A-LEVEL PHYSICS • EXERCISE SHEET

# 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** $\frac{\Delta\lambda}{\lambda} \approx \frac{v}{c}$
- 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

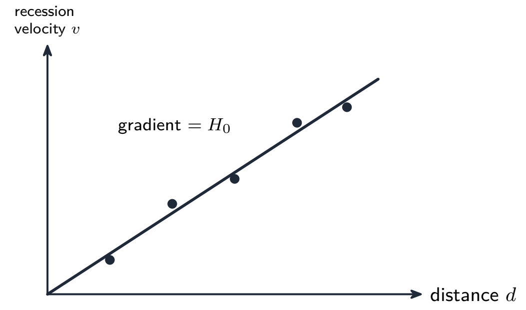
The spectral lines of distant galaxies are at **longer** wavelengths than in the lab — a **redshift**, showing the galaxy is moving **away**. For $v \ll c$:

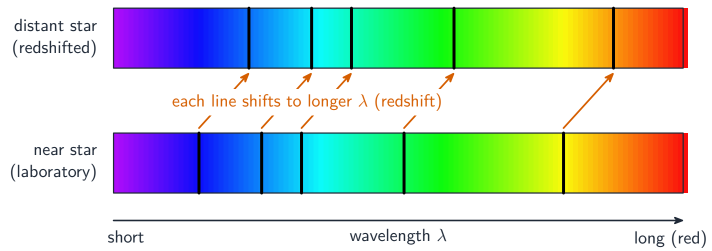
$$\frac{\Delta\lambda}{\lambda} \approx \frac{v}{c}, \qquad \Delta\lambda = \lambda_{\text{observed}} - \lambda_{\text{emitted}}.$$

### 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 $\Delta\lambda$, $\lambda$ 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 $4.62 \times 10^{-7}$ m is observed at $4.91 \times 10^{-7}$ m. Calculate the **recession velocity** of the source. [3]

**3.3** A galaxy recedes at $2.0 \times 10^{7}$ 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 $2.3 \times 10^{-18}$ 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

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**

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

$$v = \frac{\Delta\lambda}{\lambda}c = \frac{0.29 \times 10^{-7}\ \text{m}}{4.62 \times 10^{-7}\ \text{m}}(3.0 \times 10^{8}\ \text{m s}^{-1}) = \mathbf{1.9 \times 10^{7}}\ \text{m s}^{-1}$$

**3.3**

- $d = v/H_0$

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

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

$$v = \frac{\Delta\lambda}{\lambda}c = 0.01337 \times 3.00 \times 10^{8}\ \text{m s}^{-1} = \mathbf{4.0 \times 10^{6}}\ \text{m s}^{-1}$$



- **receding** — the wavelength has increased

(d) $d = v/H_0$

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

(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 $4.3 \times 10^{17}$ s, roughly 14 billion years
- it assumes the expansion rate has **not changed** over that time