interpreted by using a variety of schemes involving Ni(III)/Ni(II),[8,14b] Ni(III)/Ni(II)/Ni(I),[14a] and Ni(III)/Ni(II)/Ni(I)/Ni(0)[22] formal oxidation states. In all these schemes, the assignment of Ni(III) to the oxidized forms of the enzymes is based on the observation of hyperfine in ^{61}Ni-labeled enzymes, the similarity of the EPR spectra to EPR spectra of tetragonal Ni(III) coordination compounds, and the association of the signal with oxidized forms of the enzymes. The studies outlined here suggest that Ni(III) has no real existence in systems with simple alkyl thiolate ligation. From the viewpoint of ligand oxidation, the "Ni(III)" EPR signal could be interpreted as arising from a tetragonal $S = 1$, Ni(II) center with the spin in the $d_{x^2-y^2}$ orbital antiferromagnetically coupled to a thiyl radical. The resulting $S = {}^1/_2$ system (with an unpaired spin in the d_{z^2} orbital) is consistent with the observed EPR spectrum and with the small Ni K-edge shifts observed in XAS spectra,[20b] is more consistent with known Ni thiolate redox chemistry, and suggests that nature may have selected a *non-redox-active* metal (Ni) for these roles in order to stabilize ligand-based redox chemistry.

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Supplementary Material Available: Tables of positional and thermal parameters for **2** (2 pages). Ordering information is given on any current masthead page.

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Self-Assembling Ionophores

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One of the mechanisms by which enzyme active sites are formulated is through the assembly of subunits, which alone are incapable of substrate recognition.[1] Enzymes such as phosphofructokinase[2] and aspartate transcarbamoylase[3] exhibit this property, as do organelles such as the ribosome. In each case, the association and dissociation of a subunit regulates the biological event, whether that event is phosphorylation of fructose 6-phosphate or the biosynthesis of a polypeptide. The systems designed by Rebek,[4] Shinkai,[5] and Irie[6] have demonstrated the ability to tailor a conformational change in a single molecule to induce a chemical event. However, the *assembly* of a *functioning* binding unit from two discrete molecules has remained a phenomenon reserved exclusively for high molecular weight systems.[7,8] In this communication we demonstrate that this phenomenon may be reproduced using small molecules.

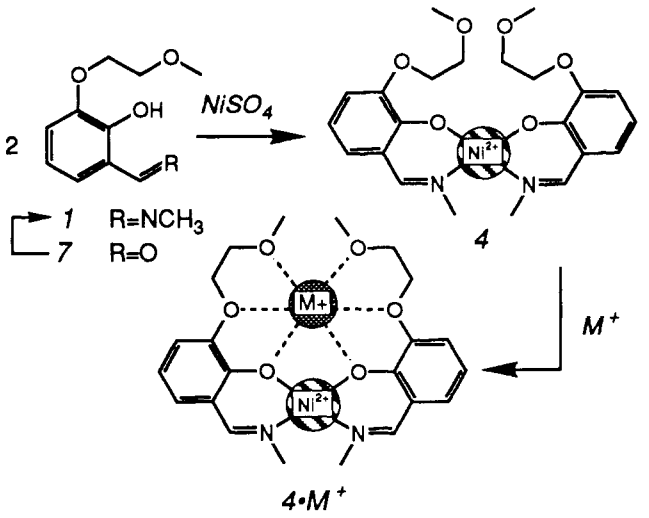

Figure 1.

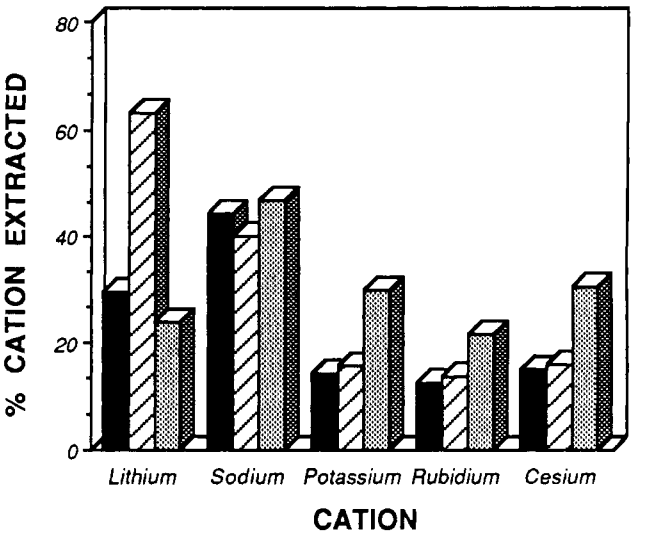

Figure 2. Extent of alkali metal ion extraction by complexes **4**, ■; **5**, ▨; and **6**, ▩ at 25 ± 5 °C. Aqueous phase: [M^+Picrate$^-$] = 7.5 mM. Chloroform phase: [host] = 2 mM. Values are averages of at least two independent determinations. All values are reproducible to within 5%.

Simple, linear polyethers with fewer than four oxygen atoms do not bind alkali metal ions tightly and are unable to transport those ions across membranes with high efficiency.[6] Binding is enthalpically disfavored by the lack of suitable ligand sites. Dimerization of two polyethers would generate the requisite number of binding sites; however, the concomitant loss in entropy is so great that it overrides any enthalpic gain.[9] We report herein that Ni(II) can act as a *template* to permit the assembly of dimeric, cation-selective inclusion complexes from imines **1**, **2**, and **3**.[10] The resulting complexes **4**, **5**, and **6**[11] are able to extract alkali metal ions efficiently from aqueous solution with selectivities

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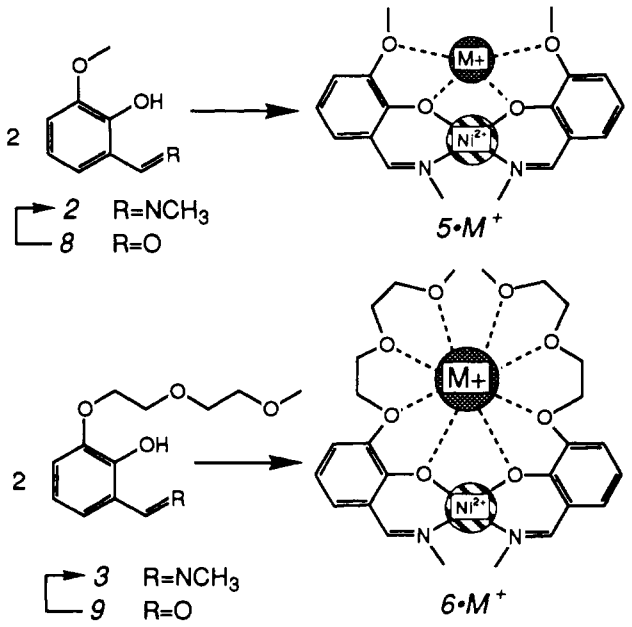

Figure 3.

that are dependent on both the structure of the polyether chain and on the structure of the Ni(II) chelate. *Most importantly, complex 4 extracts metal ions effectively even when generated in situ.*

The ability of Ni(II) complex **4** to transport alkali metal ions selectively into chloroform solution was tested with the picrate extraction technique.[12] As expected, imine **1** is unable to transport any alkali metal ion examined into chloroform solution.[13] However, nickel complex **4** functions as an ionophore and is able to transport almost 50% of the sodium ion present into chloroform.

Ionophores are typically characterized by their ability to select one metal ion over another. Cyclic ionophores exhibit significant preferences in their binding, whereas simple podands do not.[14] As can be seen in Figure 2, complex **4** displays substantial cation selectivity. Thus, the ability of complex **4** to extract Na^+ (44%) may be compared with its ability to extract Li^+ (30%), K^+ (14%), Rb^+ (13%), or Cs^+ (15%). Therefore, the rigid geometry of the transition-metal chelate has partially preorganized[15] the flexible ligand **1** and has generated a cation-selective ionophore.

We wondered if the selectivity of this ionophore would be sensitive to the structure of the polyethers on each salicylaldimine unit. It was anticipated that as the length of the polyether chain was shortened, the selectivity of the complex would shift toward smaller cations. Indeed, this is precisely what is observed. Complex **5**, with four oxygens available to bind an alkali metal ion, preferentially extracts Li^+ (63%), in comparison to Na^+ (40%), K^+ (16%), Rb^+ (15%), or Cs^+ (16%). It is interesting that this selectivity does not parallel the selectivity of 12-C-4, which prefers Na^+ in organic solvents.[16] This interesting result is presumably a reflection of the geometric constraints imposed by tetrahedral Ni(II).

The result of increasing the length of the polyether chain is more difficult to predict. A shift in selectivity toward larger cations might be anticipated, owing to the presence of eight potential ligand sites and the concomitant larger size of the receptor. Alternatively, a decrease in selectivity, caused by the increased flexibility of the ligand, might be observed. The latter of these two possibilities is realized. Although **6** does show some preference for Na^+, extraction of K^+ by this complex is almost as efficient.

To test whether these non-natural ionophores would self-assemble in situ, the following experiment was performed. A chloroform solution containing 25 mM Ni(II) bis(2-ethylhexanoate) and 50 mM imine **1** was prepared and layered below an aqueous solution of sodium picrate ($[M^+]$ = 7.5 mM). After the solution was stirred rapidly[12] for 3 min, 40% of the sodium ion in the aqueous phase had been extracted into the chloroform layer, whereas in the absence of imine **1**, 8% was extracted.[17] Importantly, even correcting for this 8%, the value of 40% is only slightly less than the value obtained when **4** is preformed in ethanol. *This indicates that the ionophore has self-assembled in situ.*

In this communication we have demonstrated that the predictable, organized geometries of transition-metal chelates can be utilized to control the orientation of two flexible polyether chains. In this way, a selective alkali metal ion binding site is generated. As is true for enzymes regulated by subunit dimerization, *this binding site may be generated in situ.* Because of the sensitivity of Ni(II) salicylaldimine complex geometry to the size of the substituent on nitrogen, it may be possible to fine-tune the selectivities of these molecules by simply altering the identity of this group. This strategy can in principle be used to control the assembly of receptors other than crown ethers, with implications for the regulation of artificial enzymes and as an approach toward protein design. The extension of this work toward the design of oriented, *peptide-based* receptors is in progress.

Supplementary Material Available: ^1H NMR and high-resolution MS data on compounds **1**, **2**, **3**, **7**, and **9** and combustion and UV–vis analysis of compounds **4**, **5**, and **6** (1 page). Ordering information is given on any current masthead page.

(12) Pedersen, C. J. *Fed. Proc.* **1968**, *27*, 1305–1309. Typical procedure: A 50 mM chloroform solution of imine **1** or a 25 mM solution of **4** was prepared, and 0.4 mL of the respective solution was layered below 0.5 mL of the specified picrate salt solution ($[M^+]$ = 7.5 mM). The two-phase system was stirred with a VWR Brand Vortexer, set at speed 7, for 3 min, and the layers were separated by centrifugation. The extent of alkali metal ion transport was determined quantitatively by spectrophotometrically measuring the loss of picrate absorbance at 356 nm in the aqueous layer. The percent of cation extracted was calculated with the formula $100 \times \{1 - [A_{356}(\text{host})/A_{356}(CHCl_3)]\}$. Control experiments indicated that stirring for 9 min did not increase the amount of metal ion extracted.

(13) An additional control experiment excluded the possibility that picrate ion itself was the complexing agent. Twenty-five mM $NiSO_4$ was added to the basic, aqueous NaPicrate solution, and the extraction experiment was repeated in the presence and absence of 50 mM **1**. In neither case was any picrate anion transported into the chloroform solution.

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(16) Massaux, J.; Desreux, J. F.; Duyckaerts, G. *J. Chem. Soc., Dalton Trans.* **1980**, 865–868.

(17) This value of 10% is likely due to the formation of $Ni^{II}(picrate)_2$.

An Alkylidene Complex of Vanadium: Synthesis and Structure of Cyclopentadienyl[bis(dimethylphosphino)ethane](neopentylidene)vanadium(III)

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Transition-metal alkylidene complexes of the nucleophilic ("Schrock") type have developed as an important class of compounds, displaying many interesting types of (catalytic) reactivity such as olefin metathesis[1] and ring-opening metathesis polymerization (ROMP).[2] These complexes have been intensively studied for the 4d/5d transition metals Nb, Ta, Mo, W, and Re[3] but are practically unknown for the 3d transition metals ($Cp_2Ti(CH_2)PMe_3$ has been described[4]). For vanadium, only

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