Government of **Western Australia**
School Curriculum and Standards Authority

ATAR course examination, 2020

Question/Answer booklet

PHYSICS

Place one of your candidate identification labels in this box.

Ensure the label is straight and within the lines of this box.

WA student number: In figures

In words

Time allowed for this paper

Reading time before commencing work: ten minutes
Working time: three hours

Number of additional answer booklets used (if applicable):

Materials required/recommended for this paper

To be provided by the supervisor

This Question/Answer booklet
Formulae and Data booklet

To be provided by the candidate

Standard items: pens (blue/black preferred), pencils (including coloured), sharpener, correction fluid/tape, eraser, ruler, highlighters

Special items: up to three calculators, which do not have the capacity to create or store programmes or text, are permitted in this ATAR course examination, drawing templates, drawing compass and a protractor

Important note to candidates

No other items may be taken into the examination room. It is **your** responsibility to ensure that you do not have any unauthorised material. If you have any unauthorised material with you, hand it to the supervisor **before** reading any further.

Ref: 20-067
PHY

2021/4237
Web version of 2020/57611

Structure of this paper

Section	Number of questions available	Number of questions to be answered	Suggested working time (minutes)	Marks available	Percentage of examination
Section One Short response	12	12	50	53	30
Section Two Problem-solving	7	7	90	92	50
Section Three Comprehension	2	2	40	39	20
				Total	100

Instructions to candidates

1. The rules for the conduct of the Western Australian external examinations are detailed in the *Year 12 Information Handbook 2020: Part II Examinations*. Sitting this examination implies that you agree to abide by these rules.

2. Write your answers in this Question/Answer booklet preferably using a blue/black pen. Do not use erasable or gel pens.

3. You must be careful to confine your answers to the specific questions asked and to follow any instructions that are specific to a particular question.

4. When calculating or estimating answers, show all your working clearly. Your working should be in sufficient detail to allow your answers to be checked readily and for marks to be awarded for reasoning.

   In calculations, give final answers to three significant figures and include appropriate units where applicable.

   In estimates, give final answers to a maximum of two significant figures and include appropriate units where applicable.

5. Supplementary pages for planning/continuing your answers to questions are provided at the end of this Question/Answer booklet. If you use these pages to continue an answer, indicate at the original answer where the answer is continued, i.e. give the page number.

6. The Formulae and Data booklet is not to be handed in with your Question/Answer booklet.

See next page

Section One: Short response **30% (53 Marks)**

This section has **12** questions. Answer **all** questions. Write your answers in the spaces provided.

When calculating numerical answers, show your working or reasoning clearly. Give final answers to **three** significant figures and include appropriate units where applicable.

When estimating numerical answers, show your working or reasoning clearly. Give final answers to a maximum of **two** significant figures and include appropriate units where applicable.

Supplementary pages for planning/continuing your answers to questions are provided at the end of this Question/Answer booklet. If you use these pages to continue an answer, indicate at the original answer where the answer is continued, i.e. give the page number.

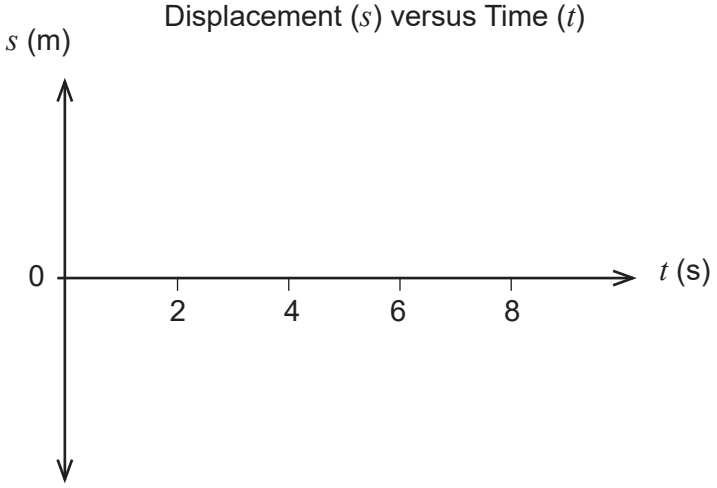
Suggested working time: 50 minutes.

See next page

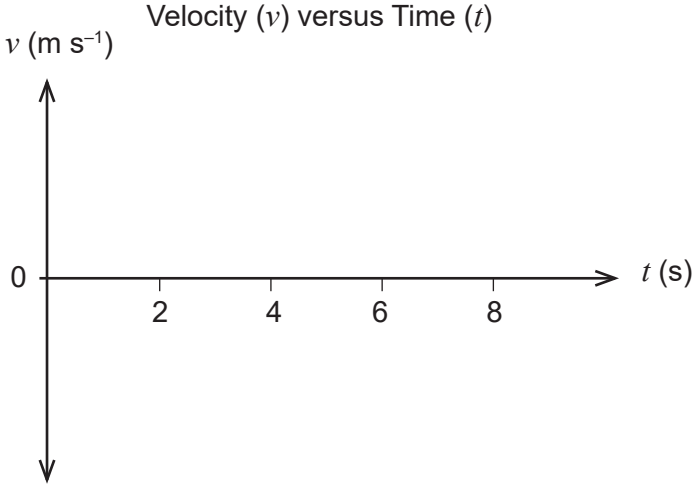
Question 1 **(3 marks)**

A ball is launched vertically into the air with an initial velocity at $t = 0$ from ground level ($s = 0$) and returns to ground level. It takes four seconds for it to reach its maximum height. Taking upwards as positive, graph the ball's displacement, velocity and acceleration versus time from take-off to landing. Ignore air resistance and do not place any values on the y-axis.

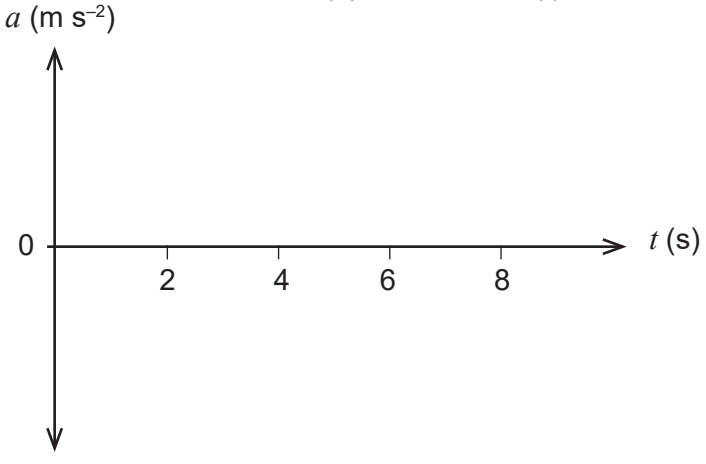
Displacement (s) versus Time (t)



Velocity (v) versus Time (t)



Acceleration (a) versus Time (t)



See next page

Question 2 **(3 marks)**

Calculate the speed of an electron with a de Broglie wavelength of 1.23 nm.

_____ m s^{-1}

Question 3 **(4 marks)**

A 10.0 watt monochromatic LED radiates light with a wavelength of 525 nm. How many photons does it emit per second? Assume all the energy is converted to light.

Answer: _____ photons per second

See next page

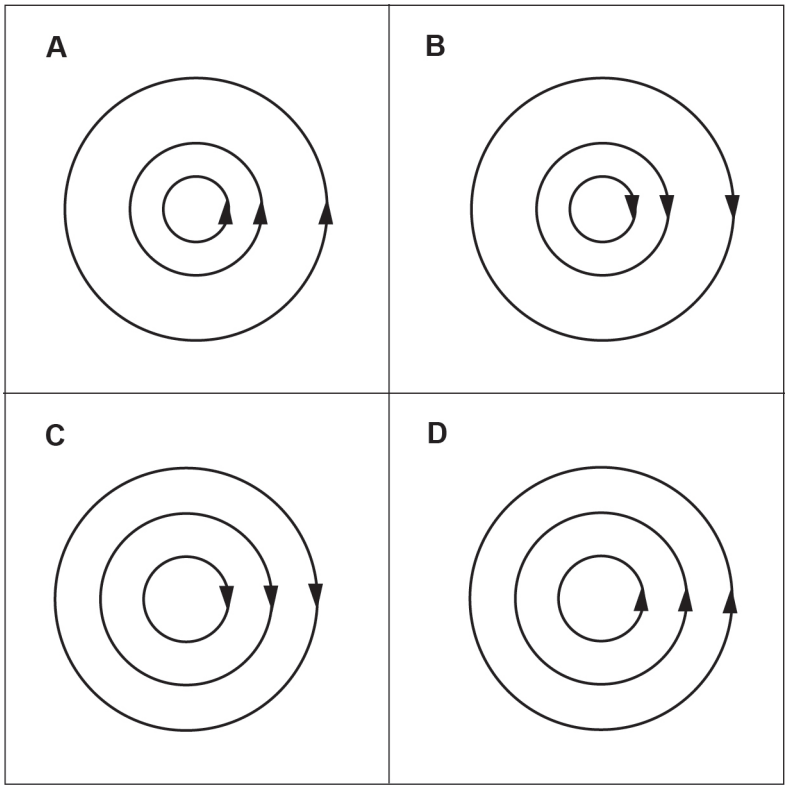
Question 4 **(4 marks)**

In a Physics experiment, a group of students run a DC current upwards through a 3.5 m long vertical wire.

(a) Calculate the magnetic field strength 25.1 cm from the vertical wire carrying a current of 2.78 A. (3 marks)

_____T

(b) Looking from above, which of the following diagrams shows the magnetic field around the wire correctly? (1 mark)

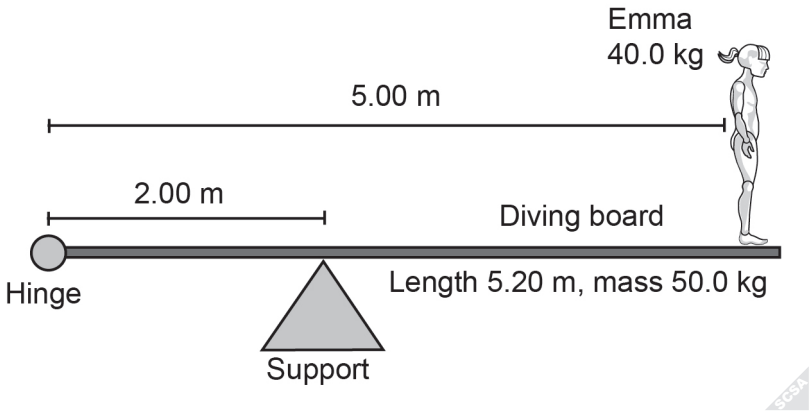


Answer: _____

See next page

Question 5 **(4 marks)**

Emma stands 20.0 cm from the end of a 5.20 m long uniform diving board. Calculate the upwards force the support must exert on the 50.0 kg board for the system to remain in equilibrium.



_____ N

Question 6 **(4 marks)**

Calculate the electric field strength 2.25×10^{-3} m from a point charge of 4.00×10^{-18} C.

_____ N C^{-1}

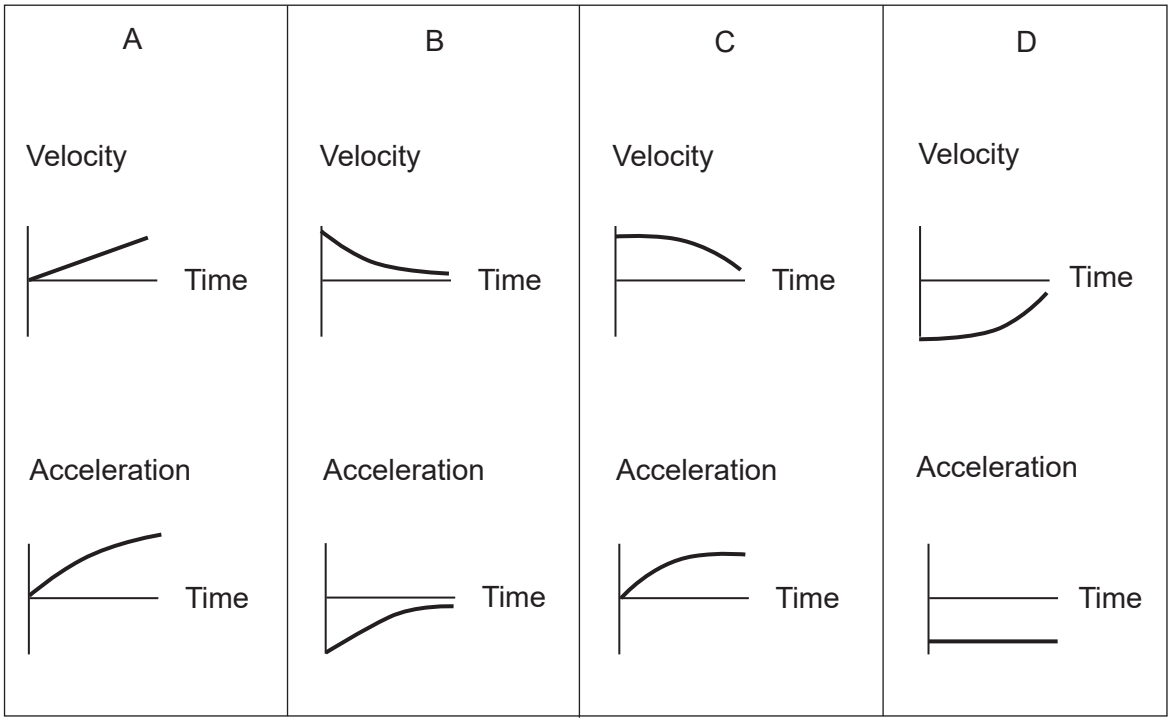
See next page

Question 7 **(5 marks)**

Students in a physics laboratory launch plastic discs across an aluminium air table. Air is blown vertically through small holes in the surface of the table, allowing the discs to float above the surface as they move. This is a nearly frictionless environment and the discs barely slow down as they cross the table. The students then attach a small but strong magnet on top of a disc and repeat the experiment. The disc slows down quite quickly, even though there is still no contact between it and the table.

(a) Explain why the disc with the magnet slows down quickly. (4 marks)

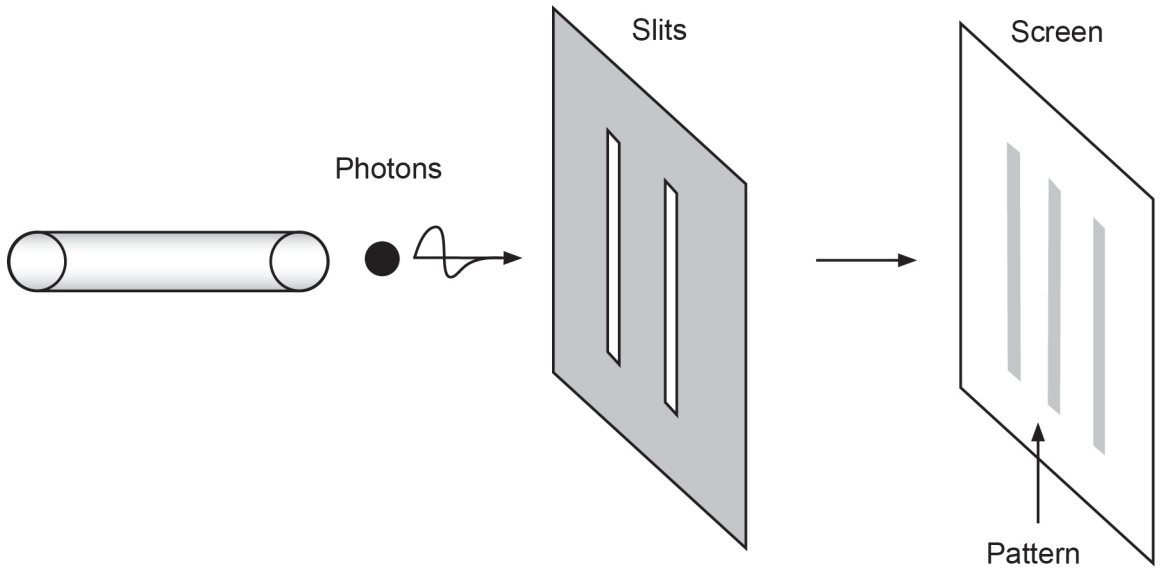
(b) The students deduce that the retarding force on the disc with the magnet is proportional to the speed of the disc. Which set of velocity and acceleration versus time graphs below best describe the motion of the disk with the magnet? (1 mark)



Answer _____

See next page

Question 8 **(5 marks)**



The diagram above shows that when monochromatic coherent light is shone through two narrow slits onto a screen, light and dark fringes appear on the screen.

(a) What property of light causes this to happen? Circle your answer. (1 mark)

Wave Particle Massless

(b) Explain how **both** the light and dark fringes are formed. (4 marks)

See next page

Question 9 **(4 marks)**

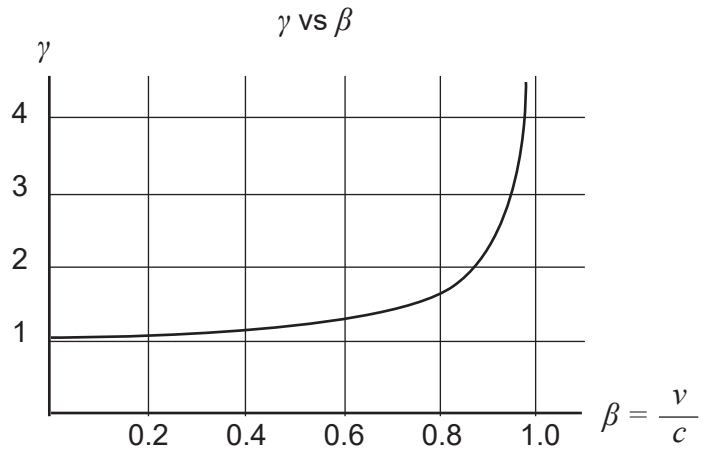
The Lorentz transformation equation for total relativistic energy states

$$E = \frac{mc^2}{\sqrt{1 - \frac{v^2}{c^2}}}$$

This can be simplified to $E = \gamma mc^2$ where

$$\gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}$$

With reference to the graph of γ vs β (v/c) and the equation for relativistic energy, explain why it is impossible for any particle with mass to achieve the speed of light.



See next page

Question 10 **(6 marks)**

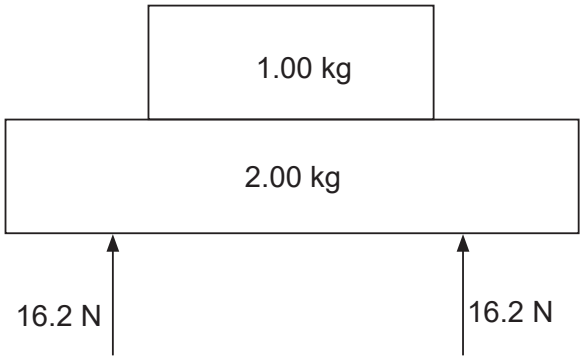
A golfer hits a ball at 37.0 m s^{-1} at 31.0° to the horizontal on a flat fairway. It travels 123 m. She wants to hit a target 135 m away, so she increases the angle at which she hits the ball, without changing the launch speed. Calculate the smallest increase of angle that allows her to reach the target. (Hint: $2\sin\theta\cos\theta = \sin 2\theta$)

°

See next page

Question 11 **(6 marks)**

Jake is lifting two books of mass 1.00 kg and 2.00 kg respectively. The lighter book sits on top of the heavier book, and each of Jake's hands exerts a vertical force of 16.2 N on the lower book, as shown in the diagram.



(a) What is the magnitude of the acceleration of the books? (3 marks)

_____ m s^{-2}

(b) What is the magnitude of the force that the 2.00 kg book exerts on the 1.00 kg book during this acceleration? (3 marks)

_____ N

See next page

Question 12 **(5 marks)**

Exchange particles (gauge bosons) mediate interactions between elementary particles such as quarks and leptons. The gauge bosons (see the Formulae and Data Booklet) have different fundamental properties.

(a) Choose the appropriate combination of relevant fundamental force and property from the table below that corresponds to the gauge bosons listed. Place the number of your choice in the spaces provided. (4 marks)

Number	Fundamental forces	Properties
1	strong nuclear	massless
2	strong nuclear	has mass
3	weak nuclear	massless
4	weak nuclear	has mass
5	electromagnetic	massless
6	electromagnetic	has mass

i. Gluon Answer: _____

ii. Photon Answer: _____

iii. Z Boson Answer: _____

iv. W Boson Answer: _____

(b) Which of the fundamental forces below has the longest range of interaction? (1 mark)

i. weak nuclear
ii. electromagnetic
iii. strong nuclear

Answer: _____

End of Section One

Section Two: Problem-solving **50% (92 Marks)**

This section has **seven** questions. Answer **all** questions. Write your answers in the spaces provided.

When calculating numerical answers, show your working or reasoning clearly. Give final answers to **three** significant figures and include appropriate units where applicable.

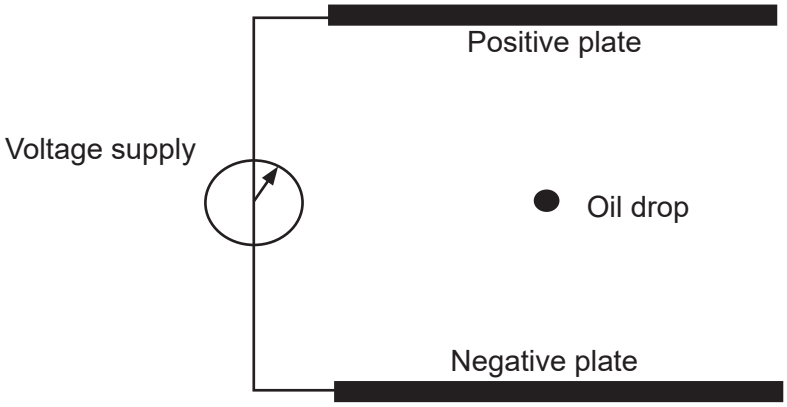
When estimating numerical answers, show your working or reasoning clearly. Give final answers to a maximum of **two** significant figures and include appropriate units where applicable.

Supplementary pages for planning/continuing your answers to questions are provided at the end of this Question/Answer booklet. If you use these pages to continue an answer, indicate at the original answer where the answer is continued, i.e. give the page number.

Suggested working time: 90 minutes.

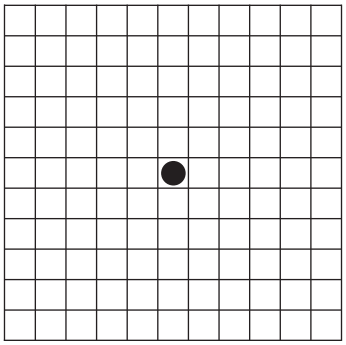
Question 13 **(10 marks)**

In an experiment to measure the charge of an electron, a student creates many tiny oil drops and allows some to enter the space between two horizontal plates that are connected to a variable voltage supply. A diagram of the apparatus is shown below.



Initially there is no potential difference between the plates and the student chooses an oil drop and, using a microscope, watches as it slowly falls, measuring its speed. The student determines that the speed is constant at 0.0313 mm s^{-1}.

(a) On the grid below, draw a free body diagram showing all the forces acting on the oil drop as it falls. (2 marks)



See next page

Using the speed of the oil drop and other known quantities the student calculates the mass of the oil drop as 6.88×10^{-16} kg. The oil drop is exposed briefly to radiation and it captures one or more electrons and hence becomes negatively charged.

The student turns on the voltage supply and adjusts the potential difference between the upper and lower plates until the oil drop stops moving. The potential difference at this point is 346 V.

(b) Name the **two** forces now acting on the oil drop. (2 marks)

One: _____

Two: _____

(c) If the plate separation is 7.71 mm, what is the electric field strength experienced by the oil drop? (2 marks)

_____ V m^{-1}

(d) Calculate the electric charge of the oil drop. (3 marks)

_____ C

The student repeats this procedure several times for different oil drops (possibly carrying different numbers of electrons), and calculates the charge for each drop.

Trial number	**Charge** ($\times 10^{-19}$ C)
1	5.99
2	2.99
3	4.49
4	7.53
5	3.01
6	7.50

(e) Solely on the basis of this data, what does the student estimate the electron charge is most likely to be? (1 mark)

Answer: _____ C

See next page

Question 14 **(15 marks)**

Muons and anti-muons are unstable, with the decay process producing three particles. When an anti-muon ($\overline{\mu}$) decays, one of these particles is an electron neutrino (ν_e).

(a) Complete the table below and use your answers to identify the missing particle X. (3 marks)

$$\overline{\mu} = \text{X} + \nu_e + \overline{\nu_\mu}$$

Reaction	$\overline{\mu}$	=	X	ν_e	$\overline{\nu_\mu}$
Conservation of electron charge	+1	=		0	0
Conservation of Lepton number	–1	=		+1	−1

Particle X: _____

Muons created in the upper atmosphere (approximately 10 km above the Earth's surface) are secondary products from highly-energetic cosmic ray interactions with nuclei of atmospheric particles. In their own frame, muons have a mean lifetime of 2.20×10^{-6} s, with some lasting for up to 3.0×10^{-6} s.

The speed of muons from cosmic rays entering the Earth's atmosphere moving in the direction of the observer on the Earth is in the range of $2.960 \times 10^8 - 2.997 \times 10^8$ m s^{-1}.
(Ignore the effect of the Earth's magnetic field on the muons when answering the following questions.)

(b) Use non-relativistic physics to calculate the mean distance muons moving at 2.991×10^8 m s^{-1} could travel. (2 marks)

_____ m

(c) (i) Calculate the mean lifetime of muons travelling at $0.997c$ as observed from the Earth. (2 marks)

_____ s

(ii) What is the actual mean distance travelled by such muons through the atmosphere as observed from the Earth? (2 marks)

_____ km

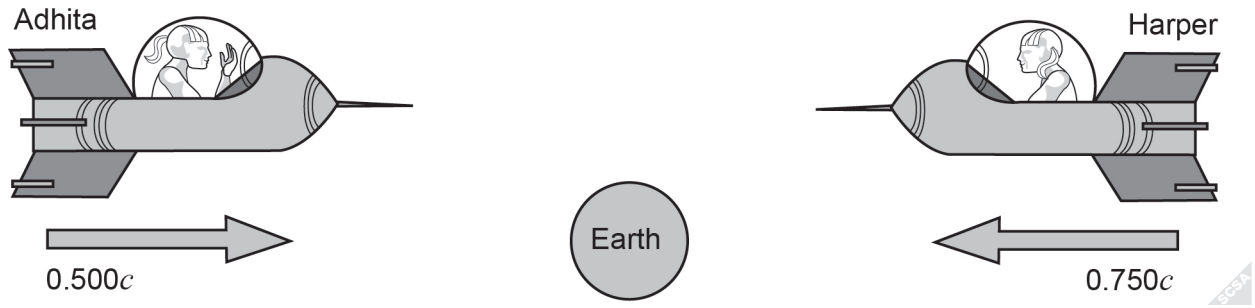
See next page

(d) Using information from the question, explain why a small number of muons reach the Earth. (2 marks)

(e) With the use of a calculation, explain why these muons reach the Earth from the perspective of the muons. (4 marks)

Question 15 **(12 marks)**

Two spaceships, captained by Adhita and Harper, are travelling toward each other. They are observed by a person on the Earth to be travelling at the velocities shown in the diagram. Take all velocities to the left as positive.



(a) Calculate the velocity of Harper as measured by Adhita. (4 marks)

_____ c

(b) Harper fires a missile with a velocity of 0.600c with respect to her in the direction of Adhita. Calculate the velocity of the missile as measured by an observer on the Earth. (4 marks)

_____ c

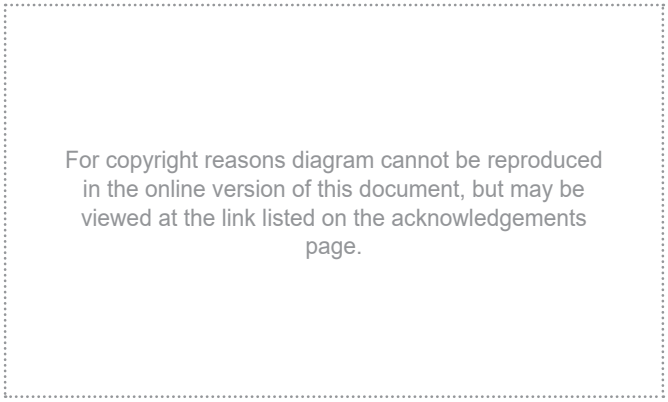
(c) Calculate the velocity of the missile as measured by Adhita. (4 marks)

_____ c

See next page

Question 16 **(12 marks)**

A group of physics students made a simple AC generator in class. It had 150 turns of wire in the 6.00 cm wide square coil and was placed in a magnetic field of strength 1.85 x 10^2 mT. They connected the handle to a motor which rotated it at 240 rpm and used the electricity produced to power a light globe.



(a) Calculate the maximum EMF produced by the generator. (5 marks)

_____ V

(b) Calculate the RMS voltage produced. (1 mark)

_____ V

Question 16 (continued)

The students removed the motor and turned the handle themselves, maintaining a constant speed of rotation. They noticed that the force required to turn it varied as the coil rotated. They also noticed that the light bulb glowed brightest when the force required was greatest and went out when the force required was virtually zero.

(c) (i) Explain why the force required varied as the handle went through one rotation. (3 marks)

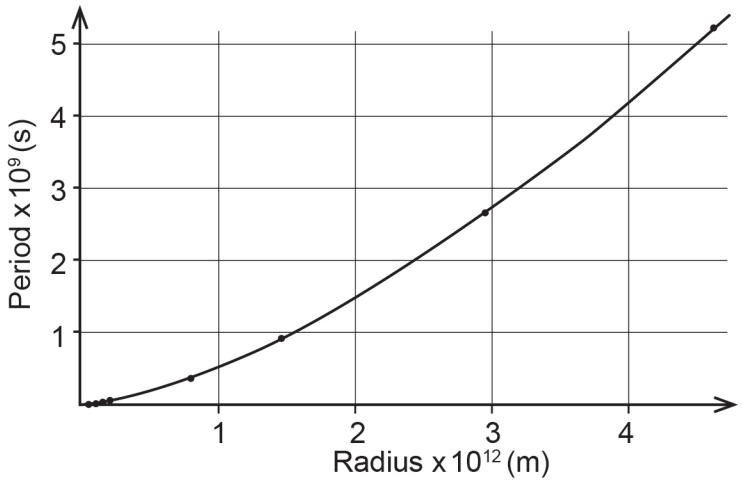
(ii) In what position was the plane of the rotating coil relative to the field when the light bulb went out? Explain why it went out. (3 marks)

Question 17 **(10 marks)**

A satellite is orbiting the Earth 4.00 x 10^3 km above its surface.

(a) Calculate the period of the satellite. (5 marks)

_____ hours



The graph shows the relationship between the period (T) and the orbiting radius (r) of all the planets in our solar system.

(b) (i) With reference to Kepler's Third Law, describe how a straight line graph could be generated using the same two variables. (Do not refer to logarithms.) (2 marks)

_____

_____

_____

_____

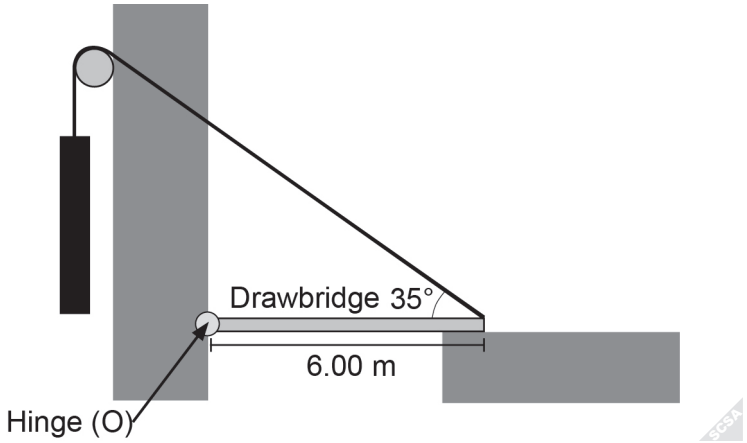
See next page

Question 17 (b) (continued)

(ii) Explain how you could use the gradient of this straight line and Kepler's Third Law to estimate the magnitude of the Newtonian constant of gravitation (G).
(Do not try to calculate G from the graph.) (3 marks)

See next page

Question 18 **(14 marks)**



A castle has a 6.00 m long drawbridge with a mass of 500 kg over its moat. It is attached to a winch by an extremely strong rope at an angle 35.0° to the horizontal.

(a) Calculate the tension in the rope when the drawbridge is just lifted off the rest on the other side of the moat. (4 marks)

_____ N

(b) Calculate the reaction force of the hinge (O) on the drawbridge at this point. (5 marks)

_____ N at _____° to the horizontal.

See next page

Question 18 (continued)

The castle comes under attack. The people inside the castle begin to raise the drawbridge. When it is at an angle of 15.0° above horizontal, the angle between the drawbridge and the rope is 40.0°. At this moment, a 95.0 kg soldier being chased by the enemy jumps onto the very end of the drawbridge.

(c) Calculate the new tension in the rope as he hangs from the end. Assume the drawbridge is stationary at this time. (5 marks)

_____ N

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See next page

Question 19 **(19 marks)**

Hubble's law states:

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From this law comes Hubble's equation:

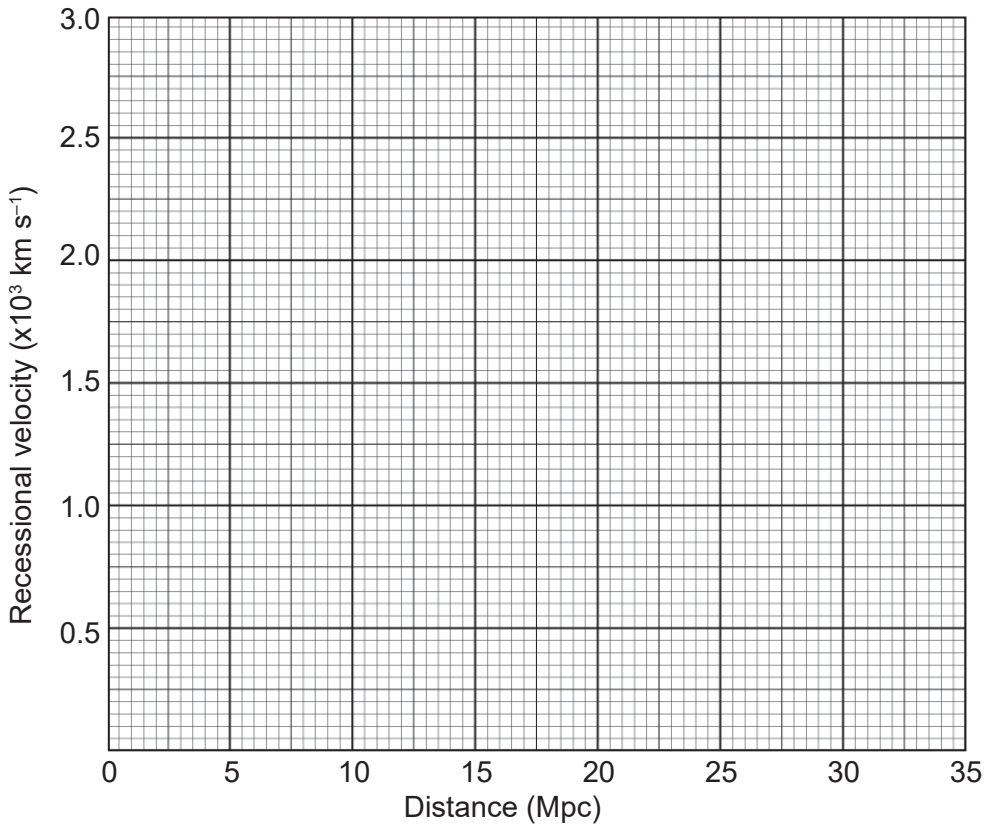
$$v = H_0 d$$

where v = recessional velocity
d = distance from the Earth
H_0 = Hubble's constant.

Below is some data Hubble used to graphically determine his constant.

Galaxy	Distance (Mpc)	Velocity (x10^3 km s^{-1})
NGC 1357	24.7	2.19
NGC 1832	31.0	2.82
NGC 2775	17.9	1.46
NGC 2903	6.96	0.45
NGC 3368	11.9	0.88

(a) Graph the recessional velocity versus distance on the set of axes provided below and draw a line of best fit. Do not take your line through the origin. (3 marks)



A spare grid is provided at the end of this question answer booklet. If you need to use it, cross out this attempt and indicate that you have redrawn it on the spare grid.

See next page

(b) Use two **non-data** points on your line of best fit to calculate Hubble's constant. Circle the two points you used and give your answer to two significant figures. (4 marks)

_____ 10^3 km s^{-1} Mpc^{-1}

Hubble measured the red shift of the galaxies to calculate their recessional velocities.
The equation for the Doppler effect is shown below:

$$\frac{\Delta\lambda}{\lambda_0} = \frac{v}{c}$$

$\Delta\lambda$ = wavelength shift
λ_0 = wavelength of source not moving
v = velocity of source – line of sight
c = speed of light.

(c) (i) The galaxy NGC 2013 is 7.42 x 10^7 ly away from the Earth. Convert this distance into megaparsecs (Mpc). (2 marks)

_____ Mpc

(ii) Using your line of best fit and the value from part (c)(i), calculate the observed red-shifted wavelength emitted from NGC 2013 if λ_0 is 840.0 nm. (6 marks)

_____ nm

See next page

Question 19 (continued)

(d) In Hubble's early data, he noticed that one particular spiral galaxy close to the Earth, seen edge on, had two values of v at its extremes. One was positive and one was negative. Assuming this was not an instrumental or human error, explain how this could occur. (4 marks)

End of Section Two

See next page

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See next page

Section Three: Comprehension **20% (39 Marks)**

This section has **two** questions. You must answer **both** questions. Write your answers in the spaces provided.

When calculating numerical answers, show your working or reasoning clearly. Give final answers to **three** significant figures and include appropriate units where applicable.

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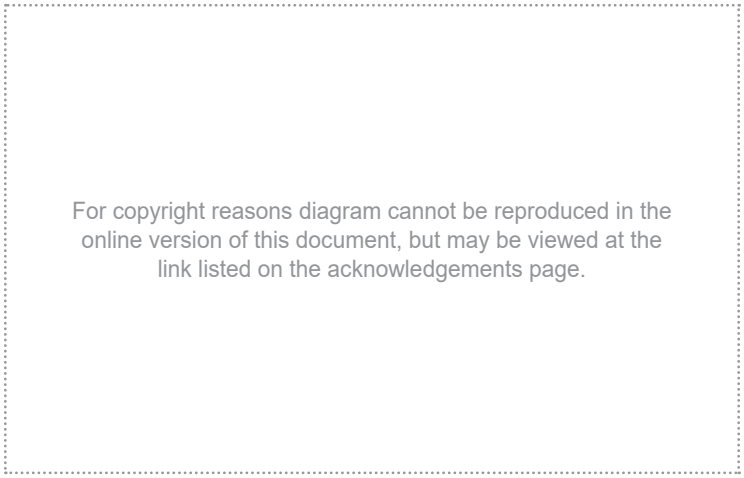
Suggested working time: 40 minutes.

Question 20 **(19 marks)**

Cyclotrons

A cyclotron is a particle accelerator. It is an electrically-powered machine that produces a beam of charged particles that can be used for medical, industrial and research purposes. A cyclotron accelerates charged particles in a spiral path, which allows for a much longer path for acceleration than a straight-line accelerator.

A cyclotron consists of two semicircular charged plates in a flat vacuum chamber called 'dees' because of their shape. The chamber sits between the poles of a magnet that creates a strong and vertical magnetic field. A stream of charged particles is fed into the centre of the chamber and a high-frequency alternating voltage is applied across the plates. This voltage accelerates the charged particles across the gap every half turn. Combined with the magnetic field, this process causes the particles to spiral outwards until they exit the cyclotron.



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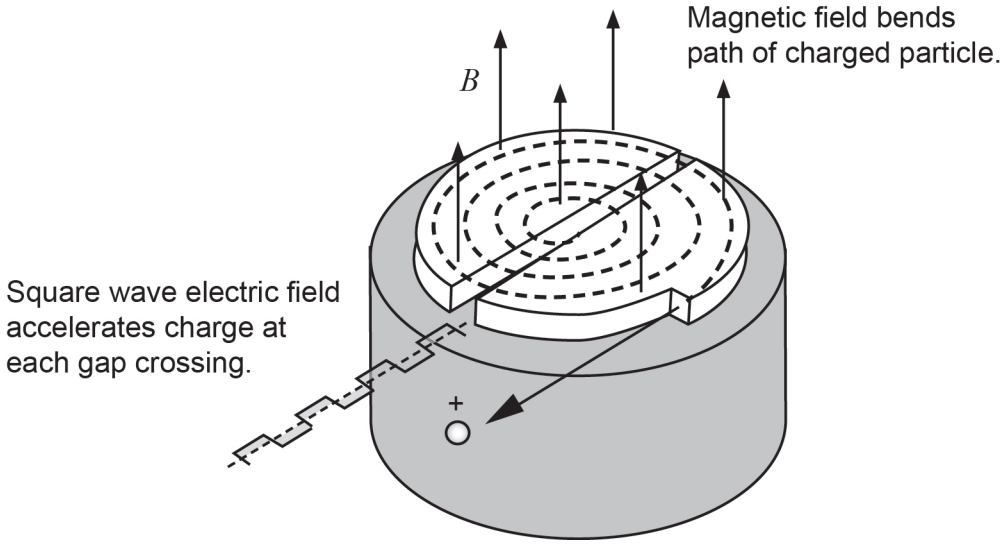


The cyclotron frequency (how often the electric field between the dees reverses) is independent of both the velocity of the particles and the radius of the circular path they follow.

Medical cyclotrons

Medical cyclotrons produce proton beams that are used to manufacture radioisotopes used in medical diagnosis. Radioisotopes produced in a cyclotron decay by either positron emission or electron capture. Positron emission tomography (PET) and single photon emission computed tomography (SPECT), which utilises gamma ray emission, are two imaging techniques that rely on cyclotron-produced radioisotopes.

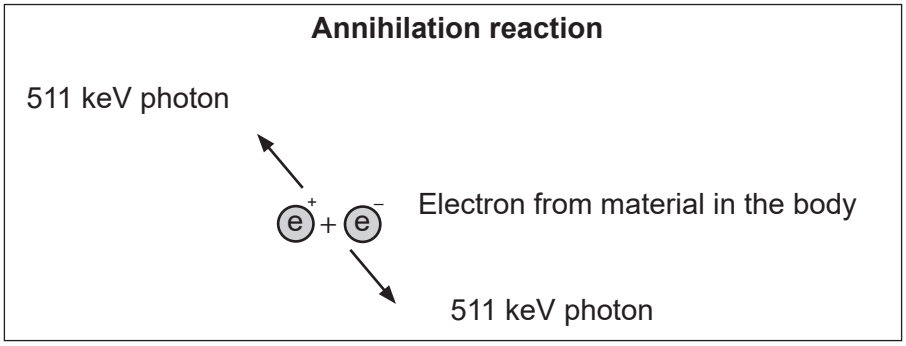
(a) The diagram above shows the acceleration of a positive particle in a cyclotron. Describe one change that would need to be made in order to use the same machine to produce a beam of negatively-charged particles exiting from the same place, and explain why.

(3 marks)

See next page

Question 20 (continued)

Positrons (e^+) are examples of antimatter and have the same properties as electrons (e^-) except for having a positive charge. When they collide with an electron, the following process occurs.



(b) (i) Calculate the wavelength of the photons produced in the annihilation described in the diagram above. (3 marks)

_____ m

(ii) To which part of the electromagnetic spectrum does the photon belong? (1 mark)

_____

(c) Explain why increasing the strength of the magnetic field would increase the velocity of the particles leaving the cyclotron. (4 marks)

_____

_____

_____

_____

_____

_____

_____

_____

(d) (i) Explain why the voltage across the dees must alternate. (2 marks)

On page 31 the text states: 'The cyclotron frequency (how often the electric field between the dees reverses) is independent of both the velocity of the particles and the radius of the circular path they follow.'

(ii) Derive an expression for the cyclotron frequency and use the expression to explain why this statement is correct. (Ignore relativistic effects.) (6 marks)

See next page

Question 21 **(20 marks)**

Wind turbines

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How do wind turbines work?

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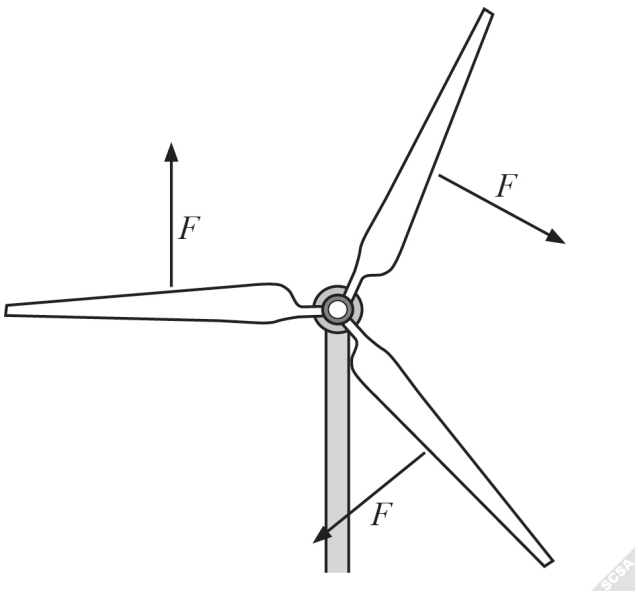
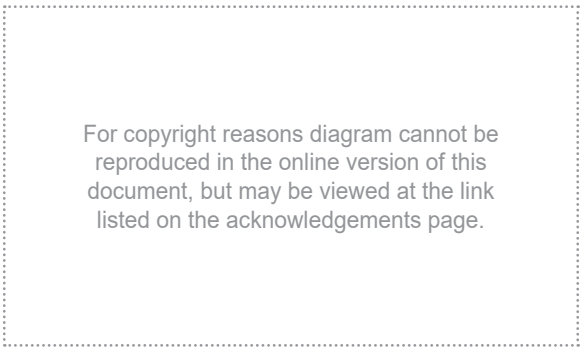


Wind turbine blades vary in length between 40 and 80 m.

A major problem with wind turbines is varying wind speed. The input power must match the output power. The output power depends entirely on rotational speed and torque so how do we keep rotational frequency constant when wind speed keeps changing? The solution is mechanical. The operators use blade pitch control which changes the angle of the blades and reduces the surface area facing the wind. This reduces the amount of energy collected by the turbine and controls the force applied to each blade.

See next page



How the pitch is altered to control the rotational speed.

Each blade experiences a gravitational torque. If the clockwise and anticlockwise gravitational torques add up to zero, the turbine is considered balanced. A symmetrical three-blade turbine is considered balanced at all times.

(a) (i) Explain why a step-up transformer is used to increase the voltage before transporting the electricity into the National Grid. Use specific equations in your answer. (4 marks)

(ii) Calculate the output voltage of the transformer if the turbine produces 690 V and the ratio of turns is 100 in the primary coil to 2500 in the secondary coil. (2 marks)

_____ kV

Question 21 (continued)

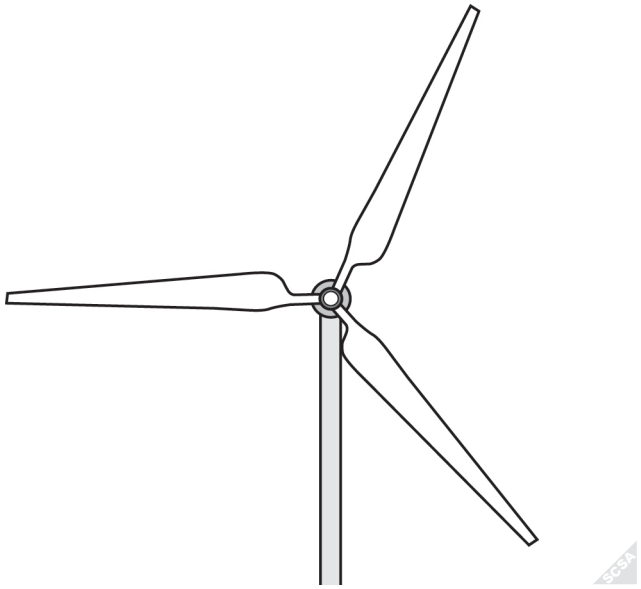
(b) With specific reference to the text, explain why the pitch of the rotor blades is changed by the operators of the turbine. (4 marks)

(c) If the 60 m long blades on an average-sized turbine are rotating at 0.20 Hz, estimate the speed of the centre of mass of one of the blades. (4 marks)

_____ m s^{-1}

Consider the three-blade turbine in the diagram to be rotating clockwise. The blade on the left hand side is parallel to the ground. The blades are identical in size and mass.

(d) (i) Draw the weight forces acting on the blades. (2 marks)



(ii) Show mathematically that the turbine is balanced in this position. (4 marks)

End of questions

Supplementary page

Question number: _____

Supplementary page

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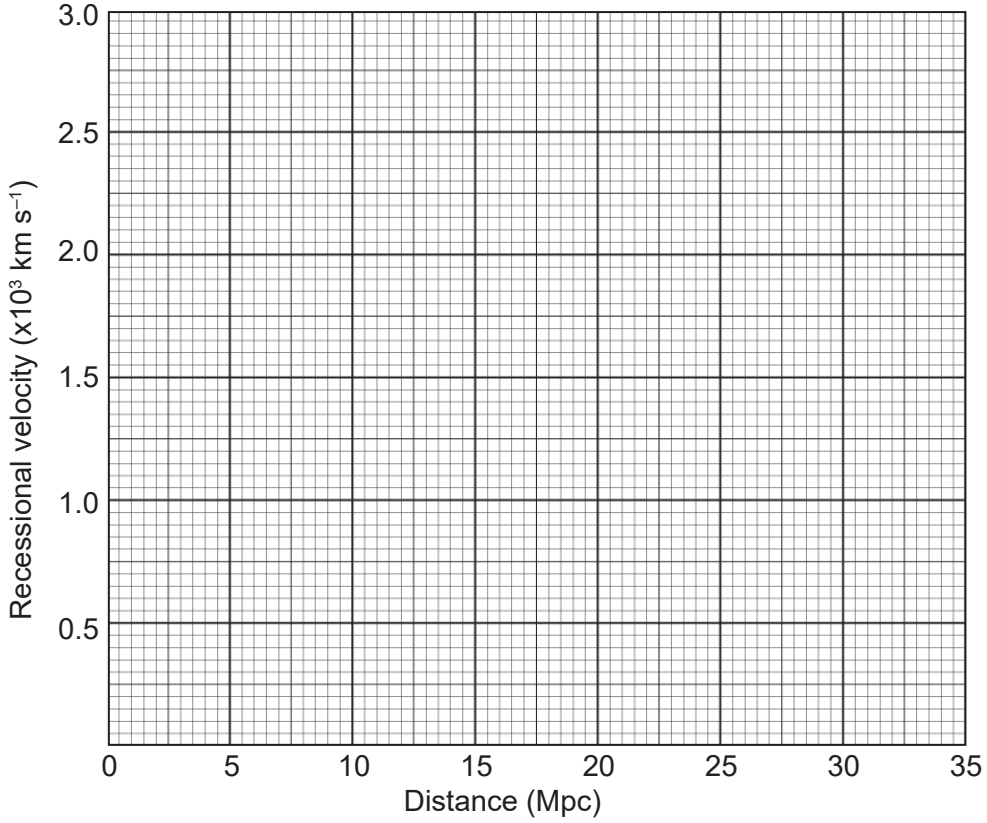
Spare grid



ACKNOWLEDGEMENTS

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