Journal of Physics Special Topics

An undergraduate physics journal

A3_4 'Afraid of a Little Lightning?': Mjolnir's Capacitance

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October 23, 2019

Abstract

Thor's hammer, Mjolnir, appears to store the energy from lighting. By modelling Mjolnir as a parallel plate capacitor, with a hollow centre, we calculated that it has a capacitance of 2.1 $\times 10^{-11}$ F. To store the energy of one lightning bolt, an electric field of 1.6 $\times 10^{12}$ Vm^{-1} is created. This would ionise any air inside Mjolnir, and so a dielectric is needed to maintain the capacitor.

Introduction

In the Marvel Cinematic Universe, Thor, the God of Thunder, uses the hammer Mjolnir to harness the power of lightning. Thor raises Mjolnir towards a thunder storm, and lightning is drawn to it and stored, until it is later directed where Thor wishes.

Mjolnir must act as a capacitor to be able to store the lightning. After calculating the capacitance, we can work out the potential difference and electric field required for Mjolnir to store a bolt of lightning.

Theory and Results

We will say that the top and bottom faces of Mjolnir act as the plates of a parallel plate capacitor. We do not know the properties of the material that Mjolnir is made of, so we will assume that there is a vacuum in between the top and bottom plates. The capacitance is therefore;

$$C = \frac{\epsilon_0 A}{d} \tag{1}$$

where C is the capacitance, ϵ_0 is the permittivity of free space, A is the area of the plate and d is the distance between the plates. The value of ϵ_0 is known to be 8.854 $\times 10^{-12}$ Fm^{-1}.

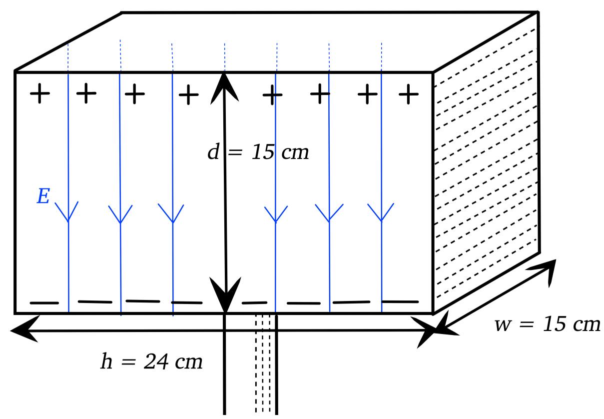

Figure 1: Mjolnir shown with its measurements, as well as the positive and negative plates, which form the capacitor. The electric field, E, is shown in blue.

We based the dimensions of Mjolnir on Thor's hammer in the Marvel Cinematic Universe. The estimated measurements are shown in Figure 1. Using equation (1) and the dimensions shown in Figure 1, we calculated the capacitance of Mjolnir to be 2.1 $\times 10^{-11}$F.

The energy stored by a capacitor is;

$$U = \frac{1}{2}CV^2 \tag{2}$$

where U is the energy and V is the potential difference between the capacitor plates. In our case, we will calculate the potential difference Mjolnir must have to be able to store the energy, U, of one lightning bolt.

We can rearrange equation (2) to equation (3).

$$V = \sqrt{\frac{2U}{C}} \tag{3}$$

The energy of a lightning bolt is simply found by;

$$U = IV_l t \tag{4}$$

where I is the current of the lightning bolt, t is the time of the event, and V_l is the potential difference of the strike. We found I to be 30 kA, V_l to be 1 GV and t to be 20 ms [1]. (1 GV was a maximum value of V given - we will use this as we are sure Thor will be able to summon the most mighty of lightning bolts). Substituting these values into equation (4) gives an energy of a lightning bolt as 6.0×10^{11} J.

Using equation (3), we find that the potential difference across the plates of Mjolnir to be 2.4×10^{11} V.

For a parallel plate capacitor;

$$E = \frac{V}{d} \tag{5}$$

where E is the electric field strength between the plates, as shown in Figure 1. Finally, using equation (5), we find that the electric field strength between the plates of Mjolnir to be 1.6×10^{12} $\mathrm{Vm^{-1}}$.

Discussion and Conclusion

The potential difference between the plates of Mjolnir required to hold a lightning bolt is 2.4×10^{11} V. For comparison, electricity in the UK is transferred at a high potential difference of up to 4.0×10^5 V [2], 6×10^5 times smaller than the potential difference across Mjolnir. In practice, it would be difficult to create a capacitor that can hold this much potential difference. We have assumed that there is a vacuum between the plates of Mjolnir, however we do not know if this is the case. We will have to ask Thor.

If there is not a vacuum inside Mjolnir, there has to be a dielectric, as air becomes ionised for electric fields greater than 3×10^6 $\mathrm{Vm^{-1}}$ [3]. The electric field strength E_d between the plates in the presence of a dielectric is,

$$E_d = \frac{E}{\kappa} \tag{6}$$

where κ is known as the dielectric constant. If we set $E_d = 3 \times 10^6$ $\mathrm{Vm^{-1}}$, and $E = 1.6 \times 10^{12}$ $\mathrm{Vm^{-1}}$, using equation (6) we find that that the dielectric in Mjolnir must have $\kappa = 5.3 \times 10^5$.

We do not know if there is a material on Earth with has such a high value of κ that can retain this value under the heating effects that would happen within Mjolnir.

Another strange property of Mjolnir is that it attracts lightning. In order to do this, assuming the lighting bolt has a negative charge, the charges in Mjolnir need to be free to move so that the top face can create a positive charge such that it attracts the lightning.

Mjolnir appears to have many fantastical properties. As well as being able to harness the power of lightning, Mjolnir can only be lifted by 'those deemed worthy'. This could be explored in a further article.

As the materials that make Mjolnir have such strange physical properties, we can conclude that such a hammer would be difficult for us to make here on Earth. Creating a capacitor like Mjolnir that can hold a potential difference of 2.4×10^{11} V seems improbable. However, who knows what technologies are available in the realm of Asgard.

References

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[2] N. Grid, *How Electricity is Made and Transmitted.* www.nationalgrid.com.

[3] G. M. Paul A. Tipler, *Physics for Scientists and Engineers.* New York: W. H. Freeman and Company, 2008.