Answers to exam-style questions

Option D

1 ✓ = 1 mark

1 a i Luminosity is the total power radiated by a star. ✓

ii Apparent brightness is the power received per unit area. ✓

b They all fuse hydrogen into helium. ✓

c i Using the mass–luminosity relation $\frac{L_A}{L_\odot} = \left(\frac{M_A}{M_\odot}\right)^{3.5}$ ✓

Hence $L_A = L_\odot \left(\frac{M_A}{M_\odot}\right)^{3.5} = L_\odot \times 6.7^{3.5} = 778 \times 3.9 \times 10^{26} = 3.04 \times 10^{29} \approx 3.0 \times 10^{29}$ W ✓

ii From $b = \frac{L}{4\pi d^2}$ we find $d = \sqrt{\frac{L}{4\pi b}} = \sqrt{\frac{3.04 \times 10^{29}}{4\pi \times 1.7 \times 10^{-8}}} = 1.19 \times 10^{18}$ m $= \frac{1.19 \times 10^{18}}{3.09 \times 10^{16}}$ pc $= 38.5 \approx 38$ pc ✓

Hence $p = \frac{1}{d} = \frac{1}{38.5} = 0.0260 \approx 0.026''$ ✓

iii $\frac{L_A}{L_\odot} = 778 = \frac{\sigma 4\pi R_A^2 T_A^4}{\sigma 4\pi R_\odot^2 T_\odot^4} = \frac{R_A^2 T_A^4}{R_\odot^2 T_\odot^4}$ ✓

$778 = \frac{R_A^2}{R_\odot^2} \times 2.6^4$ ✓

Hence $R_A = R_\odot \sqrt{\frac{778}{2.6^4}} \approx 17 R_\odot$ ✓

d i The parallax method measures the position of a star two times six months apart. ✓
The shift of the angular position of the star relative to the background of the distance stars. ✓
Allows measurement of the parallax angle which is the angle subtended by the earth's orbit radius at the star. ✓
The distance in pc is the reciprocal of the parallax angle in arc seconds. ✓

ii Yes because it is larger than the limit of 0.01 arc seconds. ✓

2 a Light reaching the Earth must go through the outer layers of the star. ✓
Photons whose energy corresponds to differences in energy between energy levels of the atoms of the star may be absorbed and so will be missing in the received light. ✓
Because the energy level differences are specific atoms determination of the chemical composition is then possible. ✓

b i Type O stars are very hot and most of the hydrogen is ionised. ✓
Hence hydrogen cannot absorb any photons. ✓

ii An M type star is relatively cool so that hydrogen atoms are mostly in their ground state. ✓
And these can only absorb ultraviolet photons not visible light photons. ✓

c The surface temperature/its magnetic field/its rotational speed. ✓

3 a The surface of the star periodically expands and contracts. ✓
It expands because radiation ionises helium atoms in the star's outer layers and the released electrons heat up the star expanding it. ✓
When most of the helium is ionised, radiation leaves the star so the star cools and contracts. ✓

b There is a relation between the average luminosity of the star and the period of variation of the luminosity. ✓
So measuring the period gives the luminosity. ✓
Measuring the (average) apparent brightness (by observing the star over a period of days) allows determination of the distance. ✓
To measure the distance to a galaxy it must be determined whether a specific Cepheid star belongs to that galaxy. ✓

c The average apparent brightness is estimated to be $2.8\times10^{-8}\ \text{W m}^{-2}$. ✓

A period of 55 days corresponds to an average luminosity of about 20000 solar luminosities. ✓

And so $d=\sqrt{\dfrac{L}{4\pi b}}=\sqrt{\dfrac{20000\times3.9\times10^{26}}{4\pi\times2.8\times10^{-8}}}\approx5\times10^{18}\ \text{m}$ ✓

4 a i Using the mass–luminosity relation $\dfrac{L_A}{L_\odot}=\left(\dfrac{M_A}{M_\odot}\right)^{3.}$ ✓

Hence $L_A=L_\odot\left(\dfrac{M_A}{M_\odot}\right)^{3.5}=L_\odot\times20^{3.5}=3.6\times10^4\times3.9\times10^{26}=1.4\times10^{31}\ \text{W}$ ✓

ii $\dfrac{L_A}{L_\odot}=3.6\times10^4=\dfrac{\sigma4\pi R^2T^4}{\sigma4\pi R_\odot^2T_\odot^4}=1.2^2\times\dfrac{T^4}{T_\odot^4}$ ✓

Hence $\dfrac{T}{T_\odot}=\sqrt[4]{\dfrac{3.6\times10^4}{1.2^2}}=12.6\approx13$ ✓

b i The surface temperature decreases. ✓

And the radius increases. ✓

ii A type II supernova is the explosion of a massive star after it has entered the red supergiant phase while a type Ia supernova involves mass accretion onto a white dwarf. ✓

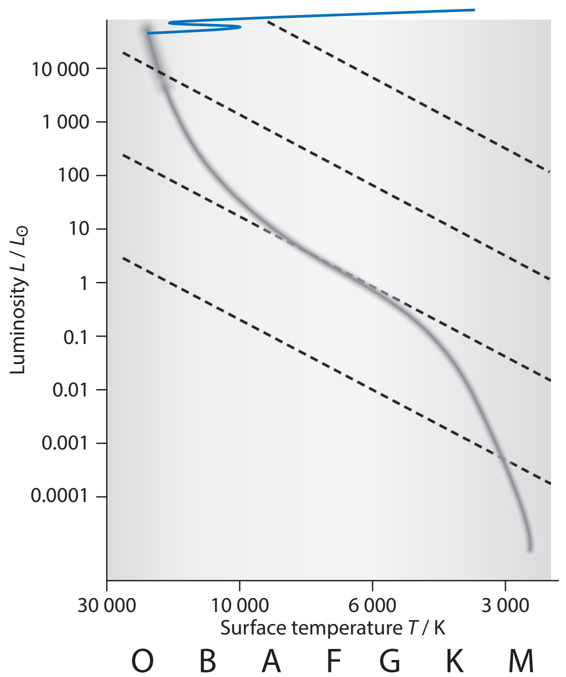
So in this case we have a type II supernova. ✓

iii The star will be a neutron star. ✓

In which the neutron degeneracy pressure. ✓

Balances the gravitational pressure in the star. ✓

c Blue line as shown starting approximately at the correct point. ✓



5 a i Strip from top left diagonally to bottom right. ✓

ii Region in lower left. ✓

iii Region to the right above main sequence. ✓

iv Region joining main sequence to red giants. ✓

b i $\dfrac{L_X}{L_Y}=\dfrac{100}{0.01}=10^4=\dfrac{\sigma4\pi R_X^2T_X^4}{\sigma4\pi R_Y^2T_Y^4}=\dfrac{R_X^2}{R_Y^2}$ ✓

Hence $\dfrac{R_X}{R_Y}=10^2$ ✓

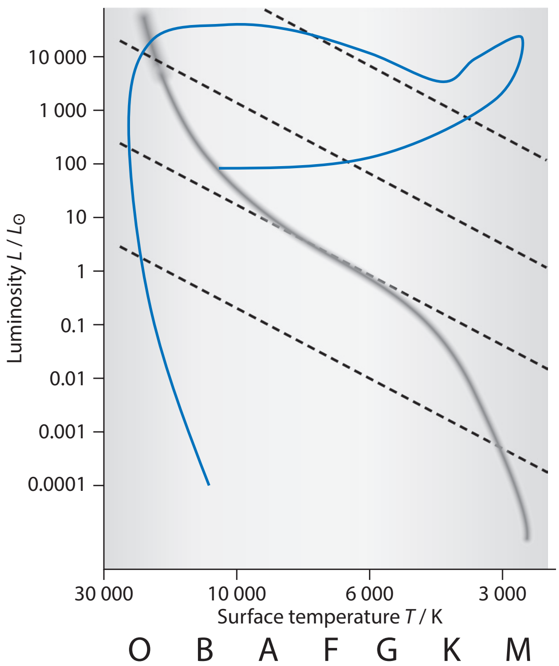
ii $\dfrac{L_X}{L_Z} = 1 = \dfrac{\sigma 4\pi R_X^2 T_X^4}{\sigma 4\pi R_Z^2 T_Z^4} = \dfrac{R_X^2}{R_Z^2} \times \left(\dfrac{12000}{3000}\right)^4 = \dfrac{R_X^2}{R_Z^2} \times 256$ ✓

Hence $\dfrac{R_X}{R_Z} = \sqrt{\dfrac{1}{256}} = \dfrac{1}{16}$ ✓

c Using the mass–luminosity relation $\dfrac{L_X}{L_\odot} = 100 = \left(\dfrac{M_X}{M_\odot}\right)^{3.5}$ ✓

Hence $\dfrac{M_X}{M_\odot} = 100^{1/3.5} = 3.7$ ✓

d i Line similar to blue line on HR diagram. ✓



ii Electron degeneracy pressure. ✓

Balances the gravitational pressure in the star. ✓

iii It has to be less than the Chandrasekhar limit of 1.4 solar mass. ✓

6 a Distant galaxies appear to move away from us with a speed that is proportional to their distance. ✓

b The received wavelength. ✓

Is larger than the wavelength at emission. ✓

c On a large scale, the space between galaxies stretches. ✓

Thus the wavelength of light emitted from a distant galaxy also stretches so it is larger at reception. ✓

d i $z = \dfrac{\Delta\lambda}{\lambda_0} = \dfrac{780 - 656}{656} = 0.189$ ✓

$z = \dfrac{v}{c} \Rightarrow v = 5.67 \times 10^7 \approx 5.7 \times 10^7 \text{ m s}^{-1}$ ✓

ii $z = \dfrac{R}{R_0} - 1 = 0.189$, i.e. $\dfrac{R}{R_0} = 1.189$ ✓

$\dfrac{R_0}{R} = 0.84$ ✓

iii The data give a Hubble value constant of: $v = Hd \Rightarrow H = \dfrac{5.67 \times 10^7}{920 \times 10^6 \times 3.09 \times 10^{16}} = 1.99 \times 10^{-18} \text{ s}^{-1}$ ✓

Hence $T = \dfrac{1}{H} = \dfrac{1}{1.99 \times 10^{-18}} = 5.0 \times 10^{17} \text{ s} \left(= \dfrac{5.0 \times 10^{17}}{365 \times 24 \times 3600} = 1.6 \times 10^{10} \text{ year} \right)$ ✓

e To see whether the universe accelerates or decelerates in its expansion distant objects of large redshift had to be investigated. ✓
In order to establish the relation between distance and redshift. ✓
Type Ia supernovae were chosen because their peak luminosity is known and hence the distance could be established by measuring the apparent brightness. ✓

7 a According to the hot big bang model the early universe contained radiation at very high temperature. ✓
As the universe expanded it cooled and the peak wavelength shifted to large microwave wavelengths with a black body spectrum. ✓
Which is what is being observed. ✓

b i $z = \frac{R}{R_0} - 1 = \frac{T_0}{T} - 1$ ✓

$z = \frac{3\times10^3}{2.7} - 1 = 1110$ ✓

ii $\frac{R}{R_0} - 1 = 1110$ ✓

Hence $\frac{R_0}{R} = 9\times10^{-4}$ ✓

8 a The result follows from $\frac{GMm}{r^2} = m\frac{v^2}{r}$. ✓

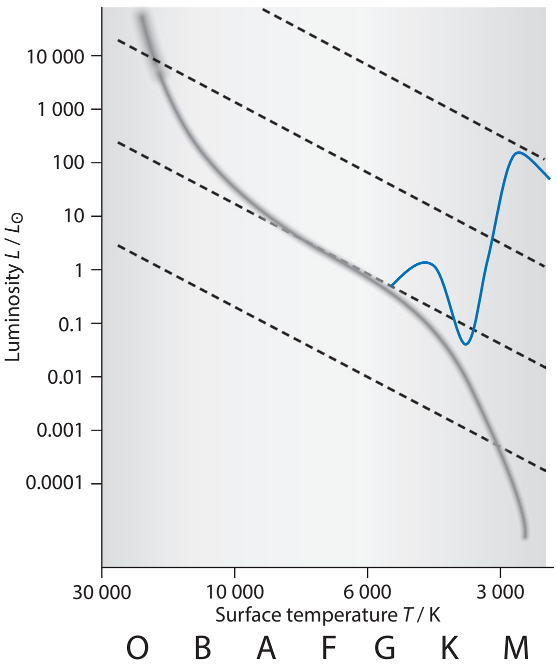
b With $M = kr$ the result in **a** becomes $v = \sqrt{\frac{Gkr}{r}} = \sqrt{Gk}$ a constant. ✓

c i The rotation curve becomes flat at large distances from the galactic centre. ✓
This is consistent with a mass distribution as in **b**. ✓
In other words with substantial mass far from the galactic centre. ✓

ii Small planets/brown dwarfs/black dwarfs. ✓
Neutrinos/exotic particle predicted by supersymmetry. ✓

9 a The Jeans criterion states that cloud of gas will begin to collapse under its own gravitation. ✓
When the gravitational potential energy of the cloud exceeds the total random kinetic energy of its particles. ✓

b Blue line as shown. ✓



c **i** Use $M = Nm$ to eliminate N so that $\frac{GM^2}{R} \approx \frac{3}{2}\frac{M}{m}kT$ or $\frac{GM}{R} \approx \frac{3}{2}\frac{kT}{m}$ ✓

Now eliminate the mass M through: $M = \rho V = \rho \frac{4\pi R^3}{3}$ so that $\frac{G\rho 4\pi R^3}{3R} \approx \frac{3}{2}\frac{kT}{m}$ ✓

Cancelling powers of R and simplifying gives the result $\left(R^2 \approx \frac{9}{8\pi}\frac{kT}{mG\rho}\right)$ ✓

ii $R^2 \approx \frac{9kT}{8\pi G\rho m} = \frac{9 \times 1.38 \times 10^{-23} \times 100}{8\pi \times 6.67 \times 10^{-11} \times 1.8 \times 10^{-19} \times 2.0 \times 10^{-27}}$ ✓

$R \approx 1.4 \times 10^{17}$ m ✓

10 **a** **i** $v = H_0 R$ ✓

ii $E = \frac{1}{2}mv^2 - \frac{GMm}{R}$ ✓

$E = \frac{1}{2}mH_0{}^2R^2 - \frac{G\rho 4\pi R^3 m}{3R} = \frac{1}{2}mH_0{}^2R^2 - \frac{G\rho 4\pi R^2 m}{3}$ ✓

Factoring gives the result.

iii To escape to infinity the total energy must be zero. ✓

This means that $H_0^2 - \frac{G\rho 4\pi}{3} = 0$. ✓

From which the result follows.

iv $\rho = \frac{3 \times \left(\frac{68 \times 10^3}{10^6 \times 3.09 \times 10^{16}}\right)^2}{8\pi \times 6.67 \times 10^{-11}}$ ✓

$\rho \approx 9 \times 10^{-27}$ kg m^{-3} ✓

b In cosmological models with matter density parameters ρ_m and dark energy density ρ_Λ the significance of the critical density is that when $\rho_m + \rho_\Lambda = \rho_c$. ✓
The geometry of the universe is flat, i.e. it has zero curvature. ✓

11 **a** The CMB is very isotropic which means that we observe the same spectrum in every direction. ✓
However there are small deviations from perfect isotropy in the sense that, in different directions, the temperature deviates from the mean temperature of T = 2.723 K by very small amounts (of order $\frac{\Delta T}{T} \approx 10^{-5}$). ✓

b These deviations are significant because fluctuations in temperature imply fluctuations in density. ✓
And these are required if structures are to develop in the universe. ✓
They are also significant because the magnitude of the fluctuations depends on the geometry of the universe. ✓
Hence study of the fluctuations places limits on the geometry of the universe. ✓

12 **a** Elements are produced by nuclear fusion. ✓
And nuclear fusion becomes energetically impossible past the peak of the binding energy per nucleon curve which is at iron. ✓

b These are produced mainly by neutron capture. ✓
Nuclei may absorb neutrons which are abundant in a supernova. ✓
As these decay by beta decay. ✓
Nuclei with higher atomic number than iron are produced. ✓

c The CNO cycle requires the fusion of nuclei of carbon, nitrogen and oxygen and since these have a high atomic number the Coulomb barrier that must be overcome is larger than that for hydrogen and helium. ✓
And this requires higher temperatures that are found in the more massive stars. ✓