

Total 43 marks.

Each marking point ends with ✓ and is worth one mark. Words in « » are not needed for the mark. A correct numerical answer with no working is awarded full marks unless the Notes say otherwise. ECF = error carried forward: award the mark if the candidate used their own wrong earlier answer correctly. Do not penalize errors in units or significant figures unless the Notes say so.

Question 1: A planet and its moon

Part	Answers	Notes	Total
1(a)	force per unit mass ✓ acting on / experienced by a small / test / point mass «placed at that point» ✓		2
1(b)	$g = GM/R^2$ seen ✓ $g = 6.67 \times 10^{-11} \times 4.8 \times 10^{24} / (5.0 \times 10^6)^2 = 12.8 \text{ «N kg}^{-1}\text{»}$ ✓	Answer to at least 2 significant figures must be seen.	2
1(c)	$g = 6.67 \times 10^{-11} \times 4.8 \times 10^{24} / (2.7 \times 10^8)^2 = 4.4 \times 10^{-3} \text{ «N kg}^{-1}\text{»}$ ✓		1
1(d)	$GM/x^2 = Gm/(d - x)^2$ «equating the two field strengths» ✓ $x/(d - x) = \sqrt{(M/m)} = \sqrt{80} = 8.9$ ✓ $x = 2.4\text{e}+08 \text{ «m»}$ ✓		3
1(e)	Kalos «and the moon» is spherical / of uniform density ✓ the separation is much larger than the sizes of the bodies ✓		2

Question 2: Orbits around Kalos

Part	Answers	Notes	Total
2(a)	clear evidence that the centripetal force is equated to the gravitational force: $GMm/r^2 = mv^2/r$ «or $m\omega^2 r$ » ✓ $v = 2\pi r/T$ «or $\omega = 2\pi/T$ » substituted and rearranged to give the result ✓	Do not allow confused algebra or methods using equations of simple harmonic motion.	2
2(b)	$r = 6.0 \times 10^6 \text{ «m»}$ ✓ $v = \sqrt{GM/r} = 7.3\text{e}+03 \text{ «m s}^{-1}\text{»}$ ✓	Award [1 max] for an answer that ignores the height above the surface.	2
2(c)	$T = 2\pi r/v = 5.2\text{e}+03 \text{ «s»}$ ✓	Allow ECF from (b).	1
2(d)	$T = 7.2 \times 10^4 \text{ «s»}$ ✓ $r = (GMT^2/4\pi^2)^{(1/3)} = 3.5\text{e}+07 \text{ «m»}$ ✓		2
2(e)	$T = 2\pi\sqrt{(r^3/GM)} = 1.56 \times 10^6 \text{ «s»}$ ✓ $= 18 \text{ «days»}$ ✓		2

2(f)	the astronaut and the satellite fall freely «towards Kalos» with the same acceleration ✓ so the floor exerts no (normal / contact) force on the astronaut «the gravitational force still acts» ✓		2
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Question 3: The potential of Kalos

Part	Answers	Notes	Total
3(a)	work done per unit mass ✓ in bringing a small mass from infinity to that point ✓	Allow “energy” for “work done”.	2
3(b)	the potential is defined to be zero at infinity ✓ the force is attractive, so positive work must be done «energy supplied» to move a mass to infinity ✓	Award [0] for “because the field points inwards”.	2
3(c)	$\Delta V = -1.6 \times 10^7 - (-6.4 \times 10^7) = 4.8 \times 10^7 \text{ «J kg}^{-1}\text{»}$ read from the graph ✓ $W = m\Delta V = 2.4 \times 10^{10} \text{ «J»}$ ✓	Accept values read from the graph within $\pm 0.1 \times 10^7 \text{ J kg}^{-1}$.	2
3(d)	tangent drawn at $r = 1.0 \times 10^7 \text{ m}$ / $g = -\Delta V/\Delta r$ used ✓ $g = 3.2 \text{ «N kg}^{-1}\text{»}$ «accept 2.8 to 3.6» ✓	A calculation using GM/r^2 without the graph scores [1 max].	2
3(e)	zero ✓ the field strength is minus the gradient of the V-r graph « $g = -\Delta V/\Delta r$ » and the gradient is zero at the maximum ✓		2

Question 4: Energy and escape

Part	Answers	Notes	Total
4(a)	total energy at the surface is zero «to just reach infinity» / KE gained = PE lost: $\frac{1}{2}mv^2 - GMm/R = 0$ ✓ rearranges to $v = \sqrt{2GM/R}$ ✓	Award [0] for answers that equate forces ($mv^2/r = GMm/r^2$) and then add a factor of 2.	2
4(b)	$v = 1.13 \times 10^4 \text{ «m s}^{-1}\text{»}$ ✓		1
4(c)	$E_T = E_k + E_p = GMm/2r - GMm/r = -GMm/2r$ ✓ $E_T = -6.67 \times 10^{-11} \times 4.8 \times 10^{24} \times 900 / (2 \times 8.0 \times 10^6) = -1.80 \times 10^{10} \text{ «J»}$ ✓		2
4(d)	new $E_T = -9.0 \times 10^9 \text{ «J»}$ ✓ energy needed = $9.0 \times 10^9 \text{ «J»}$ ✓	Allow ECF from (c).	2
4(e)	the total energy «of the satellite» decreases ✓ so the orbit radius decreases « $E_T = -GMm/2r$ » ✓ the speed increases « $v = \sqrt{GM/r}$ » ✓	Do not allow “kinetic energy reduces” for the first marking point.	3
4(f)	initial $E_k = 0.64 \times GMm/R$, so total energy = $-0.36 GMm/R$ ✓ $r_{\text{max}} = R/0.36 = 1.4 \times 10^7 \text{ «m»}$ ✓		2