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Increasing the Electric Field by Squeezing Charges

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Electrostatics is a puzzling topic. Typically, students understand quite well the concept of charges and forces between charged bodies, but when it comes to the concept of field and potential, difficulties start. Students usually first encounter electric fields as a vector property of space around a charged object. Knowing electric fields allows them to calculate the force exerted by the charged object on a test charge. Later they learn that an electric field is larger near the bodies or parts of the body where surface charge density is larger. This relation between surface charge density and electric field seems to be very abstract for many students.

A well-known Austrian physicist and great teacher, Ernest Mach, was aware of difficulties students and laymen have when trying to understand electrostatics.[1] In his book *Popular Scientific Lectures*,[2] Mach devoted one chapter to the "Fundamental Concepts of Electrostatics." The following excerpt from Mach's book talks about charges on the surface of the conducting body:

> *"We have only to give this conception free play in our minds and we shall see as in a clear picture the fluid particles, say of a positively charged conductor, receding from one another as far as they can, all making for the surface of the conductor and there seeking out the prominent parts and points until the greatest possible amount of work has been performed. On increasing the size of the surface, we see a dispersion, on decreasing its size we see a condensation of the particles."*

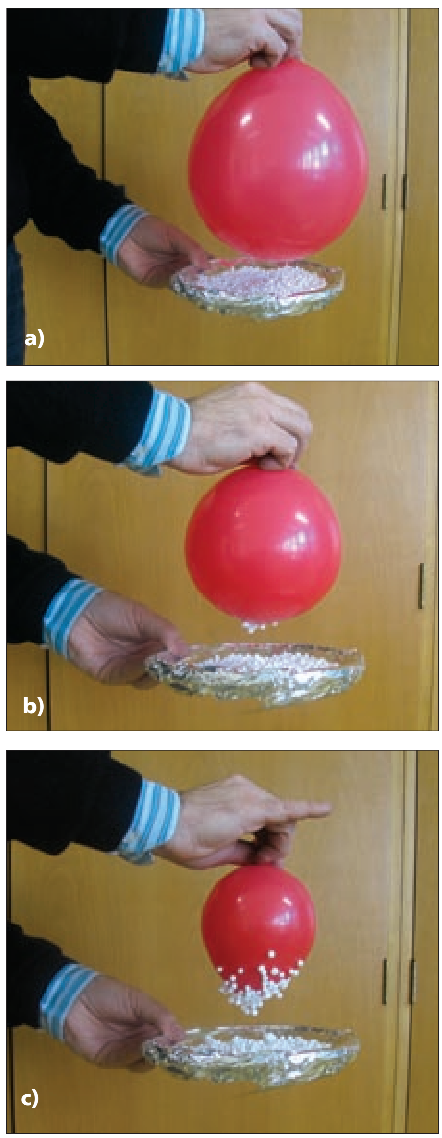

Fig. 1. As the balloon becomes smaller and smaller, the electric field at a given distance from the balloon surface increases.

This passage inspired me to design an experiment that illustrates the connection between surface charge density and electric field. Inflate a rubber balloon and keep it closed just by pressing its outlet with your fingers. Charge the balloon by rubbing it with wool or fur (I use my own hair). Place Styrofoam beads (or any other light pieces of material such as paper) on a metal plate and bring the balloon close to it but still far enough so that the particles (beads) do not start to fly off from the plate [Fig. 1(a)]. Now, slowly release the outlet of the balloon so that the balloon starts to deflate. As the balloon becomes smaller and smaller, gradually move it closer toward the plate so that the distance between the balloon and plate remains approximately constant. Suddenly you will observe

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how Styrofoam beads start to fly off the plate toward the balloon. Some will bounce from the balloon and some will stick to it [Fig. 1(b) and (c)].

What has happened? When the balloon starts to deflate, its surface starts to decrease. Since the amount of charge on the balloon does not change, the surface charge density starts to increase, and this in turn increases the electric field *at a given distance from the balloon surface.* Increased electric field causes larger forces on the Styrofoam beads, and so they fly off the plate.

Note that the electric field at a given distance from the balloon center should not change in this experiment (you may show this by using Gauss's law). As with all other experiments in electrostatics, properties of materials and air humidity can largely affect the outcome. When the balloon is almost completely deflated, you will also hear a quiet cracking caused by the discharging of the balloon in the air. This indicates that the electric field at the surface of the balloon reaches a high enough value to ionize the air. Also note that Mach was talking about conductors and here we are dealing with insulators, but this does not change the point of the demonstration.

References

1. L Mathelitsch, "Mach's popular lectures about acoustics," *Informal Learning and Public Understanding of Physics, Proceedings of the 3rd International GIREP Seminar, Ljubljana* 5-9.9.2005 (2006). Also available in electronic form at http://www.girep2005.fmf.uni-lj.si.
2. E. Mach, *Popular Scientific Lectures* (Open Court, 1986).