References and Notes

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Excitable Cells in Mimosa

Abstract. By inserting microelectrodes into cells of various tissues, it was shown that elongated parenchyma cells in the phloem and protoxylem, which have larger membrane potential than inexcitable cells of other types, generate action potentials with conduction. The electrical features of these cells are essentially similar to those of nerve and muscle cells.

Electrophysiological studies on excitatory conduction in the sensitive plant, *Mimosa pudica* L., have been performed (*1*), but no conclusive evidence has yet been obtained about which kind of cell is excitable and generates the action potential. Several workers (*2*) have surgically removed various tissues from the petiole and have concluded that excitatory conduction takes place in the phloem. However, the experiment by Bose (*3*), in which an electric probe was inserted into the petiole at various depths, showed that excitation is conducted not only in the phloem but also in the protoxylem located in the inner part of the xylem. The protoxylem was called the "internal phloem" by Bose, but the tissue consists only of elongated parenchyma cells and contains no sieve tubes. In my experiment, I inserted a microelectrode into intact cells, and found excitable cells in both the phloem and the protoxylem.

Table 1. Membrane potentials of cells in various tissues. Values are means and standard deviations of several observations in each of eight separate leaves.

Tissues	Membrane potential (mv)	
	Resting	Action*
Epidermis	−44 ± 6	
Cortex	−52 ± 5	
Sclerenchyma sheath	−52 ± 8	
Phloem:		
small cells	−161 ± 15	−22 ± 15
large cells	−61 ± 1	
Protoxylem	−154 ± 12	−19 ± 13
Pith	−58 ± 4	

* Figures showed potential values at the peak of action potential. Values of spike height were 139 ± 12 mv in phloem and 141 ± 15 mv in protoxylem.

At the middle of the petiole of a leaf detached at its base, a part on the lateral side about 3 mm in length was cut off with a razor under water. The cut surface was parallel to the median plane of the petiole. After several hours the prepared leaf was placed on the stage of a microscope; its petiole was kept horizontal and held by a Plexiglas assembly so that the cut part was immersed in a small pool of dilute saline solution (*4*) centered under the objective lens. The plane of the cut was inclined almost at 45° to perpendicular, and the cut faced upwards. All tissues exposed at the cut surface could be seen under the microscope by reflected light. The base of the petiole dipped into a water-filled vessel. Microcapillary electrodes were prepared by the ordinary method and filled with 3*M* KCl. A reference electrode was placed in the pool of saline solution. When an electrode was inserted into a cell at the cut surface, the membrane resting potential between cell interior and the external medium in the pool could be recorded on an oscillograph with a d-c amplifier of high input impedance. The cells can be divided into two groups on the basis of their resting potentials. Some cells in the phloem and all cells in the protoxylem have a resting potential of about −160 mv, all other cells about −50 mv (Table 1).

When the petiole was stimulated electrically at its apex and an excitatory conduction was generated basipetally, a membrane action potential was always elicited in the cells of larger resting potential (Fig. 1*A*). In cells of smaller resting potential there was only a slight change in potential (Fig. 1*B*). This small change is probably an electrotonic change due to the action current of the surrounding excitable cells.

The protoxylem is localized just inside the vessels, and is composed only of elongated parenchyma cells which are nearly of uniform size, 10 μ in diameter and 120 μ long. They form a number of cell rows along the longitudinal axis. All of these cells showed the larger resting potential and generated an action potential upon stimulus.

The phloem consists of several kinds of cells. Cells of large diameter (17 to 28 μ), probably the sieve tubes or

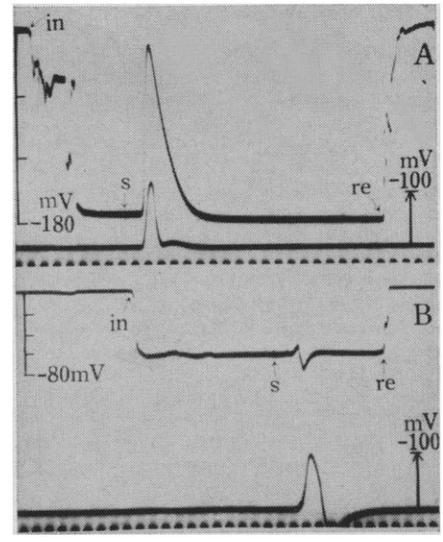

Fig. 1. Membrane potentials (upper trace) in cells of protoxylem (*A*) and pith (*B*). Microelectrodes inserted into cells at *in* and removed from cells at *re*. Petiole is stimulated at *s*. Diphasic action potentials (lower trace) led externally between the pool and the basal cut end are simultaneously recorded. Time marks, 1 sec.

tube cells, showed the smaller resting potential and no action potential. Some of the elongated parenchyma cells, on the other hand, showed the larger resting potential and an action potential, but the cells tested could not be positively identified under the microscope. Microscopic observations of longitudinal sections of the petiole revealed cells in the phloem similar to but somewhat shorter than those in the protoxylem.

The results clearly showed the site of the excitable cells, and the same cells are probably the pathway of conduction. As shown in Fig. 1*A*, the membrane of the excitable cells is polarized; the cell interior is about 160 mv negative to the exterior, and during activity the potential changes toward the direction of depolarization. This feature is essentially similar to that in the axon, muscle fiber, and characeous internode.

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4. Composition of the solution (in millimoles): KNO_3, 0.05; $NaNO_3$, 0.2; $CaCl_2$, 0.25; $MgSO_4$, 0.1.

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