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

In 1967, the first pulsar was discovered. A regular, repeating radio wave signal was found on a trace from a radio telescope near Cambridge, as shown in Fig. 8.1.

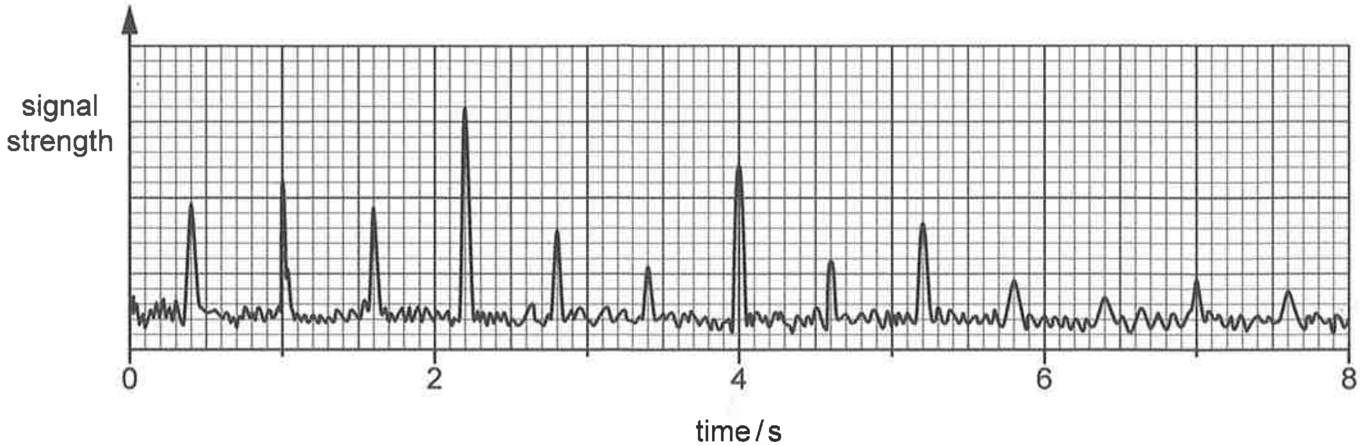

Fig. 8.1

A pulsar is a type of neutron star, formed after a supernova explosion when a star more massive than the Sun nears the end of its life. The nuclei inside the star undergo fusion to form the nuclei of heavier elements. Towards the end of the life of the star, heavier nuclei fuse together to form even heavier nuclei. Eventually, fusion stops and the core collapses under gravitational forces. The density of the core increases and a supernova explosion occurs. The pulsar that remains has an iron-rich crust.

The first pulsar discovered had a mass of approximately 1.4 solar masses, where one solar mass is the mass of the Sun, and a radius of approximately 10 km.

A pulsar spins much faster and has a much smaller period of rotation than the star from which it was formed.

Pulsars have very strong magnetic fields in the region of 10^8 T and very strong electric fields in the region of $10^9\,V\,m^{-1}$. A radio signal is emitted from each of the magnetic poles of the pulsar. The two radio signals travel in opposite directions. As the pulsar rotates, radio signals are swept across space because the magnetic poles do not coincide with the rotational poles of the pulsar. It was a radio signal from one of the poles of a pulsar that was first detected on Earth.

Pulsars can rotate many times every second. However, there are limits to the rate of rotation. One limit is that the speed of the surface cannot exceed the speed of light. A second limit is that the speed of the surface cannot be so high that the pulsar disintegrates. This would happen if, at a point on the surface of the pulsar, the centripetal acceleration exceeded the acceleration due to gravity.

A total of around 2500 pulsars have now been discovered. The Crab Pulsar, which is in the Crab Nebula, was detected in 1968. This pulsar emits photons with a maximum energy of 400 TeV. The Crab Pulsar has a period of rotation of 33.5 ms, and this period increases by 38 ns per day.

The Parkes Telescope in Australia has a diameter of 64 m and has led to the discovery of around 700 pulsars. A new telescope called the Square Kilometre Array (SKA) is to be built. The total effective collecting area of this telescope will be $1.0\,km^2$, and it is hoped that this telescope will lead to the discovery of many more pulsars.

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(a) Using Fig. 8.1, determine the angular velocity of the first pulsar discovered.

angular velocity = ... $rad\,s^{-1}$ [2]

(b) A spinning body has a quantity called angular momentum. Similar to linear momentum, the angular momentum of a closed system is conserved.

The angular momentum L of a sphere spinning on its axis is given by:

$$L = \frac{2}{5}mr^2\omega$$

where m is the mass of the sphere, r is the radius of the sphere and ω is the angular velocity of the sphere.

Suggest why a pulsar spins much faster than the star from which it was formed.

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.... [1]

(c) Explain why the iron in the iron-rich crust of the pulsar did not undergo fusion.

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.... [2]

(d) **(i)** The mass of the Sun is 2.0×10^{30} kg.

Calculate the gravitational field strength g at the surface of the first pulsar discovered.

g = ... $N\,kg^{-1}$ [2]

(ii) Determine the difference Δg in the gravitational field strength between a point at the surface of the pulsar and a second point 1.0 m vertically above the surface.

Δg = ... $N\,kg^{-1}$ [1]

(iii) A steel rod of length 1.0 m is released and falls vertically from a height of 3.0 m above the surface of the pulsar.

Suggest what happens to the length of the rod as it accelerates towards the surface of the pulsar. Give a reason for your answer.

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.... [1]

(e) **(i)** A pulsar has a radius of 100 km.

Explain why this pulsar cannot have a period of 2.0 ms. Support your answer with a calculation.

....

.... [2]

(ii) Show that the minimum average density ρ of a spherical pulsar that does not disintegrate is given by:

$$\rho = \frac{3\pi}{GT^2}$$

where G is the gravitational constant and T is the period of rotation of the pulsar.

[4]

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(iii) Use the expression in **(e)(ii)** to calculate ρ for the first pulsar discovered.

ρ = ... $kg\,m^{-3}$ [1]

(f) The age of a pulsar, in seconds, can be found using the expression:

$$\text{age} = \frac{\text{period}}{2 \times \text{rate of change of period}}.$$

Use this expression to determine the age, in years, of the Crab Pulsar.

age = ... years [1]

(g) Determine the wavelength of the highest energy photons emitted from the Crab Pulsar.

wavelength = ... m [2]

(h) Suggest why the greater effective collecting area of the SKA will enable it to detect pulsars that cannot be detected by the Parkes Telescope.

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.... [1]

[Total: 20]

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