PRESTON MANOR

A Level Physics Exam Packs

Cosmology

Name:

Form:

Question	Mark

2 **(a)** Olbers' paradox is based on two assumptions about the nature of our Universe. State these two assumptions.

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.... **[2]**

(b) Fig. 2.1 shows how the recessional speed v of galaxies varies with their distance d from the Earth.

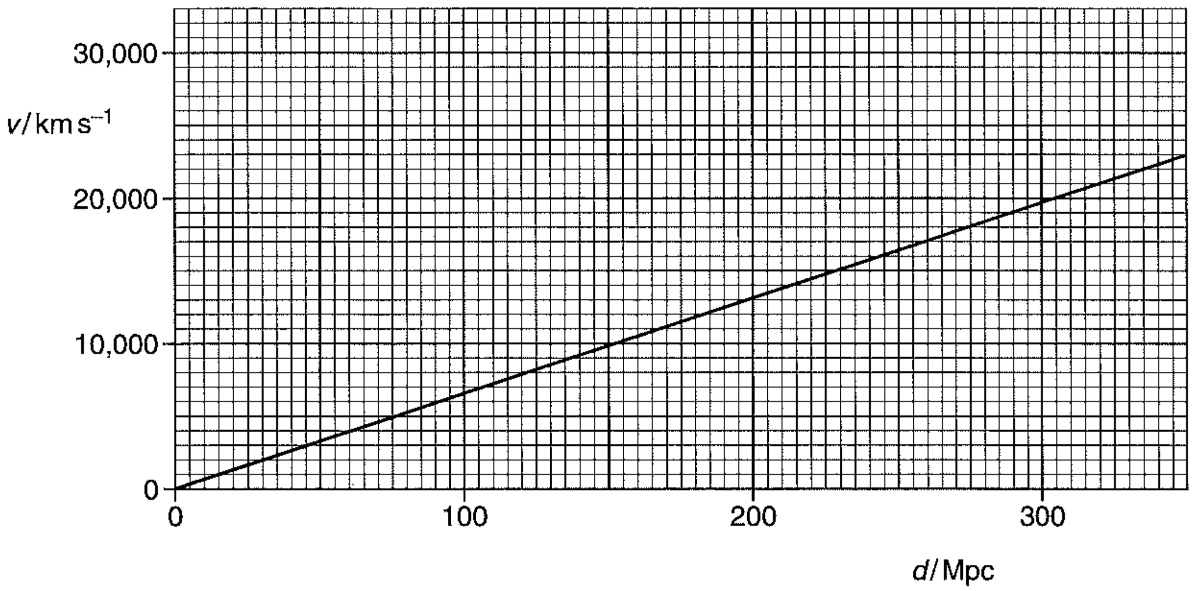

Fig. 2.1

(i) Use Fig. 2.1 to determine the Hubble constant.

Hubble constant = ... $km\,s^{-1}\,Mpc^{-1}$ **[2]**

(ii) Hence estimate the age of the Universe in years.

1 year = 3.2×10^{7} s and 1 pc = 3.1×10^{16} m

age = ... y **[3]**

(c) **(i)** Calculate the critical density of the Universe using the Hubble constant determined in **(b)(i)**.

critical density = ... kg m^{-3} **[2]**

(ii) Describe how the fate of the Universe depends on its average density.

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.... **[3]**

(d) Describe the evidence for the hot big bang model of the Universe.

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.... **[4]**

[Total: 16]

Question			Expected Answers	Marks	Additional Guidance
2	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 = $1 / H_0$ ($H_0 = 2.1 \times 10^{-18}$ 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 (4.7×10^{17} s)
			= 1.5×10^{10} (1.48×10^{10}) (year)	A1	Answer will depend on H_0 value in **(b)(i)** Minus one if Mega or kilo omitted
	c	(i)	$\rho_o = 3H_0^2 / 8\pi G$ $= [3 \times (2.1 \times 10^{-18})^2] / (8 \times \pi \times 6.67 \times 10^{-11})$	C1	If units of H_0 not converted or converted incorrectly then maximum one out of two
			= 7.9×10^{-27} (kg m^{-3})	A1	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	B1	do not allow answers open, closed and flat
			if the average density of the Universe is greater than the critical value it will cause the contraction (and produce a big crunch)	B1	
			close to critical value and therefore a universe expands that will go towards a limit / expands at an ever decreasing rate asymptotic	B1	

2	d		galaxies are moving apart / universe is expanding	(B1)	Allow stars for galaxies
			if galaxies have always been moving apart then at some stage they must have been closer together / or started from a point	(B1)	allow from a singularity
			evidence in red shift either optical / microwave	(B1)	allow statement that red shift is observed or that blue light becomes red or gamma from big bang has become microwave
			further away the galaxy the faster the speed of recession	(B1)	
			the existence of a (2.7 K) <u>microwave</u> background radiation	(B1)	
			there is more helium in the universe than expected	(B1)	
			MAX 4	**B4**	
			Total	**[16]**	

6 (a) (i) Describe the formation of a star such as our Sun and its most probable evolution.

In your answer you should make clear how the steps in the process are sequenced.

[6]

(ii) Describe the probable evolution of a star that is much more massive than our Sun.

[2]

(b) The present mass of the Sun is 2.0×10^{30} kg. The Sun emits radiation at an average rate of $3.8 \times 10^{26}\,\mathrm{J\,s^{-1}}$. Calculate the time in years for the mass of the Sun to decrease by one millionth of its present mass.

$1\,\mathrm{y} = 3.2 \times 10^{7}\,\mathrm{s}$

time = ... y **[3]**

(c) The following nuclear equation summarises a typical fusion reaction cycle that occurs in the Sun.

$$4\,{}^{1}_{1}\mathrm{H} \rightarrow {}^{4}_{2}\mathrm{He} + 2\,{}^{0}_{1}\mathrm{e} + 2\nu$$

(i) Explain the process of nuclear fusion in the core of the Sun. In your explanation refer to the conditions necessary for fusion to occur.

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.... **[4]**

(ii) Name two forms of energy produced in thermonuclear reactions.

1. ....

2. .... **[2]**

(iii) The binding energy per nucleon of ${}^{1}_{1}\mathrm{H}$ and ${}^{4}_{2}\mathrm{He}$ are 0 and 7.2 MeV respectively. Calculate the energy produced in joules for the fusion reaction above.

energy = ... J **[2]**

[Total: 19]

Question			Expected Answer	Mark	Additional Guidance
6	(a)	(i)	Any <u>five</u> from: 1. Gas / dust (cloud) drawn together by gravitational forces 2. Loss in (gravitational) PE / KE increases / PE changes KE / temperature increase 3. Fusion of protons / hydrogen <u>nuclei</u> (produces helium nuclei and energy) 4. A stable star is formed when radiation pressure is equal to gravitational pressure 5. When hydrogen runs out the <u>outer layers</u> of the star expands / <u>core</u> shrinks 6. <u>Red giant</u> formed / eventually (the core becomes) a <u>white dwarf</u> QWC mark for '*correct sequencing of the processes from birth to death*'	B1 × 5 B1	**Allow**: 'Gravitational collapse of dust cloud'
		(ii)	Supernova followed by neutron star / black hole	B1 B1	
	(b)		$\Delta E = \Delta mc^2$ energy = $2.0\times10^{30}\times10^{-6}\times(3.0\times10^{8})^2$ or $1.8(0)\times10^{41}$ (J) time = $1.80\times10^{41}/3.8\times10^{26}$ (= 4.74×10^{14} s) time = $4.74\times10^{14}/3.2\times10^{7}$ time = 1.5×10^{7} (y)	 C1 C1 A1	**Alternative**: rate = 4.22×10^{9} (kg s^{-1}) C1 time = $2.0\times10^{24}/4.22\times10^{9}$ (= 4.74×10^{14} s) C1 time = 1.5×10^{7} (y) A1

Question			Expected Answer	Mark	Additional Guidance
6	(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 × 7.2 = 28.8 (MeV) BE = 28.8 × 1.6 × 10^{-13} BE = 4.6 × 10^{-12} (J)	C1 A1	Possible ecf if BE value is incorrect
			Total	19	

4 **(a)** State Hubble's Law.

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.... **[1]**

(b) The dark lines of the spectrum observed from a distant galaxy are red-shifted by 15% of their normal wavelengths.

The Hubble constant is estimated to be $65\,\text{km}\,\text{s}^{-1}\,\text{Mpc}^{-1}$. One parsec = $3.1 \times 10^{16}\,\text{m}$.

(i) Show that the speed of the galaxy is $4.5 \times 10^{7}\,\text{m}\,\text{s}^{-1}$.

[1]

(ii) Estimate the distance of the galaxy from the Earth.

distance = ... m **[2]**

(iii) Estimate the age of the universe in years.

1 year = $3.2 \times 10^{7}\,\text{s}$

age = ... y **[2]**

(c) The age of the universe is calculated from the time of the big bang. Describe **two** observations that directly support the idea of the big bang.

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.... **[2]**

[Total: 8]

5 **(a)** Define the *parsec*. Draw a diagram to illustrate your answer.

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.... **[2]**

(b) The star Tau Ceti has a parallax of 0.275 seconds of arc.

Calculate the distance of Tau Ceti from Earth

(i) in parsec (pc)

distance = ... pc **[1]**

(ii) in light year (ly).

1 pc = 3.1×10^{16} m

distance = ... ly **[2]**

[Total: 5]

Question			Expected Answer	Mark	Additional Guidance
4	(a)		The speed of recession of a galaxy 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, $n \neq 25$
		(iii)	$H_0 = \frac{65 \times 10^3}{3.1 \times 10^{22}}$ (= 2.10×10^{-18} s^{-1}) age = $1/H_0$ = 4.77×10^{17} (s) age = 1.49×10^{10} (y)	C1 A1	**Allow**: 1 mark for 1.49×10^n, $n \neq 10$
	(c)		Any two 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 microwave background radiation (which is the same in all directions) / The temperature of universe is 3 K (after cooling due to expansion) / gamma (radiation) became microwaves (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 CMB (radiation) in 3. **Not** bald 'ripples' for 5.
			Total	8	

Question			Expected Answer	Mark	Additional Guidance
5	(a)		Diagram showing (star,) 1 AU, 1 pc and angle of 1 arc second <u>Distance</u> from a base length of 1 AU that subtends an angle of 1 (arc) second or Parsec is a <u>distance</u> that gives a (stellar) parallax of 1 second (of arc) / 1/3600°	B1 B1	 **Allow**: 1 pc is the <u>distance</u> calculated using: 1 AU/tan(1/3600°) **Not**: 1 pc = 3.26 ly **Not**: 1 pc = 3.1×10^{16} m
	(b)	(i)	distance (pc) = 1 / 0.275 distance = 3.64 (pc)	 B1	
		(ii)	distance in m = $3.1 \times 10^{16} \times 3.64 = 1.127 \times 10^{17}$ (m) distance in ly = $1.127 \times 10^{17}/9.5 \times 10^{15}$ distance in ly = 11.9	C1 A1	Possible ecf from **(b)(i)** **Alternative:** 1 pc = 3.26 ly C1 distance = 3.26×3.64 distance 11.9 (y) A1
			Total	5	

7 **(a)** Explain what is meant by the *critical density* of the universe.

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.... **[1]**

(b) Cosmologists have determined the Hubble constant to be $65\,\text{km}\,\text{s}^{-1}\,\text{Mpc}^{-1}$. Calculate the Hubble constant in s^{-1} and hence determine the critical density of the universe.

$1\,\text{pc} = 3.1 \times 10^{16}\,\text{m}$

Hubble constant = ... s^{-1}

critical density = ... $\text{kg}\,\text{m}^{-3}$ **[3]**

(c) (i) Explain the terms *open*, *closed* and *flat* when describing the possible evolution of the universe. On Fig. 7.1 sketch and label graphs to illustrate your answer.

Fig. 7.1

open ....

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closed ....

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flat ....

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.... **[3]**

(ii) Suggest a reason why it is difficult to predict the future of the universe.

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.... **[1]**

[Total: 8]

Question			Expected Answers	Marks	Additional guidance
7	(a)		The critical density is the density for which the universe will expand towards a (finite) limit or rate of expansion **tends** to zero / which will result in a <u>flat</u> universe	B1	**Not:** critical density is given by $\frac{3H_0^2}{8\pi G}$
	(b)		Hubble constant = $\frac{65\times10^3}{10^6\times3.1\times10^{16}}$ Hubble constant = 2.1×10^{-18} s^{-1} critical density = $\frac{3H_0^2}{8\pi G}$ critical density = $\frac{3\times(2.1\times10^{-18})^2}{8\pi\times6.67\times10^{-11}}$ critical density = 7.9×10^{-27} (kg m^{-3})	B1 C1 A1	Possible e.c.f. from value of Hubble constant within this calculation
	(c)	(i)	open: (density of universe < critical density hence) the universe will expand forever closed: (density of universe > critical density hence) the universe will (eventually stop expanding and then) contract / big crunch flat: (density of universe = critical density hence) the universe will expand towards a (finite) limit / rate of expansion **tends** to zero	B1 B1 B1	**Allow:** 'universe continues to expand' **Not:** 'The universe stops expanding' **Special case:** Award 1 mark for correct sketches if no explanation is given for open, closed and flat
		(ii)	Any <u>one</u> from: Existence of dark matter / black holes / neutrinos / dark energy / H_0 is not known accurately	B1	
			Total	8	

9 (a) Describe the formation of the Sun.

In your answer, you should make clear how the steps of the process are sequenced.

.... [5]

(b) After the death of a low-mass star such as our Sun, the remnant core is a white dwarf.

State two properties of a white dwarf.

.... [2]

(c) The ultimate fate of the universe depends on its density.

(i) State the fate of the universe if its density is equal to the critical density.

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.... **[1]**

(ii) According to some cosmologists, the age of the universe is 4.4×10^{17} s (about 14 billion years). Show that according to this age, the critical density of the universe is about 10^{-26} kg m^{-3}.

[3]

(iii) Estimate the number of protons per cubic metre of space.

mass of proton = 1.7×10^{-27} kg

number = ... m^{-3} **[2]**

(d) The universe began from a big bang. At an early stage of the universe, the temperature was about 10^8 K. The expansion of the universe led to cooling. The present temperature of the universe is about 2.7 K. For a single **electron**, determine the ratio

$$\frac{\text{speed of electron at } 10^8\,\text{K}}{\text{speed of electron at } 2.7\,\text{K}}.$$

ratio = ... **[2]**

[Total: 15]

END OF QUESTION PAPER

Question			Answers	Marks	Guidance
9	(a)		Any four from: 1. (Sun / star formed from) dust cloud /nebula / (hydrogen) gas 2. Gravitational collapse (AW) 3. Temperature 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 two 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 allow '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/age $H_0 = 1/4.4\times10^{17} (= 2.273\times10^{-18}\ \text{s}^{-1})$ density = $\frac{3H_0^2}{8\pi G}$ density = $\frac{3H_0^2}{8\pi G} = \frac{3\times(2.273\times10^{-18})^2}{8\pi\times6.67\times10^{-11}}$ density = 9.2×10^{-27} (kg m^{-3}) or 9.24×10^{-27} (kg m^{-3}) density is about 10^{-26} (kg m^{-3})	 C1 C1 A1 A0	 **Allow**: 2 marks for a bald 9.24×10^{-27} (kg m^{-3}) 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**	

9 (a) A star radiates energy produced from fusion reactions within its core. Explain what is meant by *fusion* and explain the conditions necessary for fusion to occur in the core of a star.

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.... **[4]**

(b) Describe and explain the evolution of a star much more massive than our Sun.

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.... **[3]**

[Total: 7]

Question			Answer	Marks	Guidance
9	(a)		Any four from: 1. (Fusion is the) joining / fusing together of ('lighter') nuclei / protons (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 / ~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 supernova is formed (Depending on the initial mass of the star the remnant is either a) neutron star or a black hole	B1 B1 B1	
			Total	**7**	

10 **(a)** In the universe there are about 10^{11} galaxies, each with about 10^{11} stars with each star having a mass of about 10^{30}kg. Estimate the attractive gravitational force between two galaxies separated by a distance of 4×10^{22}m.

force = ... N **[3]**

(b) Explain why the galaxies do not collapse on each other.

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.... **[1]**

(c) Describe qualitatively the evolution of the universe immediately after the big bang to the present day. You are not expected to state the times for the various stages of the evolution.

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.... **[6]**

(d) Fig. 10.1 shows some absorption spectral lines of the spectrum of calcium as observed from a source on the Earth and from a distant galaxy.

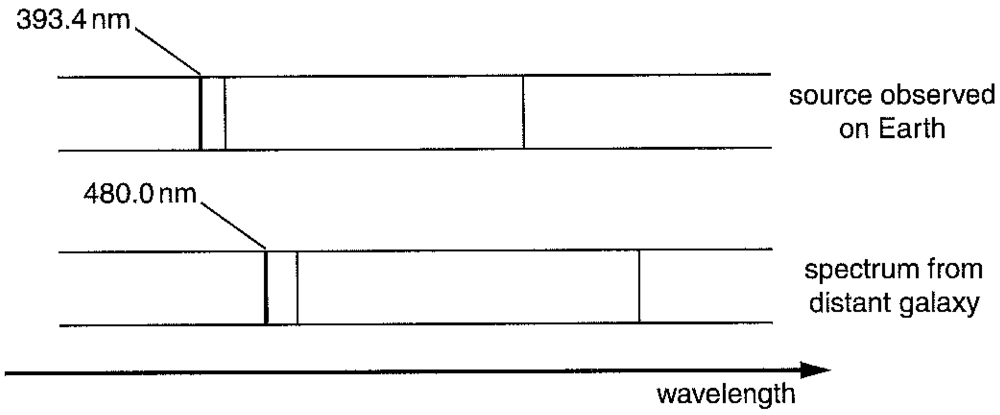

Fig. 10.1

(i) Describe an absorption spectrum.

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.... **[2]**

(ii) Use Fig. 10.1 to calculate the distance of the galaxy in Mpc. The Hubble constant has a value of 50 km s^{-1} Mpc^{-1}.

distance = ... Mpc **[3]**

[Total: 15]

END OF QUESTION PAPER

Question			Answer	Marks	Guidance
10	(a)		$F = \frac{GMm}{r^2}$ force = $\frac{6.67\times10^{-11}\times(10^{41})^2}{(4\times10^{22})^2}$ force = 4.2×10^{26} (N)	C1 C1 A1	**Allow**: 4×10^{26} (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</u> <u>spectrum</u>	M1 A1	

Question			Answer	Marks	Guidance
		(ii)	$\frac{v}{c}=\frac{\Delta\lambda}{\lambda}$ speed = $\frac{86.6}{393.4}\times 3.0\times 10^8$ (Any subject) speed = 6.6×10^7 (m s^{-1}) or 66000 (km s^{-1}) $v = H_0 d$ $66000 = 50 \times d$ distance = 1300 (Mpc)	C1 C1 A1	**Allow**: 1 mark for $\frac{86.6}{480.0}\times 3.0\times 10^8 = 5.41\times 10^7$ (m s^{-1}) **Allow**: 2 marks for 1.3×10^n; $n \neq 3$ (POT error) **Note**: Answer is 1080 (Mpc) if 5.4×10^7 (m s^{-1}) is used; this value will score 2 marks
			Total	**15**	

8 **(a)** Describe briefly the sequence of events which occur in the formation of a star, such as our Sun, from interstellar dust and gas clouds.

In your answer, you should make clear how the steps in the process are sequenced.

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.... **[4]**

(b) Fig. 8.1 shows the evolution of a star similar to our Sun on a graph of intensity of emitted radiation against temperature.

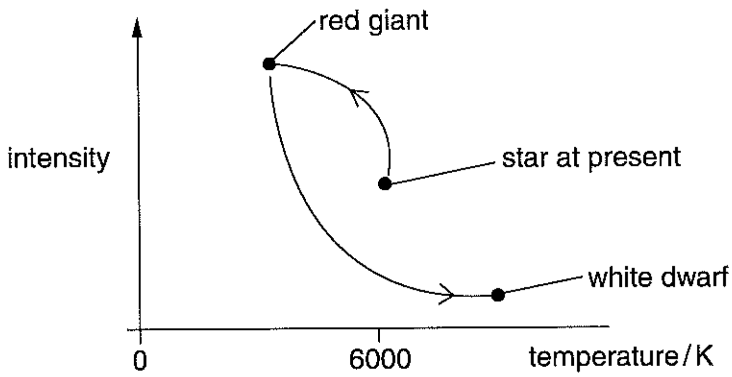

Fig. 8.1

(i) The final evolutionary stage of the star is a white dwarf. Describe some of the characteristics of a white dwarf.

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.... **[2]**

(ii) Explain why, in its evolution, the star is brightest when at its coolest.

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.... **[2]**

[Total: 8]

Question			Answer	Marks	Guidance
8	(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**	

9 **(a)** State Olbers' paradox and the two assumptions made about the Universse.

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.... **[3]**

(b) State Hubble's law and explain how it resolves Olbers' paradox.

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.... **[2]**

(c) A galaxy at a distance of 1.4×10^{25} m is observed to be receding from the Earth at a velocity of 3.4×10^{7} m s^{-1}.

(i) Calculate the Hubble constant H_0 based on this data.

H_0 = ... unit .... **[3]**

(ii) Estimate

1 the age in years of the Universe

1 year = 3.2×10^7 s

age = ...years **[2]**

2 the maximum distance in parsec (pc) we can observe from the Earth.

1 pc = 3.1×10^{16} m

distance = ... pc **[2]**

[Total: 12]

END OF QUESTION PAPER

Question			Answer	Marks	Guidance
9	(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 = 4.17×10^{17} (s) age = 1.3×10^{10} (years)	C1 A1	Possible ecf from **(i)**
		(ii)2	distance = $4.17 \times 10^{17} \times 3.0 \times 10^8$ (= 1.25×10^{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**	

10 **(a)** Calculate the distance of 1 light-year (ly) in metres.

distance = ... m **[1]**

(b) Fig. 10.1 shows an incomplete diagram drawn by a student to show what is meant by a distance of 1 parsec (pc).

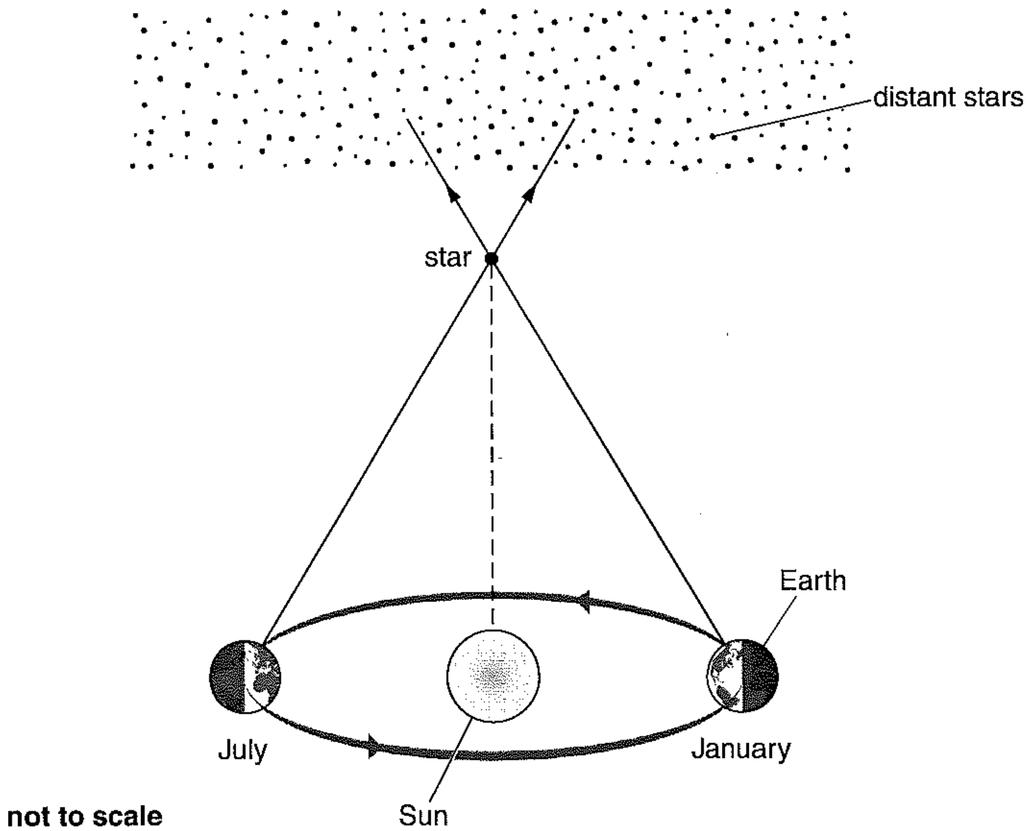

Fig. 10.1

Complete Fig. 10.1 by showing the distances of 1 pc and 1 AU, and the parallax angle of 1 second of arc (1″). **[1]**

(c) A recent supernova, SN2011fe, in the Pinwheel galaxy, M101, released 10^{44} J of energy. The supernova is 2.1×10^{7} ly away.

(i) Calculate the distance of this supernova in pc.

$1\text{ pc} = 3.1 \times 10^{16}\text{ m}$

distance = ... pc **[2]**

(ii) Our Sun radiates energy at a rate of 4×10^{26} W. Estimate the time in years that it would take the Sun to release the same energy as the supernova SN2011fe.

time = ... y **[2]**

(d) One of the possible remnants of a supernova event is a black hole. State **two** properties of a black hole.

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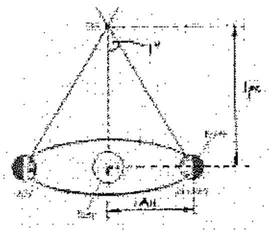
.... **[2]**

[Total: 8]

Question			Answer	Marks	Guidance
10	(a)		(distance =) $3.0 \times 10^8 \times 3.16 \times 10^7$ distance = 9.48×10^{15} (m) $\approx 9.5 \times 10^{15}$ (m)	B1	**Allow**: (distance =) $3.0 \times 10^8 \times 365(¼) \times 24 \times 3600$ **Allow** 1 mark for bald 9.48×10^{15} (m)
	(b)		Correct labelling of 1 pc, 1 AU and 1" 	B1	**Allow**: 'hypotenuse' labelled as 1 pc
	(c)	(i)	(distance =) $9.5 \times 10^{15} \times 2.1 \times 10^7$ (m) or 2.0×10^{23} (m) (distance in pc =) $2.0 \times 10^{23}/3.1 \times 10^{16}$ distance = 6.4×10^6 (pc)	C1 A1	Possible ecf from **(a)**
		(ii)	(time =) $10^{44}/4 \times 10^{26}$ (s) or 2.5×10^{17} (s) (time =) $2.5 \times 10^{17}/3.16 \times 10^7$ time = 7.9×10^9 years	C1 A1	 **Allow**: 1 sf answer of 8×10^9 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**	

11 (a) One estimate of the age of the universe is 13.7×10^9 years.

(i) Calculate the Hubble constant in $km\,s^{-1}\,Mpc^{-1}$ using this age.

1 pc = 3.09×10^{16} m

Hubble constant = ... $km\,s^{-1}\,Mpc^{-1}$ **[3]**

(ii) The wavelength of the hydrogen-alpha spectral line in the laboratory is 656 nm. Calculate the observed wavelength of this spectral line in the spectrum of the galaxy NGC 7469, which is 50.0 Mpc away from the Earth.

wavelength = ... nm **[4]**

(b) State what is meant by the big bang. Describe how it explains the origin of the microwave background radiation.

In your answer, you should make clear how the microwave background radiation supports the Cosmological Principle.

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.... **[5]**

Question 11 continues on page 22

(c) Suggest how the microwave background radiation may evolve in the future.

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.... **[2]**

(d) Recent observations of very distant supernovae have shown that the expansion of the universe may be accelerating. It is suggested that this is caused by *dark energy* which has the mysterious property of exerting a repulsive force on the universe. The universe may therefore be *open* rather than *flat* or *closed.*

Fig. 11.1

Complete Fig. 11.1 by sketching a suitable graph to illustrate an open universe. **[1]**

[Total: 15]

END OF QUESTION PAPER

Question			Answer	Marks	Guidance
11	(a)	(i)	H_0 = 1/age $H_0 = 1/(13.7 \times 10^9 \times 3.16 \times 10^7)$ $(H_0 =)\ 2.31 \times 10^{-18}$ (s^{-1}) $(H_0 =) \dfrac{2.31\times10^{-18}\times3.09\times10^{16}\times10^{6}}{10^{3}}$ Hubble constant = 71.4 (km s^{-1} Mpc^{-1})	C1 C1 A1	**Allow:** 2 sf answer **Special case**: Using $H_0 = 1/13.7 \times 10^9 = 7.30 \times 10^{-11}$ (y^{-1}) gives an answer of 2.26×10^9 (km s^{-1} Mpc^{-1}) – allow 1 mark
		(ii)	$v = H_0$ d (v =) 71.4 × 50 or 3.57×10^3 (km s^{-1}) or 3.57×10^6 (m s^{-1}) $\dfrac{\Delta\lambda}{\lambda} = \dfrac{3.57\times10^{6}}{3.0\times10^{8}} (= 1.19\times10^{-2})$ $\Delta\lambda = 656 \times 1.19 \times 10^{-2}$ or $\Delta\lambda$ = 7.80 (nm) wavelength = 656 + 7.80 wavelength = 664 (nm)	C1 C1 C1 A1	Possible ecf from **(a)** **Allow**: 2sf answer
	(b)		Big bang: Creation of the universe (from which space/time evolved) (AW) Any <u>three</u> from: 1. (At the start) the universe was hot / infinitely dense 2. Expansion of the universe led to cooling 3. The (current) temperature of universe is 2.7 K / 3 K 4. (The universe as a black body) is associated with microwaves at this temperature (AW) or The (wavelength of the) gamma radiation stretched to microwaves (by the expansion). QWC: (Cosmological principle is supported because) MBR is isotropic	B1 B1 × 3 B1	 **Not**: The universe now has microwaves. (The microwaves must be linked with current temperature) **Allow**: Microwaves have the same intensity in all directions

Question			Answer	Marks	Guidance
	(c)		(For an open / flat universe) Further expansion will lead to cooling / temperature lower than 3K / temperature tend to absolute zero (AW) The wavelength (of the EM radiation) gets longer / frequency (of the EM radiation) gets smaller / energy of photons decreases / microwaves become radio waves	B1 B1	**Alternative**: Temperature (will eventually) increases if closed universe B1 The wavelength (of EM radiation) get smaller B1
	(d)		Graph starting from origin and having a shape consistent with either open or accelerated universe	B1	**Not** a straight line
			Total	**15**	

9 Sirius A and B are binary stars in our galaxy at a distance of 8.6 ly from the Sun. Sirius B is a white dwarf of diameter 12 km and mass 2.0×10^{30} kg.

(a) Calculate the density of Sirius B.

density = ... unit .... **[3]**

(b) The mass of the Sun is the same as Sirius B. The Sun has a diameter of 1.4×10^{9} m.

Calculate the ratio

$$\frac{\text{gravitational field strength on the surface of Sirius B}}{\text{gravitational field strength on the surface of the Sun}}.$$

ratio = ... **[2]**

(c) Calculate the parallax angle in arc seconds for Sirius B.

$1\,\text{pc} = 3.1 \times 10^{16}\,\text{m}$

parallax angle = ... arc seconds **[2]**

(d) Sirius A is moving towards the Earth at a relative velocity of $7600\,m\,s^{-1}$. Calculate the percentage change in the wavelength of a spectral line observed from this star compared with an identical spectral line observed in the laboratory.

percentage change = ... % **[2]**

(e) A student suggests that the distance of Sirius A can be calculated using Hubble's law and the speed given in **(d)**. Discuss whether this suggestion is correct or incorrect.

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.... **[1]**

[Total: 10]

Question 10 begins on page 22

Question			Answers	Marks	Guidance
9	(a)		$V = \frac{4}{3}\pi \times (6\times10^3)^3$ or $V = 9.05 \times 10^{11}$ (m^3) density = $\frac{2.0\times10^{30}}{\frac{4}{3}\pi\times(6\times10^3)^3}$ density = 2.2×10^{18} 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.... $\times 10^{17}$ kg m^{-3} – 12 km used instead of 6 km for the radius.
	(b)		$g \propto 1/r^2$ ratio = $\left(\frac{1.4\times10^9}{12\times10^3}\right)^2$ or ratio = $\left(\frac{0.7\times10^9}{6\times10^3}\right)^2$ ratio = 1.4×10^{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)		($p = 1/d$) $d = \frac{8.6\times9.5\times10^{15}}{3.1\times10^{16}}$ (pc) or $d = 2.64$ (pc) $p = 0.38$ (arc seconds)	C1 A1	**Allow** full credit for alternative methods.
	(d)		($\frac{\Delta\lambda}{\lambda} = \frac{v}{c}$) fractional change = $\frac{7600}{3.0\times10^8}$ percentage change = 2.5×10^{-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 towards us' is also included.
			Total	**10**	

10 (a) Explain what is meant by a *white dwarf* when describing the evolution of a star.

....

....

.... **[1]**

(b) Antares is a red giant and one of the brightest stars in the night sky. The parallax angle for this star is 0.0059 arc seconds.

Calculate its distance in light years from us.
1 pc = 3.26 ly

distance = ... ly **[2]**

(c) Sirius-B is a white dwarf. In comparison with Sirius-B, Antares has 12 times greater mass and has 1.1×10^5 times greater radius. The surface temperatures of Sirius-B and Antares are 25000 K and 4300 K respectively.

The intensity I of electromagnetic radiation emitted from the surface of a star is related to its temperature T in kelvin as follows:

$$I \propto T^4.$$

(i) Explain what is meant by *intensity*.

....

.... **[1]**

(ii) Calculate the ratio

1 $$\frac{\text{mean density of Antares}}{\text{mean density of Sirius-B}}$$

ratio = ... **[2]**

2 $$\frac{\text{total power emitted from Antares}}{\text{total power emitted from Sirius-B}}.$$

ratio = ... **[3]**

Question			Answer	Marks	Guidance
10	(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' • 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 = mass/$\frac{4}{3}\pi r^3 \propto$ mass/r^3) ratio = $\frac{12}{(1.1\times10^5)^3}$ ratio = 9.0×10^{-15} **2** (power = intensity × surface area) power $\propto T^4r^2$ ratio = $\frac{4300^4 \times (1.1\times10^5)^2}{25000^4}$ ratio = 1.1×10^7	 C1 A1 C1 C1 A1	 **Allow**: 9.0×10^{-15} : 1 **Allow**: 1 sf answer of 9×10^{-15} **Note**: Answer to 3 sf is 1.06×10^7 **Allow**: 1.1×10^7 : 1
			Total	**9**	

11 **(a)** State Hubble's law.

....

....

.... **[1]**

(b) The redshift of a specific spectral line in the spectrum of a galaxy can be used to determine its recession velocity v. The fractional change z in the wavelength of a spectral line is given by the equation

$$z = \frac{v}{c}$$

where c is the speed of light in a vacuum.

The table of Fig. 11.1 shows data for some of our closest galaxies. The distance of the galaxy from the Earth is d.

Galaxy	z / 10^{-3}	v / 10^3 m s^{-1}	d / 10^{23} m
A	1.12	336	1.50
B	1.61	483	2.14
C	1.85	555	2.46
D	2.26	678	3.00
Messier 109	3.38		

Fig. 11.1

(i) Complete the table by determining v and d for the galaxy Messier 109. **[2]**

(ii) Fig. 11.2 shows the data for the first four galaxies plotted on a v against d graph.

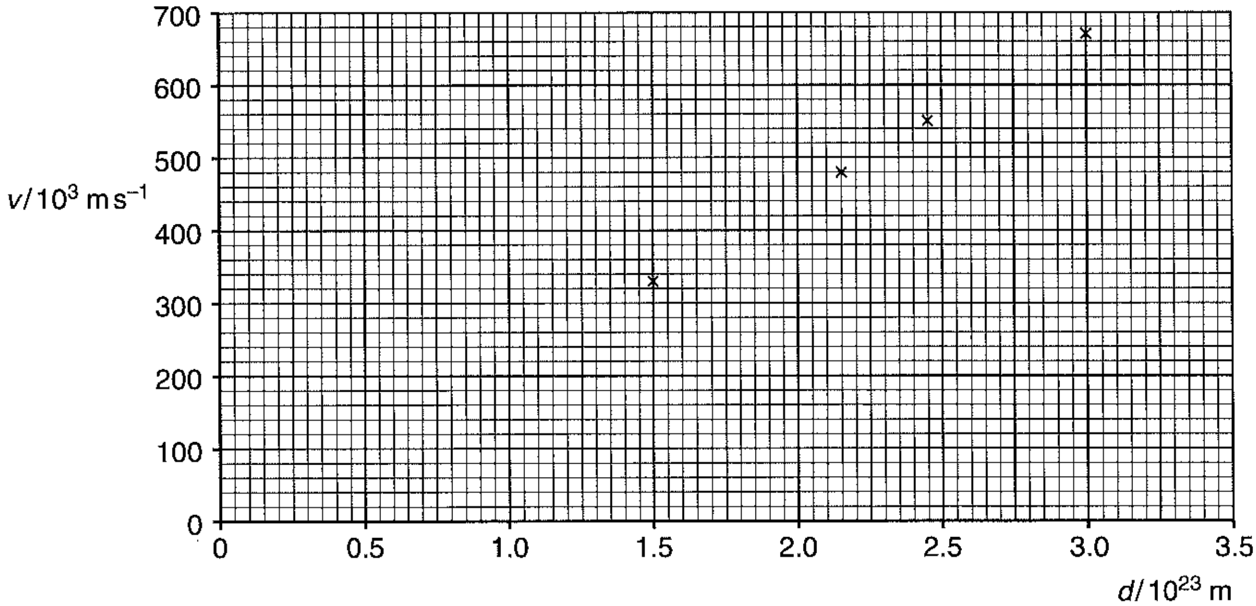

Fig. 11.2

Use Fig. 11.2 to determine the age of the Universe in years.
$1\,y = 3.16 \times 10^7\,s$

age = ... years **[3]**

(c) One piece of observational evidence for the big bang is that galaxies are receding from each other.
Explain what is meant by the big bang and suggest **two** other observations that support the big bang model of the Universe.

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.... **[3]**

END OF QUESTION PAPER

Question			Answer	Marks	Guidance
11	(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 × 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 = 2.24×10^{-18} (s^{-1}) age = $(2.24 \times 10^{-18})^{-1}$ age = 4.46×10^{17} (s) age = 1.4×10^{10} (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: • 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 × 2	 **Not**: More matter than antimatter / baryonic asymmetry
			Total	**9**	