# Mark scheme – Gravitational Fields

| Question | | | Answer/Indicative content | Marks | Guidance |
|---|---|---|---|---|---|
| 1 | | | Force is proportional to the product of the mass of each asteroid. **and** the force is inversely proportional to the distance squared between the centres of mass of the asteroids. | B1 | |
| | | | **Total** | **1** | |
| 2 | | | $V_{(g)} = -\frac{GM}{r}$ | **B1** | **Examiner's Comments** The expression for gravitational potential was listed on the Data, Formulae and Relationships in the module 5 section and was hence reproduced well by the candidates. The minus sign was required. |
| | | | **Total** | **1** | |
| 3 | | | Arrow acting along line from planet towards sun | B1 | Any arrow length |
| | | | **Total** | **1** | |
| 4 | | | C | 1 | |
| | | | **Total** | **1** | |
| 5 | | | B | 1 | |
| | | | **Total** | **1** | |
| 6 | | | **C** | **1** | **Examiner's Comments** This question requires the candidate to calculate the gravitational potential energy when r = $6.4 \times 10^3$ m and again when r = $7.6 \times 10^3$ m. The difference of those two energies gives answer C. About two thirds of all candidates got this correct. |
| | | | **Total** | **1** | |
| 7 | | | D | 1 | **Examiner's Comments** Near to the surface of the Earth, the gravitational field is approximately uniform. This means that they are parallel and equally spaced. Gravitational field lines in general show the direction of the force on a small mass. This makes all 3 statements are correct, giving the answer D. |
| | | | **Total** | **1** | |

| | | | | | |
|---|---|---|---|---|---|
| 8 | | | B | 1 | |
| | | | **Total** | **1** | |
| 9 | | | C | 1 | |
| | | | **Total** | **1** | |
| 10 | | | GPE is the work done in bringing an object from infinity (to that point) | B1 | **Ignore** any equations |
| | | | **Total** | **1** | |
| 11 | | | B | 1 | |
| | | | **Total** | **1** | |
| 12 | | | B | 1 | |
| | | | **Total** | **1** | |
| 13 | | | **C** | 1 | **Examiner's Comments**<br>This question proved particularly straightforward and accessible to nearly all candidates. |
| | | | **Total** | **1** | |
| 14 | | | C | 1 | |
| | | | **Total** | **1** | |
| 15 | | | **B** | 1 | **Examiner's Comments**<br>Virtually all questions showed a positive discrimination, except for question **10**. The questions themselves require careful inspection, as crucial information that could lead to the exclusion of many options can be obtained reducing the need for calculation and guessing. Underlining or circling key points may help candidates to converge towards the correct responses. Candidates should ensure that all letters are clearly formed. If there is a need to amend an answer crossing through the incorrect answer and writing the correct answer adjacent to the box will help avoid any potential for misunderstanding by the examiner.<br>This question proved particularly straightforward and accessible to nearly all candidates. |
| | | | **Total** | **1** | |
| 16 | | | B | 1 | **Examiner's Comments**<br><br>Answering this question needs knowledge of Kepler's Third Law and the formulae for gravitational potential and gravitational field strength, all of which are given in the data, formulae and relationships booklet.<br><br>This relationship cannot be gravitational potential or gravitational field strength, as quantity y increases with distance from the Sun.<br><br>By equating the gravitational force on a planet with the centripetal force, it can be shown also that (orbital speed)$^2$ and orbital radius are inversely proportional. This graph does not show an inversely proportional relationship. |

| | | | | | |
|---|---|---|---|---|---|
| | | | | | The formula sheet says that the square of a planet's period is directly proportional to the cube of the planet's orbital radius. In other words, the relationship shows that as orbital radius increases, so does the period, but not directly proportionally. This is the relationship shown on the graph, giving answer B. |
| | | | **Total** | **1** | |
| 17 | | | Labelled diagram showing a line joining a planet and the Sun | B1 | |
| | | | Comparing swept areas at different parts of orbit | B1 | |
| | | | **Total** | **2** | |
| 18 | | i | (Stronger) gravitational attraction between nearby galaxies affects motion / clustering of galaxies | B1 | |
| | | ii | Expansion rate may not have been constant / non-linear expansion / effect of dark energy causing accelerating rate of expansion | B1 | |
| | | | **Total** | **2** | |
| 19 | | i | Straight symmetrical radial field lines and correct direction of field | B1 | **Ignore** field lines inside the Earth |
| | | ii | X and Y labelled which should be an equal distance away from the centre of the Earth | B1 | **Note** Judge by eye<br>**Allow** X and Y both on the surface of the Earth |
| | | | **Total** | **2** | |
| 20 | | i | Two circles with centres at CoM with radii in ratio 4 :1 CoM at surface of larger star on line joining stars | B1 | **allow** diameter of m orbit through CoM as 44 ± 10 % for example; full reasonable circles required; ignore arrows; |
| | | ii | Same period/(angular) frequency of stars<br><br>but longer path for smaller star/AW **or** $v = 2\pi R/T$ **or** $v \alpha R$ **or** stars stay at opposite ends of line through CoM | B1<br><br>B1 | any arguments using $F = mv^2/r$ score zero<br><br>**<u>Examiner's Comments</u>**<br><br>Candidates should be encouraged to draw diagrams such as part (i) as accurately as they can. Some had drawing instruments and drew accurate circles. Many drew shapes which were very far from circular, making it difficult in some examples to judge whether the candidate knew the correct path. |

| | | | | | |
|---|---|---|---|---|---|
| | | | | | A secondary purpose of this part was to reinforce the idea that the stars remain diametrically opposite as in part (a) (i). Many did not respond to this trigger having Kepler's laws or centripetal force requirements central in their minds. The rest stated clearly that the orbital period for the two stars had to be the same and consequently were credited both marks. |
| | | | **Total** | **3** | |
| 21 | | | **Similarity**<br>The field strength or force ∝ 1 / separation$^2$ or both produce a radial field. | B1 | |
| | | | **Differences**<br>Gravitational field is linked to mass and electric field is linked to charge. | B1 | |
| | | | Gravitational field is always attractive whereas electric field can be either attractive or repulsive. | B1 | |
| | | | **Total** | **3** | |
| 22 | | i | $T^2 = \frac{4\pi^2}{GM} r^3$ | B1 | |
| | | ii | $86400^2 = (4\pi^2/6.0 \times 10^{24} \times 6.67 \times 10^{-11})\ r^3$ (Any subject)<br><br>radius = $4.23 \times 10^7$ (m) | C1 A1 | **<u>Examiner's Comments</u>**<br><br>The radius of the orbit of a geostationary satellite was found with ease by the majority of candidates by using the formula in the data book or by looking at their response for part 23(b)(i). There were a few ways of generating an arithmetical error, such as using the square root instead of the cube root for the final step, getting the wrong power for the time or by using a time equal to one year instead of one day. |
| | | | **Total** | **3** | |
| 23 | | | Use of $M = gr^2 / G$ (accept any subject) | C1 | Calculation using g = 1.72 at radius of 15300 km<br>Possible ecf from **(b)(i)** |
| | | | Density = $3g / 4\pi rG = 3 \times 9.81/4\pi \times 6.4 \times 10^6 \times 6.67 \times 10^{-11}$ | C1 | Density = $\frac{3 \times 1.72 \times (1.53 \times 10^7)^2}{4\pi \times (6.4 \times 10^6)^3 \times 6.67 \times 10^{-11}}$ |
| | | | = $5.49 \times 10^3$ (kg m$^{-3}$) | A1 | = $5.50 \times 10^3$ kg m$^{-3}$ |
| | | | **Total** | **3** | |
| 24 | | | Grav. potential $V_g$ at a point is defined as the work done to bring 1 kg from infinity to that point in space; | B1 | |

| | | | | | |
|---|---|---|---|---|---|
| | | | (G) force is attractive so the work done is negative (as separation is decreasing); | B1 | **or** work is required to move away from the |
| | | | $V_g$ is given the value zero at infinity so is negative nearer the Earth. | B1 | Earth / AW |
| | | | **Total** | **3** | |
| 25 | a | i | **X** at closest point on orbit to the Sun | B1 | **Allow X** on the orbit to the left of the Sun |
| | | ii | (When the asteroid orbits the sun a) line segment joining the asteroid to the Sun sweeps out equal areas in equal time (intervals)<br>Longer distance (in orbit for the same time) | B1<br>B1 | **Allow** this mark on diagram (no labelling required)<br>**Allow** 'equal area swept in same time' |
| | b | i | Work done per unit mass to move an object from infinity (to that point) | B1 | **Not '** work done on 1 kg' |
| | | ii | Manipulation of $V_{(g)} = (-)\ GM/r$ | B1 | |
| | | iii | gradient = (−)30.4 or equivalent working<br>candidate's gradient or expression = $6.67 \times 10^{-11} \times M$ and M calculated correctly from that gradient<br>$M = 4.6 \times 10^{11}$ (kg) | C1<br>C1<br>A0 | **Allow** ± 2<br>Possible ECF from incorrect gradient<br>**Allow** any subject |
| | c | | **Method 1:**<br>Evidence of $2.3 \times 10^{-3}$ and $600^{-1}$ or $(2.3 \times 10^{-3})^{-1}$ and 600<br>$\frac{1}{2} v^2 = 6.67 \times 10^{-11} \times 4.6 \times 10^{11} \times (2.3 \times 10^{-3} - 600^{-1})$<br>$v = 0.20$ (m s$^{-1}$)<br>**Method 2:**<br>Evidence of $7.0 \times 10^{-2}$ and $5.1 \times 10^{-2}$ from graph | C1<br>C1<br>A1<br>(C1)<br>(C1)<br>(A1) | Possible ECF from **(b)(iii)** for either value of *GM* or *M*<br>**Allow** $\frac{1}{2} v^2 = 30 \times (2.3 \times 10^{-3} - 600^{-1})$<br>**Note** answer can be 0.19 or 0.20 or 0.2 m s$^{-1}$<br>**Note** answer can be 0.19 or 0.20 or 0.2 m s$^{-1}$<br>**Allow** correct use of one piece of data arriving at a value for v for 1 mark max |

| | | | | | |
|---|---|---|---|---|---|
| | | | $\frac{1}{2}v^2$ (= $\Delta V_{(g)}$ ) = 7.0 × $10^{-2}$ − 5.1 × $10^{-2}$<br>$v$ = 0.19 (m $s^{-1}$) | | |
| | | | **Total** | **10** | |
| 26 | | | Appropriate test proposed, e.g. $T^2 / r^3$ = constant $k$ | B1 | |
| | | | Test carried out on **all** three pairs of data | M1 | $k$ = (1.112, 1.109, 1.113) × $10^{-5}$ respectively |
| | | | Conclusion consistent with test result | B1 | |
| | | | **Total** | **3** | |
| 27 | | i | Correct substitution of $T$= 2(.0 s) into $T^2 = \frac{4\pi^2}{g}L$<br><br>length = 0.99 (m) | **C1**<br><br>**A1** | **Note:** 1 (m) here cannot score this A1 mark<br><br>**Examiner's Comments**<br>A large majority of candidates successfully showed that the pendulum length should be 0.99m for a 'tick' length of 1.0 seconds.<br><br>Candidates that attempted the reverse argument, by assuming a length of 1 m and then calculating the corresponding length, were usually unable to show the period of the resulting pendulum was 2.01s. Candidates that showed how to arrive at this period gained full credit. |
| | | ii | Lower $g$ / gravitational field strength / acceleration (of free fall) on Moon.<br><br>$T$ is longer (on Moon) **and** justified by $T^2 = \frac{4\pi^2}{g}L$<br><br>or $T^2 \propto 1/g$ or $\frac{4\pi^2}{g}$ is larger | **B1**<br><br>**B1** | **Accept** 'g is a sixth of g on Earth' AW<br>**Not** gravity (is less)<br><br>**Examiner's Comments**<br>Many candidates suggested that $g$ is less on the Moon than it is on the Earth, gaining one mark of credit. Most candidates suggested that would mean the period of the pendulum would be larger, but did so without justification from the formula in the question or contradicted themselves by stating that would make the pendulum 'run faster'. |
| | | | **Total** | **4** | |
| 28 | | i | $F = GMm/r^2$<br><br>$F = G$ x (2.0 x $10^{41}$)$^2$ / (1.4 x $10^{23}$)$^2$<br><br>force = 1.4 x $10^{26}$ (N) | C1 A1 | **Note** the mark is for substitution, value of G is not required<br><br>**Ignore**: minus sign<br>**Allow** 1 mark for 1.4 x $10^4$ N ;use of mass of star instead of mass of galaxy.<br><br>**Examiner's Comments**<br><br>While some lower level responses included an attempt to find the gravitational field strength rather than the force most selected the correct formula. After |

| | | | | | |
|---|---|---|---|---|---|
| | | | | | selecting the correct relationship, most candidates could then correctly find the force, provided that they remembered to multiply the masses and square the distance of separation. |
| | | ii | density = $10^{11}$ x 2.0 x $10^{30}$/2.7 x $10^{69}$<br><br>density = 7.4 x $10^{-29}$ (kg $m^{-3}$) | M1 A0 | |
| | | iii | Any reasonable answers questioning modelsuch as observed average distance may be different, average mass may be wrong etc. | B1 | **e.g.**<br>black holes, dark energy/matter, expanding universe<br><br>**<u>Examiner's Comments</u>**<br><br>This was a question about challenging the model of the universe. The model takes into account an average mass and average distance of separation, so answers that referred to a variation in masses or distances between galaxies did not score. Higher level responses included that the universe was expanding, so that the distances involved were always changing, or that dark matter was not included in the calculations. There was no indication that candidates were constrained by time in this paper. |
| | | | **Total** | **4** | |
| 29 | | | $g = \frac{G \times 6.31 \times 10^{30}}{(1.90 \times 10^{9})^2}$<br><br>*g* = 117 (N $kg^{-1}$)<br><br>$2 \times \frac{0.14}{1.90} + \frac{0.42}{6.31}$ **or** 0.21 or 21%<br><br>(absolute uncertainty =) 25 (N $kg^{-1}$) | C1<br><br>C1<br><br>C1<br><br>A1 | **Reject** 0.42/($0.14^2$) = 21.4<br><br>**Note:** final answer of *g* = 117 ± 25 (N $kg^{-1}$) with no working scores all 4 marks.<br>**Allow** correct identification of %(r) and %(m) for 1 mark max if no other marks scored.<br>**Allow** alternate method using max/min values of m and r that give the correct absolute uncertainty (28) |
| | | | **Total** | **4** | |
| 30 | a | | Ensure largest possible proportion of flask is immersed. | B1 × 4 | |
| | | | Make volume of tubing small compared to volume of flask. | | |
| | | | Remove heat source and stir water to ensure water at uniform temperature throughout. | | |
| | | | Allow time for heat energy to conduct through glass to air before reading temperature. | | |

| | | | | | |
|---|---|---|---|---|---|
| | b | i | Pressure is caused by collisions of particles with sides. | B1 | |
| | | i | Velocity of particles (and volume of gas) are not zero at 0 °C. | B1 | |
| | | ii | **1:** Gradient of graph 0.75 × $10^2$ / 100 = 0.75 | | |
| | | ii | Number of moles of gas = gradient / R = 0.75 / 8.31 = 0.09 | C1 | Alternative method<br>Internal energy = 3/2 × p × V |
| | | ii | | A1 | |
| | | ii | Mass of gas = 0.09 × 6.02 × $10^{23}$ × 4.7 × $10^{-27}$ = 2.5 × $10^{-4}$ (kg) | | At θ = 100°C pV = 2.73 × $10^2$ |
| | | ii | **2:** Internal energy = 3/2 × NkT | | Internal energy = 1.5 × 2.73 × $10^2$ = 410 (J) |
| | | ii | = 1.5 × 0.09 × 6.02 × $10^{23}$ × 1.38 × $10^{-23}$ × (100 + 273) | C1 | |
| | | ii | = 410 (J) | A1 | |
| | | | **Total** | **10** | |
| 31 | | i | $F = GMm/r^2 = mv^2/r$ | C1 | where r = 6.8 × $10^6$ m |
| | | i | $v = (GM/r)^{1/2} = (g/r)^{1/2}R$ (as $g = GM/R^2$) | C1 | **N.B.** some working must be shown as a |
| | | i | v = 7.7 (km $s^{-1}$). | A1 | *show that* Q |
| | | ii | total energy = $½mv^2 - GMm/r = -GMm/2r$ | M1 | **no ecf from (i); allow** numerical values |
| | | ii | $E = -gR^2m/2r = -1.2(4) \times 10^{13}$ (J) | A1 | with no algebra if clear<br>**no mark for** correct value without the minus sign |
| | | | **Total** | **5** | |
| 32 | | | **Level 3 (5–6 marks)**<br>Clear description **and** correct calculations leading to value of total energy (must include the negative sign)<br><br>*There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and* | B1×6 | **Indicative scientific points may include:**<br><br>**Description**<br><br>• Orbit above the equator / equatorial orbit<br>• Orbit from west to east/same direction of orbit as Earth's rotation<br>• Orbital period is 24 hours / 1 (sidereal) day /23hrs 56mins (4 s)<br>• Orbit is circular / above the same point on the Earth<br><br>**Calculation**<br><br>• $E = (-)\frac{GMm}{r}$ |

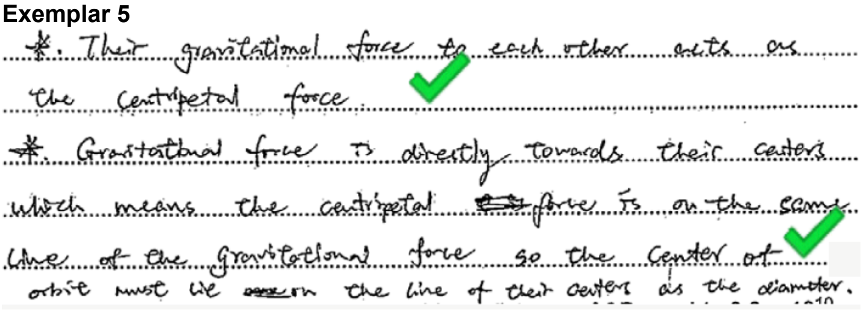
| | | | | | |
|---|---|---|---|---|---|
| | | | *substantiated.*<br><br>**Level 2 (3–4 marks)**<br>Some description and some correct calculations<br>**or**<br>Correct calculations (including the negative sign)<br><br>*There is a line of reasoning presented with some structure. The information presented is in the most-part relevant and supported by some evidence.*<br><br>**Level 1 (1–2 marks)**<br>Limited description<br>**or**<br>Limited calculations<br><br>*The information is basic and communicated in an unstructured way. The information is supported by limited evidence and the relationship to the evidence may not be clear.*<br><br>**0 marks**<br>No response or no response worthy of credit. | | • $E = \frac{6.67\times10^{-11}\times5.97\times10^{24}\times2500}{4.22\times10^{7}}$<br>= (-)2.4 × $10^{10}$ J<br>• $V = \frac{2\pi r}{T}$ $\omega r$<br>• $V = \frac{2\pi\times4.22\times10^{7}}{24\times3600}$ = 3.07 × $10^{3}$ m $s^{-1}$<br>• $E = \frac{1}{2}mv^2$<br>• $E = \frac{1}{2}\times2500\times[3.07\times10^{3}]^2$ = 1.2 × $10^{10}$ J<br>• Total energy = - 2.4 × $10^{10}$ + 1.2 × $10^{10}$ = - 1.2 × $10^{10}$ J<br>• Allow full credit for algebraic proof using $\frac{GMm}{r^2} = \frac{mv^2}{r}$, $E = (-)\frac{GMm}{r}$, $E = \frac{1}{2}mv^2$ and total energy = KE + PE<br><br>Allow higher order answers in terms of Lagrange's Identity<br><br>**Examiner's Comments**<br>This part explored multiple ideas about geostationary orbits. It was accessible to most candidates, many of whom calculated the magnitude of the GPE correctly yet forgot that this value must be negative.<br><br>Almost all candidates forgot that Gravitational Potential Energy is negative. |
| | | | **Total** | **6** | |
| 33 | | i | GPE = (−) G*Mm/r*<br><br>GPE = (−) 6.67 × $10^{-11}$ × 2 × $10^{30}$ × 810/1.5 × $10^{11}$<br><br>GPE = (−) 7.2 × $10^{11}$ (J) | C1<br><br>C1<br><br>A0 | Mark is for full substitution, including 6.67 × $10^{-11}$ for G |
| | | ii | v = 2Π*r/T* = 2Π × 1.5 × $10^{11}$ / 3.16 × $10^{7}$ (= 29.8 km $s^{-1}$)<br><br>KE = ½$mv^2$ = 0.5 × 810 × $(29.8 \times 10^{3})^2$<br><br>KE = 3.6 × $10^{11}$ (J) | C1<br><br>M1<br><br>A1 | **Allow** proof by algebraic method for full marks e.g. $mv^2/r = GMm/r^2$<br><br>so $mv^2 = GMm/r$<br><br>Therefore KE/GPE = ½$mv^2$/($GMm/r$) =½ |

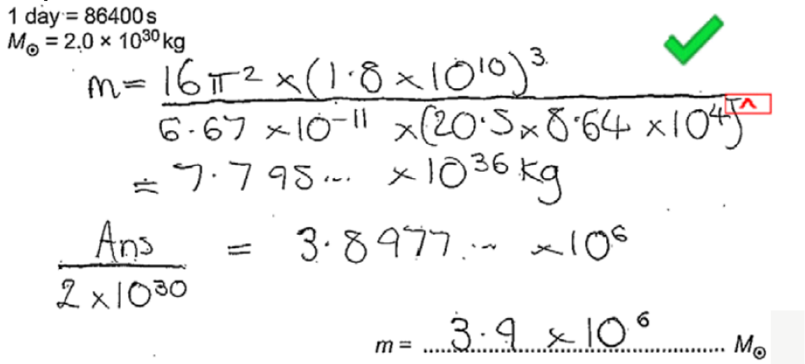
| | | | | | |
|---|---|---|---|---|---|
| | | iii | total energy = (−) (7.2 × $10^{11}$ − 3.6 × $10^{11}$)<br><br>total energy = (−) 3.6 × $10^{11}$ (J) | M1<br><br>A0 | working must be shown; **ECF (i) and (ii)** |
| | | | **Total** | **6** | |
| 34 | a | i | alpha-particle / $^{4}_{2}\mathrm{He}$ / $^{4}_{2}\alpha$ | **B1** | |
| | | ii | nucleon number for Bi = 209<br><br>antineutrino / $^{(0)}_{(0)}\bar{\upsilon}_{(e)}$ | **B1**<br><br>**B1** | **Note**: Do not allow incorrect subscript and superscript |
| | b | i | Aluminium (sheet placed between source and detector)<br><br>The count (rate) reduces<br><br>**or**<br><br>Magnetic / electric field used<br><br>Electrons identified from correct deflection / motion in field | **M1**<br><br>**A1**<br><br>**M1**<br><br>**A1** | **Allow** count (rate) drop to background / zero<br><br>**Allow** 2 marks for 'the range in air is a few m'<br><br>**<u>Examiner's Comments</u>**<br><br>This turned out to be a low-scoring question from candidates across the ability spectrum. Only a quarter of the candidates gained 2 marks for identifying aluminium as the absorber for the beta-minus radiation (electrons) and providing adequate description in terms of reduction in the count-rate. A small number of candidates opted for charged parallel plates and identified the electrons curving towards the positive plate. There were some baffling descriptions involving pointing the source at *'wires and measuring the current'*. Fluorescent screens and cloud chambers were not allowed as acceptable answers because both can be used to detect the presence of gamma-photons and alpha-particles. |
| | | ii | ($\lambda$ =) ln2/3.3 ($h^{-1}$) **or** ($\lambda$ =) 0.21 ($h^{-1}$)<br><br>($A_0$ =) 12 × $10^3$/$e^{-(0.21 \times 7.0)}$ **or** ($A_0$ =) 5.219 × $10^4$ (Bq)<br><br>($N_0$ =) 5.219 × $10^4$/5.835 × $10^{-5}$<br><br>number of nuclei = 8.9 × $10^8$ | C1<br><br>C1<br><br>C1<br><br>A1 | **Allow** credit for alternative methods<br><br>**Note** this is the same as 12 × $10^3$ ÷ $(0.5)^{7.0/3.3}$<br><br>**Note** 9.0 × $10^8$ can score full marks if numbers are rounded<br><br>Possible ECF for incorrect conversion of time |

| | | | | | |
|---|---|---|---|---|---|
| | | | **Or**<br><br>($\lambda$ =) ln2/[3.3 × 3600] ($s^{-1}$)<br>**or** ($\lambda$ =) 5.835 × $10^{-5}$ ($s^{-1}$)<br><br>($N$ =) 1.2 × $10^4$/5.835 × $10^{-5}$ **or** 2.057 × $10^8$<br><br>($N_0$ =) 2.057 × $10^8$/$e^{-(0.21 \times 7.0)}$<br><br>number of nuclei = 8.9 × $10^8$ | **C1**<br><br>**C1**<br><br>**C1**<br><br>**A1** | Note this is the same as 2.057 × 10**8** ÷ $(0.5)^{7.0/3.3}$<br><br>**Examiner's Comments**<br><br>The question was multi-stepped calculation, requiring knowledge of radioactive decay equations, half-time and activity. The final stage of the calculation was dependent on the equation $A = \lambda N$ and working consistently in Bq for the activity and in $s^{-1}$ for the decay constant. The number of nuclei $N$ could not be calculated with the activity in Bq and the decay constant in either $h^{-1}$ or $min^{-1}$.<br><br>About half of the candidates scored full marks. Those working with inconsistent units invariably ended up with the incorrect value 2.5 × $10^5$ nuclei, but this still earned them 2 marks for the preceding steps. |
| | | | **Total** | **9** | |
| 35 | | i | Any sensible suggestion, e.g. Satellites used for global communication, instant access to news, weather forecasting etc. | B1 | |
| | | ii | g = $(6400/15300)^2$ × 9.81 | C1 | |
| | | ii | g = 1.72 (N $kg^{-1}$) | A1 | |
| | | iii | Acceleration towards centre = 1.72 $ms^{-2}$ or centripetal force = mass of satellite × 1.72 N | C1 | ecf (b)(i) |
| | | iii | $T^2$ = 4 × $\pi^2$ × 1.53 × $10^7$ / 1.72 | C1 | |
| | | iii | T = 1.87 × $10^4$ (s) | A1 | Allow 1.9 |
| | | | **Total** | **6** | |
| 36 | | | **Level 3 (5–6 marks)**<br>a structured combination of at least 6 statements taken from A, B and C or A and D<br>a combination of at least 5 statements; script of a lower quality<br>**N.B.** bonus given for any of E at any level<br>*The ideas are well structured providing significant clarity in the communication of the science.*<br><br>**Level 2 (3–4 marks)**<br>a good combination of at least 4 statements taken from A and B or A and C | B1 | **A initial scenario**<br><br>• for circular orbit a centripetal force (of magnitude $mv^2$ / r) is required or AW in terms of accelerations<br>• this is provided by the gravitational force GMm/$r^2$<br>**or** G force just pulls radially inwards sufficiently to maintain orbit<br>• the speed in orbit v = $(GM/r)^{1/2}$<br><br>**B reverse thrust**<br><br>• G force causes rocket to spiral towards Earth when rocket slowed;<br>• rocket speeds up in process<br>• v in orbit is larger when radius r is smaller; condition for faster lower orbit can be achieved<br>**or** T smaller because either v is larger or r / circumference is smaller or both or 2πr/v is smaller<br><br>**C forward thrust** |

| | | | | | |
|---|---|---|---|---|---|
| | | | or B and C or A and D<br>a combination of at least 3 statements taken from two sections which are relevant together.<br>*There is partial structuring of the ideas with communication of the science generally clear.*<br><br>**Level 1 (1–2 marks)**<br>at least 2 statements from A, B, C or D which are relevant together<br>some attempt which is related to the question<br>*The ideas are poorly structured and impede the communication of the science.*<br><br>**Level 0 (0 marks)**<br>Insufficient or relevant science. | | • when rocket speeds up with engines fired forwards G force insufficient to hold orbit so spirals to larger orbit<br>• slowing as it does so<br><br>**D energy approach**<br><br>• some p.e. goes to k.e. when rocket is slowed as it moves towards Earth<br>• so v increases<br>• vice versa when rocket is accelerated<br><br>**E further comments**<br><br>• extra corrections needed to obtain circular orbit after manoeuvre (not mentioned in passage)<br>• any other relevant statement not included above |
| | | | **Total** | **6** | |
| 37 | | i | KE = $\frac{1}{2}mv^2$ **and** GPE = $GMm / r$<br><br>$\frac{1}{2}mv^2 = GMm / r$ then a valid step to<br>$v = \sqrt{(2GM / r)}$ | **C1**<br><br>**A1** | **Allow** *m* = 1 (kg) if clearly defined<br><br>**Examiner's Comments**<br>Examiners were delighted that candidates proved the relationship for escape velocity very clearly indeed with the higher ability candidates correctly suggesting that 'KE<br>+ GPE = 0' was the condition for escape, although 'KE lost = GPE gained' would have been a clear way of reconciling any minus sign confusion.<br><br>A minority of candidates tried, unsuccessfully, to invoke the expression for circular motion inappropriately. |
| | | ii | ($v^2 = 2 \times 6.67 \times 10^{-11} \times 0.131 \times 10^{23} / 1.19 \times 10^6$)<br><br>$v$ = 1200 (m $s^{-1}$) | **A1** | Answer to 3.s.f. is 1210<br><br>**Examiner's Comments**<br>Approximately four-fifths of all candidates calculated the escape velocity on Pluto correctly.<br><br>Those that did not score the mark for this item did so because of improper calculator use or, more rarely, because they selected the wrong data from the question. |

| | | | | | |
|---|---|---|---|---|---|
| | | iii | Mercury has a higher escape velocity than Pluto (ORA)<br><br>Mercury is closer to sun **and** Mercury is hott<u>er</u> (ORA)<br><br>Molecules on Mercury (are more likely to) have **speed** higher than the escape velocity | B1<br><br>M1<br><br>A1 | **Allow** a supporting calculation (speed is about 4.2 km $s^{-1}$)<br><br>**Allow** 'required speed' for 'escape velocity'<br>**Allow** 'fast enough to escape'<br><br>**Examiner's Comments**<br>Candidates found this last item very challenging indeed, with only exceptional candidates gaining two or three marks.<br><br>Many candidates suggested that the reason for Mercury's lack of atmosphere was the superior gravitational pull of the Sun, which is wholly incorrect. Others suggested that the solar wind or 'radiation' had burnt off the atmosphere.<br><br>Rather fewer candidates correctly related Mercury's smaller mean distance to the Sun and its higher temperature or reasoned that Mercury's escape velocity was higher than Pluto's.<br><br>Only a small minority of candidates recognised that even though Mercury has a higher escape velocity, its higher temperature gave the atmosphere's molecules a higher average speed which would have exceeded Mercury's escape velocity. |
| | | | **Total** | **6** | |
| 38 | | i | Horizontal arrow pointing to the right. | B1 | Judgement by eye<br><br>**<u>Examiner's Comments</u>**<br><br>The examiners were quite lenient in this series in terms of the precise direction of the arrow, which should point towards the centre of Mars. |
| | | ii | $2.14 \times 10^3 = \frac{2\times\pi\times9380\times10^3}{T}$<br><br>$T = 2.75 \times 10^4$ (s) | C1<br><br>A1 | **Allow** 2SF answer<br>**Note:** 2.75… × $10^n$ scores 1 mark.<br><br>**<u>Examiner's Comments</u>**<br><br>Around four fifths of candidates got this right. Those that did not either poorly converted the radius from km or used the area rather than the circumference of the orbit. |
| | | iii | $\frac{GMm}{r^2} = \frac{mv^2}{r}$ or $v^2 = \frac{GM}{r}$<br><br>$(2.14 \times 10^3)^2 = 6.67 \times 10^{-11} \times M/9380 \times 10^3$<br><br>$M = 6.44 \times 10^{23}$ (kg) | C1<br><br>C1<br><br>A1 | **Allow** ecf of answer for T from (a)(ii)<br><br>**Allow** 2 SF answer<br>**Note:** Use of 2.8 × $10^4$ seconds gives |

| | | | | | |
|---|---|---|---|---|---|
| | | | | | $6.3 \times 10^{23}$ (kg) for 3 marks.<br><br>**Alternative Method for C1C1**<br><br>• $M = 4\pi^2R^3/(T^2G)$ (Databook formula re–arranged with M as subject)<br>• $M = 4\pi^2(9380 \times 10^3)^3/((2.75 \times 10^4)^2 \times 6.67 \times 10^{-11})$ (i.e. M as subject)<br><br>**Note:** In alternative method, PoT error forgetting km–>m conversion gives $6.46 \times 10^{14}$ (kg) for 2 marks.<br><br>**<u>Examiner's Comments</u>**<br><br>Many candidates successfully used the equation for Kepler's Third Law, which is encouraging. A quicker route was to find the Phobos's acceleration (from $v^2/r$) and equating that to the gravitational field strength at Phobos from Mars ($GM_{mars}/r^2$) and then rearranging to find the mass of Mars. |
| | | | **Total** | **6** | |
| 39 | | i | (For circular orbit) <u>centripetal</u> force provided by <u>gravitational</u> force (of attraction)<br><br>(Gravitational / centripetal) force is along line joining stars which must therefore be diameter of circle (AW) | **M1**<br><br>**A1** | **<u>Examiner's Comments</u>**<br><br>Only a minority of candidates related the gravitational force between the stars to the centripetal force required for circular motion to occur. This candidate has written the perfect answer (exemplar 5).<br><br>There were two popular insufficient answers; that if the stars were not diametrically opposite they would collide and that the centre of mass of the system had to be at the centre of the orbit.<br><br>**Exemplar 5**<br><br>*. Their gravitational force to each other acts as the centripetal force.<br>*. Gravitational force is directly towards their centers which means the centripetal force is on the same line of the gravitational force so the center of orbit must be on the line of their centers as the diameter. |
| | | ii | $T = 20.5 \times 86400$ (= $1.77 \times 10^6$ s) **and** $R = 1.8 \times 10^{10}$ (m)<br><br>$m = 16 \times \pi^2 \times (1.8 \times 10^{10})^3/G \times (20.5 \times 86400)^2$ | **C1**<br><br>**C1**<br><br>**A1** | values of T **and** R scores first mark; **both** incorrect 0/3<br><br>correct substitution allowing $\pi^2$ and G<br>$m = 16 \times 9.87 \times 1.8^3 \times 10^{30}/6.67 \times 10^{-11} \times 1.8^2 \times 10^{12}$<br><br>using 2R gives $35.2 \times 10^{30} = 17.6\ M_{\odot}$ or using T = 1 day gives $1850 \times 10^{30} = 930\ M_{\odot}$ **award** 2/3<br><br>**<u>Examiner's Comments</u>** |

| | | | | | |
|---|---|---|---|---|---|
| | | | giving $m = 4.4 \times 10^{30}$ so<br>$m = 2.2\ M_{\odot}$ | | This question tested the candidates' ability to interpret and substitute data into an elaborate formula and then evaluate it. The most common error was to write the formula with the correct substitutions but then to omit the square symbol against T. Candidates should be encouraged to consider whether their answers are reasonable before moving on to the next question. In the calculation (exemplar 6) shown here, is it possible that these stars could be four million times the mass of the Sun? The correct answer of 2.2 Sun masses seems very plausible and should give candidates confidence.<br><br>**Exemplar 6**<br> |
| | | iii | $v = 2\pi R/T = 2 \times 3.14 \times 1.8 \times 10^{10} / 1.8 \times 10^{6}$ (giving $v = 6.3$ or $6.4 \times 10^{4}$ )<br><br>$\Delta\lambda = (v/c)\lambda = (6.3/3) \times 10^{-4} \times 656 = 0.14$ (nm) | **C1**<br><br>**A1** | **do not** penalise repeated error for R or T<br><br>**ecf** for incorrect v, gives $\Delta\lambda = v \times 2.2 \times 10^{-6}$<br>$\Delta\lambda = 0.28$ for 2R; $\Delta\lambda = 2.9$ for 1 day and $\Delta\lambda = 5.7$ for both incorrect<br><br>**Examiner's Comments**<br><br>Most of the higher performing candidates completed this problem successfully. Two common errors among the remainder were to equate the formula for central force gravitational potential energy *(GMm/r)* to kinetic energy to find a value for the speed of the stars and to rewrite incorrectly metres in powers of 10 in nanometres. |
| | | | **Total** | **7** | |
| 40 | i | | $-mV_g = ½mv^2$ or $½mv^2 + mV_g = 0$ | B1 | |
| | i | | $V_g = -GM/R = -gR$ | B1 | |
| | i | | $v = \sqrt{(2gR)}$ | B1 | Working must be shown |
| | ii | | $v = \sqrt{(2 \times 9.81 \times 6.4 \times 10^{6})} = 11 \times 10^{3}$ m s$^{-1}$ | B1 | allow 11(.2) km s$^{-1}$ |
| | iii | | $½mc^2 = 3/2\ kT$ where $m = (M/N_A) = 6.6 \times 10^{-27}$ kg | B1 | **ecf (ii); allow** m = 4u or $4 \times 1.67 \times 10^{-27}$ |
| | iii | | $T = 6.6 \times 10^{-27} \times 121 \times 10^{6} / 3 \times 1.38 \times 10^{-23}$ | C1 | |
| | iii | | $T = 1.9 \times 10^{4}$ (K) | A1 | **allow** 2 or 2.0 |
| | iv | | 1 random motion and elastic collisions of particles | B1 | **max** 4 out of 5 marking points where answer is a logical progression |

| | | | | | |
|---|---|---|---|---|---|
| | | iv | 2 lead to distribution of kinetic energies/velocities among particles | B1<br>B1 | |
| | | iv | 3 a very few will have very high velocities at top end of distribution<br>4 a long way from mean /r.m.s. velocity at 300 K<br>5 hence some able to escape | B1 | |
| | | v | helium nucleus is an α-particle | B1 | **max** 2 out of 3 marking points |
| | | v | so helium is generated by radioactive decay<br>helium is found in (natural gas) deposits underground | B1 | |
| | | | **Total** | **13** | |