Past-paper walk-through

Standard candles ▪ 25.1

eXercise

Questions in this set

- 9702/42 M25 Q10 ▪ 11 marks
- 9702/43 J24 Q10 ▪ 9 marks
- 9702/42 M23 Q10 ▪ 9 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

9702/42 M25 ▪ Q10 ▪ 11 marks

10 (a) (i) State what is meant by the luminosity of a star.

Question 10

(ii) Explain how standard candles are used to determine the distance to a galaxy.

Question 10

(b) The Sun rotates on its axis. Points X, Y and Z are on the equator of the Sun as shown in Fig. 10.1.

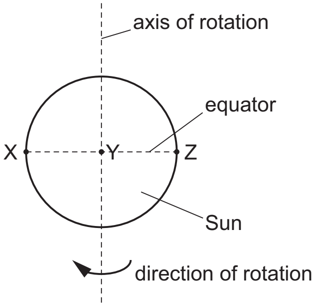

Fig. 10.1

Question 10

The wavelengths of light from points X and Y are observed and recorded in Table 10.1.

Table 10.1

observed wavelength from X / nm	observed wavelength from Y / nm
656.2877	656.2831

(i) The Sun rotates with a period of 2.07×10^{6} s.

Show that the radius of the Sun is 6.93×10^{8} m.

Question 10

Question 10

[3]

(ii) State and explain how the expected wavelength of the light observed from Z compares with the emitted wavelength.

Question 10

(iii) The luminosity of the Sun is 3.8×10^{26} W.

Use the information in **(b)(i)** to calculate the surface temperature of the Sun.

Question 10

[Total: 11]

Solution 10

(a)(i)

Mark scheme

- total power of radiation emitted (by the star)

Solution 10

(a)(ii) Worked steps

Three steps, and each is a mark:

- A standard candle is an object of **known luminosity** L.
- Measure the **radiant flux intensity** F received from it here.
- Use $F = \dfrac{L}{4\pi d^2}$ to find d — the only unknown left.

Solution 10

Mark scheme

- standard candle has known luminosity
- measure the radiant flux intensity
- use $F = L / (4\pi d\ 2)$ to calculate d

Solution 10

(b)(i) Worked steps

The shift gives the speed of the star's edge; the rotation period turns that into a radius.

- $\dfrac{\Delta\lambda}{\lambda} = \dfrac{v}{c}$, so $v = \dfrac{3.00 \times 10^8 \times (656.2877 - 656.2831)}{656.2831} = 2.10 \times 10^3$ m s^{-1}.
- A point on the equator travels $2\pi R$ in one period: $v = \dfrac{2\pi R}{T}$.
- $R = \dfrac{vT}{2\pi} = \dfrac{2.10 \times 10^3 \times 2.07 \times 10^6}{2\pi}$
- $R = 6.93 \times 10^8$ m

Solution 10

Mark scheme

- $v = 2\pi R / T$
- $v = 3.00 \times 108 \times (656.2877 – 656.2831) / 656.2831$
- $R = [3.00 \times 108 \times (656.2877 – 656.2831) / 656.2831] \times (2.07 \times 106) / 2\pi = 6.93 \times 108$ m

Solution 10

(b)(ii)

Mark scheme

- Z is moving towards Earth
- so observed wavelength is less than the emitted wavelength

Solution 10

(b)(iii) Worked steps

- $L = 4\pi R^2 \sigma T^4$, so $T = \left(\dfrac{L}{4\pi R^2 \sigma}\right)^{1/4}$.
- $T = \left(\dfrac{3.8 \times 10^{26}}{4\pi \times (6.93 \times 10^8)^2 \times 5.67 \times 10^{-8}}\right)^{1/4}$
- $T = 5800$ K

Solution 10

That is the Sun's surface temperature, which is the check worth making: the radius came out close to the Sun's too.

Mark scheme

- $L = 4\pi\sigma$ r 2T 4
- $3.8 \times 1026 = 4\pi \times 5.67 \times 10–8 \times (6.93 \times 108)2 \times$ T 4
- $T = 5800\,K$

Question 10

9702/43 J24 ▪ Q10 ▪ 9 marks

(a)(i) State what is meant by the luminosity of a star. **[2]**

(a)(ii) Explain how a standard candle in a distant galaxy can be used to determine the distance of the galaxy from an observer. **[3]**

(b)(i) Calculate the luminosity of the Sun. Give a unit with your answer. **[2]**

(b)(ii) Another star emits radiation that has a peak intensity at a wavelength of 624 nm.

Determine the surface temperature of this star. **[2]**

Solution 10

(a)(i)

Mark scheme

- total power
- power radiated (by the star)

Solution 10

(a)(ii) Worked steps

Know. A standard candle is an object whose **luminosity is already known** from its type, for example a type Ia supernova. That known power is the whole point: it turns a brightness measurement into a distance.

Step 1. The luminosity L of the standard candle is known.

Step 2. The observer measures the **radiant flux intensity** F arriving at the Earth, that is, the power received per unit area.

Solution 10

Step 3. The two are linked by $F = \dfrac{L}{4\pi d^2}$, so $d = \sqrt{\dfrac{L}{4\pi F}}$.

Solution 10

Check. All three marks are separate statements, so write all three. Saying only "compare the brightness with the known value" describes the idea but names neither quantity and earns one mark at most.

Mark scheme

- standard candle has known luminosity
- radiant flux intensity measured by observer
- (distance calculated using) $F = L/4\pi d^2$

Solution 10

(b)(i) Worked steps

Know. Treat the Sun as a black body: its luminosity depends on its surface area and on the fourth power of its surface temperature.
Equation. $L = 4\pi\sigma r^2 T^4$, with σ the Stefan-Boltzmann constant.
Substitute. $L = 4\pi \times (5.67 \times 10^{-8}) \times (6.96 \times 10^8)^2 \times (5780)^4$.
Answer. $L = 3.85 \times 10^{26}$ W, and the unit asked for is the **watt**.

Solution 10

Check. r is the **radius**, not the diameter, and T must be in kelvin. Both are already given in the right form here, so the only real risk is mis-keying the fourth power.

Mark scheme

- luminosity $= 4\pi\sigma r^2 T^4$
- $= 4\pi \times 5.67 \times 10^{-8} \times (6.96 \times 10^8)^2 \times 5780^4$
- $= 3.85 \times 10^{26}$ W

Solution 10

(b)(ii) Worked steps

Know. Wien's displacement law says the wavelength at which a black body radiates most strongly is inversely proportional to its temperature: $\lambda_{\mathsf{MAX}} T$ is a constant.
Use the Sun as the reference. The Sun peaks at 501 nm at 5780 K, so $\lambda_{\mathsf{MAX}} T = 501 \times 5780$ for any star.
Substitute. $624 \times T = 501 \times 5780.$
Answer. $T = 4640$ K.

Solution 10

Check. A **longer** peak wavelength means a **cooler** star, so the answer must come out below 5780 K, and it does. Multiplying instead of dividing gives about 7200 K and gets the physics backwards: red stars are the cool ones.

Mark scheme

- $\lambda_{\mathsf{MAX}} T =$ constant
- temperature $= (5780 \times 501)/624$
- $= 4640$ K

Question 10

9702/42 M23 ▪ Q10 ▪ 9 marks

(a) A student observes different stars from the Earth. Give **two** reasons why some stars appear brighter than others.

1. 2. **[2]**

(b) State what is meant by a standard candle. **[1]**

(c)(i) Show that the speed of the star relative to the Earth is 2.1×10^6 m s^{-1}. **[1]**

(c)(ii) Calculate the distance to the star.

The Hubble constant is 2.3×10^{-18} s^{-1}. **[2]**

(c)(iii) State and explain what can be concluded about the Universe based on this change in observed wavelength. **[3]**

Solution 10

(a)

Mark scheme

- brighter star could be closer (to Earth)
- brighter star could have a greater luminosity (in the visible wavelengths)

Solution 10

(b)

Mark scheme

- object with known luminosity

Solution 10

(c)(i) Worked steps

Know. A line in the star's spectrum is observed at a different wavelength from the one measured in the laboratory. The **fractional** change in wavelength gives the speed as a fraction of the speed of light.

Equation. $\frac{\Delta\lambda}{\lambda} \approx \frac{v}{c}$.

Solution 10

Substitute. $\dfrac{660.9 - 656.3}{656.3} = \dfrac{v}{3.0 \times 10^8}$.

Answer. $v = 2.1 \times 10^6$ m s^{-1}, as required.

Solution 10

Check. Divide by the **laboratory** wavelength, not by the shift and not by the observed value. The two wavelengths are close enough here that either denominator gives almost the same answer, but only one of them is the definition.

Mark scheme

- $\frac{660.9-656.3}{656.3} \approx \frac{v}{3.0\times10^8}$ leading to 2.1×10^6 m s^{-1}

Solution 10

(c)(ii) Worked steps

Know. Hubble's law says a distant galaxy's recession speed is proportional to its distance, with the Hubble constant as the constant of proportionality.

Equation. $v = H_0 d$, so $d = \dfrac{v}{H_0}$.

Substitute. $d = \dfrac{2.1 \times 10^6}{2.3 \times 10^{-18}}$.

Answer. $d = 9.1 \times 10^{23}$ m.

Solution 10

Check. The Hubble constant is quoted here in s^{-1}, which is why the answer comes out in metres with no further conversion. A value quoted in km s^{-1} Mpc^{-1} would need the speed in km s^{-1} and would give an answer in megaparsecs.

Mark scheme

- $v = H_0 d$
- $d = 2.1 \times 10^6 / 2.3 \times 10^{-18}$
- $= 9.1 \times 10^{23}$ m

Solution 10

(c)(iii)

Mark scheme

- wavelength has increased / light is redshifted
- star within galaxy is moving away / receding (from Earth)
- Universe is expanding