



**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.

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

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

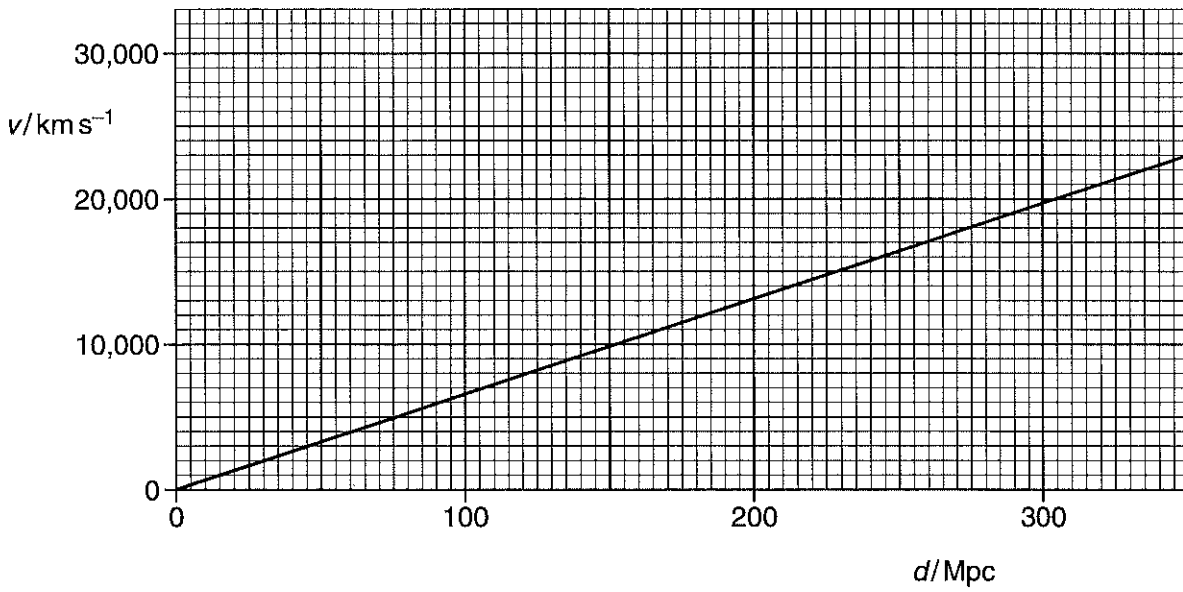


Fig. 2.1

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

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

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

$1 \text{ year} = 3.2 \times 10^7 \text{ s}$  and  $1 \text{ pc} = 3.1 \times 10^{16} \text{ m}$

age = ..... y [3]

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

critical density = .....  $\text{kg m}^{-3}$  [2]

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

.....  
.....  
.....  
.....  
.....  
..... [3]

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

.....  
.....  
.....  
.....  
.....  
..... [4]

[Total: 16]

Turn over

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 <sup>-1</sup> Mpc <sup>-1</sup> )	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)	$\rho_0 = 3H_0^2 / 8\pi G$	C1	If units of $H_0$ not converted or converted incorrectly then maximum one out of two ecf from $H_0$ value in (b)(i)
		= $[3 \times (2.1 \times 10^{-18})^2] / (8 \times \pi \times 6.67 \times 10^{-11})$	A1	
	(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	<p>galaxies are moving apart / universe is expanding</p> <p>if galaxies have always been moving apart then at some stage they must have been closer together / or started from a point</p> <p>evidence in red shift either optical / microwave</p> <p>further away the galaxy the faster the speed of recession</p> <p>the existence of a (2.7 K) <u>microwave</u> background radiation</p> <p>there is more helium in the universe than expected</p> <p style="text-align: right;"><b>MAX 4</b></p>	<p>(B1)</p> <p>(B1)</p> <p>(B1)</p> <p>(B1)</p> <p>(B1)</p> <p>(B1)</p> <p>(B1)</p> <p>B4</p>	<p>Allow stars for galaxies</p> <p>allow from a singularity</p> <p>allow statement that red shift is observed or that blue light becomes red or gamma from big bang has become microwave</p>
<b>Total</b>			<b>[16]</b>	

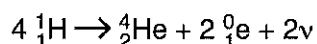


- (b) The present mass of the Sun is  $2.0 \times 10^{30}$  kg. The Sun emits radiation at an average rate of  $3.8 \times 10^{26}$  J s<sup>-1</sup>. Calculate the time in years for the mass of the Sun to decrease by one millionth of its present mass.

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

time = ..... y [3]

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



- (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.

.....  
 .....  
 .....  
 .....  
 .....  
 ..... [4]

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

1. ....

2. ....

[2]

- (iii) The binding energy per nucleon of  $^1_1\text{H}$  and  $^4_2\text{He}$  are 0 and 7.2 MeV respectively. Calculate the energy produced in joules for the fusion reaction above.

energy = ..... J [2]

[Total: 19]

Turn over





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	<b>Not:</b> 'heat' in place of temperature in 3.
		(ii)	Kinetic (energy) Electromagnetic / photons	B1 B1	<b>Not:</b> heat / thermal (energy) <b>Not:</b> 'radiation' / 'wave energy" <b>Allow:</b> Gamma
		(iii)	BE = $4 \times 7.2 = 28.8$ (MeV) BE = $28.8 \times 1.6 \times 10^{-13}$ BE = $4.6 \times 10^{-12}$ (J)	C1  A1	Possible ecf if BE value is incorrect
<b>Total</b>				19	

4 (a) State Hubble's Law.

.....  
..... [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  $65 \text{ km s}^{-1} \text{ Mpc}^{-1}$ . One parsec =  $3.1 \times 10^{16} \text{ m}$ .

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

[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.

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

[Total: 8]

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

.....  
 ..... [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).

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

distance = ..... ly [2]

[Total: 5]

Question	Expected Answer	Mark	Additional Guidance
4 (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 = $4.5 \times 10^7$ (m s <sup>-1</sup> )	M1 A0	<b>Allow:</b> '15% of $3.0 \times 10^8 = 4.5 \times 10^7$ (m s <sup>-1</sup> )' <b>Not:</b> '0.15c'
(ii)	distance = $v / H_0$ (Any subject) $\text{distance} = \frac{4.5 \times 10^7 \times 3.1 \times 10^{22}}{65 \times 10^3}$ distance = $2.15 \times 10^{25}$ (m)	C1  A1	Possible ecf from (b)(i) <b>Allow:</b> 1 mark for $2.15 \times 10^n$ , n ≠ 25
(iii)	$H_0 = \frac{65 \times 10^3}{3.1 \times 10^{22}} (= 2.10 \times 10^{-18} \text{ s}^{-1})$ age = $1 / H_0 = 4.77 \times 10^{17}$ (s) age = $1.49 \times 10^{10}$ (y)	C1  A1	<b>Allow:</b> 1 mark for $1.49 \times 10^n$ , 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	<b>Not</b> 'red-shift' for 1.  <b>Allow:</b> Reference to <u>CMB</u> (radiation) in 3.  <b>Not</b> bald 'ripples' for 5.
<b>Total</b>		<b>8</b>	

Question		Expected Answer	Mark	Additional Guidance	
5	(a)	Diagram showing (star,) 1 AU, 1 pc and angle of 1 arc second	B1	<b>Allow:</b> 1 pc is the <u>distance</u> calculated using: $1 \text{ AU} / \tan(1/3600^\circ)$ <b>Not:</b> 1 pc = 3.26 ly <b>Not:</b> 1 pc = $3.1 \times 10^{16}$ m	
		<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) / $1/3600^\circ$	B1		
	(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)  <b>Alternative:</b> $1 \text{ pc} = 3.26 \text{ ly}$ C1 distance = $3.26 \times 3.64$ distance 11.9 (y) A1
<b>Total</b>			5		

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

.....  
 ..... [1]

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

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

Hubble constant = .....  $\text{s}^{-1}$

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

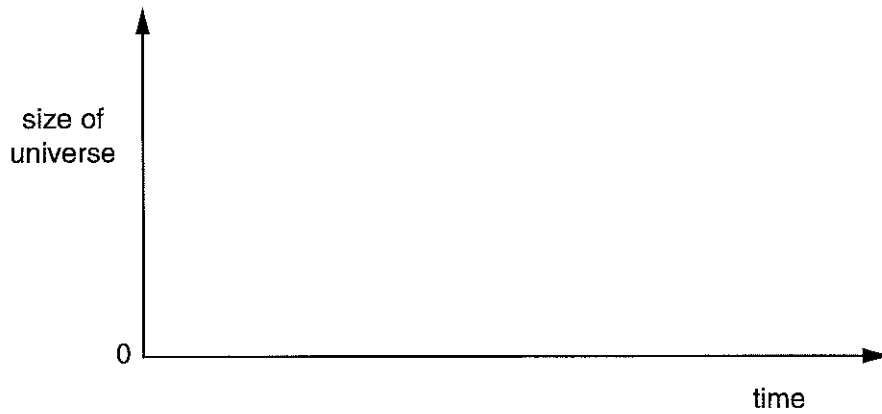


Fig. 7.1

open .....  
.....  
.....  
closed .....  
.....  
.....  
flat .....  
.....  
..... [3]

(ii) Suggest a reason why it is difficult to predict the future of the universe.  
.....  
.....  
..... [1]

[Total: 8]







(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.

.....  
 ..... [1]

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

[3]

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

mass of proton =  $1.7 \times 10^{-27} \text{ kg}$

number = .....  $\text{m}^{-3}$  [2]

(d) The universe began from a big bang. At an early stage of the universe, the temperature was about  $10^8 \text{ K}$ . The expansion of the universe led to cooling. The present temperature of the universe is about  $2.7 \text{ K}$ . 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 <u>four</u> from: 1. (Sun / star formed from) dust cloud / nebula / (hydrogen) gas 2. <u>Gravitational</u> 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 – <b>QWC mark</b>	B1×4  B1	<b>Must use ticks on Scoris to show where the marks are awarded</b>
	(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	<b>Must use ticks on Scoris to show where the marks are awarded</b>  <b>Not:</b> small in size, but <u>allow</u> 'smaller than main sequence star / Sun'
	(c)	(i)	B1	
		(ii)	C1  C1 A1 A0	<b>Allow:</b> 2 marks for a bald $9.24 \times 10^{-27}$ ( $\text{kg m}^{-3}$ ) answer <b>Note:</b> This mark can only be scored if working is shown

G485

Mark Scheme

January 2012

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 = $6.1 \times 10^3$ or $6.09 \times 10^3$	C1   A1	
	<b>Total</b>	<b>15</b>	



Question	Answer	Marks	Guidance
9 (a)	Any <u>four</u> from: 1. (Fusion is the ) joining / fusing together of ('lighter') <u>nuclei / 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	<b>Not:</b> 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	
<b>Total</b>		<b>7</b>	

- 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  $4 \times 10^{22}$  m.

force = ..... N [3]

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

.....  
.....  
..... [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.

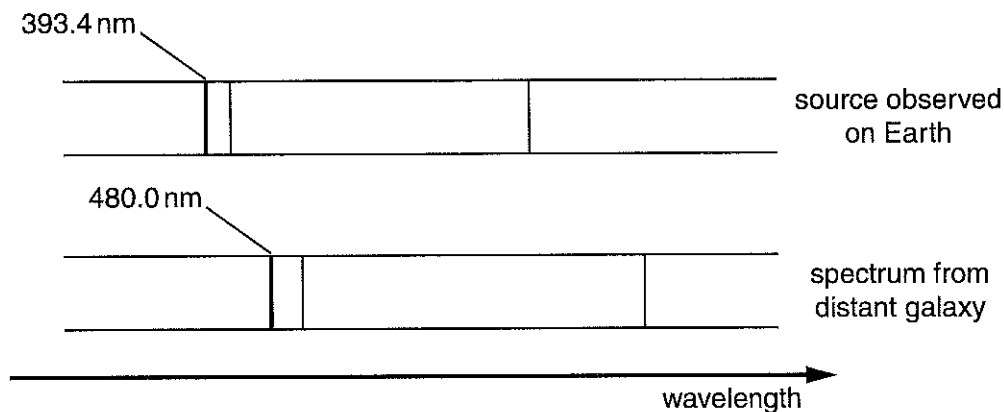


Fig. 10.1

- (i) Describe an absorption spectrum.

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

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

distance = ..... Mpc [3]

[Total: 15]

END OF QUESTION PAPER



Question	Answer	Marks	Guidance
10 (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	<b>Allow:</b> $4 \times 10^{26}$ (N) or $10^{26}$ since this is an estimation <b>Allow:</b> 2 marks for $4.2 \times 10^n$ ; $n \neq 26$ (POT error)
(b)	Allow any <u>one</u> from: <ul style="list-style-type: none"> <li>The galaxies are receding / moving away from each other (because of the big bang)</li> <li>Other galaxies may be pulling them in opposite direction</li> <li>The acceleration is too small to collapse (other than over a very long period of time)</li> </ul>	B1	
(c)	Any <u>six</u> from: <ol style="list-style-type: none"> <li>(At the start it was) very hot / extremely dense / singularity</li> <li>All forces were unified</li> <li>Expansion led to cooling</li> <li>Quarks / leptons (soup)</li> <li>More matter than antimatter</li> <li>Quarks combine to form hadrons / protons / neutrons</li> <li>Imbalance of neutrons and protons / (primordial) helium produced</li> <li>Atoms formed</li> <li>Idea of gravitational force responsible for formation of stars / galaxies</li> <li>Temperature becomes 2.7 K / 3 K or (the universe is saturated with cosmic) microwave background radiation</li> </ol>	B1×6	<b>Show annotation on Scoris</b>
(d) (i)	Dark lines / bands against a background of <u>continuous 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 = $6.6 \times 10^7$ (m s <sup>-1</sup> ) or 66000 (km s <sup>-1</sup> )  $v = H_0 d$ $66000 = 50 \times d$ 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 <sup>-1</sup> )  Allow: 2 marks for $1.3 \times 10^3$ ; n ≠ 3 (POT error) Note: Answer is 1080 (Mpc) if $5.4 \times 10^7$ (m s <sup>-1</sup> ) is used; this value will score 2 marks
	<b>Total</b>	<b>15</b>	



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

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

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

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

**[Total: 8]**



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

.....  
.....  
.....  
.....  
..... [3]

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

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

(c) A galaxy at a distance of  $1.4 \times 10^{25}$  m is observed to be receding from the Earth at a velocity of  $3.4 \times 10^7$  ms<sup>-1</sup>.

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

$H_0 = \dots\dots\dots$  unit  $\dots\dots\dots$  [3]

**(ii) Estimate****1** the age in years of the Universe

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

age = .....years [2]

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

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

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)	B1	
		The line of sight ends on (the surface of a star) or 'number of stars $\propto r^2$ and intensity $\propto 1/r^2$ '	B1	
		Any <u>two</u> assumptions about the Universe: Infinite / uniformly distributed matter or stars throughout / static / infinite age	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	<b>Allow:</b> $v = H_0 x$ , $v =$ (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	<b>Note:</b> This is an independent mark <b>Note:</b> 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
	(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 = $4.0 \times 10^9$ (pc)	C1  A1	Possible ecf from (ii)1
<b>Total</b>			<b>12</b>	



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).

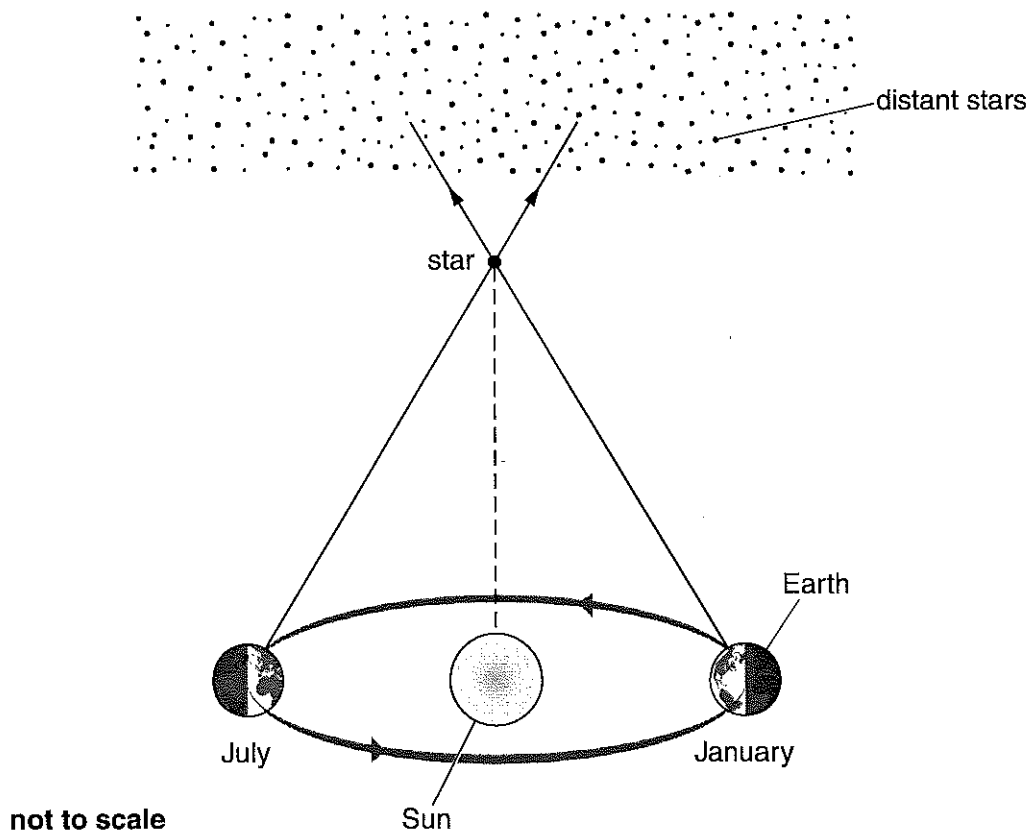


Fig. 10.1

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  $2.1 \times 10^7$  ly away.

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

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

distance = ..... pc [2]

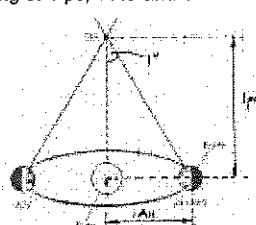
(ii) Our Sun radiates energy at a rate of  $4 \times 10^{26}$  W. Estimate the time in years that it would take the Sun to release the same energy as the supernova SN2011fe.

time = ..... y [2]

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

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

[Total: 8]

Question	Answer	Marks	Guidance
10 (a)	(distance =) $3.0 \times 10^8 \times 3.16 \times 10^7$ distance = $9.48 \times 10^{15}$ (m) $\approx 9.5 \times 10^{15}$ (m)	B1	<b>Allow:</b> (distance =) $3.0 \times 10^8 \times 365(1/4) \times 24 \times 3600$ <b>Allow 1 mark for bald</b> $9.48 \times 10^{15}$ (m)
(b)	Correct labelling of 1 pc, 1 AU and 1" 	B1	<b>Allow:</b> 'hypotenuse' labelled as 1 pc
(c) (i)	(distance =) $9.5 \times 10^{15} \times 2.1 \times 10^7$ (m) or $2.0 \times 10^{23}$ (m) (distance in pc =) $2.0 \times 10^{23} / 3.1 \times 10^{16}$ distance = $6.4 \times 10^6$ (pc)	C1 A1	Possible ecf from (a)
(ii)	(time =) $10^{44} / 4 \times 10^{26}$ (s) or $2.5 \times 10^{17}$ (s) (time =) $2.5 \times 10^{17} / 3.16 \times 10^7$ time = $7.9 \times 10^9$ years	C1 A1	<b>Allow:</b> 1 sf answer of $8 \times 10^9$ years
(d)	Any <u>one</u> from: <ul style="list-style-type: none"> <li>Very dense / infinite density / very small / singularity</li> </ul> Any <u>one</u> from: <ul style="list-style-type: none"> <li>(Very strong gravitational field therefore) light cannot escape from it / curves space / slows down time / emits Hawking radiation</li> </ul>	B1 B1	
<b>Total</b>		<b>8</b>	

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

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

$$1 \text{ pc} = 3.09 \times 10^{16} \text{ m}$$

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



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

.....

.....

.....

..... [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*.

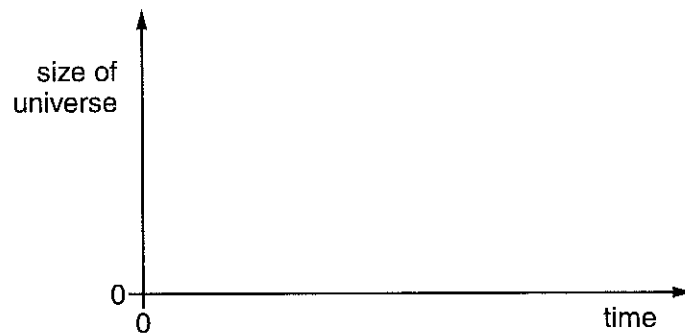


Fig. 11.1

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)	$H_0 = 1/\text{age}$ $H_0 = 1/(13.7 \times 10^9 \times 3.16 \times 10^7)$ $(H_0 =) 2.31 \times 10^{-18} \text{ (s}^{-1}\text{)}$ $(H_0 =) \frac{2.31 \times 10^{-18} \times 3.09 \times 10^{16} \times 10^6}{10^3}$ Hubble constant = 71.4 (km s <sup>-1</sup> Mpc <sup>-1</sup> )	C1 C1  A1	<b>Allow:</b> 2 sf answer <b>Special case:</b> Using $H_0 = 1/13.7 \times 10^9 = 7.30 \times 10^{-11} \text{ (y}^{-1}\text{)}$ gives an answer of $2.26 \times 10^8 \text{ (km s}^{-1} \text{ Mpc}^{-1}\text{)}$ – allow 1 mark
(ii)	$v = H_0 d$ $(v =) 71.4 \times 50 \text{ or } 3.57 \times 10^3 \text{ (km s}^{-1}\text{) or } 3.57 \times 10^6 \text{ (m s}^{-1}\text{)}$  $\frac{\Delta\lambda}{\lambda} = \frac{3.57 \times 10^6}{3.0 \times 10^8} (= 1.19 \times 10^{-2})$  $\Delta\lambda = 656 \times 1.19 \times 10^{-2} \text{ or } \Delta\lambda = 7.80 \text{ (nm)}$  wavelength = 656 + 7.80  wavelength = 664 (nm)	C1  C1  C1  A1	Possible ecf from (a)     <b>Allow:</b> 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	<b>Not:</b> The universe now has microwaves. (The microwaves must be linked with current temperature)     <b>Allow:</b> 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	<b>Alternative:</b> Temperature (will eventually) increases if <u>closed</u> 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	<b>Not a straight line</b>
	<b>Total</b>	<b>15</b>	



- 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  $2.0 \times 10^{30}$  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  $1.4 \times 10^9$  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  $7600 \text{ ms}^{-1}$ . 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.

.....  
.....  
.....  
..... [1]

[Total: 10]

Question 10 begins on page 22

Question	Answers	Marks	Guidance
9 (a)	$V = \frac{4}{3}\pi \times (6 \times 10^3)^3$ or $V = 9.05 \times 10^{11} \text{ (m}^3\text{)}$ density = $\frac{2.0 \times 10^{30}}{\frac{4}{3}\pi \times (6 \times 10^3)^3}$ density = $2.2 \times 10^{18} \text{ kg m}^{-3}$	C1 C1 A1	<b>Note:</b> An incorrect equation here for V prevents this and any subsequent marks.  The correct unit must also be included to score this A1 mark. <b>Allow 2 marks</b> for $2.76 \dots \times 10^{17} \text{ kg m}^{-3}$ – 12 km used instead of 6 km for the radius.
(b)	$g \propto 1/r^2$ ratio = $\left(\frac{1.4 \times 10^9}{12 \times 10^3}\right)^2$ or ratio = $\left(\frac{0.7 \times 10^9}{6 \times 10^3}\right)^2$ ratio = $1.4 \times 10^{10}$	C1 A1	<b>Note:</b> The answer to 3 sf is $1.36 \times 10^{10}$ . <b>Allow 1 mark</b> for $7.3 \times 10^{-11}$ – 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	<b>Allow full credit</b> for alternative methods.
(d)	$\left(\frac{\Delta\lambda}{\lambda} = \frac{v}{c}\right)$ fractional change = $\frac{7600}{3.0 \times 10^8}$ percentage change = $2.5 \times 10^{-3} \%$	C1 A1	<b>Allow 1 mark</b> for $2.5 \times 10^{-5}$ (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 <b>not</b> allow this mark if 'Sirius / star is moving <u>towards</u> us' is also included.
<b>Total</b>		<b>10</b>	

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  $1.1 \times 10^5$  times greater radius. The surface temperatures of Sirius-B and Antares are 25000K and 4300K 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	<p><b>Allow:</b> It is the core of a red giant</p> <p><b>Allow:</b> It is the remnant of a low-mass star</p> <p><b>Allow:</b> A core / 'star'</p> <ul style="list-style-type: none"> <li>supported by Fermi pressure / electron degeneracy (pressure)</li> <li>with maximum mass of 1.4(4) solar masses / 1.4(4) <math>M_{\odot}</math> / Chandrasekhar limit</li> </ul> <p><b>Not:</b> It is a collapsing red giant</p>
(b)	<p>(parallax = <math>1/d</math>)</p> <p><math>d = 0.0059^{-1}</math> (pc = 169.49 .... pc)</p> <p>distance = <math>0.0059^{-1} \times 3.26</math></p> <p>distance = 550 ly</p>	C1 A1	<b>Allow</b> other correct methods
(c) (i)	power per (unit) area or power/area	B1	<p><b>Allow</b> 'energy per (unit) area per unit time'</p> <p><b>Not:</b> power per <math>m^2</math></p>
(ii)	<p>1 (density = <math>\text{mass} / \frac{4}{3}\pi r^3 \propto \text{mass} / r^3</math>)</p> <p>ratio = <math>\frac{12}{(1.1 \times 10^5)^3}</math></p> <p>ratio = <math>9.0 \times 10^{-16}</math></p> <p>2 (power = intensity <math>\times</math> surface area)</p> <p>power <math>\propto T^4 r^2</math></p> <p>ratio = <math>\frac{4300^4 \times (1.1 \times 10^5)^2}{25000^4}</math></p> <p>ratio = <math>1.1 \times 10^7</math></p>	C1 A1 C1 C1 A1	<p><b>Allow:</b> <math>9.0 \times 10^{-16} : 1</math></p> <p><b>Allow:</b> 1 sf answer of <math>9 \times 10^{-16}</math></p> <p><b>Note:</b> Answer to 3 sf is <math>1.06 \times 10^7</math></p> <p><b>Allow:</b> <math>1.1 \times 10^7 : 1</math></p>
<b>Total</b>		<b>9</b>	

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	$z / 10^{-3}$	$v / 10^3 \text{ms}^{-1}$	$d / 10^{23} \text{m}$
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.

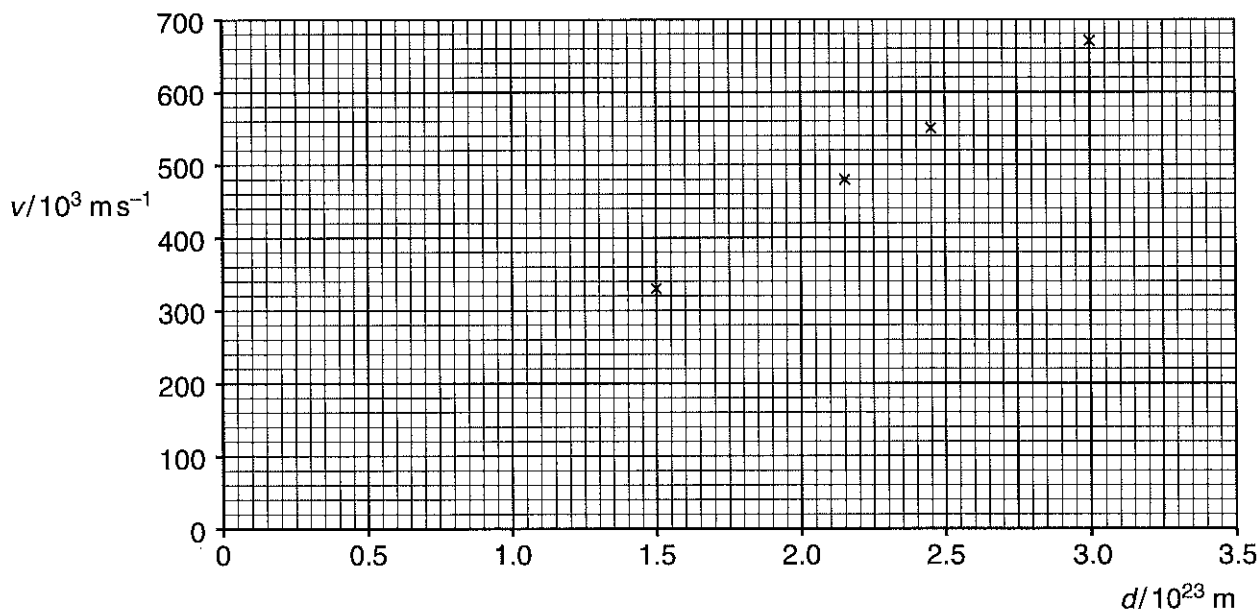


Fig. 11.2

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

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.

.....

.....

.....

.....

.....

.....

..... [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	<b>Allow:</b> recessional speed of <u>galaxy</u> = Hubble constant $\times$ distance
(b) (i)	$v = 1010 (10^3 \text{ m s}^{-1})$ $d$ in the range 4.47 to 4.54 ( $10^{23}$ m)	B1 B1	<b>Note:</b> Answer to 4 sf is 1014 ( $10^3 \text{ m s}^{-1}$ )
(b) (ii)	(Straight line drawn through the points gradient = Hubble constant, $H_0$ )  gradient = $2.24 \times 10^{-18} (\text{s}^{-1})$  age = $(2.24 \times 10^{-18})^{-1}$  age = $4.46 \times 10^{17}$ (s)  age = $1.4 \times 10^{10}$ (y)	C1  C1  A1	<b>Allow:</b> gradient in the range 2.21 to $2.27 \times 10^{-18}$  <b>Allow</b> ecf from incorrect value of the gradient  <b>Allow:</b> A maximum of 2 marks if values from the table are used instead of the gradient of the line drawn on Fig. 11.2  <b>Note:</b> 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"> <li>• Microwave / background radiation / 3 K (or 2.7 K)</li> <li>• Existence of (primordial) helium / lithium / lighter elements</li> <li>• Tiny variation (or ripples) in (background) temperature</li> </ul>	B1  B1 $\times$ 2	<b>Not:</b> More matter than antimatter / baryonic asymmetry
	<b>Total</b>	<b>9</b>	