**The Magnetic Fields of Pulsars** All stars have weak magnetic fields which are due to the movement of the charged plasma formed during nuclear fusion. A typical star has a magnetic field strength around 100 gauss compared to the Earth which has a magnetic field strength of 0.6 gauss. Towards the end of its life, when the nuclear fuel is exhausted, the gravitational force (which is balanced by the nuclear pressure throughout the life of the star) causes the star’s density to increase as it undergoes stellar collapse. This increase in density also results in an increase in the star’s magnetic field strength as the magnetic field lines are compressed closer together. According to Maxwell’s equations, as a magnitised object shrinks by a factor of two, its magnetic field strengthens by a factor of four. In other words the magnetic field strength (B) is inversely proportional to the surface area of the star. (Surface area = 4$π$r2)

 $B ∝ \frac{1}{4πr^{2}}$ which simplifies to $B ∝ \frac{1}{r^{2}}$

In figure 1 below, the Earth is theoretically compressed by a factor of two by halving its radius, thus resulting in the magnetic field strength increasing by a factor of four.



**Question 1.** Use the scroll bar below () to adjust the compression factor until the Sun is approximately the same size as the Earth (same radius). What is the magnetic field strength of the Sun when it is compressed to the size of the Earth?

 

The collapsing star will also spin faster in order to conserve angular momentum. Eventually after the stellar collapse (or supernova as it is commonly known)a very strongly magnetised rotating neutron star called a pulsar with field strengths around 1012 gauss will be left. The magnetic field which is supported by electric currents flowing inside the neutron star, rotates with the neutron star. As a result of this, beams of radio waves shine outward from the neutron star’s magnetic poles and sweep through space as it rotates, like a light house. The pulsar also blows out a wind of charged particles which carry away energy and angular momentum, causing its rate of spin to decrease gradually. For example, the Crab Nebula pulsar, a remnant of the supernova explosion that was observed in 1054 now rotates once every 33 milliseconds and is currently slowing down at a rate of about 1.3 millseconds every century. **Question 2.**  Use the scroll bar below () to determine the original spin rate (period) of the pulsar in the Crab Nebula when it was first formed in 1054.

**Question 3.** In approximately what year will the spin rate be twice as slow as the spin rate in 1054?

 

**Question 4. (i)** Use the scroll bar in the table below to determine the magnetic field strength of the Sun when its rotational period is the same as the Earth’s. (i.e. 1 day). Make a conjecture about the relationship between the magnetic field strength and the rotational period. **(ii)** Make a conjecture about the relationship between density (ρ) and magnetic field strength.

 

The table below lists the magnetic field strengths of several objects including magnetars which exhibit the most powerful magnetic fields in the galaxy. Magnetars are super-magnetized spinning neutron stars. The magnetar SGR 1900+14 has the strongest magnetic field known in the galaxy. It is approximately 1,000,000,000,000,000 times larger than the magnetic field of the Earth. If a magnet that strong were placed halfway to the Moon, it could pull metal pens out of your pocket on Earth. This magnetar has been observed to emit powerful flashes of gamma rays.

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| --- |
| **Typical Magnetic Field Strengths** |
| **Object** | **Strength (gauss)** |
| Earth’s magnetic field | 0.6 |
| Simple iron bar magnet | 100 |
| Star | 100 |
| Strongest sustained laboratory field | 4 x 105 |
| Maximum field for ordinary stars | 106 |
| Strongest man-made fields (millisecond duration) | 107 |
| Typical fields for radio pulsars | 1012 |
| Magnetars | 1014-1015 |

**Question 5. (i)** Use the scroll bar in the table below to determine the radius, rotational period and frequency of the Earth if it were possible to compress it into a pulsar with a magnetic field strength of approximately 1012 gauss. **(ii)** Suppose the Earth was compressed so that it’s magnetic field strength was between 1014 and 1015 gauss. What is the radius, rotational period and frequency of this magnetar?

**Question 6. (i)** Use the scroll bar in the table below to determine the radius, rotational period and frequency of the Sun if it were possible to compress it into a pulsar with a magnetic field strength of approximately 1012 gauss. **(ii)** Suppose the Sun was compressed so that it’s magnetic field was between 1014 and 1015 guass. What is the radius, rotational period and frequency of this magnetar.

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**ANSWERS**

1. The magnetic field strength is approximately 1,188,100 gauss. The compression factor is 109 times. (i.e. 1092 × 100 = 1,188,100 gauss)
2. The original spin rate in the year 1054 would be approximately 20 milliseconds.
3. In the year 2594, the otational period (spin rate) will be approximately 40 milliseconds.

**4.** The magnetic field strength of the Sun will be 2500 gauss (25 × 100) when the spin rate is equal to one day. The magnetic field strength is inversely proportional to the rotational period. Decreasing the rotational period by a factor of 25, causes an increase in the magnetic field strength by a factor of 25. B α $\frac{1}{rotational period}$

**5.**

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| --- | --- | --- | --- |
| **Object** | **Radius (km)** | **Period (milliseconds)** | **Frequency (Hz)** |
| (i) Earth as a pulsar | 0.0043 | 0.00003929 | 25452 |
| (ii) Earth as a magnetar | 0.0005 to 0.0002 | 0.00000008 to 0.00000031 | 3257812 to 13031249 |

 **6.**

|  |  |  |  |
| --- | --- | --- | --- |
| **Object** | **Radius (km)** | **Period (milliseconds)** | **Frequency (Hz)** |
| (i) Sun as a pulsar | 7.512 | 0.251 | 3984 |
| (ii) Sun as a magnetar | 0.664 to 0.235 | 0.00196 to 0.000246 | 510204 to 4065040 |