Application of Thiouronium Derivatives as Anion Ionophores for Ion Selective Electrodes

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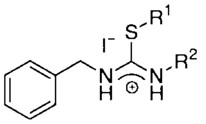
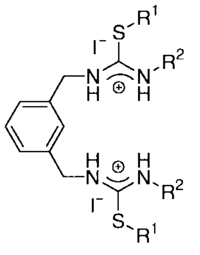
Novel anion ionophores based on thiouronium derivatives were synthesized, and their application to ion selective electrodes (ISEs) was examined. The electrodes clearly exhibited an anti-Hofmeister selectivity pattern with enhanced selectivity for the iodide anion.

The design and synthesis of new anion receptors is of current interest due to their possible application to ion selective electrodes (ISEs) or optodes.[1,2] For example, several receptors based on hydrogen bonding with urea or thiourea groups have been synthesized,[3] and applied to anion sensing as chromoreceptors in solution[4] or as ionophores for ISEs.[5] In contrast to these neutral receptors, it has been known that thiouronium compounds, which correspond to the charged derivative of thiourea, can form complexes with anions. Their binding is stronger than in the case of thiourea because of the enhanced acidity of the NH groups.[6] However, the number of thiouronium compounds used for anion sensing is quite limited except for a few examples.[7] In fact, to our knowledge, there appears to be no reports on ISEs using thiournium derivative as an anion ionophore, despite the fact that several charged ionophores having hydrogen bonding sites such as the guanidinium derivatives have been successfully used for anion selective detection with ISEs.[8] Here we report the characteristics of the thiouronium derivatives as anion ionophores for ISEs.



1a : R^1 = Me, R^2 = *n*-Bu
1b : R^1 = *n*-Bu, R^2 = *n*-$C_{12}H_{25}$



2a : R^1 = Me, R^2 = *n*-Bu
2b : R^1 = *n*-Bu, R^2 = *n*-$C_{12}H_{25}$

Ionophores **1a** and **2a**, which have *N*-butyl side chains and *S*-methyl groups, were prepared by the reaction of the corresponding thiourea[9] with methyl iodide. In order to increase the solubility of the charged ionophores in the membrane solvent, ionophores **1b** and **2b** were also synthesized. Thiourea compounds having dodecyl groups were prepared by the reaction of benzylamine or *m*-xylylenediamine with dodecyl isothiocyanate, and then converted into thiouronium iodide salts by the reaction with butyl iodide in methanol in quantitative yield.

Among the synthesized ionophores, it turned out that the doubly charged ionophore **2a** having short alkyl chains did not show enough solubility in the membrane solvent. The chloride salts of the ionophores were also examined,[10] but none of them gave clear PVC membranes due to their limited solubility. Thus, three ionophores **1a**, **1b**, and **2b** were successfully incorporated in PVC electrode membranes and examined for their potentiometric response to several representative anions. The membrane composition was 1% (by weight) ionophore, 66% membrane solvent *o*-NPOE and 33% PVC in all cases. The electrode potential (emf) measurements were performed according to the reported procedure at 25 ± 0.5 °C using the following cell assembly;[11]

$$\mathrm{Ag|AgCl|KCl(satd.)|0.3\ M\ NH_4NO_3||sample\ solution|}$$
$$\mathrm{ISE\ membrane|0.1\ M\ NaCl|AgCl|Ag}$$

All sample solutions were made from sodium salts and adjusted to pH 7.0 using 0.1 M HEPES-NaOH buffer solution. The selectivity coefficients were calculated from the response potentials using the separate solution method, based on the IUPAC recommendation.[12]

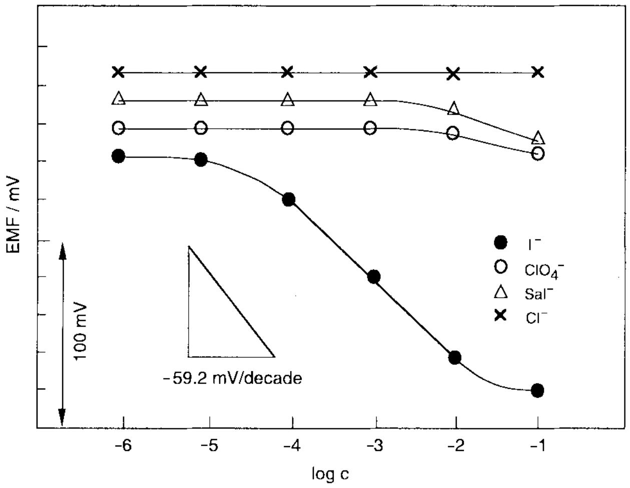


Figure 1. Response curves of the ISE based on ionophore **1a**.

The ISEs based on these charged ionophores responded to several anions without the addition of a cationic additive. The ISE based on ionophore **1a** exhibited a sub-Nernstian response to I^- (slope = –44 mV/decade) as shown in Figure 1. A weak anionic response to lipophilic anions like ClO_4^- or salicylate was observed at relatively high anion concentrations. The ISEs based on **1b** and **2b** exhibited essentially the same response characteristics as the ISE based on **1a** (the response to I^- was –45 and –44 mV/decade, respectively), and no structural effects such as the number of anion binding sites or the length of the alkyl chains could be observed.

The selectivity coefficients are summarized in Figure 2. Although the theoretical response slope could not be observed,

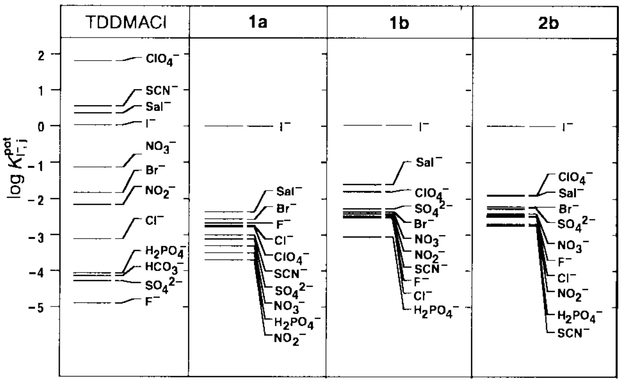


Figure 2. Potentiometric selectivity coefficients of the ISEs based on ionophores **1a**, **1b**, and **2b**.

every electrode exhibited a high selectivity to I^-, which is different from the well known Hofmeister series (TDDMACl, column 1). Moreover, it should be noted that the interference from other anions is quite limited since only a weak response to highly lipophilic anions is observed. This behavior is comparable to those of the ISEs based on other iodide selective ionophores represented by metal complexes or quaternary ammonium salts.[13] Although it is reported that thiouronium derivatives effectively form complexes with oxoanions such as phosphate or acetate in organic solution,[6,7b] ISEs based on **1a**, **1b**, and **2b** showed almost no response to phosphate which is located in the last part of the Hofmeister sequence. Since the positive charge in the thiouronium group is delocalized, the interaction of this functional group with anions seems rather weak compared to that of the quaternary ammonium salts such as TDDMACl. Therefore, it is postulated that the high selectivity to iodide ions is the result of the lipophilicity.

In summary, we have demonstrated that the nature of the thiouronium group is promising for the development of new anion ionophores for ISEs. Further attempts for improving the selectivity caused by factors other than the ionophore, for example, the addition of a cationic additive, are now in progress.

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