8 Read the passage below and answer the questions that follow.

Exoplanets

An exoplanet is any planet beyond our solar system. Most orbit other stars, but free-floating exoplanets, called rogue planets, orbit the galactic centre and are not bound to any star.

The first exoplanets were discovered in the 1990s and since then we have identified thousands more using a variety of detection methods. It is pretty rare for astronomers to see an exoplanet through their telescopes the way they might see Saturn through a telescope from Earth. This method is called direct imaging, and only a handful of exoplanets have been found this way. Most exoplanets are found through indirect methods, such as the transit method.

When a planet passes directly between an observer and the star it orbits, it blocks some of that starlight, as shown in Fig. 8.1. For a brief period of time, that brightness of the star decreases. It is a tiny change, but it is enough for astronomers to detect the presence of an exoplanet around a distant star. This is known as the transit method.

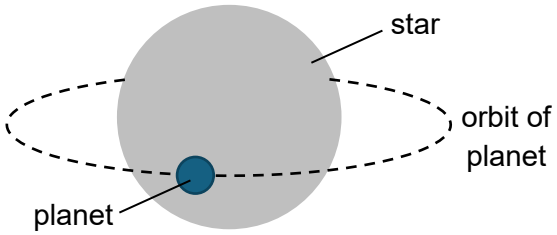

Fig. 8.1

HD 209458 b, also known as Osiris, is an exoplanet that orbits the star HD 209458. Osiris was the first exoplanet to be discovered using the transit method.

Some data of the star HD 209458 are given below.

mass = 2.28×10^{30} kg

distance from Earth = 159 light-years

orbital speed = 84.3 m s^{-1}

temperature = 6070 K

age = 3.5×10^{9} years

Fig. 8.2 shows the variation with time *t* of the brightness of the star HD 209458.

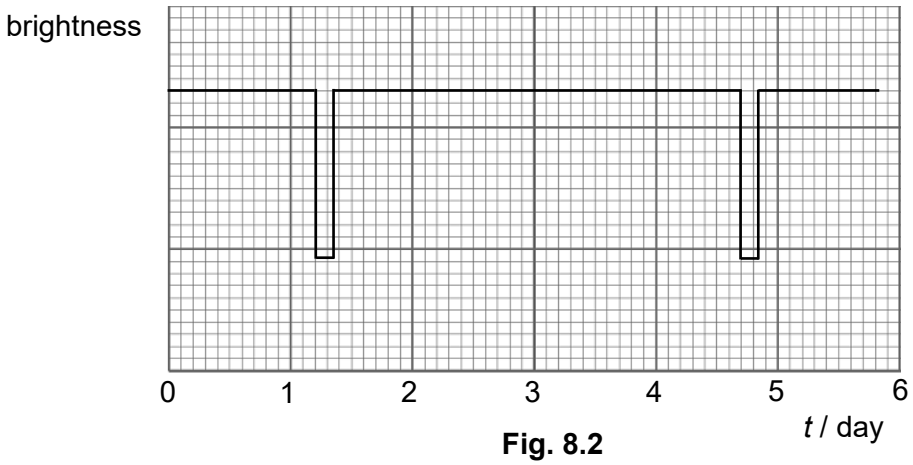

Fig. 8.2

(a) Determine the period of orbit of Osiris.

period = ... days [1]

(b) In a particular planetary system, a star of mass M_S and a planet of mass M_P move in circular orbits of radii x and y respectively, about their common centre of mass O, with a period T as shown in Fig. 8.3.

The star and planet are separated by a distance d apart.

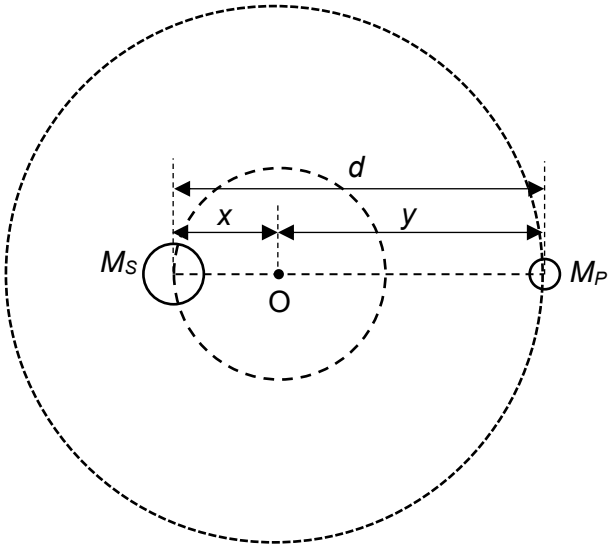

Fig. 8.3

(i) Show that $M_S = \left(\frac{4\pi^2}{G}\right)\frac{yd^2}{T^2}$ and $M_P = \left(\frac{4\pi^2}{G}\right)\frac{xd^2}{T^2}$. Explain your working.

[3]

(ii) Hence, show that $M_S + M_P = \left(\frac{4\pi^2}{G}\right)\frac{d^3}{T^2}$.

[1]

(c) Use the equation from **(b)(ii)** to calculate the distance between HD 209458 and Osiris.

Assume that the mass of Osiris is negligible compared to the mass of HD 209458.

distance = ... m [2]

(d) Show that the orbital speed of Osiris about the common center of mass is 1.47×10^5 m s^{-1}.

[1]

(e) Hence, by considering the momentum of HD 209458 and Osiris, determine the mass of Osiris.

Assume that the centre of mass of HD 209458 and Osiris is stationary.

mass = ... kg [2]

(f) Suggest two limitations of the transit method in detecting exoplanets.

1 .....

.....

2 .....

[2]

(g) A light-year is the distance that light travels in one year.

Show that one light-year is 9.5×10^{15} m.

[1]

(h) The James Webb Space Telescope (JWST) is set to launch in October 2021. It is planned to succeed the Hubble Space Telescope as the world's most powerful space telescope. The JWST will be used to observe some of the most distant events and objects in space using infrared radiation. The telescope has a large aperture size of 6.5 m.

(i) Explain what is meant by the Rayleigh criterion.

.....

.....

.....

[2]

(ii) Fig. 8.4. shows a possible arrangement of the relative positions of HD 209458, Osiris and JWST.

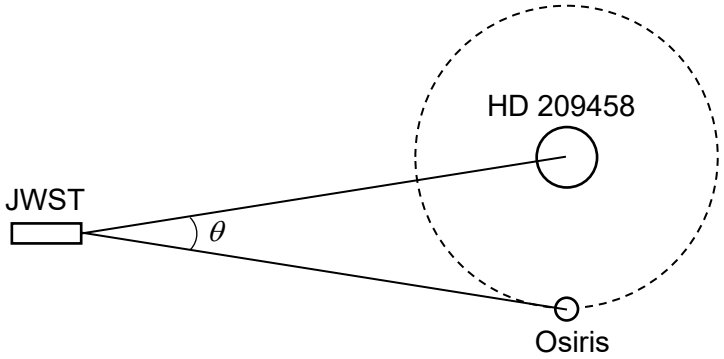

Fig. 8.4 (not to scale)

Calculate the maximum angle θ subtended by HD 209458 and Osiris at the JWST.

θ = ... rad [2]

(iii) Use the Rayleigh criterion to determine whether the JWST is able to distinguish Osiris from HD 209458 at a wavelength of 14 μm.

[3]

[Total: 20]