Journal of Physics Special Topics
An undergraduate physics journal

# A2 5 Localised Entirely Within Your Kitchen

E. Steele, S. Cooper, C. Hamade

*Department of Physics and Astronomy, University of Leicester, Leicester, LE1 7RH*

December 15, 2023

**Abstract**

In the Simpsons segment known as "Skinner And The Superintendent", Skinner claims the aurora borealis is localised entirely within his kitchen, which shocks the Superintendent. In this paper we found the magnetic field strength required for a magnet, placed in the middle of Skinner's kitchen, to produce an aurora with the radius of said kitchen through collisional ionisation. We find this to be $5.65 \times 10^{16}$ Tesla, a million times greater then the magnetic field produced by the strongest neutron stars [3].

## Introduction

In the Simpsons episode "22 Short Films About Springfield" there is a segment known as "Skinner And The Superintendent". In this, Skinner claims that an alarming glow is the aurora borealis (the Northern Lights), localised entirely within his kitchen. This is false; the kitchen is burning down. In this paper we aim to estimate the magnitude of the magnetic field required to create an aurora within his kitchen, using a magnet placed in the middle of the room.

## Initial conditions and Assumptions

The system involves a strong magnet in centre of the room, orientated so the field lines point upwards such that the "north pole" is at the top of the room. Charged particles oscillate in circular motion above and around the magnet due to the Lorentz force. If they have a high enough velocity, they can collisionally ionise the gas in the air, producing an aurora. Since the atmosphere is stated to be $\sim 70\%$ $N_2$ at sea level, we only focus on the ionisation of this molecule. Finally, the dimensions of the room are estimated from the TV clip to be 6 m $\times$ 6 m [1], with the aurora itself having a radius of 3 m. The assumptions made are that: the magnetic field strength is constant throughout the room; the aurora is occurring at the top of the room; the electrons are always at 90° to the magnetic field lines; the number of electrons required can be supplied with the correct velocity (by a device such as a cathode ray gun); and all effects from intense magnetic fields and accelerating charged particles are ignored.

## Theory

As stated, the force on the charged particles, in this case electrons, is given by the Lorentz force perpendicular to the magnetic field:

$$F_B = qvB \tag{1}$$

where $q$ is the charge of the particle, $v$ is the particles velocity and $B$ is the strength of the magnetic field. Assuming stable circular motion, this can then be equated to the centripetal force equation:

$$F_B = F_C, \qquad m_e v^2/R = qvB \tag{2}$$

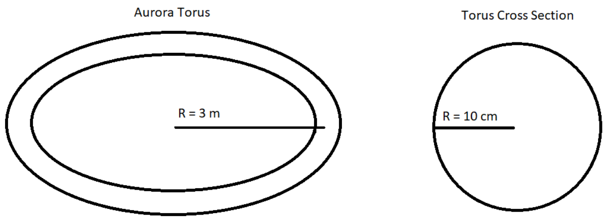


Figure 1: Diagram showing the radius of the torus (L) and its cross section (R)

where $m_e$ is the mass of an electron, $v$ is the velocity of the electron and $R$ is the radius of the electrons orbit/the auroras radius. Finally, equation two can be rearranged to get an expression for the magnetic field strength.

$$B = m_e v/qR \tag{3}$$

The velocity of the electron is derived from the kinetic energy required to collisionally ionise one $N_2$ molecule, which is assumed to be ∼15.58 eV [2], N2's minimum ionisation energy. Equation 3 only reflects the magnitude of the magnetic field for one single electron, therefore an additional $N$ term needs to be included for the total number of $N_2$ molecules that are ionised over the total circular path. This was found by first calculating the total volume of a torus, the dimensions of which are seen in figure 1. This was then multiplied by the density of $N_2$, 1.25 kg/$m^3$, to find the total mass of $N_2$ in the torus. Finally, this is then divided by the molecular mass of of one $N_2$ molecule, 28.01 u [2], where u = $1.66 \times 10^{-24}$ kg, to find $N$. Applying this to equation 3 achieves:

$$B = N m_e v/qR \tag{4}$$

## Discussion and Conclusion

The resultant magnetic field required to keep $1.27 \times 10^{22}$ electrons travelling at a velocity of $2.34 \times 10^6$ m/s to produce an aurora, is $5.65 \times 10^{16}$ Tesla. This is extremely high as only one Tesla is considered to be a very strong magnetic field; no conventional magnet would be able to produce such fields. Turning to astrophysics to find a suitable candidate for comparison, the strongest constant magnetic fields in the universe originate from compact objects called magnetars. These are neutrons stars that have extreme magnetic fields in the range of $\sim 10^9 - 10^{10}$ Tesla [3]. It is important to note that the calculations done in this investigation are crude estimations as the torus diameter constructed and the type of charged particle used is arbitrary. However we believe that these points are not important as any finer details would not change the fact that the magnetic field required is still of enormous magnitude. Therefore, we can conclude that Skinner would not be able to have an aurora localised entirely within his kitchen, if using a magnet, as he would require a magnetic field several orders of magnitude greater then that of a neutron star.

## Bibliography

[1] *Steamed hams.* (2015) Available at: `https://www.youtube.com/watch?v=4jXEuIHY9ic` (Accessed: 05/12/2023)

[2] *Nitrogen.* (2023) Available at: `https://webbook.nist.gov/cgi/cbook.cgi?ID=C7727379\&Mask=20` (Accessed: 05/12/2023)

[3] Kaspi, V.M. and Beloborodov, A.M. (2017) 'Magnetars', *Annual Review of Astronomy and Astrophysics,* 55, pp. 261-301. Available at: 10.1146/annurev-astro-081915-023329;. (Accessed: 05/12/2023)