Question			Expected Answers	Additional guidance	Marks
1	(a)		Sun at centre		1
	(b)		Phases of Venus/Venus changes size or shape - Venus orbits Sun or not Earth Moons of Jupiter - orbit Jupiter or not Earth	Or other valid point and explanation: **NOT** mountains on Moon, sunspots, stars in milky way, telescope	1 1 1 1
2	(a)	(i)	When X and Y separate – max brightness Y in front of X Y behind X Different size dips due to different brightnesses	Give 1 for idea of dips corresponding to one star passing in front of other Any 3 from 4	1 1 1
		(ii)	1 - small/big dip 2 - between dips 3 - lhs shoulder of big/small dip 4 - rhs shoulder of big/small dip	**Allow any consistent solution**	1 1 1
	(b)	(i)	-46, 121, 176, 68, -103, -178, -88, 84, 178, 107, -64, -175, -124	(-1 each error)	2
		(ii)	13 points correctly plotted to define cycle of sine wave all points must be on the lines for time, and ± ½ division for the vertical axis some attempt at a smooth curve	Only one mark for 12 points Ecf	2 1
		(iii)	Period = 12.5 ± 0.5 hour 43000 < T < 47000 s		1 1
		(iv)	v_{max} = 178-185 km s^{-1} $a = v_{max}T/2\pi 179 \times 10^3 \times 45000 /2\pi$ = 1.28 x 10^9 m($1.2 \times 10^9 < a < 1.4 \times 10^9$)		1 1 1
		(v)	$M = 4\pi^2 \times (1.28 \times 10^9)^3/(6.67 \times 10^{-11} \times 45000^2)$ = 6.1 x 10^{29} kg $4.9 \times 10^{29} < M < 8.4 \times 10^{29}$	Allow ecf for *a* and *T*	1 1
		(vi)	(B is more massive) Because it moves more slowly.		1

3	(a)		(Obtain) spectrum Identify lines due to different elements Alternative response: Allow full credit for argument that 1st generation stars contain only H/He, subsequent generations contain heavier elements		1 1
	(b)	(i)	Change in position/apparent motion when viewpoint is changed		1 1
		(ii)	Distance at which the radius of the Earth's orbit subtends an angle of 1 arcsec		1 1
	(c)		$m - M = 5 \lg(d/10)$ $d = 4.3 \times 10^{17} / 3 \times 10^{16} = 14.3$ pc $M = 0.1 - 5 \lg(14.3/10) = -0.68$ $-0.47 < M < -0.68$ (from allowed range of m → pc conversion)		1 1 1
4	(a)		MS - diagonal top left to lower right Red giants - above MS White dwarfs - below MS Sun - in lower half of MS Track - MS→ red giant		1 1 1 1 1
	(b)		low mass star ($< 3 M_o$) Red giant Planetary nebula or description Mass of remnant < Chandrasekhar limit OR too small to form neutron star OR Fermi pressure		1 1 1 1
5	(a)		description of CMB (~3 K, blackbody, uniform, isotropic) universe much hotter in the past/has cooled Hubble law/expanding universe/galaxy redshift beginning in finite past/implies cooling **OR** Helium abundance He formed in hot BB	Or valid alternative	1 1 1 1
	(b)	(i)	Collapse → explosion	Or other detail eg neutron star or Black hole formation	1 1
		(ii)	Universe contains insufficient mass to halt expansion, Expansion continues forever	Density < critical density	1 1
		(iii)	Increase		1

6	(a)	(i)	The same for all observers/unchanging		1
		(ii)	Laws of physics same/invariant for all (inertial) observers/frames of reference		1
	(b)		• Observer A at rest at midpoint of tunnel • Observer B on train moving (at const velocity) • Train same length as tunnel according to stationary observer A (who sees lights flash simultaneously) • Train longer than tunnel according to observer B on train (who sees flashes at different times) • Explanation of what length contraction is • Any other valid point eg symmetry, c is constant, explanation of how lights come on	Any 5 Allow argument based on time dilation	5
	(c)		$\gamma = 1/\sqrt{(1-v^2/c^2)} = 1.67$ or $\sqrt{(1-v^2/c^2)} = 0.6$ $l = l_o/\gamma$ or equivalent = 20.0/1.67 = 12.0 m		1 1 1
7	(a)	(i)	Reluctance to change motion (as in $F = ma$) m = F/a	Link to inertia	1
		(ii)	Source of the gravitational field m = W/g	Link to gravity	1
	(b)		Drop a particle of mass *m* through a height h so its total energy increases by *mgh*. Convert mass to a photon and send back to start point. $mc^2 = hf$ Convert photon back to a particle of mass $m' > m$! Perpetual motion? Frequency *f* of photon must have decreased as it moved up through the gravitational field - the photon's 'clock' is going slower. **OR** ---------- • Observer in accelerating spacecraft • with front and rear clocks • Each pulse from front clock arrives before pulse from rear clock • Rear clock appears to be slower than front clock • gravity equivalent to acceleration (=EP) • so clocks run slower in gravity fields	allow valid alternatives NOT: Twins paradox, airborne atomic clocks 5 from 6	1 1 1 1 1 1 1 1 1 1 1
	(c)		Stronger gravity at Greenwich will cause more gravitational time dilation that at Boulder. OR cause it to run more slowly		1 1

8	(a)		Quieter Less pollution/more environmentally friendly	Or other valid point, eg petrol supplies finite, safety(batteries less of fire hazard), can utilise renewable energy	2
	(b)		$P = VI$ 750 Wh = 750/12 = 62.5 Ah	0/3 for wrong ans no working 0.75/12=0.0625 (2/3) 3/3 for correct ans.	1 1 1
	(c)	(i)	No. of batteries = 960/16 = 60 No of kWh = 0.75 x 60 = 45 kWh = 45 x 1000 x 3600 =162 MJ	-1 for each error 1.62×10^8 MJ (2/3)	1 1 1
		(ii)	Work done = Fd D = 162 x 10^6/300 = 540 km	Allow 1sf if working shown	1 1 1
	(d)	(i)	Mass of petrol = 162/50 kg = 3.24 kg Volume = m/ρ (stated or implied) =3.24/700 = 4.6 x10^{-3} m^3	Ecf Or equivalent	1 1 1 1
		(ii)	Energy lost/not 100% efficient As heat etc.	General comment + detail	1 1
	(e)		Compare :- • mass, • size, • likely performance of petrol vs batteries, • sensible statement about range Concluding comment	Any 3 from 4	3