CfE Advanced Higher Physics

Rotational Motion & Astrophysics Past Paper Homework

4. Gravitation

1. The gravitational pull of the Earth keeps a satellite in a circular orbit.

   (a) Show that for an orbit of radius r the period T is given by

   $$T = 2\pi\sqrt{\frac{r^3}{GM_E}}$$

   where the symbols have their usual meanings.   3

   (b) A polar orbiting satellite is used to map the Earth by photographing strips of the surface as it orbits, as shown in Figure 1
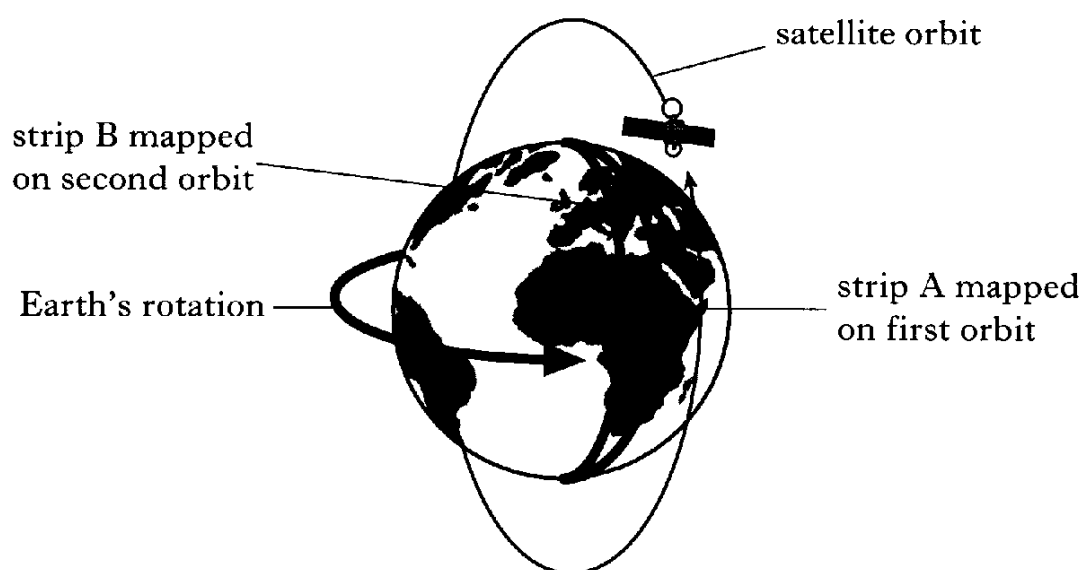
Figure 4

The plane of the satellite orbit is fixed. The Earth rotates and so the satellite maps a different strip on each orbit.

   (i) The satellite orbits at a height of 80 km above the surface of the Earth. Assuming the Earth to be spherical, show that the period of the orbit is approximately 86 minutes.   3

   (ii) The Earth's angular velocity is $7 \cdot 3 \times 10^{-5}$ rad s^{-1}.

   Calculate the distance along the equator between strips A and B which are mapped on consecutive orbits.   3

2. (*a*) (i) A satellite orbits a planet of mass M. The orbital radius of the satellite is R and the orbital period is T.

Show that

$$T^2 = \frac{4\pi^2 R^3}{GM}.$$

3

(ii) Calculate the time taken by the Moon to make one complete orbit of the Earth.

3

(*b*) A satellite orbits 400 km above the Earth's surface as shown in Figure 4.
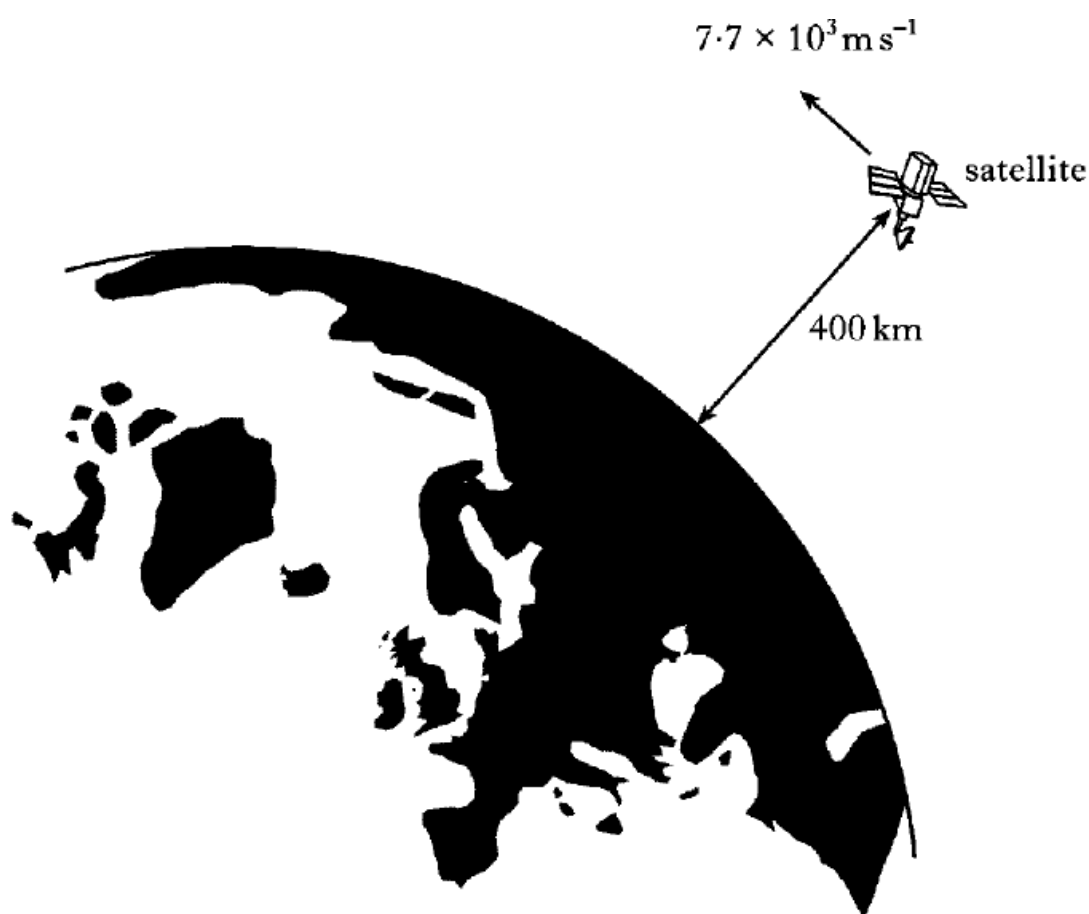
$$7{\cdot}7 \times 10^3\,\mathrm{m\,s^{-1}}$$

satellite

400 km

Figure 2.

The satellite has a mass of 900 kg and a speed of $7{\cdot}7 \times 10^3\,\mathrm{m\,s^{-1}}$.

(i) Show that the potential energy of the satellite is $-5{\cdot}3 \times 10^{10}\,\mathrm{J}$.

3

(ii) Calculate the total energy of the satellite.

3

(12)

3. (*a*) (i) State what is meant by *gravitational field strength*.   1

(ii) The gravitational field strength at the surface of Mars is $3 \cdot 7 \, \text{N kg}^{-1}$.

The radius of Mars is $3 \cdot 4 \times 10^3 \, \text{km}$.

(A) Use Newton's universal law of gravitation to show that the mass of Mars is given by the equation

$$M = \frac{gr^2}{G}$$

where the symbols have their usual meaning.   3

(B) Calculate the mass of Mars.   2

(*b*) A spacecraft of mass 100 kg is in circular orbit 300 km above the surface of Mars.

(i) Show that the force exerted by Mars on the spacecraft is $3 \cdot 1 \times 10^2 \, \text{N}$.   3

(ii) Calculate the period of the spacecraft's orbit.   4

(13)

4. (*a*) The Moon orbits the Earth due to the gravitational force between them.

(i) Calculate the magnitude of the gravitational force between the Earth and the Moon.   3

(ii) Hence calculate the tangential speed of the Moon in its orbit around the Earth.   3

(iii) Define the term *gravitational potential* at a point in space.   1

(iv) Calculate the potential energy of the Moon in its orbit.   3

(v) Hence calculate the total energy of the Moon in its orbit.   3

(*b*) (i) Derive an expression for the escape velocity from the surface of an astronomical body.   3

(ii) Calculate the escape velocity from the surface of the Moon.   3

(19)

Total Marks - 53

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5. General Relativity

1)

Einstein's theory of general relativity can be used to describe the motion of objects in non-inertial frames of reference. The equivalence principle is a key assumption of general relativity.

    (a) Explain what is meant by the terms:

        (i) *non-inertial frames of reference;*   1

        (ii) *the equivalence principle.*   1

2) How does the equivalence principal link the effects of gravity with acceleration?   1

3) A star which is approximately the same size as our Sun has an average density of 2.7×10^3 kg m^{-3}.

If this star collapsed to form a Black Hole, calculate the Schwarzschild radius of the Black Hole.   5

4) Explain what is meant by the term *geodesic*.   1

5) What effect does mass have on spacetime?   1

6) Mercury's orbit around the Sun could not be predicted accurately using classical mechanics. General relativity was able to predict Mercury's orbit accurately. Investigate this using a suitable search engine and write a short paragraph summarising your results.   3

7)

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.
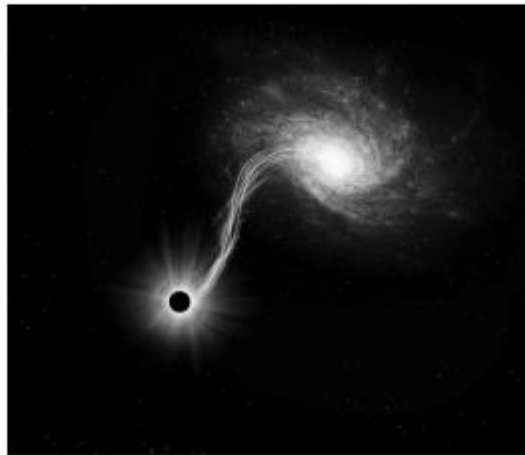

Figure 4A

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.   4

                                                                                            (5)

8)

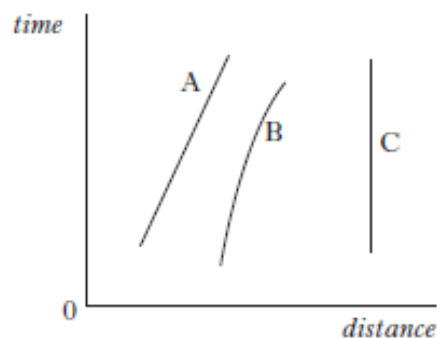(a) The world lines for three objects A, B and C are shown in Figure 4A.

Figure 4A

To which of these objects does the General Theory of Relativity apply? Explain your choice.   **2**

(b) A rocket ship is accelerating through space. Clocks P and Q are at opposite ends of the ship as shown in Figure 4B. An astronaut inside the rocket ship is beside clock P and can also observe clock Q.
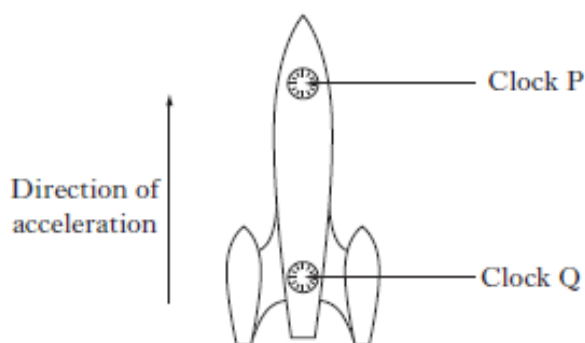

Figure 4B

What does the astronaut observe about the passage of time for these clocks? Justify you answer.   **2**

(c) Part of an astronaut's training is to experience the effect of "weightlessness". This can be achieved inside an aircraft that follows a path as shown in Figure 4C.

Figure 4C

Use the equivalence principle to explain how this "weightlessness" is achieved.   **2**

(6)

Total Marks - 24

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6. Stellar Physics

1) A star with a radius of 8.7 x 10^9m and a surface temperature of 6100K is 42 ly from Earth.

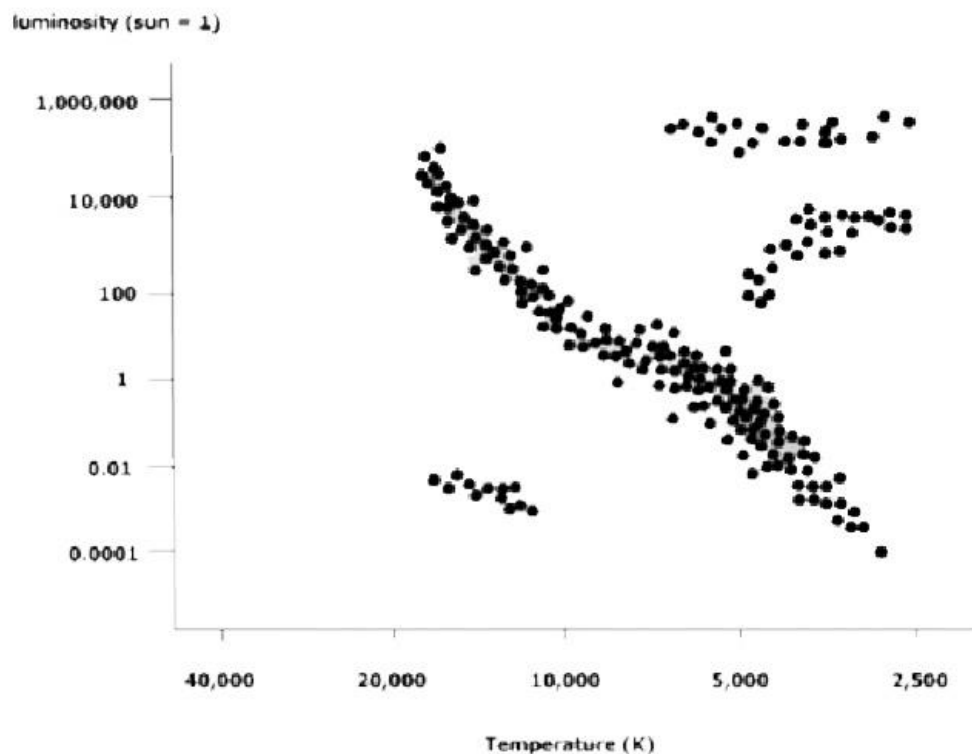   Calculate the apparent brightness of the star.   5

2)

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.   3

3) The diagram below shows one way of classifying stars. Each dot on the diagram represents a star.

luminosity (sun = 1)

The stars are arranged into 4 main groups; the main sequence, giants, super giants and white dwarfs.

a) In which of the regions on the diagram is the Sun?   **1**

b) The surface temperature of the Sun is approximately 5800K.
Explain why the scale on the temperature axis makes it difficult to

Identify which dot represents the Sun.   **2**

c) In time, the Sun's nuclear fuel will be used up. Explain what will then
happen to the Sun's position in the above diagram and why.   **3**

4)

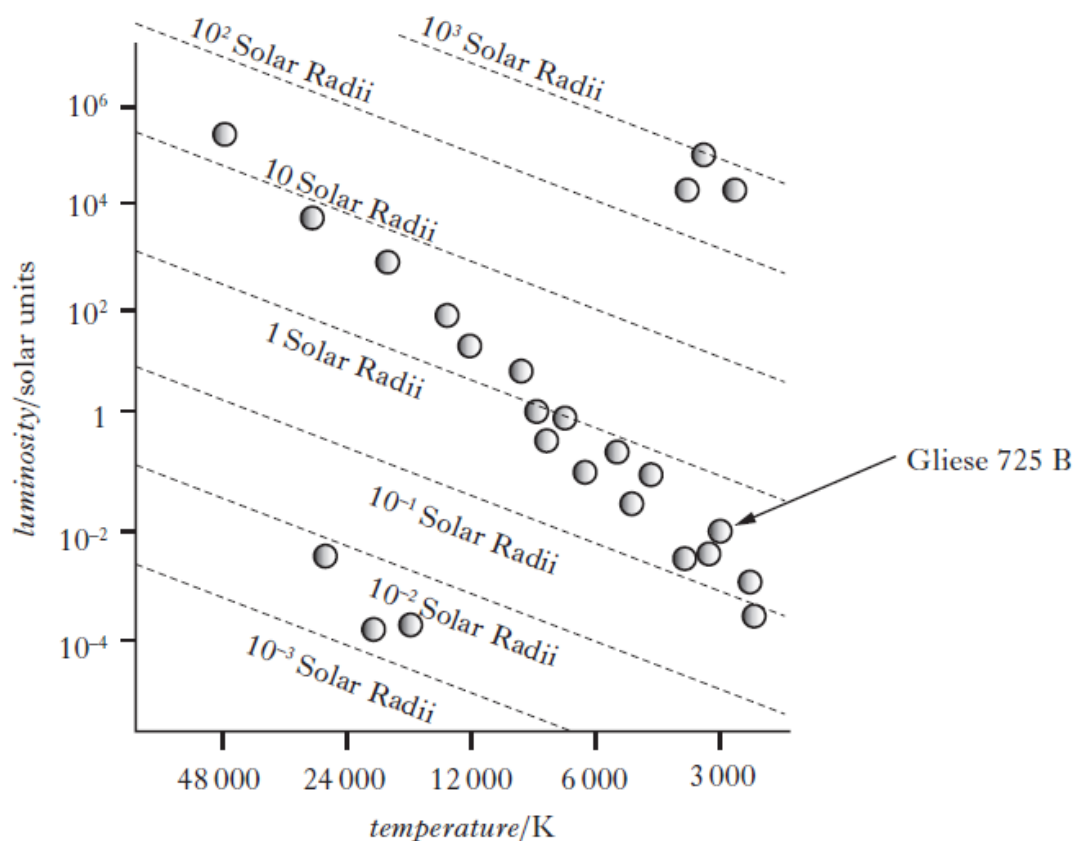A typical Hertsprung-Russell (H-R) diagram is shown in Figure 5A.

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;   2

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

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

          (6)

5)

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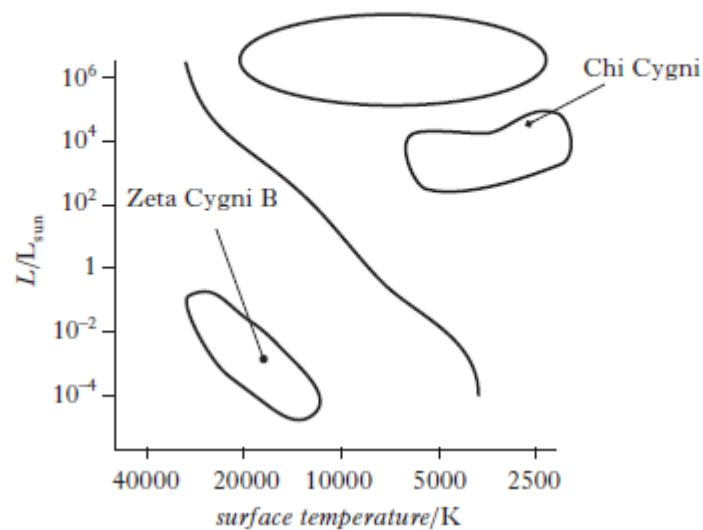

Figure 4B

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 $6 \cdot 16 \times 10^{17}$ 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.   3

  (ii) Calculate the apparent brightness of Aldebaran B as observed from Earth.   3

                                                                          (8)

Total Marks - 28