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## A2 6 Flash Royale

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### Abstract

In this paper, we find the charge and voltage associated with Clash Royale's 'Electro Giant' to cause the breakdown of air and produce an electric shock from 3 m away, considering both of his conducting spheres. By modelling as point charges, we find a required charge of  $1.52 \times 10^{-3}$  C for each sphere. Using this along with the method of images for capacitance, we find a required voltage of  $1.26 \times 10^8$  V for each sphere.

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### Introduction

The 'Electro Giant' (EG) is a troop in the popular mobile game, Clash Royale. Within a 3 tile radius, his 'Zap Pack', consisting of two spherical conductors at approximately shoulder width apart, zaps any attacking troop with a flash of electricity, including those at range [1]. By considering these spheres as identical and as perfect conductors, this paper calculates the voltage  $V$  and charge  $Q$  required to produce this effect.

### Theory and Results

As it is not officially given, we assume the EG's conducting spheres have a radius  $a$  of 0.15 m and a centre-to-centre distance  $d$  of 0.5 m. If the EG is considered at the origin, with the spheres lying on the x-axis, then the spheres lie at  $(\pm \frac{d}{2}, 0)$ . As a basis of reference, we consider an arbitrary point  $b$  along the y-axis of the EG,  $(0, b)$ . With this in mind, the distance  $r$  from each sphere from this point can be written as

$$r = \sqrt{\frac{d^2}{4} + b^2}, \quad (1)$$

from Pythagorean analysis. If each sphere is approximated as a point charge, they each con-

tribute an electric field  $E$  of  $k\frac{Q}{r^2}$  at this point, where  $k$  is Coulomb's constant. With this, the vertical component from a single sphere  $E_{y1}$  along the  $\hat{y}$  vector up to this point can be written as  $E_{y1} = E \cdot \hat{y} = E\frac{b}{r}$ . Considering both charges, horizontal components cancel by symmetry [2] and thus the net electric field  $E_y$  can be written as

$$E_y = 2E_{y1} = 2k\frac{Qb}{r^3}. \quad (2)$$

If we assume a uniform air gap at standard temperature and pressure (STP), air ionises at a breakdown field  $E_b$  of  $3.0 \times 10^6$  V m<sup>-1</sup> [3]. By letting  $E_y$  equal  $E_b$ , the charge required for zapping at a point on the y-axis is

$$Q = \frac{E_b r^3}{2kb}. \quad (3)$$

If we consider  $b$  to be at maximum range (a magnitude of 3 m), then Equation (1) gives  $r = 3.01$  m. Coupling this with Equation (3), the required charge of each conducting sphere is  $Q = 1.52 \times 10^{-3}$  C.

Because the EG's conducting spheres are in close proximity with one another, we must consider the mutual capacitance caused by their

interactions with one another. In our model, spheres are assumed to be perfect conductors: both having equipotential surfaces that are electrically influenced only by each other, isolated from other external electric fields. We can then consider the equation for a system involving two conducting spheres of equal radius. The capacitance  $C$ , in units farads F, is governed by [4]

$$C = 2\pi\epsilon a \sum_{n=1}^{\infty} \frac{\sinh(\ln(D + \sqrt{D^2 - 1}))}{\sinh(n \ln(D + \sqrt{D^2 - 1}))}, \quad (4)$$

where  $D = \frac{d}{2a}$ ,  $\epsilon$  is the dielectric constant of air at STP (which is  $\approx \epsilon_0$  [5]) and  $n$  is the number of terms. This is valid for  $D > 1$ , which is true given our parameters ( $\approx 1.67$ ). The equation comes from applying the method of images. The sum component refers to the inclusion of a series of induced, imaginary ‘image’ charges, solved using boundary conditions such that conductor surfaces remain at an equipotential. This set-up is mathematically identical to a physical charge distribution whose combined potential satisfies the same boundary conditions. This can be used to find the voltage through

$$V = \frac{Q}{C}, \quad (5)$$

where  $Q$  is assumed to be constant, at the value previously calculated. Solving Equation (4) and Equation (5) computationally with our parameters, we find the values in Table 1.

Terms $n$	Capacitance F	Voltage V
1	$8.34 \times 10^{-12}$	$1.82 \times 10^8$
2	$1.08 \times 10^{-11}$	$1.40 \times 10^8$
4	$1.19 \times 10^{-11}$	$1.27 \times 10^8$
6	$1.21 \times 10^{-11}$	$1.26 \times 10^8$
8	$1.21 \times 10^{-11}$	$1.26 \times 10^8$

Table 1: Capacitance and Voltage Calculations for Increasing Series Terms

As  $C$  converges within 3 significant figures by the  $n = 8^{th}$  term, we use this as a cut-off approximation. The voltage of each conducting sphere is therefore  $1.26 \times 10^8$  V.

## Discussions and Conclusion

As can be seen in Table 1 and Figure 1, the series starts at a maximum and rapidly converges within the first few terms. This shows the total mutual capacitance of image charges is dominated by the first few images.

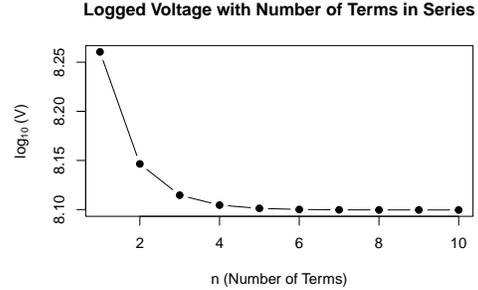


Figure 1: Logged Voltage for 10 Series Terms

There are several weaknesses in our model. First, we assume ideal conditions: uniform air at STP, ignoring factors such as temperature and humidity, which would alter  $E_b$ . We also treat the conductors as point charges to find  $Q$  and then as a spherical conductor to find  $V$ . If initially treated as a sphere, the surface charge distribution and electrostatic interactions would alter the charge needed to reach  $E_b$ . Additionally, we assume the conductors are electrically isolated. In the game, there are walls and nearby troops, some of which generate electricity [6, 7, 8]. This would distort the field such that Equation (4) cannot be applied. It is also unrealistic for the spheres to maintain charge and voltage as significant leakage and breakdown would occur at the magnitudes calculated due to surrounding air around the spheres ionising more readily. To conclude, this paper finds required charges and voltages of  $1.52 \times 10^{-3}$  C and  $1.26 \times 10^8$  V per sphere for an electric field 3 metres outward from the origin to reach electrical breakdown values, but does not capture all details of the EG’s zapping interactions; it provides an order-of-magnitude estimate under ideal conditions. Future work would improve upon this by considering environmental effects, nearby objects and a consistent model of conductors.

## References

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