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P2 4 Sparks in the Hive: How Much Charge Can a Honeybee Carry?

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Abstract

Real honeybees carry a positive charge of about 120 pC, which is enough to attract pollen. We calculate the charge at which a honeybee would cause electrical breakdown of the surrounding air, treating the bee as an isolated conducting sphere. We find a breakdown charge of about 8 nC, roughly 70 times the natural value. We then examine the effects of such charge on foraging and on swarms. A bee carrying 8 nC would stick to a flower from about 1 cm away, and a swarm of 10,000 such bees would repel itself with a force on its outer bees of about six times their weight. We find that a swarm would disperse at about 28 times the natural charge, well before a single bee could spark.

Introduction

Flying insects can acquire electric charge through interactions between their bodies, wings and the surrounding environment. Honeybees have been reported to carry a positive charge of approximately (+120) pC, while flowers can carry a small negative charge, creating an electrostatic attraction that contributes to pollen transfer [1][5]. Electric fields may also provide information to pollinators, with research showing that bumblebees can detect weak electric fields using mechanosensory hairs. These findings establish the importance of electrostatics in pollination and raise a broader physical question: what would happen if a bee carried substantially more charge than normal?

This paper investigates the consequences of increasing a honeybee's charge using a simplified physical model. Three effects are considered. First, the electric field at the bee's surface is used to estimate the charge at which the surrounding air undergoes electrical breakdown, providing an approximate upper limit before ionisation and potential electrical discharge occur. Second, the electrostatic repulsion between bees at the edge of a swarm is estimated to determine whether collective repulsion could become disruptive before this limit is reached. Third, the attraction between a charged bee and a flower is calculated to assess how increasing charge affects the distance at which the bee is pulled towards the flower. Comparing these effects aims to identify which physical constraint becomes significant first as the charge per bee increases. The calculations provide order-of-magnitude estimates using idealised geometries rather than detailed models of real bees or swarms.

Method

We model a honeybee as a conducting sphere of radius $a = 5$ mm [2] and mass $m = 100$ mg [3]

(weight $W = 9.8 \times 10^{-4}$ N). Using Tipler [4], the electric field at the surface of a sphere carrying charge Q is

$$E = \frac{Q}{4\pi\varepsilon_0 a^2}. \tag{1}$$

Air undergoes breakdown at a field of about $E_\mathrm{b} = 3$ MV/m. Rearranging Eq. (1), the maximum charge is

$$Q_\mathrm{max} = 4\pi\varepsilon_0 a^2 E_\mathrm{b}. \tag{2}$$

We use three further results, each with q the charge on one bee.

Swarm repulsion. We treat a swarm of N bees as a uniformly charged sphere of radius R. The field at its surface is $E_\mathrm{s} = Nq/(4\pi\varepsilon_0 R^2)$, so the outward force on a bee at the surface is

$$F_\mathrm{s} = \frac{Nq^2}{4\pi\varepsilon_0 R^2}. \tag{3}$$

Attraction to a flower. We treat the flower as a conducting plane. A bee at distance d feels the force from its image charge,

$$F_\mathrm{f} = \frac{q^2}{16\pi\varepsilon_0 d^2}. \tag{4}$$

Setting $F_\mathrm{f} = W$ gives the distance within which the bee cannot escape,

$$d_\mathrm{stick} = \frac{q}{\sqrt{16\pi\varepsilon_0 mg}}. \tag{5}$$

Stored energy. The energy stored on an isolated charged bee, with potential $V = Q/(4\pi\varepsilon_0 a)$, is $U = \frac{1}{2}QV$, so

$$U = \frac{Q^2}{8\pi\varepsilon_0 a}. \tag{6}$$

Results

From Eq. (2), $Q_\mathrm{max} = 8.3$ nC, which is 70 times the natural charge. The potential of the bee is then about 15 kV, and the stored energy is about 63 μJ. That is enough to lift the bee by about 6 cm.

For the swarm we take $N = 10{,}000$ and $R = 1$ m. At 8.3 nC per bee, the surface field of the swarm is 0.75 MV/m, well below breakdown, so the swarm itself would not spark. The repulsive force on an outer bee is 6.3 mN, about 6.4 times its weight.

Since $F_\mathrm{s} \propto q^2$ and $d_\mathrm{stick} \propto q$, the swarm force grows with the square of the charge, and the sticking distance grows linearly. Setting $F_\mathrm{s} = W$ gives $k \approx 28$, so the swarm would be forced apart at about 3.3 nC per bee.

Discussion

The main finding is that electrostatic repulsion between bees would disrupt a swarm before an individual bee reached the charge required for electrical breakdown of the surrounding air. This suggests that the collective behaviour of the swarm places a greater limitation on increasing the charge of individual bees than the risk of electrical discharge.

However, these results rely on several idealised assumptions. The breakdown field varies with atmospheric conditions, including humidity, and the bee's hairs and fine structures may concentrate the electric field, causing discharge at lower charges than predicted. Similarly, treating a flower as a perfect conductor may overestimate the attractive force, while modelling the swarm as a uniformly charged sphere ignores its irregular structure and the potential neutralisation of charge by atmospheric ions. Consequently, the results should be interpreted as order-of-magnitude estimates rather than precise predictions. Nevertheless, the model indicates that swarm repulsion would become significant before an individual bee reaches its estimated breakdown limit.

Conclusion

We find a breakdown charge of about 8 nC for a honeybee, 70 times its natural charge. Below this, the physics of a swarm becomes important first. A swarm of 10,000 bees would be forced apart by electrostatic repulsion at about 28 times the natural charge. A bee at the spark limit would also stick to a flower from about 1 cm away.

References

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