# 13.2 **Measuring the Universe** Name _____

Past Paper Questions

- Describe and explain evidence for a 'hot big bang' origin of the universe from cosmological red-shifts (Hubble's law); cosmological microwave background.
- Make calculations and estimates of distances and ages of astronomical objects.

## Jan 2001 2863

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.

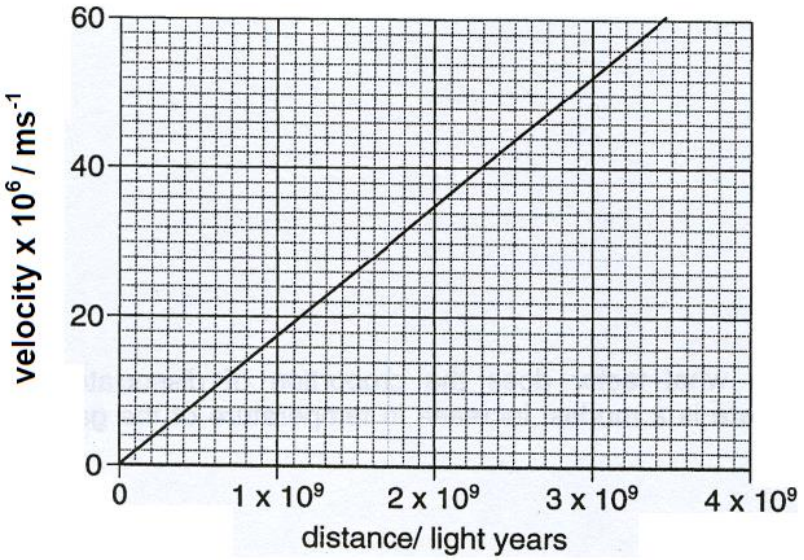


Fig 10.1

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

1 *light year* = $9.5 \times 10^{15}$m

*Ho*= ..... units= .....

[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.

(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.

[7]

**2863 June 2002**

12 This question is about the expansion of the Universe.

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

[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.

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

[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'.

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

(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.

[6]

**2863 June 2003 Q11**

**(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 $1.0 \times 10^6 \text{ m s}^{-1}$.

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

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

[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 = $3.2 \times 10^7$ s

[2]

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

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

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

[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.

[1]

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

[2]

**2863 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.

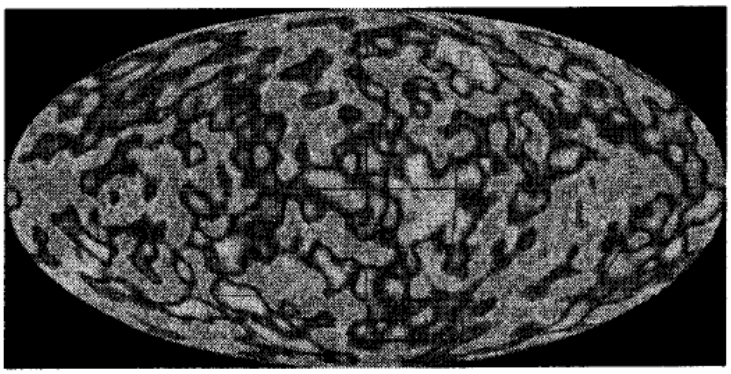

**Fig. 7.1**

**(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.

[2]

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

[2]

**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 $\dfrac{\text{energy of photons at 3 K}}{\text{energy of photons at 3000 K}}$

ratio = ..... [1]

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

ratio = ..... [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.

[1]

**2** Which of these ages is estimated correctly?

**A** The Earth is about 4 billion years old.

**B** The Sun is about 14 billion years old.

**C** The Milky Way Galaxy is about 20 billion years old.

**D** The Universe is about 20 billion years old.

Your answer ☐ **[1]**

**2863 June 2006**

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.

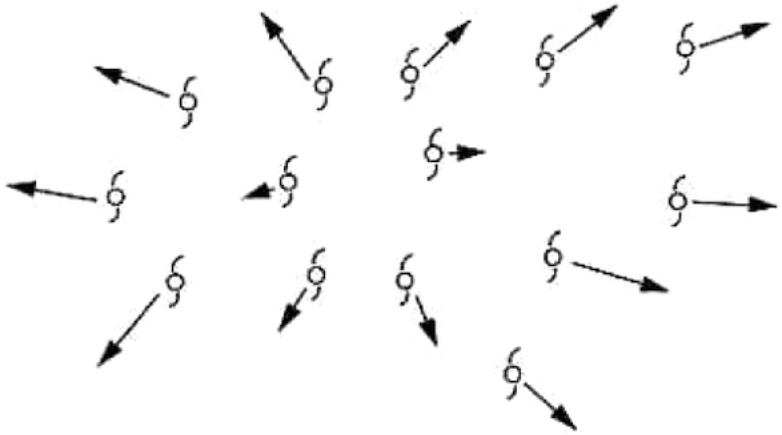

**Fig. 5.1**

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.

[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 = $3.2 \times 10^7$ s

[2]

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

[1]

**2863 Jan 2007**

**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.

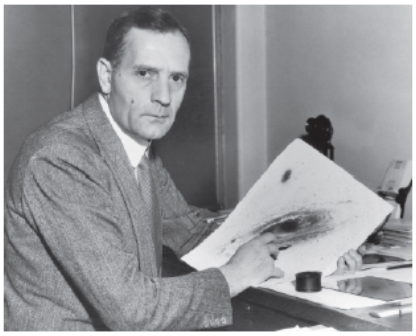



**Fig. 11.1**

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

| galaxy | distance to galaxy / light years | velocity of recession / $m\,s^{-1}$ |
|---|---|---|
| NGC 221 | $9.0 \times 10^5$ | $2.0 \times 10^5$ |
| NGC 379 | $2.3 \times 10^7$ | $2.2 \times 10^6$ |
| Gemini cluster | $1.4 \times 10^8$ | $2.3 \times 10^7$ |

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

test proposed:

working:

conclusion:

[4]

Hubble's Law can be written in the form

*velocity of recession* = $H_o$ × *distance from galaxy*

where $H_o$ is the Hubble constant.

The accepted value of $H_o$ 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 $H_o$. Show that this value is about eight times the modern value.

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

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

[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*.

[1]

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

[2]

**2863 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.

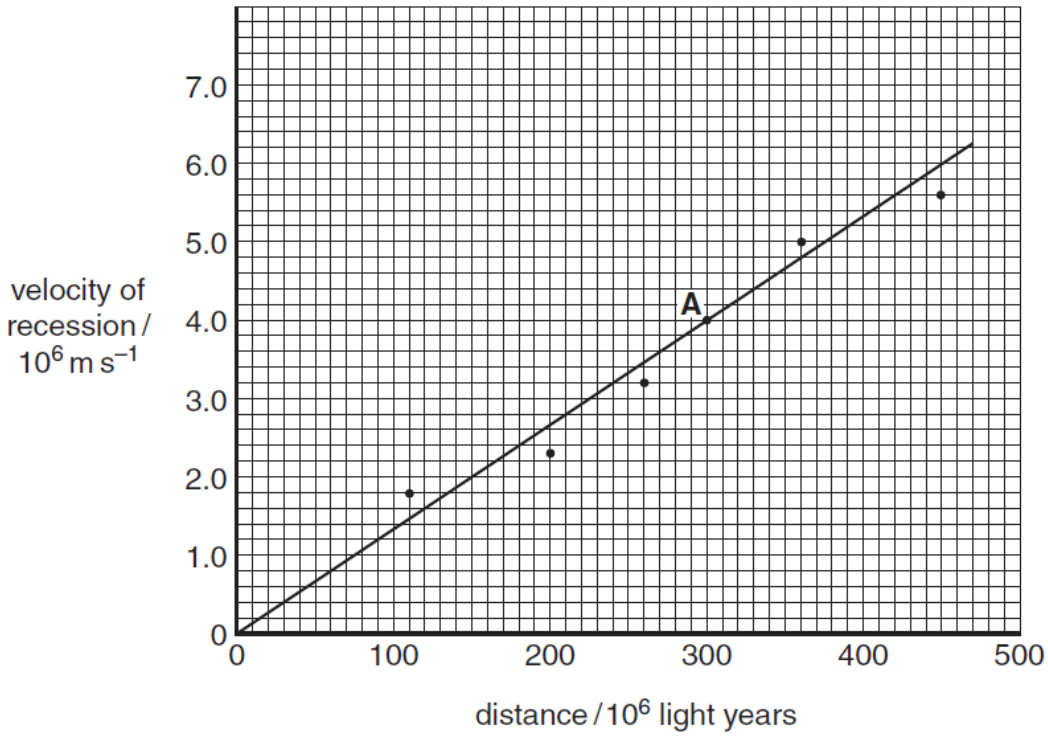


**Fig. 2.1**

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

[1]

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

1 light year = $9.6 \times 10^{15}$ m

[1]

**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'.

**(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.

[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$^{-1}$ |
|---|---|---|
| $2.2 \times 10^{24}$ | 4000 | $1.8 \times 10^{-18}$ |
| $3.4 \times 10^{24}$ | 7500 | |
| $1.2 \times 10^{24}$ | 2600 | |
| $1.0 \times 10^{24}$ | 2200 | |

**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 $H_0$ = ..... s$^{-1}$

Reasoning:

[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 = $3.2 \times 10^7$ s.

time since galaxies were close together = ..... years [2]

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

[1]

## 2863 June 2002

**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.

**[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 $4.5 \times 10^{20}$ 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.

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

## 2863 Jan 2010 (also used in 2002)

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

**2863 June 2010 (also used in 2003)**

**(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*.

**[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 $9.0 \times 10^5\,\text{m s}^{-1}$.

Calculate the distance to this galaxy.

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

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

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

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

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

**[2]**

## G494 Jan 2010

**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]**

## G494 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.

**[1]**

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

**[2]**

**G494 June 2011**

**8** A satellite in orbit around Mars uses pulses of light to map the surface of the planet.

**(a)** The satellite emits a brief pulse of light towards the surface.
The satellite detects a reflected pulse after a time delay of 840 μs.

Calculate the distance $d$ of the planet surface below the satellite.

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

$d =$ ..... m **[1]**

**(b)** State an assumption you have made in your calculation in **(a)**.

**[1]**

**(c)** Suggest how the satellite could use the pulses of light to check whether the altitude of its orbit was decreasing gradually.

**[1]**

**G494 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.

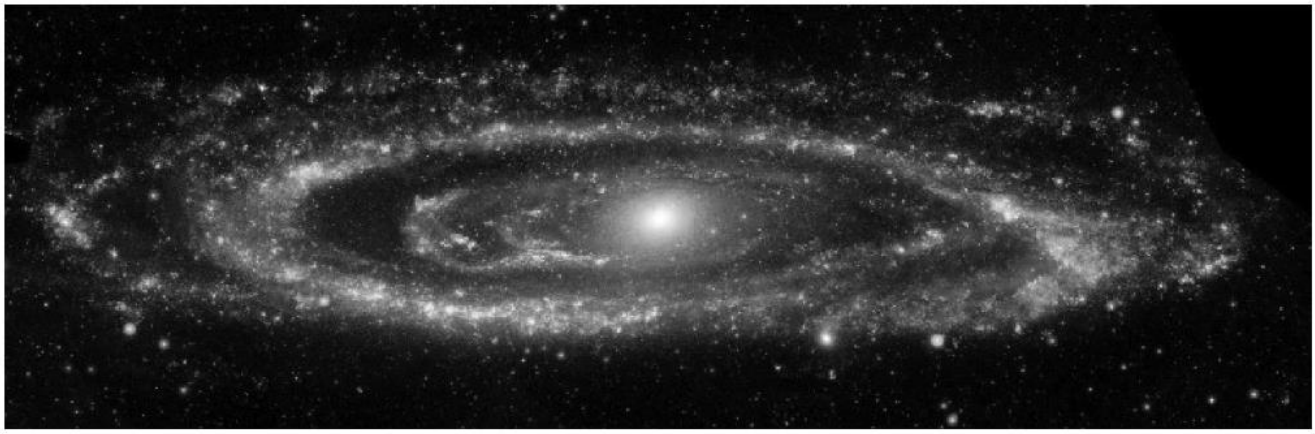

**Fig. 7.1**

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

**[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.

**[1]**

**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?

**[2]**

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

**[1]**

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

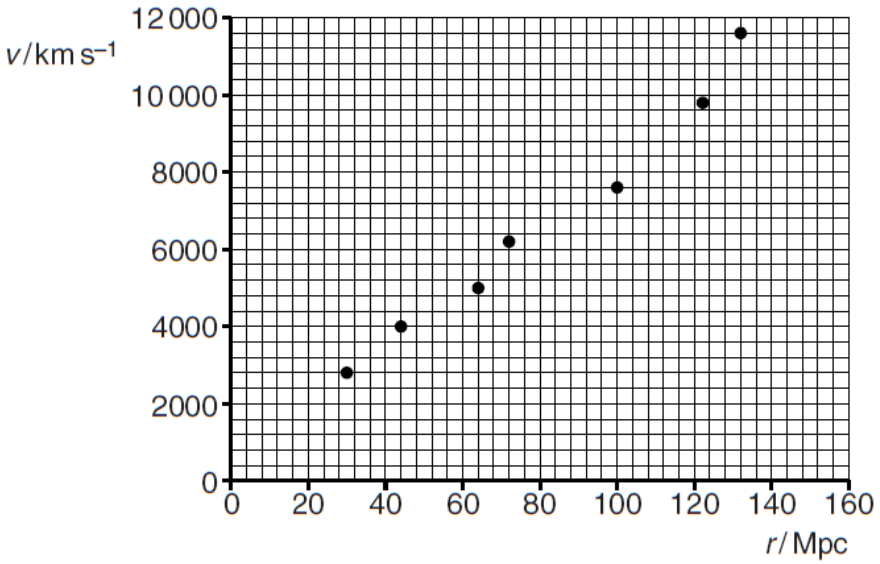


**Fig. 10.1**

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

1 MPc = $3.1 \times 10^{22}$ m

$H_0$ = ..... $s^{-1}$ **[4]**

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

**[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.

**[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.

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

age = ..... yr **[1]**

## G494 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]**

## G494 June 2014

**8** The recessional velocity of a distant galaxy is measured to be $3.5 \times 10^3 \,\text{km}\,\text{s}^{-1}$.

Use the age of the Universe ($14 \times 10^9$ years) to estimate the distance from Earth to this galaxy. State the assumption you have to make.

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

distance = ..... m **[3]**

## G494 June 2015

**2** The Big Bang theory states that the Universe has been expanding ever since it first appeared.

State and explain **one** piece of evidence for this theory.

**[2]**

## G494 June 2016

**7** The idea that the Universe started with a big bang almost 14 billion years ago is now a widely accepted theory.
Explain how the red shift of distant galaxies provides evidence for this theory.

**[2]**

## G494 June 2017

**4** Hydrogen atoms can emit ultraviolet light of wavelength 122 nm. A spectrum from a distant astronomical source shows that this light has been stretched to a wavelength of 420 nm.

**(a)** Calculate the factor by which the Universe has expanded since the light was emitted by the source.

factor = ..... **[1]**

**(b)** Explain why the cosmological redshift observed in light received from a source increases with the distance of the source from Earth.

**[2]**

## Specimen 557/01

**35** Theory suggests that about $14 \times 10^9$ years ago the Universe was much smaller than it is now and that the temperature of the Universe was about 3000 K. Since that time, the Universe has expanded and cooled to a background temperature of about 2.8 K.

**(a)** State the observation that suggests that the Universe is continuing to expand.

.....

.....

.....

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

**(b)** The energy of photons released in the very early Universe has reduced by a factor of about 1000. Calculate the factor by which the wavelength of the photons has changed during this time.

**[2]**

**36** This question considers some of the evidence for a Hot Big Bang start to our expanding universe.

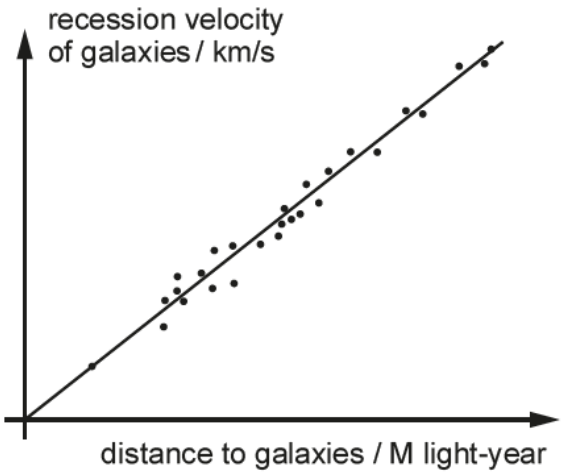


**Fig. 36.1**

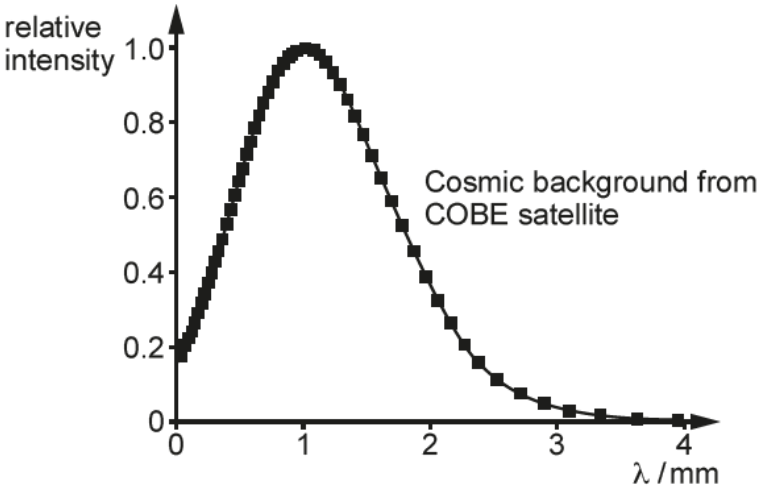


**Fig. 36.2**

**(a)** Explain how the graph(s) show evidence that the universe started from:

**(i)** a big bang expansion

.....

.....

.....

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

**(ii)** a hot state.

.....

.....

.....

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