25.3 Hubble's law and the Big Bang theory

Name: ______ Class: ______ Date: ______ **Total: 25 marks**

KEY WORDS redshift 红移 • hubble's law 哈勃定律 • big bang 大爆炸 • recession 退行 • spectral lines 谱线

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** $\dfrac{\Delta\lambda}{\lambda} \approx \dfrac{v}{c}$
- 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.

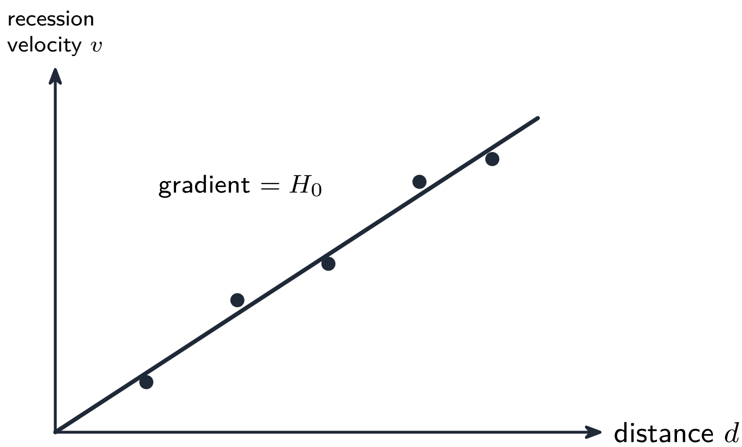
Redshift

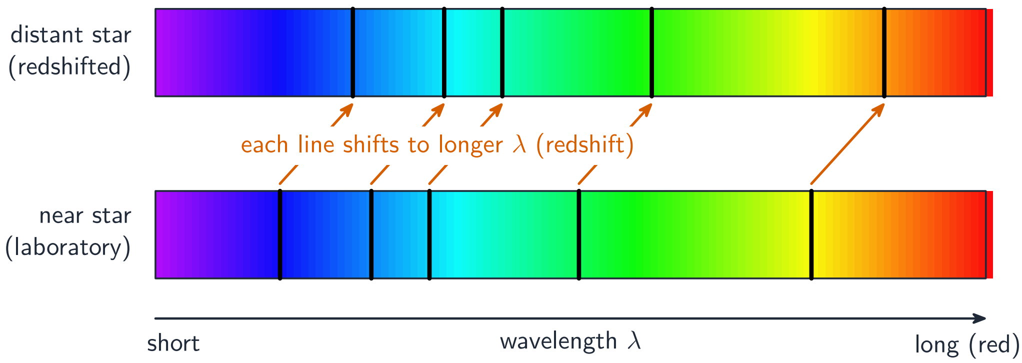
The spectral lines of distant galaxies are at **longer** wavelengths than in the lab — a **redshift**, showing the galaxy is moving **away**. For $v \ll c$:

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

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 2.0×10^{7} m s^{-1}. Taking $H_0 = 2.2 \times 10^{-18}$ 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 $c = 3.00 \times 10^8$ m s^{-1} and the Hubble constant as 2.3×10^{-18} 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

2.1 The **increase in wavelength** of light from a source moving **away** from the observer.

2.2 $\dfrac{\Delta\lambda}{\lambda} \approx \dfrac{v}{c}$.

2.3 $v \approx H_0 d$.

2.4 It is **expanding** (galaxies are moving apart).

3.1 **B** — the Universe is expanding.

3.2 $\Delta\lambda = 4.91 \times 10^{-7} - 4.62 \times 10^{-7} = 0.29 \times 10^{-7}$ m; $v = \dfrac{\Delta\lambda}{\lambda}c = \dfrac{0.29 \times 10^{-7}}{4.62 \times 10^{-7}}(3.0 \times 10^{8})$ $= 1.9 \times 10^{7}$ m s^{-1}.

3.3 $d = \dfrac{v}{H_0} = \dfrac{2.0 \times 10^{7}}{2.2 \times 10^{-18}} = 9.1 \times 10^{24}$ 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) $\dfrac{\Delta\lambda}{\lambda} = \dfrac{492.6 - 486.1}{486.1} = 0.01337$; $v = \dfrac{\Delta\lambda}{\lambda}c = 0.01337 \times 3.00 \times 10^{8} = 4.0 \times 10^{6}$ m s^{-1}, **receding** — the wavelength has increased.
(d) $d = \dfrac{v}{H_0} = \dfrac{4.01 \times 10^{6}}{2.3 \times 10^{-18}} = 1.7 \times 10^{24}$ m.
(e) If every galaxy has been moving apart at a constant speed since the beginning, the time since they were all together is $\dfrac{d}{v} = \dfrac{1}{H_0}$, which gives about 4.3×10^{17} s, roughly 14 billion years. It assumes the expansion rate has **not changed** over that time.