# SPECIAL ARTICLES

## RADIOACTIVE ION EXCHANGES IN LIVING PROTOPLASM

PENETRATION curves for the entrance of radioactive ions into living cells of *Nitella coronata* have been described by Brooks,[1] who has also suggested that the initial increase in ion concentration in protoplasm during the first phase, which is at a maximum in about 15 minutes, is due to an exchange of a radioactive ion for some inactive ion. In the present study, the loss of radioactive ions from the protoplasm of *Nitella* by means of exchange was investigated. Ion exchange is here used to connote the replacement of an ion, possibly bound to an electrolyte by another ion. Ion exchange studies on barley roots have been described by Jenny and Overstreet[2] and on *Elodea* by Mazia.[3]

*Nitella* were taken from large outdoor ponds, separated into single cells and allowed to remain in pond water at 10° C. for a week. Only turgid cells with a length of 3.5 to 4.5 cm were used, in order to secure material which was as uniform as possible. Cells were immersed in 0.01 M solutions of K*Cl or Na*Cl dissolved in pond water at pH 8.2. After 15 minutes the cells were removed from the radioactive solutions, washed in triple distilled water, and the number of radioactive impacts measured with a Geiger-Müller counter. Cells were then placed in 0.01 M solutions of either LiCl, NaCl, KCl, RbCl or CsCl. Cells placed in either quartz-distilled $CO_2$-free water or in an ion-free 0.02 M sucrose solutions were used as controls. The temperature was $15 \pm 0.1°$ C. After a 15-minute immersion, measurements of radioactive counts on each cell were made after 1, 2, 3, 5 and 10 minutes. Whole cells were used, the method of measuring consisting simply of placing each cell on a glass slide and putting this slide a known distance from the Geiger-Müller counting tube. The cell could then be returned to its solution and subsequent loss of radioactivity followed. There is no error because of the presence of sap, since there is no loss of Na* or K* to the sap as shown by separate analyses of the sap, protoplasm and wall in 15 minutes. The curves for the loss of radioactive ions from *Nitella* were exponential and followed equation (1)

$$C_p = C_o e^{-kt}, \qquad (1)$$

where $C_p$ is the concentration of radioactive ion in the protoplasm, $C_o$ the initial concentration of ions in the protoplasm, $k$ a constant giving the slope of the logarithmic curve and $t$ the time of immersion of the cell in the solution of inactive ion. The values of $k$ which were found are given in Table I, and they represent the rate of loss of ions from the cell.

TABLE I

| Ion Exchanged | Value of k for | | | | | |
|---|---|---|---|---|---|---|
| | Li | Na | K | Rb | Cs | HOH |
| Na* ..... | 0.33 | 0.26 | 0.23 | 0.20 | 0.19 | 0.05 |
| K* ..... | 0.12 | 0.16 | 0.83 | 2.00 | ... | 0.05 |

[1] S. C. Brooks, *Proc. Soc. Exp. Biol. Med.*, 38: 856–858, 1938.

[2] H. Jenny and R. Overstreet, *Proc. Nat. Acad. Sci.*, 24: 384–392, 1938.

[3] D. Mazia, *J. Cell. Comp. Physiol.*, 11: 193–203, 1938.

Some preliminary experiments with Rb*Cl and the alkali cation series indicate that in the exchange of Rb* for Li, Na, K, Rb or Cs, the results are similar to those in which K* was used, but the rate of loss is much greater.

Further preliminary experiments on the ion exchange properties of the vacuolar membrane of *Nitella* have been carried out by studying the changes in concentration of either K* or Rb* in both sap and protoplasm after the cell had been immersed in radioactive solutions for 24 hours, to allow for accumulation in the vacuole, and then placed in solutions of inactive alkali cations. The rate of loss of ions from the protoplasm was slower than when the cells had been immersed only 15 minutes. In the sap there was an initial rise after one minute and then a falling off in concentration. In the case of anions, where radioactive phosphorus (as $HPO_4^=$) was used and its exchange for the series F, Cl, Br, I, tested, there is a more rapid loss of P* in $F^-$ than in $I^-$ solutions.

In summary one may say that in the case of K*, the rate of loss followed the Hofmeister series, $Rb^+$ was the fastest and $Li^+$ the slowest in replacing K*. For Na* the Hofmeister series was reversed, $Li^+$ was the most rapid and $Cs^+$ the slowest in replacing Na*. In distilled water the rate of loss of ions was very low. It is suggested that there are at least two factors in operation, namely (1) a permeability effect which in the case of Na* reverses the lyotropic series because ions may not directly exchange, but, rather, be removed because of a decrease in the number of exchange positions on the membrane, and (2) the lyotropic series which governs the loss of ions from the cell in the case of K*.

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## THE DENATURATION OF PROTEINS BY DETERGENTS AND BILE SALTS

ALL the synthetic detergents and bile salts I have tried denature ordinary proteins such as hemoglobin and egg albumin at the isoelectric point and keep the denatured isoelectric protein in solution. Some detergents, such as Duponol PC,[1] in sufficiently high concentration, can prevent the precipitation of denatured protein by trichloracetic acid, tungstic acid and acid ferric sulfate.

Screenivasaya and Pirie[2] observed that the syn-

[1] Sodium dodecyl sulfate is the $C_{12}$ compound of the series $CH_3(CH_2)_nCH_2OSO_3Na$. Duponol Special WA Paste (du Pont) consists mainly of the $C_{12}$ compound. Duponol PC is a mixture of the $C_{10}$–$C_{18}$ compounds.

[2] M. Screenivasaya and N. W. Pirie, *Biochem. Jour.*, 32: 1707, 1938.