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# A4_1 Gigavolt Flop

Thomas, E.M., Ward, K.E., Ballantine, K.M. and Pain, C.T.

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

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**Abstract**

With the popularity of Pokémon peaking, we carried out an investigation into the energy of Pikachu's new 'Gigavolt Havoc' attack, and its thermal effect on the ice-shelled Pokémon Sandshrew. With the assumption of a parallel plate capacitor layout, we found the energy of this attack (when fully converted to thermal energy) would melt 0.2 % (at 273 K) of Sandshrew's shell.

## Introduction

With less than two months until the release of the latest installment in the Pocket Monsters (Pokémon) franchise, we carried out a brief analysis of the game's battles from the early 2016 trailer. A new addition to the game is the 'Z move', which is a Pokémon's strongest possible attack. For the yellow mouse Pokémon Pikachu, this move is known as 'Gigavolt Havoc' [1]. The trailer showed that this attack caused damage to Sandshrew (an ice-armoured armadillo).

However, this new battling technique leaves an unanswered question: Would the energy from a gigavolt of electricity melt Sandshrew's shell?

## Theory

To answer that question, firstly we must find the width of Sandshrew's shell with Equation 1. It is assumed that the external environment is at 273 K or less (to keep the ice shell solid).

$$\rho = \frac{m}{\frac{4}{3}\pi({r_s}^3 - {r_f}^3)} \tag{1}$$

where $\rho$ is the density of ice, $m$ is the ice shell mass, and $r_s$ and $r_f$ is the radius of Sandshrew with and without shell, respectively.

Following this, 'Gigavolt Havoc' is an electric type move, within the game, and acts similarly to a discharge from one conducting surface to another, a behaviour seen in discharging parallel plate capacitors. In this set-up Pikachu acts as the negatively charged plate which transfers a gigavolt of charge to Sandshrew (which acts as the positively charged plate assuming it conducts electricity [2] and is at 0 V). To calculate the electric field between the two Pokémon, the following equation is required [3]:

$$E_o = \frac{V\kappa}{d} \tag{2}$$

where $E_o$ is the electric field between Pikachu and its opponent, $V$ is the voltage of Pikachu's attack, $\kappa$ is the dielectric constant of the air between the monsters and $d$ is the separation. The electric field between two surfaces can then be related to the potential energy of the attack [3]:

$$U = \frac{\epsilon_o \kappa E_o^2 A d}{2} \tag{3}$$

where $U$ is the potential energy of Pikachu's gigavolt attack, $\epsilon_o$ is the permittivity of space

and $A$ is the surface area of the discharge. Substituting Equation 2 into Equation 3 via the electric field $E_o$ produces Equation 4.

$$U = \frac{\epsilon_o \kappa^3 V^2 A}{2d} \tag{4}$$

If the total potential energy is converted into thermal energy, then the width of shell lost by this attack can be approximated with Equations 1 and 5 [3]. At 273 K all energy is used to change the state of Sandshrew's ice shell.

$$Q = m_i L_f \tag{5}$$

where $Q$ is the total thermal energy, $m_i$ is the mass of ice melted by this attack and $L_f$ is the latent heat of fusion of ice. By substituting Equation 1 into Equation 5 and then equating Equations 4 and 5, Equation 6 can be obtained.

$$r_m = \sqrt[3]{r_i^3 - \frac{3\epsilon_o \kappa^3 V^2 A}{8\pi d L_f \rho}} \tag{6}$$

where $r_i$ is the inital radius of the shell and $r_m$ is the shell radius after the attack. It is understood that $\Delta$r is the change in radius of Sandshrew's shell due to the attack, and so is equal to the difference between $r_i$ and $r_m$. Equation 6 is then modified to include this.

$$\Delta r = r_i - \sqrt[3]{r_i^3 - \frac{3\epsilon_o \kappa^3 V^2 A}{8\pi d L_f \rho}} \tag{7}$$

## Discussion

With the use of Equation 1, $r_f$ is found to be 330 mm (if $r_s$ is 350 mm [4], m is equal to the mass difference between the two Sandshrew varieties, 28 kg [4] and has a density of 920 kgm$^{-3}$ [3]), hence the shell width is 20 mm.

Before further calculations can occur, the electric field of this attack must exceed the dielectric strength of air (2.9 MVm$^{-1}$ $\pm$ 0.1 MVm$^{-1}$ [5]) to be successful. Separation $d$ is 30 m, as suggested by the manual [6] this is the maximum distance two trainers (gamers) can battle at. With Equation 2, the electric field was found to be 33 MVm$^{-1}$ which exceeds the requirement.

The values that each variable takes is: voltage $V$ is 1 GV, the dielectric constant $\kappa$ of air is 1.00059 [3]. The surface area $A$ is 0.1 m$^2$ (assuming the attack's area to be circular and have a radius equal to half Pikachu's height [1] [7]) lastly $L_f$ is 333.5 kJkg$^{-1}$ [3].

From Equation 7, the change in radius of Sandshrew's shell is found to be 0.03 mm.

## Conclusion

We suggest that the thermal energy of Pikachu's 'Gigavolt Havoc' can cause a minute fraction (0.2 % at 273 K) of the damage to Sandshrew's shell seen in the trailer. In further investigations, we suggest to calculate the current that enters the shell and its consequences.

## References


[1] `https://www.youtube.com/watch?v=3AZHowhxM0U` accessed on 31/09/16.

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[3] Tipler, P.A. and Mosca, G., *Physics For Scientists and Engineers*, (W. H. Freeman, New York, Sixth Edition, 2008), p. 818, 821, 819, 424 and 596.

[4] `http://bulbapedia.bulbagarden.net/wiki/Sandshrew_(Pok%C3%A9mon)` accessed on 13/09/16.

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[6] `http://www.nintendo.com/consumer/downloads/CTR_ops_eng.pdf` accessed on 15/10/16.

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