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Draw a cross through the box (☒) if you have NOT written in this booklet

Mana Tohu Mātauranga o Aotearoa
New Zealand Qualifications Authority

Level 2 Earth & Space Science 2023

91192 Demonstrate understanding of stars and planetary systems

Credits: Four

Achievement	Achievement with Merit	Achievement with Excellence
Demonstrate understanding of stars and planetary systems.	Demonstrate in-depth understanding of stars and planetary systems.	Demonstrate comprehensive understanding of stars and planetary systems.

Check that the National Student Number (NSN) on your admission slip is the same as the number at the top of this page.

You should attempt ALL the questions in this booklet.

If you need more room for any answer, use the extra space provided at the back of this booklet.

Check that this booklet has pages 2–16 in the correct order and that none of these pages is blank.

Do not write in any cross-hatched area (DO NOT WRITE IN THIS AREA). This area will be cut off when the booklet is marked.

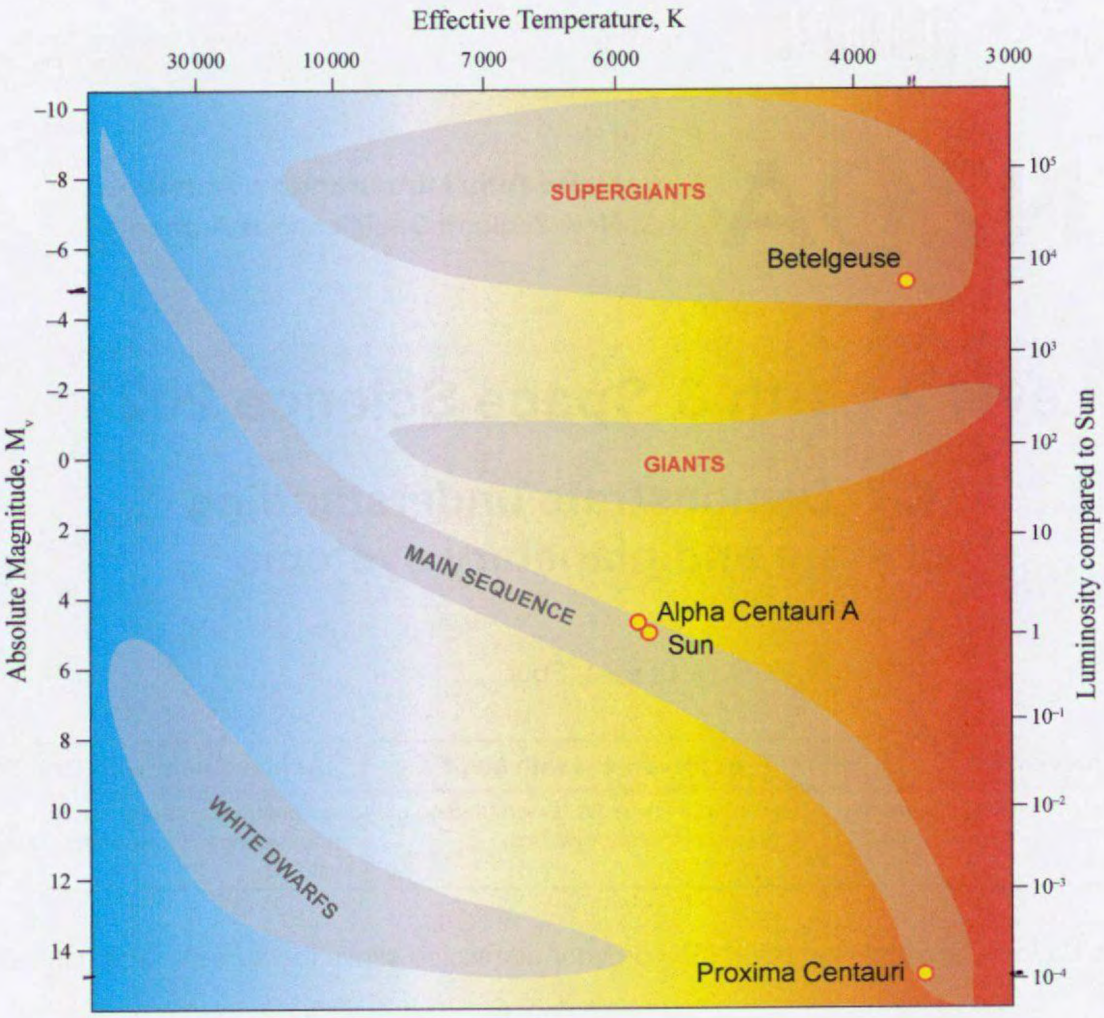
YOU MUST HAND THIS BOOKLET TO THE SUPERVISOR AT THE END OF THE EXAMINATION.

Merit

TOTAL 17

RESOURCE

HR (Hertzsprung-Russell) diagram



Adapted from: http://www.atnf.csiro.au/outreach/education/senior/cosmicengine/stars_hrdiagram.html

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The assessment begins on the following page.

QUESTION ONE: RED STARS

Betelgeuse and Proxima Centauri are both red stars. Betelgeuse is easily seen in the constellation of Orion. Proxima Centauri is a star that forms part of the triple star system in the constellation of Centauri. Betelgeuse is 642.5 light years away from Earth, and has a mass of approximately 17 solar masses, while Proxima Centauri is only 4.2 light years away, and has a solar mass of 0.12.

(a) Using the HR diagram on page 2, complete the table comparing the properties of Betelgeuse and Proxima Centauri.

Star	Life Stage	Temperature	Absolute Magnitude	Luminosity
Betelgeuse	Super Giant	3500k	$-5\ M_v$	10^4
Proxima Centauri	Main Sequence red dwarf	3500k	$15\ M_v$	10^{-4}

(b) Explain, in detail, using the information from the HR diagram and the star properties in part (a), the reason for the difference in absolute magnitudes of Betelgeuse and Proxima Centauri.

In your answer you should consider:

- the difference between luminosity and absolute magnitude
- surface temperature
- surface area.

Betelgeuse and Proxima Centauri are in different stages of life. Betelgeuse is a Red Super Giant. This means that when it ran out of H to fuse to He it had a solar mass greater than 10. Whereas Proxima Centauri is a MSS. This means that it is actively fusing H to He and is emitting the excess energy created by the fusion. Betelgeuse's main fuel source is the heat created from the contractions of its core. While it is fusing He to denser materials like carbon its main energy source is the contractions of its core. This means that it is cooler ~~than it was~~ and emitting less light than it was as a MSS. This is shown in its Luminosity of 10^4. Luminosity is how much energy is being emmitted per second by a star.

Betelgeuse and Proxima Centauri are in different stages of their life cycle as stars. Betelgeuse is a Red Super Giant, while Proxima centauri is a main-sequence star. While their surface temperatures are similar at approximately 3500K they have very different absolute magnitudes and luminosities. Due to the differences in size, with Betelgeuse being approximately 17 solar masses while Proxima Centauri's only 0.12 solar masses, they are presumedly not producing equal amounts of heat, and energy its just harder to maintain surface temperatures when you're larger. This explains the discrepencies between the absolute magnitudes and the luminosities of the 2 stars. ~~With Betelgeuse~~ Absolute magnitude is the measure of how bright a star is without its distance effecting it. While luminosity is how much energy is being emmitted per second by the star. Betelgeuse has an absolute magnitude of -5 Mv, while having a luminosity of 10^4. This is very different to Proxima Centauri's Absolute magnitude of 15 Mv and luminosity of 10^{-4}. This shows that Betelgeuse emitts a lot more energy per second while having a reasonably small absolute magnitude due to the sheer size of the star.

Whereas Proxima Centauri has a higher Absolute magnitude as the light energy has less to travel from the core.

(c) Explain, in detail, how the luminosity of Betelgeuse will change over its life stages, whereas the luminosity of Proxima Centauri will not change until the end of its life.

In your answer you should consider:

- star mass
- surface area
- surface temperature
- life stages.

An annotated diagram may assist your answer.

GMC → Protostar → MSS $\xrightarrow{\text{Greater than } 10Sm}$ Red Supergiant → Planetary Nebula → Supernova ↗ Neutron star → Pulsar ↘ Black hole

MSS $\xrightarrow{\text{Smaller than } 8Sm}$ Red Giant → Planetary Nebula → White dwarf → Black dwarf

Due to the vast differences in the solar mass of Betelgeuse and Proxima centauri the end stages of their lifes as stars will be different. To become a Supergiant you have to have a solar mass greater than 10 Sm. Due to Proxima Centauri's size of 0.12 solar mass it won't become a Red super-giant. It might not even become a Red giant due to it being a Red dwarf. Red dwarfs are small dim MS stars. They fuse H to He at such a slow pace that they might not ever run out. Due to Proxima Centauri being a Red dwarf it will remain at the same luminosity until the very end of its life cycle when it eventually runs out of H to fuse and instead dies. This means that proxima Centauri will be stuck at approximately 3500k, 15 M_v and 10^{-4} for the rest of its life.

Whereas Betelgeuse is currently a Red Super Giant. This means that it has at least another 3 life stages to go through where its temperature, luminosity, and absolute magnitude will change. When it stops fusing He to other denser elements like Carbon it will change to a Planetary Nebula. In this stage its outer gaseous shell will detatch and float off into space to become a planetary nebula. This will leave only the core left which becomes a SuperNova. At this point all fusion will stop, ~~breaking the~~ leading to no fuel source. The hydrostatic equillibrium will break again causing ~~sending~~ the core to collapse quickly in on itself. At this point Betelgeuse's core will either collide with ~~itself~~ with enough force that a black hole will form. Or the core ~~with~~ collision will send it flying out and a Neutron Star will be formed. ~~[illegible]~~ The collision of the core on itself will create a powerful shockwave. This means that Betelgeuse will have multiple changes in temperature, luminosity, and absolute magnitude over the rest of its life stages.

QUESTION TWO: MATARIKI

Source: www.sciencelearn.org.nz/images/697-matariki-pleiades-star-cluster

Matariki is a star cluster indicating the beginning of the New Year to many Māori iwi. It contains many young stars, the brightest of these being 14 young, blue, main-sequence stars that have formed in the associated stellar nebula. These stars have masses in the range of 3 solar masses to 6 solar masses for the largest.

(a) Describe what is meant by the term "stellar nebula".

A Stellar Nebula is a collection of stars within a nebula. They are all close together and rotate ~~around~~ together around the galaxy.

(b) Explain, in detail, how these young blue stars would have formed.

In your answer you should consider the role gravity plays in star formation.

An annotated diagram may assist your answer.

GMC → Protostar → MSS

~~Accretion~~
- Disturbance causes collapse

- Accretion around a gravitational center

- Hydrostatic equilibrium reached
- Nuclear fusion started

The stars in the star cluster Matariki would have all formed from the collapse of a Giant Molecular cloud. The cloud would have been disturbed by something, perhaps some solar wind and that would have caused all the dust and gas molecules to collapse inwards towards a newly formed gravitational center. As the matter moved inwards there would have been collisions between the molecules. These collisions caused the materials to accrete, and to create friction. The change of gravitational potential energy into heat from the friction created by the collisions would have melded the material together. This would end up with ~~a~~ protostars being formed from the accretion. The protostars would form the new gravitational centers and they'd continue accreting until they reached a high enough temperature where the fusion of H to He begins. ~~Eventually~~ The ~~s~~ start of nuclear fusion would mean that the star reached Hydrostatic equillibrium and could no longer take in new materials. This would leave enough materials for the other stars in the stellar nebula. Eventuallly all 14 of the young ~~st~~ stars would reach main-sequence and begin nuclear fusion.

(c) Explain, in detail, the life cycle of the smallest (3 solar masses) of these young blue stars from main sequence to the end of its life.

In your answer you should consider:

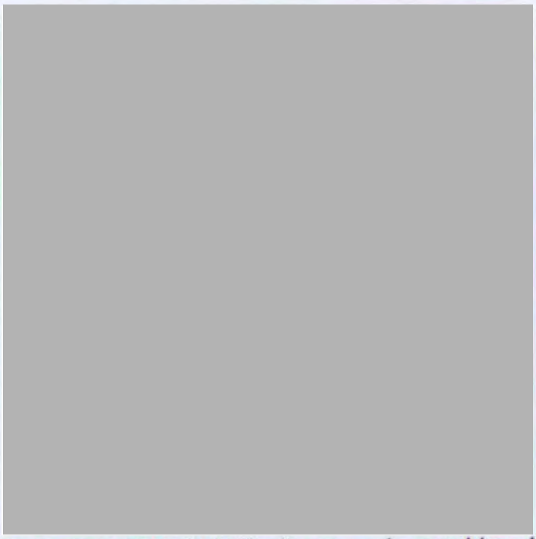
- the role of gravity in the changing life stages
- fuel usage during the different life stages
- energy changes during the different life stages.

An annotated diagram may assist your answer.

GMC → Protostar → MSS $\xrightarrow{\text{less than 10 solar masses}}$ Red Giant → Planetary nebula → White dwarf → Black dwarf

The smallest star of the Matariki cluster has a solar mass of 3. This means that once it runs out of Hydrogen to fuse to Helium it would become a Red Giant. As a red giant its core would start contracting. These contractions would create more ~~heat~~ energy going out than in on the outer gaseous shell. This would cause the hydrostatic equillibrium to be broken causing the outer shell to expand until it reaches its next life stage. In the next stage the outer shell would detatch from the core and would float off and become a Planetary Nebula. This would leave a dense C core which is a White dwarf. The White dwarf has no fuel source and is just slowly radiating the heat Leftover from its previous life stages. Once the core ran out of heat to emit it becomes a black dwarf. This is the end stage of the smallest star from the stellar nebula of Matariki.

QUESTION THREE: JUPITER AND THE SOLAR SYSTEM



Source: https://blogs.nasa.gov/Watch_the_Skies/2022/09/16/jupiter-to-reach-opposition-closet-approach-to-earth-in-70-years/

Our solar system consists of eight planets, with Jupiter the largest.

(a) Describe the difference between a star and planet.

A star has a core, in which nuclear fusion has taken place, they are hotter ~~and~~, denser ~~than~~ and larger, than planets. ~~and~~ Whereas Planets are smaller and rely on heat created by stars, they don't produce their own.

(b) Explain, in detail, how gas giant planets like Jupiter are formed.

In your answer you should consider:

- the role of gravity
- temperature
- solar winds.

An annotated diagram may assist your answer.

GMC → Protostar → MSS → Protoplanetary disc → Planetesimals → Proto-planets

- Hydrostatic equilibrium reached

Outside the frost line → Gas Planets

Within the frost line → Rocky Planets

Gas planets like Jupiter are formed from protoplanetary discs. Once a Protostar begins fusing H to He and becomes a Main-sequence star the star no longer wants to take in new materials. This is due to the hydrostatic equillibrium being reached which means that the outward and inward pressure are equal. Thusly being at equillibrium. Once that equillibrium is reached the leftover materials start to form a proto-planetary disc. As this disc flattens out and the materials are pushed around by the solar wind and gravity collisions start to occur. Through these collisions the materials begin to accrete and form clumps. Once the accreted materials reached approximately 1km in diameter gravity started pulling other materials towards them. This increased the rate of accretion and soon planetesimals were formed. On the protoplanetary disc there was a frost line, the materials inside were rockier and denser materials. Since the solar winds couldn't as easily push them away. Whereas the lighter materials like gasses and ice were pushed by the solar wind out past the frost line. This means that the planetesmals that formed out beyond the frost line were icy and ~~gassy~~ ~~planets~~ As the ~~p~~ materials continued to accrete the ~~plan~~ proto-planets out past the frost line were larger due to their being more gasses present than any other element. The role of the frost line, gravity, and solar winds play a key role in the creation of gas planets like Jupiter.

Question Three continues on the next page.

(c) The picture below shows Jupiter's three rings, and the four rocky moons that accompany the rings. The rings are mainly made up of very fine dust particles.

Source: https://upload.wikimedia.org/wikipedia/commons/thumb/b/b8/Jupiter_Rings_ca.svg/2560px-Jupiter_Rings_ca.svg.png

Explain, in detail, how Jupiter's four rocky moons and ring system could possibly have been formed.

In your answer you should consider:

- the planet's gravity
- how moons may have formed around Jupiter
- the material making up Jupiter's rings.

An annotated diagram may assist your answer.

GMC → Protostar → MSS → Protoplanetary disc → Protoplanets ↗ Rocky Planets
↘ Gaseous Planets → comets being caught
→ Planetesimals colliding
→ leftover materials forming a moon disc

Jupiter has 4 rocky moons and a ring system that orbits it. It is most likely that its 4 rocky moons formed from accretion of the leftover materials from Jupiters formation. This is due to their close proximity to Jupiter as captured asteroids and comets are usually further out. This combined with them being found within Jupiters ring system which is made up of leftover dust particles from Jupiters formation. The rings are made up of very fine dust particles which means that they are the materials leftover from the protoplanetary disc that Jupiter formed from. Since the 4 moons are all located in Jupiters ring system it is clear that they formed from leftover material that Jupiter didn't use up from the Proto-Planetary disc.

It is also unlikely that they formed from a ~~protoplanet~~ planetesimal colliding with the Jupiter Planetesmal. as there are multiple of them and the moons formed that way tend to be closer in size to the Planet they orbit.

This is why I believe that the moons and rings surrounding Jupiter were formed from ~~[illegible]~~ material leftover from Jupiters formation.

Extra space if required.
Write the question number(s) if applicable.

QUESTION NUMBER

91192

Merit

Subject: Earth & Space Science

Standard: 91192

Total score: 17

Q	Grade score	Marker commentary
One	M5	The candidate clearly defines luminosity and absolute magnitude within the context of the question. The significance of the numerical values is not clearly understood. Luminosity is linked to surface area for the stars and the lack of probable change in the luminosity of the red dwarf is explained in terms of fusion, mass and outcome.
Two	M6	The candidate provides clear explanation of the link between gravity and star formation process until fusion occurs. The continued “life cycle” process is explained in terms of fuel use through to a white dwarf. Reference is made to the Matariki stars but does not include the significance of the colour.
Three	M6	The candidate explains how gravitational forces become and are involved in the formation of planets. The role of the frostline and solar winds are given and the influence they have on planet formation. The resulting formation of Jupiter’s moons are explained in terms of gravitational forces linked to left over materials from planet formation.