Mark scheme for Option E

1 **a** Apparent magnitude is a logarithmic measure of the apparent brightness of a star.

Absolute magnitude is the apparent magnitude the star would have from a distance of 10 pc. **[2]**

Exam tip: You can also say that absolute magnitude is a logarithmic measure of the luminosity of a star.

b **i** M class. **[1]**

Exam tip: You must have a basic understanding of the temperatures corresponding to spectral classes.

ii $m - M = 5\log\frac{d}{10}$ so $2.06 - (-1.60) = 5\log\frac{d}{10}$.

$\log\frac{d}{10} = 0.732 \Rightarrow d = 10\times 10^{0.732} = 53.95 \approx 54\text{ pc}$. **[2]**

c **i** Realization that $\frac{L_M}{L_0} = 100^{\frac{M_0 - M_M}{5}}$

Exam tip: Notice that $100^{\frac{1}{5}} = 2.511886$.

$$\frac{L_M}{L_0} = 100^{\frac{4.82-(-1.60)}{5}}$$

$$\frac{L_M}{L_0} = 369.8$$

$$\frac{L_M}{L_0} \approx 370$$ **[3]**

ii $$\frac{L_M}{L_0} = \frac{\sigma 4\pi R_M^2 T_M^4}{\sigma 4\pi R_0^2 T_0^4}$$

Exam tip: You must know the formula for the area of a sphere, $A = 4\pi R^2$.

$$370 = \frac{R_M^2 \, 3000^4}{R_0^2 \, 6000^4}$$

$$\frac{R_M^2}{R_0^2} = 5920$$

$$\frac{R_M}{R_0} = 76.9 \approx 77$$ **[4]**

iii Mirach is a red giant,

based on its low temperature/large radius/large luminosity. **[2]**

d The wavelengths corresponding to dark lines correspond to photons that have been absorbed by gases in the star (in the atmosphere of the star).

Since specific elements have specific absorption lines.

Study of the absorption spectrum determines the chemical composition of the star. **[3]**

2 **a** **i** The outer surface of the star undergoes periodic expansions and contractions.

The star is brightest when it is at its largest size/is dimmest when at its smallest size. **[2]**

ii The period is 20 days and so the average luminosity is $\log L = 1.13 \log 20 + 29.2 = 30.67$.

So that $L = 10^{30.67} = 4.679 \times 10^{30}$ W.

Hence $\frac{4.679 \times 10^{30}}{4\pi d^2} = 7.0 \times 10^{-9} \Rightarrow d = \sqrt{\frac{4.679 \times 10^{30}}{4\pi \times 7.0 \times 10^{-9}}} = 7.29 \times 10^{18}$ m $\approx 7.3 \times 10^{18}$ m. **[3]**

Exam tip: You need to estimate the average apparent brightness from the graph.

b We can easily determine the average luminosity of a Cepheid from knowledge of its period, i.e. a Cepheid is a star of known luminosity a ‘standard candle’.

If we can be sure that a particular Cepheid star belongs to a particular galaxy then another star in the same galaxy has essentially the same distance.

If we then compare its apparent brightness to that of the Cepheid we will get information on the star’s luminosity: $L_{\text{star}} = \frac{b_{\text{star}}}{b_{\text{Cepheid}}} L_{\text{Cepheid}}$. **[3]**

3 **a** *Black body* radiation in the microwave region:

that fills the universe/has no specific origin/is very isotropic. **[2]**

b The measured temperature of the CMBR today is very small but, since the universe is expanding,

the temperature in the past must have been enormous (because the peak wavelength would have been much smaller). **[2]**

c From $\lambda T = 2.9\times10^{-3}$ m K, $\lambda = \dfrac{2.9\times10^{-3}}{2.7}$ m.

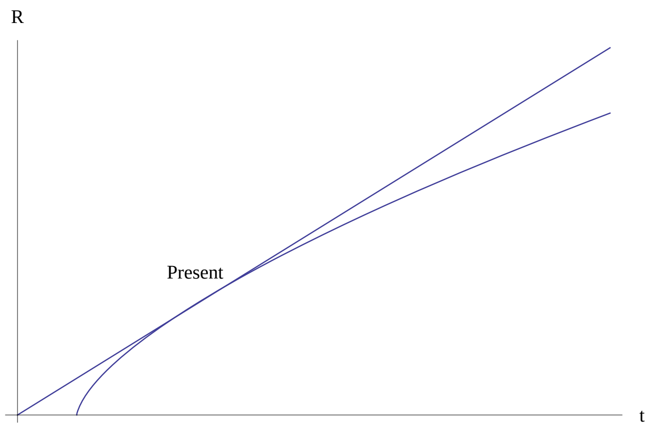
$\lambda = 1.07 \approx 1.1$ mm. **[2]**

d **i** A flat universe will expand forever,

at a rate that approaches zero after an infinite time. **[2]**

ii Curve beginning to the right of the origin, with slope decreasing with time.

Tangent to empty universe graph at present time.



[2]

Exam tip: The fact that the curve starts to the right of the origin shows that the age of the universe depends on the model chosen.

iii To determine that the universe is flat, one must compare the density of the universe to the critical density,

and this is difficult because the universe contains a lot of matter (dark matter) that cannot easily be detected (because it does not radiate). **[2]**

4 **a** Star X is on the main sequence; it obeys the mass–luminosity relation,

which states that the greater the luminosity the greater the mass of the star. **[2]**

b **i** A star will leave the main sequence when it exhausts its hydrogen in the core,

and star X burns its hydrogen (proportionately) much faster than the sun (because the luminosity is higher). **[2]**

ii In star X, nuclear reactions involving the formation of heavier nuclei (like carbon, oxygen and magnesium) will take place,

whereas in the sun no elements heavier than helium will be formed. **[2]**

iii Star X will probably evolve to a neutron star,

whereas the sun will become a white dwarf. **[2]**

c Star X will evolve into a red supergiant and will explode as a supernova.

If the core that is left behind has a mass that is less then the Chandrasekhar limit (of about 1.4 solar masses),

It, too, will become a white dwarf like the sun. **[3]**

5 **a** Distant galaxies move away from each other with a speed that is proportional to their separation. **[2]**

Exam tip: you may give the formula but then you must define all symbols.

b **i** $\frac{\Delta\lambda}{\lambda} = \frac{v}{c}$ so $\frac{v}{c} = \frac{678-656}{656}$

$v = 1.01\times10^{7}\ \mathrm{m\,s^{-1}} = 1.01\times10^{4}\ \mathrm{km\,s^{-1}}$

$v = Hd \Rightarrow H = \frac{1.01\times10^{4}}{130} = 77.4 \approx 77\ \mathrm{km\,s^{-1}\,Mpc^{-1}}$. **[3]**

ii An estimate of the age of the universe is $\frac{1}{H}$

$\frac{1}{H} = \frac{1}{77.4}\frac{1}{10^{3}\,\mathrm{m}}\times \mathrm{s}\times10^{6}\times3.26\times9.46\times10^{15}\,\mathrm{m} = 3.98\times10^{17}\ \mathrm{s} \approx 12.6\times10^{9}\ \mathrm{yr}$,

i.e. 13 billion years. **[2]**

iii It is an overestimate.

This is based on the present rate of expansion; in the past the universe was expanding faster. **[2]**

Exam tip: Look at the graph of **Q3**.

