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P5_9 Harnessing a Neutron Star

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Abstract

This paper investigates the potential power that could be harnessed from a neutron star using Faraday's law, and finds it to be a rate of 8.2×10^{20} W. We concluded that a rate of transfer of energy this high would be enough to injure Thor in a scene from Marvel's "Avengers: Infinity War".

Introduction

We investigate in this paper the potential power that could be harnessed from a neutron star using a large loop of metal, as well as what would happen in the scene from Marvel's "Avengers: Infinity War", where this energy is channelled through Thor.

Theory and Results

A neutron star forms from the collapsing core of a giant star, they possess relatively small radii of approximately 10 km [1], they are extremely dense, and possess some of the largest magnetic fields found in the universe to the order of $\times 10^{11}$ T [2].

It would be possible to harness this energy using a large metal wire over the star, in accordance with Faraday's law, which states that a time varying magnetic field applied over a conductive loop will always produce an electromotive force. This is known as inductance, and is given by Equation 1 [3],

$$\epsilon = \Delta\phi_B/\Delta t, \tag{1}$$

where ϵ is the electromotive force (EMF), or voltage, induced, $\Delta\phi_B$ is the changing magnetic flux passing through the loop, and Δt is the time taken for this change in flux.

It is important to note that neutron stars rotate very rapidly, with even the slowest of them reaching rotation periods of 30 s [4], this means that if the metal loop is stationary, then the star will be rotating inside of it, and therefore a magnetic flux is being swept over the loop, allowing inductance to occur.

We shall assume that a large loop of copper wire has been placed over the entire diameter of the neutron star, and rests just above the surface. The flux passing through this loop can then be calculated from Equation 2 [5],

$$\phi_B = BA, \tag{2}$$

where B is the magnetic field strength of the neutron star, and A is the area created by the loop of copper wire. We shall be assuming this neutron star is a relatively old neutron star, and therefore has a smaller magnetic field of the order of $\times 10^4$ T. The radius of the loop shall be assumed to be roughly the same as the radius of the star, 10 km, as it just above the surface, using $A = \pi r^2$ this gives an area of 314×10^6 m^2.

We shall assume the magnetic field of the neutron star is on the weaker end of the spectrum being of the order of $\times 10^4$ T, using Equation 2 with our previously calculated area, a magnetic flux of 3.14×10^{12} Wb is obtained. We shall also assume that as the neutron star is older, it is rotating slowly, at a rate of one rotation per 30 s.

We can now use Equation 1 with our calculated magnetic flux, and time of 30 s to calculate a value for the induced EMF of 1.05×10^{11} V. In order to calculate the power generated by this EMF, we need to know the current induced, and therefore the resistance of the wire.

The resistance of the wire can be calculated from Equation 3 [6],

$$R = \rho l/A, \tag{3}$$

where ρ is the resistivity of the material used to create the wire, l is the length of the wire, and A is the cross sectional area. We assumed this was a copper wire, and therefore has a resistivity of 1.68×10^{-8} Ωm. The length of the wire can be calculated using the circumference of the loop, $l = 2\pi r$, giving 62.8 km. Finally we shall assume the radius of the wire is 1 cm, therefore its cross sectional area can be calculated from $A = \pi r^2$, giving 7.85×10^{-5} m^2. Using Equation 3 a final value for the resistance of the wire can be calculated to be 13.4 Ω.

Using $I = V/R$, and our previously calculated values for EMF and resistance, we calculated the current to be 7.81×10^9 A. Therefore using $P = IV$, we calculated the power induced by the neutron star to be 8.2×10^{20} W.

Discussion

This means that if, as shown in the film, someone was exposed to this power, they would be experiencing 8.2×10^{20} J every second, which is the equivalent of experiencing 3.4 million large nuclear explosions every second [7]. Even though the character Thor is a form of god it is within reason that this amount of energy would cause some long lasting damage.

In the film, Thor does shortly 'die' after experiencing the power of the neutron star, which makes the scene more credible than initially thought.

However, an issue with our assumptions is the fact that neutron stars have incredibly strong gravitational fields due to their extreme density, so it would be impossible to suspend a stationary ring of wire around it for any period of time, meaning that harnessing the energy of a neutron star using this Faraday method is unfeasible.

Conclusion

Therefore we conclude large amounts of energy can potentially be tapped from neutron stars, however, the very hostile conditions of the neutron star would needed to be overcome in order to access this energy. We also conclude that the events of the film "Avengers: Infinity War" are not completely out of reason, as the extreme energy released by the neutron star was enough to kill a God.

References

[1] "Astronomy: The Solar System and Beyond", M. Seeds, D. Backman, 2009

[2] https://www.space.com/22180-neutron-stars.html Accessed 05/12/2019

[3] http://hyperphysics.phy-astr.gsu.edu/hbase/electric/farlaw.html Accessed 05/12/2019

[4] https://en.wikipedia.org/wiki/Neutron_star Accessed 05/12/2019

[5] http://hyperphysics.phy-astr.gsu.edu/hbase/magnetic/fluxmg.html Accessed 05/12/2019

[6] http://hyperphysics.phy-astr.gsu.edu/hbase/electric/resis.html Accessed 05/12/2019

[7] http://nuclearweaponarchive.org/Russia/TsarBomba.html Accessed 05/12/2019