

25.3 Hubble's law and the Big Bang theory

Name: _____ Class: _____ Date: _____

Total: 25 marks

KEY WORDS redshift

• hubble's law

• big bang

• recession

• spectral lines

Objective

Build the skills to answer exam questions on **redshift**, **Hubble's law** and the **Big Bang**.

You must be able to:

- use the **redshift** $\frac{\Delta\lambda}{\lambda} \approx \frac{v}{c}$
- use **Hubble's law** $v \approx H_0 d$
- explain how redshift and Hubble's law support the **Big Bang**

1 Worked examples

Study these first. Each one shows the method for a question type used later – follow the steps and you can do the Practice and Exam-style questions yourself.

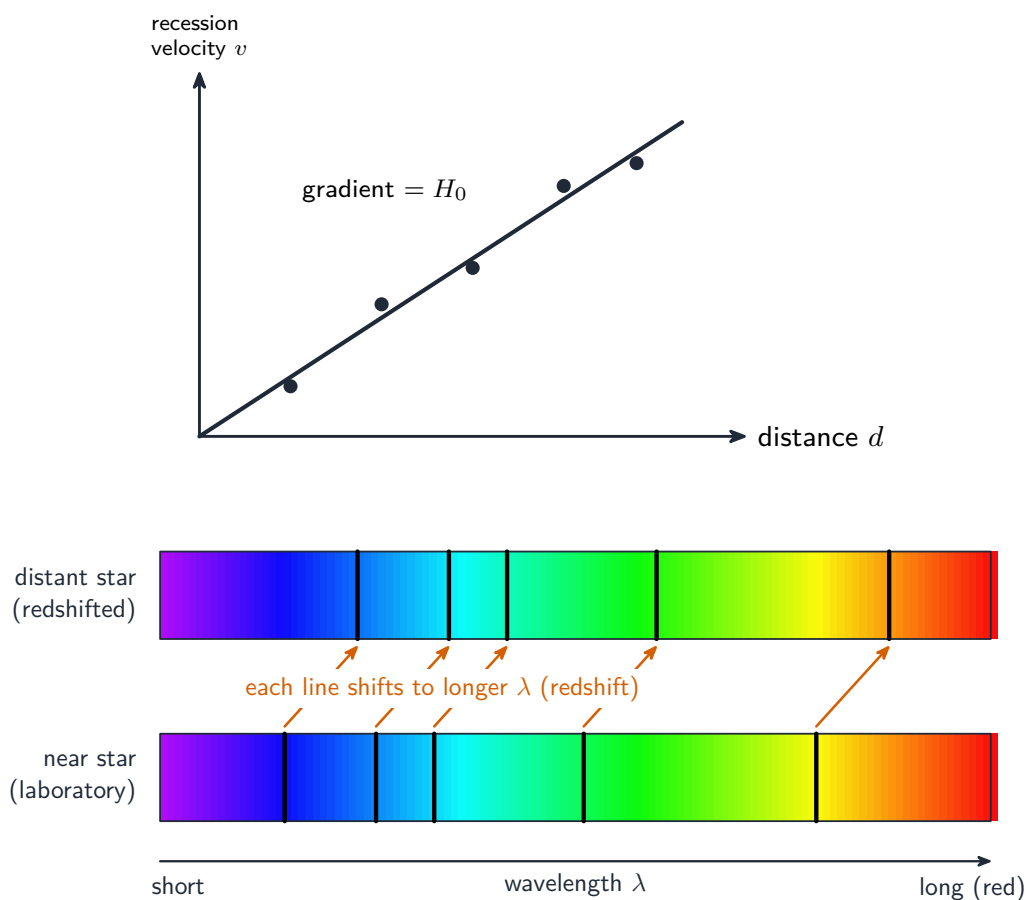
■ Redshift

The spectral lines of distant galaxies are at **longer** wavelengths than in the lab – a **redshift**, showing the galaxy is moving **away**. For $v \ll c$:

$$\frac{\Delta\lambda}{\lambda} \approx \frac{v}{c}, \quad \Delta\lambda = \lambda_{\text{observed}} - \lambda_{\text{emitted}}.$$

■ Hubble's law

The recession speed is **proportional to distance**:



Redshift in a galaxy spectrum

$$v \approx H_0 d.$$

Every galaxy moving away (faster if further) means the Universe is **expanding** – so in the past it was smaller and denser, leading to the idea that it began from a single point: the **Big Bang**.

2 Practice

Now apply the methods above.

2.1 State what is meant by **redshift**.

[1]

2.2 Write the **redshift** equation linking $\Delta\lambda$, λ and v .

[1]

2.3 Write **Hubble's law**. [1]

2.4 State what the redshift of distant galaxies tells us about the Universe. [1]

3 Exam-style questions

3.1 The redshift of distant galaxies is evidence that: [1]

- ☐ **A** the Universe is static
B the Universe is expanding
C galaxies are approaching us
D light slows down over distance

3.2 A spectral line emitted at 4.62×10^{-7} m is observed at 4.91×10^{-7} m. Calculate the **recession velocity** of the source. [3]

3.3 A galaxy recedes at $2.0 \times 10^7 \frac{\text{m}}{\text{s}}$. Taking $H_0 = 2.2 \times 10^{-18} \text{ s}^{-1}$, calculate its **distance**. [2]

3.4 Explain how **Hubble's law** leads to the **Big Bang** theory. [3]

3.5 A spectral line emitted at 486.1 nm in the laboratory is observed at 492.6 nm in the light from a distant galaxy. Take $c = 3.00 \times 10^8 \frac{\text{m}}{\text{s}}$ and the Hubble constant as $2.3 \times 10^{-18} \text{ s}^{-1}$.

(a) **State** Hubble's law. [2]

(b) **Explain** why the observed and emitted wavelengths differ. [2]

(c) **Determine** the speed of the galaxy relative to the Earth, and state whether it is approaching or receding. [3]

(d) **Determine** the distance of the galaxy from the Earth. [2]

(e) **Suggest** why an estimate of the age of the Universe can be made from the Hubble constant, and **state** one assumption that estimate depends on. [3]

Solutions

Each answer shows the steps, then the **result**.

2.1

- the **increase in wavelength** of light from a source moving **away** from the observer

2.2

- $\Delta\lambda/\lambda \approx v/c$

2.3

- $v \approx H_0 d$

2.4

- it is **expanding** (galaxies are moving apart)

3.1 B

- Hubble's law means the **Universe is expanding**

3.2

- $\Delta\lambda = 4.91 \times 10^{-7} \text{ m} - 4.62 \times 10^{-7} \text{ m} = 0.29 \times 10^{-7} \text{ m}$

$$v = \frac{\Delta\lambda}{\lambda} c = \frac{0.29 \times 10^{-7} \text{ m}}{4.62 \times 10^{-7} \text{ m}} (3.0 \times 10^8 \frac{\text{m}}{\text{s}}) = \mathbf{1.9 \times 10^7 \frac{\text{m}}{\text{s}}}$$

3.3

- $d = v/H_0$

$$d = \frac{v}{H_0} = \frac{2.0 \times 10^7 \frac{\text{m}}{\text{s}}}{2.2 \times 10^{-18} \text{ s}^{-1}} = \mathbf{9.1 \times 10^{24} \text{ m}}$$

3.4

- all galaxies are moving **away**, faster the further they are
- so the Universe is **expanding** – in the past it was smaller and denser
- extrapolating back, everything began from a single point/event – the **Big Bang**

3.5

(a) the **recession speed** of a galaxy is **directly proportional to its distance** from us

- $v = H_0 d$, for galaxies far enough away

(b) the galaxy is **moving away** from us, so each wave takes slightly longer to reach us than the one before

- the waves are stretched, the observed wavelength is longer, and the light is **redshifted**

(c) $\Delta\lambda/\lambda = (492.6 - 486.1)/486.1 = 0.01337$

$$v = \frac{\Delta\lambda}{\lambda}c = 0.01337 \times 3.00 \times 10^8 \frac{\text{m}}{\text{s}} = \mathbf{4.0 \times 10^6 \frac{m}{s}}$$

- **receding** – the wavelength has increased

(d) $d = v/H_0$

$$d = \frac{v}{H_0} = \frac{4.01 \times 10^6 \frac{\text{m}}{\text{s}}}{2.3 \times 10^{-18} \text{ s}^{-1}} = \mathbf{1.7 \times 10^{24} \text{ m}}$$

(e) if every galaxy has been moving apart at a constant speed since the beginning, the time since they were all together is $d/v = 1/H_0$

- which gives about 4.3×10^{17} s, roughly 14 billion years
- it assumes the expansion rate has **not changed** over that time