# A Level AQA Physics

## 14 Gravitational fields – answers

OXFORD Revise

| Question | Answers | Extra information | Mark | AO Spec reference |
|---|---|---|---|---|
| **01.1** | $g$ is the (gravitational) force per unit mass | Allow $\frac{F}{m}$ if $F$ and $m$ are explained. | 1 | 3.7.2.2<br>AO1 |
| **01.2** | $\rho = \frac{M}{V}$, $V = \frac{4}{3}\pi r^3$<br>$g = \frac{GM}{r^2} = \frac{G\rho \frac{4}{3}\pi r^3}{r^2} = G\rho\frac{4}{3}\pi r$<br>If density constant, $g \propto r$<br>If $g$ less, then $r$ must be less | | 1<br>1<br>1 | 3.7.2.2<br>AO2 |
| **01.3** | Area under the existing curve shaded in<br>from 2.4 ($\times 10^6$) to the right/infinity | | 1<br>1 | 3.7.2.3<br>AO1 |
| **01.4** | Either by estimating area under curve:<br>220 squares ±5<br>Each square = $0.1 \times 0.4 \times 10^6$ J kg$^{-1}$<br>$V_g = 220 \times 0.1 \times 0.4 \times 10^6$ J kg$^{-1}$<br>$= 8.8 \times 10^6$ J kg$^{-1}$<br>OR<br>Use of surface data to gain $GM$<br>$g = \frac{GM}{r^2}$ and $gr^2 = GM$<br>$V_g = \frac{GM}{r} = \frac{gr^2}{r} = gr = 3.7 \times 2.4 \times 10^6 = 8.9 \times 10^6$ (J kg$^{-1}$) | | 1<br>1 | 3.7.2.3<br>AO2 |
| **01.5** | $\frac{GMm}{r} = \frac{1}{2}mv^2$<br>$\frac{2GM}{r} = v^2$<br>$v^2 = 2 \times 9 \times 10^6$<br>$v = 4200$ m s$^{-1}$ | All values of $V_g$ yield 4200 m s$^{-1}$ to 2 s.f. | 1<br>1 | 3.7.2.4<br>AO2 |
| **01.6** | Straight line drawn from (0, 0) to (2.4, 3.7) | | 1 | 3.7.2.2<br>AO1 |

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| **02.1** | $g = \frac{GM}{r^2}, V_g = \frac{GM}{r}$<br>$V_g = \left(\frac{GM}{r^2}\right) V_g = gR$ | | 1 | 3.7.2.2<br>3.7.2.3<br>AO1 |
| **02.2** | $\frac{GMm}{r} = \frac{1}{2}mv^2$<br>$\frac{GM}{r} = \frac{1}{2}v^2$<br>$gR = \frac{1}{2}v^2$<br>$v = \sqrt{2gR}$ | Algebra must be clear<br>Alternative $mv_g = \frac{1}{2}mv^2$<br>$\therefore v = \sqrt{2V_g} = \sqrt{2gR}$ | 1<br>1 | 3.7.2.4<br>AO2 |
| **02.3** | $v = \sqrt{2gR}$<br>$v = \sqrt{2 \times 9.81 \times 6.37 \times 10^6} = 11\,000\ \text{m s}^{-1}$ (11 200) | | 1 | 3.7.2.4<br>AO1 |
| **02.4** | Mass of hydrogen $= \frac{0.002}{6.02 \times 10^{23}} = 3.32 \times 10^{-27}$ kg<br>$\frac{1}{2}m(c_{rms})^2 = \frac{3}{2}kT$<br>$\left(\frac{m}{3k}\right)(c_{rms})^2 = T$<br>$T = \frac{3.32 \times 10^{-27}\ \text{kg}}{3 \times 1.38 \times 10^{-23}} \times 11\,000^2$<br>$T = 9700$ K (using all unrounded numbers gives 10 000 K) | | 1<br>1<br>1 | 3.6.2.3<br>AO3 |
| **02.5** | Value used in **02.4** uses the mean speed of the molecules<br>At 650 K there will be a range of molecular speeds and some will have enough speed to escape the atmosphere | | 1<br>1 | 3.6.2.3<br>AO3 |
| **03.1** | Gravitational potential $V_g$ at a point is defined as the work done/energy <u>required</u> to bring <u>1 kg/unit</u> mass from infinity to that point in space | | 1 | 3.7.2.3<br>AO1 |

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| 03.2 | If $V \propto \frac{1}{r}$ Then $Vr$ should equal a constant<br>Take pairs of data (at least 2) and see if this is correct | Allow plot of a graph of $V$ vs $\frac{1}{r}$<br>Should be a straight line through the origin | 1<br>1 | 3.7.2.3<br>MS0.3<br>AO2 |
| 03.3 | Tangent drawn at $14 \times 10^6$ m<br>Gradient calculated, e.g., $\frac{58 \times 10^6}{27 \times 10^6}$<br>$g = 2.1 \pm 0.2$ | Allow for 1 mark value calculated using $g = \frac{GM}{r^2}$, which gives value of 2.0 | 1<br>1 | 3.7.2.3<br>AO2 |
| 03.4 | Graph rising as it moves towards the Moon and then decreasing closer to the Moon<br>Starts at –63 and Earth's surface , ends at a value smaller at Moon's surface<br>Does not go to zero | | 1<br>1<br>1 | 3.7.2.3<br>AO3 |
| 04.1 | The potential difference between the lines is constant but the distance is not | | 1 | 3.7.2.3<br>AO2 |
| 04.2 | Lines drawn towards the centre of the Earth perpendicular to surface (by eye) and potential lines<br>Arrow pointing to the centre | Should stop at the surface | 1<br>1 | 3.7.2.2<br>AO1 |
| 04.3 | $V_g = \frac{GM}{r}$<br>$r = \frac{GM}{V_g}$<br>$r = \frac{6.67 \times 10^{-11} \times 5.97 \times 10^{24}\,\text{kg}}{40 \times 10^6} = 1 \times 10^7$ m | | 1<br>1 | 3.7.2.3<br>AO1 |
| 04.4 | gravitation potential remains constant / $\Delta V_g = 0$<br>Since $V_g = \frac{GM}{r}$ and (the mass of the Earth is constant and) the height of orbit is constant | | 1<br>1 | 3.7.2.3<br>AO1 |

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|---|---|---|---|---|
| **05.1** | Arrow down labelled $W$ / $mg$ / weight<br>Arrow along string labelled Tension (pointing away from bob)<br>Arrow to the left labelled Force/gravitational force of attraction | | 1<br>1<br>1 | 3.4.1.5<br>AO1 |
| **05.2** | The force of attraction between two masses is proportional to the product of the masses and inversely proportional to the distance between them squared. | Allow equation but terms must be defined | 1 | 3.7.2.1<br>AO1 |
| **05.3** | $T\cos\theta = \frac{GmM_E}{R^2}$ or $T\sin\theta = \frac{GMm}{d^2}$<br>Divide one equation by the other (or substitute for $T$)<br>$\frac{T\sin\theta}{T\cos\theta} = \frac{\frac{GMm}{d_2}}{\frac{GmM_E}{R_2}}$<br>$\tan\theta = \frac{MR^2}{M_E d^2}$ | Allow force triangle from **05.2** and use of $\tan = \frac{\text{opp}}{\text{adj}}$ | 1<br>1<br>1 | 3.4.1.1<br>AO2 |
| **05.4** | % difference $= \frac{\text{measured} - \text{actual}}{\text{actual}}$<br>$= \frac{4560 - 5510}{5510} \times 100\% = (–)17\%$ | ignore minus sign | 1 | 3.1.2<br>AO2 |

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| Question | Answers | Extra information | Mark | AO Spec reference |
|---|---|---|---|---|
| **06.1** | $F = \frac{GMm}{r^2}$ and $F = \frac{mv^2}{r}$ or $g = \frac{GM}{r^2}$ and $a = \frac{v^2}{r}$<br>$\frac{GMm}{r^2} = \frac{mv^2}{r}$<br>$\frac{GM}{r} = v^2$<br>$v = \frac{2\pi r}{T}$<br>$\frac{GM}{r} = \frac{4\pi^2 r^2}{T^2}$<br>$T^2 = \frac{4\pi^2 r^3}{GM}$<br>Since others constant $T^2 \propto r^3$ | | 1<br><br>1<br><br>1 | 3.7.2.4<br>3.6.1.1<br>AO1 |
| **06.2** | Appropriate test proposed $\frac{T^2}{r^3}$ = constant<br>Data tested at least three times<br>Relationship holds for the moons | See table below | 1<br>1<br>1 | 3.7.2.4<br>AO2 |

Extra information for 06.2:

| Moon | $\frac{T^2}{r^3}$ / $\times 10^{-8}$ days$^2$ Mm$^{-3}$ | $\frac{r^3}{T^2}$ / $\times 10^6$ Mm$^3$ days$^{-2}$ |
|---|---|---|
| Io | 4.164 | 24.02 |
| Europa | 4.174 | 23.96 |
| Ganymede | 4.179 | 23.93 |
| Callisto | 4.172 | 23.97 |

# A Level AQA Physics

## 14 Gravitational fields – answers

| Question | Answers | Extra information | Mark | AO<br>Spec reference |
|---|---|---|---|---|
| **06.3** | $\frac{T^2}{r^3} = \frac{4\pi^2}{GM}$ use of constant in appropriate units or pair of data from the table<br>$\frac{T^2}{r^3} = 3.1 \times 10^{-16}\ \text{s}^2\ \text{m}^{-3}$<br>$M = \frac{4\pi^2}{G \times 3.1\times10^{-16}} = 1.9\times10^{27}\ \text{kg}$ | | 1<br>1 | 3.7.2.4<br>AO3 |
| **06.4** | $T^2 \propto r^3$<br>$2 \log T \propto 3 \log r$<br>$\log t \propto \frac{3}{2} \log r$<br>Straight-line graph with gradient $= \frac{3}{2}$ | | 1<br>1 | 3.7.2.4<br>MS3.11<br>AO3 |
| **07.1** | Arrow pointing towards centre of Earth (judged by eye) | | 1 | 3.7.2.1<br>AO1 |
| **07.2** | To remain in orbit, there must be a force perpendicular to direction of motion<br>This satellite could not maintain this orbit without an engine/other force/ energy input | owtte | 1<br>1 | 3.6.1.1<br>AO1 |
| **07.3** | Use of $r = (36\times10^6 + 6.37\times10^6)$<br>$T = 24 \times 60 \times 60 = 86400\ \text{s}$<br>use of $v = \frac{2\pi r}{T} = 3081\ \text{m s}^{-1} \approx 3\ \text{km s}^{-1}$ | $\frac{GMm}{r^2} = \frac{mv^2}{r}$<br>$\frac{GM}{r} = v^2$<br>$v = \sqrt{\frac{GM}{r}}$<br>$v = \sqrt{\frac{6.67\times10^{-11} \times 5.97\times10^{24}}{36\times10^6 + 6.37\times10^6}}$<br>$v = 3100\ \text{m s}^{-1}$ | 1<br>1<br>1 | 3.6.1.1<br>3.7.2.1<br>AO2 |

# A Level AQA Physics

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| Question | Answers | Extra information | Mark | AO Spec reference |
|---|---|---|---|---|
| **07.4** | Use of $E = E_k + E_p$<br>$E_k = \frac{1}{2}mv^2 = \frac{GMm}{2r}$<br>$E_p = -\frac{GMm}{r}$<br>$E = \frac{GMm}{2r} - \frac{GMm}{r} = -\frac{GMm}{2r}$<br>$E = \frac{6.67\times10^{-11} \times 5.97\times10^{24} \times 282}{2 \times (36\times10^6 + 6.37\times10^6)} = \frac{GMm}{2r}$<br>$E = -1.3\times10^9$ J | Students may also have used $\frac{1}{2}mv^2$ to yield same answer<br><br>Do not award final mark if minus sign not included | 1<br><br>1<br><br>1 | 3.7.2.4<br>AO2 |
| **08.1** | Arrow drawn pointing to centre of the space station | | 1 | 3.6.1.1<br>AO1 |
| **08.2** | $a = \omega^2 r$<br>$\frac{9.81}{25} = \omega^2$<br>$\omega = 0.63$ rad s$^{-1}$<br>$\omega = \frac{2\pi}{T}$<br>$T = \frac{2\pi}{\omega} = 10$ s | | 1<br><br>1 | 3.6.1.1<br>3.7.2.2<br>AO2 |
| **08.3** | Suggested height: 1.8 m (allow between 1.5 m and 2.0 m)<br>$r = 25 - 1.8 = 23.2$ m<br>$a = \omega^2 r$<br>$a = 0.63^2 \times 23.2 = 9.2$ m s$^{-2}$ | | 1<br><br>1 | 3.1.3<br>3.6.1.1<br>AO3 |
| **08.4** | Larger radius means the height of astronaut is a smaller fraction of the radius – so difference over body marginal (or wtte)<br>Difficulty/expense of taking such large amounts of material into space | | 1<br><br>1 | 3.1.2<br>AO3 |

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**Skills box answers**

| Question | Answer |
|---|---|
| **1** | Plot a graph of ln($T$ / days) against ln($r$ / $10^3$ km). Obtain a straight-line graph of gradient 1.5 and intercept −7.9. |
| **2** | $T^2 = \frac{4\pi^2}{GM}r^3$<br>Substituting in values for $G$, $M$ and $r$ gives $T^2 = \frac{4\pi^2\,(3.5 \times 10^8)^3}{6.67\times10^{-11} \times 1.02\times10^{26}}$<br>$T^2 = 2.49\times10^{11}\,s^2$. Therefore $T = \sqrt{(2.49\times10^{11}\,s^2)} = 4.99\times10^5$ s or 5.77 days. |
| **3** | Rearranging the equation for $M$ gives $M = \frac{4\pi^2 r^3}{GT^2}$.<br>Converting the values of $r$ and $T$ into standard form:<br>$r = 2.38\times10^8$ m and $T = (1.37 \times 24 \times 60 \times 60) = 1.18\times10^5$ s.<br>Substituting these into the rearranged equation gives $M = \frac{4\pi^2\,(2.38\times10^8)^3}{6.67\times10^{-11}\,(1.18\times10^5)^2} = 5.7\times10^{26}$ kg |