

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