South Australian
Certificate of Education

1

Physics
2022

Question booklet 1

- Questions 1 to 10 (58 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

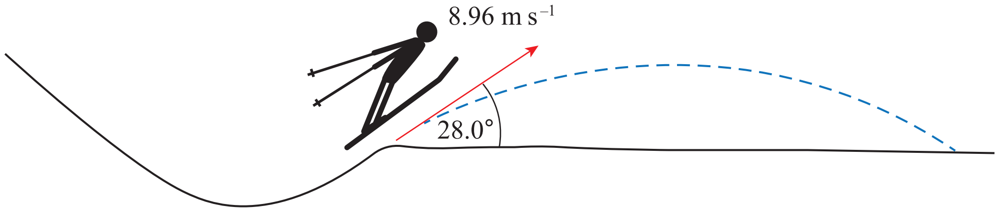
Instructions
- Use black or blue pen
- You may use a sharp dark pencil for diagrams and other representations
- Approved calculators may be used

Total time: 130 minutes
Total marks: 120

Attach your SACE registration number label here

Government
of South Australia

1. A skier in a skiing event launched from a ramp with a velocity of 8.96 m s^{-1} at an angle of $28.0°$ above the horizontal, as shown in the diagram below.



[This diagram is not drawn to scale.]

Assume that air resistance is negligible in all parts of this question.

(a) Show that the initial horizontal speed was 7.91 m s^{-1} and the initial vertical speed was 4.21 m s^{-1}.

____

____

____

____ (2 marks)

(b) Show that the skier reached their maximum height after 0.430 s.

____

____

____

____

____

____ (2 marks)

(c) Determine the horizontal distance travelled by the skier while in the air.

____

____

____

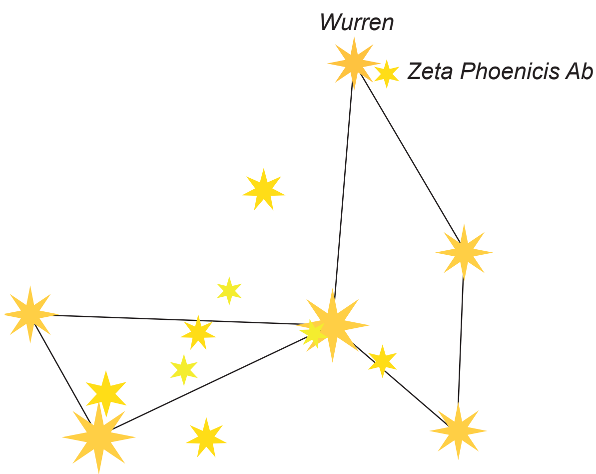
____

____ (2 marks)

2. The International Astronomical Union recognises *Wurren* as the official name of a star in the Phoenix constellation. The name was first used by the Wardaman — a First Nations cultural group in the Northern Territory of Australia — to describe stars in the region.

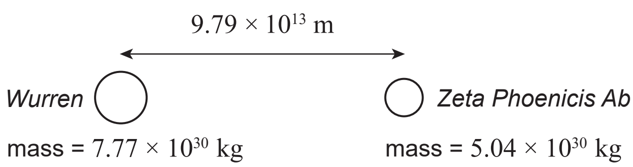
The closest star to *Wurren* is *Zeta Phoenicis Ab*.

Both stars are shown in the diagram of the Phoenix constellation below.



[This diagram is not drawn to scale.]

Wurren and *Zeta Phoenicis Ab* are separated by 9.79×10^{13} m. *Wurren* has a mass of 7.77×10^{30} kg and *Zeta Phoenicis Ab* has a mass of 5.04×10^{30} kg, as shown in the diagram below.



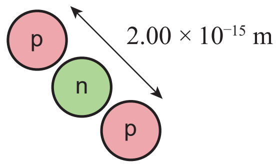
(a) Calculate the magnitude of the gravitational forces between *Wurren* and *Zeta Phoenicis Ab*.

____ (2 marks)

(b) Explain how gravitational forces are consistent with Newton's third law.

____ (2 marks)

3. The centres of two protons (p) in a nucleus are separated by 2.00×10^{-15} m. A neutron (n) is located between the two protons, as shown in the diagram below.



[This diagram is not drawn to scale.]

(a) (i) Calculate the magnitude of the electric forces between the two protons.

____

____

____

____ (2 marks)

(ii) State the gauge boson that mediates the electromagnetic force.

____ (1 mark)

(b) Protons and neutrons are composed of up quarks and down quarks.

State whether the quark composition of a proton is uud or udd. Give a reason for your answer.

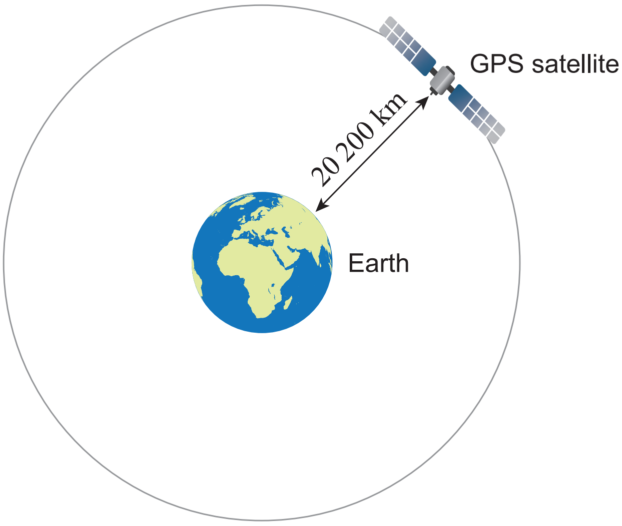
____

____

____

____ (2 marks)

4. A Global Positioning System (GPS) satellite moves in a circular orbit at an altitude of 20 200 km, as shown in the diagram below.



[This diagram is not drawn to scale.]

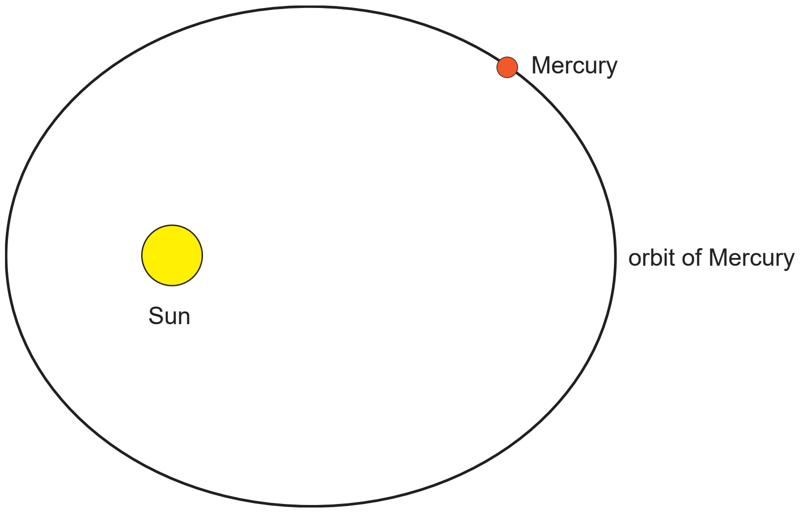
(a) Calculate the orbital velocity of the GPS satellite.

(3 marks)

(b) Calculate the orbital period of the GPS satellite.

(2 marks)

5. The diagram below shows Mercury in its elliptical orbit around the Sun.



[This diagram is not drawn to scale.]

The orbital speed of Mercury varies as it travels in its elliptical orbit.

(a) On the diagram above, indicate *one* position on the orbit where Mercury would have a higher orbital speed than it has at the position shown. (1 mark)

(b) Use Kepler's second law to justify your answer to part (a).

____

____

____

____

____

____ (3 marks)

6. The transmitting antenna shown below is connected to an alternating potential difference and produces a radio wave of frequency 206 MHz.

This image cannot be reproduced here for copyright reasons.

Source: adapted from Elti n.d.'VHF and DAB+ dipole antennas', viewed 9 June 2022, www.elti.com/p/9/70/vhf-and-dab-dipole-antennas.html

(a) Calculate the wavelength of the radio wave.

____

____

____

______________________________________ (3 marks)

(b) Explain how oscillating electrons in transmitting antennas produce electromagnetic waves.

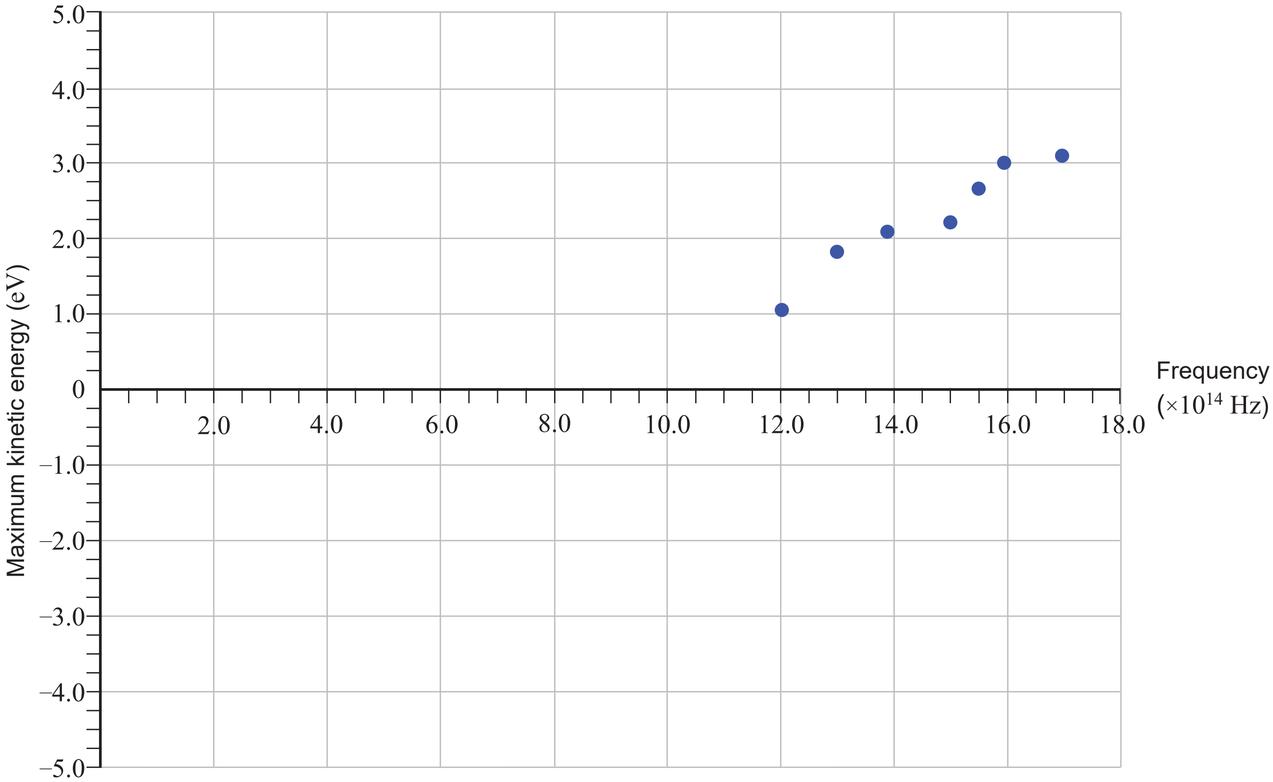
____

____

____

______________________________________ (2 marks)

7. A group of students undertook an experiment to determine the work function of a metal surface using the photoelectric effect. The students projected different light sources separately onto the metal surface and determined the maximum kinetic energy of the electrons emitted for each light source. Their results are shown in the graph below.



(a) Draw a line of best fit through the data. (1 mark)

(b) Use your line of best fit to determine:

(i) the work function of the metal surface.

____ (1 mark)

(ii) the threshold frequency of the metal surface.

____ (1 mark)

(c) Use the law of conservation of energy to explain why there is a threshold frequency for the metal surface.

____

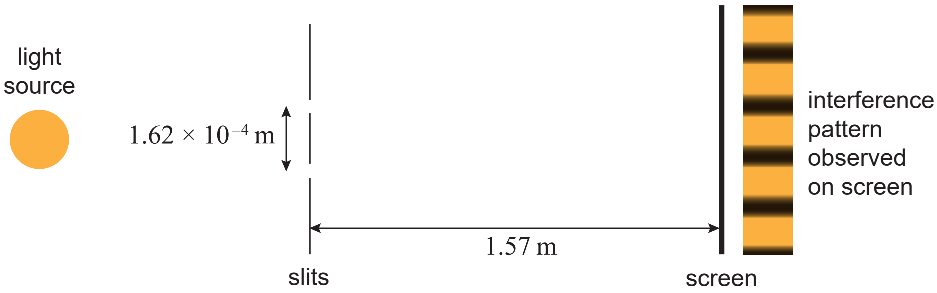
____

____

____

____ (3 marks)

8. An orange light with a wavelength of 589 nm was incident on two slits and produced an interference pattern on a screen, as shown in the diagram below.



[This diagram is not drawn to scale.]

The distance between the two slits was $1.62 \times 10^{-4} \text{ m}$. The two slits were positioned 1.57 m from the screen.

(a) (i) Show that the distance between adjacent fringes observed on the screen was 5.71 mm.

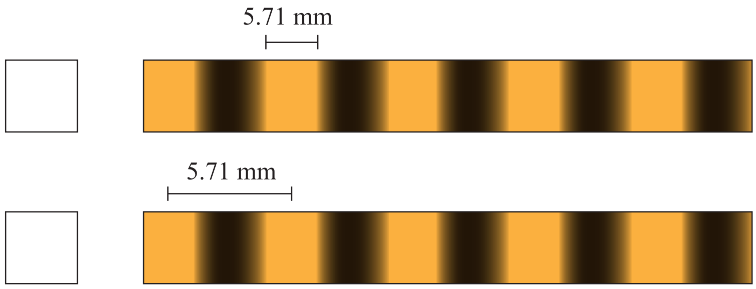
____

____

____

____ (1 mark)

(ii) Indicate which one of the following diagrams shows the interference pattern observed on the screen, by ticking the appropriate box.



(1 mark)

(b) Explain how the bright fringes in a two-slit interference pattern are produced.

____

____

____

____

____

____ (3 marks)

The same light source was then used in a transmission diffraction grating experiment. The light was incident on a grating with slits that were separated by 1.00×10^{-5} m.

(c) Determine the angular position of the second-order maxima.

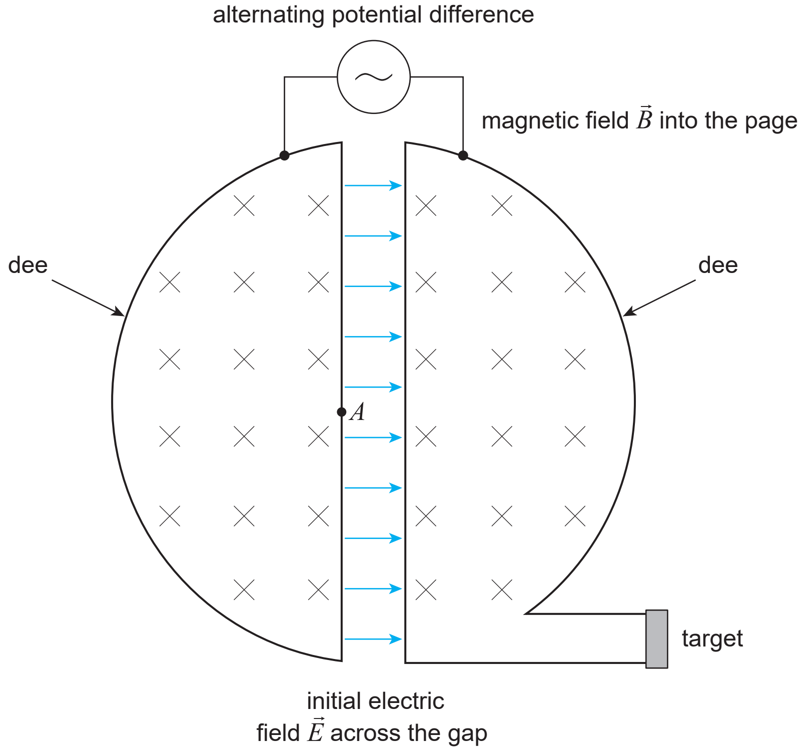
____

____

____

____ (2 marks)

9. The diagram below shows the main components of a cyclotron, which is used to accelerate protons.



[This diagram is not drawn to scale.]

(a) Describe the purpose of the magnetic field in a cyclotron.

(2 marks)

An experiment was conducted to accelerate protons to a high speed towards the target. Protons were released at point A, shown on the diagram above.

(b) The period of rotation of the protons inside the cyclotron was 4.68×10^{-8} s.

Determine the magnitude of the magnetic field inside the dees of the cyclotron.

(3 marks)

The potential difference between the dees was $15.0\ \mathrm{kV}$. The protons crossed the gap in the cyclotron 500 times before they collided with the target.

(c) Determine the kinetic energy of the protons after they had crossed the gap in the cyclotron 500 times.

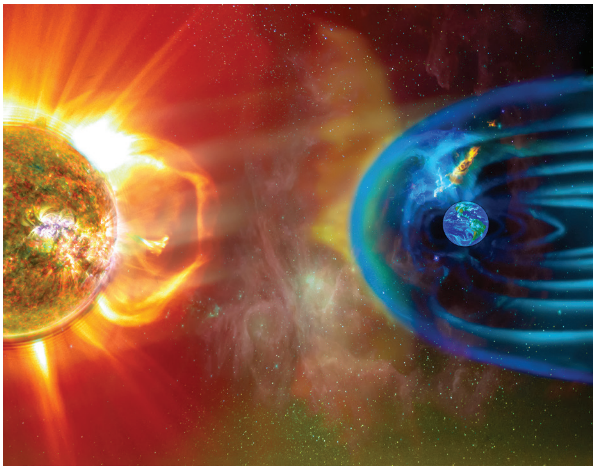
(2 marks)

(d) The experiment required the protons to have a greater kinetic energy than that determined in part (c).

Explain why increasing the potential difference between the dees does ***not*** increase the kinetic energy of the protons as they exit the cyclotron.

(3 marks)

10. A solar storm is a disturbance on the surface of the Sun which can cause electrons to be accelerated away from the Sun. If these electrons approach the Earth, they interact with the Earth's magnetic field. The image below depicts a solar storm with electrons approaching the Earth.



[This image is not drawn to scale.]

Source: © Elen33 | Dreamstime.com; elements of this image were furnished by NASA

An electron entered a uniform region of the Earth's magnetic field perpendicularly at a speed of $4.30 \times 10^{7}\ \mathrm{m\,s^{-1}}$. The magnitude of the Earth's magnetic field in this region was $3.50 \times 10^{-5}\ \mathrm{T}$.

(a) Calculate the magnitude of the magnetic force that acted on the electron.

____

____

____

______________________________________ (2 marks)

(b) After the electron entered the Earth's magnetic field, it underwent circular motion.

Show that the radius of the circular path of the electron was $7.00\ \mathrm{m}$.

____

____

____

____

______________________________________ (1 mark)

(c) Determine the de Broglie wavelength of the electron.

____

____

____

____

____

____ (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. 7(b)(ii) continued).

South Australian Certificate of Education

Physics
2022

Question booklet 2

- Questions 11 to 20 (62 marks)
- Answer ***all*** questions
- Write your answers in this question booklet
- You may write on page 15 if you need more space
- Allow approximately 65 minutes

2

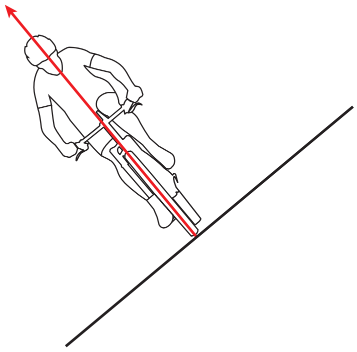
Copy the information from your SACE label here

SEQ	FIGURES	CHECK LETTER	BIN

Government of South Australia

11. A velodrome is a cycling track with banked curves that allow cyclists to maintain high speeds as they move around the track.

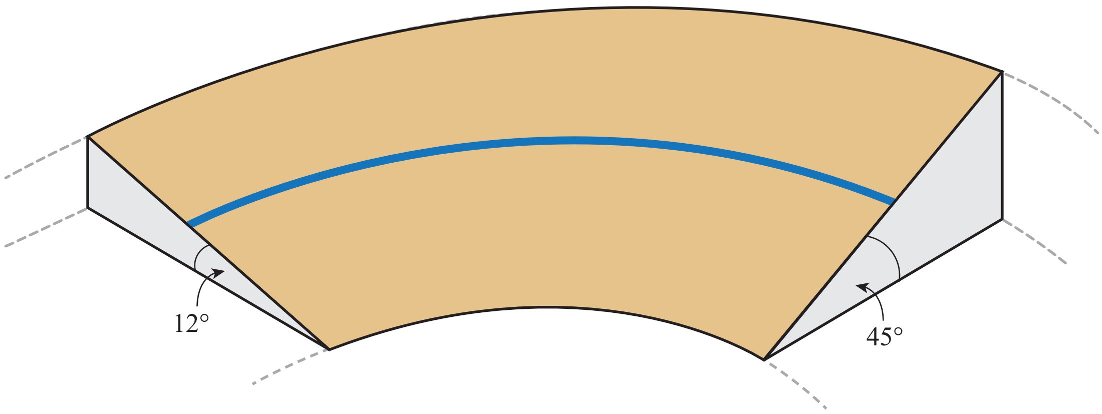
The diagram below shows a cyclist on a banked curve. The normal force vector acting on the cyclist is also shown.



Source: adapted from © Michal Sanca | Shutterstock.com

(a) On the diagram above, draw vectors to show the horizontal component and the vertical component of the normal force on a cyclist moving with uniform circular motion around a banked curve. (2 marks)

(b) Some parts of cycling tracks are banked at different angles. The diagram below shows a section of a track that is banked at $12°$ at one end and at $45°$ at the other end.



[This diagram is not drawn to scale.]

The centripetal acceleration of the cyclist is partially caused by the friction between the tyres on the bicycle and the track.

A cyclist relies on this friction to travel around the track at high speed.

Explain whether a cyclist's reliance on friction is greater when the track is banked at $12°$ or when the track is banked at $45°$.

____

____

____

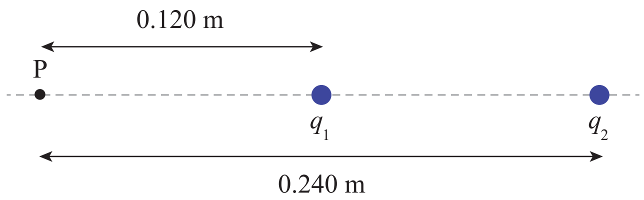
____ (2 marks)

12. Two point charges, $q_1 = +3.00\ \mu C$ and $q_2 = -3.00\ \mu C$, were positioned in a vacuum.

(a) On the diagram below, sketch the electric field surrounding the point charges.

(2 marks)

(b) Point P was 0.120 m from q_1 and 0.240 m from q_2. It was on the same line as both charges, as shown in the diagram below.



(i) Show that the magnitude of the electric field at point P due to q_2 was $4.69 \times 10^5\ N\,C^{-1}$.

(1 mark)

(ii) Determine the magnitude and direction of the net electric field at point P.

(4 marks)

PLEASE TURN OVER

13. A kaon minus particle (K^-) is a meson. A student suggests that the kaon minus particle decays into a muon and a muon antineutrino.

$$K^- \longrightarrow \mu^- + \overline{v}_\mu$$

(a) Complete the table below.

Particle	*Charge* (e)	*Baryon number*	*Muonic lepton number*
K^-			
μ^-			
$\overline{v}_\mu$			

(3 marks)

(b) Hence explain whether this decay is possible.

(2 marks)

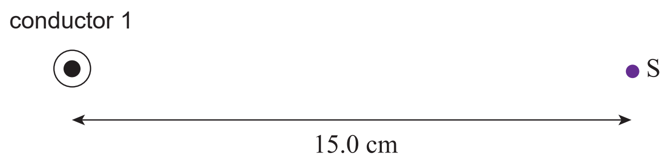
(c) One group of scientists in Mexico determined the mean lifetime of a kaon minus particle to be 12.500 ns.

Another group of scientists in Italy determined the mean lifetime of a kaon minus particle to be 12.385 ns.

Explain how the science as a human endeavour key concept of 'Communication and Collaboration' can be applied by the two groups of scientists to determine which group had a more reliable value.

(3 marks)

14. Conductor 1 is a straight conductor. It carries a current of 1.40 A, flowing perpendicularly out of the page. Point S is 15.0 cm from the centre of conductor 1, as shown in the diagram below.



[This diagram is not drawn to scale.]

(a) (i) Draw a vector at point S on the diagram above to show the direction of the magnetic field due to the current flowing through conductor 1. (1 mark)

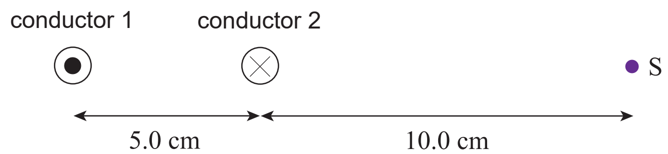
(ii) Show that the magnitude of this magnetic field at point S is 1.87×10^{-6} T.

____

____

____(1 mark)

(b) Conductor 2 is also a straight conductor. It was placed between conductor 1 and point S such that the centre of conductor 2 was 5.0 cm from the centre of conductor 1 and 10.0 cm from point S, as shown in the diagram below.



[This diagram is not drawn to scale.]

The current in conductor 2 is flowing perpendicularly into the page. This current was adjusted until the net magnetic field at point S was zero.

Determine the magnitude of the current in conductor 2.

____

____

____

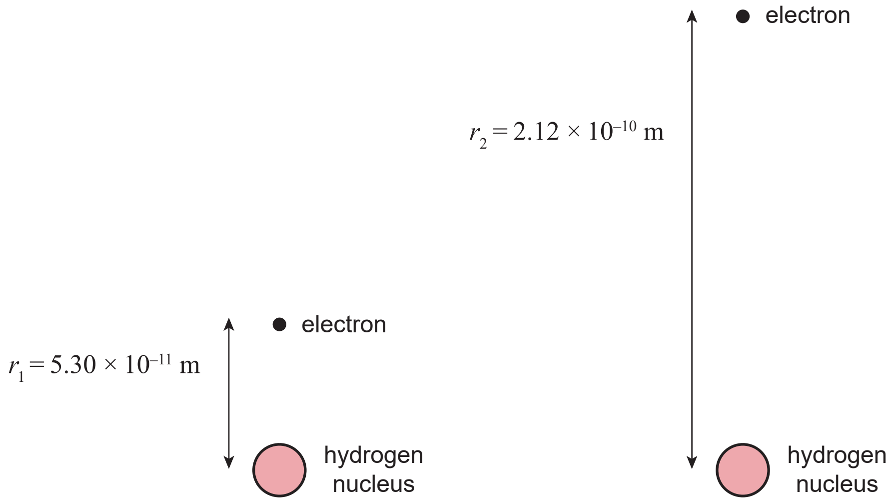
____

____ (3 marks)

15. The nucleus of a hydrogen atom consists of a single proton.

An electron in a hydrogen atom was located at a distance of $r_1 = 5.30 \times 10^{-11}$ m from the nucleus in the $n = 1$ electron energy level.

The electron transitioned to the $n = 2$ electron energy level. At this level the electron was located at a distance of $r_2 = 2.12 \times 10^{-10}$ m from the nucleus.

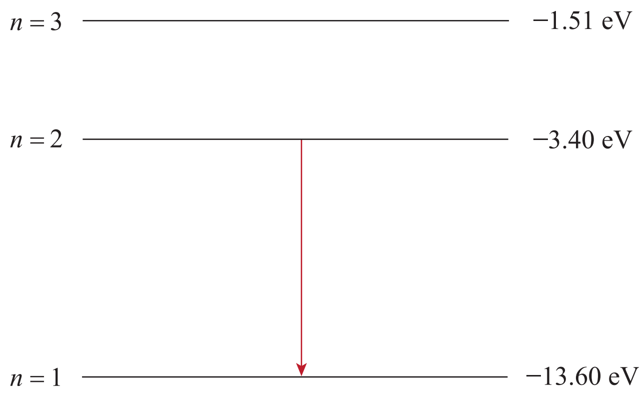


[These diagrams are not drawn to scale.]

(a) Determine the ratio: $\dfrac{\text{electric force on electron at } r_1}{\text{electric force on electron at } r_2}$.

(3 marks)

(b) The electron then transitioned from the $n = 2$ to the $n = 1$ electron energy level, as shown in the diagram below.



(i) Calculate the frequency of the photon that was emitted as the electron transitioned to the $n = 1$ electron energy level.

(3 marks)

(ii) State whether this photon is in the infrared, visible, or ultraviolet region of the electromagnetic spectrum.

(1 mark)

(c) A photon of 12.09 eV was incident on the hydrogen atom.

Use the electron energy level diagram above to explain whether this photon can be absorbed by the hydrogen atom.

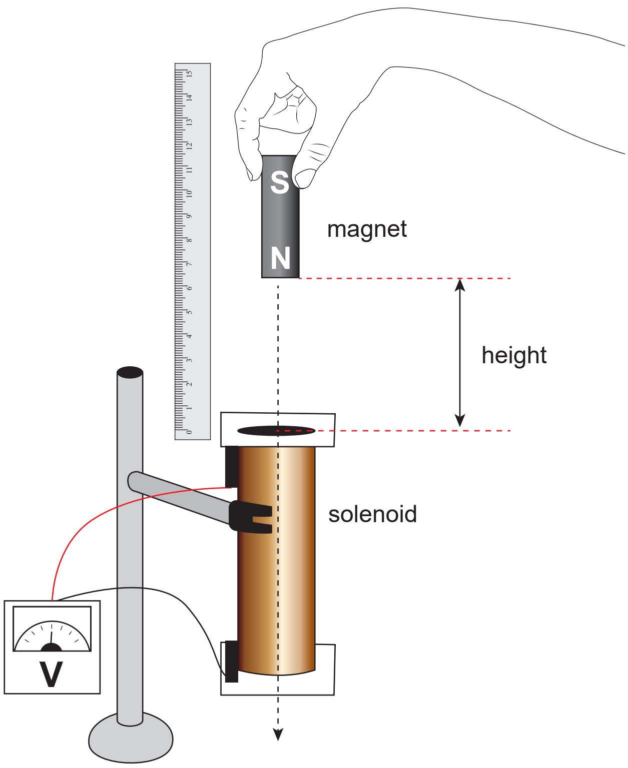
(2 marks)

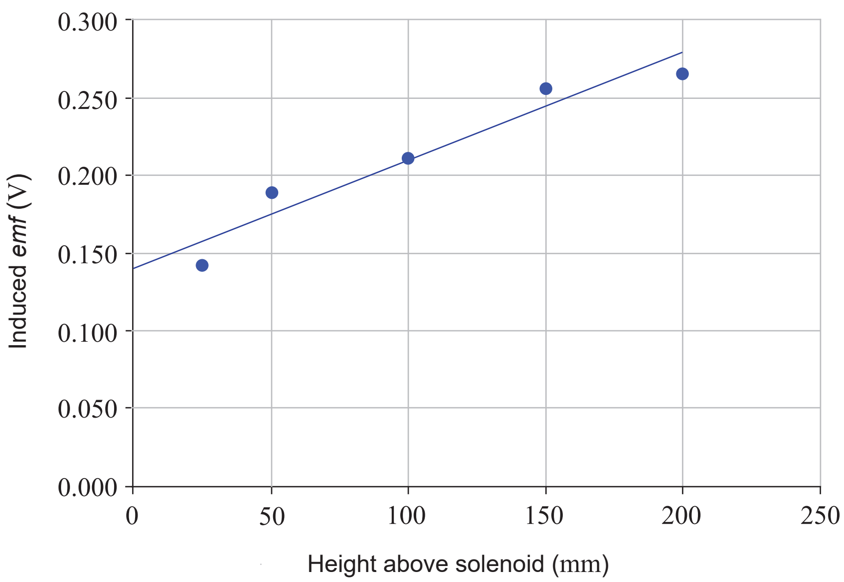
16. A group of students investigated the relationship between the speed of a magnet falling into a solenoid and the electromotive force (*emf*) induced in the solenoid. The students released a magnet from different heights above the solenoid.

A ruler was used to measure the height of the end of the magnet above the solenoid for each trial.

A voltage sensor and software were used to measure the induced *emf* for each trial.

The apparatus and results are shown below.





(a) State the dependent variable in this investigation.

____ (1 mark)

(b) Explain how dropping the magnet through a solenoid induces an *emf* in the solenoid.

____

____

____

____ (2 marks)

(c) Explain why the *emf* induced in the solenoid is larger when the magnet is released from a greater height above the solenoid.

____

____

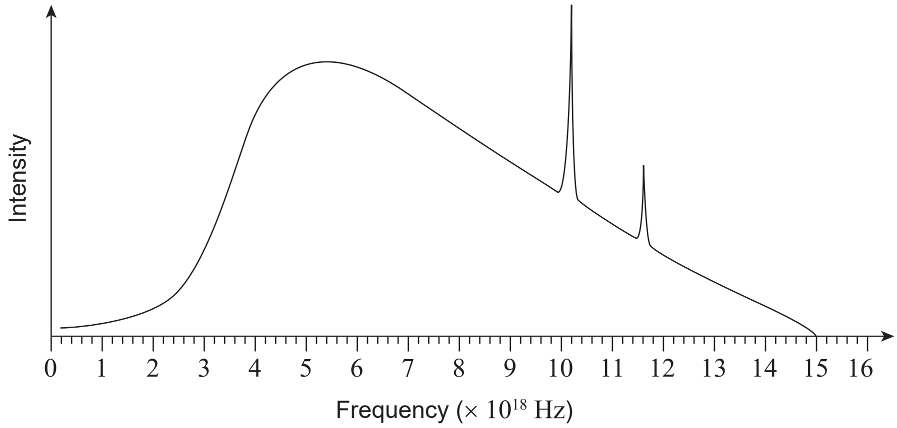
____

____

____

____ (3 marks)

17. The graph below shows a spectrum produced by an X-ray tube.



(a) (i) Use the graph to state the maximum frequency of the X-rays emitted.

____ (1 mark)

(ii) Hence calculate the potential difference that produces the X-rays of maximum frequency.

____

____

____

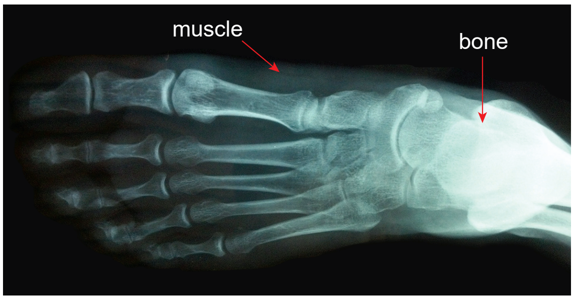
____

____

____ (3 marks)

(b) An X-ray photograph of a foot is shown at right.

Explain why there is greater attenuation of X-rays in bone than in muscle.



Source: © segt16 | Pixabay.com

____

____

____

____ (2 marks)

18. Quasars are some of the brightest objects in the universe. They are moving away from the Earth at relativistic velocities.

One quasar was observed from the frame of reference of the Earth for 252 seconds. The same time interval measured from the frame of reference of the quasar would be 120 seconds.

(a) (i) Show that the Lorentz factor for the quasar was $\gamma = 2.10$.

____

____ (1 mark)

(ii) Hence show that the speed of the quasar as measured from the frame of reference of the Earth was $v = 0.88c$.

____

____

____

____

____

____ (2 marks)

(b) The distance travelled by the quasar during the observation period, as measured from the frame of reference of the Earth, was 6.65×10^{10} m.

Determine the distance travelled by the quasar, as measured from the frame of reference of the quasar.

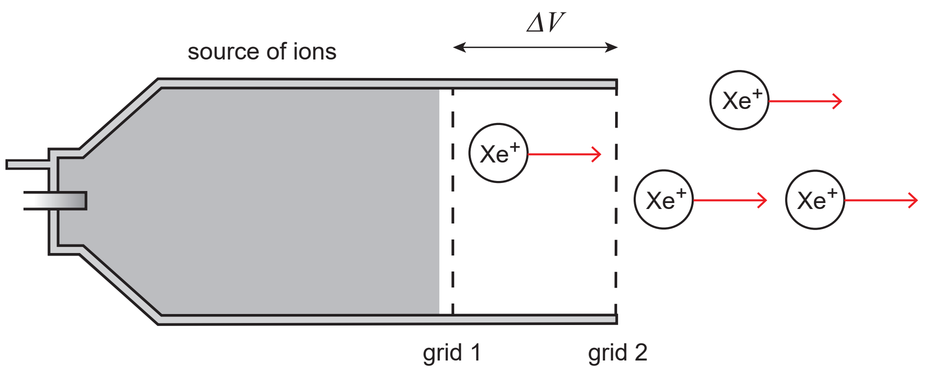
____

____

____

____ (2 marks)

19. One ion thruster operates by accelerating xenon ions (Xe^+) between two parallel grids which have a potential difference, ΔV, across them. The xenon ions are then emitted from the thruster, as shown in the diagram below.



[This diagram is not drawn to scale.]

(a) Show that the speed of a xenon ion, of mass m and charge q, as it passes through grid 2 is given by $v = \sqrt{\dfrac{2q\Delta V}{m}}$.

Assume that the xenon ions are stationary at grid 1.

____

____

____

____

____

____

____ (3 marks)

Each xenon ion has a mass of 2.18×10^{-25} kg and a charge of 1.60×10^{-19} C.

The potential difference between the first grid and the second grid is 1.50×10^{3} V.

(b) (i) Use the formula given in part (a) to show that the magnitude of the change in momentum of a single xenon ion as it moves between the grids is 1.02×10^{-20} kg m s^{-1}.

Assume that the xenon ion is stationary at grid 1.

____

____

____

____ (2 marks)

(ii) The ion thruster was connected to a spacecraft. The spacecraft and thruster had a combined mass of 3100 kg.

The change in momentum of each xenon ion occurred in a time interval of $6.90 \times 10^{-7} \text{ s}$.

Determine the magnitude of the acceleration of the spacecraft caused by the emission of 6.10×10^{12} xenon ions.

____

____

____

____

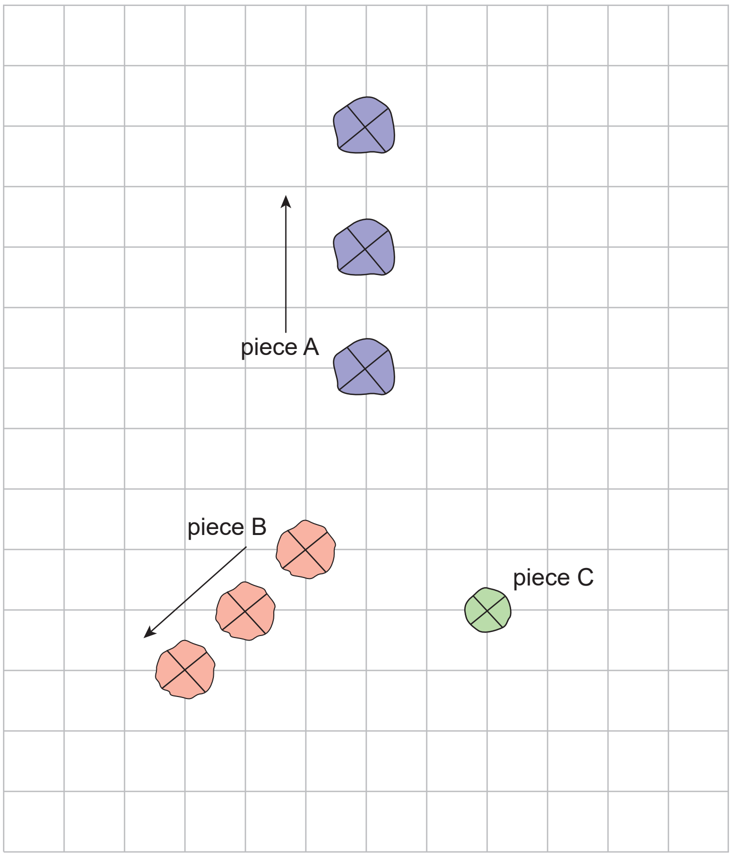
____

____ (3 marks)

20. A stationary mass exploded into three pieces, A, B, and C. Piece A had a mass of $2m$, piece B had a mass of $2m$, and piece C had a mass of m.

The multi-image diagram below shows the motion of the three pieces after the explosion. Only the first image for piece C is shown.

Assume that the system is isolated, and that the time between each image is constant.



Use the law of conservation of momentum and a vector diagram to determine the position of the next image for piece C after the explosion. Draw this image on the diagram above.

____

____

____

____

____ (4 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. 15(b)(i) 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	emf	magnetic field	$\vec{B}$	potential difference	ΔV		

Magnitude of physical constants

acceleration due to gravity at the Earth's surface	$g = 9.80\ \mathrm{m\,s^{-2}}$	Planck's constant	$h = 6.63 \times 10^{-34}\ \mathrm{J\,s}$
constant of universal gravitation	$G = 6.67 \times 10^{-11}\ \mathrm{N\,m^2\,kg^{-2}}$	charge of the electron	$e = 1.60 \times 10^{-19}\ \mathrm{C}$
speed of light in a vacuum	$c = 3.00 \times 10^{8}\ \mathrm{m\,s^{-1}}$	mass of the electron	$m_e = 9.11 \times 10^{-31}\ \mathrm{kg}$
Coulomb's Law constant	$\frac{1}{4\pi\varepsilon_0} = 9.00 \times 10^{9}\ \mathrm{N\,m^2\,C^{-2}}$	mass of the proton	$m_p = 1.67 \times 10^{-27}\ \mathrm{kg}$
constant for the magnetic field around a conductor	$\frac{\mu_0}{2\pi} = 2.00 \times 10^{-7}\ \mathrm{T\,m\,A^{-1}}$	mass of Earth	$5.97 \times 10^{24}\ \mathrm{kg}$
		mean radius of Earth	$6.37 \times 10^{6}\ \mathrm{m}$

Topic 1: Motion and relativity

$\vec{v} = \vec{v}_0 + \vec{a}t$	$\vec{v}$ = velocity at time t; $\vec{v}_0$ = velocity at time 0	$v = \frac{2\pi r}{T}$	
$\vec{s} = \vec{v}_0 t + \frac{1}{2}\vec{a}t^2$		$\vec{g} = \frac{\vec{F}}{m}$	$\vec{g}$ = 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

$F = \dfrac{1}{4\pi\varepsilon_0}\dfrac{q_1 q_2}{r^2}$	r = distance between charges q_1 and q_2	$F = qvB\sin\theta$	θ = angle between field $\vec{B}$ and velocity $\vec{v}$
$\vec{E} = \dfrac{\vec{F}}{q}$	$\vec{E}$ = electric field	$r = \dfrac{mv}{qB}$	r = radius of circle
$E = \dfrac{1}{4\pi\varepsilon_0}\dfrac{q}{r^2}$	r = distance from charge	$T = \dfrac{2\pi m}{qB}$	
$W = q\Delta V$	W = work done	$E_K = \dfrac{q^2B^2r^2}{2m}$	r = radius at which ions emerge from cyclotron
$E = \dfrac{\Delta V}{d}$	d = distance between parallel plates	$\Phi = BA_\perp$	$A_\perp$ = area perpendicular to the magnetic field
$\vec{a} = \dfrac{q\vec{E}}{m}$		$emf = \dfrac{\Delta\Phi}{\Delta t}$	
$B = \dfrac{\mu_0}{2\pi}\dfrac{I}{r}$	r = distance from conductor	$emf = \dfrac{N\Delta\Phi}{\Delta t}$	N = number of conducting loops
$F = IlB\sin\theta$	θ = angle between field $\vec{B}$ and current element $I\vec{l}$	$\dfrac{V_p}{V_s} = \dfrac{N_p}{N_s}$	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 mth maximum m = integer $(0, 1, 2, \ldots)$	$E_{K\,\max} = eV_s$	$E_{K\,\max}$ = maximum kinetic energy of electrons V_s = stopping voltage
$\Delta y = \dfrac{\lambda L}{d}$	Δy = distance between adjacent minima or maxima L = slit-to-screen distance	$E_{K\,\max} = hf - W$	
$E = hf$	E = energy of photon	$f_{\max} = \dfrac{e\Delta V}{h}$	ΔV = potential difference across the X-ray tube
$p = \dfrac{h}{\lambda}$		$E = \Delta mc^2$	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	$-\frac{1}{3}$