1. Study on Surface Electricity.(XV)[1]

On Counter U-effect

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We have related in the preceding papers[2] on U-effect, which was a phenomenon converting mechanical energy of vibration into electrical one by the interfacial electrical double layers. As this convertor can be considered to be a sort of four terminal networks consisting of electrical, acoustical and electro-acoustical mutual impedances,[3] we can make an electro-acoustical transducer when we interchange the input and output terminals one another.

As has been already related before,[2] U-effect can be classified in two classes, and the one, called "U-effect I", occurs by the disturbance of the electrical double layer at glass-dil. solution interfaces, and the other, called "U-effect II", of the mercury-solution interfaces. Although they resemble each other in point of the use of interfacial electrical double layers, their mechanisms and the concrete shapes of the conversion systems are different. Hence, we shall here relate on them in separate chapters.

1. Counter U-effect I

A glass filter of high porosity is dipped in a beaker filled with distilled water. When an alternating current is fed from two brass net electrodes on both sides of the glass filter (Fig.1), the last mentioned vibrates with the same frequency as the original a.c. source and produces sound. This effect is due, of course, to the mechanical work done by the equivalent condensers of the electrical double layers at glass-water interfaces, and is the result of the so-called "electro-osmosis" (or rather "electro-phoresis")[4] occurring in case of an alternating current. This is demonstrated by the following facts: (1) It does not take place without the glass filter. (2) The finer the glass filter is, the larger the intensity of sound is, because the effective impedance of the interfacial capacitance and so the conversion efficiency increases. (4) Addition of a small amount of sulphuric acid (or any electrolytes) into the water reduces the resistance of the system and the sound disappears.

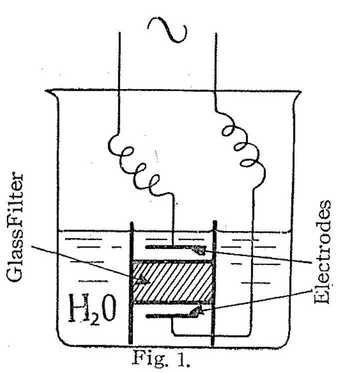

Fig. 1.

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We can observe this effect at the frequency of the applied a. c. from 60 cps. to the upper limit of audio-frequency with the glass filter of No.4.

Now, considering the equivalent circuit of the capillary in the glass filter to be as shown in Fig.2, it is obvious that the effective power which can be converted is only a few part of the whole input power. Hence, it cannot give good practical applications, like the generator of a supersonic wave or the speaker *etc.*, from the point of conversion efficiency, though it attracts our theoretical interests.

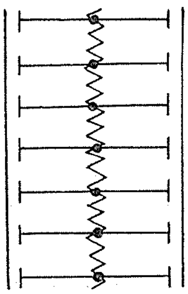

Fig. 1.

With all the defects, it can be used as a convertor when we device the good matching of the mechanical impedance. In fact, when we connect the electrodes to the output terminals of a radio receiving set and attach a speaker cone to the glass filter, considerable acoustical output can be obtained and music or speech can be clearly understood.

2. Counter U-effect II

When we feed to an element (E) an alternating voltage V supplied from a valve oscillator (Osc) (Fig.3), the element vibrates with the same frequency as

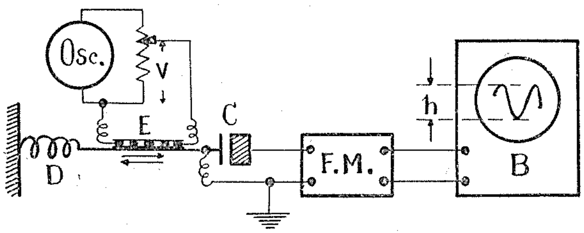

Fig. 3.

the source V. This we call "Counter U-effect II". The amplitude of mechanical vibration of the element is observed by a frequency modulation system (FM) and a cathode ray oscilloscope (B), the details of which were described in the preceding paper.[5] The outline of this device is as follows. The periodical capacity change of a condenser C produced by the vibration of the element modulates the high frequency of an oscillator set in FM, and this frequency change is converted into a voltage change by a detector also set in FM. This voltage regenerates on the screen of the oscilloscope. Accordingly, the height of the oscillographic wave h is a measure of the efficiency of the effect. Damper (D) in the figure represents the sum of the damping effects, in which are included those of the rubber cement at the piston electrode of the element *etc.* In our experiment the static stiffness of the damper was as high as 2,000 [gw/cm.].

The experimental procedure is as follows. The piston electrode of an element, whose diameter is about 0.375 cm. and inner impedance $45K\Omega$ (at 600cps.), containing 18 mercury- N.HCI aq. interfaces, is fixed and the capillary wall is made movable (Fig.3). Investigation of the amplitude of vibration at several frequencies of input alternating voltage produced by counter U-effect II gave maximum at $500\sim600$ cps. This natural frequency was dependent on the stiffness of the vibrating system. As it was in this region of frequencies that the observation was capable, we took the amplitude-input relation at 600 cps., which showed saturating tendency (Fig.4). This property is due to the over-damping in our apparatus.

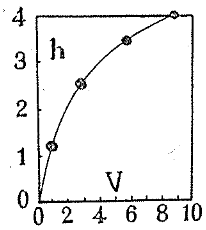

Fig. 4.

As is easily shown, our phenomenon is no more than a case of the capillary electrometer applied to the alternating current. That is, as the interfacial tension between mercury and solution is a function of the polarizing potential, when the last mentioned changes periodically, the tension also changes periodically with it. This change of tension induces the change of the position of the interface, generating a mechanical vibration of the element in case of alternating potential change.

This interface is a sort of electrodes,[6] which permit considerably high cathodic polarizing potential (ca.2V), owing to the high hydrogen overpotential of mercury, while at anodic polarization as small as ca. 0.5V, the dissolution of mercury contaminates the interface. Hence, the permissible alternating potential is limited within this value. In our experiment of 18 interfaces in series, we perceived the production of bubbles in solution phase at a.c. voltage of 20V.

Although this permissible range of potential can be widened by increasing the number of interfaces, this induces the linear increase in the inner impedance of the element, composed of the (capacitive) impedance of interfaces and the solution resistance. So, the power which can be fed to the element is limited by this impedance. In addition, the increase of the interfaces induces the stiffness of the piston, which is a cause of energy loss in this system.

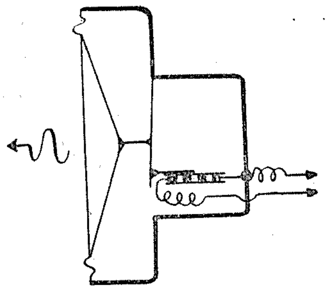
Fig. 5.

The interest in this phenomenon lies in the following fact rather than in its practical applications. Almost all of the studies on the electrode phenomena of mercury in the past have based on the assumption that the application of an alternating current did not induce the change of the shape of the electrode.

However, as is shown in this experiment, the perturbation due to this effect may induce secondary effect of an impedance change at interfaces or of a back electromotive forces, which may influence on the amplitude and phase factors of the applied alter- nating potential.

One of the most handy application of thish penomenon is the speaker of the radio-receiving set. Its schematical diagram is shown in Fig.5. In our experiment, the diameter of the cone was 5 inches and this speaker was connected to a home radio receiving set. Wecan perceive the broadcasting, discriminating music and speech. The efficiency was not better than in case of counter U-effect I.

Summary

When we interchange the input and output terminals of U-effect each other, we can make an electro-acoustic transducer. Though we can make it in both cases of U-effect I and II, the efficiency of conversion is very small in both cases, and it attracts our attention in theoretical sense only. We must notice that counter effect may perturb the liquid electrode phenomenon (e.g. in Hg).

The authors have a pleasure of confessing their gratitude to prof. I. Tachi for his continued interest and encouragement.

References

(1) Read before the Semi-Annual Meeting of this Institute, held June 7, 1952.
(2) S. Ueda, A. Watanabe and F. Tsuji, *This Bulletin*, **30**, 15 (1952). See also the reference 2) in the same article.
(3) For instance K. Kobayashi, "Electro-acoustics." (in Japanese) Kyoritsu-sha, p. 355 (1950).
(4) For instance, Abramson, "Electrokinetic Phenomena."
(5) S. Ueda, A. Watanabe and F. Tsuji, *This Bulletin*, **28**, 47 (1952) ; K. Maeda and T. Hayashi, "Frequency Modulation," (in Japanese), Shukyo-sha, p. 354 (1946).
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