

Electrostatic Deformation of Liquid Surfaces by a Charged Rod and a Van de Graaff Generator

Josip Slisko, Benemérita Universidad Autónoma de Puebla, Puebla, Mexico

Rafael García-Molina, Universidad de Murcia, E-30100 Murcia, Spain

Isabel Abril, Universitat d'Alacant, E-03080 Alacant, Spain

Authors of physics textbooks frequently use the deflection of a thin, vertically falling water jet by a charged balloon,¹⁻³ comb,⁴⁻⁶ or rod⁷⁻⁹ as a visually appealing and conceptually relevant example of electrostatic attraction. Nevertheless, no attempts are made to explore whether these charged bodies could cause visible deformation of a horizontal water surface. That being so, we were quite surprised when we discovered that a 19th-century French book¹⁰ contained a drawing showing an appreciable deformation of an oil surface caused by a charged rod. When we initially tried to recreate this electrostatics demonstration, we didn't succeed in reproducing the effect with a charged rod. Despite the initial unsuccessful try, we were not discouraged and we modified the demonstration a little bit, finding that it was possible to cause visible deformations of different liquid surfaces by using a Van de Graaff generator, as we will explain later.

It is worth mentioning the latent controversy related to the proper explanation for the deflection of the water jet. For some authors the usually claimed electrical force on liquid-water permanent dipoles is due to the gradient of the electric field produced by the charged object,¹¹ while for others it is due to the electrostatic attraction between the induced electrical charge carried by the liquid leaving the faucet and the external electric field.¹² Both of these behaviors have been documented in recent research,^{13,14} but unfortunately without elucidating their role in the old simple physics demonstration.

In contrast to this straightforward popular demonstration of electric fields acting on liquids, a more sophisticated one has recently emerged where an unsupported bridge of water connects two neighboring beakers containing water at a high potential difference.¹⁵ This interesting phenomenon is the subject of further academic studies.¹⁶

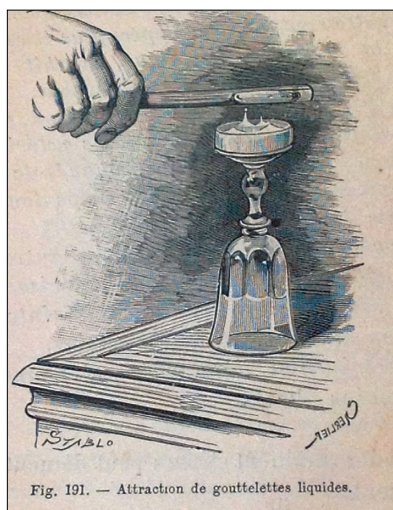


Fig. 1. Demonstration of the electrostatic attraction between a charged rod and an oil surface.¹⁰

Enigmatic drawing of oil surface deformation in a 19th-century book

Somewhere in between these two effects of electric fields on liquids lies an experimental demonstration we found in a 19th-century French book, written by science popularizer Desbeaux.¹⁰ The author writes that “instead of small light bodies, it is possible to attract drops of liquid if, for example, a rubbed body is brought near to the oil filling a small glass.” This affirmation is illustrated by a drawing of a charged rod attracting a horizontal oil surface (Fig. 1), as is usually done with paper bits. As can be seen, due to the electrostatic attraction of the rod, a few protuberances are drawn from the oil surface.

We tried to repeat the described demonstration as related in the book, but without any success. Namely, by rubbing fur with glass and ebonite rods, as is usually done in electrostatic demonstrations, we were not able to cause any visible deformation of the oil surface, even when the rod was almost touching the liquid surface. Indirect evidence of such an attraction has recently been reported for water.¹⁷ The authors observed a floating light coin moving away from a charged rod and explained that motion as due to a slight incline of the water surface.

We felt disappointed and could not figure clearly what was going on. The most plausible explanation for our initial failure was the high humidity (typically around 70%) in the city where the experiment was tried, as well as the usage of the common (glass or ebonite) rods found in a laboratory. Recently, after this paper was submitted and following the advice of the referee, we successfully reproduced the demonstration by doing the experiment on a very (and unusually) dry day using a methacrylate rod (see Fig. 2). We checked that it did not work with glass and ebonite rods even on that dry day.

Visible deformations of liquid surfaces caused by a Van de Graaff generator

In what follows, we present the results obtained after our initial failure. As we didn't want to give up, we upgraded technologically our electric field-producing tool. Instead of a rubbed rod, we used the charged dome of a Van de Graaff generator, which was leaned to be close enough to the liquid surface.

A modest quantity of vegetable oil was poured into a

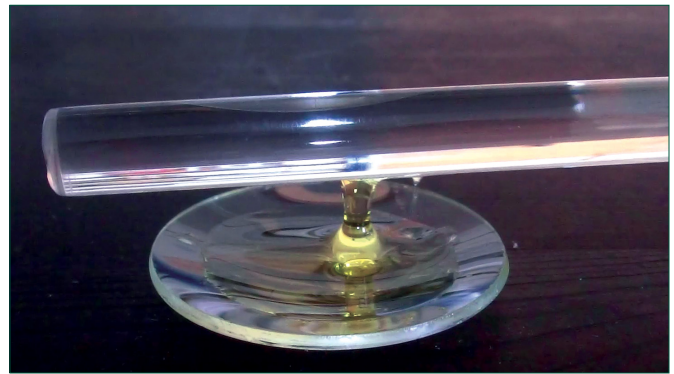
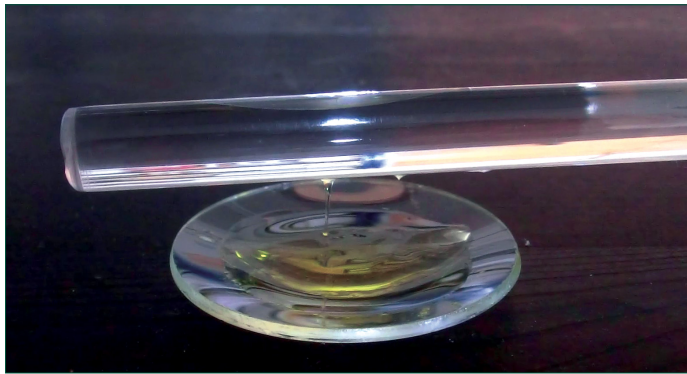


Fig. 2. Our successful second-try demonstration of the electrostatic attraction between a charged methacrylate rod and an oil surface.

watchglass (5 cm diameter) and when the charged dome of the Van de Graaff was put very near, the effect of the electrostatic attraction between the oil surface and the sphere was nicely seen (Fig. 3).

Several oil jets were formed, flowing up and down between the oil surface and the charged dome. A plausible explanation of this behavior might be the following. The liquid surface

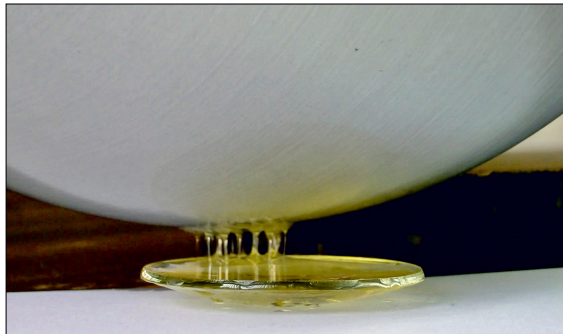


Fig. 3. Jets of oil attracted to the charged dome of a Van de Graaff generator.

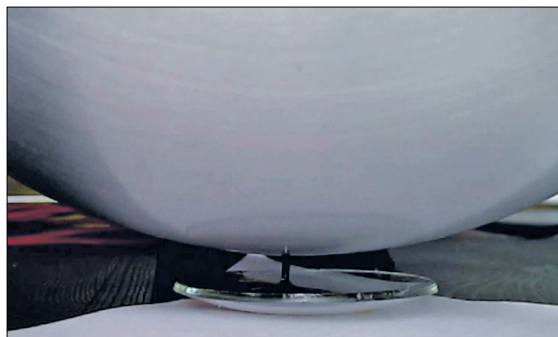


Fig. 4. Effect caused by the charged dome of a Van de Graaff generator on the petroleum surface.

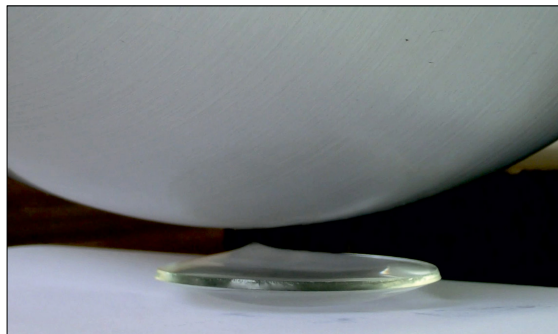


Fig. 5. Effect caused by the charged dome of a Van de Graaff generator on the water surface.

is attracted due to the induced polarization of the oil molecules in the electrically neutral liquid and the strong (and inhomogeneous) electric field produced by the Van de Graaff generator. When the liquid gets into contact with the dome, it acquires its same charge, so the jets go down immediately because of electrostatic repulsion.

If, instead of vegetable oil, petroleum or water is used, their surfaces are also attracted to the Van de Graaff dome. Whereas the former behaves (in a qualitative way) similar to the vegetable oil, the latter shows remarkably different behavior.

In contrast with the oil, from the petroleum surface only a single columnar jet flows up and down between the liquid surface and the dome (Fig. 4). In the case of the water, no jet is formed and its surface is only slightly lifted (Fig. 5).

It is almost amazing that a charged balloon is able to attract and strongly deflect a water jet, but a powerful Van de Graaff generator (a voltage source of $\sim 10^5$ V) causes only very modest lifting of the water surface.

The difficulty to lift a water surface by applying an electric field might be, in a first approximation, ascribed to the surface tension of the liquid, which produces a force that acts in the opposite direction to the liquid surface deformation. Note that at 20 °C the surface tension of water is roughly 70 mN/m,¹⁸ whereas for vegetable oil¹⁸ or petroleum¹⁹ its value is around 30 mN/m. In the case of the lateral deflection of a water jet, the liquid surface area was not increased and therefore the surface tension force was not opposing the jet's deflection.

The interaction of liquids with electric fields has been a subject of intense research in areas related to atomic force microscopy^{20,21} or aerosols,^{22,23} among others. The physics and mathematics involved in such studies are complicated, especially at the microscopic level, but lead to results similar to the ones reported in this work, such as the absence of an equilibrium shape of the liquid surface in the presence of an electric field, and the abrupt jump of the liquid when the charged body is close enough, forming a liquid connection or, metaphorically speaking, "bridges" between both surfaces.

Conclusion

Regarding many aspects, like content, organization, illustrations and the presence of formulas and numerical problems, today's physics textbooks are quite different from those

written and used in the 18th and 19th centuries. Nevertheless, in the process of “modernization,” it sometimes happens that some once-common and impressive physics demonstrations are left out and forgotten, despite being powerful resources for teaching purposes.²⁴ Now, when digital libraries²⁵⁻²⁷ make it possible for interested persons to have access to many old physics textbooks, it might be good to review carefully the demonstrations they include. Such a review might bring back some forgotten pedagogical wisdoms.

The demonstration of electrostatic attraction between a charged rod and oil surface, which inspired this article, was a little bit enigmatic because it is the only one we could find in old physics texts presenting electrostatic attraction between a charged rod and a liquid surface, but more because we initially were not able to replicate it, due to the humidity and the use of inadequate rods, as has been previously stated.

The author of the book¹⁰ either had highly chargeable sticks and experimental skills, or a strong physical intuition of what should happen in such a situation (not with water but with oil!) and which non-trivial suggestions should be given to the artists who made the drawing. Whichever was the case, that drawing was a good inspiration for starting the exploration reported in this article.

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Josip Slisko is a professor–researcher at the Benemérita Universidad Autónoma de Puebla (Mexico). His research interest is focused on physics learning and teaching. Since 1993, he has organized yearly an international workshop titled “New trends in physics teaching.” jslisko@cfm.buap.mx

Rafael García-Molina is professor of applied physics at the University of Murcia, where he teaches computational, simulation and recreational physics. He is the associate editor of *Revista Eureka sobre Enseñanza y Divulgación de las Ciencias* (<http://reuredc.uca.es>). His current research interest is in simulation for ion beam cancer therapy. rmg@um.es

Isabel Abril is a professor of applied physics at the Universitat d'Alacant, where she teaches physics to biology students. She is in charge of the Playground of Science (El Pati de la Ciència; <http://rua.ua.es/dspace/handle/10045/15064>), a project to bring science to young people. She does research in simulation for ion beam cancer therapy. ias@ua.es