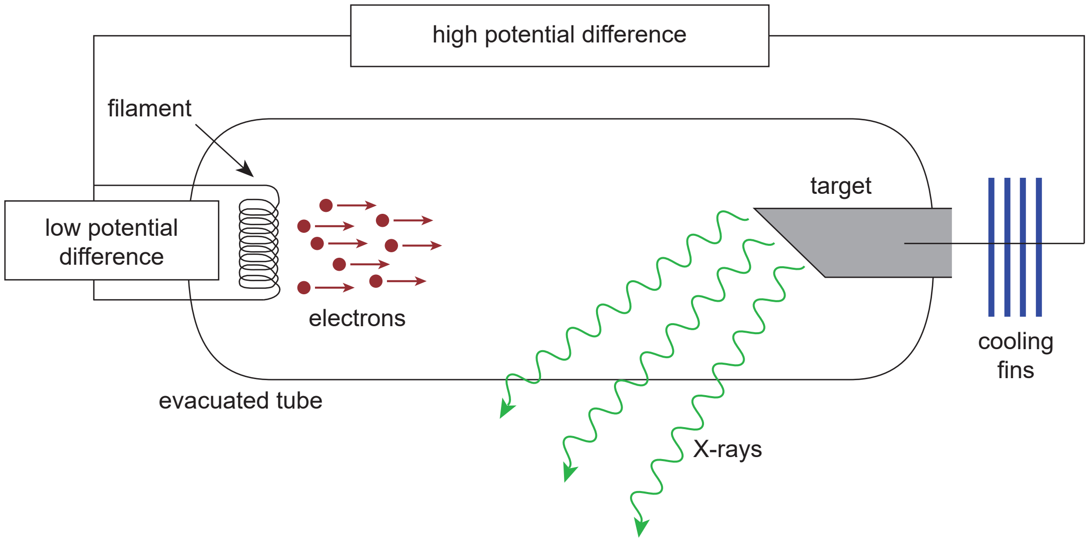
____ (2 marks)

15. The diagram below shows an X-ray tube.



[This diagram is not drawn to scale.]

(a) Explain why an X-ray tube needs to be cooled during use.

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____ (2 marks)

(b) The X-ray tube has a potential difference of $100\ \mathrm{kV}$ across the tube.

Calculate the maximum frequency of the X-rays that are produced by this X-ray tube.

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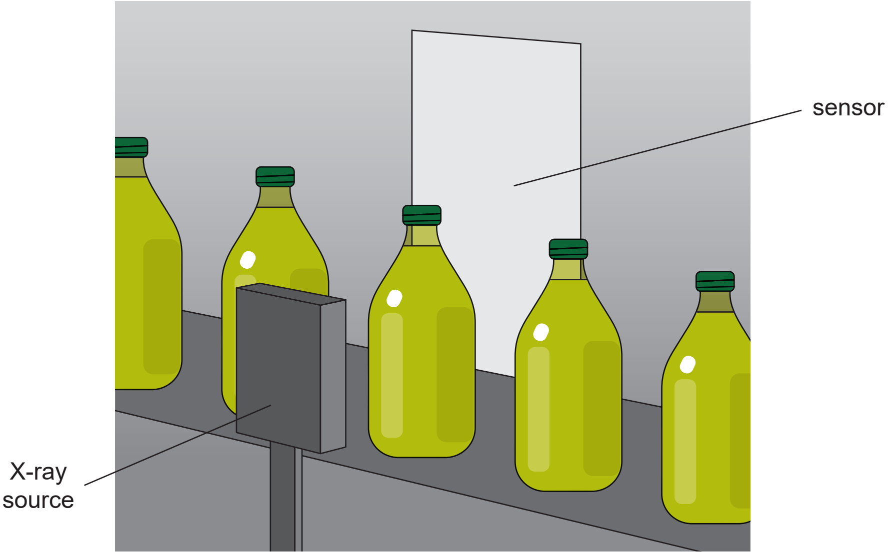
____ (2 marks)

(c) A company that sells olive oil uses X-rays to determine if its bottles of olive oil contain metallic contaminants. X-rays are incident on the bottles and are detected by a sensor behind the bottles, as indicated in the diagram below.



Explain how X-rays could be used to detect metal contaminants.

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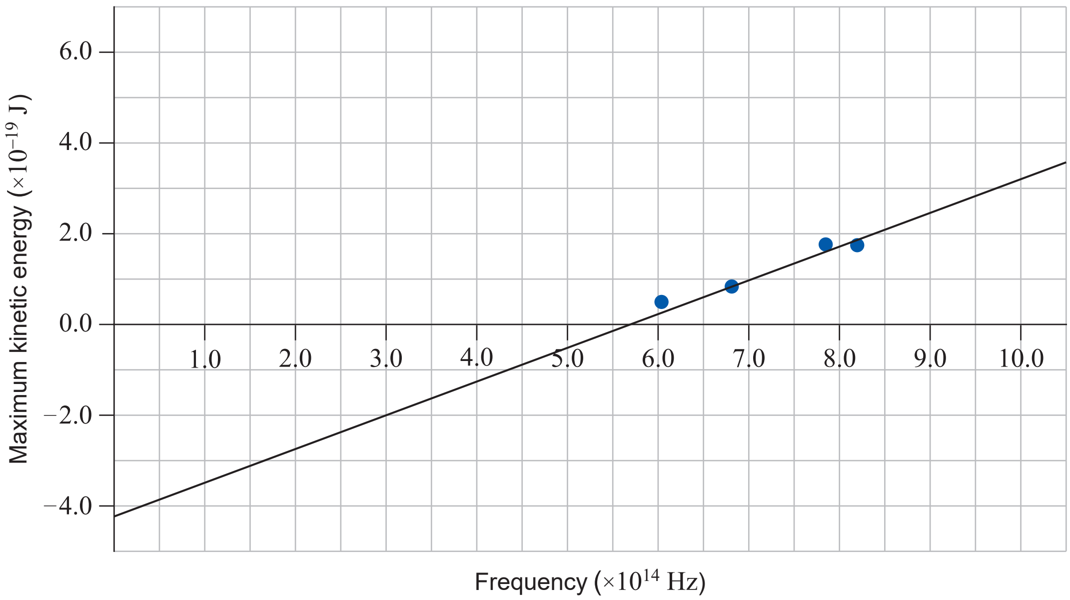
____ (3 marks)

16. A group of students conducted an experiment to determine the work function of a caesium surface using the photoelectric effect. The students directed four different frequencies of light separately onto a caesium surface and determined the maximum kinetic energy of the electrons that were emitted from the surface for each light source.

Their results are shown on the graph below. A line of best fit has been included.



(a) (i) Use the graph to determine a value of the work function of caesium. Give your answer in eV.

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____ (2 marks)

(ii) The accepted value of the work function of caesium is 2.1 eV.

Explain whether or not the value for the work function that you determined in part (a)(i) is accurate.

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____ (1 mark)

(iii) Describe *one* way that the students could improve their data collection to give a more accurate value for the work function of caesium.

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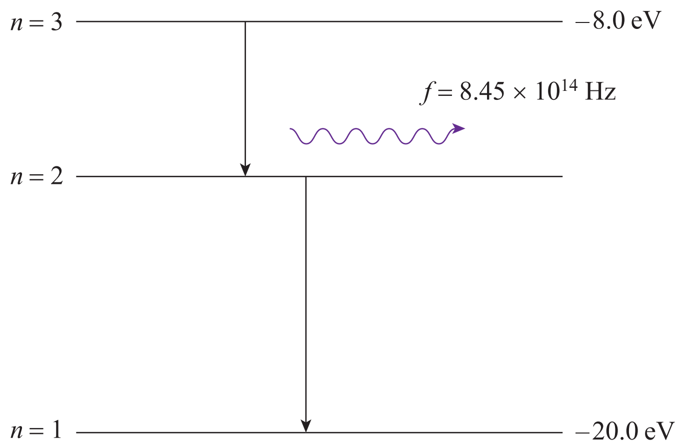
____ (1 mark)

(b) Calculate the maximum kinetic energy of an electron emitted from the caesium surface if light with a frequency of 1.30×10^{15} Hz was incident upon the surface.

(2 marks)

17. The following diagram shows some of the electron energy-levels of an atom.

An electron was raised to the $n = 3$ electron energy-level. The electron then transitioned from $n = 3$ to $n = 2$, then from $n = 2$ to $n = 1$. When the electron transitioned from $n = 3$ to $n = 2$, a photon was emitted with a frequency of 8.45×10^{14} Hz.



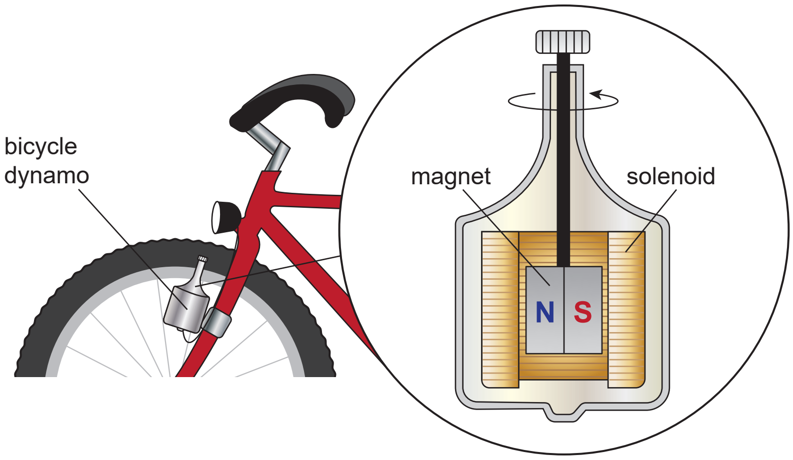
[This diagram is not drawn to scale.]

Determine the energy-level of the $n = 2$ state. Give your answer in eV.

(4 marks)

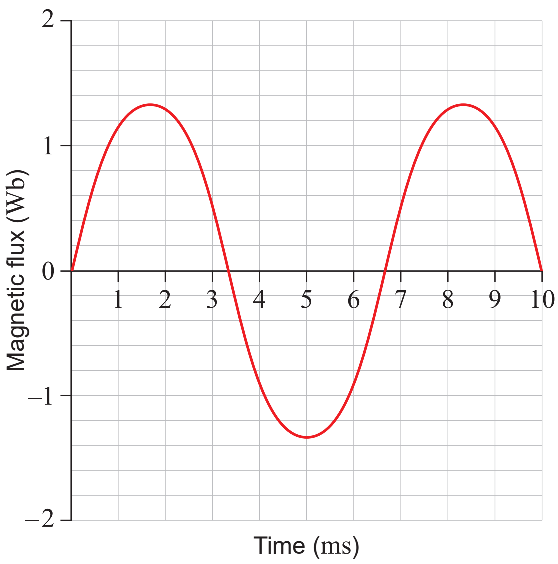
PLEASE TURN OVER

18. A bicycle dynamo is a simple generator. The moving wheel of a bicycle causes a permanent magnet within the dynamo to rotate within a solenoid, as illustrated in the diagram below. The rotating magnet induces an electric current in the solenoid.



[This diagram is not drawn to scale.]

The following graph shows how the magnetic flux through the solenoid in the bicycle dynamo varied with time during its operation.



Use the graph to explain how an electric current is induced in the solenoid.

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____ (2 marks)

19. The positron is the antiparticle of the electron.

An electron and a positron annihilated, producing two gamma photons.

(a) Determine the total energy released in the annihilation.

____ (2 marks)

(b) Use the law of conservation of momentum to explain why the two gamma photons moved in opposite directions.

Assume that both the electron and the positron were stationary before the annihilation.

____ (3 marks)

20. Muons can be detected at the Earth's surface by scientists.

(a) Stationary muons have a mean lifetime of $2.20\ \mu s$ before they decay, as measured in the scientists' frame of reference.

The scientists measured the speed of the muons to be $0.993c$.

(i) Show that the muons moving at a speed of $0.993c$ have a mean lifetime of $18.6\ \mu s$, as measured in the scientists' frame of reference.

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____ (3 marks)

(ii) Determine the mean distance travelled by the moving muons before they decay, as measured in the scientists' frame of reference.

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____ (2 marks)

(b) Muons are unstable and may decay into an electron, a muon-neutrino, and another particle, X, as shown in the decay equation below.

$$\mu^- \rightarrow e^- + v_\mu + X$$

(i) Complete the table below for the decay equation shown.

Particle	*Charge* (e)	*Electronic lepton number*	*Muonic lepton number*
muon	-1		$+1$
electron	-1	$+1$	
muon-neutrino	0	0	$+1$
X			

(2 marks)

(ii) Use the table to determine particle X.

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____ (1 mark)

(c)

The Standard Model is a theory which describes how the fundamental forces and the fundamental particles interact. This theory also describes other particle properties, such as the magnetic moment of some particles. The magnetic moment of a particle is a measure of the strength and orientation of the magnetic field that is produced by the particle.

In 2004, the Brookhaven Muon g-2 experiment measured the magnetic moment of the muon. The results of this experiment were significantly different from the values predicted by the Standard Model.

In 2021, the Fermilab Muon g-2 experiment measured the magnetic moment of the muon. This experiment used new technology to produce the most reliable measurements at the time for magnetic moments. The Fermilab Muon g-2 experiment confirmed the results of the Brookhaven Muon g-2 experiment.

Both of the experiments suggest that the Standard Model does not currently describe the properties of muons accurately.

The magnetic moment of muons will be further investigated in 2025 at the Japan Proton Accelerator Research Complex. It is expected that these experiments will provide the most precise measurements of the muon's magnetic moment yet.

Source: adapted from 'A moment for muons.' Nature Physics 17, 541 (2021), viewed 18 August 2023, www.nature.com

Explain how the experiments above demonstrate *one* key concept of science as a human endeavour.

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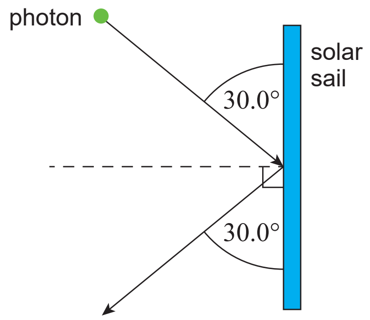
____ (3 marks)

21. A solar sail is attached to a space probe.

This image cannot be reproduced here for copyright reasons.

Source: adapted from Max Polyakov 'Solar sail: The driving force of light', viewed 9 August 2023, maxpolyakov.com

A photon was incident on the solar sail at an angle of $30.0°$ from the surface of the sail. The photon was reflected from the solar sail at $30.0°$ as shown in the diagram below.



[This diagram is not drawn to scale.]

The photon has a wavelength of 508 nm.

(a) Show that the magnitude of the initial momentum of the photon is $1.31 \times 10^{-27} \text{ kg m s}^{-1}$.

(1 mark)

(b) Use a vector diagram to determine the magnitude and direction of the change in momentum of this photon.

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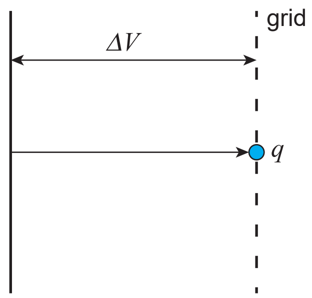
____ (4 marks)

22. The mass of ions can be determined using a mass spectrometer. In a spectrometer, ions are accelerated by a potential difference to a speed v. The mass of the ion can be calculated once the speed v has been determined.

(a) An ion with mass m and charge q was accelerated from rest through a potential difference of ΔV to a grid.



[This diagram is not drawn to scale.]

Show that the mass of the ion once it passes through the grid can be calculated using the formula $m = \dfrac{2q\Delta V}{v^2}$.

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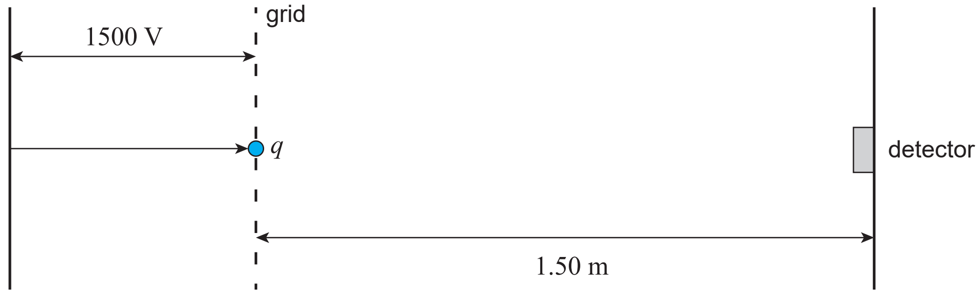
____ (3 marks)

(b) After the ions have passed through the grid they travel a fixed distance at a constant speed towards a detector. The time taken for the ion to reach the detector is measured.

An ion in the spectrometer was accelerated through a potential difference of $1500\ \text{V}$ and travelled $1.50\ \text{m}$ at a constant speed until it reached the detector. It took $2.80 \times 10^{-6}\ \text{s}$ for the ion to reach the detector after it had passed through the grid. The ion has a charge of $q = +1.60 \times 10^{-19}\ \text{C}$.



[This diagram is not drawn to scale.]

Determine the mass of the ion.

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____ (4 marks)

 PLEASE TURN OVER

You may write on this page if you need more space to finish your answers to any of the questions in this question booklet. Make sure to label each answer carefully (e.g. 20(a)(ii) continued).

PHYSICS FORMULA SHEET

Vectors are indicated by arrows. If only the magnitude of a vector quantity is used, the arrow is not used.

Symbols of common quantities

acceleration	$\vec{a}$	force	$\vec{F}$	magnetic flux	Φ	time	t
charge	q	frequency	f	mass	m	velocity	$\vec{v}$
displacement	$\vec{s}$	kinetic energy	E_K	momentum	$\vec{p}$	wavelength	λ
electric current	I	length	l	period	T		
electromotive force	ε	magnetic field	$\vec{B}$	potential difference	ΔV		

Magnitude of physical constants

acceleration due to gravity at the Earth's surface	$g = 9.80\ \text{m s}^{-2}$	Planck's constant	$h = 6.63 \times 10^{-34}\ \text{J s}$
constant of universal gravitation	$G = 6.67 \times 10^{-11}\ \text{N m}^2\ \text{kg}^{-2}$	charge of an electron	$e = 1.60 \times 10^{-19}\ \text{C}$
speed of light in a vacuum	$c = 3.00 \times 10^8\ \text{m s}^{-1}$	mass of an electron	$9.11 \times 10^{-31}\ \text{kg}$
Coulomb's Law constant	$\frac{1}{4\pi\varepsilon_0} = 8.99 \times 10^9\ \text{N m}^2\ \text{C}^{-2}$	mass of a proton	$1.67 \times 10^{-27}\ \text{kg}$
constant for the magnetic field around a conductor	$\frac{\mu_0}{2\pi} = 2.00 \times 10^{-7}\ \text{T m A}^{-1}$	mass of Earth	$5.97 \times 10^{24}\ \text{kg}$
		mean radius of Earth	$6.37 \times 10^6\ \text{m}$

Topic 1: Motion and relativity

$\vec{v} = \vec{v}_0 + \vec{a}t$	$\vec{v}$ = velocity at time t $\vec{v}_0$ = initial velocity	$v = \frac{2\pi r}{T}$	
$\vec{s} = \vec{v}_0 t + \frac{1}{2}\vec{a}t^2$		$\vec{g} = \frac{\vec{F}}{m}$	$\vec{g}$ = gravitational field strength
$v^2 = v_0^2 + 2as$		$F = G\frac{m_1 m_2}{r^2}$	r = distance between masses m_1 and m_2
$v_H = v\cos\theta$ $v_V = v\sin\theta$	θ = angle to horizontal	$v = \sqrt{\frac{GM}{r}}$	M = mass of object orbited by satellite r = radius of orbit
$E_K = \frac{1}{2}mv^2$		$T^2 = \frac{4\pi^2}{GM}r^3$	
$\vec{a} = \frac{\Delta\vec{v}}{\Delta t}$		$\gamma = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}}$	γ = Lorentz factor
$\vec{F} = m\vec{a}$		$t = \gamma t_0$	t_0 = time interval in the moving frame of reference
$\vec{F} = \frac{\Delta\vec{p}}{\Delta t}$		$l = \frac{l_0}{\gamma}$	l_0 = length in the moving object's frame of reference
$\vec{p} = m\vec{v}$		$p = \gamma m_0 v$	m_0 = mass in the frame of reference where the object is stationary
$a = \frac{v^2}{r}$	r = radius of circle		

Topic 2: Electricity and magnetism

$F = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2}$	r = distance between charges q_1 and q_2	$F = qvB\sin\theta$	θ = angle between magnetic field $\vec{B}$ and velocity $\vec{v}$
$\vec{E} = \frac{\vec{F}}{q}$	$\vec{E}$ = electric field	$r = \frac{mv}{qB}$	r = radius of circle
$E = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}$	r = distance from charge	$T = \frac{2\pi m}{qB}$	
$W = q\Delta V$	W = work done	$E_K = \frac{q^2B^2r^2}{2m}$	r = radius at which ions emerge from cyclotron
$E = \frac{\Delta V}{d}$	d = distance between parallel plates	$f = \frac{1}{T}$	f = frequency of the alternating potential difference
$\vec{a} = \frac{q\vec{E}}{m}$		$\Phi = BA_\perp$	$A_\perp$ = area perpendicular to the magnetic field
$B = \frac{\mu_0}{2\pi}\frac{I}{r}$	r = distance from conductor	$\varepsilon = \frac{N\Delta\Phi}{\Delta t}$	N = number of conducting loops
$F = IlB\sin\theta$	θ = angle between magnetic field and direction of current	$\frac{V_{input}}{V_{output}} = \frac{N_{input}}{N_{output}}$	V = potential difference in transformer coils

Topic 3: Light and atoms

$v = f\lambda$		$W = hf_0$	W = work function of the metal f_0 = threshold frequency
$d\sin\theta = m\lambda$	d = distance between slits θ = angular position of m^{th} maximum m = integer $(0, 1, 2, \ldots)$	$E_{K\,max} = eV_s$	$E_{K\,max}$ = maximum kinetic energy of electrons V_s = stopping voltage
$\Delta y = \frac{\lambda L}{d}$	Δy = distance between adjacent minima or maxima L = slit-to-screen distance	$E_{K\,max} = hf - W$	
$E = hf$	E = energy of photon	$f_{max} = \frac{e\Delta V}{h}$	ΔV = potential difference across the X-ray tube
$p = \frac{h}{\lambda}$		$E = \Delta mc^2$	E = energy

Table of prefixes

Prefix	Symbol	Value
tera	T	10^{12}
giga	G	10^{9}
mega	M	10^{6}
kilo	k	10^{3}
centi	c	10^{-2}
milli	m	10^{-3}
micro	μ	10^{-6}
nano	n	10^{-9}
pico	p	10^{-12}
femto	f	10^{-15}

Quarks

Quark	Symbol	Charge (e)
Up	u	$\frac{2}{3}$
Down	d	$-\frac{1}{3}$
Strange	s	$-\frac{1}{3}$
Charm	c	$\frac{2}{3}$
Top	t	$\frac{2}{3}$
Bottom	b	$-\frac{1}{3}$