Advanced Higher Physics

Past Paper Questions

1.6 Stellar Physics

6. A Hertzsprung-Russell (H-R) diagram is shown in Figure 6A.

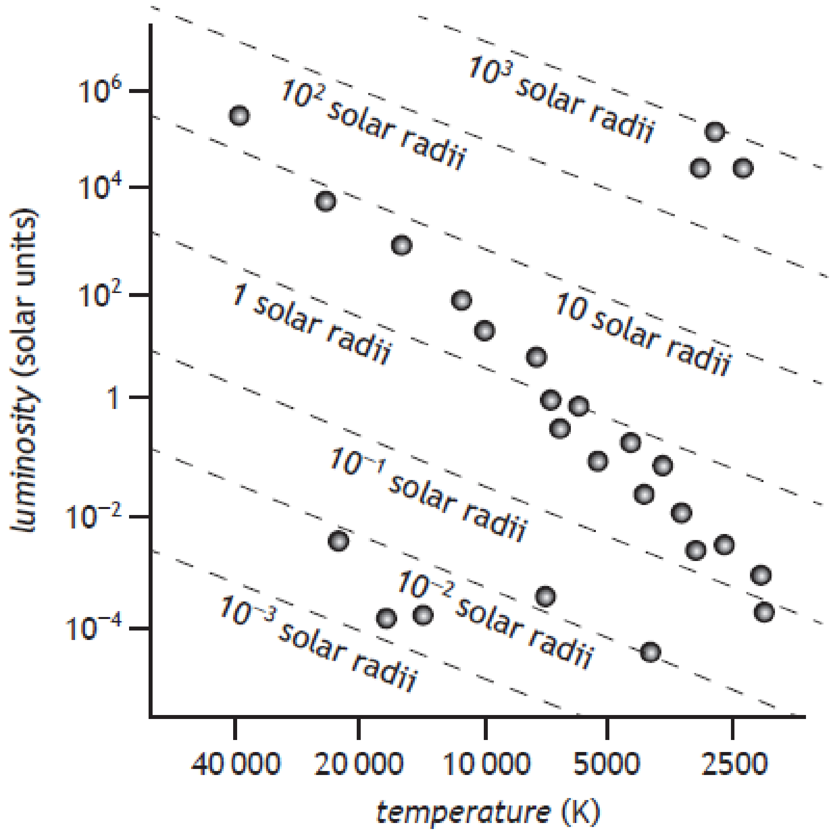


Figure 6A

(a) All stars on the main sequence release energy by converting hydrogen to helium. This process is known as the proton-proton (p-p) chain. One stage in the p-p chain is shown.

$$^{1}_{1}\mathrm{H} + ^{1}_{1}\mathrm{H} \rightarrow ^{2}_{1}\mathrm{H} + \mathrm{x} + \mathrm{y}$$

Name particles x and y. **2**

(b) The luminosity of the Sun is $3{\cdot}9 \times 10^{26}$ W. The star Procyon B has a luminosity of $4{\cdot}9 \times 10^{-4}$ solar units and a radius of $1{\cdot}2 \times 10^{-2}$ solar radii.

(i) On the H-R diagram, circle the star at the position of Procyon B. **1**

(An additional diagram, if required, can be found on *Page 42*.)

(ii) What type of star is Procyon B? **1**

(iii) The apparent brightness of Procyon B when viewed from Earth is $1{\cdot}3 \times 10^{-12}$ W m^{-2}.

Calculate the distance of Procyon B from Earth. **4**

(c) The expression

$$\frac{L}{L_0} = 1 \cdot 5\left(\frac{M}{M_0}\right)^{3 \cdot 5}$$

can be used to approximate the relationship between a star's mass M and its luminosity L.

L_0 is the luminosity of the Sun (1 solar unit) and M_0 is the mass of the Sun.

This expression is valid for stars of mass between $2M_0$ and $20M_0$.

Spica is a star which has mass $10 \cdot 3M_0$.

Determine the approximate luminosity of Spica in solar units. **2**

2016

4. Epsilon Eridani is a star $9 \cdot 94 \times 10^{16}$ m from Earth. It has a diameter of $1 \cdot 02 \times 10^{9}$ m. The apparent brightness of Epsilon Eridani is measured on Earth to be $1 \cdot 05 \times 10^{-9}$ W m^{-2}.

(a) Calculate the luminosity of Epsilon Eridani. 3

(b) Calculate the surface temperature of Epsilon Eridani. 3

2015

4. The constellation Orion, shown in Figure 4A, is a common sight in the winter sky above Scotland.

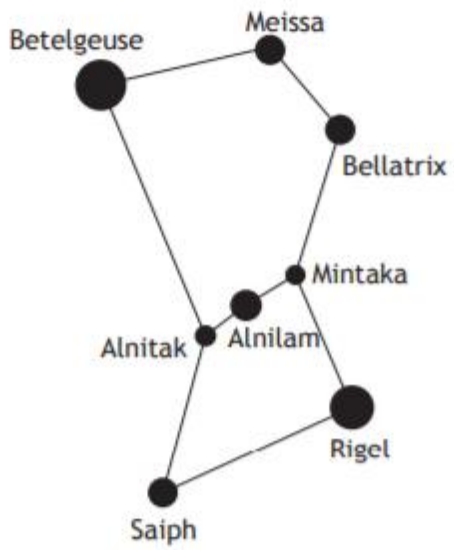
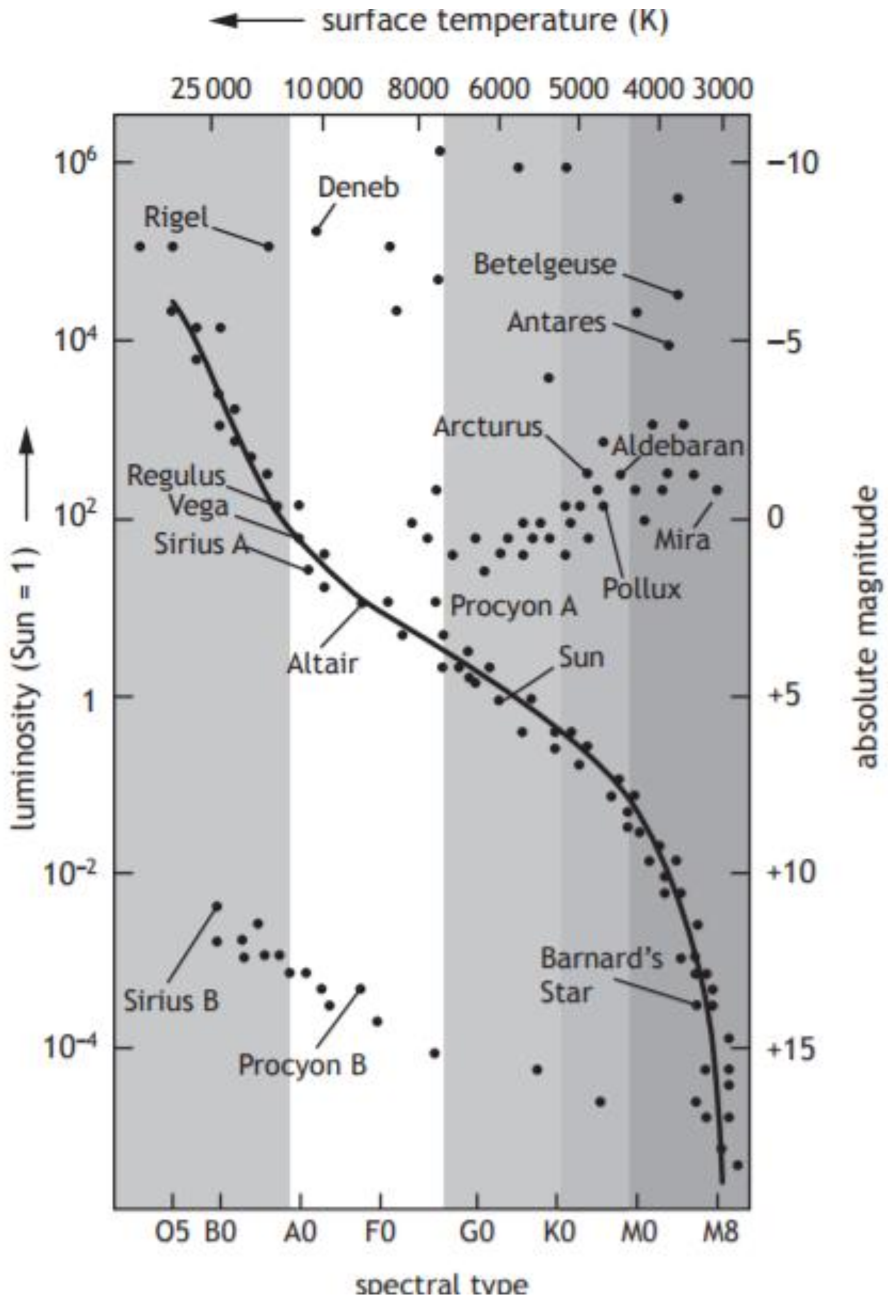


Figure 4A

Two of the stars in this constellation are known as Betelgeuse and Rigel. Their positions are shown on the Hertzsprung-Russell (H-R) diagram in Figure 4B.



(a) Using the H-R diagram, predict the colour of Betelgeuse. **1**

(b) The table shows some of the physical properties of Rigel.

Property of Rigel	
Surface temperature	$(1{\cdot}20 \pm 0{\cdot}05) \times 10^4$ K
Radius	$(5{\cdot}49 \pm 0{\cdot}50) \times 10^{10}$ m
Mass	18 ± 1 solar masses
Distance to Earth	773 ± 150 light years

(i) (A) Calculate the luminosity of Rigel. **3**

(B) State the assumption made in your calculation. 1

(ii) Calculate the absolute uncertainty in the value of the luminosity of Rigel. 4

(c) Calculate the apparent brightness of Rigel as observed from the Earth. 4

(d) Betelgeuse is not on the Main Sequence region of the H-R diagram. Describe the changes that have taken place in Betelgeuse since leaving the Main Sequence. 2

Revised Advanced Higher 2015

3. The luminosity of the Sun is $3{\cdot}9 \times 10^{26}$ W and the mean radius of the Earth's orbit around the Sun is 1 astronomical unit (AU).

(*a*) Calculate the Sun's apparent brightness at the surface of the Earth. 2

(*b*) The distance *d* to a star can be calculated using the relationship:

$$10^{0{\cdot}2(m-M)} = \frac{d}{10}$$

This gives a distance in parsecs. 1 parsec is equivalent to 3·26 light years.

The apparent magnitude (m) of a celestial body is a measure of its brightness as viewed from Earth. The absolute magnitude (M) of a celestial body is a measure of its intrinsic brightness.

The following data was obtained for a star.

Apparent magnitude = 5·62
Absolute magnitude = −4·38

Calculate the distance in light years to this star from Earth. 3

(5)

4. The lyrics of the song Woodstock contain the lines "We are stardust; we are golden. We are billion year old carbon".

Use your knowledge of Physics to comment on these lyrics. **(3)**

5. A typical Hertsprung-Russell (H-R) diagram is shown in Figure 5A.

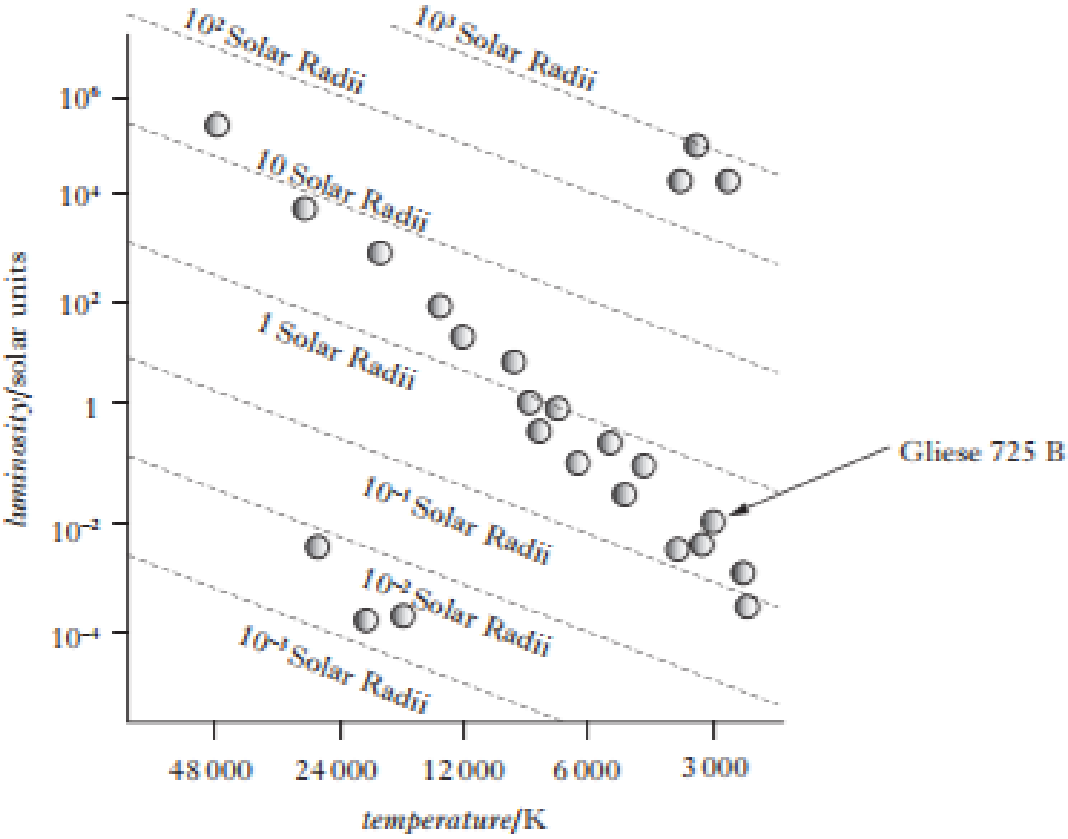


Figure 5A

(*a*) The luminosity of the Sun is $3{\cdot}9 \times 10^{26}$ W.

Using information from Figure 5A:

(i) determine the luminosity in watts of Gliese 725 B; **1**

(ii) show that the radius of Gliese 725 B is 3×10^8 m; **2**

(iii) explain why it would be inappropriate to give the answer for part (ii) to more than one significant figure. **1**

(b) Figure 5B shows how the radiation intensity varies with frequency for a black body radiator.

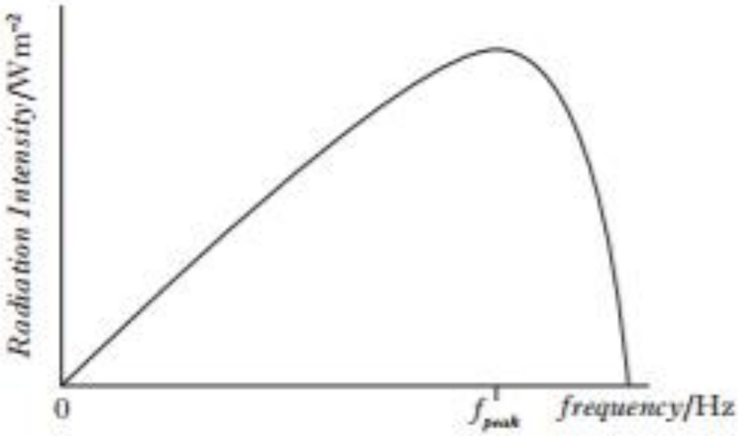


Figure 5B

This spectrum has a peak intensity at a frequency of f_{peak}.
f_{peak} can be estimated using the relationship

$$f_{peak} = \frac{2 \cdot 8 k_b T}{h}$$

where $k_b = 1{\cdot}38 \times 10^{-23}$ J K^{-1} (Boltzmann constant) and the other symbols have their usual meanings.

(i) Estimate f_{peak} for Gliese 725 B. **2**

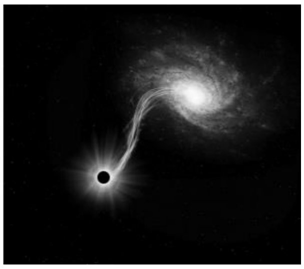
(ii) The cosmic microwave background radiation (CMBR) has a spectrum which peaks at a wavelength of 1·9 mm. Calculate the temperature of the CMBR. **3**

(c) Some astronomers have suggested that primordial black holes of mass $1{\cdot}0 \times 10^{-10}$ solar masses could make up the dark matter in our galaxy.

Determine the Schwarzchild radius of such a black hole. **3**

(12)

4. Cygnus X-1 is an X-ray source in the constellation Cygnus that astrophysicists believe contains a black hole. An artist's impression is shown in Figure 4A.

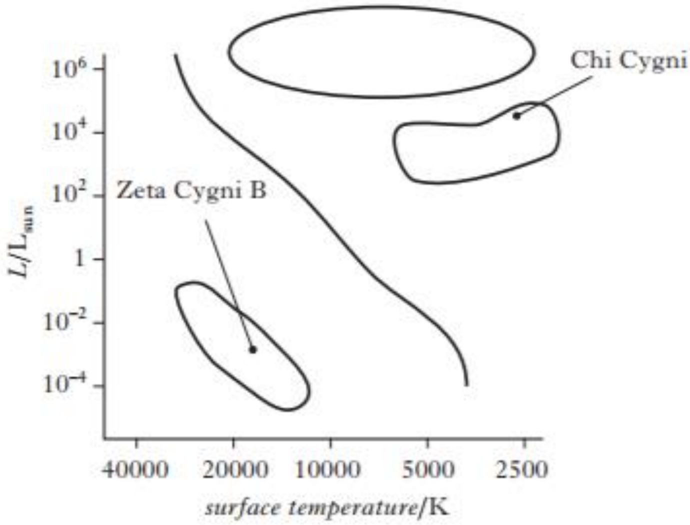


The mass of the black hole has been determined to be 14·8 Solar masses.

(*a*) (i) State what is meant by the Schwarzschild radius of a black hole. **1**

(ii) Calculate the Schwarzschild radius of the black hole in Cygnus X-1. **3**

(*b*) The Hertzsprung-Russell (H-R) diagram shown in Figure 4B shows the relationship between the luminosity and surface temperature of stars.



Zeta Cygni B and Chi Cygni are two stars in the constellation Cygnus. They are shown on the H-R diagram. Chi Cygni is more luminous than Zeta Cygni B.

Describe **two** other differences between these stars. **2**

(*c*) Another star, Aldebaran B, is a distance of $6{\cdot}16 \times 10^{17}$ m from the Earth.

The luminosity of Aldebaran B is $2{\cdot}32 \times 10^{25}$ W and its temperature is determined to be $3{\cdot}4 \times 10^3$ K.

(i) Calculate the radius of Aldebaran B. **2**

(ii) Calculate the apparent brightness of Aldebaran B as observed from Earth. **2**

(10)

5. Hertzsprung-Russell (H-R) diagrams are widely used by physicists and astronomers to categorise stars. Figure 5A shows a simplified H-R diagram.

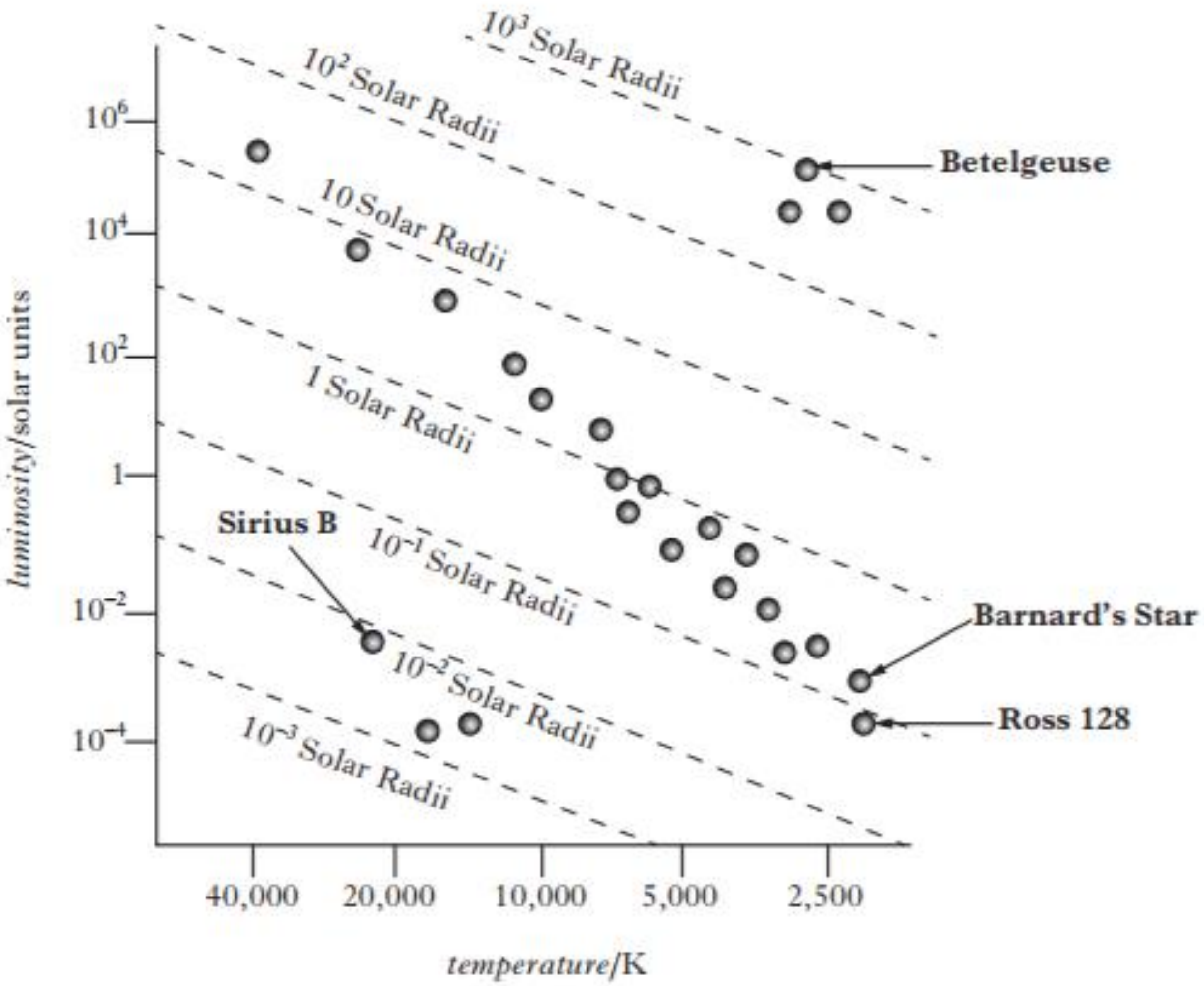


Figure 5A

(a) What class of star is Sirius B? **1**

(b) Estimate the radius in metres of Betelgeuse. **2**

(c) Ross 128 and Barnard's Star have a similar temperature but Barnard's Star has a slightly greater luminosity. What other information does this tell you about the two stars? **1** (*d*) During the life cycle of the Sun its position in the H-R diagram is expected to change as shown by the arrowed line in Figure 5B.

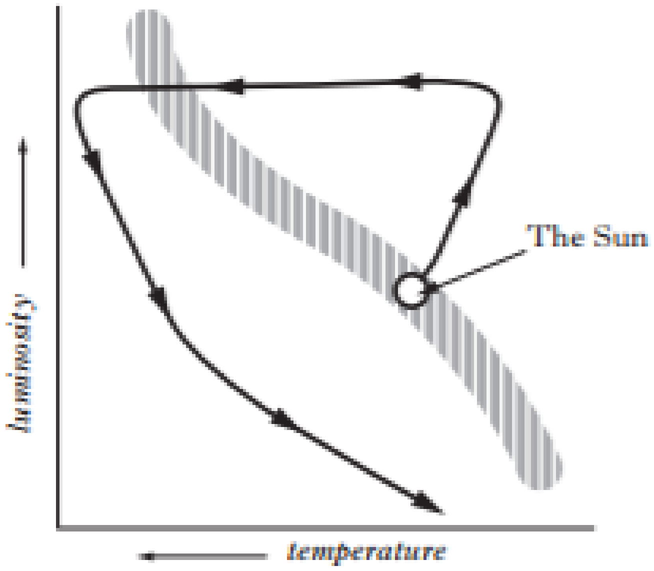


Figure 5B

Describe the changes that occur to the Sun during its expected life cycle. **3**

(*e*) Hydrogen fusion in a star is a result of a proton-proton chain. The process eventually results in the production of a helium-4 nucleus.

(i) Show that the percentage loss of mass from four protons to one helium-4 nucleus is 0·7%. **2**

(ii) The luminosity of the Sun is $3{\cdot}8 \times 10^{26}$ W. Using Einstein's energy equation, show that the mass of hydrogen lost per second in the Sun is $4{\cdot}2 \times 10^{9}$ kg. **1**

(iii) Estimate the lifetime of the Sun in seconds. Assume the mass of hydrogen in the Sun to be the same as the mass of the Sun. **1**

(*f*) The "no greenhouse" temperature of a planet is the average surface temperature of a planet in the absence of any greenhouse effect. The "no greenhouse" temperature of a planet in kelvin in given by

$$T = 280\left(\frac{(1 - reflectivity)}{d^2}\right)^{\frac{1}{4}}$$

where *d* is the distance from the Sun in astronomical units (AU).

The reflectivity is a measure of the percentage of energy reflected from the surface, 1 represents 100% reflectivity and 0 represents no reflectivity.

Mercury has a reflectivity of 0·12 and is $5{\cdot}8 \times 10^{10}$ m from the Sun.

Calculate its "no greenhouse" temperature. **2**

(13)