OCR

A Level

A Level Physics

Astrophysics 1 (Answers)

Name:

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Total Marks: /30

1. Amongst all that you see in the night sky, there exist a variety of stars. Yet, it is thought that all stars originate from clouds of dust and gas. Understanding how stars are formed and how they evolve is an important aspect of our understanding of the universe.

Total for Question 1: 12

(a) A protostar is an extremely hot, dense sphere of dust and gas. Why don't all protostars evolve to form stars? [2]

Solution: Nuclear fusion must take place.
Extremely high temperatures and pressures are required to overcome the electrostatic repulsion between hydrogen nuclei. In some cases, when sufficient mass is added to the protostar, its core may become sufficiently hot for the KE of the nuclei to overcome this repulsion. This results in fusion and the formation of a main sequence star.

(b) The majority of most stars' lives are spent in the main sequence phase. During this time they are stable and maintain an approximately constant size. Therefore, since gravitational forces act to compress the star, other forces must resist this compression. What are they and what is responsible for them? [2]

Solution:
1/ Gas pressure; nuclei in the core.
2/ Radiation pressure; photons emitted during fusion.

(c) Electron degeneracy pressure prevents the gravitational collapse of white dwarfs if their masses are less than the Chandrasekhar limit.

i. What is the origin of the electron degeneracy pressure? [2]

Solution: The Pauli exclusion principle states that two electrons cannot exist in the same energy state. When the core of a star begins to collapse, matter is compressed into a small volume. This forces electrons into close proximity - something that is resisted (because of the Pauli principle) and that results in an outward pressure.

ii. Briefly describe the possible fates of stars whose masses exceed the limit. [2]

> **Solution:** Red supergiant forms with concentric shells that fuse higher mass elements in their centres. This continues until a solid iron core is formed, at which point the star is destabilised. The result is a supernova. The remnant core collapses to form either a neutron star (if the core mass exceeds $2M_\odot$) or a black hole (if the core mass exceeds $3M_\odot$).

(d) A Hertzsprung-Russell diagram is a graph showing the relationship between stellar luminosity and temperature.

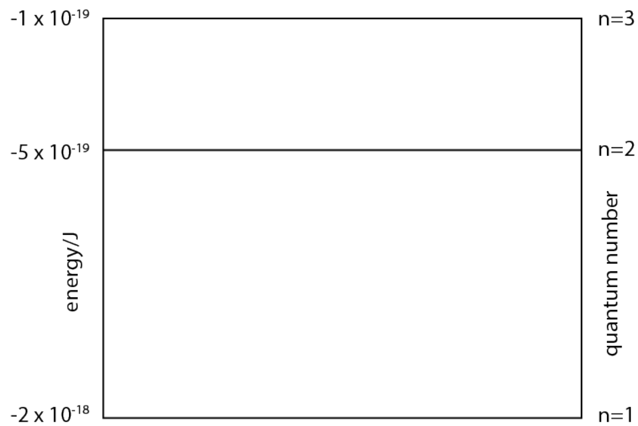
i. Explain why, when a red giant becomes a white dwarf, it moves towards the lower left of the diagram. [2]

> **Solution:** The fusing shell of a red giant drifts off to form planetary nebula. This leaves behind the very hot core - a white dwarf. Since this core is hotter than the shell (which has been cooling), the star moves left on the diagram.
> Its luminosity decreases because the only emission of energy is because of photons formed in earlier stages of evolution.

ii. Black holes are not usually plotted on Hertzsprung-Russell diagrams. Explain why this is the case. [2]

> **Solution:** Black holes emit no light since photons cannot have a velocity greater than the escape velocity of a black hole (speed of light). Therefore they would plot off the bottom of the scale, at approximately L=0.

2. The sketch below shows the first three electron energy levels in an isolated gas atom. These have been annotated with their energies and their quantum numbers. Total for Question 2: 8



(a) An electron is excited to the n=3 energy level. What was the frequency of the photon it absorbed? [2]

> **Solution:** 3×10^{15} Hz

(b) The excited electron later de-excites. Rather than falling down to the ground state, it comes to an intermediate halt in the n=1 level. Explain, quantitatively where appropriate, what happens. State the frequency of any new particles created. [3]

> **Solution:** The electron loses an amount of energy corresponding to the difference in energy of the levels: 4×10^{-19} J. This, by conservation of energy, is emitted as a photon with the same energy. Its frequency will be 6×10^{14} Hz.

(c) Compare and contrast *emission, absorption* and *continuous* line spectra. [3]

Solution:
Emission spectra: energetic electrons can be de-excited to lower energy levels and in the process emit photons.
Absorption spectra: as light with a continuous spectrum passes through a gas, some photons are absorbed by the gas. This excites electrons into higher energy levels. Since levels are discrete, only photons with the exact energy of the level change are absorbed. Thus, only particular wavelengths are absorbed, creating dark lines in the spectrum.
Continuous spectra: all visible wavelengths are present.

3. The Sirius system is the brightest star system visible in the night sky. Sirius B is a white dwarf with a luminosity of only 0.056 $L_{\odot}$ and a peak spectral wavelength of $\lambda_{max} = 1.2 \times 10^{-7}$ m. In contrast, the red supergiant Betelgeuse has a peak wavelength of $\lambda_{max} = 8.5 \times 10^{-7}$ m and a surface temperature of 3400 K. The luminosity of our sun ($L_{\odot}$) is 3.85×10^{26} W. Total for Question 3: 10

   (a) Define the term *black body*. [1]

   Solution: A black body is an idealised object that absorbs all EM radiation that shines onto it and emits a characteristic distribution of wavelengths at a specified temperature.

   (b) The wavelength of a light source, such as a star, can be calculated experimentally using a diffraction grating. Outline how you would do this, taking care to include details of the experimental setup, any measurements that must be taken and any calculations required. [3]

   Solution: Shine coherent monochromatic light through the grating onto a screen.
   Measure the angle between bright fringes (numbered n, from centre outwards) and the central maximum
   Plot $\sin\theta$ against n
   Gradient will be λ/d since $n\lambda = d\sin\theta$; λ is equal to the gradient times the slit spacing.

(c) Arnav is asked to calculate the wavelength of starlight from Zeta. He measures the angle between the beam and the eighth-order maximum as $0.14°$and uses a grating with a slit spacing of 1 mm. What is the wavelength of the light used? [2]

Solution: 310 nm

(d) Using a combination of Wien's displacement law and Stefan's law, calculate the radius of Sirius B. [4]

Solution: 9500 km