

SECTION B

Answer all questions.

8. Read through the following article carefully.

Paragraph

A little bit of information about stars by Ignasi Lluís Marxuach

Figure 1 shows the three different routes for the life cycle of different sized stars, from small stars, through medium (Sun-like) stars to explosive high mass stars. For some reason, exam boards tend to ignore the smallest category of stars (red dwarfs) because their cores never become hot enough to produce red giant stars.

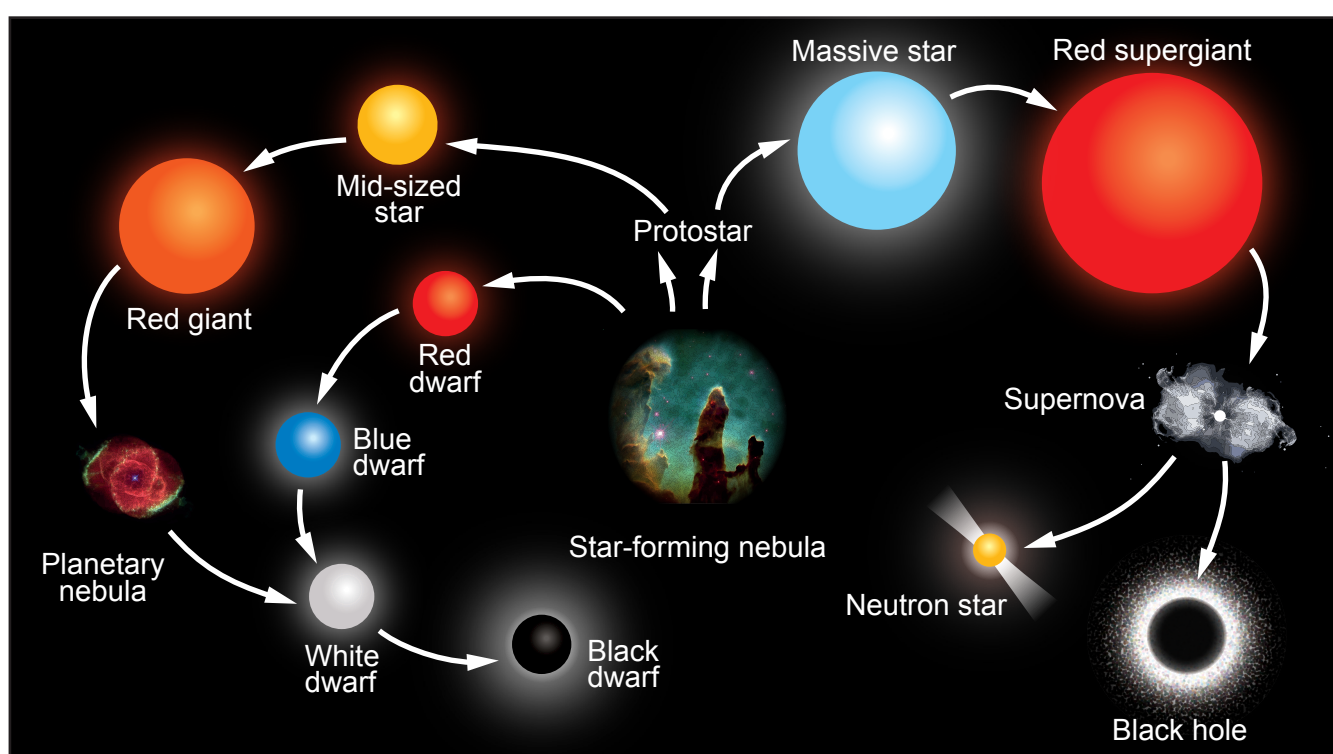


Figure 1

Stars are formed from the gravitational collapse of gas clouds called *nebulae*. Gravitational potential energy is converted to internal energy of hot gases which then emit radiation. This means that the search for new stars usually involves the use of infra-red telescopes in space.

The images on the next page show the same gas clouds but the image on the right (**Figure 3**) is taken with visible light while the image on the left (**Figure 2**) is taken with infra-red. Notice how the gas clouds are transparent to infra-red so that stars behind the gas clouds become visible at infra-red wavelengths. The areas where stars are forming are those areas of the gas cloud that appear to be emitting radiation at both infra-red and visible wavelengths.

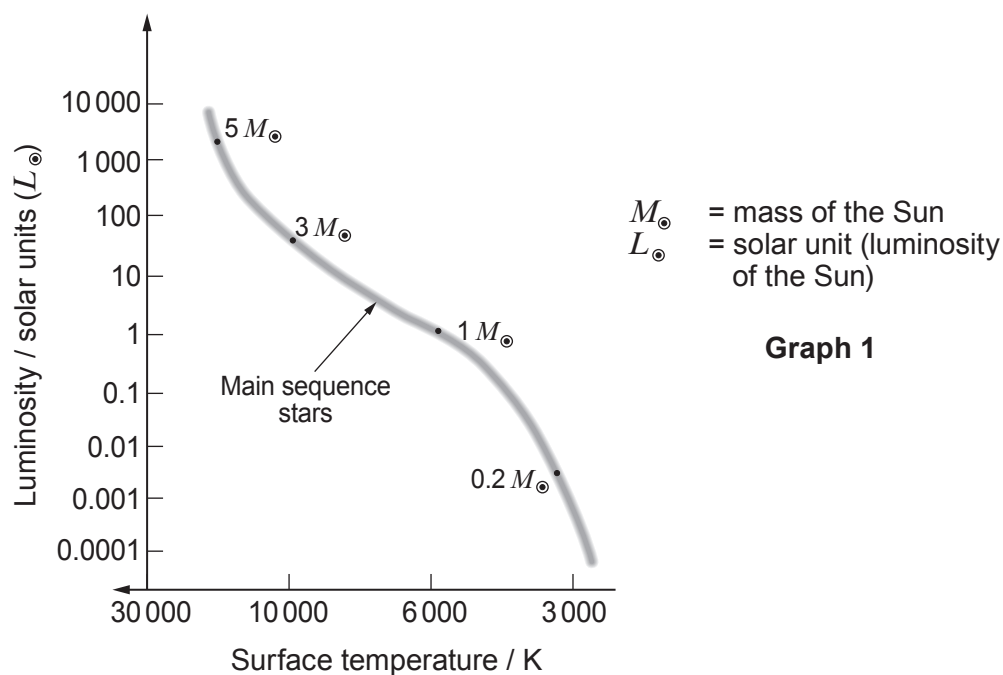


Figure 2 (infra-red image)



Figure 3 (visible light image)

Once the core of a young star is hot enough to initiate hydrogen fusion it is called a *main sequence star*. Such stars are stable, lasting for millions or billions of years and account for around 90% of all stars. They are stable because the outward pressures due to hot gases and electromagnetic radiation are balanced by the inward pressure due to gravity. Larger main sequence stars have denser cores which means that the rate of fusion and the temperature are also greater. A graph of luminosity against temperature for main sequence stars is rather useful, although slightly less useful than it should be because astronomers, apparently, don't realise that values should increase going to the right on normal graphs.



Notice that nearly all main sequence stars have surface temperatures in the range 3000K to 20000K. This makes them suitable for analysing using visible light.

Another thing to note from the luminosity against surface temperature graph is that these factors seem to depend on the mass of the star. It turns out that there is only one factor that determines a star's position on the graph – its mass. The relationship between mass and luminosity for a star is quite complicated and comes in four parts. 6

$$L = 0.23 M^{2.3} \quad \text{for} \quad M < 0.43 \quad \text{Equation 1}$$

$$L = M^4 \quad \text{for} \quad 0.43 < M < 2 \quad \text{Equation 2}$$

$$L = 1.5 M^{3.5} \quad \text{for} \quad 2 < M < 20 \quad \text{Equation 3}$$

$$L = 3200 M \quad \text{for} \quad M > 20 \quad \text{Equation 4}$$

Note that these equations have been simplified by having the mass of the star (M) in units of the solar mass (M_{\odot}), and luminosity in units of the solar luminosity (L_{\odot}).

These relationships are rather useful and should explain why large mass stars can be found more easily using ultraviolet telescopes, but they can do so much more when combined with Einstein's equation. 7

$$E = \Delta mc^2 \quad \text{Equation 5}$$

You might, in the first instance, be excused for thinking that a $10 M_{\odot}$ star will burn 10 times longer than the Sun. This, however, could not be further from the truth. Use of Equation 3 should tell you that a $10 M_{\odot}$ star will burn approximately 5000 times brighter. By using Einstein's equation and making a few simplifying assumptions, we find the expected lifetime of a $10 M_{\odot}$ star to be, in fact, approximately 500 times less than that of the Sun. Some might say that a large star "burns the candle at both ends" but it's more accurate to say that it burns the candle at 5000 ends simultaneously. 8

It should be reasonably clear that there is a negative correlation between the mass of a star and its lifetime. Another two star variables that are (bizarrely) negatively correlated are the mass of a white dwarf and its radius. However, that is a completely different story which is beyond the remit of this 2019 Space Odyssey. 9