Stellar Physics

2013 Revised AH Physics

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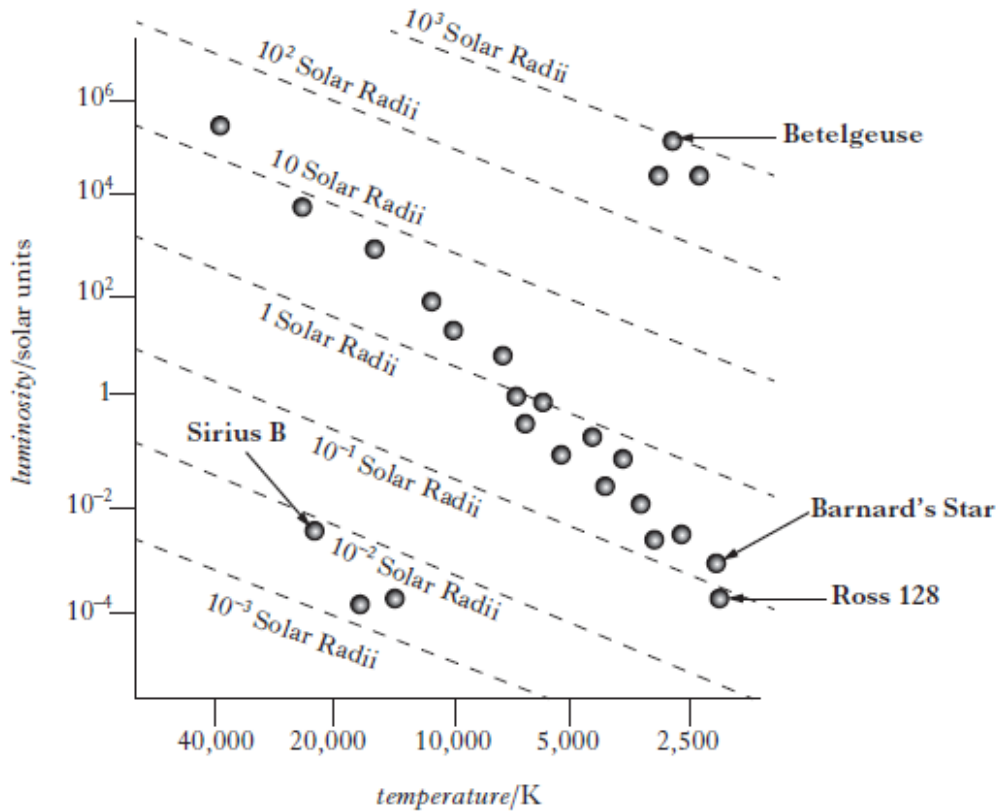

Figure 5A

(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

5. (continued)

(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.
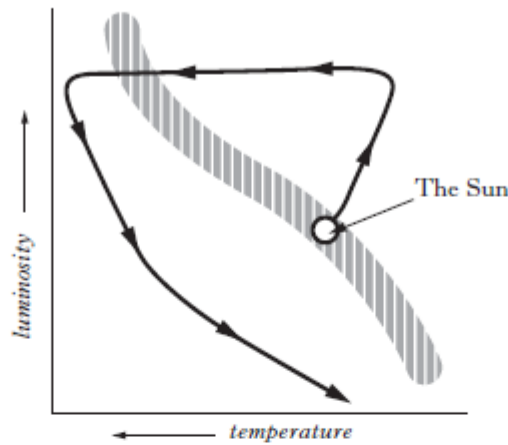

Figure 5B

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 3.8×10^{26} W. Using Einstein's energy equation, show that the mass of hydrogen lost per second in the Sun is 4.2×10^{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 5.8×10^{10} m from the Sun.

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

(13)

Marks

6. Detailed observations of sunspots have been obtained by the Royal Greenwich Observatory since 1874. These observations include information on the sizes and positions of sunspots as well as their numbers. The number of sunspots is an indication of solar activity. A graph of the average number of sunspots since 1950 is shown in Figure 6.
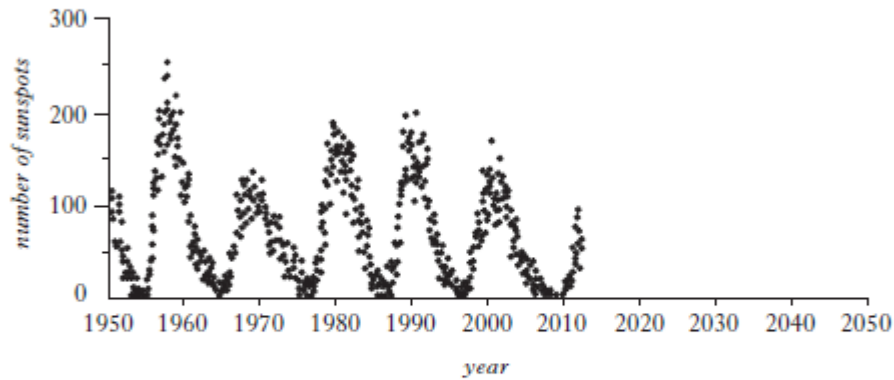

Figure 6

Coronal mass ejections (CME) are one type of solar activity. CMEs are huge magnetic bubbles of plasma that expand away from the Sun at speeds as high as $2000\,km\,s^{-1}$. A single CME can carry up to ten million tonnes ($10^{10}\,kg$) of plasma away from the Sun.

Use your knowledge of physics to discuss the potential effects that solar activity could have on Earth over the next few years. **(3)**

4. **(continued)**

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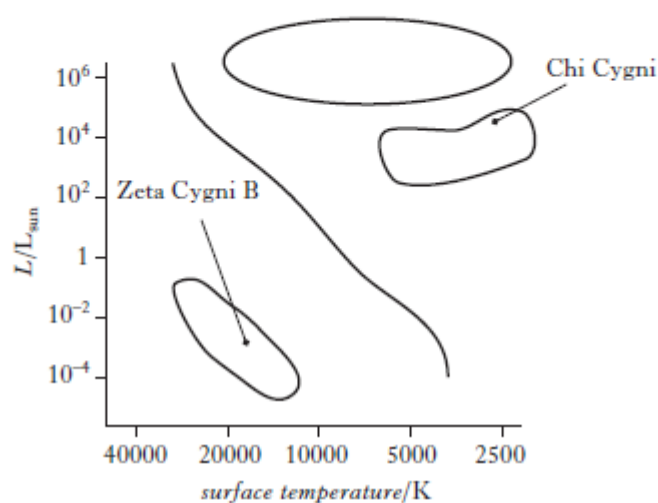

   Figure 4B

   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 6.16×10^{17} m from the Earth.

   The luminosity of Aldebaran B is 2.32×10^{25} W and its temperature is determined to be 3.4×10^{3} K.

   (i) Calculate the radius of Aldebaran B.   2

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

       (10)

Marks

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 $3{\cdot}26$ 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.

   $\qquad$ Apparent magnitude $= 5{\cdot}62$
   $\qquad$ Absolute magnitude $= -4{\cdot}38$

   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)**

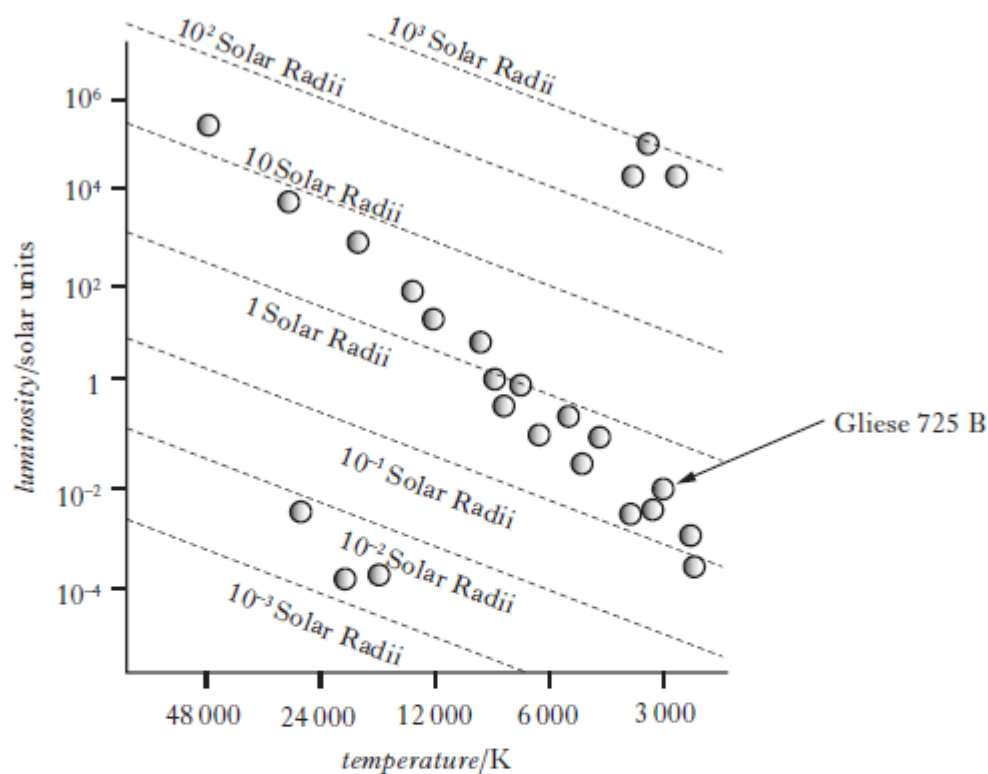5. A typical Hertsprung-Russell (H-R) diagram is shown in Figure 5A.

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

5. **(continued)**

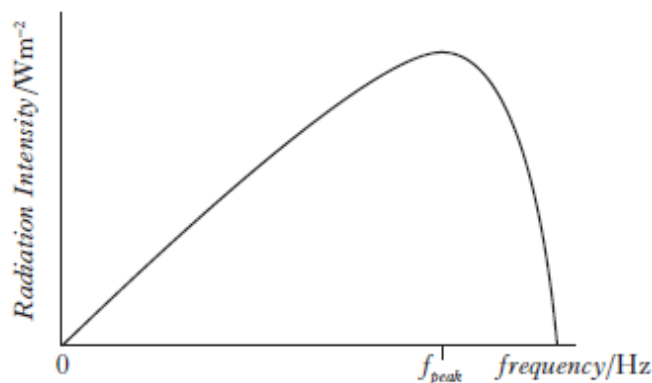(b) Figure 5B shows how the radiation intensity varies with frequency for a black body radiator.

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 $k_b = 1 \cdot 38 \times 10^{-23}\,\text{J K}^{-1}$ (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

MARGIN

4. Epsilon Eridani is a star 9.94×10^{16} m from Earth. It has a diameter of 1.02×10^9 m. The apparent brightness of Epsilon Eridani is measured on Earth to be 1.05×10^{-9} W m^{-2}.

(a) Calculate the luminosity of Epsilon Eridani.　　　　　　　3

Space for working and answer

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

Space for working and answer

(c) State an assumption made in your calculation in (b).　　　1

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

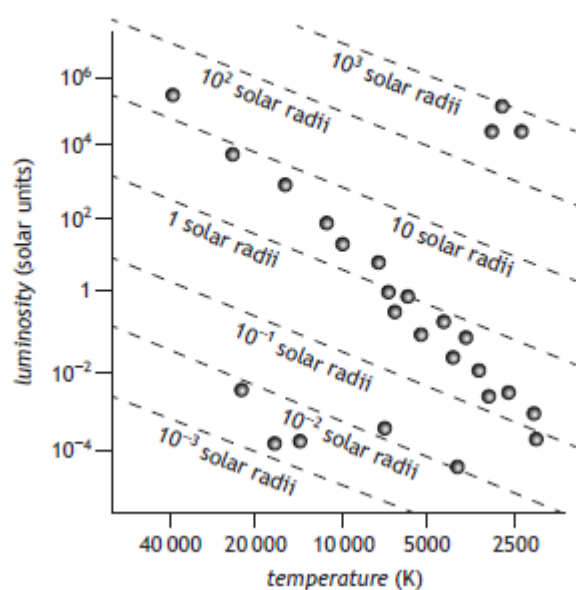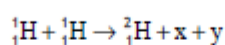

Figure 6A

(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.

$$^1_1H + ^1_1H \rightarrow ^2_1H + x + y$$

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

6. **(b)** **(continued)**

    (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**

        Space for working and answer

(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**

Space for working and answer

7. (continued)

(b) The Hertzsprung-Russell (H-R) diagram shown in Figure 7B shows the relationship between the luminosity and the surface temperature of stars.
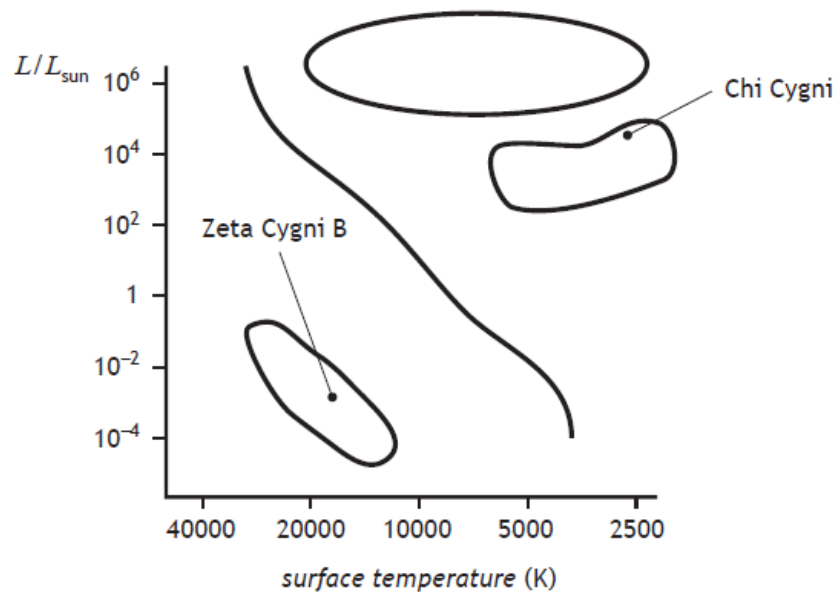

Figure 7B

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

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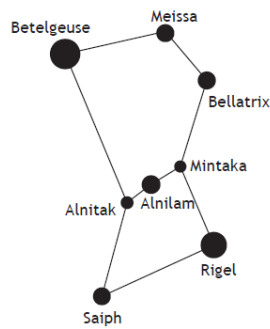4. The constellation Orion, shown in Figure 4A, is a common sight in the winter sky above Scotland.

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.
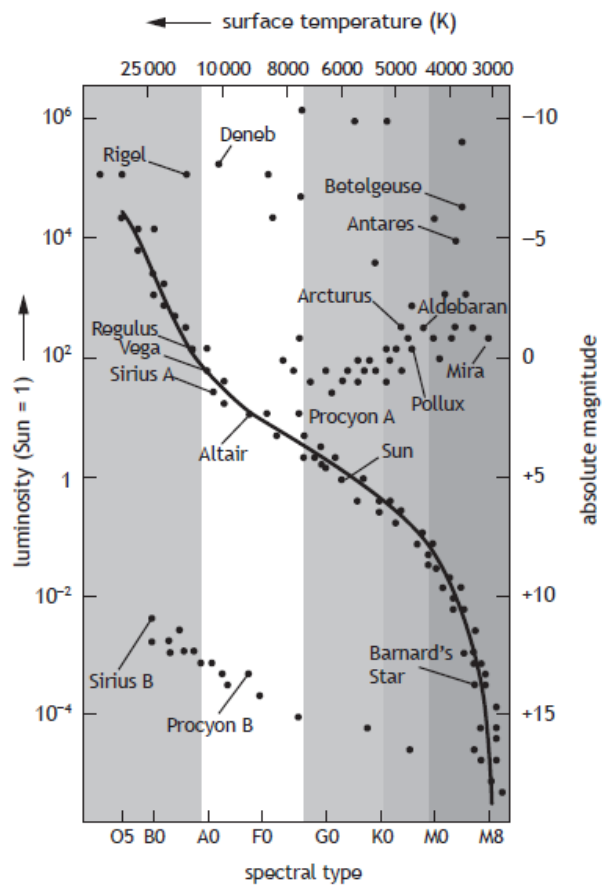
4. (continued)

Figure 4B

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

4. (continued)

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

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

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

Space for working and answer

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

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

Space for working and answer

4. **(continued)**

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

   Space for working and answer

   (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