Chapter 12 Past Paper Questions

2863 followed by G494

Jan 2001

10 This question is about evidence of a 'hot big bang' origin of the Universe.

(a) Fig. 10.1 shows how the speed of recession of galaxies, v, is related to distance, d, from the Earth.

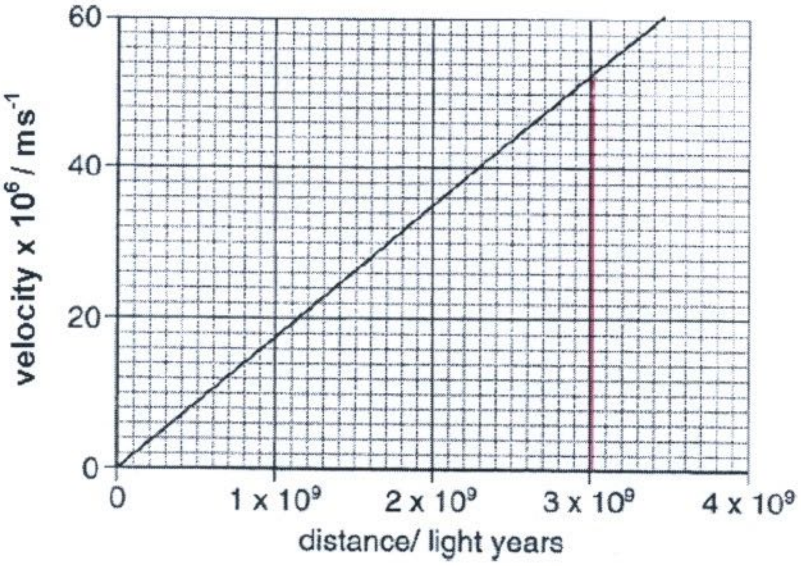


Fig 10.1

Use the graph to determine a value for the Hubble constant, H_0, where $v = H_0 d$

1 *light year* = 9.5×10^{15}m

gradient $= \dfrac{52\times10^{6}}{3\times10^{9}\times9.5\times10^{15}} = 1.824\times10^{-18}$

H_0= 1.8×10^{-18} units= s^{-1}

[3]

The recession of the galaxies was first observed by the astronomer Edwin Hubble in 1925. Since that time the strongest evidence for a hot big bang has come from observations of cosmological red shift and the cosmological microwave background.

(b) (i) Describe how the cosmological red shift is observed and explain how it supports the big bang model.

cosmological red shift is observed as cosmic microwave background radiation.
It is evidence of photons produced when the universe became cool enough to become transparent. They have red shifted such that they are now observed as microwave photons Such a large red shift implies a large velocity away from everything in the universe and hence a large expansion

(ii) The cosmological microwave background has been described as 'the biggest red-shift known'. It is detectable in all directions. Explain why the microwave background gives evidence of events further back in time than any other red shift observations.

It's a much greater red shift, the greater the red shift, the longer the time for the expansion.

[7]

Jan 2002

2 Here is a list of astronomical phenomena,

A red shift of distant galaxies

B microwave background radiation

C stellar parallax

D black holes

From the list, choose the phenomenon that gives the **clearest** evidence that the universe has evolved from an initial hot, uniform, dense state.

answer ....B.......... [1]

3 Which of the following is currently the best estimate for the age of the Universe?

A. 1.5×10^6 year **B** 1.5×10^8 year **C** 1.5×10^{10} year **D** 1.5×10^{12} year

answer ....B.......... [1]

5 The distance from Earth to a comet can be found by firing a pulse of radio waves at the comet and recording the time for the reflected pulse to return. On one occasion the pulse took 500 s to make the round trip.

(a) Show that the distance from Earth to the comet at the time of measurement was 7.5×10^{10} m.

$\frac{500}{2} = 250$s.

$d = 3 \times 10^8 \times 250 = 7.5 \times 10^{10}$ s.

[1]

(b) Describe how this technique could be used to find the speed of a comet which is directly approaching Earth.

Take two measurements ~~ato~~ a known time apart.

The change in distance in the time gives the average velocity

[2]

14 This question is about using the rate at which radiation emitted by stars (luminosity) is used to measure distances across the galaxy.

The luminosity of a type of star known as a 'Cepheid' oscillates periodically. The period of oscillation is related to the luminosity of the star.

(a) Study the data below.

Cepheid	period of oscillation of Cepheid / days	luminosity of Cepheid (Sun = 1)
A	1	200
B	5	1 500
C	10	10 000

Demonstrate how the data show that luminosity is **not** proportional to period.

$200 \times 5 \neq 1500$

or $1500 \times 2 \neq 10000$

or $200 \times 10 \neq 10000$

Luminosity does not increase in the same proportion as period

[2]

(b) The *apparent* brightness of a star depends upon its luminosity and its distance from Earth. The relationship is described by

$$\textit{Apparent brightness} \propto \frac{\textit{luminosity}}{(\textit{Distance from Earth})^2}$$

Cepheid *A*, with a period of 1 day has the same apparent brightness as Cepheid *B* with a period of 5 days.

The more distant star is 1×10^{21} m away from Earth.

Calculate the distance from the Earth to the nearer star.

$$\frac{\text{luminosity A}}{(\text{distance A})^2} = \frac{\text{luminosity B}}{(\text{distance B})^2}$$

$$\frac{200}{x^2} = \frac{1500}{(1 \times 10^{21})^2}$$

$$x = \sqrt{\frac{200 \times (1 \times 10^{21})^2}{1500}}$$

[3]

$$x = 3.65 \times 10^{20}$$

$$= 3.7 \times 10^{20} \text{ m.}$$

12 This question is about the expansion of the Universe.

(a) The speed of light is 3.0×10^8 m s^{-1}. Show that the distance light will travel through space in one year is about 10^{16} m.
(assume one year = 3.2×10^7 s)

$3 \times 10^8 \times 3.2 \times 10^7 = 9.6 \times 10^{15}$
$\simeq 10^{16}$ m.

[1]

(b) (i) During the past century it has been possible to observe galaxies which are receding from Earth.
One such galaxy is observed in the area of the sky known as Virgo. The distance to this galaxy is 10 000 million light years.
Explain why the galaxy is observed as it was 10 000 million years ago.

The light has taken 10 000 years to reach Earth.

(ii) Show that the galaxy is about 1.0×10^{26} m from Earth.

$1 \times 10^{16} \times 10\,000 \times 10^6 = 1 \times 10^{26}$ m.

[2]

(c) The light from the galaxy shows 'red-shift'. This is thought to be due to the expansion of space and is called 'cosmological red-shift'.

(i) Explain what is meant by 'red-shift'.

The increasing of the wavelength (or shift) of spectral lines towards the red end of the spectrum. 1

(ii) Explain how the expansion of space causes a cosmological red-shift.

As radiation travels through space, it's wavelength increases, as the univese expands 2

(iii) The cosmological red-shift is greater for galaxies further away from the Earth. Describe how the model of an expanding universe explains this observation.

The further away a galaxy is, the longer its light will have been travelling, so there will have been more time for the wavelength to stretch. 2.

[6]

(c) The Hubble Law, based on observation of cosmological red shifts, suggests that the universe is much older than the age of the stars measured by cosmochronometry.

The Hubble law suggests that the age of the universe is of the order $\frac{1}{H_0}$ where H_0 is the Hubble parameter.

Estimating the value of H_0 is an extremely important task. Until recently the values ranged from $1.6 \times 10^{-18}\,s^{-1}$ to $3.2 \times 10^{-18}\,s^{-1}$.

(i) Estimate the minimum and maximum age of the universe in years from the values of H_0.

$\frac{1}{1.6 \times 10^{-18}} = 6.25 \times 10^{17}\,s \div 31.536 \times 10^{6} = 1.98 \times 10^{10}$

$\frac{1}{3.2 \times 10^{-18}} = 3.125 \times 10^{17} \div 31.536 \times 10^{6} = 9.91 \times 10^{9}$

minimum age = 9.9×10^{9} years   maximum age = 2.0×10^{10} years [2]

11 This question is about measuring distances and velocities in the Universe.

Distances and velocities of planets and asteroids within the Solar System can be measured by radar pulses from Earth reflected from the distant objects.

(a) A radar pulse from Earth was aimed at an asteroid. The time interval between the pulse leaving the transmitter and the detection of the reflected pulse was 40.2 s.

Show that the distance to the asteroid at the time of measurement was about 6×10^9 m. State any assumption you make.

$c = 3.00 \times 10^8 \text{ m s}^{-1}$

- Assume speed of light is constant
- Assume trip time is same in both directions

$\frac{40.2}{2} = 20.1 \text{ s}$ $\quad 20.1 \times 3 \times 10^8 = 6.03 \times 10^9 \text{ m}$

[2]

(b) The measurement was repeated 14 minutes later. The time interval was then 40.0 s.

(i) Show that the change in distance between the Earth and the asteroid was about 3×10^7 m during the period the measurements were taken.

New distance $= 20.0 \times 3 \times 10^8 = 6.00 \times 10^9$

change in distance $= 6.03 \times 10^9 - 6.00 \times 10^9 = 0.03 \times 10^9$
$= 3 \times 10^7 \text{ m}$

[2]

(ii) Calculate the average velocity of approach of the asteroid at the time of the measurements.

av. velocity $= \frac{\Delta s}{\Delta t} = \frac{3 \times 10^7}{14 \times 60} = 35.71 \times 10^3$

average velocity = 35.7×10^3 m s^{-1} [2]

−1 mark if more than 3 sf.

(c) This radar-ranging method is impractical for measuring the distance or velocity of a star such as Sirius which lies about 7 light years from Earth.
Suggest **two** reasons why this is so.

There would be a long wait to get the signal back. (14 years)

Signal would be very weak by the time it got back to Earth.

[2]

(d) Distant galaxies are observed to be receding (moving away) from the Earth at high velocities. The velocity of a galaxy in deep space is calculated from its redshift. The distance d to the object can be determined from its velocity of recession v using the relationship

$$v = H_0 d$$

where H_0 is the Hubble constant.

(i) Galaxy Y is observed to be receding at a velocity of $1.0 \times 10^6 \, m \, s^{-1}$.

Show that the distance from the Earth to galaxy Y is about 4.5×10^{23} m.

In the year 2001, $H_0 = 2.2 \times 10^{-18} \, s^{-1}$.

$d = v/H_0 = \dfrac{1 \times 10^6}{2.2 \times 10^{-18}} = 4.5 \times 10^{23}$ m.

[1]

(ii) Observations of distant galaxies show how the galaxies appeared millions of years ago.

Use your answer to **(d)(i)** to explain why this is so.

1 year = 3.2×10^7 s

Light takes a long time to reach us from distant galaxies

For Y $t = \dfrac{4.5 \times 10^{23}}{3 \times 10^8} = 1.5 \times 10^{15}$ s

$\dfrac{1.5 \times 10^{15}}{3.2 \times 10^7} = 46.9 \times 10^6$ years

[2]

(e) The value of H_0 given in **(d)(i)** as $H_0 = 2.2 \times 10^{-18} \, s^{-1}$ is often given in the alternative form $H_0 = 70 \, km \, s^{-1} \, Mpc^{-1}$.

One megaparsec (Mpc) is an astronomical unit of distance equal to 3.1×10^{22} m.

Show that the value $70 \, km \, s^{-1} \, Mpc^{-1}$ is approximately equivalent to $2.2 \times 10^{-18} \, s^{-1}$.

$70 \, kms^{-1} \, Mpc^{-1}$

$\dfrac{70 \times 10^3}{3.1 \times 10^{22}} = 2.2 \times 10^{-18} \, s^{-1}$

[2]

4 Read the short passage and answer the questions below.

Most physicists accept the Hot Big Bang model of the origin of the Universe. Two pieces of evidence for this model are (i) the expansion of space and (ii) the microwave background radiation that is observed to be of almost equal intensity in all directions.

(a) State an observation that leads physicists to suggest that space is expanding.

Red shift.

[1]

(b) Explain why the second piece of evidence suggests that all the early Universe was at approximately the same temperature.

The microwave radiation is the photons remaining when the universe became transparent.
As their intensity is equally distributed now, it must have also been equally distributed earlier.

[2]

Jan 2005

7 The image in Fig. 7.1 comes from the COBE satellite. It shows the differences in the mean wavelength of microwave background radiation in different parts of the sky. The differences are very small.

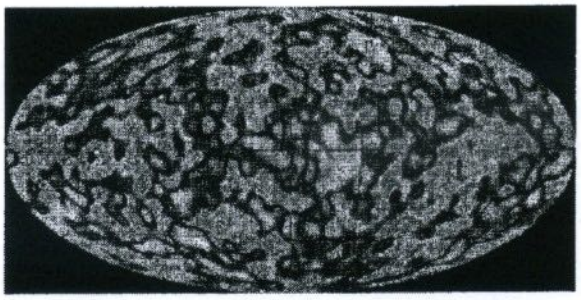


Fig. 7.1

(a) When the radiation was first emitted 300 000 years after the Big Bang during the so-called **era of recombination**, it was in the visible region of the spectrum. Explain why the visible radiation emitted during the era of recombination is now observed in the microwave region.

It's wavelength has stretched, as the universe has expanded.

[2]

(b) State and explain what the COBE data tell scientists about the temperature variation of the early Universe.

Temperature was almost uniform in the early universe since the intensity now is almost uniform.

[2]

June 2005

3 About three hundred thousand years after the Big Bang, the Universe was at a temperature of roughly 3000 K.

The photons emitted at that time are now observed to be at a temperature of around 3 K.

(a) Calculate the ratio $\dfrac{\text{energy of photons at 3 K}}{\text{energy of photons at 3000 K}}$ $\dfrac{3}{3000} = 0.001$

$E \propto T$

ratio = 0.001. [1]

(b) Calculate the ratio $\dfrac{\text{wavelength of photons at 3 K}}{\text{wavelength of photons at 3000 K}}$ $\dfrac{3000}{3} = 1000$

$\lambda \propto \dfrac{1}{E}$

ratio = 1000 [1]

(c) Suggest why the answer to **(b)** gives a measure of how the radius of the Universe has changed since the photons were emitted.

wavelength has stretched due to the expansion of the universe.

[1]

Jan 2006

1 The nearest star, Proxima Centauri, is at a distance of 4.3 **light years** from Earth.

Calculate the distance to Proxima Centauri in metres.

$c = 3.0 \times 10^8 \text{ m s}^{-1}$

1 year $= 3.2 \times 10^7$ s

$4.3 \times 3.2\times10^7 \times 3\times10^8$

distance = 4.1×10^{16} m [2]

June 2006

3 The speed of a comet approaching the Earth can be measured by reflecting radar pulses off the approaching body.

The tables give results from a pair of measurements to determine the speed of a comet directly approaching the Earth. The first measurement took place at 12:00 hours.

time pulse sent			time reflected pulse received		
hours	minutes	seconds	hours	minutes	seconds
12	00	00	12	00	55.0

time pulse sent			time reflected pulse received		
hours	minutes	seconds	hours	minutes	seconds
12	35	00	12	35	54.9

(a) Show that the distance to the comet at 12:00 hours was about 8.3×10^9 m.

$c = 3.00 \times 10^8 \text{ m s}^{-1}$

$3\times10^8 \times 55/2 = 8.250\times10^9$ m

$\simeq 8.3\times10^9$ m.

[2]

(b) Use the data in the tables to calculate the average velocity of approach of the comet during the measurement period.

average velocity $= \dfrac{\Delta s}{\Delta t} = \dfrac{8.250\times10^9 - 8.235\times10^9}{35\times60} = 7.1\times10^3 \text{ ms}^{-1}$

2nd ~~distan~~ distance $= 3\times10^8 \times 54.9/2 = 8.235\times10^9$ m

average velocity = ... m s^{-1} [2]

OR// $v = \dfrac{0.05 \times 3\times10^8}{35\times60} = 7.1\times10^3 \text{ ms}^{-1}$

5 Hubble's Law states that the velocity of recession of a galaxy is proportional to the distance to the galaxy as measured from Earth. The further away a galaxy is, the faster it recedes from us.

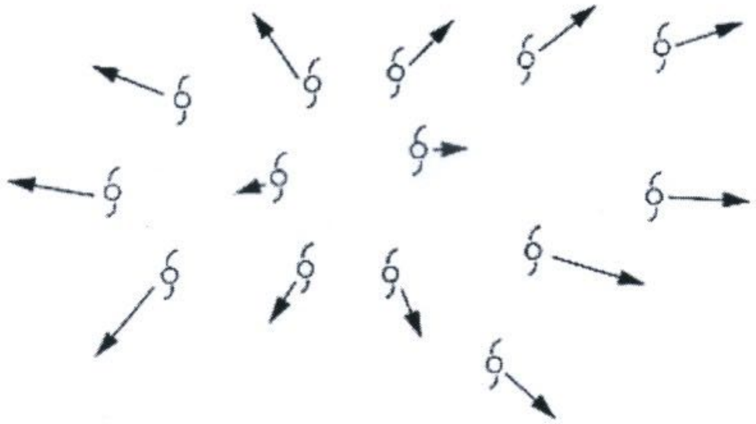


Fig. 5.1

Hubble's Law can be written as

$$v = H_0 d$$

where v is the velocity of recession
d is the distance from Earth
H_0 is the Hubble constant = $2.2 \times 10^{-18}\ s^{-1}$.

(a) State the observational evidence that supports Hubble's Law.

Red shift.

[1]

(b) The value of $1/H_0$ gives an estimate of the time passed since all the galaxies were close together. This gives an estimate of the age of the Universe.

Use the value of H_0 to estimate for the age of the Universe in years.
1 year = 3.2×10^7 s

$\frac{1}{2.2 \times 10^{-18}} = 4.5 \times 10^{17}$

$\frac{4.5 \times 10^{17}}{3.2 \times 10^{7}} = 1.4 \times 10^{10}$ years

[2]

(c) Suggest one reason why the age of the Universe may be larger than this value.

Galaxies formed some time after the universe began.

[1]

11 This question is about observations which suggest that space is expanding.

In 1929 Edwin Hubble (Fig. 11.1) suggested that distant galaxies were moving away (receding) from our own galaxy with velocities that are directly proportional to the distance to the galaxy. This is known as Hubble's law.

Fig. 11.1

Some data collected by Hubble are given in the table below.

	galaxy	distance to galaxy / light years	velocity of recession / m s^{-1}
1	NGC 221	9.0×10^5 0.039	2.0×10^5 0.09
2	NGC 379	2.3×10^7 0.16	2.2×10^6 10.4
3	Gemini cluster	1.4×10^8	2.3×10^7

(a) Propose and carry out an arithmetical test to decide if velocity of recession is directly proportional to distance.

test proposed:

~~The ratios~~ distance ratio = velocity ratio.

working:

1 to 2. $9 \times 10^5 / 2.3 \times 10^7 = 0.039$ $\quad$ $2 \times 10^5 / 2.2 \times 10^6 = 0.09$

2 to 3 $2.3 \times 10^7 / 1.4 \times 10^8 = 0.16$ $\quad$ $2.2 \times 10^6 / 2.3 \times 10^7 = 10.4.$

conclusion:

The ratios are quite different so the two are not directly proportional.

[4]

Hubble's Law can be written in the form

velocity of recession = $H_0 \times$ *distance from galaxy*

where H_0 is the Hubble constant.

The accepted value of H_0 in 2005 was $2.2 \times 10^{-18}\,s^{-1}$. This is considerably lower than Hubble's early results suggested.

(b) Use the data on the Gemini cluster given in the table to calculate a value for H_0. Show that this value is about eight times the modern value.

One light year is the distance light travels in one year.

1 year = 3.2×10^7 s
velocity of light = $3.0 \times 10^8\,ms^{-1}$

$V = H_0 \times$ distance.

$$H_0 = \frac{2.3 \times 10^7}{1.4 \times 10^8 \times 3 \times 10^8 \times 3.2 \times 10^7}$$

$$= 1.7 \times 10^{-17}\,s^{-1}$$

$$\frac{1.7 \times 10^{-17}}{8}$$

$$= 2.1 \times 10^{-18}\,s^{-1}$$

approx 8 × higher.

[3]

The speed of recession of the galaxies is found from observations of *redshift*. It is thought that distant galaxies show *cosmological redshift* which gives evidence that the speed of recession is due to the expansion of the Universe.

(c) (i) State what is meant by the term *redshift*.

increase in wavelength

[1]

(ii) Explain why the expansion of space will cause light from more distant galaxies to show greater redshift.

wavelength expands/lengthens as space expands.
The longer the time, the greater the expansion.

[2]

Jan 2008

2 Distant galaxies are observed to be receding from Earth at velocities approximately proportional to the distance from Earth. This relationship is shown in Fig. 2.1. Each point represents a galaxy.

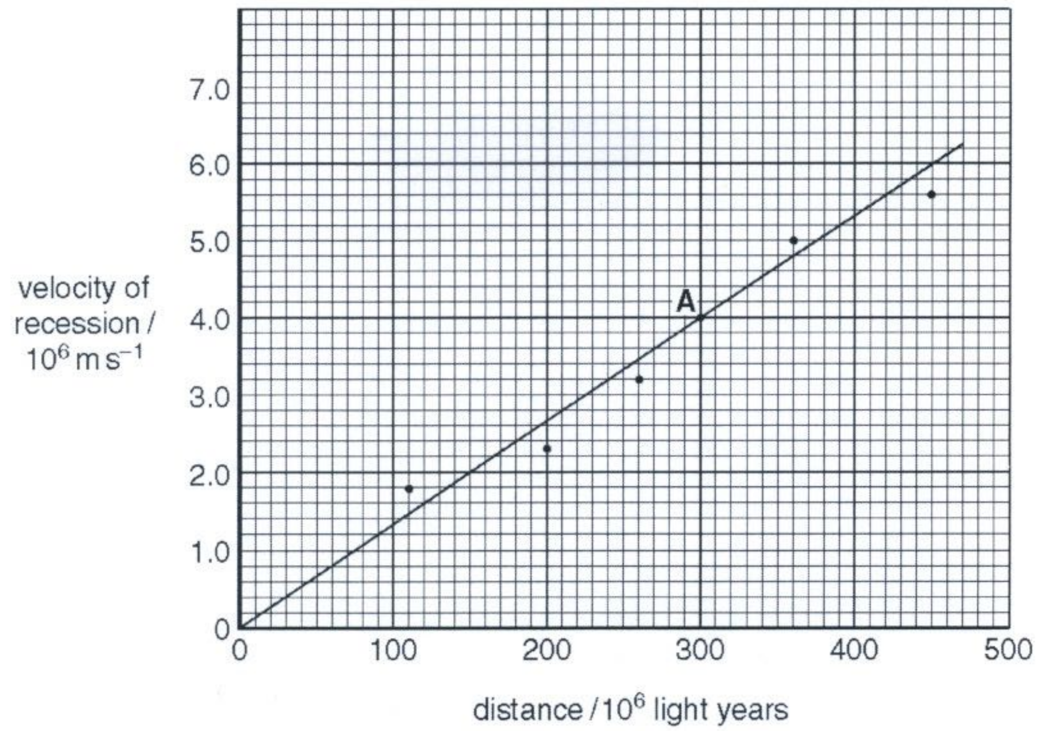


Fig. 2.1

(a) State the observational evidence that allows the velocities of distant galaxies to be calculated.

red shift

[1]

(b) Show that the galaxy represented by point **A** is about 3×10^{24} m from Earth.

1 light year = 9.6×10^{15} m

300×10^6 light years $\times 9.6 \times 10^{15}$

$= 2.88 \times 10^{24}$ m.

[1]

June 2008

11 This question is about the expansion of the Universe and measurements of its age.

Distant galaxies are observed to show redshifts. The further away a galaxy is the greater the redshift that is observed.

(a) (i) State what is meant by the term 'redshift'.

The lengthening of the wavelength of EM waves.

(ii) Use the concept of the expansion of space to explain

- the redshift of light from distant galaxies
- why light from more distant galaxies shows greater redshift.

wavelength increases as space itself expands.
The more distant the galaxy, the longer there has been for the wavelength of its light to expand.

[3]

(b) The Hubble Law states:

$v = H_0 d$

where v is the velocity of recession, d is the distance to the galaxy and H_0 is the Hubble constant.

Fig. 11.1 shows data for four galaxies.

distance/ m	velocity of recession / $km\,s^{-1}$	H_0 / s^{-1}
2.2×10^{24}	4000	1.8×10^{-18}
3.4×10^{24}	7500	2.2×10^{-18}
1.2×10^{24}	2600	2.2×10^{-18}
1.0×10^{24}	2200	2.2×10^{-18}

Fig. 11.1

Use the data to estimate a value for the Hubble constant H_0. Explain how you reached your value.

estimated value for H_0 = 2.2×10^{-18} s^{-1}

Reasoning:

convert distance to km.

$H_0 = v/d$

[3]

(c) $1/H_0$ gives an estimate of the time since all the galaxies were close together. This gives a lower limit on the age of the Universe.

(i) Use the value $H_0 = 2.2 \times 10^{-18}\,s^{-1}$ to estimate the time in years since the galaxies were close together.
1 year = 3.2×10^7 s.

$\frac{1}{2.2 \times 10^{-18}} = 4.5 \ldots \times 10^{17}$ $\qquad \frac{4.5 \times 10^{17}}{3.2 \times 10^{7}}$

time since galaxies were close together = 1.4×10^{10} years [2]

(ii) Suggest why this gives a **lower** limit for the age of the Universe.

Can only measure light from galaxies/stars and these were not formed at the start of the universe. [1]

Jan 2009

7 Asteroids are lumps of rocky material. Some are the size of mountains or even larger. Occasionally these asteroids pass near to the Earth.

The distance to an asteroid can be found by measuring the time for a radar pulse to travel to the asteroid and back. In one measurement the delay between the transmission of the pulse and receiving the reflected pulse was 53 seconds.

(a) Show that the asteroid was at a distance of about 8×10^9 m.

$c = 3.0 \times 10^8\ \mathrm{m\,s^{-1}}$

$t/2 = 26.5\mathrm{s}.$ $\quad d = 3 \times 10^8 \times 26.5$

$= 7.95 \times 10^9\ \mathrm{m}.$

[1]

(b) Suggest one factor that makes an accurate measurement of this distance difficult.

c could change as it travels through the atmosphere

or the asteroid could be moving

or the signal could be very weak by the time it returns to earth.

[1]

June 2009

1 Sirius is the brightest star visible in the night sky from Britain. It is about 1.1×10^{17} m from Earth.

Calculate the distance to Sirius in light years.

$c = 3.0 \times 10^8\ \mathrm{m\,s^{-1}}$

1 year = 3.2×10^7 s

1 light year = $3 \times 10^8 \times 3.2 \times 10^7 = 9.6 \times 10^{15}$ m.

$1.1 \times 10^{17} / 9.6 \times 10^{15} = 11.458$

$= 11.5$ light years

distance = ... light years **[2]**

6 Distant galaxies are observed to be moving away (receding) from the Earth at high velocities.

(a) State the observation that indicates that distant galaxies are receding from the Earth.

red shift.

[1]

(b) If the velocity of recession v of a distant galaxy is known, its distance from Earth can be determined using the relationship

$$v = H_0 d$$

where H_0 is the Hubble constant.

A galaxy, X, is at a distance of 4.5 x 10^{20} km and is observed to be receding at a velocity of about 1000 km s^{-1}.

Another galaxy, Y, is observed to recede at a velocity of about 800 km s^{-1}.

Calculate the distance to galaxy Y.

$H_0 = v/d = 1000/4.5 \times 10^{20} = 2.2 \times 10^{-18}$.

$d = v/H_0 = \frac{800}{2.2 \times 10^{-18}} = 3.6 \times 10^{20}$

distance to galaxy Y = ... km **[2]**

Jan 2010

3 Here is a list of astronomical phenomena:

A red shift of light from distant galaxies
B microwave background radiation
C stellar parallax
D black holes

From the list, choose the phenomenon that gives the clearest evidence that the Universe is expanding.

answer ......A.......... **[1]**

6 The nearest star, Proxima Centauri, is at a distance of 4.1×10^{16} m from Earth.

Calculate the distance to Proxima Centauri in **light years**.

$c = 3.0 \times 10^8$ m s^{-1}
1 year $= 3.2 \times 10^7$ s

1 light year $= 3 \times 10^8 \times 3.2 \times 10^7 = 9.6 \times 10^{15}$

$\frac{4.1 \times 10^{16}}{9.6 \times 10^{15}} = 4.27$

distance = ...4.3...... light years **[2]**

9 This question is about measuring distances and velocities in the Universe.

Distances and velocities of planets and other objects within the Solar System can be measured by radar pulses from Earth reflected from distant objects.

(a) A radar pulse from Earth was aimed at an asteroid. The time interval between the pulse leaving the transmitter and the detection of the reflected pulse was 42.4 s.

Show that the distance to the asteroid at the time of measurement was about 6.4×10^9 m. State any assumptions you make.

$c = 3.00 \times 10^8 \text{ m s}^{-1}$ Assuming c is constant

$t = \frac{42.4}{2} = 21.2\text{ s.}$

$d = 3 \times 10^8 \times 21.2 = 6.36 \times 10^9 \text{ m.}$

[2]

(b) The measurement was repeated 780 s later. The time interval had reduced to 42.2 s.

Calculate the average velocity of approach of the asteroid between the two measurements. Show your method clearly.

New distance $= 3 \times 10^8 \times 21.1 = 6.33 \times 10^9$.

average velocity $= \frac{6.36 \times 10^9 - 6.33 \times 10^9}{780} = 38.46 \times 10^3$

average velocity = 38×10^3 m s^{-1} **[3]**

(c) This radar-ranging method is impractical for measuring the distance or velocity of a star such as Sirius which lies about 7 light years from Earth.

Suggest **two** reasons why this is so.

The reflected signal would be very weak

The time delay for the return signal is very large.

[2]

(d) Distant galaxies are observed to be receding (moving away) from the Earth at high velocities. The velocity of recession of a galaxy in deep space is calculated from its red-shift.

Explain the meaning of the term *red-shift*.

increasing wavelength of light from stars/galaxies

[1]

(e) The distance d to a galaxy can be determined from its velocity of recession v using the relationship

$$v = H_0 d$$

where H_0 is the Hubble constant.

A galaxy is observed to be receding at a velocity of $9.0 \times 10^5\,\mathrm{m\,s^{-1}}$.

Calculate the distance to this galaxy.

$H_0 = 2.2 \times 10^{-18}\,\mathrm{s^{-1}}$

$d = v/H_0 = 9 \times 10^5 / 2.2 \times 10^{-18} = 4.09 \times 10^{23}$

distance = 4.1×10^{23} m **[2]**

(f) The value of H_0 given above is often given in the alternative form $H_0 = 70\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$.

One megaparsec (Mpc) is an astronomical unit of distance equal to $3.1 \times 10^{22}\,\mathrm{m}$.

Show that the value $70\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$ is approximately equivalent to $2.2 \times 10^{-18}\,\mathrm{s^{-1}}$.

$$\frac{70 \times 10^3}{3.1 \times 10^{22}} = 2.2 \times 10^{-18}\,s^{-1}$$

[2]

G494

Jan 2010

4 The relativistic time dilation factor γ is given by $\gamma = \dfrac{1}{\sqrt{1-\dfrac{v^2}{c^2}}}$.

(a) Show that the value of γ for a particle moving in a beam at a relative speed of $2.0 \times 10^8\,\mathrm{m\,s^{-1}}$ is about 1.3.

$c = 3.0 \times 10^8\,\mathrm{m\,s^{-1}}$

$$\gamma = \frac{1}{\sqrt{1-\dfrac{(2\times10^8)^2}{(3\times10^8)^2}}} = 1.3$$

[1]

(b) The particle is unstable and decays with a half-life $T_{½}$ of 8.2×10^{-7} s when it is at rest. Calculate the observed half-life of the particles moving in the beam.

$1.3 \times 8.2 \times 10^{-7}$

$= 1.066 \times 10^{-6}$

$T_{½}$ = 1.1×10^{-6} s **[1]**

8 The Universe is believed to be expanding, starting from an original 'hot big bang'.

Put ticks in the boxes next to the **two** statements which provide support for this picture of the Universe.

Distant and close galaxies are very similar in shape and structure.	☐
Microwave radiation from the Universe can be detected in all directions.	✓
Massive stars explode as supernovae at a certain point in their lifecycle.	☐
Much of the mass of the Universe does not appear to emit electromagnetic radiation.	☐
The red-shift of lines in a galaxy's spectrum is proportional to its distance from our galaxy.	✓

[2]

June 2010

11 This question is about measuring the relative velocity of asteroids.

An asteroid is displaced from its orbit around the Sun and heads towards Earth.

(a) A concerned astronomer uses radar to measure the distance of the asteroid from the Earth. This is the method:

- a short radar pulse is emitted at time 0.00 s
- an echo from the asteroid is detected at 8.00 s.

(i) On the axes of Fig. 11.1, draw two straight lines to show the space-time worldline of the radar pulse.

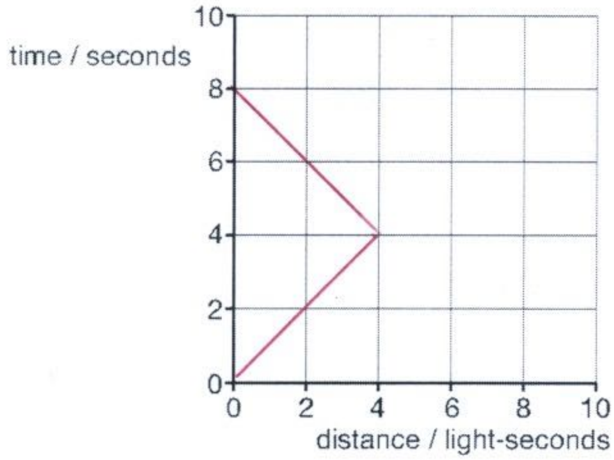


Fig. 11.1

[2]

(ii) Explain why the astronomer can assume that the radar pulse reflects off the asteroid at time 4.00 s.

speed of light is constant so time out to asteriod = time back.

[2]

(iii) Calculate the distance from the asteroid to the Earth at time 4.00 s.

$c = 3.00 \times 10^8 \, \text{m s}^{-1}$

$d = 3 \times 10^8 \times 4$

$= 12 \times 10^8$ m

distance = ...12×10^8........ m **[1]**

(b) The astronomer sends out a second pulse at time 946.33 s, receiving an echo at time 953.67 s.

(i) Explain how the astronomer's data show that the asteroid is getting closer to the Earth.

$$\begin{array}{r} 953.67 \\ -\ 946.33 \\ \hline 7.34 \end{array}$$

Time taken for journey has decreased by 0.66 seconds

[2]

(ii) Use the data to calculate the component of the velocity of the asteroid towards the Earth.

new distance $= 3 \times 10^8 \times \left(\frac{7.34}{2}\right) = 1.1 \times 10^9$

velocity $= \frac{12 \times 10^8 - 1.1 \times 10^9}{946.33} = 105.67 \times 10^3$

component velocity = 106×10^3 ms^{-1} **[2]**

(c) Explain how the astronomer could use the wavelength of a **single** radar echo to confirm the measurement of the asteroid's component of velocity towards the Earth.

measure the change in wavelength from doppler shift.

Use $z = \frac{\Delta\lambda}{\lambda} = \frac{v}{c}$ to calculate v.

[2]

Jan 2011

5 The Universe is believed to be expanding, starting from an original 'big bang'.

One piece of evidence for this is provided by the cosmological red-shift of galaxies.

(a) State what property of light is measured to determine the red-shift of a galaxy.

change in wavelength

[1]

(b) Explain how cosmological red-shift provides evidence for an original 'big bang'.

red shift and velocity increase as distance increases
Therefore if you go back in time all the galaxies
and stars were at the same point

[2]

13 This question is about time dilation for particles called muons moving at high speed.

(a) Muons are short-lived particles which are created when protons collide with nuclei at high energy. They decay randomly into electrons and anti-neutrinos, with a half-life of 1.5 μs. The process can be modelled with the expression

$$\frac{\Delta N}{\Delta t} = -\lambda N.$$

(i) Explain the meaning of the decay constant λ in the expression.

probability that a single nucleon will decay in one second.

[2]

(ii) Calculate the value of λ for the decay of a muon.

$$\frac{\ln 2}{1.5 \times 10^{-6}} = 462 \times 10^{-3}$$

$\lambda =$ ....462×10^{-3}.... s^{-1} **[1]**

(b) In a recent experiment, a beam of high-energy muons was created with a speed of almost $3.0 \times 10^{8}\,ms^{-1}$. They were trapped in a magnetic field so that they travelled in a circular path until they decayed into electrons. Non-relativistic calculations were made to estimate the time and distance for the muons to decay.

(i) Show that when only one-eighth of the original number of muons remain in the beam, they have travelled about 1.4 km.

The half-life of a muon is 1.5 μs.

To get to 1/8 requires 3 half lives

$3 \times 1.5 = 4.5\,\mu s.$

$3 \times 10^{8} \times 4.5 \times 10^{-6} = 1350\,m$

[3]

(ii) On the axes of Fig. 13.1, sketch a graph to show how the proportion of muons still in the beam should vary with the distance that they have travelled, assuming the non-relativistic calculation of **(i)**.

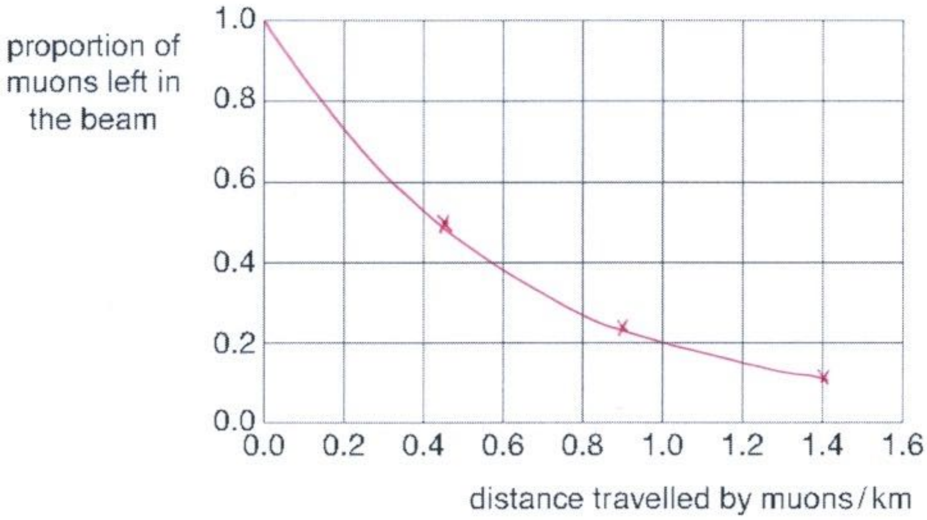


Fig. 13.1

[2]

(iii) The experiment shows that the non-relativistic calculation of **(i)** is wrong.

The muons in the beam are able to travel a distance of 4.0 km before only one-eighth of them are left undecayed. Use the formula

$$\gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}$$

to help explain why this is different from your answer to **(i)**.

Your answer should include a value for γ.

$\gamma = \frac{4}{1.35} = 2.96$

Due to the high speed, time dilation has occured and time runs nearly 3 × slower.

[3]

$2.96 = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}$

$1 - v^2/c^2 = 0.114$

$v^2/c^2 = 0.88$

$\frac{v}{c} = 0.94$

$v = 2.8 \times 10^8 \; ms^{-1}$

Jan 2012

7 The rate of rotation of a distant spiral galaxy, like that shown in Fig. 7.1, can be found by comparing the light from the left and right hand side of the galaxy.

Fig. 7.1

(a) Explain why there will be a difference in the redshift of the light from the left and right hand sides of the galaxy.

The whole galaxy is moving away but because it's spinning one side will be moving towards us relative to the other side. This results in more red shift for one side. **[2]**

(b) State what effect, if any, the motion of a distant galaxy relative to Earth has on the speed of light from it measured by observers on the Earth.

no effect, the speed of light is constant.

[1]

12 Fig. 12.1 shows the worldline of a spacecraft which passes the Earth and then returns.

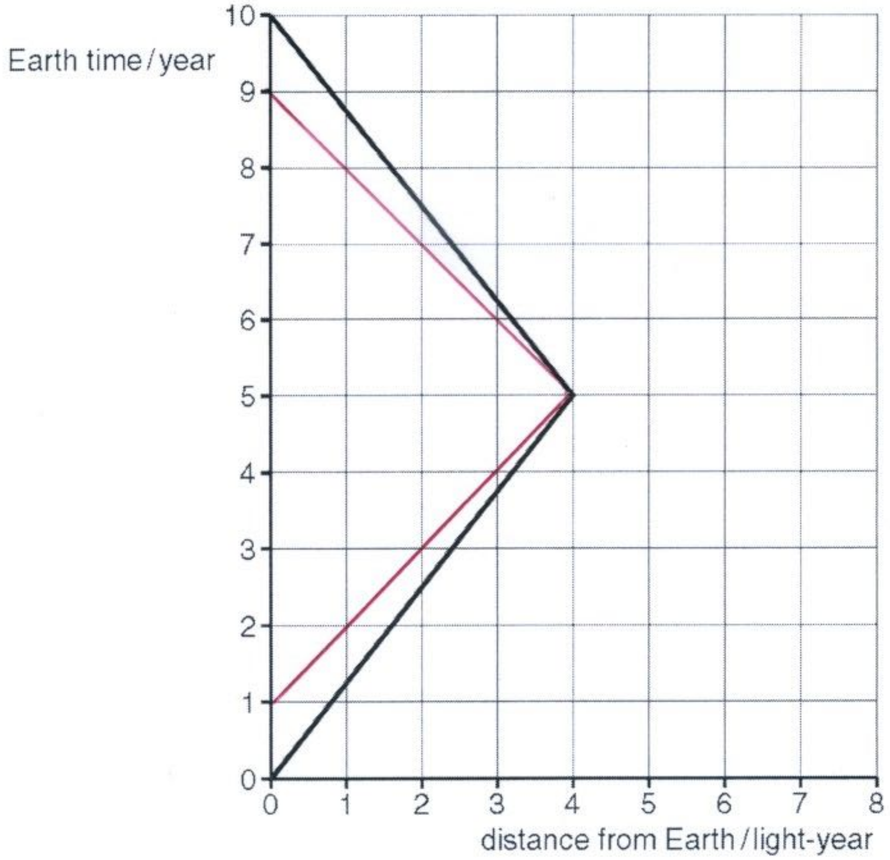


Fig. 12.1

Clocks on the Earth and spacecraft are zeroed at the instant that the spacecraft passes the Earth.

(a) The worldline for the spacecraft is a straight line until $t = 5$ year.
What does this tell you about the motion of the spacecraft?

It has constant velocity

[1]

(b) A single pulse of light is sent towards the spacecraft from the Earth when the Earth clock reads $t = 1.0$ year. It reflects off the spacecraft and returns to Earth.

(i) Why is the worldline for light always at 45° on Fig. 12.1?

light travels at one light year per year

[1]

(ii) Draw the complete worldline of the pulse of light on Fig. 12.1. **[2]**

(c) The arrival of the pulse of light at the spacecraft is the signal for it to turn around and return to the Earth.

(i) Explain how an observer on Earth can use the times of emission and reception of the pulse to calculate that the spacecraft was 4.0 light-year from the Earth when the pulse reached it.

total trip time = 9 - 1 = 8 years

So distance to spacecraft = 8/2 = 4 light years

[2]

(ii) Explain how an observer on the Earth can use the time of emission and return of the pulse to deduce that the spacecraft turned round when the Earth clock reads $t = 5.0$ year.

light reaches ship halfway though its journey = $\frac{9+1}{2}$ = 5 years.

OR ~~Plus~~ pulse sent out after 1 year, then takes 4 years to get there

[2]

(iii) Show that the outward speed of the spacecraft relative to the Earth is $2.4 \times 10^8\,\text{m s}^{-1}$.

$c = 3.0 \times 10^8\,\text{m s}^{-1}$

$$V = \frac{\text{distance}}{\text{time}} = \frac{4 \times 3 \times 10^8}{5} = 2.4 \times 10^8\ \text{ms}^{-1}$$

[1]

(d) (i) Show that the time dilation factor γ for a spacecraft travelling relative to the Earth at velocity $v = 2.4 \times 10^8\,\text{m s}^{-1}$ is about 1.7.

$$\gamma = \frac{1}{\sqrt{1 - v^2/c^2}} = \frac{1}{\sqrt{1 - \frac{2.4 \times 10^{8\,2}}{3 \times 10^{8\,2}}}} = 1.\dot{6}$$

$$= 1.7$$

[1]

(ii) Here are some possible times in year for the round trip according to observers on the spacecraft. Put a ring around the correct value.

6.0 **8.0** **10** **17**

[1]

$\frac{10}{1.7} = 5.88$

10 This question is about the Hubble law and the age of the Universe.

(a) The Hubble law can be expressed by the equation

$$v = H_0 r$$

where H_0 is the Hubble constant.

(i) What are the meanings of the terms v and r in the expression for the Hubble law?

v is (recessional) velocity of a galaxy

r is the distance of a galaxy

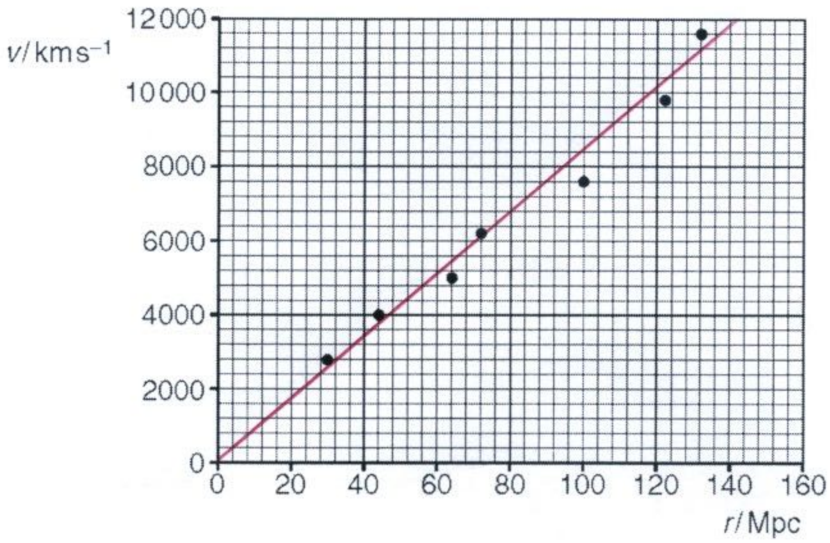
[2]

(ii) Show that the unit of the Hubble constant is s^{-1}.

$H_0 = \frac{v}{r} = \frac{ms^{-1}}{m} = s^{-1}$

[1]

(b) The graph of Fig. 10.1 gives some data for v and r.



line must go through origin.

Fig. 10.1

Use the graph to determine a value for the Hubble constant H_0.

1 MPc = 3.1×10^{22} m

$H_0 = \frac{v}{r} = \frac{12000 \text{ kms}^{-1}}{140 \text{ Mpc}} = \frac{12 \times 10^{6}}{140 \times 3.1 \times 10^{22}} = 2.76 \times 10^{-18}$

H_0 = ... 2.8×10^{-18} .... s^{-1} **[4]**

1 mark for line

$(2.4 \times 10^{-18} - 2.9 \times 10^{-18})$ = 3 marks

$(2.4 \times 10^{-21} - 2.9 \times 10^{-21})$ = 2 marks

$(7.5 \times 10^{4} - 8.8 \times 10^{4})$ = 2 marks $(75 - 88)$ = 1 mark.

(c) (i) Explain how the Hubble law $v = H_0 r$ supports the idea that the Universe started with a Big Bang.

It suggests that galaxies are moving apart

This means that earlier on they were in the same place.

[2]

(ii) If the value of v for a particular galaxy has remained constant, explain why the value of $\frac{1}{H_0}$ gives an estimate of the age of the Universe.

Galaxy will travel (at constant velocity) a known distance, r, in time t.

Since $t = r/v = 1/H_0$

[1]

(iii) Recent data from the Hubble telescope allows the value of H_0 to be determined as $2.40 \times 10^{-18}\,s^{-1}$. Use this value of H_0 to estimate the age of the Universe in years.

1 yr = 3.2×10^7 s

$\frac{1}{2.4 \times 10^{-18}} = 4.16 \times 10^{17}$ s $\qquad \frac{4.16 \times 10^{17}}{3.2 \times 10^{7}} = 1.3 \times 10^{10}$

age = 1.3×10^{10} yr **[1]**

Jan 2013

2 Here are some observations about the Universe.

Put ticks (✓) in the boxes next to the **two** observations which provide evidence for a big bang at the start of the Universe.

Some nearby galaxies emit blue-shifted light.	
Microwave radiation is detected from all directions in space.	✓
X-rays from galaxies imply the presence of black holes at their core.	
The red-shift of light from most galaxies increases with increasing distance.	✓
Most of the visible matter in the Universe appears to be clumped in galaxies.	

[2]

Q10

(d) Explain how you could use electromagnetic waves to verify that the radius of the Moon's circular orbit is 3.8×10^8 m.

Your answer should clearly explain how the radius is derived from the measurements.

Reflect EM radiation from the surface of the moon and measure the time it takes to return

$$\text{orbit radius} = \frac{\text{time of pulse}^*}{2} \times 3\times10^8$$

[3]

June 2013

3 The distance of an asteroid from the Earth can be measured by firing a pulse of electromagnetic radiation at the asteroid and measuring how long it takes for the pulse to return to Earth.

One of the following assumptions is needed to calculate the distance.

Put a tick (✓) in the box next to the **one** necessary assumption.

The asteroid is not moving relative to the Earth.	
None of the radiation is absorbed by the asteroid.	
The outward and returning pulses travel for the same time.	✓
The outward and returning pulses have the same wavelength.	

[1]

9 The idea that the Universe started with a hot big bang almost 14 billion years ago is now a widely accepted theory.

Explain how the cosmological background radiation provides evidence for this theory.

microwave background rahion is red shifted light from early on in the history of the universe.
It has been red-shifted due to the expension of space since the big bang.

[2]