

1

Question	Answers	Marks	Guidance
(a)	The universe is homogeneous and isotropic (on a large scale).	B1 B1	
(b)	The <u>intensity</u> of the microwaves is the same in all directions. These microwaves correspond to a temperature of 2.7 K or The temperature of the universe is 2.7 K. The expansion of the universe following the big bang led to cooling and hence we observe microwaves rather than short wavelength e.m. waves / gamma waves.	B1 B1 B1	Allow the microwave (background radiation) is <u>isotropic</u> . Allow 3 K Allow - The short e.m. / gamma waves during the early stages of the universe have been 'stretched out' / 'red-shifted' to microwaves by the expansion.

2)

Question	Answer	Marks	Guidance
(a)	The night sky should be bright / have uniform brightness (but it is not) The line of sight ends on (the surface of a star) or 'number of stars $\propto r^2$ and intensity $\propto 1/r^2$ ' Any <u>two</u> assumptions about the Universe: Infinite / uniformly distributed matter or stars throughout / static / infinite age	B1 B1 B1	
(b)	(recessional) speed of <u>galaxy</u> \propto its distance (from the Earth) The universe is finite / it is expanding / it has a beginning / visible light is red-shifted (because of expansion of space) (AW)	B1 B1	Allow: $v = H_0 x$, v = (recessional) speed of galaxy, x = distance and H_0 is Hubble constant / a constant
(c) (i)	$v = H_0 x$ $3.4 \times 10^7 = H_0 \times 1.4 \times 10^{25}$ $H_0 = 2.4 \times 10^{-18}$ unit: s^{-1}	C1 A1 B1	Note: This is an independent mark Note: Allow full credit for an Hubble constant of 75 with unit $km\ s^{-1}\ Mpc^{-1}$
(ii)1	$age = \frac{1}{2.4 \times 10^{-18}}$ $age = 4.17 \times 10^{17}$ (s) $age = 1.3 \times 10^{10}$ (years)	C1 A1	Possible ecf from (i)
(ii)2	distance = $4.17 \times 10^{17} \times 3.0 \times 10^8$ ($= 1.25 \times 10^{26}$ m) distance = $\frac{4.17 \times 10^{17} \times 3.0 \times 10^8}{3.1 \times 10^{16}}$ distance = 4.0×10^9 (pc)	C1 A1	Possible ecf from (ii)1
	Total	12	

3)

Question	Answer	Marks	Guidance
(a)	A core / 'star' left behind after a red giant (has shed its outer layers)	B1	Allow: It is the core of a red giant Allow: It is the remnant of a low-mass star Allow: A core / 'star' <ul style="list-style-type: none"> supported by Fermi pressure / electron degeneracy (pressure) with maximum mass of 1.4(4) solar masses / 1.4(4) M_{\odot} / Chandrasekhar limit Not: It is a collapsing red giant
(b)	(parallax = $1/d$) $d = 0.0059^{-1}$ (pc = 169.49 pc) distance = $0.0059^{-1} \times 3.26$ distance = 550 ly	C1 A1	Allow other correct methods
(c) (i)	power per (unit) area or power/area	B1	Allow 'energy per (unit) area per unit time' Not: power per m^2
(ii)	1 (density = $\text{mass} / \frac{4}{3}\pi r^3 \propto \text{mass}/r^3$) ratio = $\frac{12}{(1.1 \times 10^5)^3}$ ratio = 9.0×10^{-15} 2 (power = intensity \times surface area) power $\propto T^4 r^2$ ratio = $\frac{4300^4 \times (1.1 \times 10^5)^2}{25000^4}$ ratio = 1.1×10^7	C1 A1 C1 C1 A1	Allow: $9.0 \times 10^{-15} : 1$ Allow: 1 sf answer of 9×10^{-15} Note: Answer to 3 sf is 1.06×10^7 Allow: $1.1 \times 10^7 : 1$
Total		9	

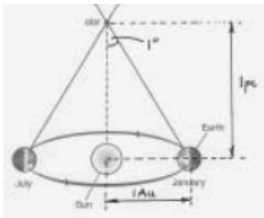
4)

Question	Answer	Marks	Guidance
(a)	recessional speed / velocity of <u>galaxy</u> is proportional to its distance (from us)	B1	Allow: recessional speed of <u>galaxy</u> = Hubble constant \times distance
(b) (i)	$v = 1010$ (10^3 m s^{-1}) d in the range 4.47 to 4.54 (10^{23} m)	B1 B1	Note: Answer to 4 sf is 1014 (10^3 m s^{-1})
(ii)	(Straight line drawn through the points gradient = Hubble constant, H_0) gradient = $2.24 \times 10^{-18} \text{ (s}^{-1}\text{)}$ age = $(2.24 \times 10^{-18})^{-1}$ age = $4.46 \times 10^{17} \text{ (s)}$ age = $1.4 \times 10^{10} \text{ (y)}$	C1 C1 A1	Allow: gradient in the range 2.21 to 2.27×10^{-18} Allow ecf from incorrect value of the gradient Allow: A maximum of 2 marks if values from the table are used instead of the gradient of the line drawn on Fig. 11.2 Note: No marks for a bald 14 billion years
(c)	Big bang: Creation / birth / expansion / evolution of the universe or The universe was very hot / very dense / singularity (at the start) Evidence: Any <u>two</u> from: <ul style="list-style-type: none"> Microwave / background radiation / 3 K (or 2.7 K) Existence of (primordial) helium / lithium / lighter elements Tiny variation (or ripples) in (background) temperature 	B1 B1 \times 2	Not: More matter than antimatter / baryonic asymmetry
Total		9	

5)

Question	Answers	Marks	Guidance
(a)	$V = \frac{4}{3} \pi \times (6 \times 10^3)^3$ or $V = 9.05 \times 10^{11} \text{ (m}^3\text{)}$ $\text{density} = \frac{2.0 \times 10^{30}}{\frac{4}{3} \pi \times (6 \times 10^3)^3}$ $\text{density} = 2.2 \times 10^{18} \text{ kg m}^{-3}$	C1 C1 A1	Note: An incorrect equation here for V prevents this and any subsequent marks. The correct unit must also be included to score this A1 mark. Allow 2 marks for $2.76 \dots \times 10^{17} \text{ kg m}^{-3}$ – 12 km used instead of 6 km for the radius.
(b)	$g \propto 1/r^2$ $\text{ratio} = \left(\frac{1.4 \times 10^9}{12 \times 10^3} \right)^2$ or $\text{ratio} = \left(\frac{0.7 \times 10^9}{6 \times 10^3} \right)^2$ $\text{ratio} = 1.4 \times 10^{10}$	C1 A1	Note: The answer to 3 sf is 1.36×10^{10} . Allow 1 mark for 7.3×10^{-11} – inverse of the ratio.
(c)	$(p = 1/d)$ $d = \frac{8.6 \times 9.5 \times 10^{15}}{3.1 \times 10^{16}} \text{ (pc)}$ or $d = 2.64 \text{ (pc)}$ $p = 0.38 \text{ (arc seconds)}$	C1 A1	Allow full credit for alternative methods.
(d)	$\left(\frac{\Delta \lambda}{\lambda} = \frac{v}{c} \right)$ $\text{fractional change} = \frac{7600}{3.0 \times 10^8}$ $\text{percentage change} = 2.5 \times 10^{-3} \%$	C1 A1	Allow 1 mark for 2.5×10^{-5} (factor of 100 missed out).
(e)	The suggestion is incorrect because Hubble's law applies to (distant receding) galaxies. or The suggestion is incorrect because Hubble's law does not apply to stars in our own galaxy.	B1	Do not allow this mark if 'Sirius / star is moving <u>towards</u> us' is also included.
Total		10	

6)

Question	Answer	Marks	Guidance
(a)	(distance =) $3.0 \times 10^8 \times 3.16 \times 10^7$ distance = $9.48 \times 10^{15} \text{ (m)}$ $\approx 9.5 \times 10^{15} \text{ (m)}$	B1	Allow: (distance =) $3.0 \times 10^8 \times 365(1/4) \times 24 \times 3600$ Allow 1 mark for bald $9.48 \times 10^{15} \text{ (m)}$
(b)	Correct labelling of 1 pc, 1 AU and 1" 	B1	Allow: 'hypotenuse' labelled as 1 pc
(c) (i)	(distance =) $9.5 \times 10^{15} \times 2.1 \times 10^7 \text{ (m)}$ or $2.0 \times 10^{23} \text{ (m)}$ (distance in pc =) $2.0 \times 10^{23} / 3.1 \times 10^{16}$ distance = $6.4 \times 10^6 \text{ (pc)}$	C1 A1	Possible ecf from (a)
(ii)	(time =) $10^{14} / 4 \times 10^{26} \text{ (s)}$ or $2.5 \times 10^{17} \text{ (s)}$ (time =) $2.5 \times 10^{17} / 3.16 \times 10^7$ time = $7.9 \times 10^9 \text{ years}$	C1 A1	Allow: 1 sf answer of $8 \times 10^9 \text{ years}$
(d)	Any <u>one</u> from: • Very dense / infinite density / very small / singularity Any <u>one</u> from: • (Very strong gravitational field therefore) light cannot escape from it / curves space / slows down time / emits Hawking radiation	B1 B1	
Total		8	

8)

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9)

Question	Expected Answer	Mark	Additional Guidance
(a)	The speed of recession of a <u>galaxy</u> is proportional to its distance (from Earth / observer)	B1	
(b) (i)	$v = \frac{\Delta\lambda}{\lambda} \times c$ $v = 0.15 \times 3.0 \times 10^8$ speed = 4.5×10^7 (m s ⁻¹)	M1 A0	Allow: '15% of $3.0 \times 10^8 = 4.5 \times 10^7$ (m s ⁻¹)' Not: '0.15c'
(ii)	distance = v / H_0 (Any subject) distance = $\frac{4.5 \times 10^7 \times 3.1 \times 10^{22}}{65 \times 10^3}$ distance = 2.15×10^{25} (m)	C1 A1	 Possible ecf from (b)(i) Allow: 1 mark for 2.15×10^n , n ≠ 25
(iii)	$H_0 = \frac{65 \times 10^3}{3.1 \times 10^{22}}$ (= 2.10×10^{-18} s ⁻¹) age = $1 / H_0 = 4.77 \times 10^{17}$ (s) age = 1.49×10^{10} (y)	C1 A1	 Allow: 1 mark for 1.49×10^n , n ≠ 10
(c)	Any <u>two</u> from: 1. Spectra from galaxies show shift to longer wavelengths (suggests galaxies are moving away from the Earth) 2. The more distant galaxies are moving faster (than the ones closer to our galaxy) 3. Existence of <u>microwave</u> background radiation (which is the same in all directions) / The temperature of universe is 3 K (after cooling due to expansion) / gamma (radiation) became <u>microwaves</u> (as the universe expanded) 4. Existence of primordial helium (produced in the early stages of the universe) 5. Temperature fluctuations (predicted and observed)	B1 × 2	Not 'red-shift' for 1. Allow: Reference to <u>CMB</u> (radiation) in 3. Not bald 'ripples' for 5.
	Total	8	

10)

Question	Expected Answer	Mark	Additional Guidance
(c) (i)	Any <u>four</u> from: 1. Protons / hydrogen <u>nuclei</u> to produce He <u>nuclei</u> (positrons and neutrinos) 2. There is electrostatic repulsion (between the protons) / The protons repel (each other because of their positive charge) 3. High temperatures / 10^7 K needed (for fusion) 4. (At high temperatures some of the fast moving) protons come close enough to each other for the strong (nuclear) force (to overcome the electrostatic repulsion) 5. High density / pressure (in the core of the Sun) 6. There is a decrease in mass, hence energy is released / products have greater binding energy	B1 × 4	Not: 'heat' in place of temperature in 3.
(ii)	Kinetic (energy) Electromagnetic / photons	B1 B1	Not: heat / thermal (energy) Not: 'radiation' / 'wave energy' Allow: Gamma
(iii)	BE = $4 \times 7.2 = 28.8$ (MeV) BE = $28.8 \times 1.6 \times 10^{-13}$ BE = 4.6×10^{-12} (J)	C1 A1	 Possible ecf if BE value is incorrect
	Total	19	

Question	Expected Answer	Mark	Additional Guidance
(c) (i)	Any <u>four</u> from: 1. Protons / hydrogen <u>nuclei</u> to produce He <u>nuclei</u> (positrons and neutrinos) 2. There is electrostatic repulsion (between the protons) / The protons repel (each other because of their positive charge) 3. High temperatures / 10^7 K needed (for fusion) 4. (At high temperatures some of the fast moving) protons come close enough to each other for the strong (nuclear) force (to overcome the electrostatic repulsion) 5. High density / pressure (in the core of the Sun) 6. There is a decrease in mass, hence energy is released / products have greater binding energy	B1 × 4	Not: 'heat' in place of temperature in 3.
(ii)	Kinetic (energy) Electromagnetic / photons	B1 B1	Not: heat / thermal (energy) Not: 'radiation' / 'wave energy' Allow: Gamma
(iii)	BE = $4 \times 7.2 = 28.8$ (MeV) BE = $28.8 \times 1.6 \times 10^{-13}$ BE = 4.6×10^{-12} (J)	C1 A1	Possible ecf if BE value is incorrect
Total		19	

11)

Question	Answers	Marks	Guidance
(a)	Any <u>four</u> from: 1. (Sun / star formed from) dust cloud / nebula / (hydrogen) gas 2. <u>Gravitational</u> collapse (AW) 3. <u>Temperature</u> of (dust) cloud increases / KE (of cloud) increases / (cloud) heats up 4. Fusion occurs (when temperature is about 10^7 K) 5. Protons / hydrogen nuclei combine to make helium (nuclei) 6. Stable size star is produced when thermal / radiation pressure is equal to gravitational pressure Steps sequenced correctly – QWC mark	B1 × 4 B1	Must use ticks on Scoris to show where the marks are awarded
(b)	Any <u>two</u> from: 1. Very dense star 2. Hot star / high surface temperature / low luminosity 3. No fusion reactions take place / leaks away photons (from earlier fusion reactions) 4. Its collapse is prevented by Fermi pressure / mass less than 1.4 solar masses (AW)	B1 × 2	Must use ticks on Scoris to show where the marks are awarded Not: small in size, but <u>allow</u> 'smaller than main sequence star / Sun'
(c) (i)	Flat or universe will expand towards a (finite) limit or the rate of expansion will become/tend to zero	B1	
(ii)	Hubble constant = $1/\text{age}$ $H_0 = 1 / 4.4 \times 10^{17} (= 2.273 \times 10^{-18} \text{ s}^{-1})$ density = $\frac{3H_0^2}{8\pi G}$ density = $\frac{3H_0^2}{8\pi G} = \frac{3 \times (2.273 \times 10^{-18})^2}{8\pi \times 6.67 \times 10^{-11}}$ density = $9.2 \times 10^{-27} \text{ (kg m}^{-3}\text{)}$ or $9.24 \times 10^{-27} \text{ (kg m}^{-3}\text{)}$ density is about $10^{-26} \text{ (kg m}^{-3}\text{)}$	C1 C1 A1 A0	Allow: 2 marks for a bald $9.24 \times 10^{-27} \text{ (kg m}^{-3}\text{)}$ answer Note: This mark can only be scored if working is shown
Question	Answers	Marks	Guidance
(iii)	number = $9.24 \times 10^{-27} / 1.7 \times 10^{-27}$ number = 5.4 (Allow 5)	C1 A1	Possible ecf from (c)(ii) Allow: 2 marks for ' $10^{-26} / 1.7 \times 10^{-27} = 5.9$ or 6'
(d)	$\frac{1}{2}mv^2 = \frac{3}{2}kT$ / speed $\propto \sqrt{T}$ ratio = $\sqrt{\frac{10^8}{2.7}}$ ratio = 6.1×10^3 or 6.09×10^3	C1 A1	
Total		15	

12)

Question	Answer	Marks	Guidance
(a)	Any <u>four</u> from: 1. (Fusion is the) joining / fusing together of ('lighter') <u>nuclei</u> / <u>protons</u> (to make 'heavier' nuclei) 2. Mass decreases in the reaction and this is transformed into energy OR the products have greater binding energy 3. High temperatures / $\sim 10^7$ K needed for fusion 4. High pressure / density (required in the core) 5. The protons / nuclei repel (each other because of their positive charge) 6. The strong (nuclear) force comes into play when the protons / nuclei are close to each other	B1×4	Not: Atoms / particles for nuclei / protons.
(b)	(When hydrogen / helium runs out) the outer layers of the star expands / a (super) red giant is formed The core (of the star) collapses (rapidly) / a <u>supernova</u> is formed (Depending on the initial mass of the star the remnant is either a) <u>neutron star</u> or a <u>black hole</u>	B1 B1 B1	
Total		7	

13)

Question	Answer	Marks	Guidance
(a)	$F = \frac{GMm}{r^2}$ $\text{force} = \frac{6.67 \times 10^{-11} \times (10^{41})^2}{(4 \times 10^{22})^2}$ $\text{force} = 4.2 \times 10^{26} \text{ (N)}$	C1 C1 A1	Allow: $4 \times 10^{26} \text{ (N)}$ or 10^{26} since this is an estimation Allow: 2 marks for 4.2×10^n ; $n \neq 26$ (POT error)
(b)	Allow any <u>one</u> from: • The galaxies are receding / moving away from each other (because of the big bang) • Other galaxies may be pulling them in opposite direction • The acceleration is too small to collapse (other than over a very long period of time)	B1	
(c)	Any <u>six</u> from: 1. (At the start it was) very hot / extremely dense / singularity 2. All forces were unified 3. Expansion led to cooling 4. Quarks / leptons (soup) 5. More matter than antimatter 6. Quarks combine to form hadrons / protons / neutrons 7. Imbalance of neutrons and protons / (primordial) helium produced 8. Atoms formed 9. Idea of gravitational force responsible for formation of stars / galaxies 10. Temperature becomes 2.7 K / 3 K or (the universe is saturated with cosmic) microwave background radiation	B1×6	Show annotation on Scoris
(d) (i)	Dark lines / bands against a background of <u>continuous spectrum</u>	M1 A1	

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15)

Question	Expected Answers	Marks	Additional Guidance
a	static / homogeneous	B1	Uniform (density)
	infinite / infinite number of stars	B1	Do not allow isotropic or fixed
b	(i) gradient of graph = H_0	C1	
	value $H_0 = 66 \pm 4$ (km s ⁻¹ Mpc ⁻¹)	A1	
	(ii) age = $1 / H_0$ ($H_0 = 2.1 \times 10^{-18} \text{ s}^{-1}$)	C1	ecf from H_0 value
	= $(1 / 66 \times 3.2 \times 10^{-20} \times 3.2 \times 10^7)$	C1	Or correct age in seconds ($4.7 \times 10^{17} \text{ s}$)
	= $1.5 \times 10^{10} (1.48 \times 10^{10})$ (year)	A1	Answer will depend on H_0 value in (b)(i) Minus one if Mega or kilo omitted
c	(i) $\rho_c = 3H_0^2 / 8\pi G$ = $[3 \times (2.1 \times 10^{-18})^2] / (8 \times \pi \times 6.67 \times 10^{-11})$ = 7.9×10^{-27} (kg m ⁻³)	C1 A1	If units of H_0 not converted or converted incorrectly then maximum one out of two ecf from H_0 value in (b)(i)
	(ii) if average density of the Universe is less than critical then it will be too small to stop it expanding / it goes on forever if the average density of the Universe is greater than the critical value it will cause the contraction (and produce a big crunch) close to critical value and therefore a universe expands that will go towards a limit / expands at an ever decreasing rate asymptotic	B1 B1 B1	do not allow answers open, closed and flat
d	galaxies are moving apart / universe is expanding if galaxies have always been moving apart then at some stage they must have been closer together / or started from a point evidence in red shift either optical / microwave further away the galaxy the faster the speed of recession the existence of a (2.7 K) <u>microwave</u> background radiation there is more helium in the universe than expected MAX 4	(B1) (B1) (B1) (B1) (B1) (B1) B4	Allow stars for galaxies allow from a singularity allow statement that red shift is observed or that blue light becomes red or gamma from big bang has become microwave
Total		[16]	

16)

Question	Answer	Marks	Guidance
(a)	Any <u>three</u> from: 1. (Interstellar dust and gas) cloud is drawn together by gravitational force / gravity 2. Loss in (gravitational) PE / KE increases / temperature increases 3. Fusion (of protons / hydrogen nuclei) takes place 4. Energy is released in fusion reactions 5. A stable star is formed when gravitational pressure is equal to internal / gas / radiation pressure QWC: The steps in the process are correctly sequenced	B1 × 3 B1	Allow: 'gravitational collapse'
(b) (i)	Any <u>two</u> from: • (extremely) dense / (very) hot / low luminosity • no fusion reactions occur • it is a remnant of a low-mass star • correct reference to Fermi pressure / electron degeneracy / Chandrasekhar's limit	B1 × 2	
(ii)	Red giant identified (It is cooler but has) large <u>surface</u> area (and therefore radiates large amounts of energy)	B1 B1	
Total		8	

17)

Question	Answer	Marks	Guidance
(a)	The night sky should be bright / have uniform brightness (but it is not) The line of sight ends on (the surface of a star) or 'number of stars $\propto r^2$ and intensity $\propto 1/r^2$ ' Any <u>two</u> assumptions about the Universe: Infinite / uniformly distributed matter or stars throughout / static / infinite age	B1 B1 B1	
(b)	(recessional) speed of <u>galaxy</u> \propto its distance (from the Earth) The universe is finite / it is expanding / it has a beginning / visible light is red-shifted (because of expansion of space) (AW)	B1 B1	Allow: $v = H_0 x$, v = (recessional) speed of galaxy, x = distance and H_0 is Hubble constant / a constant
(c) (i)	$v = H_0 x$ $3.4 \times 10^7 = H_0 \times 1.4 \times 10^{25}$ $H_0 = 2.4 \times 10^{-18}$ unit: s^{-1}	C1 A1 B1	Note: This is an independent mark Note: Allow full credit for an Hubble constant of 75 with unit $km\ s^{-1}\ Mpc^{-1}$
(ii)1	$age = \frac{1}{2.4 \times 10^{-18}}$ $age = 4.17 \times 10^{17}$ (s) $age = 1.3 \times 10^{10}$ (years)	C1 A1	Possible ecf from (i)
(ii)2	distance = $4.17 \times 10^{17} \times 3.0 \times 10^8$ ($= 1.25 \times 10^{26}$ m) $distance = \frac{4.17 \times 10^{17} \times 3.0 \times 10^8}{3.1 \times 10^{16}}$ distance = 4.0×10^9 (pc)	C1 A1	Possible ecf from (ii)1
Total		12	