The Electrical Resistance of the Tarsal Chemosensory Hair of the Butterfly, *Vanessa indica*[1)]

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(*With 2 Text-figures*)

We reported in the preceding paper (Morita *et al.* 1957) on the electrophysiological method of studying the single contact chemosensory hairs of insects. This method is surprisingly similar to that of Hodgson *et al.* (1955), but there is a difference in the input stage of picking up electrical activities of the hair. While no grid leak was used in the latter, a grid of the input stage was grounded through a resistance as high as 50 meg ohms in the former. Thus, in this case, an indifferent electrode could be grounded through a pulse generator of low resistance and the amplitude of impulse generated in the hair could be calibrated. This enabled us, also, to recognize the characteristic variation of the electrical resistance of the hair according to the difference in solutions applied. In the present work the resistance of the chemosensory hair was analysed systematically and some possibility of sucrose to excite the sensory nerve was suggested.

Material and methods

The larvae of *Vanessa indica* collected in the autumn were cultivated in the laboratory and used for experiments at the adult stage in December of the same year. The leg was cut from the body at the base of the tarsus aud prepared for the experiment and a test solution was applied in quite the same manner as in the preceding paper (Morita *et al.* 1957).

Fig. 1 shows the principle of measurement of a resistance. The potential difference between B and C is amplified and led to a cathod-ray oscilloscope. Then, the potential drop (e) between B and C which is induced by the electromotive force (e_0) is $e_0 r_1/(r_1+r_2)$, where r_1 and r_2 are electrical resistances. As the height of the deflection of the base-line of the oscilloscope is proportional to the amplitude of e,

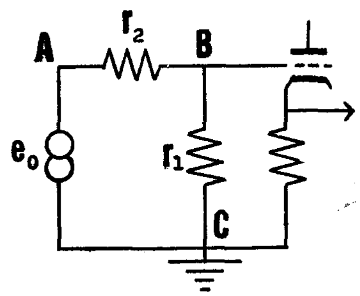

Fig. 1. Scheme to show the principle of measurement of resistance.

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$$h/h_0 = e/e_0 = e_0\, r_1/e_0\,(r_1+r_2), \tag{1}$$

where h : height of deflection due to e,

h_0 : the same due to e_0, the amplitude of e when $r_2=0$.

From (1), the following equation can be obtained :

$$r_2 = r_1\,(h_0-h)/h\,. \tag{2}$$

Therefore, the electrical resistance of the chemosensory hair interposed between A and B in Fig. 1 can be calculated after the equation (2), when values of h and h_0 are measured and that of r_1 is known.

A test solution was applied to the tip of the sensory hair and the electrical resistance between two platinum electrodes was measured. Between these electrodes, there were in series the balanced salts solution, tarsal segments, the sensory hair, and the test solution contained in a glass capillary. The diameter of the capillary was 40–60 micra at the tip, and the resistance of the solution was supposed to be fairly high. But when the tip of the capillary was dipped directly into the balanced salts solution, the resistance of the solution in the capillary was found to be too small to be maesured (Fig. 2). The same was the case, when the tip was dipped into the same solution as that in the capillary instead of the balanced salts solution. The resistance of the leg between the cut end and the chemosensory hair was not measured directly, but it could be expected to be extremely small because the diameter of the leg was several times larger than that of the tip of the capillary and the salts concentration of the body fluid was considered to be sufficiently high.

The value of resistance corresponding to r_1 in Fig. 1 was fixed at 5×10^7 ohms in a whole course of this study, and by insertion of a resistor of known value in the position of r_2 it was acertained that this procedure was available.

Results and Discussion

The lower the concentration of NaCl solution applied is, the higher is the resistance of the chemosensory hair. This characteristic is represented with respect to one of the hairs tested in Fig. 2. The resistance of the intact hair was measured five times under each application of solution which was performed in a random order. The values of the resistance obtained with the same solution at different times of application never showed significant difference so that they were averaged totally except in the case of M/8 NaCl (Curve A). In the case of M/8 NaCl, either of the two following possibilities could be the cause of the difference between the values obtained at different times : 1) the lower value was obtained at the first test and the hair might be under a somewhat particular condition; 2) the resistance of the hair might be brought to an extraordinary level, as the result of the preceding application of the solution of concentration as low as M/64 NaCl (the higher value in curve A). The latter case is suggested from the phenomenon which will be described later.

Curve A seems to be composed of two straight lines, indicating the dependence of the resistance on the concentration of NaCl in an area of lower concentration and the independence in an area of higher concentration respectively. Probably, the latter corresponds to the "saturation" of the frequency of the impulses responding to NaCl at its high concentrations. The electrical conductivity between the hair and the test solution is confined to the tip, in the wall of which a hole of one micron or less in diameter can be observed histologically in *Vanessa* as well as in the labellar chemosensory hair of the fly reported by Dethier and Wolbarsht (1956). This locally limited conductivity is also demonstrated by amputation of the tip from the hair (curve B in Fig. 2). (The resistance was measured 5 times in each application of a solution as in the case of the intact hair but the applica-

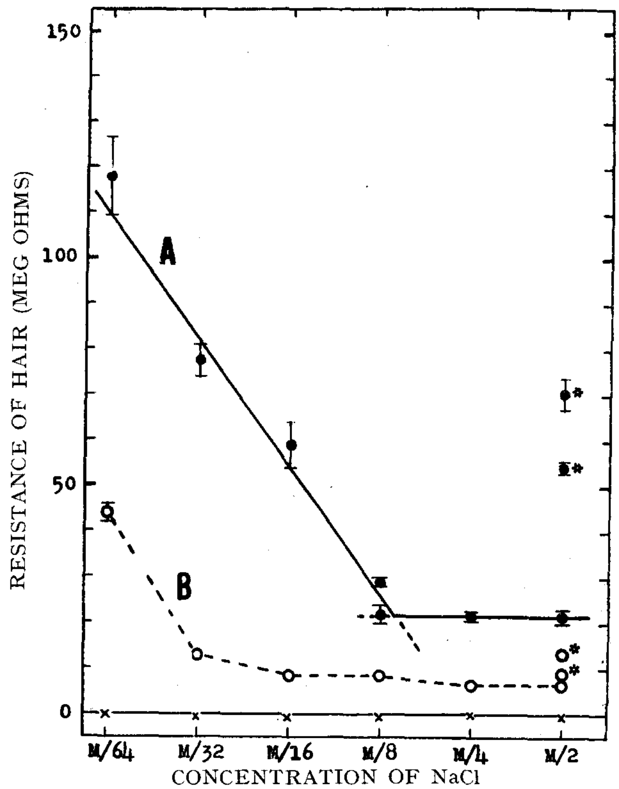

Fig. 2. Relation between the resistance of sensory hair and the concentration of NaCl. Closed circles, intact hair; open circles, the same hair after the amputation of the tip; ×, capillary resistance; *, values when M/2 sucrose was added. Variations are standard errors of means, and in some cases they are too small to be indicated in the figure.

tions were carried out in an order of decending series of concentration in this case.) The resistance of the cut hair in M/64 NaCl seems as though it is much higher than those in other concentrations shown in curve B in Fig. 2, but this value may be extraordinary because of a viscous, caramel-like substance which was observed at the cut end of the hair on application of this solution. The substance is sticky in a solution of low concentration of salt. This substance has been observed not only at the cut end of the hair but also sometimes between the tips of the intact hair and the glass capillary on the application of distilled water, and seems to change into a droplet at high concentrations of NaCl. This substance is thought to cause the resistance to rise. For instance, it has been measured in the case of application of M/2 NaCl+M/2 sucrose solution as follows: 165.5 ± 6.5 MΩ, with the appearance of the substance; 107 ± 10 MΩ, after removal of the substance: 25.9 ± 1.4 MΩ, thereafter, preceded by the application of M/2 NaCl. (cf. the values in the same cut hair in the same solution: 13.5 ± 1.0 MΩ, just after the amputation of the tip; 8.9 ± 0.6 MΩ, after the application of M/2 NaCl and 30 min. after the amputation. These are plotted in Fig. 2 with the mark*.) It will be a kind of protecting substance to prevent the solute of the body fluid to diffuse from the cut end to the external dilute salts solution, and is presumed to fill the hair up to the tip where it protects the body fluid from diffusion and evaporation. If the substance filling the hair had completely the same character as that in the tip, the ratio of the resistance of the cut hair to that of the intact one should be constant at all concentrations of NaCl, but the fact is in a different case. In both the intact and cut states, however, the resistance of the hair in the M/2 NaCl+M/2 sucrose solution has been found always to be higher than in M/2 NaCl. Therefore, the substance filling the hair is judged to some extent to have the same characteristics as that in the tip or at the cut end of the hair, and the ratio of the resistance of the cut hair to that of the intact one might be constant if it were measured after the removal of the "protecting" substance. (On applications of solutions, impulses were observed in the intact hair in every case except in the first one of M/8 NaCl, and even in the cut hair within 1½ hours after the amputation though some deformation could be detected. ——— cf. Hodgson and Roeder, 1956. They have not observed impulses responding to a chemical stimulus after the amputation. —— With the appearance of the "protecting" substance at the cut end the impulses disappeared and then the measurements were ceased.) The elevation effect of sucrose on the resistance of the hair can not be expected in a simple ionic solution in a space of one micron in diameter which is large compared with the molecular size. Presumably, it is caused by sucrose changing the colloidal state of the "protecting" substance or being absorbed selectively in the substance and dispelling ions. If the latter is the case, sucrose should be able to have an electrical effect on the ending of the sensory nerve fiber. The resistance variation of the hair is rapid enough to expect the above-mentioned possibility and the values obtained by five repetitions of measurements under the application of the solution are distributed evenly in a range characteristic to the solution. (The first measurement was performed within a few seconds after the application of a solution.)

The resistance was measured always with 2 mV D.C. pulse positive with reference to the ground (e_0 in Fig. 1) but in some instances of the application of M/2 NaCl it was measured with the negative pulse of the same amplitude, and statistically no significant difference could be detected. On the other hand, in another preparation, an electrotonus of large amplitude was found to be effective on the resistance in the case of a somewhat high concentration of NaCl. In a solution of M/8 NaCl, the hair showed a lower resistance under the anodal polarization (the current flows into the hair from the test solution) than under the reversed one. In a solutlon of M/32 NaCl, however, no significant difference could be detected between the values in both cases. An anodal acceleration of impulse responding to the solution was observed at the same time, and the precise description of the electrical effect on the sensory hair will appear in a future paper.

The effect of the calcium ion on the resistance of the hair was studied, but its effect varied from hair to hair in such a way that the resistance of one hair was too large to be measured and that of another hair was not modified at all.

Summary

The resistance of the tarsal chemosensory hair of *Vanessa* was studied, and its values characteristic to the applied solutions were shown.

The existence of the "protecting" substance which was considered to fill the hair up to the tip was indicated, and it was suggested that this substance would be directly related to the excitation of the chemosensory neuron.

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Literature cited

Dethier, V. G. and M. L. Wolbarsht 1956. Experientia 12 : 335-337.

Hodgson, E. S., J. Y. Lettvin and K. D. Roeder 1955. Science 122 : 417.

Hodgson, E. S. and K. D. Roeder 1956. J. Cell. & Comp. Physiol. 48 : 51-75.

Morita, H., S. Doira, K. Takeda and M. Kuwabara 1957. Mem. Fac. Sci. Kyushu Univ. Japan, Ser. E (Biol.) 2 : 119-139.