Questions

Module 8: From the Universe to the Atom

8.1 Origins of the elements

Multiple-choice questions: 1 mark each

1. Which of these statements best describes the Big Bang model of the Universe's origins?

(A) A model about how hydrogen and helium with a trace of lithium formed the first atoms of the Universe.

(B) A cosmological model about cosmic microwave background radiation.

(C) A model of the Universe beginning as energy at a single point and having expanded ever since.

(D) A model explaining the formation of all the elements found in the Periodic Table.

2. Which of the following does NOT provide evidence for the Big Bang model?

(A) The more distant, older galaxies are less densely packed than galaxies closer to us.

(B) The abundance of simple elements in the Universe.

(C) The expansion of the Universe.

(D) The existence of cosmic microwave background radiation.

3. What evidence did Edwin Hubble provide to show that the Universe was expanding?

(A) Hubble found that stars emit absorption spectra and nebulae emit emission spectra.

(B) Hubble found spectral evidence that the more distant a galaxy is, the greater its red-shift.

(C) Hubble found spectral evidence that the closest galaxies have a greater red-shift.

(D) Hubble estimated that the age of the Universe was 2 billion years.

For Questions 4–7, you will need to refer to the following Hertzsprung-Russell (HR) diagram below, showing the Sun, star *W* and star *Z*.

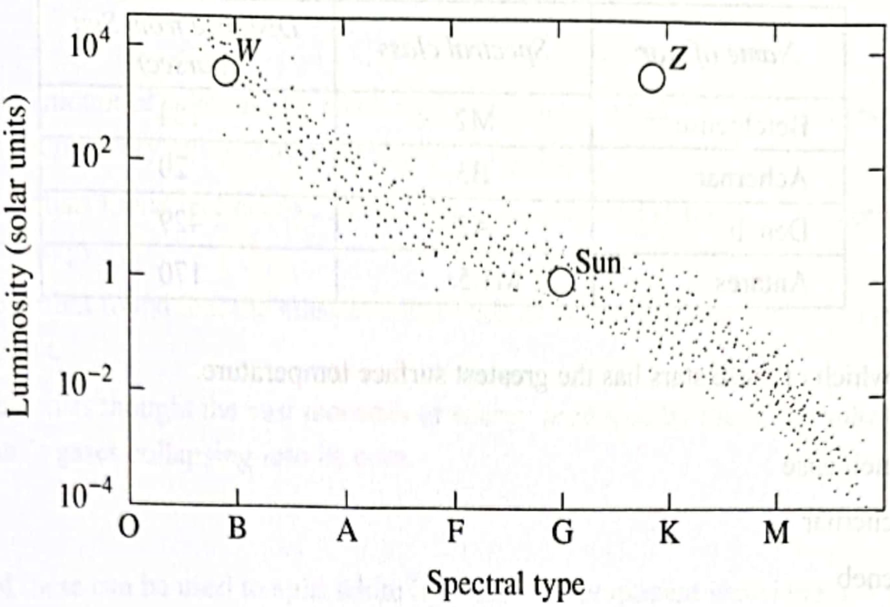


Diagram from 2015 HSC Q33(b)

4. What is being shown about stars on the HR diagram above?

(A) Apparent magnitude versus the spectral type of the stars.
(B) Surface temperature versus the luminosity of the stars.
(C) Surface temperature versus the spectral type of the stars.
(D) Luminosity versus the surface temperature of the stars.

5. Which of these statements about the Sun, star *W* and star *Z* is correct?

(A) Star *W* is a white dwarf star, while *Z* is a red giant star.
(B) Star *W* is on the Main Sequence, while *Z* is above the Main Sequence.
(C) Star *W* is a white star, while *Z* is a blue star.
(D) Star *Z* and star *W* are both Main Sequence stars.

6. What is being shown about the stars in the HR diagram above?

(A) The Sun has a much higher luminosity than stars *W* and *Z*.
(B) Star *W* and star *Z* have the same luminosity, while Star *Z* is hotter than star *W*.
(C) Star *W* and star *Z* have the same luminosity, while Star *W* is hotter than star *Z*.
(D) Both Star *W* and star *Z* are in a similar spectral class, but different to that of the Sun.

7. Use the HR diagram above, as well as the table below to answer this qu...

The table shows information about three stars in the Milky Way galaxy.

Name of star	*Spectral class*	*Distance from Sun (parsec)*
Betelgeuse	M2	184
Achernar	B5	20
Deneb	A2	429
Antares	M1.5	170

Identify which of these stars has the greatest surface temperature.

(A) Betelgeuse

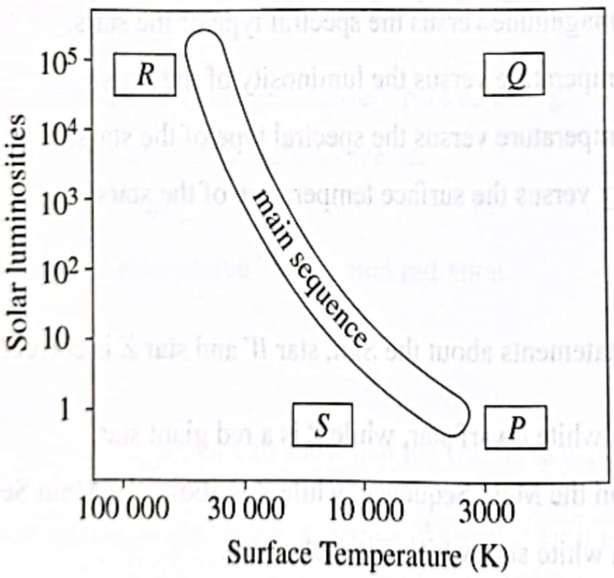
(B) Achernar

(C) Deneb

(D) Antares

Adapted from 2001 HSC Q29(b)(i)

8. The HR diagram below shows the evolutionary path of some stars.



In which position (*P*, *Q*, *R* or *S*) on the HR diagram would a star have the same surface temperature as a star on the Main Sequence?

(A) *P*

(B) *Q*

(C) *R*

(D) *S*

Diagram from 2002 HSC Q30(c) with new question

9. Before Einstein proposed that $E = mc^2$, scientists thought that chemical reactions similar to combustion reactions on Earth were generating the Sun's vast amounts of solar energy.

Why were such chemical reactions dismissed as being the energy source for a star such as the Sun?

(A) The amount of solar energy reaching Earth indicated that the Sun's fuel would be consumed very quickly by such chemical reactions.

(B) Scientists found that nuclear fission reactions occurred in the Sun, thus producing all of its energy.

(C) Scientists found that the mass of a star such as the Sun was equivalent to its energy output.

(D) Scientists thought the vast amounts of energy produced by the Sun resulted from the Sun's gases collapsing into its core.

10. Which of these can be used to split white light into its component wavelengths?

(A) Diffraction grating

(B) Microscope

(C) Telescope

(D) Polarising lens

11. What is nucleosynthesis?

(A) Nuclear fusion process which results in the formation of protons and neutrons.

(B) Nuclear fusion process which results in the release of electrons from atoms.

(C) Nuclear fusion process which results in the formation of the nuclei of heavier elements.

(D) Nuclear fusion process which results in the formation of the nuclei of lighter elements.

12. Which of the following objects will produce a continuous spectrum?

(A) Exited gases in nebulae

(B) The core of stars

(C) A black hole

(D) Ultraviolet light

13. Einstein's equivalence of mass and energy through the equation, $E = mc^2$, and other calculations helped scientists to determine the Sun's mass and energy output.

What did scientists work out about the source of energy in a star such as the Sun?

(A) The release of energy from the Sun is due to nucleosynthesis involving both nuclear fission and nuclear fusion reactions.

(B) Solar energy is released by the Sun in vast amounts due to the gravitational collapse of its huge mass.

(C) The small mass loss that occurs during the fusion of protons in the Sun's core is sufficient to release huge amounts of energy.

(D) The Sun's iron core, which is so massive, is responsible for the release of a huge amount of solar energy.

14. What is the difference between nuclear fission reactions and nuclear fusion reactions?

(A) A nuclear fusion reaction can only occur on Earth, while a nuclear fission reaction can only occur in a star.

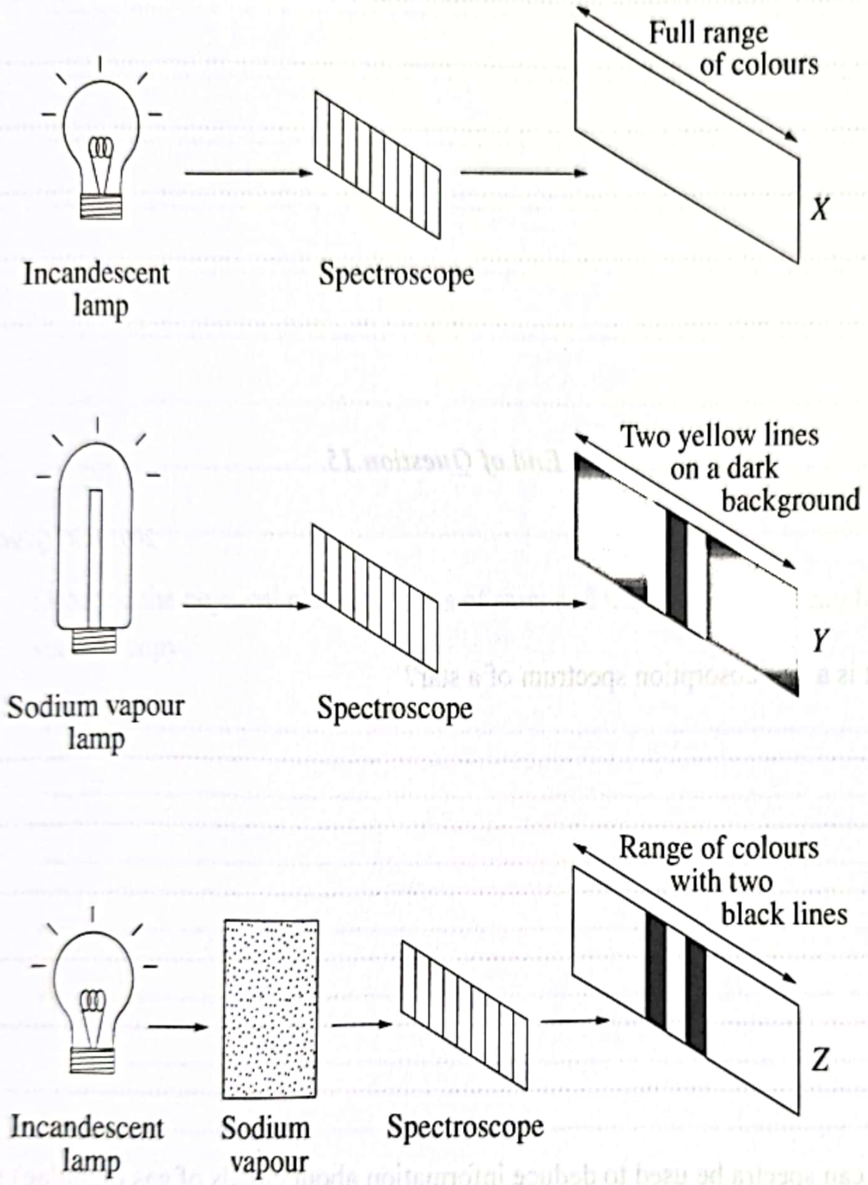
(B) In nuclear fission reactions two small nuclei fuse into one larger one, while in nuclear fusion reactions a large nucleus splits into two smaller nuclei.

(C) A nuclear fission reaction releases a much greater amount of energy than a nuclear fusion reaction.

(D) In nuclear fission reactions a large nucleus splits into two smaller nuclei, while in nuclear fusion reactions two small nuclei fuse into one larger one.

Short-answer questions

15. A student carried out an experiment to examine the spectra of various light sources through spectroscopes as shown in the diagram. The student observed three different spectra.



Account for the differences in the three observed spectra.

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Question 15 continues

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End of Question 15

2001 HSC Q29(c) ... 4 marks

16. (a) What is a line absorption spectrum of a star?

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(b) How can spectra be used to deduce information about clouds of gas (nebulae) that are found in space?

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Adapted from 1992 HSC Q Elective 5(d) ... 2 + 2 = 4 marks

17. The analysis of electromagnetic radiation is widely used by astronomers.

(a) Contrast emission and absorption spectra in terms of how they are produced.

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(b) Describe the physical characteristics of stars and their motion that can be revealed by spectroscopy.

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2008 HSC Q30(a) ... 4 + 4 = 8 marks

18. Describe how a spectrum from a star can provide information on the surface temperature of that star.

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2003 HSC Q30(c)(ii)(2) ... 2 marks

19. Explain how emission spectra and absorption spectra are produced by specific types of celestial objects.

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2015 HSC Q33(c) ... 4 marks

20. (a) Identify the initial and final elements of the principal sequence of nuclear reactions for a star on the Main Sequence.

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(b) Identify the type of star that the Sun will initially turn into after it completes its Main Sequence evolution. State the main source of energy in the core at this stage.

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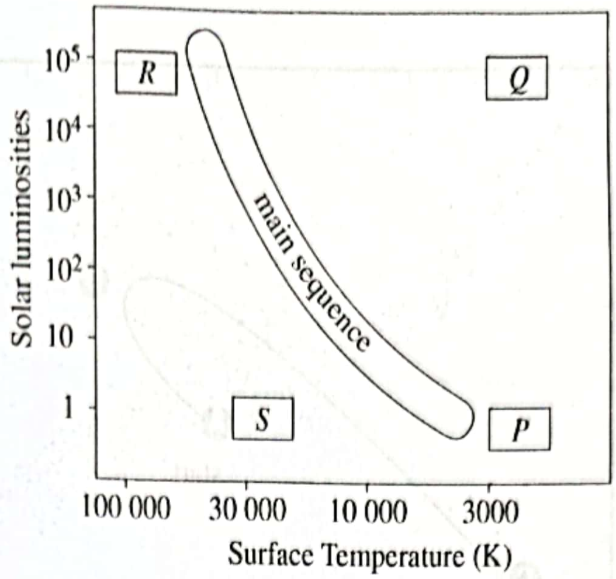
2004 HSC Q30(a) ... 2 + 2 = 4 marks

21. An H-R diagram can be used to show the evolutionary track of stars.



(a) Select the position P, Q, R or S on the H-R diagram in which white dwarfs would be found. Justify your choice.

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(b) A white dwarf is considered to be in a stable condition. Explain why a white dwarf does not continue to shrink in size.

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(c) Describe ONE nuclear reaction taking place in a star located on the main sequence.

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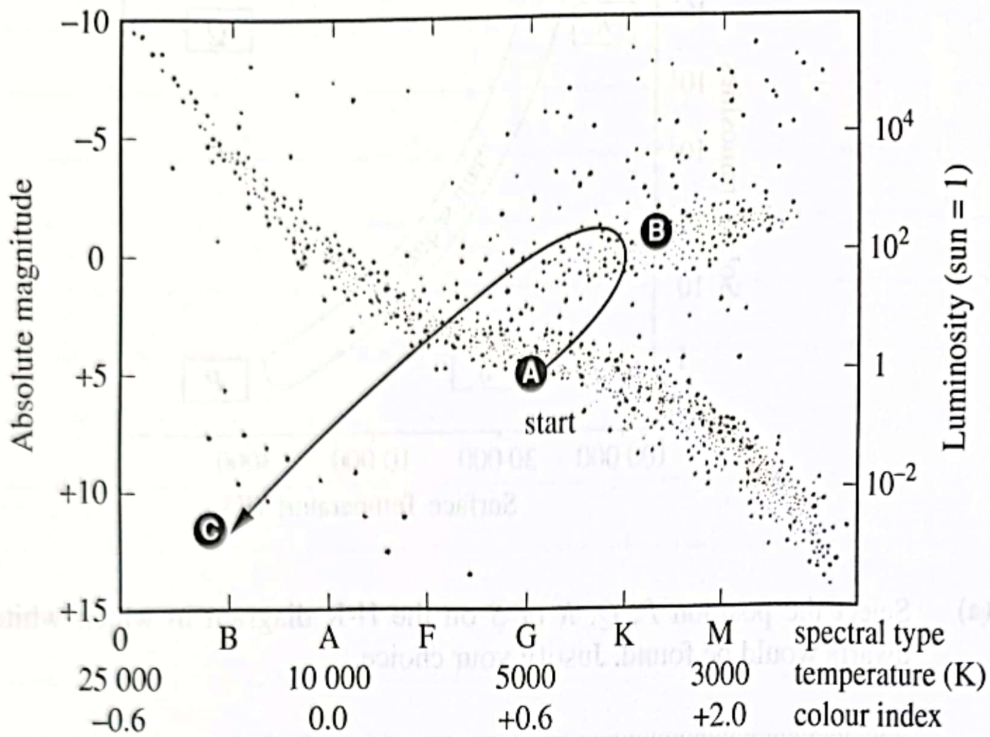
2002 HSC Q30(c) ... 2 + 2 + 2 = 6 marks

22. The Hertsprung-Russell (H-R) diagram depicts a possible life cycle path of a known star.



(a) Describe the reactions that occur in stars at the points marked **A, B** and **C** in its life cycle.

(b) Use the H-R diagram to give the characteristics of a star that would most likely be formed at point A.

2006 HSC Q30(d)(i), new (ii) ... 3 + 2 = 5 marks

13. One possible evolutionary pathway of a star is shown on the Hertzsprung-Russell diagram below.

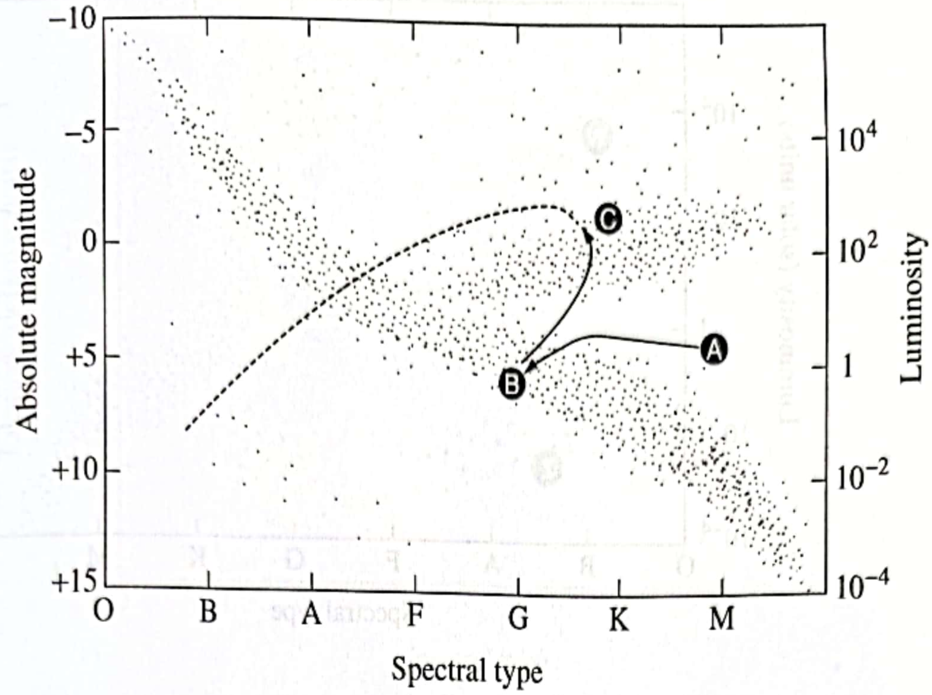


Diagram used from 2009 HSC Q30(e)

(a) At what evolutionary stages are Star B and Star C?

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(b) Most stars are found in the same diagonal band of stars on an HR diagram as Star B. What name is given to this diagonal band of stars from the lower right to the upper right of the diagram? ....

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(c) Compare the physical processes and nucleosynthesis reactions producing energy in stars B and C.

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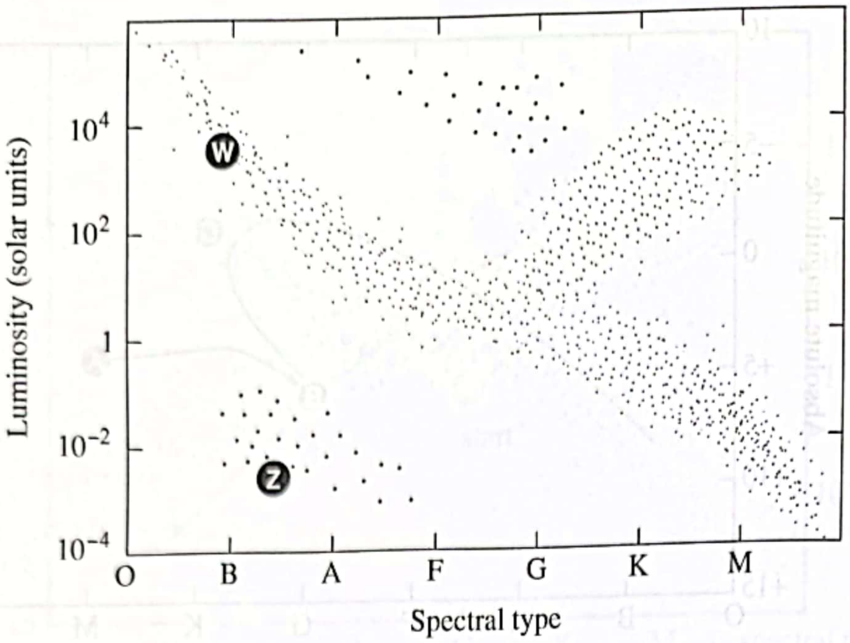
... 1 + 1 + 3 = 5 marks

24. Hertzsprung-Russell diagrams can be used to deduce the properties of stars.



(a) What type of stars are found in region **Z** on the above diagram?

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(b) Earth's Sun has a G spectral type and a luminosity of 1.

How does the surface temperature of stars at **W** and **Z** compare to the surface temperature of the Sun?

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(c) Compare the energy production processes of stars in regions **Z** and **W**.

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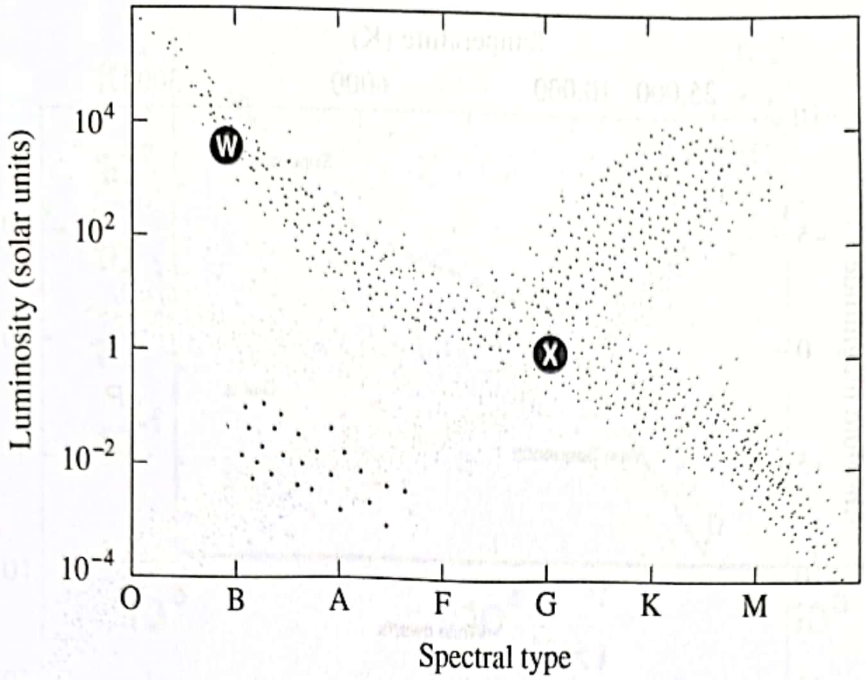
Adapted from 2010 HSC Q35(c)(i) and (iii) with a new part (b) ... 1 + 1 + 2 = 4 marks

25. This Hertzsprung-Russell diagram shows the evolutionary position for two regions of stars, **W** and **X**.



(a) Compare stars found at **W** and **X** on the Hertzsprung-Russell diagram and outline the difference in the nuclear processes in a star found at **W** to a star found at **X**.

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(b) How do the products of the proton-proton chain differ from the products of the CNO cycle?

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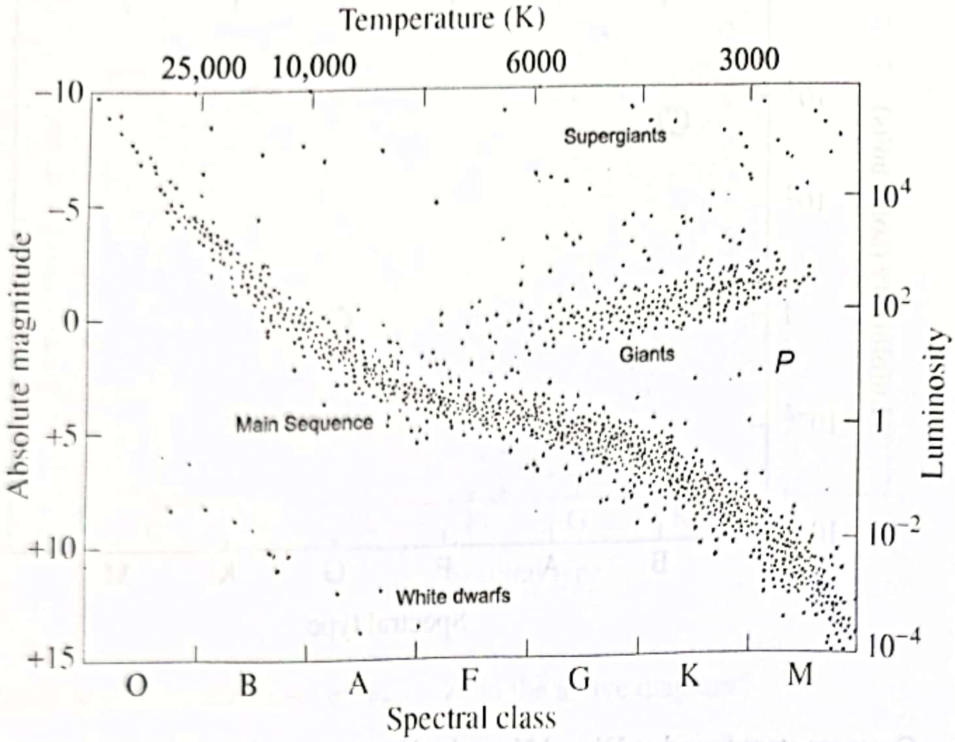
(a) = adapted Q using diagram from 2011 HSC Q33(b)(i)
(b) with new Q for part (b) ... 4 + 1 = 5 marks

26. The evolution of star *P* in the diagram below after it leaves the Main Sequence can be summarised as follows: red giant → planetary nebula → white dwarf



Complete this table.

Type	*Surface temperature compared to the Sun*	*Luminosity relative compared to the Sun*
Red giant		
White dwarf		

Adapted 1999 HSC Q36(b)(iv)
(with a new diagram) ... 2 marks

27. Describe how a spectroscope can be used to obtain the spectrum of an individual star.

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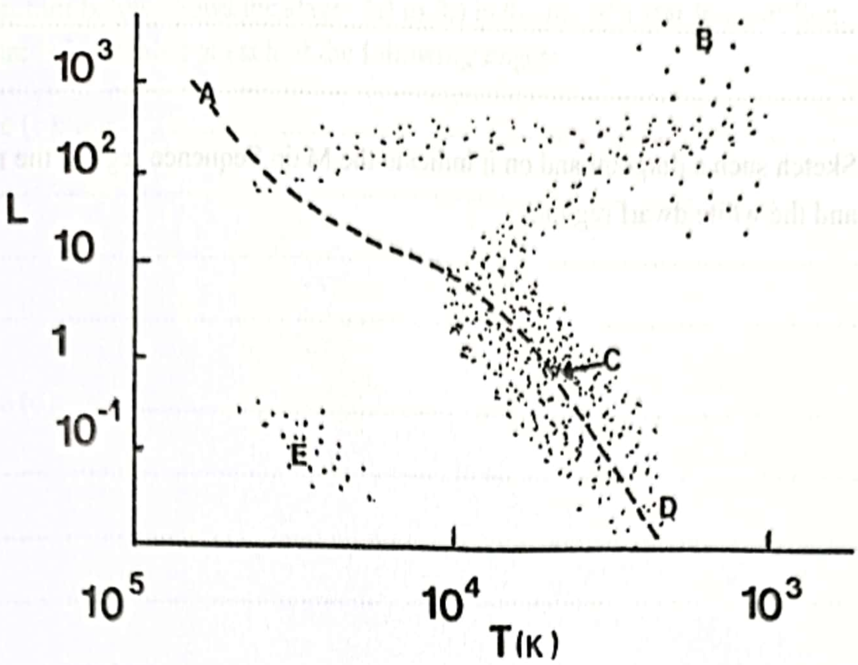
2017 HSC Q33(b)(ii) ... 3 marks

28. This HR diagram is for a galaxy similar to our local galaxy. The axes show L, the luminosity relative to the Sun and T, the temperature.



Regions **A**, **B**, **C**, **D**, and **E** are marked.

(a) Which of these regions has red giant stars? Justify your choice.

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(b) Which of these regions has white dwarf stars? ....

(c) Stars in region **E** have much lower luminosity than stars on the Main Sequence with the same surface temperature.

What property of stars in region **E** would account for this?

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Adapted 1982 HSC Q Elective 5(b)(i), (ii), new Q for (c)... 1 + 1 + 1 = 3 marks

29. An important way of classifying stars is to plot them on a Hertzsprung-Russell diagram.

(a) What do the axes of such a diagram represent? ....

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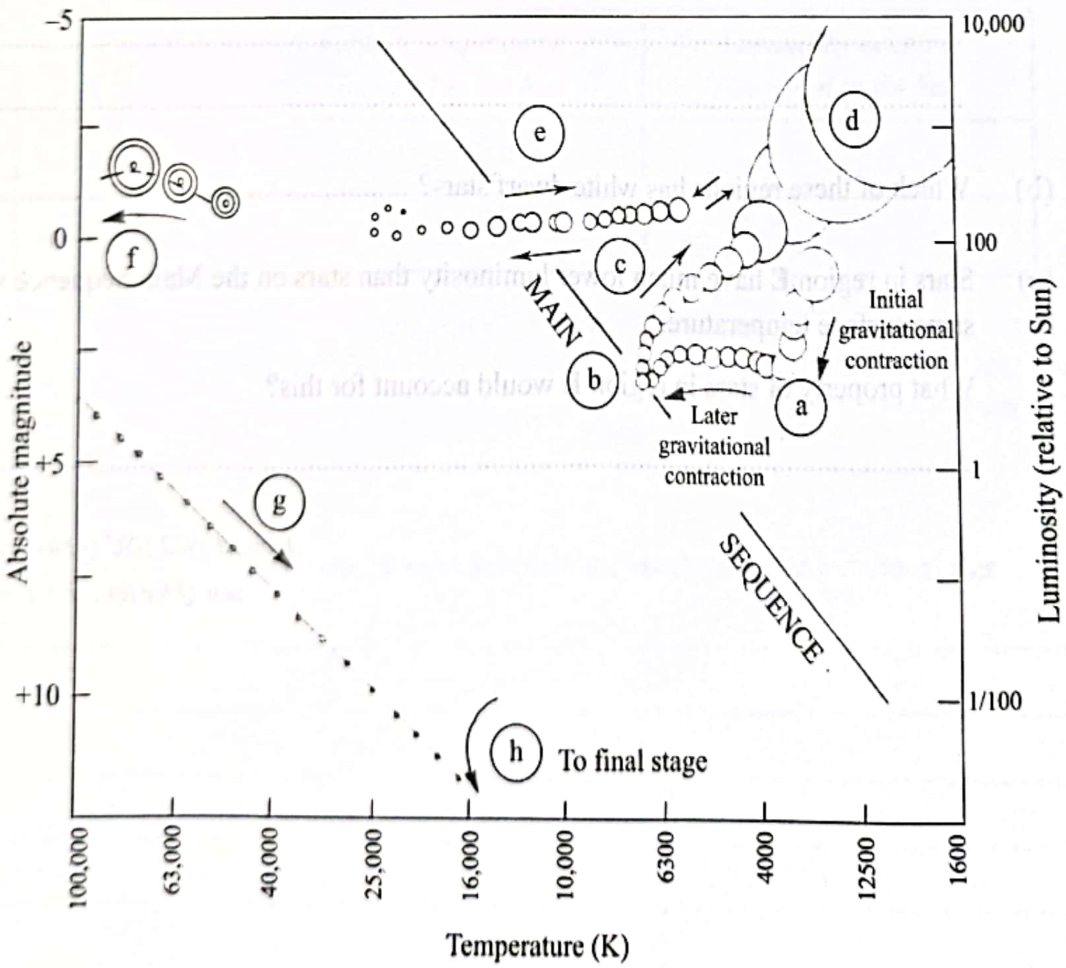
(d) Sketch such a diagram and on it indicate the Main Sequence region, the red giant region and the white dwarf region.

1983 HSC Q Elective 5 (d) ... 3 marks

30. The HR diagram below shows the stages (a) to (h) in the life of a star like our Sun. At stage (d), the star is a red giant.



Question 30 continues

The HR diagram below shows the stages (a) to (h) in the life of a star like our Sun. Explain what is happening at each of the following stages:

(a) Stage (b): ....

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(b) Stage (d): ....

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(c) Stage (g): ....

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End of Question 30

Adapted 1987 HSC Q Elective 5 (d) ... 2 + 2 + 2 = 6 marks

31. Describe how the distribution of stars on a Hertzsprung–Russell diagram relates to the processes that occur during their evolution.

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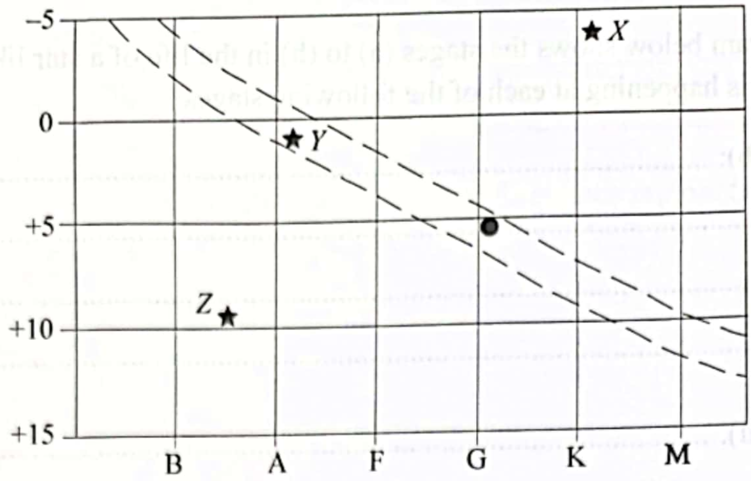
2016 HSC Q33(e) ... 6 marks

32. The HR diagram below shows the position of three single stars, *X*, *Y* and *Z*



(a) Which of these three stars, *X*, *Y* and *Z*, is the oldest? ....

Justify your answer: ....

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(b) Explain why Star *Z* cannot become a supernova. ....

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(c) Once a massive star with a mass greater than 20 solar masses runs out of fuel, all its matter simply appears to collapse into what is called a 'black hole'.

Is there a region on a Hertzsprung-Russell diagram where black holes appear? ....
If so, in what region are they found. If not, state why.

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Adapted from 1991 HSC Q Elective 5 (a) ... 2 + 2 + 2 = 6 marks

33. (a) What do continuous stellar spectra of stars reveal that can be used to classify stars?

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(b) What do the lines in a star's absorption spectrum reveal about the star?

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... 2 + 1 = 3 marks

34. The carbon cycle (CNO cycle) is thought to be the source of energy for many large stars. The complete cycle is represented by the following set of nuclear reactions.

$$^{12}C + {}^{1}H \rightarrow {}^{13}N + \gamma$$
$$^{13}N \rightarrow {}^{13}C + \beta^{+} + \nu$$
$$^{13}C + {}^{1}H \rightarrow {}^{14}N + \gamma$$
$$^{14}N + {}^{1}H \rightarrow {}^{15}O + \gamma$$
$$^{15}O \rightarrow {}^{15}N + \beta^{+} + \nu$$
$$^{15}N + {}^{1}H \rightarrow {}^{12}C + \alpha$$

In what way, apart from the production of energy, is the CNO cycle similar to the proton–proton cycle in the Sun?

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1996 HSC Q36(g)(iii)(2) ... 1 mark

35. Describe the nuclear reactions occurring in the cores of the following:

(a) stars on the Main Sequence: ....

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(b) red giants: ....

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1992 HSC Q Elective 5(b) ... 2 + 2 = 4 marks

36. Energy can be produced in the cores of Main Sequence stars by two different nuclear processes.

(a) Name the two nuclear processes.

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(b) Describe ONE similarity and ONE difference between these two processes.

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(c) Explain which features of a star determines which of the two processes will be predominant in that star.

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1999 HSC Q36(g) ... 2 + 2 + 2 = 6 marks

Answers

Module 8: From the Universe to the Atom

8.1 Origins of the elements

Multiple choice: 1 mark each

1. C	2. A	3. B	4. D	5. B	6. C	7. B	8. D
9. A	10. A	11. C	12. B	13. C	14. D		

Explanations:

1. **C** One cosmological model of the Big Bang theory proposes that the Universe went through an extremely rapid expansion from a singularity about 13.8×10^9 years BP and has expanded ever since ... as in (C). The early formation of light elements, such as hydrogen, helium and lithium, is part of the Big Bang Theory, as is cosmic background radiation. However, the Big Bang theory is about more than just these. So (A) and (B) are incorrect. The formation of heavier elements came after the Big Bang, so (D) is incorrect.

2. **A** The more distant, older galaxies are *more* densely packed than the galaxies near us, not less densely packed. This is because we see these galaxies as they were billions of years ago at a time when the Universe had not undergone as much expansion. So (A) is the answer. The statements in (B), (C) and (D) are all true and provide support for the Big Bang theory. So (B), (C) and (D) cannot be the answer to this question.

3. **B** Hubble used the Doppler shift in which a shift towards the red end of the spectrum indicates a star is moving away, and a shift towards the blue indicates it is moving towards us. Using a spectroscope, he observed that, in general, the more distant a galaxy was, the faster it was moving away and the greater its red-shift. This supported the idea of an expanding Universe, so (B) is the answer. Stars emitting absorption spectra and nebulae emitting emission spectra are not evidence. So (A) is incorrect. Hubble found closer galaxies have a smaller, not greater red shift. So (C) is incorrect. Hubble's two methods to estimate the Universe's age gave 13 and 14 billion years, not 2 billion years, and this is not evidence for an expanding Universe. So (D) is incorrect.

4. **D** Luminosity is on the vertical Y axis. Spectral type is on the X axis. Since spectral type is determined by the surface temperature of a star (and its evolutionary stage), the horizontal X axis plots both the surface temperature and spectral type. Only (D) gives this combination.

5. **B** Star W is shown in the upper region of the Main Sequence, while star Z is above the Main Sequence in the red giant region. So (B) is the answer and (D) is incorrect. White dwarf stars are found on the lower left, well below the Main Sequence. So (A) is incorrect as star W is not a white dwarf. Since star Z is a red giant, it is red in colour, not blue. So (C) is incorrect.

6. **C** Star W and star Z have the same luminosity. However, spectral class B is much hotter than spectral class K, so Star W is hotter than star Z. Hence (C) is the answer and (B) is incorrect. The Sun has a lower luminosity than both stars W and Z. So (A) is incorrect. Stars W and Z are in different spectral classes. So (D) is incorrect.

7. **B** The stars in the table belong to the M2, B5, A2 and M1.5 spectral classes. The star Achernar, which is in B5, has the greatest surface temperature. So (B) is the answer. All the other stars in the table are cooler stars. So (A), (C) and (D) are incorrect.

   [Note: The star classifications 'O, B, A, F, G, K, M' represent a decreasing order of surface temperature from O to M. So a star in B5 has a greater surface temperature than any star in spectral classes A to M.]

8. **D** Looking at the surface temperatures along the X-axis, only stars in Position S are located in a region where they could have the same surface temperature as a star on the Main Sequence. So (D) is the answer. Stars at position R would have lower surface temperatures, while positions Q and P would have higher surface temperatures. So (A), (B) and (C) are incorrect.

9. **A** The amount of solar energy reaching Earth indicated that the Sun's fuel would be consumed very quickly by such chemical reactions, as in (A). After Einstein's work and the discovery of fusion, scientists proposed that fusion was the source of the Sun's energy, not fission. So (B) is incorrect. The energy released in a fusion reaction is equivalent to the mass lost, not the total mass of the Sun. So (C) is incorrect. The Sun is on the Main Sequence and so is past the evolutionary stage where clouds of gases collapse inwards as a star begins its life. So (D) is incorrect.

10. **A** A diffraction grating splits white light up into its component colours, according to the wavelength of each colour. So (A) is the answer. A telescope or microscope focuses light to give a magnified image of either a distant or close object, respectively. So (B) and (C) are incorrect. A polarising lens will only transmit the wavelengths that have the axis of vibration matching that of the polarising lens, and so would not split white light into all of its component wavelengths. So (D) is incorrect.

11. **C** In nuclear fusion, two smaller nuclei combine to form a heavier nucleus. So (C) is the answer and (D) is incorrect. Fusion does not break up nuclei into protons and neutrons, so (A) is incorrect. Ionisation, not fusion, releases electrons from atoms. So (B) is incorrect.

12. **B** The cores of stars typically have temperatures of several thousand degrees Kelvin and so are incandescent and hence they produce a continuous spectrum. So (B) is the answer. Excited gases in nebulae have very high temperatures, but their spectrum is an absorption spectrum with dark lines. So (A) is incorrect. A black hole releases no light, so (C) is incorrect. Ultraviolet light has only a limited portion of the spectrum, so (D) is incorrect.

13. **C** The small mass loss that occurs during the fusion of protons in the Sun's core is sufficient to release huge amounts of energy, as in (C). Nuclear fusion occurs in stars, not nuclear fission. So (A) is incorrect. Gravitational collapse can occur at the end of a star's lifetime, after its hydrogen has been used up. It does not occur during its lifetime, which is the stage that a star like the Sun is at, as it is still on the Main Sequence. So (B) is incorrect. The Earth has an iron core, but the Sun and stars like the Sun do not. So (D) is incorrect.

14. **D** In nuclear fission reactions, a large nucleus splits into two smaller nuclei. Whereas in nuclear fusion reactions, two small nuclei fuse into one larger one. So (D) is the answer and (B) is incorrect. Nuclear fission reactions do not occur in stars and can occur wherever there are very large atomic species, such as on Earth. Whereas nuclear fusion reactions can occur in stars and wherever the conditions are suitable on Earth. So (A) is incorrect. Nuclear fusion reactions release more energy than nuclear fission reactions. So (C) is incorrect.

Short-answer questions

15. The colours in all spectra correspond to different wavelengths (or frequencies) which are produced when atomic electrons orbiting the nucleus absorb energy and then return to their original lower energy level, emitting the excess energy in the form of light or photons:

- SPECTRUM *X* is a continuous spectrum. The heated filament produces a full range of electron level transitions, emitting photons at all visible frequencies, and so a full range of colours.
- SPECTRUM *Y* is an emission line spectrum. 'Excited' electrons have dropped from a higher to a lower energy level, releasing photons with frequencies that correspond to the yellow lines, characteristic of sodium.
- SPECTRUM *Z* is an absorption spectrum. The sodium vapour absorbs photons with corresponding frequencies and re-emits them in all directions. These energies do not appear on the screen and dark lines are seen in their place.

16. (a) The line absorption spectrum of a star is the series of narrow dark lines produced when continuous light from the star passes out through cooler gases in its atmosphere. Electrons in any elements present in the gas absorb specific wavelengths. They re-emit the absorbed energy in all directions. This removes these frequencies from the continuous spectrum observed on Earth. So a series of black lines is seen in their place.

(b) Clouds of gas produce emission spectra. These are produced as a result of electrons within an atom being excited to a higher energy level. This can happen when the gases become excited by a nearby energy source, such as a very hot star. As the electrons return to a lower level energy, they release photons of light of very specific frequencies that are seen as bright lines against a dark background.

17. (a) Emission spectra are produced when a vapour is excited by an energy source, such as heat or electricity. Atoms absorb this energy causing electrons to be excited to higher energy levels. As electrons drop back to their normal energy level, they release a photon with a wavelength exactly corresponding to the energy change. The spectral lines appear as bright lines against a dark background.

Absorption spectra are produced when white light is transmitted through a gas. Atoms and ions in the gas absorb specific wavelengths corresponding to energy gaps between their various energy levels. The absorbed energy is soon re-emitted in random directions, so dark spectral lines are seen in their place against a continuous background of colours.

(b) Spectroscopy enables the relative intensity of light of different wavelengths in a star's spectrum to be measured and compared with known radiation curves to determine the star's surface temperature. The absorption spectral lines in a star's spectrum indicate the elements present in a star's surface layers.

Spectroscopy and the Doppler Shift in the wavelengths of the spectra compared to on Earth, can determine whether the star is approaching towards or receding from Earth, plus its velocity relative to Earth. Analysis of the spectrum can sometimes determine the rate at which a star is spinning on its axis by measuring the widening of the spectral lines.

18. How strongly an element on the 'surface' of a star absorbs light passing through it depends largely on the temperature. Therefore, the intensity or strength of the spectral lines (mostly the dark absorption lines) is a good indicator of the star's surface temperature.

19. Emission spectra are produced as a result of electrons within an atom being excited to a higher energy level. As they return to a lower level energy, they release photons of particular frequencies. These form the spectral lines (bright lines against a dark background) in the emission spectrum. This can happen when the hot, diffuse gases in quasars or in nebulae are excited by a nearby energy source, usually a very hot star.

Absorption spectra are produced when a continuous spectrum of light, e.g. from stars, passes through a cloud of gas, e.g. hydrogen. The absorbed photons raise electrons within the atoms to higher energy levels. As they drop back to their original energy levels, they emit the absorbed energy in all directions. This removes these frequencies from the continuous spectrum observed on Earth. So a series of black lines is seen in their place.

20. (a) Hydrogen is the initial element, while helium is the final element.

(b) The Sun will become a *red giant*. It will therefore have a helium-burning core, so the main source of energy will be helium fusion..

[Note: The main source of energy in the outer shell of the Sun when on the Main Sequence is the fusion of hydrogen to form helium in its core.]

21. (a) *S* – white dwarfs are relatively small in diameter, so have a lower luminosity than the Sun which means lower down on the H–R diagram than the Sun. They have higher surface temperatures than the Sun (a Main Sequence star), so are further left on the H-R diagram than the Sun.

(b) 'Stable' means that the inward force of gravity is balanced by the outward forces acting within the star. In a white dwarf, the nuclear fusion reactions are no longer occurring. So the radiation pressure outwards can withstand the inward acting gravity.

[Note: The effect of gravity is balanced mainly by the fact that white dwarf matter is very compressed and therefore very dense and the pressure created by the closeness of electrons to nuclei provides most of the outward force This pressure, which is known as 'degeneracy' pressure, is the result of the Pauli exclusion principle (see Module 8.3), which states that no two electrons can occupy the same set of 'quantum states'.]

(c) [Note: On the Main Sequence, the principle nuclear reaction that occurs is the *fusion of hydrogen* into helium. This occurs either by the proton-proton chain reaction or the CNO cycle. Choose ONE of these to answer this question.]

Either ONE of the following:

- PROTON-PROTON CHAIN – a 3-step process in which protons are joined to form helium nuclei. Initially, two protons combine to form deuterium (heavy hydrogen). Then another proton is added to form light helium. Finally, two light helium nuclei combine to form a normal helium nucleus. The energy released is equivalent to the binding energy of the helium nucleus.

  This method is relatively slow and occurs in cooler Main Sequence stars with core temperatures below about 15 million K.

- CNO CYCLE – a 6-step process which fuses hydrogen into helium nuclei, using carbon as a catalyst. It involves adding 4 protons onto either a carbon nucleus or a nitrogen nucleus or an oxygen nucleus, until a helium nucleus is formed and this is ejected away at high speed releasing large amounts of energy.

  This method is relatively fast and occurs at temperatures above about 15 million Kelvin, so it occurs in more massive and therefore hotter stars.

22. (a) At **A**: this is where Main Sequence stars occur, so the reactions here involve the fusion of hydrogen nuclei to form helium (predominantly by the proton-proton chain, but possibly by the CNO cycle).

At **B**: this is where red giants are found, so the reactions here involve helium fusing to form carbon (and oxygen) (through the triple-alpha reaction).

At **C**: this is where white dwarfs are found, so there are no nuclear reactions taking place in the exposed core.

(b) A star at **A** would be on the Main Sequence. It would be a G spectral class star, with an absolute magnitude of +5 and a luminosity of 1. It would be very similar therefore to our Sun with respect to temperature, colour and brightness.

23. (a) Star **B** is a Main Sequence star, while star **C** is a red giant.

(b) Main sequence.

(c) Being a Main Sequence star, **B** is characterised by the fusion of hydrogen to helium in its core. So the nucleosynthesis reactions are the proton-proton cycle, which is dominant, and the CNO cycle.

Whereas star **C** is above the Main Sequence. Its core is mostly non-reacting helium, so its energy output decreases and the star contracts. This leads to the unused hydrogen in the shell undergoing fusion to produce helium. This heats the outer layers, causing them to expand. Then, as the surface temperature decreases, the star becomes redder.

24. (a) Region **Z** = white dwarf stars [Note: W = Main Sequence stars]

(b) Stars at **W** and **Z** will have a higher surface temperature than the Sun.

(c) Stars in region **Z** have no energy production, as no fusion reactions are occurring in their cores. These stars are merely radiating the last of their heat and light energy away as they gradually cool down. Whereas stars in region **W** are on the Main Sequence and so producing energy from the fusion of hydrogen atoms to form helium.

[Note: 1. At **W**, the CNO cycle dominates in more massive, hotter stars, higher on the Main Sequence. Lower on the Main Sequence, the proton-proton chain occurs in cooler, less massive stars.
2. At **Z**, the stars consist of mainly oxygen and carbon and no longer undergo fusion of hydrogen or any other elements.

25. (a) Stars at **W** are brighter, hotter, bluer and more massive stars, higher on the Main Sequence than stars at **X**, which are like Earth's Sun and so more yellow. At both **W** and **X**, the source of energy is the fusion of hydrogen atoms to form helium. However, at **X** the proton-proton chain dominates to produce helium, while at **W** the CNO cycle will dominate.

(b) Both the proton-proton chain and the CNO cycle produce the same products.

[Note: The overall equations for both reactions are nearly identical. The products they both produce are: one helium-4 nucleus, 2 positrons, 2 neutrinos and 3 gamma photons.]

26.

Type	*Surface temperature compared to the Sun*	*Luminosity relative compared to the Sun*
Red giant	Less	Much greater
White dwarf	More	Much less

27. Light would be collected from the star by an optical telescope. A spectroscope with a diffraction grating would be placed over the opening of the telescope – this would refract different wavelengths of light by different amounts and so split the light into its different wavelengths. An array of digital light sensors would then detect the light and measure the intensity at each wavelength to give the star's spectrum.

[Note: Spectroscopes use any process that disperses light into its constituent wavelengths. Either a prism or a diffraction grating can be used to do this.]

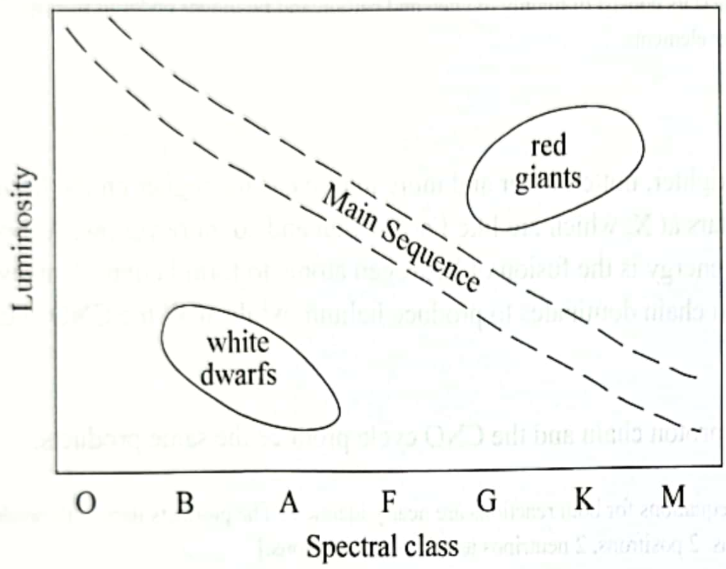
28. (a) Region **B** has red giant stars – these stars are very large and so have a high luminosity, and being red, have a lower surface temperature. Red giants are found above the Main Sequence on the upper right side of an HR diagram.

(b) Region **E** has white dwarf stars.

(c) These stars are very small, and so have a low luminosity.

29. (a) They represent star luminosities or absolute magnitudes on the Y axis, and star spectral types or surface temperatures on the X axis.

(b)



[Note: The Y axis could also have been labelled 'absolute magnitude', while the X axis could also have been labelled 'Surface temperature'.]

30. (a) Stage (b) is on the Main Sequence. The energy generated within a star here will come from the fusion of hydrogen to helium in its core. The proton–proton chain will be more dominant than the CNO cycle.

(b) Stage (d) is post the Main Sequence. Most of the hydrogen in the core of a star here has fused to become helium. The hydrogen that remains at the core's edge will undergo fusion and heat up the outer layers, causing them to expand and appear red.

[Note: The helium in the core then begins to fuse into carbon (in the triple alpha process).]

(c) Stage (g) is when a star has exhausted all its fuel. So, nucleosynthesis reactions have ceased and the star is a white dwarf that radiates heat as it is cooling.

35. (a) These reactions involve the fusion of hydrogen nuclei to form helium, predominantly by the proton-proton chain, but also partly by the CNO cycle.

(b) These reactions involve helium fusing to form carbon-12 nuclei through the triple-alpha reaction.

36. (a) 1. Proton–proton chain. 2. CNO cycle (OR Carbon-nitrogen-oxygen cycle)

(b) SIMILARITY – *Any ONE of the following:*

- Both convert hydrogen into helium.
- Both require temperatures of millions of degrees.
- Both are exothermic.
- Both produce huge numbers of neutrinos.

DIFFERENCE – *Any ONE of the following:*

- CNO cycle occurs in larger stars, where the proton–proton chain occurs in most stars..
- CNO cycle is much faster than the proton–proton chain.
- CNO cycle predominates at higher temperatures, whereas the proton–proton chain predominates at lower temperatures.
- CNO cycle relies on carbon-12 being present, whereas the proton–proton chain does not.
- CNO cycle is a 6-step reaction, whereas only the proton–proton chain is a 3-step process.

(c) The mass of a star determines which process predominates, as the temperature of the core is greater for more massive stars. The CNO cycle predominates in stars with higher core temperatures, whereas the proton–proton chain occurs at lower temperatures.

31. Stars are plotted on a Hertzsprung-Russell (H–R) diagram in regions that relate to the processes occurring during their evolution. Around 80-90% of all stars are Main Sequence stars. This is the first stage of a star's life. Stars spend about 90% of their lives on the Main Sequence, burning hydrogen into helium in their cores.

Once stars have exhausted their hydrogen fuel, they enter the next evolutionary stage and start to burn helium in their core. Depending on their size, these are red giants or supergiants – these stars occupy the top right region of the H–R diagram.

The final evolutionary stage for most stars, when all their nuclear fuel is exhausted, involves gravitational collapse whereby gravitational potential energy is converted to heat energy. Such stars are found on the bottom left of the HR diagram and are known as white dwarfs.

[Note: Your answer could have included: • an H–R diagram (labelled); • how every star forms from a protostar in which there are no nuclear reactions.]

32. (a) Star Z – this is a white dwarf and so is the oldest as it is further along the evolutionary pathway in a star's life cycle, whereas Star Y is on the Main Sequence and Star X is a red giant and so younger than Star Z.

(b) Being a white dwarf, Star Z is less than 8 solar masses. Only massive stars with a mass greater than 8 solar masses end their life cycle in a supernova.

(c) No – if all matter is collapsing into a black hole, no light is escaping. Hence a black hole does not have a spectral class, nor luminosity and is not a star. So a black hole is not on an HR diagram.

33. (a) The continuous spectra of stars appear different as they depend on the star's surface temperature. These differences can be used to classify star into their spectral types, in order from hottest to coldest: O, B, A, F, G, K and M.

(b) The absorption lines in a star's spectrum indicate what elements are present in the star's outer layers.

34. Both of these reactions involve the conversion of hydrogen into helium by fusion.

OR Both produce the same overall products, i.e. a helium-4 nucleus, 2 positrons, 2 neutrinos and 3 gamma photons.

[Note: A helium-4 nucleus = α = ${}^4_2He$, ν= neutrino, β^+= positron, γ = gamma photon]