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Observation of Electroconductive Convection in Electrolytes

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Several series of experiments of a qualitative character were carried out to clarify spontaneous movement in distilled water, the electroconductivity of which in some places is increased by the addition of a dyed electrolyte. The experiments substantiated the assumed properties of the phenomenon, in particular, it was possible to produce a model of the phenomenon of corona discharge from a point. Fluctuating characteristics were noted.

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1. INTRODUCTION

PREVIOUSLY[1] it was shown theoretically that there exists the possibility of the appearance of spontaneous motion in a moving medium in an electric field under the condition that the medium is heterogeneous with respect to specific resistance or conductivity. This possibility is dependent on the appearance in the medium of the volume force

$$\frac{\mathbf{D}}{4\pi}(\mathbf{E}\,\nabla \ln \rho),$$

directed along the line of the electric induction (compare reference 2). Here **E** denotes the strength of the electric field at a given point of the medium, **D** is the vector of electric induction and ρ is the specific resistance.

If this force is substituted into the hydrodynamic equation of Navier-Stokes, then one could conclude the following. During slow motions of the medium, when

$$\gamma\frac{v^2}{l} < \mu\frac{v}{l^2}, \qquad \text{i.e.} \quad \mathrm{Re} \equiv \frac{vl\gamma}{\mu} < 1,$$

the velocity of motion v can be evaluated thus:

$$\mu\frac{v}{l^2} \approx \frac{\varepsilon}{4\pi}\frac{E^2}{\rho}\frac{\Delta\rho}{l}$$

or

$$v \approx \frac{1}{4\pi}\frac{\varepsilon}{\mu}\,l\Delta\rho P.$$

Here the general constants are collected in the first factor; in the second factor the constants characterizing the properties of the medium: the dielectric constant ϵ and the dynamic viscosity μ; the third factor characterizes the flow: its linear dimensions l and the difference in the specific resistances $\Delta\rho$; the fourth factor gives the specific force produced by the electric current per unit volume of the medium $P \equiv E^2/\rho$; γ denotes the mechanical density of the medium. As is evident, the velocity of such a movement is proportional to the force, to the difference in the specific resistances encountered in the medium, and also to its dielectric constant.

For fast movements (Re > 1) we obtain

$$\gamma\frac{v^2}{l} \approx \frac{\varepsilon}{4\pi}\frac{E^2}{\rho}\frac{\Delta\rho}{l}$$

or

$$v^2 \approx \frac{1}{4\pi}\frac{\varepsilon}{\gamma}\,\Delta\rho P.$$

It is evident that in this case the square of the velocity is proportional to the force and to the difference in the specific resistances.

Thus for the observation of electroconductive convection it is necessary to select a medium with a fairly high specific resistance, otherwise the force produced will mask the phenomenon with thermal effects. The direction of the current does not play any part.

2. APPARATUS

For the observation of electroconductive convection an apparatus was used which is shown schematically in Fig. 1. The bent glass tube, having a diameter of 5/7 mm and extending into a capillary, connects two vessels. Of these the vessel A, with dimensions of $50 \times 50 \times 25$ mm, is filled with distilled water and contains two electrodes: + and −. The vessel B contains a solution of potassium permanganate, the concentration of which is such that even in the capillary it appears opaque. The vessel B can be moved in a vertical direction by means of a micrometer screw, so that the solution in vessel B can be established at a level considerably higher than the level of the water in vessel A. By this method it

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[1] G. A. Ostroumov, Zh. Tekh. Fiz. **24**, 1915 (1954).

[2] J. A. Stratton, *Electromagnetic Theory*, p. 222, problem 31.

is possible to regulate the force of the jet of the solution flowing out from vessel *B* through the capillary into vessel *A*. A mirror photographic apparatus records on film the picture observed through a light filter.

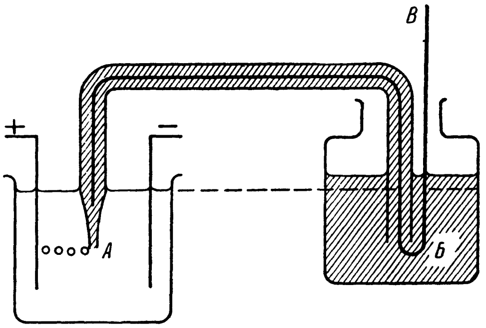

FIG. 1. Schematic diagram of the apparatus.

3. FIRST SERIES OF EXPERIMENTS

One would expect [3] that the anions would be pulled out from the flowing out jet by the force of the electric field, so that we would see in the water a pinkish band directed towards the anode, as is indicated in Fig. 1 by a dotted line (compare reference 4). One would also expect to see a similar colorless jet of potassium cations in the direction of the cathode. But thus far we have not succeeded in obtaining such an effect in pure water, irrespective of how the force of the efflux jet and the electrode voltage were regulated. On the contrary, it was always necessary to deal with an electroconductive effect which can be described as follows. When the jet of the solution flows out into the water in the absence of a field, it appears as a thin, somewhat velvety, pile-like, cylindrical rod, with a characteristic cup-like figure at its end in the initial stages. Later this figure submerges to the bottom, and the jet flows over the bottom in a uniform layer. In the presence of an electric field, the jet flattens out fan-like along the lines of force in the field. The outside contour of this fan forms a fairly well-defined curve, resembling an exponential curve. The fan spreads out symmetrically in the directions of both electrodes, and its form is independent of the direction (sign) of the field. In addition, by applying to the electrodes an alternating field of commercial frequency, one can observe exactly the same stages and forms of the jet as at a d-c voltage of either direction.

FIG. 2. Breaks in the jet of the electrolyte in an electric field of moderate intensity; electrodes on the right and on the left. Scale 2:1.

When the intensity of the jet is low, then the fan-like, flattened out jet reduces to zero at its lower section and is lost in the water. With the strengthening of the jet the intensity of its coloration is increased at all heights, so that the behavior of the lower section of the flattened out jet is clearly visible. At the same time it becomes apparent that the degree of flattening of the jet decreases; it now deviates more slowly from the cylindrical form. The velocity of its submergence increases.

With an increase in the applied voltage the degree of deviation of the jet from the cylindrical form increases: the jet broadens, undergoing a number of characteristic changes. The successive stages of these changes are shown in the photographs 2-5. With an increase in voltage it is as though a jet of average intensity breaks up in a few places at first (Fig. 2). Upon an increase in the voltage, the number and intensity of the breaks increases; moreover, threadlike whiskers branch out towards the electrodes from each bend (Fig. 3). Upon a further increase in the voltage, the velocity of the movement of sections of the jet towards the opposite electrodes increases; this produces a turbulence in the liquid at a sufficient intensity of the jet (Fig. 4). A weak jet at sufficiently high voltages splits up into two threads directed

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[3] V. G. Levich, *Physico-chemical Hydrodynamics*, Acad. Sciences Publishing House, 1952, p. 191.

[4] K. A. Putilov, *Course of Physics*, Uchpedgiz, 1937, p. 495, Fig. 426.

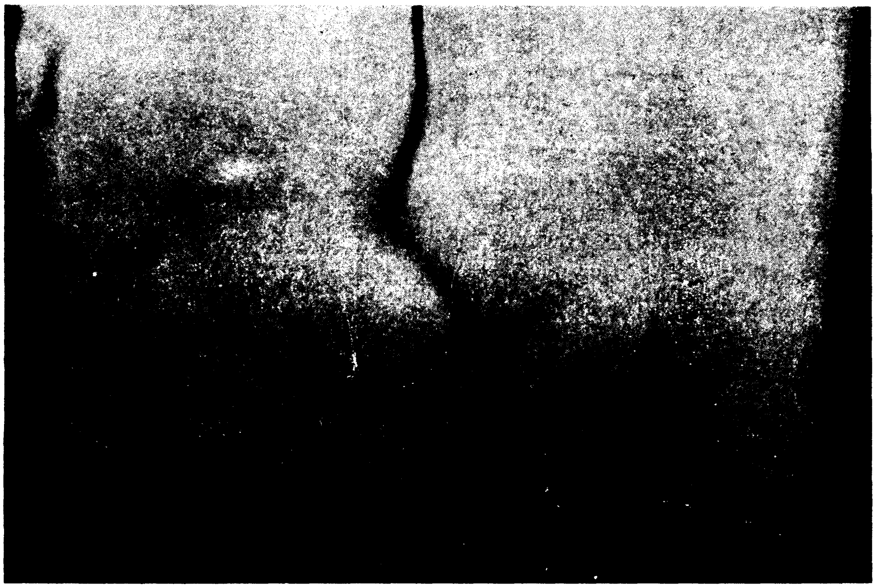

FIG. 3. Breaks in the jet in a strong electric field. Scale 2:1.

FIG. 4. Turbulent electroconductive convection. Scale 2:1.

towards the opposite electrodes (Fig. 5). Sometimes there are observed ripples or folds in the body of the flattened out jet. This appears in the lower and the peripheral sections of the flattened out jet and often spreads out over almost the entire area.

It is essential to carry out the experiments each time using fresh distilled water. If the water is contaminated by the electrolyte of the previous experiment, or if we use tap water instead of distilled water, the experiment is greatly complicated, with a decrease in its reproducibility and, as one would expect, production of parasitic thermal effects.

Thus, the concentrated sections of the solution in a medium of high resistance are in reality attracted to the electrodes, following the force lines of the electric field. Such an attraction produces

FIG. 5. Splitting of the jet in a very strong electric field., Scale 2:1.

hydrodynamic phenomena in the surrounding medium. These experiments demonstrate that electroconductive convection is possible and that it can be easily realized by mixing electrolytes with distilled water.

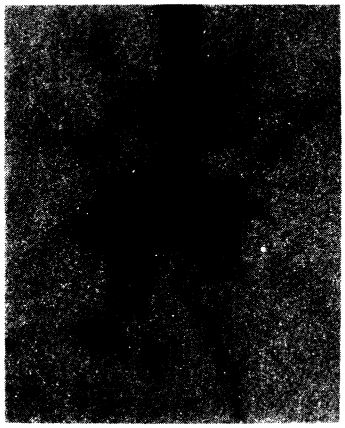

FIG. 6. Electroconductive convection at the outlet of the capillary; one electrode inside the capillary, the other at the right and at the left. Scale 4:1.

4. SECOND SERIES OF EXPERIMENTS

In other cases in which a similar situation is produced, for example, in non-uniformly ionized gases, this type of convection is also possible. To explain the character of the phenomenon under conditions resembling the conditions of point corona discharge, a second series of experiments was carried out. Both electrodes (the + and –) in the vessel *A* were joined together, forming one electrode. The second electrode was represented by the copper wire *B* (Fig. 1), introduced into the capillary through the wider section of the tube. Thus, within the weakly electroconductive distilled water the potassium permanganate solution produces a hydrodynamically movable electrode of high conductivity. As in the previous apparatus, we were unable to detect any phenomena of the dissociation of the anions of the permanganic acid and of the cations of the potassium. But the phenomenon of electroconductive convection revealed itself in a new light.

In the presence of an electric field a turbulence is produced in the outlet opening of the capillary. A great/number of rays, replacing each other, emerge vigorously in various directions from the solution, and it appears as though the end of the capillary is boiling (Fig. 6).

Similar experiments showed that neither a drop nor a jet of an electroconductive solution in distilled water appeared at the flat electrodes. The haphazard and chaotic character of the deformations of such electrodes, obtained in the presence of an electric field, as well as the visible velvetiness or "pile-like appearance" of the jet of the solution which flows out into the water necessitates a more thorough investigation of the actual state of conditions.

5. THIRD SERIES OF EXPERIMENTS

A small quantity of mercury was poured into a high prismatic vessel with dimensions of 30 × 30 × 90 mm so arranged as to produce a strictly horizontal bottom, which served as the lower electrode. The end of a wire, which was insulated along the rest of its extension was submerged in the mercury. Distilled water was poured into the vessel up to the top, and just under its upper surface a second flat electrode was located, which served as the upper electrode. Several crystals of potassium permanganate were placed carefully on the surface of the mercury. After 3-4 hours the crystals dissolved, forming a layer of concentrated dyed solution on the surface of the mercury with a thickness of 10-15 mm. Above this was pure water. We thus obtained a flat condenser with an imperfect double-layer dielectric.

A careful examination of the solution layer showed that it did not possess any regular laminations. The surface of the solution appeared velvety or pile-like. This property should be assigned to two factors: first to the fluctuations in the density of the solution, and second to the presence of an absorption band in the visible region of the spectrum. The combined effect of these two

FIG. 7. Electroconductive convection in the body of a movable imperfect double-layer dielectric between the horizontal plates of a flat condenser. Scale 5:2.

factors provides the conditions for the sharp distortion of the coherence of the visible light rays and gives the surface of the solution a characteristic rough appearance.

One would expect that having set up a voltage between the electrodes we could amplify the lifting force which is produced on the movable electrode in the almost nonconducting water by the layer of the concentrated solution. The resulting hydrodynamic instability would lead to the condition that this solution would begin to be attracted to the upper electrode, moving along one side of the vessel; to replace it pure water would descend in an anti-symmetric convection flow along the other side of the vessel. Numerous experiments did not even once substantiate these expectations. In reality it was found that the applied voltage of the order of 200 v pulls out only individual thin threads from the surface of the solution. These threads are located at random, and are often far from vertical (Fig. 7). The development of these thread-like rays causes the solution to mix with the water, and when its concentration in the vessel approaches a certain (not very high) value (hardly noticeable pink coloring), the phenomenon ceases.

Thus, the results of the second and third series of experiments showed that the microscopic hydrodynamic process under conditions of electroconductive convection may be strongly dependent on the specific molecular conditions, in particular, on the fluctuations in the electroconductivity, determined by the fluctuations in the concentration (during the diffusion of the solution). The experiments on the whole qualitatively substantiated the theoretically predicted properties of electro - conductive convection.

Translated by E. Rabkin
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