CORPUS CHRISTI COLLEGE
SEQUERE DOMINUM

12 ATAR Physics

Hubble's Law Investigation
Data Gathering 2016 (3%) 2%

Student name: Soln.

The Big Bang Theory & Hubble's Law

The Big Bang theory is the prevailing cosmological model for the universe from the earliest known periods through its subsequent large-scale evolution. The model accounts for the fact that the universe expanded from a very high density and high temperature state, and offers a comprehensive explanation for a broad range of phenomena, including the abundance of light elements, the cosmic microwave background, large scale structure and Hubble's Law.

Since Georges Le Maître first noted, in 1927, that an expanding universe might be traced back in time to an originating single point, scientists have built on his idea of cosmic expansion. In 1929, from analysis of galactic redshifts, Edwin Hubble concluded that galaxies are drifting apart; this is important observational evidence consistent with the hypothesis of an expanding universe.

1. Show how the mathematics of Hubble's Law can be used to calculate the age of the universe. **[3 marks]**

$V = H_o d$ & $v = \frac{d}{t}$. ✓

$\therefore H_o d = \frac{d}{t}$ (d cancels) ✓

$\therefore \frac{1}{t} = H_o$ (or) $t = \frac{1}{H_o}$. ✓

(3)

2. Explain how the recessional velocity data is collected. **[4 marks]**

1. LIGHT IS COLLECTED FROM THE SOURCE. ✓
2. THE SPECTRUM OF LIGHT IS PRODUCED ✓
3. THE VARIATION OF THE STATIONARY ABSORPTION ARE COMPARED WITH THE NEW SOURCE; $\Delta\lambda$ IS CALC'D. ✓
4. RECESSIONAL VEL = $\frac{\Delta\lambda}{\lambda} c$ ✓

(4)

3. Use the table below and your digital device, to collect your data. This data will then be required for completion of the second stage of this investigation. Leave you data table with your teacher, you will be able to collect it at the start of part 2. **[10 marks]**

https://en.wikipedia.org/wiki/NGC_5001

New General Catalogue (NGC) Table

NGC #	Type of object	Redshift (z)	Distance (Lyrs)	Recessional Speed (kms^{-1})	Distance (MPc)
5005	Spiral Galaxy	0.0032	65×10^6	946	20
5010	Lenticular Galaxy	0.2	140×10^6	2975	43
5055	Spiral Galaxy	0.002	37×10^6	484	11
5068	Spiral Galaxy	0.002	22×10^6	600	7
5078	Spiral Galaxy	0.007	94×10^6	2168	29
5090	Elliptical Galaxy	0.011	150×10^6	3420	46
5112	Spiral Galaxy	0.003	62×10^6	900	19
5170	Spiral Galaxy	0.005	96×10^6	1500	29
5236	Spiral Galaxy	0.002	15.21×10^6	513	5
5248	Spiral Galaxy	0.004	59×10^6	1151	18
5364	Spiral Galaxy	0.004	54.5×10^6	1241	17
5408	Irregular Galaxy	0.002	15.7×10^6	506	5

CORPUS CHRISTI COLLEGE
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12 ATAR Physics

38.

Hubble's Law Investigation
Data Analysis 2016 (4%)

Student name: Soln.

The Big Bang Theory & Hubble's Law

When a source of waves is moving, a stationary observer notices an apparent change in frequency of the waves. This effect is observed for both longitudinal and transverse waves. For example, if an ambulance moves towards you the sound frequency you hear is higher than the frequency its siren is emitting. This is known as the Doppler Effect.

If a source of electromagnetic waves, such as a star, is travelling away from an observer then the wavelengths of the lines in its electromagnetic spectrum are shifted to higher values. This is called red shift. An equation for the relationship is as follows:

$$z = \frac{\Delta\lambda}{\lambda}$$

It can also be shown that: $z = \frac{v}{c_0}$

Where:
- z = red shift
- $\Delta\lambda$ = change in wavelength (moving source) (nm)
- λ = wavelength of stationary source (nm)
- v = recessional speed of galaxy (ms^{-1})
- c_0 = speed of light in a vacuum (ms^{-1})

Edwin Hubble analysed the red shifts of various galaxies in 1920 and deduced that most galaxies are moving away from the Earth, this suggests that the Universe is expanding. Hubble also discovered that the further away a galaxy is, the bigger its red shift and the faster it is moving away. This relationship is known as Hubble's Law and can be stated algebraically as follows:

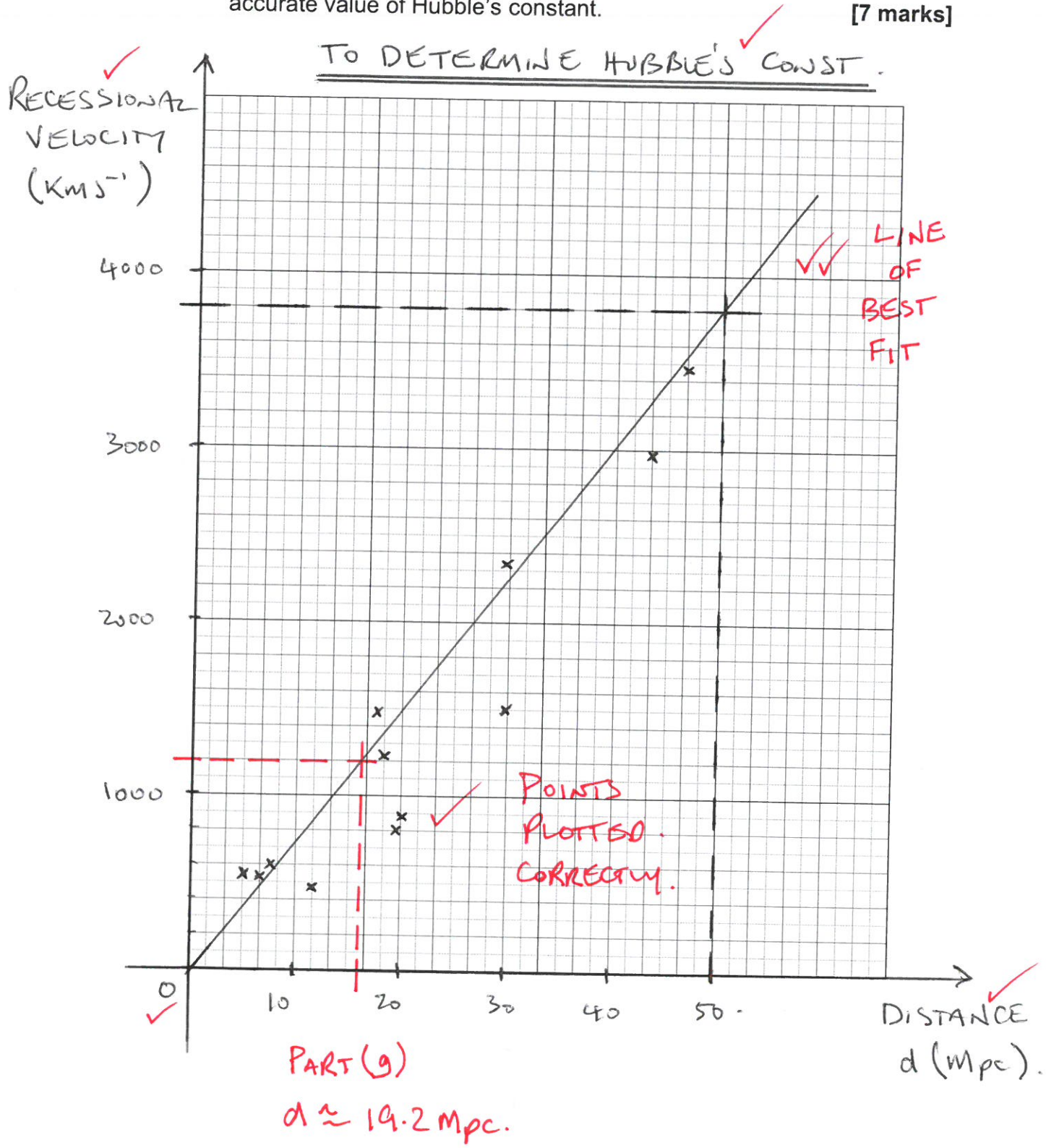
$$v_{galaxy} = H_0 . d$$

V_{galaxy} = recessional speed of galaxy (ms^{-1})
d = distance to galaxy (Mpc)
H_o = Hubble's constant ($Kms^{-1}Mpc^{-1}$)

The distances to galaxies can be estimated by observing Cepheid Variables within a galaxy. A Cepheid Variable is a class of star that pulsates. The relationship between the period of pulsation and the size of the star is very precise. An understanding of how brightness diminishes with distance allows

astronomers to estimate distances to galaxies with a high degree of confidence.

a) Using the data points collected previously in part 1 and a line of best fit, plot a correctly labelled graph that will allow you to determine an accurate value of Hubble's constant. **[7 marks]**



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b) Calculate a value for Hubble's constant, in the correct units, showing how you obtained this value from your graph. **[4 marks]**

$$m = H_0 = \frac{y_2 - y_1}{x_2 - x_1} = \frac{3800 - 0}{50 - 0}.$$

4

$\therefore H_0 = 76 \text{ km s}^{-1}$.

(-1 IF POINTS NOT FROM GRAPH).

c) Write the equation of the line you have drawn. **[2 marks]**

FROM $y = mx + c$.

$v = 76d$.

2

d) State three reasons why you think that measurements of Hubble's constant have varied widely since Hubble's first determination in 1920. **[3 marks]**

1) NEW TECHNOLOGY FOR IMPROVED MEASURES OF DISTANCE.

2) NEW TECHNOLOGY FOR IMPROVED MEASURES OF RECESSIONAL SPEED.

3

3) SUPER COMPUTERS TO PROCESS LARGE DATA SETS.

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e) Explain why the value of red shift z has no units? **[2 mark]**

$z = \frac{v}{c} = \frac{ms^{-1}}{ms^{-1}}$ (units cancel). (2)

f) A line in the spectrum of ionised calcium has a wavelength of 393.3 nm when measured in the laboratory. When similar light from the galaxy NGC 3350 is measured; its wavelength is 394.64 nm.

i. Calculate the redshift of this galaxy. **[2 marks]**

$z = \frac{\Delta\lambda}{\lambda} = \frac{394.64 - 393.3}{394.64}$ (2)

$z = 0.0034.$

ii. Calculate the recessional speed of this galaxy in kms^{-1}. **[3 marks]**

$V = zc = (0.0034)(3 \times 10^8)$

$= 1.02 \times 10^6\ m.$ (3)

$= 1020\ kms^{-1}$

g) For the recessional speed previously calculated, use your graph and the line of best fit to determine the distance to this galaxy in Mpc. **[1 mark]**

FROM GRAPH (P2)

$d \simeq 19.2\ Mpc.$ (1)

h) Determine how many years it takes for light from galaxy NGC 3350 to reach Earth. **[2 marks]**

DISTANCE LYRS = $(19.2)(3.26)$

$= 62.6$ LYRS. (2)

$\therefore t = 62.6$ YEARS.

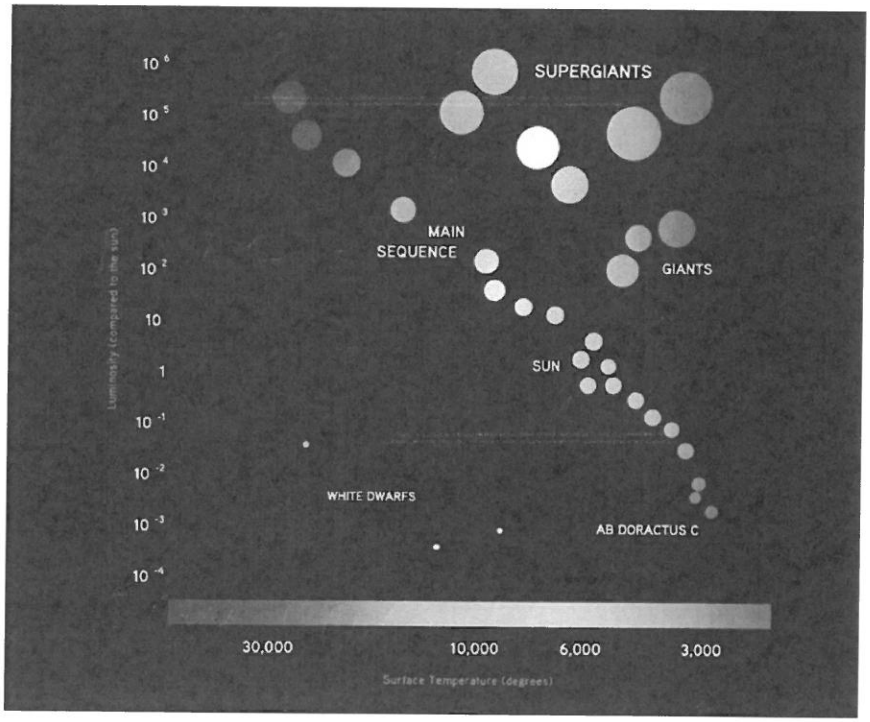
(10)

Classifying Stars

H-R Diagrams

The Hertzsprung–Russell diagram, abbreviated H–R diagram or HRD, is a scatter graph of stars showing the relationship between the stars' absolute magnitudes or luminosities versus their spectral classifications or effective temperatures. More simply, it plots each star on a graph measuring the star's brightness against its temperature (colour). It does not map any locations of stars.

The diagram was created circa 1910 by Ejnar Hertzsprung and Henry Norris Russell and represents a major step towards an understanding of stellar evolution or "the way in which stars undergo sequences of dynamic and radical changes over time".



Now watch this you-tube video and answer the following questions:

https://www.youtube.com/watch?v=UwW_FbPE1R8

a) Use the data table shown below to construct a H-R diagram for the stellar objects shown in the table. Use the identification number, 33, 34, 35, etc. to show where the object lies on the diagram. **[4 marks]**

	Group 3	Visual Magnitude (Apparent)	Distance (light-years)	Temperature (Kelvin)	Luminosity (Sun = 1) (Absolute)
* 33	Sirius B	+8.5	8.7	10,700	0.0024
* 34	Procyon B	+10.7	11.3	7,400	0.00055
* 35	Grw +70 8247	+13.19	49	9,800	0.0013
* 36	L 879-14	+14.10	63?	6,300	0.00068
* 37	Van Maanen's Star	+12.36	14	7,500	0.00016
* 38	W 219	+15.20	46	7,400	0.00021
* 39	Barnard's Star	+9.54	6.0	2,800	0.00045
* 40	Luyten 789-6	+12.58	11.0	2,700	0.00009
* 41	Canopus	-0.72	100.0	7,400	1,500.0
* 42	Capella	+0.05	47.0	5,900	170.0
* 43	Rigel	+0.14	800.0	11,800	40,000.0
* 44	Alpha Crucis	+1.39	400.0	21,000	4,000.0

b) Complete the table (below) for the group 3 objects shown above. **[4 marks]**

Group 3 object	H-R classification of object
Sirius B	(33) WHITE DWARF. ✓
Barnard's Star	(39). MAIN SEQ. (RED) ✓
Rigel	(43). MAIN SEQ (BLUE) ✓
Alpha Crucis	(44) MAIN SEQ (BLUE). ✓

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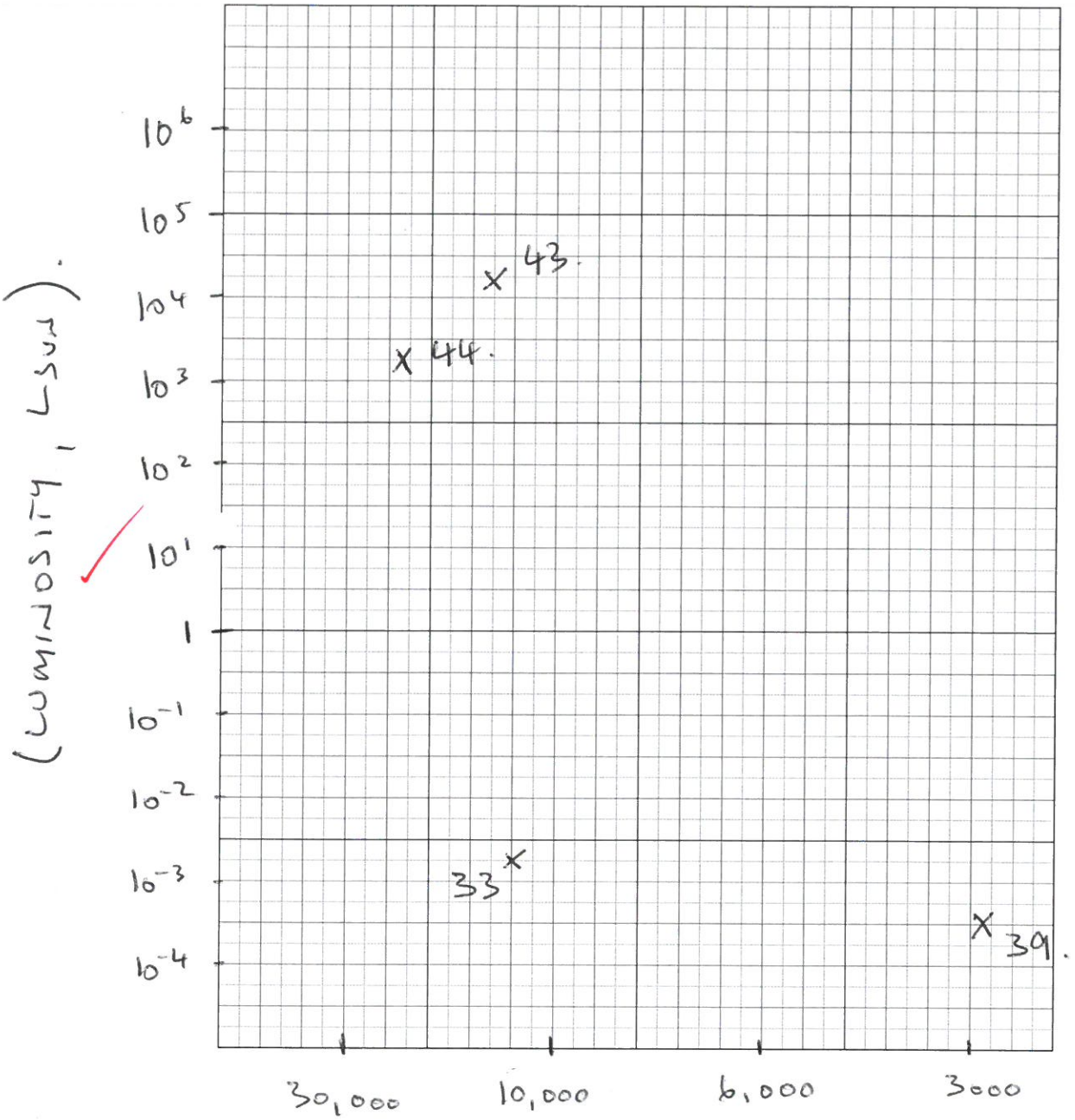
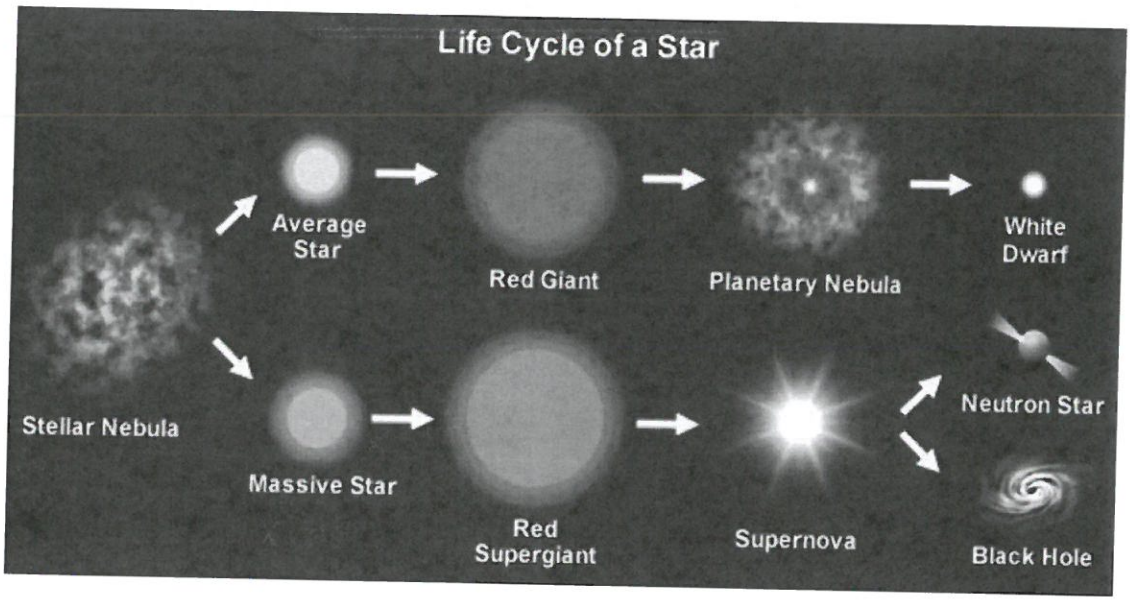
H-R DIAGRAM.



NOTE: APPROX COORDINATES OKAY.

(4)

Consider the diagram shown below. It shows a very simplified life cycle of a star.



c) Use this to suggest what the future of the sun might be. Explain your answer.

[4 marks]

1) THE SUN IS AN AVERAGE STAR FROM THE MAIN SEQUENCE.
2) IT WILL EVENTUALLY BECOME A RED GIANT
3) PLANETARY NEBULA.
4) FINALLY A WHITE DWARF.

4

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