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Further Investigations on Displacement Potentials

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By the aid of a vibrating reed electrometer it is shown that displacement potentials of the order of 100—150 mV can be generated when very high molecular hyaluronate is used. The phenomenon exhibits effects of fatigue and hysteresis.

It was shown by Jensen, Koefoed and Vilstrup [1] that if a solution of high molecular hyaluronate is displaced in a glass capillary an electric potential is generated which is characterized by the fact that the potential difference persists as long as the solution is strained. The same phenomenon was observed with regard to genuine endolymph from the piked dogfish *(Acanthias vulgaris)*, and Vilstrup, Jensen and Koefoed [2] suggested that these potentials might be of the greatest importance for the function of the labyrinth. Very recently also Dohlman [3] has accepted the conclusion that the transformation of mechanical movements to electrical charges is what we have reason to believe to be the fundamental potential, influencing the generation of excitatory reactions in the nerve endings at the crista. The presence of acid mucopolysaccharides in the gelatinous substance in the internal ear (Jensen and Vilstrup [4], Dohlman, Ormerod and Mc Lay [5], and Poulsen [6]) suggests reversible electrical changes due to displacement potentials which might be collected by the hairs, acting as electro-sounds for the hair cells of the sound-perceiving organs of the inner ear (suggested in an oral discussion, 1955, by J. A. Christiansen).

In the first published experiments the electrical effect seemed to be relatively small, varying from fractions of mV to a few mV, but recently it was found (Jensen, Christiansen and Vilstrup [7]) that the potentials resulting from displacements of very high molecular polyelectrolytes in a glass capillary and measured potentiometrically amounted to about 100 mV.

In the present work this observation has been confirmed by using a vibration reed electrometer, and further it is shown that the relation between displacement and potential can be described by hysteresis loops, and that the phenomenon exhibits an effect of fatigue.

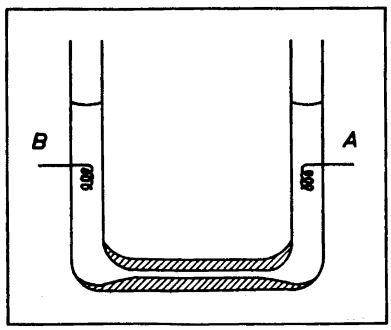

Fig. 1. U-Tube in which palladium electrodes are inserted.

MATERIALS

The sample of alginate used was a commercial preparation ("Protanal HF", manufactured and kindly supplied to us by A/S Protan, Drammen, Norway). The number average molecular weight was determined to be about 1×10^5 after the osmotic method of Christiansen and Jensen [8]. By fractional precipitation with alcohol we obtained a sample with a molecular weight of about 2×10^5.

The sample of potassium hyaluronate employed was prepared from human umbilical cords according to Jensen [9]. The molecular weight of hyaluronate obtained by this method is about 5×10^5 (determined at a concentration of 1 %). By adding alcohol to an 0.1 % aqueous solution of this precipitation until the solution was about 35 % in respect of alcohol we obtained a preparation which had a molecular weight greater than 1.5×10^6 as judged from osmotic measurements. In all experiments care was taken to avoid bacterial contamination. All measurements of the potentials were performed at room temperature.

EXPERIMENTS AND RESULTS

The employed glass apparatus with palladium electrodes is shown in Fig. 1. The deflection of a highly sensitive galvanometer (aperiodically damped; resistance 455 ohms) connected to the electrodes indicated their potential difference.

With distilled water in the apparatus no significant potentials were observed. However, when a 0.05 % solution of alginate was introduced into the apparatus through the branch called A in Fig. 1 the electrode in branch B became positive. The magnitude of the potential difference (called V_0 below) depended upon the concentration of the solute, the method of filling and the dimensions of the apparatus.

Taking V_0 as a zero point, displacement of the solution towards A rendered this branch negative relative to B as long as the solution was moving, but positive when the solution came at rest. By displacing the solution towards B the temporary as well as the final potential differences changed their signs. Repeating of this procedure decreased the potential differences (effect of fatigue, shown in Fig. 2). After some days, however, the effect regenerated.

The potentials appeared to be a function not only of the actual displacement. They were also influenced by the magnitude and direction of former

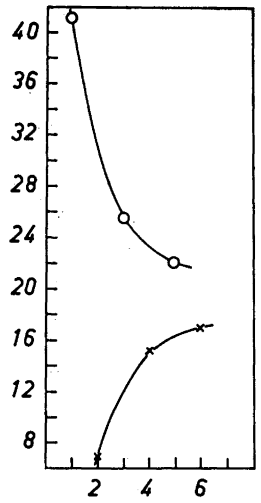

Fig. 2. Curves showing the phenomenon of fatigue. Ordinates: Arbitrary galvanometer readings. Abscissae: Sequence of displacements. Circles represent the potentials following displacements to the right, crosses to the left.

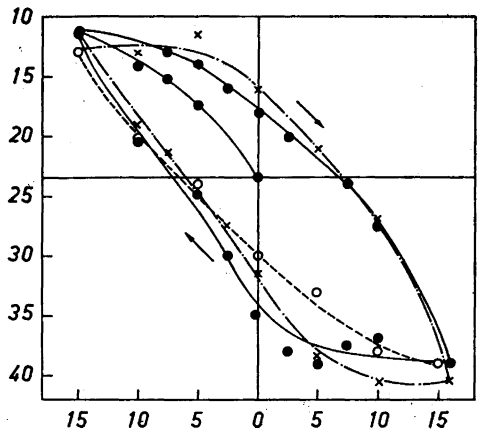

Fig. 3. Hysteresis loops. Ordinates: Arbitrary galvanometer readings. Abscissae: Displacements in mm to the right and to the left.

displacements (hysteresis, shown in Fig. 3). Increased potentials were observed upon insertion of thin glass rods in the capillary tube.

By recent application of a vibrating reed electrometer the electric current through the apparatus became negligible. Under these circumstances values of V_0 up to 140 mV were registered after filling the apparatus with a 0.25 % solution of hyaluronate. Furthermore potentials of the order of 10 mV occurred as a result of displacements of the order of 1 cm. V_0 was not quite constant in time, but generally the drift was less than 20 % during several days.

DISCUSSION

The experiments reported here show that under laboratory conditions the displacement potential may exceed 100 mV, and although such high voltages may not be present in the sensulae of the inner ear, an even much smaller voltage may be considered sufficient for adequate stimulation of the hair cells, *i. e.* for the modulation of the spontaneous cell action.

As shown above the displacement potential displays the phenomenon of fatigue; in this connection it may be mentioned that the phenomenon of fatigue is also well-known in the labyrinth.

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REFERENCES

1. Jensen, C. E., Koefoed, J. and Vilstrup, Th. *Nature* **174** (1954) 1101.
2. Vilstrup, Th., Jensen, C. E. and Koefoed, J. *Ann. Otol. Rhinol. Laryngol.* **64** (1955) 406.
3. Dohlman, G. *J. Laryngol. Otol.* **73** (1959) 154.
4. Jensen, C. E. and Vilstrup, Th. *Acta Oto-laryngol. In press.*
5. Dohlman, G., Ormerod, F. C. and Mc Lay, K. *Acta Oto-laryngol.* **50** (1959) 243.
6. Poulsen, H. *Myxoedematøse bindevævsforandringers indflydelse på labyrinthens funktion.* (With a summary in English). Munksgaard, Copenhagen 1959.
7. Jensen, C. E., Christiansen, J. A. and Vilstrup, Th. *Symposium über Makromoleküle in Wiesbaden 1959.*
8. Christiansen, J. A. and Jensen, C. E. *Acta Chem. Scand.* **7** (1953) 1247.
9. Jensen, C. E. *Acta Chem. Scand.* **7** (1953) 603.

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