CAMBRIDGE INTERNATIONAL A LEVEL • PHYSICS 9702

Topical Questions

Unit 13: Gravitation

Past Papers 2021 – 2025

MARK SCHEME 19 Questions

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Question 1 — Mark Scheme

9702/41 Cambridge International AS & A Level – Mark Scheme October/November 2021
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Question	Answer	Marks
2(a)	work done per unit mass	**B1**
	(work done in) moving mass from infinity	**B1**
2(b)(i)	(gravitational) fields from the Earth and Moon are in opposite directions	**B1**
	(resultant is zero where gravitational) fields are equal (in magnitude)	**B1**
2(b)(ii)	$g \propto M / r^2$	**C1**
	$5.98 \times 10^{24} / x^2 = 7.35 \times 10^{22} / (3.84 \times 10^8 - x)^2$ leading to $x = 3.5 \times 10^8$ (m)	**A1**
2(b)(iii)	ϕ (Earth) $= (-)6.67 \times 10^{-11} \times (5.98 \times 10^{24} / 3.5 \times 10^8)$ **and** ϕ (Moon) $= (-)6.67 \times 10^{-11} \times (7.35 \times 10^{22} / 0.38 \times 10^8)$	**C1**
	$\phi = (-)6.67 \times 10^{-11} \times [(5.98 \times 10^{24} / 3.5 \times 10^8) + (7.35 \times 10^{22} / 0.38 \times 10^8)]$	**C1**
	$= -1.3 \times 10^6$ J kg^{-1}	**A1**

Question 2 — Mark Scheme

9702/42 Cambridge International AS & A Level – Mark Scheme October/November 2021
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Question	Answer	Marks
2(a)	(gravitational) field strength equals (gravitational) potential gradient	**M1**
	reference to minus sign	**A1**
2(b)(i)	potential is zero at infinity	**B1**
	(gravitational) force is attractive	**B1**
	(test) mass getting closer (from infinity) loses potential energy	**B1**
2(b)(ii)	• potential at (surface of) planet is smaller than at (surface of) moon • potential gradient at (surface of) planet is smaller than at (surface of) moon • magnitude of potential varies inversely with distance from centre near the spheres • (point of) maximum potential is nearer to moon than planet *Any two points, 1 mark each*	**B2**
2(b)(iii)	sketch: one curve, starting with gradient of decreasing magnitude at $2R$ and finishing with gradient of increasing magnitude at $D - R$	**B1**
	field strength shown as zero (only) near the point of maximum potential	**B1**
	negative field strength near one sphere and positive field strength near the other	**B1**

Question 3 — Mark Scheme

9702/41 Cambridge International AS & A Level – Mark Scheme **PUBLISHED** May/June 2021

Question	Answer	Marks
1(a)	force per unit mass	B1
1(b)	$GMm / r^2 = mr\omega^2$ **and** $\omega = 2\pi/T$ **or** $GMm / r^2 = mv^2 / r$ **and** $v = 2\pi r / T$	C1
	$6.67 \times 10^{-11} \times 6.0 \times 10^{24} = r^3 \times [2\pi / (94 \times 60)]^2$	C1
	$r = 6.9 \times 10^6$ m	A1
1(c)(i)	$r^3\omega^2$ = constant **or** r^3 / T^2 = constant	C1
	$r^3 / (6.9 \times 10^6)^3 = (150 / 94)^2$ so $r = 9.4 \times 10^6$ m	A1
	or	
	$GMT^2/4\pi^2 = r^3$ **and** clear that M is 6.0×10^{24}	(C1)
	$6.67 \times 10^{-11} \times 6.0 \times 10^{24} = r^3 \times [2\pi / (150 \times 60)]^2$ so $r = 9.4 \times 10^6$ m	(A1)
1(c)(ii)	separation increases so (potential energy) increases **or** movement is against gravitational force so (potential energy) increases	B1
1(c)(iii)	potential energy = $(-)GMm / r$	C1
	$\Delta E_P = 6.67 \times 10^{-11} \times 6.0 \times 10^{24} \times 1200 \times [(6.9 \times 10^6)^{-1} - (9.4 \times 10^6)^{-1}]$	C1
	$= 1.9 \times 10^{10}$ J	A1

Question 4 — Mark Scheme

Question	Answer	Marks
1(a)	(gravitational) force per unit mass	**B1**
1(b)(i)	$g = GM / r^2$	**C1**
	$= (6.67 \times 10^{-11} \times 6.42 \times 10^{23}) / (3.39 \times 10^{6})^2$ $= 3.73\ \text{N kg}^{-1}$	**A1**
1(b)(ii)	$a = r\omega^2$ **and** $\omega = 2\pi / T$ **or** $a = v^2 / r$ **and** $v = 2\pi r / T$	**C1**
	$a = 3.39 \times 10^{6} \times (2\pi / (24.6 \times 3600))^2$ $= 0.0171\ \text{m s}^{-2}$	**A1**
1(b)(iii)	force per unit mass $= 3.73 - 0.0171$ $= 3.71\ \text{N kg}^{-1}$	**A1**

Question 5 — Mark Scheme

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Question	Answer	Marks
1(a)	(gravitational) force is (directly) proportional to product of masses	B1
	force (between point masses) is inversely proportional to the square of their separation	B1
1(b)	correct read offs from the graph with correct power of ten for R^3	C1
	$M = \frac{4\times\pi^2\times1.2\times10^{34}}{6.67\times10^{-11}\times2.4\times(365\times24\times3600)^2}$	C1
	$=3.0\times10^{30}$ kg	A1
1(c)(i)	potential energy is zero at infinity	B1
	(gravitational) forces are attractive	B1
	work must be done on the rock to move it to infinity	B1
1(c)(ii)	$\frac{GMm}{r^2}=\frac{mv^2}{r}$ OR $v^2=\frac{GM}{r}$ OR $v=\sqrt{\frac{GM}{r}}$	M1
	use of ½ mv^2 (e.g. multiplication by ½ m) leading to $\frac{GMm}{2r}$	A1
1(c)(iii)	$E_p = \phi m$ and $\phi = \frac{-GM}{r}$ or $E_p = \frac{-GMm}{r}$ Total energy = $E_k + E_p$	C1
	Total energy $= \frac{GMm}{2r}+\frac{-GMm}{r}=\frac{-GMm}{2r}$	A1

Question 6 — Mark Scheme

9702/41 Cambridge International AS & A Level – Mark Scheme **PUBLISHED** May/June 2022

Question	Answer	Marks
1(a)(i)	(gravitational) force is (directly) proportional to product of masses	B1
	force (between point masses) is inversely proportional to the square of their separation	B1
1(a)(ii)	$g = F / m$	C1
	$F = GMm / r^2$ and so $g = [GMm / r^2] / m = GM / r^2$	A1
1(b)(i)	$g = (6.67 \times 10^{-11} \times 7.35 \times 10^{22}) / (1.74 \times 10^6)^2 = 1.62$ N kg^{-1}	A1
1(b)(ii)	fields (due to Earth and the Moon) have equal magnitudes	B1
	fields (due to Earth and the Moon) are in opposite directions	B1
1(b)(iii)	distance of X from Earth = $(3.84 \times 10^8 - x)$	C1
	$(G \times) 7.35 \times 10^{22} / x^2 = (G \times) 5.98 \times 10^{24} / (3.84 \times 10^8 - x)^2$	C1
	$x = 3.8 \times 10^7$ m	A1

Question 7 — Mark Scheme

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Question	Answer	Marks
1(a)(i)	work (done) per unit mass	**B1**
	work (done on mass) in moving mass from infinity (to the point)	**B1**
1(a)(ii)	$E_P = \phi m$ $E_P = (-GM/r) \times m = -GMm/r$ **or** $\phi = -GM/r$ **and** $E_P = \phi m = -GMm/r$	**B1**
1(b)(i)	$\Delta E_P = 6.67 \times 10^{-11} \times 1.99 \times 10^{30} \times 2.20 \times 10^{14} \times [1/(6.38 \times 10^{10}) - 1/(8.44 \times 10^{11})]$	**C1**
	$= 4.23 \times 10^{23}$ J	**A1**
1(b)(ii)	(gravitational) force is attractive so decrease **or** (gravitational) force does work so decrease	**B1**
1(b)(iii)	$\Delta E_P = \frac{1}{2}m(v_2^2 - v_1^2)$	**C1**
	$4.23 \times 10^{23} = \frac{1}{2} \times 2.20 \times 10^{14} \times (v^2 - 34\,100^2)$	**C1**
	v (= 70 800 m s^{-1}) = 70.8 km s^{-1}	**A1**
1(c)	both PE and KE equations include m, so path is unchanged	**B1**

Question 8 — Mark Scheme

9702/42 Cambridge International AS & A Level – Mark Scheme February/March 2022
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Question	Answer	Marks
1(a)	at least 4 straight radial lines to P 	**B1**
	all arrows pointing along the lines towards P	**B1**
1(b)	**Any 2 from:** gravitational force provides the centripetal force (centripetal or gravitational) force has constant magnitude (centripetal or gravitational) force is perpendicular to velocity (of moon) / direction of motion (of moon)	**B2**
1(c)(i)	$\frac{GMm}{r^2} = mr\omega^2$	**M1**
	$M = \frac{r^3\omega^2}{G}$ and gradient = $r^3\omega^2$ hence $M = \frac{\text{gradient}}{G}$ or $r^3 = GM \times 1/\omega^2$ so gradient = GM hence $M = \frac{\text{gradient}}{G}$	**A1**
1(c)(ii)	$M = 4.1 \times 10^{23} / (6.0 \times 10^7 \times 6.67 \times 10^{-11}) = \mathbf{1.0 \times 10^{26}}$ kg	**B1**

Question	Answer	Marks
1(c)(iii)	$\frac{GMm}{r^2}=\frac{mv^2}{r}$ $\frac{GM}{r}=v^2$	**C1**
	$v^2=\frac{6.67\times10^{-11}\times1.0\times10^{26}}{1.2\times10^{8}}$ $v^2=5.6\times10^{7}\ \text{m s}^{-1}$	**C1**
	$v=7500\ \text{m s}^{-1}$	**A1**

Question 9 — Mark Scheme

Question	Answer	Marks
1(a)	$F = (Gm_1m_2) / r^2$	M1
	where G is the gravitational constant	A1
1(b)	gravitational force provides the centripetal force	B1
	$mR\omega^2 = GMm / R^2$ **and** $\omega = 2\pi / T$ **or** $mv^2 / R = GMm / R^2$ **and** $v = 2\pi R / T$ **or** $4\pi^2 mR / T^2 = GMm / R^2$	M1
	correct completion of algebra to get $T^2 = (4\pi^2 / GM) R^3$, with identification of $(4\pi^2 / GM)$ as k	A1
1(c)(i)	$(24 \times 3600)^2 = (4\pi^2 \times R^3) / (6.67 \times 10^{-11} \times 6.0 \times 10^{24})$	C1
	$R = 4.2 \times 10^7$ m	A1
1(c)(ii)	(orbit) must be above the Equator	B1
	(direction) must be from west to east	B1

Question 10 — Mark Scheme

Question	Answer	Marks
1(a)	force per unit mass	**B1**
1(b)(i)	lines drawn are radial from the surface	**B1**
	arrows show pointing towards planet	**B1**
1(b)(ii)	field lines show force (on satellite) is towards centre of planet **or** velocity of satellite is perpendicular to field lines	**B1**
	(gravitational) force perpendicular to velocity causes centripetal acceleration	**B1**
1(c)(i)	$T = 24$ hours	**C1**
	$a = r\omega^2$ **and** $\omega = 2\pi / T$ **or** $a = v^2 / r$ **and** $v = 2\pi r / T$ **or** $a = 4\pi^2 r / T^2$	**C1**
	$a = (4\pi^2 \times 6.4 \times 10^6) / (24 \times 60 \times 60)^2$ $= 0.034\ \text{m s}^{-2}$	**A1**
1(c)(ii)	identification of the two forces acting on the object as gravitational force and (normal) contact force	**M1**
	gravitational force and normal contact force are in opposite directions, and their resultant causes the (centripetal) acceleration	**A1**

Question 11 — Mark Scheme

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Question	Answer	Marks
1(a)(i)	force per unit mass	**B1**
1(a)(ii)	force per unit positive charge	**B1**
1(a)(iii)	similarity: • inversely proportional to distance (from point) • points of equal potential lie on concentric spheres • zero at infinite distance *Any point, 1 mark*	**B1**
	difference: • gravitational potential is (always) negative • electric potential can be positive or negative *Any point, 1 mark*	**B1**
1(b)(i)	$g = GM / r^2$	**M1**
	$E = Q / 4\pi\varepsilon_0 r^2$	**M1**
	algebra showing the elimination of r leading to $M / Q = (1 / 4\pi G\varepsilon_0)(g / E)$	**A1**
1(b)(ii)	$\alpha = 1 / (4\pi \times 6.67 \times 10^{-11} \times 8.85 \times 10^{-12}) = 1.35 \times 10^{20}$ (kg^2 C^{-2}) **or** $\alpha = (8.99 \times 10^9) / (6.67 \times 10^{-11}) = 1.35 \times 10^{20}$ (kg^2 C^{-2})	**A1**
1(c)(i)	$E = \alpha g Q / M$ $= (1.35 \times 10^{20} \times 9.81 \times 4.80 \times 10^5) / (5.98 \times 10^{24})$	**C1**
	$= 106$ N C^{-1} **or** 106 V m^{-1}	**A1**
1(c)(ii)	same (direction)	**B1**

Question 12 — Mark Scheme

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Question	Answer	Marks
1(a)	(gravitational) force is (directly) proportional to product of masses	B1
	force (between point masses) is inversely proportional to the square of their separation	B1
1(b)	$GMm / R^2 = mR\omega^2$	M1
	$\omega = 2\pi / T$ and algebra leading to $4\pi^2R^3 = GMT^2$	A1
	or	
	$GMm / R^2 = mv^2 / R$	(M1)
	$v = 2\pi R / T$ and algebra leading to $4\pi^2R^3 = GMT^2$	(A1)
1(c)	$4\pi^2 \times R^3 = 6.67 \times 10^{-11} \times 5.98 \times 10^{24} \times (24 \times 60 \times 60)^2$ $(R = 4.22 \times 10^7$ m)	C1
	$h = R - (6.37 \times 10^6)$	C1
	$h = (4.22 \times 10^7) - (6.37 \times 10^6)$ $= 3.6 \times 10^7$ m	A1
1(d)(i)	$\omega = 2\pi / T$	C1
	$= 2\pi / (24 \times 60 \times 60)$ $= 7.3 \times 10^{-5}$ rad s^{-1}	A1
1(d)(ii)	orbit is from east to west	B1
	orbit is not equatorial / orbit is polar	B1

Question 13 — Mark Scheme

Question	Answer	Marks
1(a)	work done per unit mass	B1
	work (done on mass) moving mass from infinity (to the point)	B1
1(b)(i)	-3.55×10^7 J kg^{-1}	B1
1(b)(ii)	$\phi = -\frac{GM}{r}$ $M = -\frac{-3.55\times10^7\times4800000}{6.67\times10^{-11}}$ $= 2.55 \times 10^{24}$ kg	B1
1(b)(iii)	$g = \frac{GM}{r^2}$ **or** $g = -\frac{\phi}{r}$	C1
	$= \frac{6.67\times10^{-11}\times2.55\times10^{24}}{4800000^2}$ **or** $= \frac{3.55\times10^7}{4800000}$ $= 7.4$ N kg^{-1}	A1
1(b)(iv)	r in range 2.60×10^7 to 2.65×10^7 m	C1
	$\frac{mv^2}{r} = \frac{GMm}{r^2}$ **and** $v = \frac{2\pi r}{T}$ **or** $mr\omega^2 = \frac{GMm}{r^2}$ **and** $\omega = \frac{2\pi}{T}$	C1
	$T^2 = \frac{4\pi^2 r^3}{GM} = \frac{4\pi^2\times(2.65\times10^7)^3}{6.67\times10^{-11}\times2.55\times10^{24}} = 4.20 \times 10^9$	C1
	$T = 64\,800$ s $= 18$ hours	A1

Question	Answer	Marks
1(c)	similarity – any one point from • inversely proportional to distance (from point) • points of equal potential lie on concentric spheres • zero at infinite distance	**B1**
	difference – any one point from • gravitational potential is (always) negative • electric potential can be positive or negative	**B1**

Question 14 — Mark Scheme

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Question	Answer	Marks
1(a)(i)	direction of the force acting on a (test) mass placed at the point	**B1**
1(a)(ii)	change in height negligible compared with radius (of Earth)	**B1**
	(so) field lines are (effectively) parallel	**B1**
1(b)(i)	$Y = GM / R^2$	**M1**
	G is the gravitational constant	**A1**
1(b)(ii)	gravitational force is (always) attractive **or** gravitational force (always) acts towards the centre of the sphere	**B1**
	force is in opposite direction to displacement **or** at a point to the right of the centre, force acts to the left **or** at a point to the left of the centre, force acts to the right	**B1**
1(b)(iii)	sketch: smooth curve with decreasing positive gradient, starting at (R, $-Y$) and reaching $3R$ with g still negative **or** smooth curve with increasing positive gradient, ending at ($-R$, Y) and reaching $-3R$ with g still positive	**B1**
	both of the above curves, in correct quadrants	**B1**
	curve passing through ($\pm 2R$, $\pm 0.25Y$) and ($\pm 3R$, $\pm 0.11Y$)	**B1**

Question 15 — Mark Scheme

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Question	Answer	Marks
2(a)(i)	work done per unit mass	B1
	work (done) moving mass from infinity (to the point)	B1
2(a)(ii)	$\phi = -GM/r$ $= -(6.67 \times 10^{-11} \times 7.3 \times 10^{22})/(1.7 \times 10^{6})$	C1
	$= -2.9 \times 10^{6}$ J kg^{-1}	A1
2(b)(i)	$E_P = m\phi$	B1
2(b)(ii)	$\frac{1}{2}mv^2 + m\phi = 0$	M1
	correct algebra leading to $v = \sqrt{(-2\phi)}$	A1
2(c)	speed $= \sqrt{(2 \times 2.9 \times 10^{6})}$ $= 2400$ m s^{-1}	A1
2(d)	$\frac{1}{2}m\langle c^2\rangle = (3/2)kT$	C1
	$3.34 \times 10^{-27} \times \langle c^2\rangle = 3 \times 1.38 \times 10^{-23} \times 400$	C1
	$c_{r.m.s.} = 2200$ m s^{-1}	A1
2(e)	r.m.s. speed is an average so many molecules have speeds greater than the escape speed **or** there is a distribution of molecular speeds (around the r.m.s. value) so many molecules have speeds greater than the escape speed	B1

Question 16 — Mark Scheme

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Question	Answer	Marks
1(a)	work done per unit mass	**B1**
	work done moving mass from infinity (to the point)	**B1**
1(b)(i)	potential is zero at infinity	**B1**
	work is done **by** (two) masses in moving them **closer** together **or** work is done **on** (two) masses in moving them **apart**	**B1**
1(b)(ii)	magnitude of potential shown as 4Φ	**B1**
	potential negative **and** shown as a multiple of $-\Phi$ [potential = -4Φ if fully correct]	**B1**
1(b)(iii)	field strength at X: $\Phi / 4R$	**A1**
	field strength at Y: $4\Phi / R$	**A1**
	potential energy at X: $-M\Phi$	**A1**
	potential energy at Y: $-8M\Phi$	**A1**

Question 17 — Mark Scheme

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Question	Answer	Marks
1(a)	(gravitational) potential is zero at infinity (gravitational force between two masses is attractive so)	B1
	either work is done on a mass to move it away from another mass **or** work is done on a mass to move it to infinity	B1
1(b)(i)	M = (–) gradient / G	C1
	e.g. $M = (1.76 \times 10^{8}) / (3.0 \times 10^{-8} \times 6.67 \times 10^{-11}) = 8.8 \times 10^{25}$ kg	A1
1(b)(ii)	**either** $GMm / r^2 = mr\omega^2$ **and** $\omega = 2\pi / T$ **or** $GMm / r^2 = mv^2 / r$ **and** $v = 2\pi r / T$ **or** $GMm / r^2 = 4\pi^2 mr / T^2$	C1
	$R^3 = 6.67 \times 10^{-11} \times 8.8 \times 10^{25} \times (0.72 \times 24 \times 60 \times 60)^2 / 4\pi^2$	C1
	$R = 8.3 \times 10^{7}$ m	A1
1(b)(iii)	$\Delta E = (GMm / r) - \frac{1}{2}mv^2$ kinetic energy = $(\frac{1}{2} \times 1200 \times 8400^2)$	C1
	potential energy = $(-)[(6.67 \times 10^{-11} \times 8.8 \times 10^{25} \times 1200) / (8.3 \times 10^{7})]$	C1
	$\Delta E = [(6.67 \times 10^{-11} \times 8.8 \times 10^{25} \times 1200) / (8.3 \times 10^{7})] - (\frac{1}{2} \times 1200 \times 8400^2)$ $= 4.3 \times 10^{10}$ J	A1

Question 18 — Mark Scheme

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Question	Answer	Marks
1(a)	(gravitational) force is (directly) proportional to product of masses	B1
	force (between point masses) is inversely proportional to the square of their separation	B1
1(b)(i)	(gravitational) force acts perpendicular to direction of motion	B1
	gravitational force provides centripetal acceleration	B1
1(b)(ii)	$(F =)\ GMm / x^2 = mx\omega^2$ **and** $\omega = 2\pi / T$ **or** $GMm / x^2 = 4\pi^2 mx / T^2$	M1
	completion of algebra leading to $x^3 = GMT^2 / 4\pi^2$	A1
	clear indication that B = radius of planet **and** that A = mass (of planet)	B1
1(b)(iii)	gradient = $\sqrt[3]{(4\pi^2 / GA)}$	C1
	e.g. $(1280 - 360) / (12 \times 10^6) = \sqrt[3]{(4\pi^2 / [6.67 \times 10^{-11} \times A])}$	C1
	$A = 1.3 \times 10^{24}$ kg	A1
	intercept = gradient × B	C1
	e.g. $360 = ((1280 - 360) \times B) / (12 \times 10^6)$ $B = 4.7 \times 10^6$ m	A1

Question 19 — Mark Scheme

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Question	Answer	Marks
1(a)(i)	$v = r\omega$	C1
	$= 0.85 \times 140$ $= 120\ \text{m s}^{-1}$	A1
1(a)(ii)	$a = r\omega^2$ **or** $a = v^2 / r$	C1
	$a = 0.85 \times 140^2$ **or** $120^2 / 0.85$ $= 1.7 \times 10^4\ \text{m s}^{-2}$	A1
1(b)(i)	direction of (induced) e.m.f.	M1
	is such as to (produce effects that) oppose the change that caused it	A1
1(b)(ii)	$T = 2\pi / \omega$ $= 2\pi / 140 = 0.045\ \text{s} = 45\ \text{ms}$	A1
1(b)(iii)	$\Phi = BA$	C1
	$= 0.18 \times \pi \times 0.85^2$	C1
	$= 0.41\ \text{Wb}$	A1
1(b)(iv)	$E = \Phi / t$	C1
	$= 0.41 / 0.045$ $= 9.1\ \text{V}$	A1
1(b)(v)	force (on spoke) must be anticlockwise, so current is from A to X (by Fleming's left hand rule), so X is at the higher potential	B1

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