Methodological Notes

LECTURE DEMONSTRATION OF PONDEROMOTIVE FORCES IN ELECTROSTATICS WITH THE AID OF A SOAP FILM

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THE idea of using soap bubbles for the demonstration of ponderomotive forces acting on the surface of a charged conductor is not new[1]. However, in realizing such a demonstration under the conditions of a large auditorium the experimenter meets a number of difficulties due to the low degree of stability of soap bubbles. It is practically impossible to communicate to a soap bubble blown at the end of a tube a sufficient electric charge to enable one to observe an increase in the diameter of the bubble. The difficulties are considerably reduced if for such a demonstration one uses a soap film consisting of a large number of spherical segments (Fig. 1). Such a film can be easily obtained in a laboratory bowl filled with a solution of soap and water by blowing through a tube lowered into the solution.

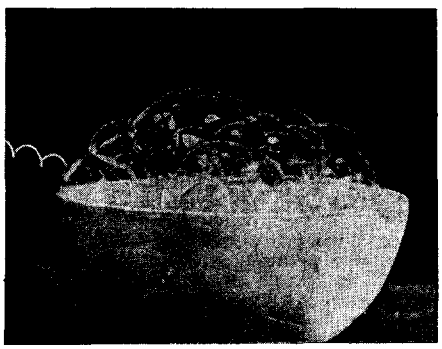

FIG. 1

For the demonstration of ponderomotive forces the bowl with the soap film is placed on a well insulated stand, for example made of ebonite or porcelain. An electrode connected to one of the poles of an electric induction machine is lowered into the bowl. The other pole of the machine is grounded. If suitable precautions are taken one can utilize instead of the induction machine some other form of voltage of the order of 10—30 kV. At a height of 10—30 cm above the bowl, or at approximately the same distance beside it, one should place grounded metallic objects having the shape, for example, of a rod, a sphere or a disc.

On turning on the induction machine the soap film is charged and under the action of the ponderomotive forces the convex portions of its surface begin to stretch noticeably in the direction of the grounded objects. An example of such stretching of a film is shown in the photograph of Fig. 2. As the charge on the film is increased further its most strongly deformed portions, which assume the shape of a point, break. The photograph of Fig. 3 shows the film an instant before it ruptures. This photograph clearly shows the "soap needlepoint" that is formed. Droplets of solution and small soap bubbles detach themselves from the needlepoint in the direction of the metallic objects and follow trajectories close to the lines of force of the electric field. Thus, it turns out to be possible at the same time to demonstrate the leakage of charge from sharp projections of a conducting body.

When the experiment is demonstrated in a large auditorium the general illumination should be switched off and the bowl containing the film should be illuminated by one laboratory lamp from above and by another from below from the side of the audience.

A quantitative interpretation of the experiment is very complicated, but it is sufficient to give a quali-

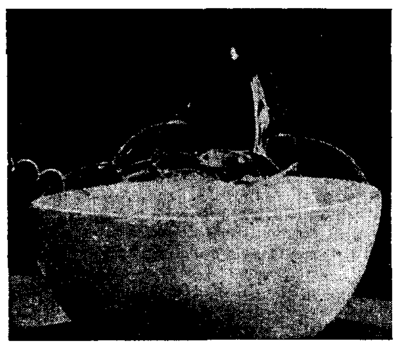

FIG. 2

FIG. 3

tative explanation of the experiment. Under the conditions of a lecture demonstration one can restrict oneself to the following explanation. The following forces act on the surface of the uncharged film: air pressure within the segment bounded by the film directed outwards; atmospheric pressure p_a and the pressure p_s due to the surface tension of the film. The pressure p_a and p_s are directed towards the interior of the segment. If the film is sufficiently thin then the force of gravity may be neglected. The enumerated pressures come into equilibrium for a given radius of the segment and this equilibrium is stable[2].

When the film is electrically charged then to the already existing pressures there is added the pressure p_e due to the ponderomotive forces which acts on the external surface of the film considered as a conductor. The pressure p_e is directed outwards and is equal to $2\pi\sigma^2$ where σ is the surface charge density. The electrostatic repulsion due to σ and, consequently, p_e is greater on the more strongly protruding parts of the film than on its other parts. Therefore, the pressure p_e is maximum in the middle portions of the external segments and these parts of the film are stretched out which leads to a further increase in the charge density σ at those points. However, as the segment is stretched out the radius of curvature R of its central portion is diminished, and this leads to an increase of the pressure $p_s = \alpha/R$ where α is the coefficient of surface tension. An increase in p_s within certain limits compensates for an increase in the pressure p_e. Therefore, the stretched-out portions of the charged film are sometimes able to retain their shape for fairly long periods of time before they are ruptured.

If the auditorium has a source of compressed air it is easily possible to show the following variation of this demonstration which can be described as the "bombardment" of a metallic sphere by soap bubbles.

A glass tube is provided with a paper tip on which are wound several turns of copper wire. The wire is connected to the grounded pole of the induction machine. A metal sphere (or disc) placed on an insulating stand is connected to the ungrounded pole of the machine. The glass tube is inserted into a rubber tube connected to the source of compressed air. Then the paper tip on the glass tube is lowered into the soap solution and a weak stream of air is admitted into the tube. As the open end of the horizontally held tube is brought near to the sphere soap bubbles are expelled from the tube and projected towards the sphere. Sufficiently large bubbles are appreciably deformed under the action of the ponderomotive forces as they approach the sphere. The size of the soap bubbles can be easily controlled by varying the rate of flow of air from the tube and the distance between the tube and the sphere.

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[1] I. E. Tamm, Osnovy teorii élektrichestva (Fundamentals of the Theory of Electricity) Moscow, Gostekhizdat, 1954.

[2] Strelkov, Él'tsin, and Yakovlev, Sbornik zadach po obshchemu kursu fiziki (Collection of Problems for a General Course in Physics), 2nd edition, Part 1, explanation of problem 475, Moscow, Fizmatgiz, 1960.

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