**1.** (a) $E = \sigma T^4$ (or$P = A\sigma T^4$)
where $E$ = energy radiated per second per m$^2$ (of surface)
[or $P$ = (total) power output and $A$ = area (of surface)] **(1)**

$\sigma$ = constant (*)
$T$ = temperature (*)

(*) **(1)**
(or $P$ = total power output and $A$ = area of surface) 3

(b) (i) (distance from Sun to Earth = $R$)
total power from Sun = $1400 \times 4\pi R^2$ **(1)**
(Voyager distance $x$ from Sun)

power per unit area at $x = 1400 \times \dfrac{4\pi R^2}{4\pi x^2}$ **(1)**

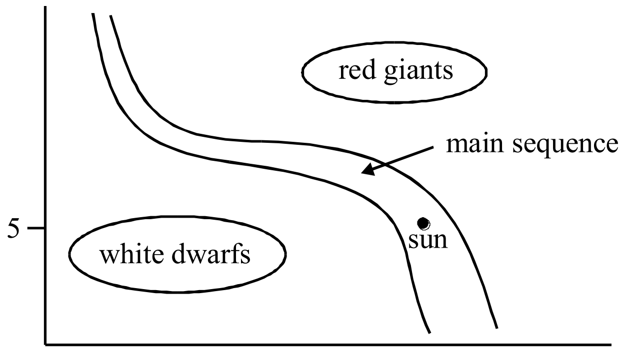
$400 = 1400 \times \dfrac{R^2}{x^2} \times A$ **(1)**

$A = \dfrac{400 \times (8 \times 10^9)^2}{1400 \times (1.5 \times 10^8)^2}$ = 812 m$^2$ **(1)** (accept 800 m$^2$)

(ii) assumption: solar panels 100% efficient **(1)**
(or any other sensible assumption) 5

**[8]**

**2.** (a)




Main Sequence **(1)**
giants and dwarfs **(1)**
position of Sun **(1)** 3

(b) (i) brightest: Aldebaran **(1)**
smallest value of apparent magnitude **(1)**

(ii) reddest: Aldebaran **(1)**
spectral class K **(1)** 4

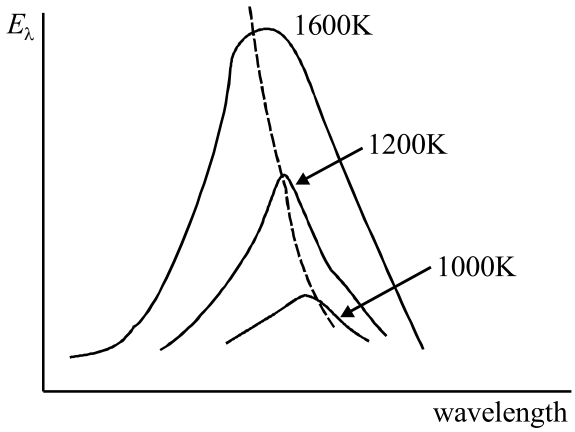
(c) (i) approx absolute magnitude = 6 **(1)**

(ii) $[m - M = 5 \log\left(\frac{d}{10}\right)]$ gives $3.5 - 6 = 5 \log\left(\frac{d}{10}\right)$ **(1)**

$d = 10(10^{-2.5/5}) = 3.2$(pc) **(1)** 3

**[10]**

**3.** (a)




peaks displaced towards increasing wavelength **(1)**
steeper slope on left hand side **(1)**
correct temperatures **(1)** 3

(b) (i) $\lambda_{max}$ is wavelength at which maximum intensity occurs **(1)**

(ii) constant = $2.9 \times 10^{-3}$mK **(1)**
for $T$ = 1600K, gives $\lambda_{max}$ = 1800 nm **(1)**

(iii) $\lambda_{max} \approx 550$ nm **(1)**

$T = \frac{2.9 \times 10^{-3}}{550 \times 10^{-9}}$ = 5272K **(1)** (accept 5300K) 5

(c) (i) E is the area under one of the curves in the graph **(1)**

(ii) $P = A\sigma T^4$ **(1)** 2

(d) (i) (total power output from Sun = $E$)

power arriving at Earth = $\dfrac{E}{4\pi R^2}$ **(1)**

= 1400 (W m$^{-2}$) **(1)**

$E = 1400 \times 4\pi \times (1.5 \times 10^{11})^2 = 4.0 \times 10^{26}$ (W) **(1)**

(ii) ($P = A\sigma T^4$) gives $T^4 = \dfrac{4.0 \times 10^{26}}{4\pi(7 \times 10^8)^2 \times 5.7 \times 10^{-8}}$ **(1)** (= $1.12 \times 10^{15}$)

T = 5800 K **(1)** max 4

**[14]**

**4.** (a) (i) correct Red Giants and White Dwarfs

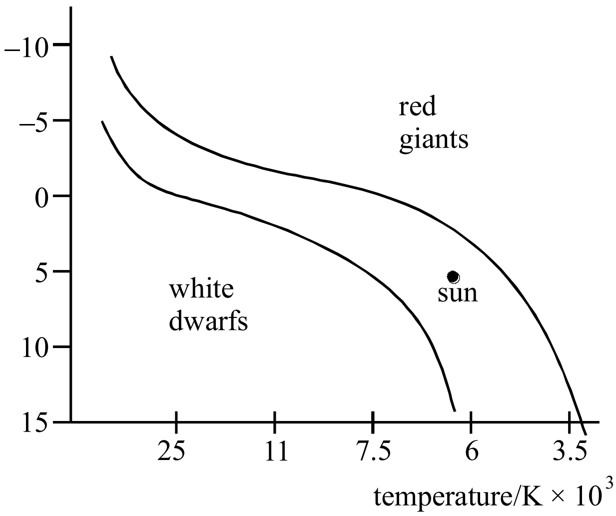
(ii) Red Giants colder than White Dwarfs **(1)**
but Red Giants are brighter **(1)**
must have larger surface area **(1)** 4

(b) (i) correct OBAFGKM **(1)**

(ii) class O: strong He lines present **(1)**
$H_2$ lines present, but weak **(1)**
class A: $H_2$ lines at max strength **(1)**
ionised metals at max strength [or (neutral) metal lines begin to appear] **(1)**
class M: (neutral) metal lines strong **(1)**
molecular bands prominent **(1)** max 6

**[10]**

**5.** (a)




correct position of main sequence **(1)**

correct position of White Dwarfs and Red Giants **(1)**

correct position of Sun labelled **(1)** 3

(b) (i) brightness when Red Giant > brightness when in main sequence **(1)**

(ii) hydrogen exhausts itself **(1)**

core collapses causing temperature to increase **(1)**

outer part of star expands **(1)**

causes decrease in temperature **(1)**

causing star to appear red **(1)** max 4

(c) (i) very large gravitational field **(1)**

prevents light escaping **(1)**

(ii) event horizon is boundary or surface at which escape speed = $c$ **(1)**

radius $\left(= \frac{2GM}{c^2}\right) = \frac{2 \times 6.67 \times 10^{-11} \times (3 \times 2 \times 10^{30})}{9 \times 10^{16}}$ **(1)**

$= 8.9 \times 10^3$ m **(1)** 5

**[12]**

**6.** (a) (i) *apparent magnitude:* brightness of star as seen from Earth **(1)**
*absolute magnitude:* apparent magnitude at a distance of 10 pc **(1)**

(ii) one star is much brighter **(1)**
has lower value of apparent magnitude **(1)** 4

(b) (i) correct main sequence **(1)**
correct Giants and White Dwarfs **(1)**

(ii) $m - M = 5\log\left(\frac{d}{10}\right)$ **(1)**

gives $11 - M = 5\log\left(\frac{1.3}{10}\right)$ **(1)**

$M = 11 + 4.43 = 15.4$ **(1)**

(iii) correct position on diagram (spectral class M, abs magnitude –5) **(1)** 6

(c) (i) same temperature [or temperature less than 3500K ] **(1)**
same spectral class **(1)**

(ii) Antares is brightest (and at same temperature) **(1)**
so has largest surface area [diameter] **(1)** 4

**[14]**

**7.** (a) region of white dwarfs drawn around X and
region of red giants drawn around Z **(1)**
main sequence (band from W, dipping, flatter at Y, down to right) **(1)** 2

(b) (i) (apparent magnitude) brightness (of star) as seen from Earth **(1)**

(ii) $d = \frac{1350}{3.26} = 414$ (pc) **(1)**

(iii) (use of $m - M = 5\log\frac{d}{10}$ gives) $M = 1.7 - 5\log\left(\frac{414}{10}\right)$ **(1)**
(allow C.E. for value of $d$ from (b)(ii))
$M = -6.39$ **(1)**

(iv) (Alnilam is) W **(1)**
correct absolute magnitude **(1)**
B or A class due to strong Balmer lines **(1)** 7

(c) (evolution of the Sun is) Y → Z → X 1

**[10]**

**8.** (a) (i) (use of $\lambda_{max}T = 0.0029$ gives) $\lambda = \frac{0.0029}{6000}$ **(1)**

$= 4.8 \times 10^{-7}$ m **(1)**

(ii) values on axis : 0.5 1.0 1.5 2.0 **(1)**

(iii) similar shaped curve with peak shifted to right **(1)** max 4

(b) (i) <u>difference</u> in absolute magnitude = 5 **(1)**
corresponds to × 100 difference in brightness,
some reference to absolute scale **(1)**
Arcturus lower absolute magnitude, therefore brighter **(1)**

(ii) ( use of $P = \sigma A T^4$ gives) $\frac{P_A}{P_S} = 100 = \frac{A_A T_A^4}{A_S T_S^4}$ **(1)**

$\frac{A_A}{A_S} = 100 \times \left(\frac{6000}{5000}\right)^4$ **(1)** (= 200) max 4

**[8]**

**9.** (a) (i) exploding (super)giant star
[or reference to a sudden, very large, short lived increase in luminosity] **(1)**

(ii) very dense
powerful radio source
spinning (any two) **(1) (1)**
faint
strong magnetic field 3

(b) (i) <u>boundary</u> of a black hole, where escape velocity = $c$
or light cannot escape **(1)**

(ii) $R = \frac{2GM}{c^2}$ **(1)**

$= \frac{2 \times (6.67 \times 10^{-11}) \times (10^6 \times 2.0 \times 10^{30})}{(3 \times 10^8)^2}$ **(1)**

$= 3.0 \times 10^9$ m **(1)** 4

**[7]**

**10.** (a) (i) (continuous spectrum emitted), but light of particular wavelengths absorbed by (excited) hydrogen atoms (in star's atmosphere)
absorbed wavelengths correspond to particular energy level transitions by electrons in hydrogen atoms
light re-emitted in all directions, thereby reduced in direction of Earth
any two **(1) (1)**

QWC 2

(ii) arrow upwards from n = 2 to n = 6 **(1)**

(iii) 410 nm **(1)**

(iv) Balmer **(1)**

(v) A and B **(1)** max 4

(b) (i) (use of $\lambda_{max}T = 0.0029$ gives) $T = \dfrac{0.0029}{300\times10^{-9}}$ **(1)** (= 9700 K)

(ii) Vega behaves like a black body **(1)** 2

(c) A, because the temperature is that of class A **(1)** 1

**[7]**

**11.** (a) (i) apparent magnitude: brightness as seen from Earth **(1)**

(ii) absolute magnitude: inherent brightness or brightness seen from 10 pc **(1)** 2

(b) (i) distance = $\dfrac{470}{3.26}$ = 144 (pc) **(1)**

(ii) $m - M = 5\log\left(\dfrac{d}{10}\right)$ **(1)**

$m = -4.2 + 5\log\left(\dfrac{144}{10}\right) = 1.6$ **(1)**

(allow C.E. for value of $d$ from (i))

(iii) Elnath **(1)**
reason: (either by calculation or reference to – 4.2 being brighter than – 3.2)
Elnath is actually dimmer than Bellatrix **(1)**
but appears to have same brightness, so must be closer **(1)** 6

**[8]**

**12.** (a) Hertzsprung -Russell diagram to show:
absolute magnitude scale from +15 to –10 **(1)**
temperature scale from 50 000 to 2500 (K) **(1)**
main sequence drawn correctly **(1)**
giants and dwarfs shown in correct areas **(1)** 4

(b)

| | | | |
|---|---|---|---|
| Alnitak | : helium (absorption) **(1)** | | |
| Sirius | : hydrogen Balmer (absorption) lines | 4 correct **(1)** | |
| Sun | : metals (absorption) | 2 correct | |
| Antares | : molecular bands | | 2 |

(c) reference to $P = \sigma A T^4$ **(1)**
class M (Antares) cooler than class O (Alnitak) **(1)**
but same brightness, therefor cooler star bigger **(1)**
so Antares has larger surface area **(1)** max 3
QWC 2

**[9]**

**13.** (a) (i) supernova: star whose luminosity increase enormously due to it exploding **(1)**

(ii) neutron star: star with the density of nuclear matter **(1)**

(iii) black hole: an object whose escape velocity is greater than speed of light **(1)** 3

(b) $\left(\text{use of } R = \frac{2GM}{c^2} \text{ gives}\right)$ $R = \frac{2 \times 6.67 \times 10^{-11} \times 10 \times 2 \times 10^{30}}{(3 \times 10^8)^2}$ **(1)** 2

**[5]**

**14.** (a) (i) light year : distance travelled by light in one year **(1)**

(ii) parsec : distance to an object subtending 1 sec of arc to Earth's orbit **(1)** 2

(b) (i) $d = \left(\frac{450}{3.26}\right) = 123$ pc **(1)**

$m - M$ (= 5 log($d$/10)) = 5 log(123/10) = 5.5 **(1)** (5.45)
$M$ = (5.1 – 5.5) = – 0.4 **(1)**
(allow C.E. for value of $d$)

(ii) A OBAFGKM is order of spectra for decreasing temperature
(or similar reference to spectral class related to temperature) **(1)**

(iii) G same brightness/power, but G is cooler **(1)**
∴ since $P = \sigma AT$, star A must be larger for smaller T **(1)** max 5

(c) $\theta$ (= 1.8 × $10^{-3}$ °) = 3.1 × $10^{-5}$ rad **(1)**

(use of $\theta = \frac{\lambda}{d}$ gives) $d = \frac{5.0 \times 10^{-7}}{3.1 \times 10^{-5}}$ = 1.6 × $10^{-2}$m **(1)** 2

**[9]**

**15.** (a) (i) correct shape of graph (steeper on left of peak) **(1)**

(ii) region to left of peak **(1)**

(iii) ozone **(1)**

(iv) lower temperature, shifts peak ($\lambda_{max}$) to longer wavelengths **(1)**
$\lambda_{max}T$ = constant **(1)** max 4

(b) (i) (use of $f = \frac{c}{\lambda}$ gives) $f\left(= \frac{3 \times 10^8}{2.7}\right)$ = 1.1 × $10^8$ Hz,

(in range) **(1)**

(ii) (double) Doppler **(1)**

(iii) (reflection off moving object gives double Doppler),
frequency shift = 150 Hz

$v = \frac{150 \times 3 \times 10^8}{1.1 \times 10^8}$ **(1)**
(allow C.E. for shift = 300 Hz)
= 4.1 × $10^2$ m $s^{-1}$ (towards each other) **(1)** 5

**[9]**

**16.** (a) (i) main sequence correct **(1)**
Giants and Dwarfs correct **(1)**
OBAFGKM **(1)**

(ii) X at G, 5 **(1)**
line up to Red Giant, down to White Dwarf **(1)** max 4

(b) (i) temperature and colour [or reference to correct spectral line] **(1)**

(ii) $\frac{330}{3.26} = 100(\text{pc})$ **(1)**

(iii) $m - M = 5 \log \frac{d}{10}$ gives $m - M = 5$ **(1)**
$M = -2.1$ **(1)**
(allow C.E. for value of $d$ from (ii)

(iv) Matar is brighter (but at same temperature) **(1)**
(since $P = \sigma AT^4$), Matar must have larger $A$, therefore larger **(1)** 6

**[10]**

**17.** (a) (i) P has the lowest peak wavelength ($\lambda_{max}$) **(1)**
(since) $\lambda_{max}T$ = constant, lowest $\lambda_{max}$ means highest $T$ **(1)**
[or P has highest peak intensity **(1)**
intensity is power per unit area, or ref to Stefan's law **(1)**]

(ii) $\lambda_{max} = 300 \times 10^{-9}$(m) **(1)**
(use of $\lambda_{max}T = 0.0029$ gives) $T = 9.7 \times 10^3$K **(1)** ($9.67 \times 10^3$ K) max 3

(b) (i) A and B **(1)**

(ii) light from the star passes through the atmosphere of the star **(1)**
which contains hydrogen with electrons in $n = 2$ state **(1)**
electrons in this state absorb certain energies and (hence) frequencies of light **(1)**
the light is re-emitted in all directions, so that the intensity of these frequencies is reduced in any given direction,
resulting in absorption lines **(1)** max 4

**[7]**

**18.** (a) (i) event horizon (for a black hole) is the surface where the escape velocity equals the speed of light **(1)**

(ii) $R_S = \frac{2GM}{c^2}$ ,where
$G$ is the gravitational constant,
$M$ is the mass of the black hole, and $c$ is the speed of light **(1)** 2

(b) (use of $R_S = \frac{2GM}{c^2}$ gives) $M = \left(\frac{R_S c^2}{2G}\right) = \frac{6.4 \times 10^6 \times (3 \times 10^8)^2}{2 \times 6.67 \times 10^{-11}}$ **(1)**
$= 4.3(2) \times 10^{33}$ kg **(1)** 2

**[4]**

**19.** (a) (i) Segin: spectral class B is hottest **(1)**

(ii) Shedir: class K is closest towards red end **(1)**

(iii) Shedir: 2.2 is smallest value of apparent magnitude **(1)**

(iv) Achird: apparent magnitude lower (brighter) than absolute magnitude and they are equal when star is 10 pc away **(1)** 4

(b) (i) (use of $m - M = 5\log(d/10)$ gives) $2.2 - (-4.6) = 5\log\left(\frac{d}{10}\right)$ **(1)**

$d = 229$ pc **(1)**

(ii) (use of $\lambda_{max}T = 0.0029$ gives) $\lambda_{max} = \frac{0.0029}{12000} = 2.4(2) \times 10^{-7}$ m **(1)** 3

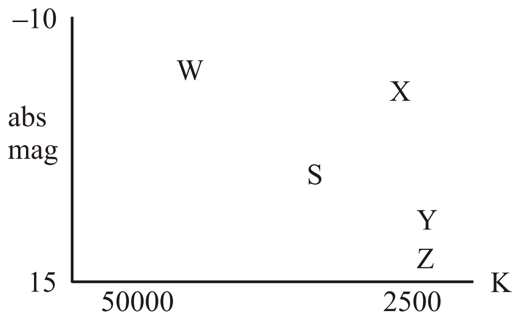
**[7]**

**20.** (a) brightness (or apparent magnitude) of star from a distance of 10 pc **(1)** 1

(b) (i) temperature from 50000 K to 2500 K **(1)**
absolute magnitude from +15 to –10 **(1)**

(ii) S at 6000 K, and abs mag 5 **(1)**

(iii) W above and to left of S **(1)**
X above and to right of S **(1)**
Y below and to right of S **(1)**
Z below and to right of S **(1)** 7




**[8]**

**21.** (a) (use of $m - M = 5\log(d/10)$ gives)
$3.54 - (-20.62) = 5\log(d/10)$ **(1)**

$d = 6.7(9) \times 10^{5}$ pc **(1)** 2

(b) use of $\frac{\Delta\lambda}{\lambda} = -\frac{v}{c}$ **(1)**

$$\Delta\lambda = -\frac{0.21121 \times 105 \times 10^3}{3.0 \times 10^8} = -7(.4) \times 10^{-5}$$

$\lambda' = 0.21121 - 7(.4) \times 10^{-5} = 0.21114m$ **(1)**

*(allow C.E. for incorrect value of Δλ)* 2

(c) $t\left(= \frac{d}{v}\right) = \frac{6.79 \times 10^5 \times 3.08 \times 10^{16}}{105 \times 10^3}$ **(1)**

$=2.0\times10^{17}$s **(1)**

($1.99\times10^{17}$s) 2

*(allow C.E. for value of d from (a))*

**[6]**

**22.** (a) (i) P, it has the lowest peak wavelength $\lambda_{max}$ **(1)**

and $\lambda_{max}$ T = constant, so lowest $\lambda_{max}$ means highest T **(1)**

use of $\lambda_{max}$ T = 0.0029 and $\lambda_{max} = 300 \times 10^{-9}$ m **(1)** gives T = 9700K **(1)** max 3

(b) (i) A and B **(1)**

(ii) light from the star passes through the atmosphere of the star **(1)**

which contains hydrogen with electrons in the n = 2 state **(1)**

electrons in the n = 2 state absorb certain energies and therefore frequencies of light **(1)**

the light is reemitted in all directions and therefore the intensity of the light of these frequencies in the direction of the observer is reduced, resulting in absorption lines in the spectrum **(1)** max 4

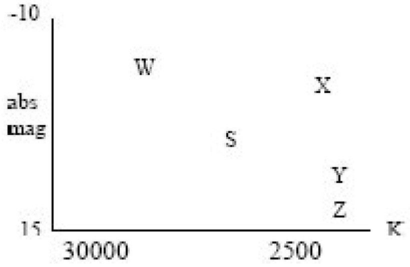
**[7]**

**23.** (a) brightness of star from a distance of 10 pc **(1)** 1

(b) (i) temperature from 30000 K to 2500 K **(1)**
absolute magnitude from +15 to -10 **(1)**

(ii) S at 6000, 5 **(1)**

(iii)




W above and to left of S **(1)**
X above and to right of S **(1)**
Y below and to right of S **(1)**
Z below and to right of S **(1)** 7

**[8]**