Science Education Collection

Electric Fields

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Overview

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An electric field is generated by a charged object (referred to as the source charge) in the space around it, and represents the ability to exert electric force on another charged object (referred to as the test charge). Represented by a vector at any given point in the space, the electric field is the electrical force per unit test charge placed at that point (the force on an arbitrary charge would be the charge times the electric field). The electric field is fundamental to electricity and effects of charges, and it is also closely related to other important quantities such as electrical voltage.

This experiment will use electrified powders in an oil that line up with electric fields produced by charged electrodes to visualize the electric field lines. This experiment will also demonstrate how an electric field can induce charges and how charges respond to the electric field by observing the effect of a charged rod on a nearby soda can.

Principles

A charged object produces an electric field in the surrounding space. For example, according to the Gauss's law, a point charge Q located at the origin produces an electric field:

$E = \left(\frac{1}{4\pi\varepsilon\varepsilon_0}\right) Q/r^2$ **(Equation 1)**

at any point in the space with a distance r from the charge (at origin r = 0), and the direction of the electric field is along the radial direction (away from the charge if Q is positive, and towards the charge if Q is negative). A collection of charges would produce a total electric field according to the superposition principle, namely the total electric field is the vector sum of the electric fields produced by individual charges. For a uniformly charged sphere with total charge Q, the electric field produced outside the sphere is the same as the electric field (given by **Equation 1**) due to a point-like charge Q located at the center of the sphere, whereas the electric field inside the sphere would be zero.

If one follows the local direction of the electric field to trace out the vector field lines, these lines (whose tangent reflects the local direction of the electric field, and the density of the lines reflects the strength of the local electric field) are known as "electric field lines". They are fictitious lines that help visualize the distribution and direction of electric fields.

An electric field is closely related to electric potential. An electric field would produce a potential drop (or "voltage drop") along the direction of the field. Conversely, a convenient way to generate an electric field is to apply a potential difference. For example, if two different voltages are applied on two separated conductors (or a nonzero voltage applied on a conductor, while keeping another conductor "grounded" at zero voltage), then an electric field in the space between the two conductors pointing in the direction from the higher voltage conductor to the lower voltage conductor is generated.

An electric field (E) will exert a force,

$F = qE$

on a charge (q). The direction of the force is the same as the electric field for positive q, and opposite to the electric field for negative q. If a conductor (such as a metal) containing mobile charges is placed in an electric field, the electric field will push positive charges "downstream" in the direction of the electric field and pull negative charges (such as electrons) "upstream" opposite to the direction of the electric field, until the charges accumulate at the boundary (surface) of the conductor and cannot move further. This results in a separation of negative and positive charges in the conductor in an electric field, a phenomenon also known as "polarization" by the electric field. Even for insulators where charges are much less mobile than those in a conductor, a partial "polarization" (where the negative and positive charges are slightly displaced) can occur in an electric field. The electric field will try to make the displacement from the negative to the positive charges aligned with the direction of the field. If the electric field is spatially inhomogeneous such that the forces on the separated positive and negative charges do not cancel, a net force will be exerted on a polarized object.

Procedure

1. Visualize Electric Field Lines

1. Obtain an electrostatic generator (such as a handheld Static Genecon or a van der Graff generator), a pair of electrodes arranged in a concentric circle configuration, and a pair of electrodes arranged parallel to each other.
2. Obtain a Petri dish or an observation tank, fill it with oil (such as Castor oil), and add electrified/polarizable powders (such as semolina seeds) in the oil.

3. Load the electrodes with the parallel electrode configuration onto the observation tank holder. Connect the two electrodes to the "−" (ground) and "+" (charged) terminals of the electrostatic generator, respectively, as in **Figure 1**. The connection can be made by cables with clamps.

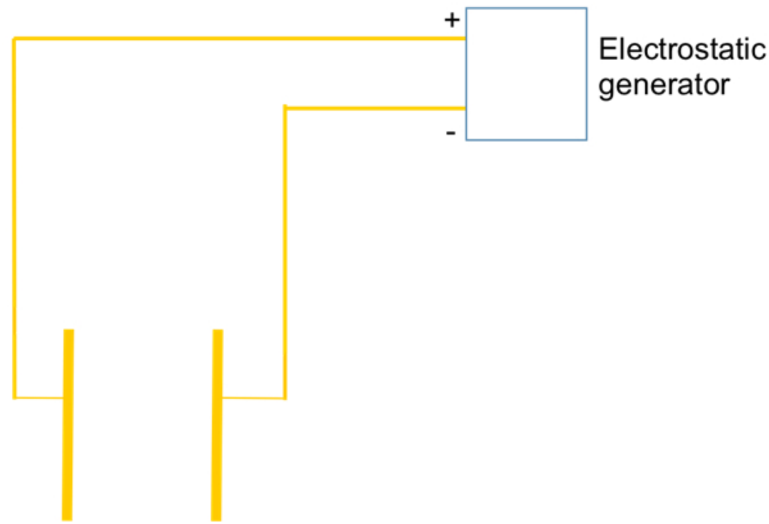

Figure 1: Diagram showing the schematics of two copper wires connected to an electric generator, the other ends (dipped into an oil) of the wires are connected to a pair of parallel electrodes.

4. Turn the crank of the generator which will put positive charges on the electrode connected to the "+" terminal. Make at least 5 full turns. Observe the behavior of the powders.
5. Use a cable to directly short the "−"and "+" terminals to neutralize the charges. Disconnect the electrode from the terminals.
6. Next, load the concentric circle electrode configuration onto the holder and connect the electrodes to the terminals of the generator again, as shown in **Figure 2**. Stir the oil in the dish to randomize the powders.

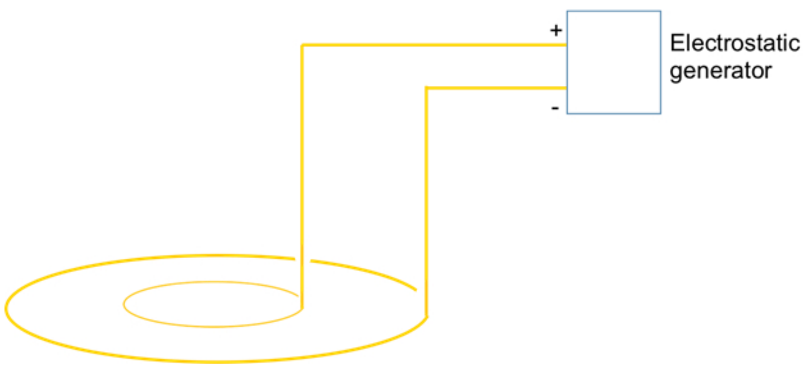

Figure 2: Diagram showing the schematics of two copper wires connected to an electric generator, the other ends (dipped into an oil) of the wires are connected to a pair of electrodes shaped as an inner ring and an outer ring respectively.

7. Crank up the generator (at least 5 turns) and charge the electrodes, and observe the behavior of the powders in the dish.

2. Effect of Electric Field

1. Obtain an empty soda can and rest it on its side (so it can roll freely) on a table
2. Obtain an acrylic rod; rub it with fur to charge it.
3. Bring the rod close to the empty soda can, and observe the response of the soda can.
4. Tear a small strip of paper and bring it to the charged rod, observe its behavior.

Results

For step 1.4, the powder will start to form line patterns between the electrodes as shown in **Figure 3**. This is because the powders are polarized and will line up with the electric field. They are also attracted toward where the field is stronger, namely closer to the positive electrode. The powders do not move appreciably because the oil is very viscous. The pattern of the powders visualizes the "electric field lines".

Figure 3: Diagram showing representative line patterns that may be formed by the powder, in the oil, aligning to the electric field produced by the charged electrodes corresponding to **Figure 1**. The line patterns reflect the electric field lines and visualize the electric field.

For step 1.7, the powder outside the center ring (made by the "+" electrode) forms a radial line pattern, as shown in **Figure 4**. This indicates that an electric field exists outside the inner ring. However, the powder inside the inner ring appears random and does not form aligned patterns. This reflects the fact that the electric field inside the ring is approximately zero.

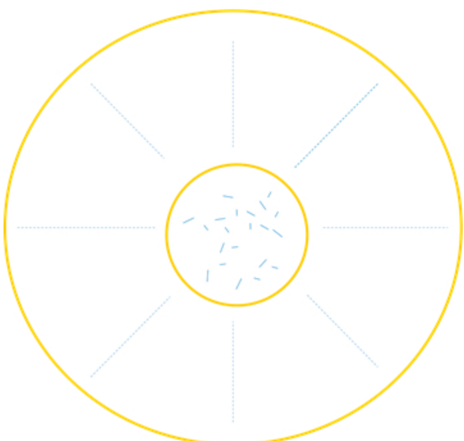

Figure 4: Diagram showing representative line patterns that form by the powder in the oil in response to the electric field produced by the charged electrodes corresponding to **Figure 2**. The line patterns reflect the electric field lines and visualize the electric field. Random distribution (lack of line patterns) of the powder inside the inner ring reflects the lack of alignment or lack of sufficient strength of electric fields there.

For steps 2.3 and 2.4, both the soda can and paper strip will be attracted by and move toward the charged rod. This is because both the soda can and paper strip will be polarized by the electric field, and the electric field is stronger closer to the rod and weaker farther away from the rod. Therefore, the charges pulled by the electric field to be closer to the rod, are pulled by a stronger force compared to those opposite charges pushed away from the rod. This produces a net attractive force toward the rod.

Applications and Summary

In this experiment, we have visualized electric fields using electrified powders in an oil that align with the electric field lines. We also demonstrated the effect of an electric field produced by a charge rod to attract polarizable objects toward the rod, *i.e.*, the source of the electric field where the electric field is stronger.

Electric fields are ubiquitous. There are electric fields whenever there are charges or voltage (electric potential) differences. Electric fields provide the force to push charges (usually electrons) to form electrical current in any circuits. Electric fields are also responsible for the sparks we see and experience in dry climate (typically in winter time). When a certain action (for example, rubbing a sweater when removing it) produces a sufficient amount of charges and thus a sufficiently strong electric field, the field can cause transient electrical conduction in air (also known as "electric breakdown", where the electric field is strong enough to not only polarize the air molecules, but to even rip off electrons from air molecules), and cause sparks.

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