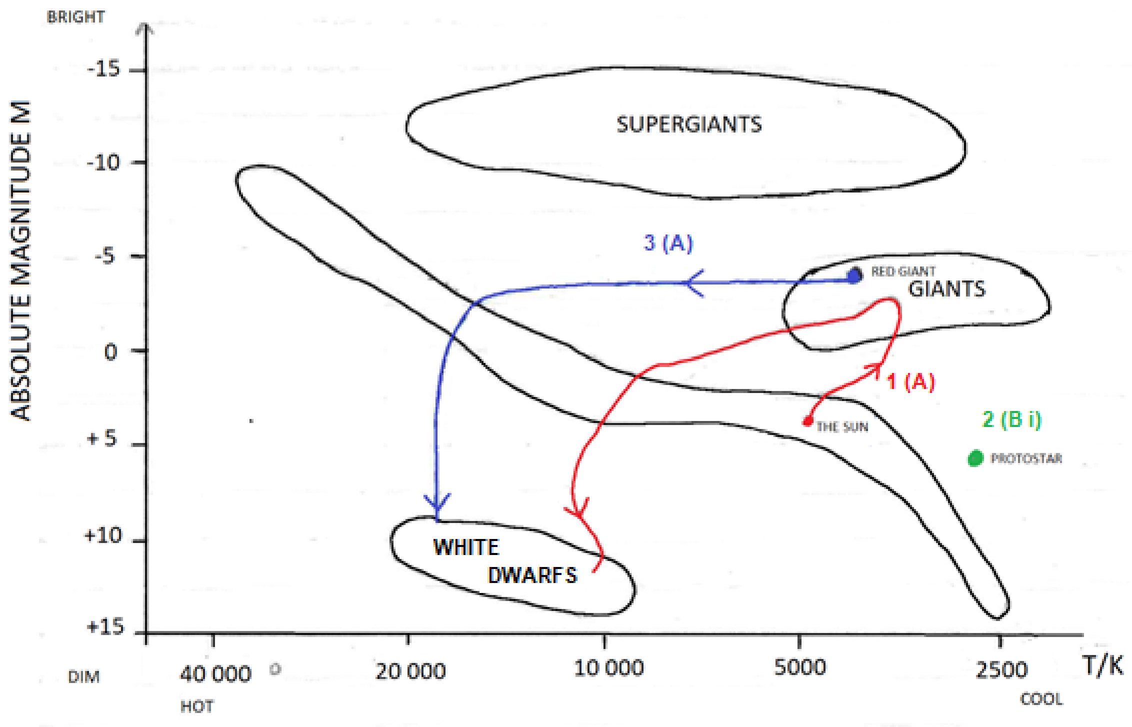
ASTROPHYSICS

2-3 The Hertzspung-Russell diagram

1. (a)



(b) See above on the diagram – red path marked 1 (A).

2. (a) As a dust/gas cloud contracts due to the gravitational attraction between the particles, it becomes denser and denser and a protostar is formed. In this process gravitational potential energy is lost and the atoms and molecules gain kinetic energy so the interior becomes hotter. If there is enough material, the temperature will reach that required for nuclear fusion. The fusion process releases more energy as the hydrogen nuclei fuse to form helium and the core becomes hotter still. The outer layers then heat up sufficiently for the outer layer to emit light and a star is born.

(b) (i) See above on the diagram – green protostar marked as 2 (B i)

(ii) The physical property of a star determining its position on the main sequence is its mass.

3. (a) See above on the diagram – blue path marked 3 (A)

(b) A white dwarf star has an absolute magnitude between +15 and +10 and is hotter than the Sun
A white dwarf emits less power than the Sun.
A white dwarf has a smaller diameter than the Sun.

4. T_X = 4000 K $\quad$ T_Y = 8000 K $\quad$ T_Z = 20 000 K

M_X = -2 $\quad$ M_Y = +4 $\quad$ M_Z = + 10

(a) The more negative the absolute magnitude, the greater the power output so in order of increasing power output they are:

Z Y X

(b) Looking at the Hertzsprung-Russell diagram:

X lies in the red giant region
Y lies in the main sequence region
Z lies in the white dwarf region

Each has an absolute magnitude and temperature characteristic of the region.

(c) A magnitude 1 star is, by definition, defined to be 100 times brighter than a magnitude 6 star.

If x is the factor giving a change in magnitude of 1 then

$X^5 = 100$ so $x = 100^{(1/5)} = 2.512 = 2.5$

So the brightness/power ration for two stars is given by

Ratio = $2.5(12)^n$ where n is the difference in magnitude.

Star X and star Z

X is brighter than Z by 12 magnitudes so its power output is 2.5^{12} times greater than Z's.

Hence $\frac{P_X}{P_Z} = 2.512^{12} = 6.313 \times 10^4 = 6.3 \times 10^4$

Stefan's law states that $P = \sigma T^4 = \sigma\pi d^2 T^4$ where d is the diameter (surface area of a sphere = πd^2)

$$d_X^2 = \frac{P_X}{\sigma\pi T_X^4} \text{ and } d_Z^2 = \frac{P_Z}{\sigma\pi T_Z^4}$$

Hence $\frac{d_X^2}{d_Z^2} = \frac{P_X}{\sigma\pi T_X^4} \times \frac{\sigma\pi T_Z^4}{P_Z} = \frac{P_X}{P_Z} \times \frac{T_Z^4}{T_X^4}$

$$\frac{d_X}{d_Z} = \sqrt{\frac{P_X}{P_Z} \times \frac{T_Z^4}{T_X^4}} = \sqrt{6.313 \times 10^4 \times \frac{(20\,000)^4}{(4\,000)^4}} = \sqrt{6.313 \times 10^4 \times 5^4} = 6281 = 6300 \text{ to 2 sf}$$

Star Yand star Z

X is brighter than Z by 12 magnitudes so its power output is 2.5^6 times greater than Z's.

Hence $\frac{P_X}{P_Z} = 2.512^6 = 251.3$

Stefan's law states that $P = \sigma T^4 = \sigma\pi d^2 T^4$ where d is the diameter (surface area of a sphere = πd^2)

$$d_X^2 = \frac{P_X}{\sigma\pi T_X^4} \text{ and } d_Z^2 = \frac{P_Z}{\sigma\pi T_Z^4}$$

Hence $\frac{d_X^2}{d_Z^2} = \frac{P_X}{\sigma\pi T_X^4} \times \frac{\sigma\pi T_Z^4}{P_Z} = \frac{P_X}{P_Z} \times \frac{T_Z^4}{T_X^4}$

$$\frac{d_X}{d_Z} = \sqrt{\frac{P_X}{P_Z} \times \frac{T_Z^4}{T_X^4}} = \sqrt{251.3 \times \frac{(20\,000)^4}{(8\,000)^4}} = \sqrt{251.3 \times 2.5^4} = 99.06\ldots = 99 \text{ to 2 sf or 100 to 1 sf}$$