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EDEXCEL A LEVEL PHYSICS: QUESTIONS BY TOPIC

Gravitational Fields (12)

A Level Physics Topic 12

13 questions · 76 marks · Mark schemes included

A Level only content · Pearson Edexcel 8PH0 / 9PH0 papers, 2016–2025

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HOW TO USE THIS BOOKLET

Questions are grouped by specification sub-topic and run from the lowest mark tariff to the highest within each one.

Click any row below to jump straight to that sub-topic or question.

On every question page, click ANSWER in the top-right corner to jump to its mark scheme.

Diagrams, graphs, tables and data are printed exactly as they appeared in the original papers.

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12.2 GRAVITATIONAL POTENTIAL AND ORBITS		8 Qs · 71 marks	5
2. Q2	A Level Paper 2 June 2024	1	6
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QUESTIONS

13 questions · 76 marks · 3 sub-topics



SUB-TOPIC 12.1

GRAVITATIONAL FIELD STRENGTH AND NEWTON'S LAW OF GRAVITATION

Sub-topic 12.1 · 1 question · 1 marks · lowest tariff first



- 8 The acceleration of free fall at the surface of the Earth is 9.81 ms^{-2} .
The mass of the Earth is M and the diameter of the Earth is D .

Which of the following gives the acceleration of free fall, in ms^{-2} , at the surface of a

planet with diameter $\frac{D}{2}$ and mass $\frac{M}{9}$?

☐ A $\frac{9.81 \times 2}{9}$

☐ B $\frac{9.81 \times 4}{9}$

☐ C $\frac{9.81 \times 2}{3}$

☐ D $\frac{9.81 \times 9}{4}$

(Total for Question 8 = 1 mark)



SUB-TOPIC 12.2

GRAVITATIONAL POTENTIAL AND ORBITS

Sub-topic 12.2 · 8 questions · 71 marks · lowest tariff first



2 A satellite of mass m orbits the Earth with speed v .

What is the speed of a satellite of mass $2m$ orbiting at the same distance from the Earth?

☐ A $\frac{v}{2}$

☐ B v

☐ C $v\sqrt{2}$

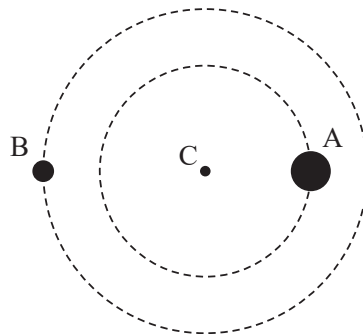
☐ D $2v$

(Total for Question 2 = 1 mark)



12 The diagram shows two black holes, A and B, orbiting each other.

Assume that the centre of mass C of the system is the centre of a circular orbit for each black hole as shown in the diagram.



Black hole A is in an orbit of radius $2.9 \times 10^{10} \text{ m}$ and black hole B is in an orbit of radius $3.6 \times 10^{10} \text{ m}$. Both orbit with the same period, so the total distance between them is $6.5 \times 10^{10} \text{ m}$.

(a) Calculate the force between the black holes.

mass of Sun, $M_{\odot} = 1.99 \times 10^{30} \text{ kg}$

mass of black hole A = $36M_{\odot}$

mass of black hole B = $29M_{\odot}$

(2)

Force = ...

(b) By considering the orbit of one black hole about C, determine the period of the orbit.

(3)

Period = ...

(Total for Question 12 = 5 marks)



17 The asteroid Bennu is in an approximately circular orbit around the Sun. Scientists consider that Bennu may collide with Earth within the next century.

(a) In 2060 Bennu will be 7.49×10^8 m from the Earth.

(i) Show that the mass of Bennu is about 7.8×10^{10} kg.

mean radius of Bennu = 245 m

average density of Bennu = 1260 kg m^{-3}

(3)

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(ii) Calculate the magnitude of the force F between Bennu and Earth in 2060.

mass of Earth = 5.98×10^{24} kg

(2)

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$F =$

(b) The orbital time of Bennu around the Sun is 1.17 years.

Calculate the mass of the Sun.

average distance of Bennu from the Sun = 1.70×10^{11} m

mass of Bennu = 7.8×10^{10} kg

1 year = 3.15×10^7 s

(4)

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Mass of Sun = ...

(Total for Question 17 = 9 marks)



- 15** In 2015 the Messenger spacecraft crashed into the surface of the planet Mercury after four years in orbit observing the surface of Mercury.

Messenger's orbit was highly elliptical, varying between 200 km and 15 000 km above the surface of Mercury. Messenger completed one full orbit every 12 hours.

mass of Messenger spacecraft = 565 kg
mass of planet Mercury = 3.30×10^{23} kg
radius of planet Mercury = 2430 km

- (a) It has been suggested that the same orbital period of about 12 hours could have been achieved if Messenger was in a circular orbit 7690 km above the surface of Mercury.

- (i) Determine whether this suggestion is correct.

(4)

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- (ii) The elliptical orbit chosen had advantages over this circular orbit.

Explain one advantage.

(2)

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- (b) Calculate the velocity an object would have as it reached the surface of Mercury if it was released from Messenger's maximum orbital height.
Assume the object is released from rest and that Mercury has no atmosphere.

(4)

Velocity = ...

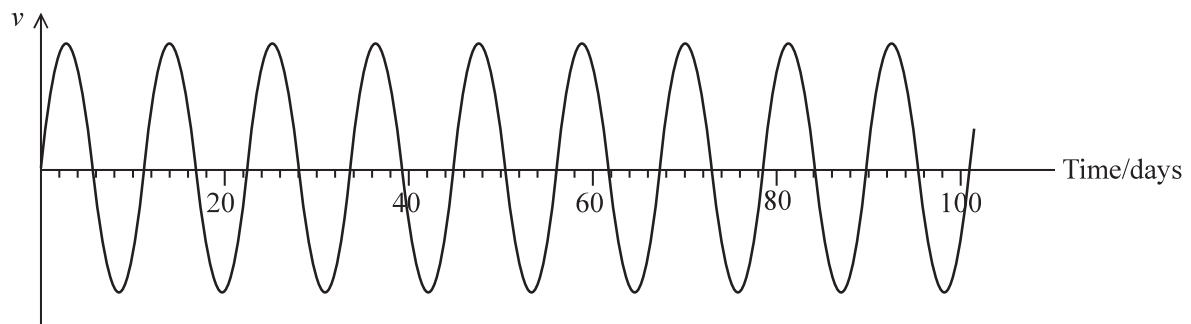
(Total for Question 15 = 10 marks)



- 14 In 2016 astronomers announced the discovery of an Earth-like planet orbiting Proxima Centauri, the closest star to the Sun.

The planet was detected because of the small movement of the star as the planet orbited. The movement was detected using the Doppler shift in the frequency of light travelling to the Earth.

The graph shows how the component of the star's velocity v towards the Earth varied over time.



- (a) Explain how the Doppler shift was used to obtain the data shown on the graph.

(4)

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- (b) (i) Use the graph to show that the angular velocity of the planet is about $6 \times 10^{-6} \text{ radian s}^{-1}$.

(3)

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- (ii) The mass of Proxima Centauri is 0.12 times the mass of the Sun.

Determine the distance of the planet from Proxima Centauri.

mass of Sun = $1.99 \times 10^{30} \text{ kg}$

(3)

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Distance = ...

(Total for Question 14 = 10 marks)



17 Astronomers observing stars at the centre of our galaxy have suggested that many of them are orbiting a supermassive black hole. The mass of this black hole is $9.2 \times 10^{36} \text{ kg}$.

- (a) Calculate the orbital period for a star in a circular orbit at a distance of $1.9 \times 10^{14} \text{ m}$ from a black hole of this mass.

(3)

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Orbital period = ...

- (b) The star S0-2 is in a highly elliptical orbit around the position of the black hole.

At its point of closest approach, S0-2 is at a distance of $1.8 \times 10^{13} \text{ m}$ from the centre of the black hole.

At the most distant point of its orbit, S0-2 is $2.7 \times 10^{14} \text{ m}$ from the black hole.

- (i) Show that the change in gravitational potential between the closest and most distant points in this orbit is about $3 \times 10^{13} \text{ J kg}^{-1}$.

(2)

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- (ii) At its point of closest approach, the star is travelling at a speed of $8.1 \times 10^6 \text{ m s}^{-1}$.

Calculate the speed of S0-2 at the furthest point in its orbit using the change in gravitational potential.

$$\text{mass of S0-2} = 2.4 \times 10^{31} \text{ kg}$$

(3)

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Speed = ...

- (c) Trigonometric parallax and Hubble's law are two methods used to determine astronomical distances.

Explain whether either of these methods is suitable to determine the distance to S0-2.

(3)

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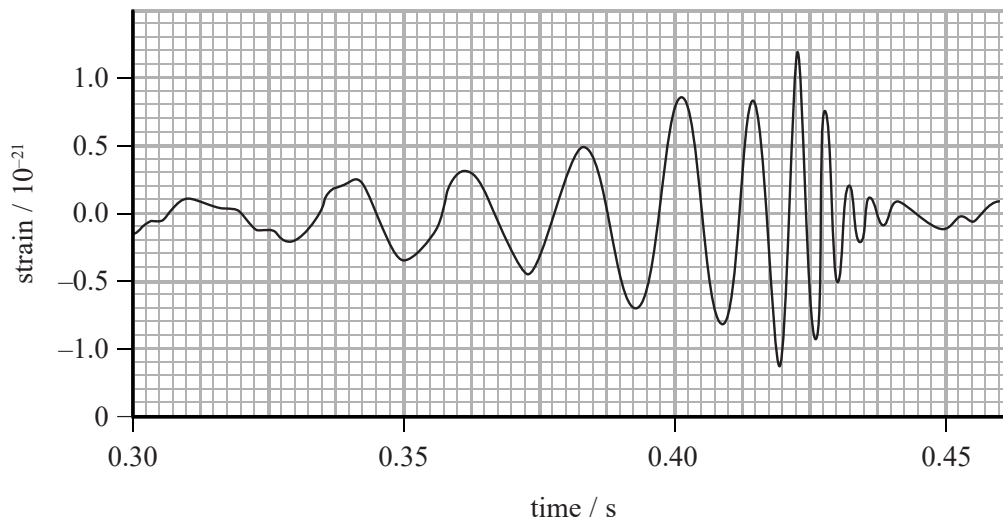
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(Total for Question 17 = 11 marks)



- 20** In 2016 scientists at the Laser Interferometer Gravitational-Wave Observatory (LIGO) announced that gravitational waves had been detected.

The signal they detected is shown on the graph.



- (a) Gravitational waves travel at the speed of light.

Determine the mean wavelength of the waves detected between 0.30 s and 0.35 s on the graph.

(3)

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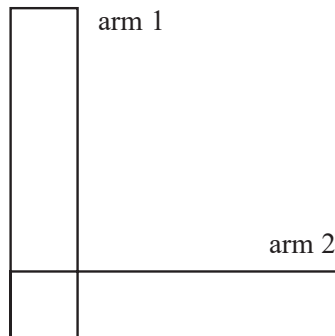
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Mean wavelength = ...

- (b) Gravitational waves alternately compress and stretch matter by very small amounts as they pass through.

The LIGO detector has two arms, at 90° to each other, each 4 km long. As a gravitational wave passes the detector, the arms change length. The detector continuously compares the lengths of the two arms.



- (i) An article states that ‘the maximum change in the 4 km length of the arm is about 0.001 times the diameter of a proton’.

Determine whether this statement applies to the gravitational wave shown in the graph.

$$\text{diameter of proton} = 8.8 \times 10^{-16} \text{ m}$$

(3)

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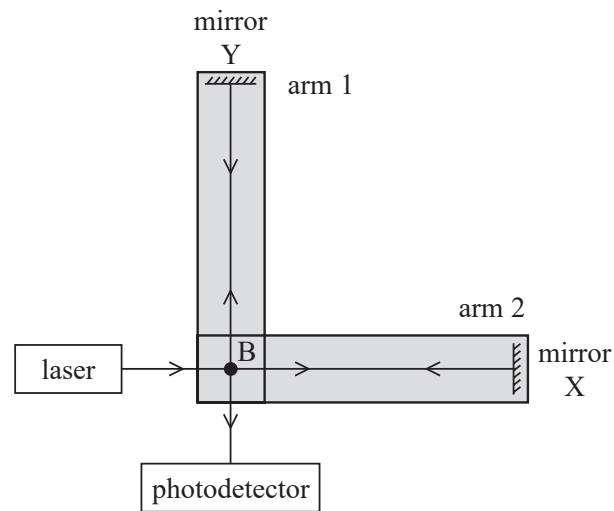
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- (ii) In the LIGO detector, any change in the lengths of the arms is detected using a laser beam and photodetector.



The laser beam is split into two at B, one beam travelling to one mirror and the other beam travelling to the other mirror. After reflection at the mirrors, the beams are recombined at B and reach the photodetector. The photodetector measures the intensity of the incident light.

The system is arranged so that when no gravitational waves are present, the beams have a path difference of half a wavelength at the photodetector.

Explain how the photodetector detects very small changes in the length of one arm, when the other arm stays the same length.

(4)

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- (iii) The system could be arranged so that when no gravitational waves are present, the beams have zero path difference at the photodetector.

Explain whether using an initial path difference of half a wavelength is a more sensitive way of detecting changes in length than having an initial path difference of zero.

(2)

(Total for Question 20 = 12 marks)



- 6 In 1990, the Hubble Space Telescope (HST) was launched into a low Earth orbit above the Earth's atmosphere.

(a) HST orbits the Earth in a circular orbit with a speed of 7.59 km s^{-1} .

mass of Earth = $5.97 \times 10^{24} \text{ kg}$

radius of Earth = $6.37 \times 10^6 \text{ m}$

(i) Show that the height of HST above the surface of the Earth is about $6 \times 10^5 \text{ m}$.

(3)

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(ii) Calculate the increase in the gravitational potential energy as HST is raised, from its initial position at the Earth's surface, to its orbital height.

mass of HST = $11\,600 \text{ kg}$

(2)

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Increase in gravitational potential energy = ...



- (iii) A student suggests that giving HST more energy than that required in (ii) would result in the satellite orbiting at a greater height and with a greater speed.

Assess the validity of the student's suggestion.

(4)

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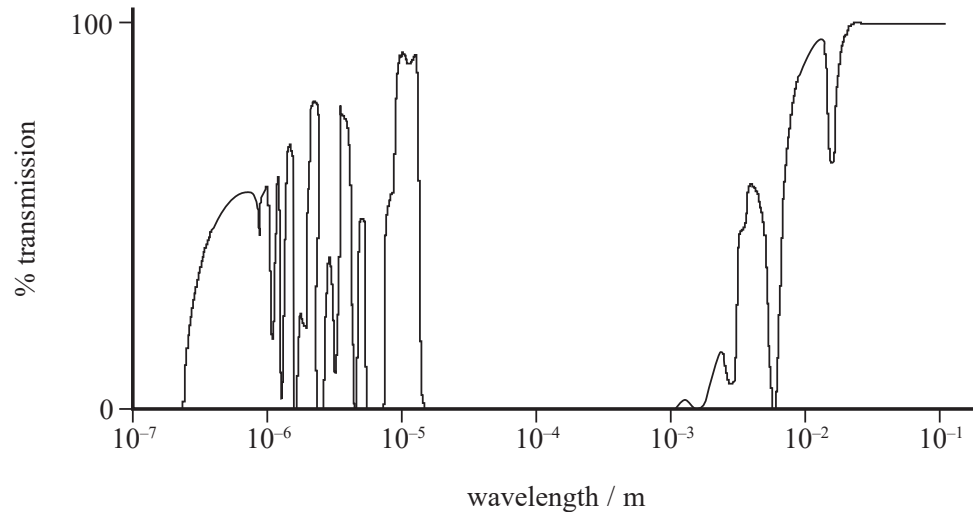
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- (b) The transmission of electromagnetic radiation through the atmosphere is shown on the graph.



State one advantage shown by this graph of positioning a telescope above the atmosphere.

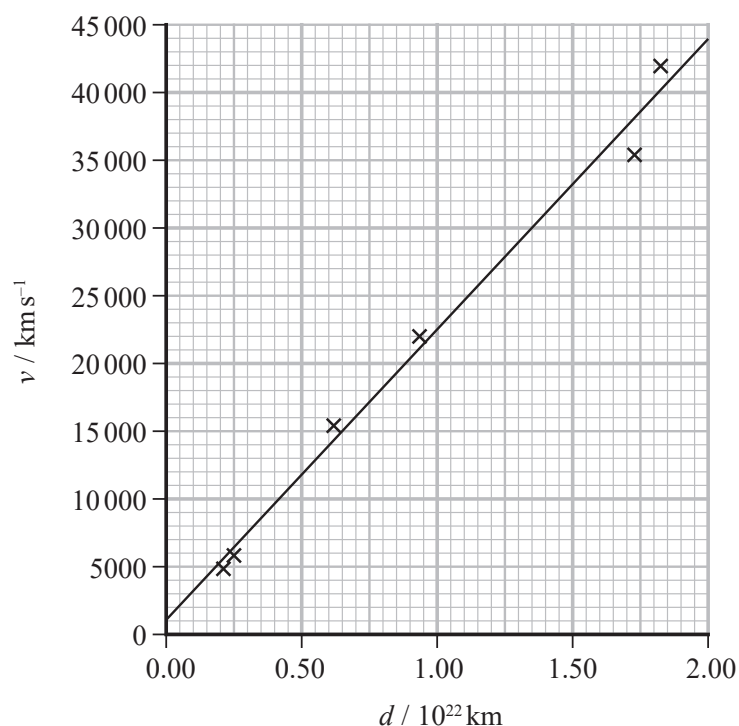
(1)

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- (c) High resolution images from HST allow astronomers to make detailed measurements of very distant galaxies. The graph shows how the recessional velocities of distant galaxies depend on their distance from Earth.



Determine an age for the universe.

(3)

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Age for the universe = ...

(Total for Question 6 = 13 marks)

SUB-TOPIC 12.3

COMPARING GRAVITATIONAL AND ELECTRIC FIELDS

Sub-topic 12.3 · 4 questions · 4 marks · lowest tariff first



4 Which of the following is **not** a similarity between gravitational fields and electric fields?

- ☐ A For a point charge or point mass, the field follows the inverse square law.
- ☐ B For a point charge or point mass, the field is radial.
- ☐ C Both fields act at a distance.
- ☐ D Both fields act on all particles.

(Total for Question 4 = 1 mark)



9 Electric and gravitational fields have a number of similarities and differences.

An electric field is produced by a point charge and a gravitational field is produced by a point mass.

Which of the following statements applies to both of these fields?

- ☐ A The field causes a force on all particles.
- ☐ B The force caused by the field can be attractive or repulsive.
- ☐ C At a distance x from the centre of the field, field strength is proportional to x^2 .
- ☐ D At a distance x from the centre of the field, potential is proportional to $1/x$.

(Total for Question 9 = 1 mark)



- 6 A proton can be considered to be both a point charge and a point mass. There is an electric field and a gravitational field associated with the proton.

Which of the following statements about the fields is **not** correct?

- ☐ A Field strength is a vector.
- ☐ B Potential is always less than 0.
- ☐ C Potential is proportional to $\frac{1}{\text{distance from proton}}$
- ☐ D Field strength is proportional to $\frac{1}{(\text{distance from proton})^2}$

(Total for Question 6 = 1 mark)



- 5 A particle P has charge and mass. The particle causes an electric field and a gravitational field.

Which of the following statements is correct, at a distance r from P?

- ☐ A gravitational field strength is proportional to $\frac{1}{r}$
- ☐ B electric field strength is proportional to $\frac{1}{r}$
- ☐ C gravitational potential is always positive
- ☐ D electric potential is proportional to $\frac{1}{r}$

(Total for Question 5 = 1 mark)

MARK SCHEMES

official mark schemes



Question Number	Answer	Mark
8	The only correct answer is B because $mg = GMm/r^2$ so acceleration of free fall is proportional to mass / diameter ² = $g(M/9)/(D/2)^2 = \frac{9.81 \times 4}{9}$	1



Question Number	Answer	Mark
2	The only correct answer is B <i>A is not correct because gravitational force is equal to centripetal force, so the velocity is independent of the mass of the satellite</i> <i>C is not correct because gravitational force is equal to centripetal force, so the velocity is independent of the mass of the satellite</i> <i>D is not correct because gravitational force is equal to centripetal force, so the velocity is independent of the mass of the satellite</i>	1



Question Number	Acceptable answers	Additional guidance	Mark
12(a)	- use of $F = Gm_1m_2/r^2$ - force = 6.5×10^{31} N	(1) <u>Example of calculation</u> $F = 6.67 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2} \times 29 \times 1.99 \times 10^{30} \text{ kg} \times 36 \times 1.99 \times 10^{30} \text{ kg} / (6.5 \times 10^{10} \text{ m})^2$ force = 6.5×10^{31} N	2
12(b)	Either - use of $F = mv^2/r$ ecf from (a) - use of $v = 2\pi r/T$ $T = 1.1 \times 10^6$ s Or - use of $F = m\omega^2 r$ ecf from (a) - use of $\omega = 2\pi/T$ $T = 1.1 \times 10^6$ s	(1) <u>Example of calculation</u> $F = mv^2/r = m(2\pi r/T)^2/r$ $T^2 = 4\pi^2 mr/F$ $= 4\pi^2 \times 29 \times 1.99 \times 10^{30} \text{ kg} \times 3.6 \times 10^{10} \text{ m} / 6.5 \times 10^{31} \text{ N}$ $= 1.21 \times 10^{12} \text{ s}^2$ $T = 1.12 \times 10^6 \text{ s}$ $= 18700 \text{ min}$ $= 312 \text{ hours}$ $= 13 \text{ days}$ (1) (1) (1)	3

(Total for Question 12 = 5 marks)



Question Number	Acceptable Answer	Additional Guidance	Mark
17(a)(i)	- Use of $V = \frac{4}{3}\pi r^3$ (1) - Use of $\rho = \frac{m}{V}$ (1) $m = 7.76 \times 10^{10}$ (kg) (1)	<u>Example of calculation</u> $V = \frac{4}{3}\pi(245 \text{ m})^3 = 6.16 \times 10^7 \text{ m}^3$ $1.26 \times 10^3 \text{ kg m}^{-3} = \frac{m}{6.16 \times 10^7 \text{ m}^3}$ $m = 1.26 \times 10^3 \text{ kg m}^{-3} \times 6.16 \times 10^7 \text{ m}^3$ $\therefore m = 7.76 \times 10^{10} \text{ kg}$	3
17(a)(ii)	- Use of $F = \frac{Gm_1m_2}{r^2}$ (1) $F = 5.5 \times 10^7 \text{ N}$ (ecf m from (a)(i)) (1)	<u>Example of calculation</u> $F = \frac{6.67 \times 10^{-11} \text{ N}^2 \text{ m}^2 \text{ kg}^{-2} \times 5.98 \times 10^{24} \text{ kg} \times 7.76 \times 10^{10} \text{ kg}}{(7.49 \times 10^8 \text{ m})^2}$ $\therefore F = 5.53 \times 10^7 \text{ N}$	2
17(b)	- Use of $T = \frac{2\pi}{\omega}$ Or use of $v = \frac{2\pi r}{T}$ (1) - Use of $F = m\omega^2 r$ Or Use of $F = \frac{mv^2}{r}$ (1) - Use of $F = \frac{Gm_1m_2}{r^2}$ (1) $M = 2.1 \times 10^{30} \text{ kg}$ (1)	<u>Example of calculation</u> $\omega = \frac{2\pi}{T} = \frac{2\pi \text{ rad}}{1.17 \times 3.15 \times 10^7 \text{ s}} = 1.70 \times 10^{-7} \text{ rad s}^{-1}$ $F = m\omega^2 r = 7.8 \times 10^{10} \text{ kg} \times (1.70 \times 10^{-7} \text{ rad s}^{-1})^2 \times 1.70 \times 10^{11} \text{ m}$ $\therefore F = 3.83 \times 10^8 \text{ N}$ $M = \frac{Fr^2}{Gm} = \frac{3.83 \times 10^8 \text{ N} \times (1.70 \times 10^{11} \text{ m})^2}{6.67 \times 10^{-11} \text{ N}^2 \text{ m}^2 \text{ kg}^{-2} \times 7.8 \times 10^{10} \text{ kg}}$ $\therefore M = 2.14 \times 10^{30} \text{ kg}$	4

(Total for Question 17 = 9 marks)



Question Number	Acceptable answers	Additional guidance	Mark
15(a)(i)	• use of $F = Gm_1m_2/r^2$ and use of $F = mr\omega^2$ Or use of $F = Gm_1m_2/r^2$ and use of $F = mv^2/r$ (1) • use of $T = 2\pi/\omega$ Or use of $T = 2\pi r/v$ (1) • $T = 12$ hours Or $F = 120$ N by gravitational approach and centripetal force approach Or $\omega = 1.45 \times 10^{-4}$ radians s^{-1} by gravitational approach and circular motion approach (1) Or height of orbit = 7700 km • Comparative statement consistent with their value(s) (1)	MP3 and 4 - for force and angular velocity, both approaches required <u>Example of calculation</u> $T^2 = 4\pi^2 r^3 / G m_1$ $T^2 = 4\pi^2 \times (2\,430\,000\text{ m} + 7\,690\,000\text{ m})^3 / 6.67 \times 10^{-11}$ $\text{N m}^2 \text{ kg}^{-2} \times 3.30 \times 10^{23} \text{ kg}$ $T = 43115 \text{ s} = 11.98 \text{ hours}$	4
15(a)(ii)	Max 2 • Allows satellite to get (much) closer to surface (1) • So more detailed photographs/scans possible (1) OR • Allows satellite to spend time further from the surface (1) • So prevents exposure to prolonged heat from planet damaging probe (1) OR • Satellite varies distance from surface (1) • So it can take wide-angle and close-up pictures of the planet (1)	For each, the second marking point is dependent on the first. Award second marking point for other sensible advantages	2



Question Number	Acceptable Answers	Additional Guidance	Mark
15(b)	- Use of $V_{\text{grav}} = -GM/r$ Or Use of $E_p = -GMm/r$ with an assumed mass (1) - Subtraction of potential at surface from potential at orbital height Or Subtraction of potential energy at surface from potential energy at orbital height (1) - Use of difference in potential $= E_K/m = \frac{1}{2} v^2$ Or Use of difference in potential energy $= E_K = \frac{1}{2} mv^2$ (1) $v = 3948 \text{ m s}^{-1}$ (1)	<u>Example of calculation</u> $\Delta V = 6.67 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2} \times 3.30 \times 10^{23} \text{ kg} (1/2.43 \times 10^6 \text{ m} - 1/1.743 \times 10^7 \text{ m}) = 7.795 \times 10^6 \text{ J kg}^{-1}$ $\frac{1}{2} mv^2 = 7.795 \times 10^6 \text{ J kg}^{-1} \times m$ Assume 1 kg $v = 3948 \text{ m s}^{-1}$	4

(Total for Question 15 = 10 marks)



Question Number	Acceptable answers	Additional guidance	Mark
14a	- The frequency/wavelength (of a line in the spectrum) emitted by the star must be measured (1) - Determine the difference between this frequency/wavelength and that emitted in the lab (1) (The Doppler equation is used to) determine the speed of the star (relative to the Earth) $v/c = \Delta f/f_0$ or $v/c = \Delta \lambda/\lambda_0$ (1) - Clear indication (stated in words or via a formula) that v is positive/approaching when the frequency has increased and negative/receding when it has decreased (1) Or corresponding statement about wavelength (1)	MP2 – accept in terms of difference between measured frequency/wavelength with average frequency/wavelength	4
bi	- Use of $\omega = 2\pi/T$ (1) - For at least 2 full cycles (1) $\omega = 6.5 \times 10^{-6}$ (radian s^{-1}) (1)	For MP3, accept correctly rounded answers in range 6.5×10^{-6} radian s^{-1} to 6.6×10^{-6} radian s^{-1} <u>Example of calculation</u> $\omega = 5 \times 2\pi / (56 \times 24 \times 60 \times 60) \text{ s}$ $= 6.49 \times 10^{-6} \text{ radian s}^{-1}$	3
bii	- Equates $F = Gm_1m_2/r^2$ and $F = m\omega^2r$ (1) Or $F = Gm_1m_2/r^2$ and $F = mv^2/r$ with $v = 2\pi r/T$ (1) - Correct rearrangement and substitution (e.g. in $r^3 = Gm_1/\omega^2$) (1) $r = 7.2 \times 10^9$ m (ecf from (b)(i))	<u>Example of calculation</u> $r^3 = 6.67 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2} \times 0.12 \times 1.99 \times 10^{30} \text{ kg} / (6.5 \times 10^{-6} \text{ radian s}^{-1})^2$ $r = 7.2 \times 10^9 \text{ m}$ ($r = 7.6 \times 10^9$ m for ‘show that’ value)	3

(Total for Question 14 = 10 marks)



Question Number	Acceptable answers	Additional guidance	Mark
17 (a)	Use of $F = mv^2 / r$ with $F = Gm_1 m_2 / r^2$ (1) Use of $v = 2\pi r / T$ (1) $T = 6.64 \times 10^8$ s (= 21 years) (1) Or Use of $F = m\omega^2 r$ with $F = Gm_1 m_2 / r^2$ Use of $\omega = 2\pi / T$ $T = 6.64 \times 10^8$ s (= 21 years)	<u>Example of calculation</u> $F = Gm_1 m_2 / r^2 = m_2 v^2 / r = (2\pi r)^2 m_2 / r T^2$ $T^2 = 4\pi^2 r^3 / G m_1$ $= 4\pi^2 \times (1.9 \times 10^{14} \text{ m})^3 /$ $(6.67 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2} \times 9.2 \times 10^{36} \text{ kg})$ $T = 6.64 \times 10^8$ s (= 21 years)	3
17 (b)(i)	- Use of $V = -Gm / r$ (1) - Change in $V = 3.18 \times 10^{13} \text{ (J kg}^{-1}\text{)}$ (1)	<u>Example of calculation</u> $\Delta V = -Gm (1/r_2 - 1/r_1)$ $= -6.67 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2} \times 9.2 \times 10^{36} \text{ kg} \times$ $((1/2.7 \times 10^{14} \text{ m} - 1/1.8 \times 10^{13} \text{ m}))$ $= 3.18 \times 10^{13} \text{ J kg}^{-1}$	2
17 (b)(ii)	- Equate change in gravitational potential energy to change in kinetic energy Or use of $E_p = mV$ (1) - Use of $E_k = \frac{1}{2} mv^2$ (1) $v = 1.4 \times 10^6 \text{ m s}^{-1}$ (1)	<u>Example of calculation</u> $m \times 3.18 \times 10^{13} \text{ J kg}^{-1}$ $= (0.5 \times m \times (8.10 \times 10^6 \text{ m s}^{-1})^2) - (0.5 \times m v_2^2)$ $v_2 = 1.4 \times 10^6 \text{ m s}^{-1}$	3
17(c)	An explanation that makes reference to the following points: - Hubble is for cosmological distances (1) - is not suitable since S2 is in our galaxy (1) - trigonometrical parallax is suitable for local stars because the parallax angles produced are large enough to measure accurately (1)	e.g. to distant galaxies	3
(Total for Question 17 = 11 marks)			



Question Number	Acceptable answers	Additional guidance	Mark
20(a)	- use of $f = 1/T$ (1) - use of $v = f\lambda$ (1) - wavelength = 7.5×10^6 m (1)	MP3: accept variations e.g. 1.75 waves or two wavelengths averaged with correct calculation <u>Example of calculation</u> 2 waves $2T = 0.05$ s $T = 0.025$ s $f = 1/0.025$ s = 40 Hz $\lambda = 3.00 \times 10^8$ m s ⁻¹ ÷ 40 Hz = 7.5×10^6 m	3
20(b)(i)	- use of strain = extension / length (1) - change in length = 4.8×10^{-18} (m) Or max strain for $0.001 \times$ proton size = 2.2×10^{-22} (1) - comparison of their change in length to 8.8×10^{-19} (m) Or comparison of their max strain to 1.2×10^{-21} (1)	<u>Example of calculation</u> Change in length = $1.2 \times 10^{-21} \times 4000$ m = 4.8×10^{-18} m Fraction of proton diameter = 4.8×10^{-18} m ÷ 8.8×10^{-16} m = 0.0055	3
20(b)(ii)	- half wavelength path difference means waves in antiphase (1) - so destructive interference takes place (1) - this results in zero amplitude, (so no signal detected) (1) - a change in length will result in a change in path difference, so signal detected Or a change in length will result in a change in phase difference, so signal detected (1)	Do not accept 'out of phase' for MP1 Accept reference to being 'not out of phase' for MP4	4
20(b)(iii)	- if initially the path difference is zero there will be a maximum signal (1) - a change from max amplitude would represent a much smaller percentage (therefore less sensitive) (1)	MP2 alternative: a change from minimum amplitude would represent a much larger percentage (therefore more sensitive) MP2 Accept 'it is easier to detect the change from no light to light' MP2 Accept suitable reference to uncertainty	2

(Total for Question 20 = 12 marks)



Question Number	Acceptable Answer	Additional Guidance	Mark
6(a)(i)	- Use of $F = \frac{GMm}{r^2}$ with $F = \frac{mv^2}{r}$ (1) - Correct substitutions to calculate r (1) $h = 5.4 \times 10^5 \text{ m}$ (1) OR - Use of $g = \frac{GM}{r^2}$ to find value of g at orbit height (1) - Use of $a = \frac{v^2}{r}$ with value of g at orbit height (1) $h = 5.4 \times 10^5 \text{ m}$ (1)	Example of calculation: $\frac{GMm}{r^2} = \frac{mv^2}{r}$ $r = \frac{GM}{v^2}$ $r = \frac{6.67 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2} \times 5.97 \times 10^{24} \text{ kg}}{(7.59 \times 10^3 \text{ m s}^{-1})^2}$ $r = 6.91 \times 10^6 \text{ m}$ $\therefore h = (6.91 \times 10^6 - 6.37 \times 10^6) \text{ m} = 5.42 \times 10^5 \text{ m}$	3
6(a)(ii)	- Use of $GPE = \frac{GMm}{r}$ (1) $GPE = 5.7 \times 10^{10} \text{ J}$ (ecf from (a)(i)) (1)	Example of calculation: $GPE = GMm \left(\frac{1}{r_1} - \frac{1}{r_2} \right)$ $\therefore GPE = 6.67 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2} \times 5.97 \times 10^{24} \text{ kg}$ $\times 11600 \text{ kg} \left(\frac{1}{6.37 \times 10^6 \text{ m}} - \frac{1}{6.91 \times 10^6 \text{ m}} \right)$ $\therefore GPE = 5.67 \times 10^{10} \text{ J}$	2



6(a)(iii)	- This would bring the gravitational potential energy closer to zero (1) - This would mean that the satellite would orbit at a greater height as $GPE \propto \frac{1}{r}$ (1) - To remain in orbit the centripetal acceleration must equal the gravitational field strength at the orbit height Or Since gravitational force smaller, $\frac{mv^2}{r}$ would be reduced (1) (Hence) r is greater so v must be smaller Or $v^2 = \frac{GM}{r}$ and satellite would orbit at lower speed (1) OR - HST will have more kinetic energy at the original orbit height (1) - The centripetal force will be too small to keep it in this orbit (1) - The satellite would be travelling too fast, so it would move to a higher orbit (1) (Hence) r is greater so v must be smaller Or $v^2 = \frac{GM}{r}$ and satellite would orbit at lower speed (1)		4
6(b)	- Stars emitting infra-red radiation can be detected above the atmosphere Or Some visible wavelengths emitted by stars reduced to 50% intensity or less by the atmosphere (1)	Accept identified wavelength range	1
6(c)	- Gradient of graph determined (1) $v = Hd$, so $t = 1/H = 1/\text{gradient}$ (1) $t = 4.7 \times 10^{17} \text{ s}$ (1)	Example of calculation: $\text{Gradient} = \frac{(44000-1000) \text{ km s}^{-1}}{(2.00-0.00) \times 10^{22} \text{ km}} = 2.15 \times 10^{-18} \text{ s}^{-1}$ $t = \frac{1}{2.15 \times 10^{-18} \text{ s}^{-1}} = 4.65 \times 10^{17} \text{ s}$	3

(Total for Question 6 = 13 marks)



Question Number	Answer	Mark
4	D Both fields act on all particles. Incorrect Answers: A – this is a similarity B – this is a similarity C – this is a similarity	1



9	D	The only correct answer is D : potential is proportional to $1/x$ A is not correct because electric fields do not cause a force on uncharged particles B is not correct because the force caused by gravitational field has only ever been shown to be attractive C is not correct because field strength is inversely proportional to x^2	1
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Question Number	Acceptable answer	Additional guidance	Mark
6	B	The only correct answer is B because the electric field is always positive except at infinity, when it is zero A is not the correct choice because the statement is correct C is not the correct choice because the statement is correct D is not the correct choice because the statement is correct	1



Question Number	Answer	Mark
5	The only correct answer is D <i>A is not correct because gravitational field strength is proportional to $1/r^2$</i> <i>B is not correct because electric field strength is proportional to $1/r^2$</i> <i>C is not correct because gravitational potential is always negative</i>	1

