

CHEMISTRY

ELECTROCHEMICAL BEHAVIOUR OF ION-EXCHANGING  
SUBSTANCES. VIII.  
ROOT POTENTIALS IN SODIUM CHLORIDE SOLUTIONS

BY

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*Summary*

It was possible to obtain stable and reproducible potentials of roots of Lucerne clover in NaCl-HCl solutions as well as in KCl-HCl solutions. Evidence was obtained indicating that the behaviour of potentials in the NaCl-HCl solutions is different from the behaviour in the KCl-HCl solutions.

The behaviour of electric potentials of young roots in electrolyte solutions has been investigated in this laboratory for a number of years <sup>1</sup>).

Strong evidence was adduced indicating that steady potentials may be established in KCl solutions, often within a few minutes. It was shown, furthermore, that these potentials may be interpreted in terms of a Donnan membrane equilibrium. The theoretical formula for the dependence of potential on the concentrations of K<sup>+</sup> and H<sup>+</sup> ions contains two constants which are characteristic of each plant species. The quotient of these two constants, it was explained in a recent article <sup>2</sup>), may be interpreted as the effective isoionic point of the ion-exchanging material inside the membrane where the shift of electric potential occurs.

It appeared desirable to take up the study of root potentials in solutions containing other univalent cations. A comparative study of Na<sup>+</sup> and K<sup>+</sup> ions would be of interest. The theory of Donnan equilibria, as developed further by TENDELOO and VERVELDE, involves only the charge of permeating ions. Still, from a biological point of view, a difference in behaviour between Na<sup>+</sup> and K<sup>+</sup> ions might well be expected.

In this communication a short account will be given of root potentials in NaCl solutions. Seeds of Lucerne clover (Provence or Northern France) were grown from 10 to 30 days on distilled water. Then, using the whole

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<sup>1</sup>) H. J. C. TENDELOO, G. J. VERVELDE and A. J. ZWART VOORSPUY, *Rec. trav. chim.* **63**, 97 (1944); **65**, 539 (1946); *Versl. Ned. Akad. v. Wetenschappen* **53**, 169 (1944).

G. J. VERVELDE, *Proc. Koninkl. Ned. Akad. v. Wetenschappen* **51**, 308 (1948).

G. J. VERVELDE and H. J. C. TENDELOO, *Rec. trav. chim.* **72**, 62 (1953).

<sup>2</sup>) D. MACGILLAVRY and H. J. C. TENDELOO, *Rec. trav. chim.* **73**, 15 (1954).

seedlings, potentials were measured with the technique described by TENDELOO, VERVELDE and ZWART VOORSPUY<sup>1)</sup>. Some modifications of apparatus and procedure were adopted. These will be described more in detail in another publication.

The following points need here be mentioned. Before starting measurements, the mounted seedlings were pretreated in a KCl or NaCl solution<sup>2)</sup>, usually during a whole night. Then measurements were taken first in a set of NaCl solutions and then in a similar set of KCl solutions, or sometimes in reversed order. All solutions contained also  $5 \times 10^{-5}$  N HCl. The potentials were measured with a Cambridge or an Electrofact electrometer.

It was possible to obtain stationary potentials in NaCl as in KCl solutions, often after a few minutes, sometimes more slowly. These potentials were reproducible and reversible with respect to variations in concentration or changes from NaCl to KCl or vice versa, as far as could be judged from available observations. The average values obtained for the potentials, averaged over all roots measured, at the different concentrations are listed in Table I.

TABLE I  
Average root potentials

Molarity NaCl				Molarity KCl			
$10^{-5}$	$10^{-4}$	$10^{-3}$	$10^{-2}$	$10^{-5}$	$10^{-4}$	$10^{-3}$	$10^{-2}$
-15.5	-14.8	+ 4.2	+35.8	-41.3	-34.4	+ 3.5	+40.0

An arbitrary reference point has been chosen, as the correct location of zero potential for the effective Donnan membrane equilibrium has to be derived by further analysis.

The measurements, the averages of steady potentials for individual roots, are presented in Table II.

TABLE II

	Root	Pretreatment <sup>1)</sup>	Electro-meter <sup>2)</sup>	Molarity NaCl <sup>1)</sup>				Molarity KCl <sup>1)</sup>			
				$10^{-5}$	$10^{-4}$	$10^{-3}$	$10^{-2}$	$10^{-5}$	$10^{-4}$	$10^{-3}$	$10^{-2}$
1	3-B-111	KCl	C	-12	-13	- 7	+26	(-45) <sup>3)</sup>	-31	- 1	+31
2	5-B-124	NaCl	C	-30	-29	-14	+22	-52	-45	-12	+28
3	8-B-132	NaCl	C	- 9	-16	+ 6	+25	-47	-36	+11	+37
4	9-B-141	NaCl	C	-12	-11	+ 5	+34	-27	-15	+19	+43
5	19-C-29	KCl	E	-12	- 7	+10	+39	-37	-18	+ 5	+40
6	3-C-39	KCl	E	-15	-13	+ 9	+41	-32	-27	+11	+49
7	4-C-46	KCl	E	- 3	- 9	+18	+50	-60	-55	- 2	+43
8	7-C-52	KCl	E	+13	+14	+34	+58	-24	-21	+17	+50
9	8-C-59	KCl	E	-53	-48	-23	+16	-44	-55	-19	+27
10	10-C-70	KCl	C	-22	-16	+ 4	+47	-45	-41	+ 6	+52

<sup>1)</sup> All solutions contain also  $5 \times 10^{-5}$  N HCl.

<sup>2)</sup> C: Cambridge pH-Electrometer; E: Electrofact Electrometer.

<sup>3)</sup> This root was not measured in  $10^{-5}$  M KCl; the value listed was estimated by means of the missing plot technique.

<sup>4)</sup> Containing  $10^{-4}$  M salt and  $5 \times 10^{-5}$  N HCl.

In general a correspondence of behaviour in NaCl and KCl solutions is evident. A variance analysis was made to account for the main effects, of concentration, medium, root mean, and "interaction". Results are given in table III.

TABLE III

Source of variation	Sum of squares	Dimension	Variance	F
Concentration	56,626.24	3	18,875.41	271.9
Medium	2,194.51	1	2,194.51	31.6
Root mean	9,770.31	9	1,085.59	15.6
Interaction (concentration × medium)	3,145.14	3	1,048.38	15.1
Residual	4,303.99	62	69.42	$F_{.05}(1,62) = 4.00$
Total	76,040.19	78		

It may be verified with the F tables that at the 5 % level all effects are significant. Thus, the potentials in the NaCl-HCl solutions studied may not be considered identical with those in the corresponding KCl-HCl solutions. It may here be stated that the differences between the potential averages of NaCl or KCl (see Table I) at the same molarity apparently are too large to be attributed to the differences of diffusion potentials set up between the solutions and the saturated KCl bridge. The difference in behaviour between NaCl and KCl must then be attributed to the response of the roots themselves. The significance will be discussed further

TABLE IIIA

Source of variation	Sum of squares	Dimension	Variance
Differences due to pretreatment	196.80	1	196.80
Differences within groups	9,573.51	8	1,196.69
Differences between roots	9,770.31	9	

TABLE IIIB

Source of variation	Sum of squares	Dimension	Variance
Differences due to electrometer	316.02	1	316.02
Differences within groups	9,454.29	8	1,181.79
Differences between roots	9,770.31	9	

in a later publication. Other conditions not kept strictly uniform, especially pretreatment and electrometer used, apparently did not influence the potentials to any extent. This was checked by splitting up the sum of squares for the variation between roots. See Tables IIIA and IIIB.

There are no indications that differences may be ascribed to an influence caused by the pretreatments or to the use of the Electrofact electrometer instead of the Cambridge pH-electrometer.

In conclusion it may be stated that evidence was obtained indicating that the behaviour of root potentials in NaCl-HCl solutions is different from the behaviour in KCl-HCl solutions. The investigation is being continued.

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