GCE PHYSICS

S21-A420QS

Assessment Resource number 6

Comprehension Resource F

1	Read through the following article carefully.	Paragraph

A little bit of information about stars by Ignasi Lluis 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. 1

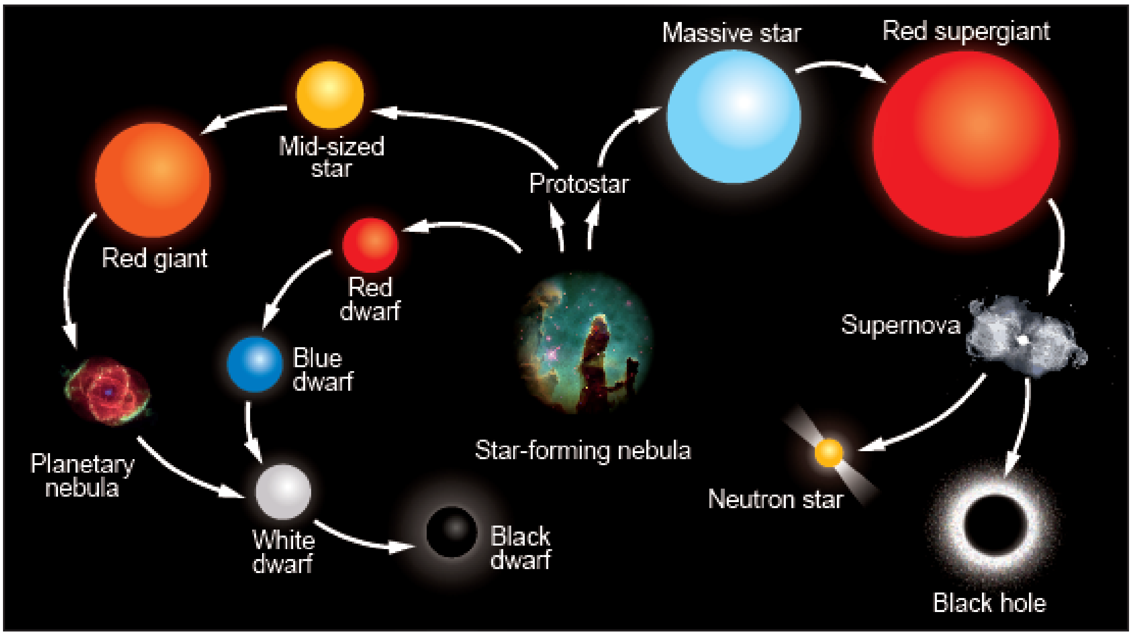


Figure 1

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. 2

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. 3

Paragraph

Figure 2 (infra-red image)

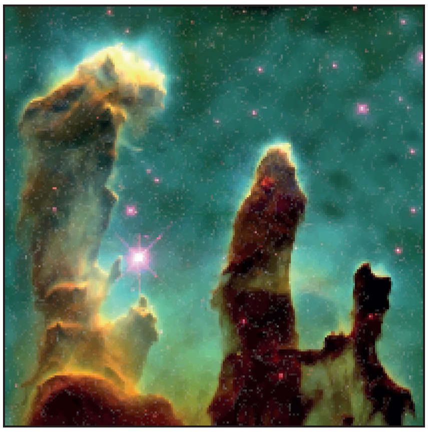
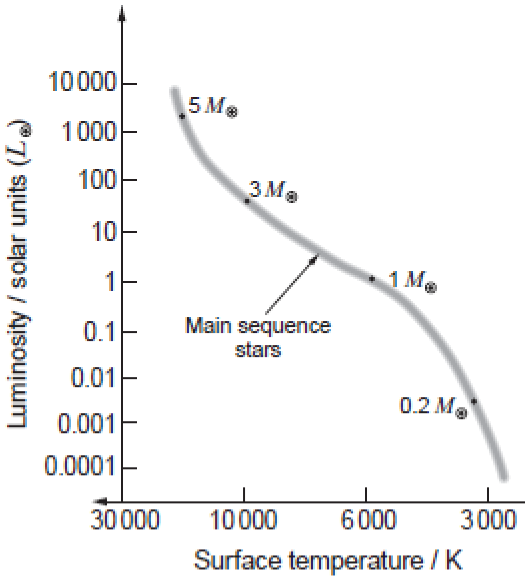


Figure 3 (visible light image)

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. 4
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.



$M_\otimes$ = mass of the Sun
$L_\otimes$ = solar unit (luminosity of the Sun)

Graph 1

Notice that nearly all main sequence stars have surface temperatures in the range 3000 K to 20 000 K. This makes them suitable for analysing using visible light. 5

Paragraph

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 6
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.

$L = 0.23M^{2.3}$	for	$M < 0.43$	**Equation 1**
$L = M^4$	for	$0.43 < M < 2$	**Equation 2**
$L = 1.5M^{3.5}$	for	$2 < M < 20$	**Equation 3**
$L = 3200M$	for	$M > 20$	**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 7
with Einstein's equation.

$$E = \Delta mc^2 \qquad \textbf{Equation 5}$$

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 8
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.

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 9
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.

Answer the following questions in your own words. Extended quotes from the original article will not be awarded marks.

(a) Write down the complete life cycle of a mid-sized star (see **Figure 1**). [1]

Star-forming nebula →

(b) Suggest an advantage of placing telescopes *in space* to observe new stars (see Paragraph 2). [1]

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(c) In **Figure 2** or 3 below, mark with an **X** one area where new stars are forming (see Paragraph 3 and **Figures 2** & 3). [1]

Figure 2 (infra-red image)

Figure 3 (visible light image)

(d) Explain, using Newton's 2nd law, how electromagnetic radiation exerts pressure inside a main sequence star (see Paragraph 4). [3]

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(e) Explain why a more massive star has a higher density in its core and why this leads to a higher temperature (see Paragraph 4). [3]

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(f) (i) Show that the wavelength of maximum emission for the hottest main sequence stars is approximately 150 nm (see Paragraph 5 or Graph 1). [2]

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(ii) Discuss whether or not it is appropriate to analyse the hottest main sequence stars using visible light when their wavelength of maximum emission is 150 nm (see Paragraph 5). [2]

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(g) Determine whether or not the star of mass $0.2\,M_{\odot}$ is plotted at approximately the correct luminosity in Graph 1 (see Equations 1–4 and Graph 1). [2]

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(h) Explain why a $10\,M_{\odot}$ star has a lifetime that is 500 times shorter than that of the Sun, including any simplifying assumptions (see Paragraph 8 and Equations 1–5). [4]

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(i) Explain **briefly** what the author means when he states that a white dwarf's mass and radius are negatively correlated (see Paragraph 9). [1]

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