Past-paper walk-through

Hubble's law and the Big Bang theory ▪ 25.3

eXercise

Questions in this set

- 9702/41 J25 Q10 ▪ 10 marks
- 9702/43 N24 Q10 ▪ 10 marks

Reading the mark scheme

- **B1** a mark that stands on its own – the point is either made or not.
- **M1** a *method* mark: the right approach, even if the number is wrong.
- **A1** an *answer* mark, and it usually needs its M mark first.
- **C1** a working mark on the way to the answer.
- // separates answers the examiner accepts equally.
- **ecf** = error carried forward: a later part is marked on your own earlier answer.
- **owtte** = "or words to that effect" – the wording need not match.

Question 10

9702/41 J25 ▪ Q10 ▪ 10 marks

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

(b)(i) Explain why the observed wavelength and the emitted wavelength have different values. **[2]**

(b)(ii) Calculate the speed of the star relative to the Earth. **[2]**

(b)(iii) The wavelength of maximum intensity of emission is used to determine a value for the surface temperature of the star.

Explain how the temperature determined using the observed wavelength compares with the true value of temperature determined using the emitted wavelength. **[2]**

(c) A value for the Hubble constant is 2.3×10^{-18} s^{-1}.

Use your answer in **(b)(ii)** to determine the distance of the star in **(b)** from the Earth. **[2]**

Solution 10

(a)

Mark scheme

- speed is (directly) proportional to distance **M1**
- speed is speed of recession of galaxy from an observer, and distance is the distance of the galaxy from the observer **A1**

Solution 10

(b)(i)

Mark scheme

- galaxy is receding from the Earth **B1**
- observed wavelength is redshifted from emitted wavelength **B1**

Solution 10

(b)(ii) Worked steps

Redshift relates the **fractional** change in wavelength to the speed as a fraction of the speed of light.

- $\dfrac{\Delta\lambda}{\lambda} = \dfrac{v}{c}$
- $\Delta\lambda = 4.91 - 4.62 = 0.29$ (in whatever unit the two are quoted — the ratio is what matters, so no conversion is needed)
- $\dfrac{0.29}{4.62} = \dfrac{v}{3.00 \times 10^{8}}$
- $v = 1.9 \times 10^{7}\ \mathrm{m\,s^{-1}}$

Solution 10

Divide by the **emitted** wavelength, not the observed one: λ in the formula is the laboratory value the shift is measured from. The difference is small here, but it is the difference between a method mark and none.

Mark scheme

- $\Delta\lambda$ / λ = v / c
- (4.91 – 4.62) / 4.62 = v / (3.00 × 108) **C1**
- v = 1.9 × 107 m s–1 **A1**

Solution 10

(b)(iii) Worked steps

Wien's displacement law makes this a one-step comparison.

- $\lambda_{\max} T =$ constant, so $\lambda_{\max} \propto \dfrac{1}{T}$ — the peak wavelength and the temperature are **inversely** proportional.
- The star is receding, so the observed peak wavelength is **longer** than the emitted one.
- A longer wavelength substituted into Wien's law gives a **lower** temperature.

So the temperature found from the observed wavelength is **too low** compared with the true value.

Solution 10

Both marks are for the reasoning, not the conclusion: state the inverse proportionality, then say which way the wavelength moved. A bare "too low" earns one mark at most.

Mark scheme

- wavelength (of maximum intensity) is inversely proportional to temperature **B1**
- observed wavelength too high, so determined temperature too low **B1**

Solution 10

(c) Worked steps

Hubble's law connects recession speed to distance directly.

- $v = H_0 d$, so $d = \dfrac{v}{H_0}$
- $d = \dfrac{1.9 \times 10^{7}}{2.3 \times 10^{-18}}$
- $d = 8.3 \times 10^{24}$ m

Solution 10

The Hubble constant is given in s^{-1}, so the answer comes out in metres with no conversion — which is why the question quotes it that way rather than in $km\,s^{-1}\,Mpc^{-1}$.

Use your own speed from (b)(ii); the mark is for the method.

Mark scheme

- v = H0d **C1**
- d = (1.9 × 107) / (2.3 × 10–18)
- = 8.3 × 1024 m **A1**

Question 10

9702/43 N24 ▪ Q10 ▪ 10 marks

This question is about redshift and the expansion of the Universe.

(a) Explain how redshift leads to the idea that the Universe is expanding. **[3]**

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

(b)(ii) Determine the speed v of the galaxy relative to the Earth. **[2]**

(c)(i) On Fig. 10.1, sketch the variation of v with d. **[2]**

(c)(ii) State the name of the quantity represented by the gradient of the line in Fig. 10.1. **[1]**

Solution 10

(a)

Mark scheme

- redshift is the increase in observed wavelength / decrease in observed frequency (caused by Doppler effect)
- radiation from distant galaxies is observed to be redshifted
- redshift provides evidence that galaxies are moving apart
- galaxies moving apart means Universe must be expanding

Any three points, 1 mark each

Solution 10

(b)(i) Worked steps

Know. The galaxy's light spreads out over a sphere as it travels, so the flux measured at the Earth falls as the inverse square of the distance.

Equation. $F = \dfrac{L}{4\pi d^2}$, so $d = \sqrt{\dfrac{L}{4\pi F}}$.

Solution 10

Substitute. $d = \sqrt{\dfrac{1.90 \times 10^{36}}{4\pi(8.42 \times 10^{-16})}}$.

Answer. $d = 1.34 \times 10^{25}$ m.

Solution 10

Check. Take the square root at the end. Stopping at 1.8×10^{50} leaves a distance **squared**, and the size of the number is the giveaway: no distance in the observable Universe reaches 10^{27} m.

Mark scheme

- $F = L/4\pi d^2$
- $d = \sqrt{1.90 \times 10^{36}/[4\pi \times 8.42 \times 10^{-16}]}$
- $= 1.34 \times 10^{25}$ m

Solution 10

(b)(ii) Worked steps

Know. The spectral line arrives stretched, and the fraction it has stretched by equals the speed of recession as a fraction of the speed of light.

Equation. $\dfrac{\Delta\lambda}{\lambda} = \dfrac{v}{c}$.

Substitute. $\dfrac{726 - 658}{658} = \dfrac{v}{3.00 \times 10^8}$.

Solution 10

Answer. $v = 3.1 \times 10^7$ m s^{-1}.
Check. That is about 10% of the speed of light, which is fast but not impossible for a distant galaxy. Dividing by the *observed* wavelength instead of the laboratory one changes the answer by only a few per cent here, but the laboratory value is the one in the definition.

Mark scheme

- $\Delta\lambda/\lambda = v/c$
- $(726 - 658)/658 = v/(3.00 \times 10^8)$
- $v = 3.1 \times 10^7$ m s^{-1}

Solution 10

(c)(i)

Worked steps

Know. Hubble's law states that recession speed is **directly proportional** to distance: $v = H_0 d$. Direct proportion means a straight line through the origin.
Draw. A single straight line with a positive gradient, starting at $(0,\ 0)$.
Gradient. The gradient is the Hubble constant H_0 itself, which is why plotting real galaxies this way is how it is measured.
Check. Both marks are in the shape: a line that misses the origin would say a galaxy at zero distance is already moving, and a curve would break the proportionality the law asserts.

Mark scheme

- line with positive gradient passing through the origin
- straight line with positive gradient

Solution 10

(c)(ii)

Mark scheme

- Hubble constant