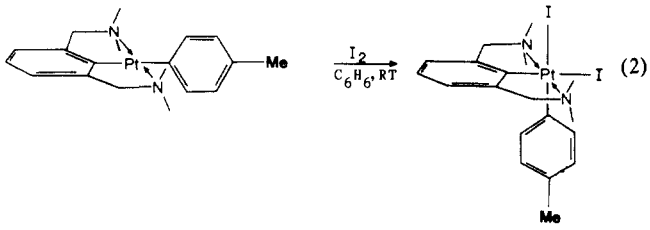
in oxidative addition reactions of X_2 to platinum(II) complexes.[16] The fact that **2** is stable and does not react further either to $PtI_3(NCN)$ or to Pt–C bond cleavage products is therefore surprising and may be partly brought about by steric factors. This seems to be substantiated by the observation that Pt(*p*-tolyl)(NCN) reacts with I_2 cleanly to the oxidative addition product PtI_2(*p*-tolyl)(NCN)[17] (see eq 2).



(2)

In the latter, octahedral Pt(IV) complex the formerly trans orientation of the carbon ligands has changed to a cis arrangement. ^1H NMR studies have revealed that the flat *p*-tolyl group is fixed in a position perpendicularly to the N–Pt–N axis.

The mechanistic aspects of oxidative addition reactions of X_2 and alkyl and aryl iodides to PtX(NCN) complexes are currently investigated.

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Registry No. **1**, 82112-97-8; **2**, 103148-37-4; I_2, 7553-56-2.

Supplementary Material Available: Fractional atomic coordinates, anisotropic thermal parameters, all bond distances and angles, and observed and calculated structure factors of **2** (16 pages). Ordering information is given on any current masthead page.

(16) (a) Skinner, C. E.; Jones, M. M. *J. Am. Chem. Soc.* **1969**, *91*, 4405. (b) Hopgood, D.; Jenkins, R. A.; *J. Am. Chem. Soc.* **1973**, *95*, 4461.

(17) (a) This was confirmed by an X-ray structure determination of PtI_2(*p*-tolyl)(NCN): Terheijden, J. Ph.D. Thesis, 1986, University of Amsterdam, the Netherlands. (b) van Beek, J. A. M.; van Koten, G.; Dekker, G. P. C. M.; Terheijden, J.; Muller, F.; Stam, C. H., unpublished results.

Slow Complexation Rates of Crown Ethers: What Is Taking So Long?

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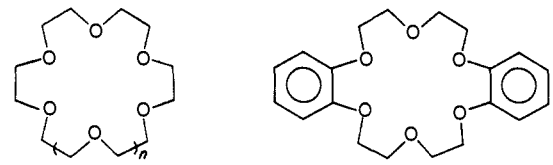
Cation complexation by simple crown ethers is a fast process. Association rates are typically in the megahertz range and can be determined by ultrasonic techniques,[1] while exchange rates between ions and their complexes are generally fast on the NMR time scale.[2] We have recently determined that complexation rates for crown ethers and certain organomercurials are slow on the *human time scale*; here we report our methods and suggest a probable cause for the sluggishness of the reactions.

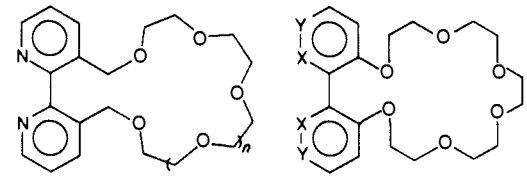
In organic solvents, the binding of 18-crown-6 **2** to $Hg(CN)_2$ can be conveniently measured by ^1H NMR through the disappearance of the singlet for the free crown (3.54 ppm) or the appearance of the singlet for the 1:1 complex[3] (3.40 ppm). The



1, *n* = 0
2, *n* = 1
3, *n* = 2

4

reaction is second order and the rate constant (Table I) corresponds to half-life of nearly 1 h at ambient temperature and 0.01 M reactants. In the range 273–313 K, the Arrhenius parameters E_{act} = 11.4 kcal/mol and log A = 6.9 were determined. No binding between $Hg(CN)_2$ and the smaller **1** could be detected, but very fast complexation ($t_{1/2}$ < 1 s at these concentrations) was observed with the larger **3**, or even the 20-membered **7**.



5, *n* = 1
6, *n* = 2

7, X = Y = CH
8, X = N, Y = CCH_3

Conformational mobility of the crown further affects the rate. The dibenzo derivative **4** showed a rate (Table I) some 60 times slower than **2** with $Hg(CN)_2$. Exchange of this Hg derivative between **2** and **4** was very slow; gradual changes were observed in the NMR spectra of either complex in the presence of the other crown over a period of months.

With $Hg(CF_3)_2$ rates can be even slower. Earlier[4] we described how the 2,2′-bipyridyl function of **6** can act as an on–off switch for the uptake and release of $Hg(CF_3)_2$ by the ethereal cavity. Rapid exchange occurs with the 22-membered ring of **6**, but metals which are chelated by the bipyridyl, i.e., $PdCl_2$, cause a conformational change (allosteric effect) that reduces the effective size of the macrocycle. With the 21-membered ring of **3**, uptake of $Hg(CF_3)_2$ is also rapid but its release is slow. Since $Hg(CN)_2$ binds even more tightly to this ether, the release of $Hg(CF_3)_2$ by **3** could be measured by the substitution reaction of eq 1. The

$$\mathbf{3}\cdot Hg(CF_3)_2 \underset{\text{slow}}{\overset{k_1}{\rightleftharpoons}} Hg(CF_3)_2 + \mathbf{3} \xrightarrow[\text{fast}]{Hg(CN)_2} \mathbf{3}\cdot Hg(CN)_2 \qquad (1)$$

reaction rate (Table I) was independent of the concentration of $Hg(CN)_2$ and corresponds to a dissociation barrier $\Delta G^{\ddagger}$ of 21.7 kcal/mol.

No binding of $Hg(CF_3)_2$ to **2** or the 19-membered **5** was observed, but the slow complexation with 20-membered rings[5] **7** and **8** could be measured. With **7** the association rate was determined over a period of days by ^{19}F NMR in $CDCl_3$ (free, −36.6 ppm; complex, −38.6 ppm from internal $CFCl_3$). The release rate was measured by using the substitution reaction of eq 2; this corre-

$$\mathbf{7}\cdot Hg(CF_3)_2 + Hg(CN)_2 \rightarrow \mathbf{7}\cdot Hg(CN)_2 + Hg(CF_3)_2 \qquad (2)$$

$$\mathbf{8}\cdot Hg(CF_3)_2 + Hg(CN)_2 \rightarrow \mathbf{8}\cdot Hg(CN)_2 + Hg(CF_3)_2 \qquad (3)$$

sponds to a half-life of about 1 month and $K_{eq} \approx 1700\ M^{-1}$. The rates and equilibrium for the bipyridyl **8** were measured in a similar manner (eq 3). The lower K_{eq} for **8** (K_{eq} *a*pp 200 M^{-1}) reflects a 20-fold slower uptake rate and 2.5-fold slower release rate in the reactions of **8** vs **7**.

Why are these reactions so slow? For complexation of *ions* in polar solvents,[6] *desolvation* generally contributes to the rate-determining step (the Eigen–Winkler mechanism[7]) rather than

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(2) Shchori, E.; Jagur-Grodzinski, J.; Shporer, M. *J. Am. Chem. Soc.* **1973**, *95*, 3842–3846. For an excellent recent review, see: Izatt, R. M.; Bradshaw, J. S.; Nielsen, S. A.; Lamb, J. D.; Christensen, J. J. *Chem. Rev.* **1985**, *85*, 271–339.

(3) All new compounds were characterized by a full complement of high-resolution spectra and/or elemental analyses.

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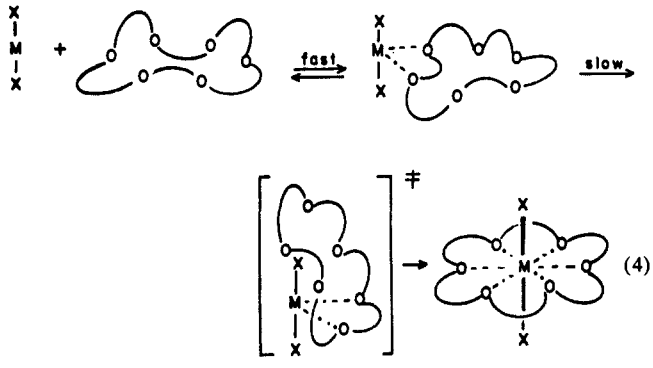
Table I.

reaction	rate constant (23 °C)	solvent	approx half-life[b]
$Hg(CN)_2 + 2 \xrightleftharpoons{k_2} 2{\cdot}Hg(CN)_2$	3.1×10^{-2} M^{-1} s^{-1}	A/B[a]	1 h
$Hg(CN)_2 + 2 \xrightleftharpoons{k_2} 2{\cdot}Hg(CN)_2$	1.7×10^{-2} M^{-1} s^{-1}	A/C[c]	2 h
$Hg(CN)_2 + 4 \xrightleftharpoons{k_2} 4{\cdot}Hg(CN)_2$	2.75×10^{-4} M^{-1} s^{-1}	A/C	4-5 days
$3{\cdot}Hg(CF_3)_2 \xrightleftharpoons{k_1} 3 + Hg(CF_3)_2$	5.5×10^{-4} s^{-1}	A/B	15 min
$Hg(CF_3)_2 + 7 \xrightleftharpoons{k_2} 7{\cdot}Hg(CF_3)_2$	4.0×10^{-4} M^{-1} s^{-1}	$CDCl_3$	3 days
$Hg(CF_3)_2 + 7 \xrightleftharpoons{k_1} 7{\cdot}Hg(CF_3)_2$	2.6×10^{-7} s^{-1}	$CDCl_3$	1 month
$Hg(CF_3)_2 + 8 \xrightleftharpoons{k_2} 8{\cdot}Hg(CF_3)_2$	2×10^{-5} M^{-1} s^{-1}	$CDCl_3$	2 months
$Hg(CF_3)_2 + 8 \xrightleftharpoons{k_1} 8{\cdot}Hg(CF_3)_2$	1×10^{-7} s^{-1}	$CDCl_3$	3 months[d]

[a] Acetone-d_6/benzene-d_6 (1:1, v/v); solubility problems precluded the use of a single solvent system for all reactions. [b] Calculated for 0.01 M reactants in the solvent indicated. [c] Acetone-$d_6$0$CDCl_3$ (1:0.8, v/v). [d] Extrapolated from the initial rate (10%) reaction.

preassociation conformational changes in the macrocycle (the Chock mechanism[8]). For the cases at hand, solvation forces between the organomercurials and solvents are expected to be weak and short-lived, and the structural dynamics of the crown ethers become important. The facts best fit a combined mechanism (eq 4).



(4)

A rapidly formed initial complex exists in which the metal center binds to a few of the ethereal oxygens of the macrocycle. The rearrangement of this complex to the rotaxane-type structure[9] of the final complex is slow. The macrocycle must assume an improbable, high-energy conformation in order to permit the covalently bound ligands of the Hg to penetrate the ring. The severe restrictions on the internal rotations caused by this motion are consistent with the large negative activation entropy observed ($\Delta S^{\ddagger}$ = −25 eu). For a spherical ion, on the other hand, sequential replacement of solvent is not expected to require such drastic conformational changes in the macrocycle. Indeed, we found that allosteric effects involving these macrocycles and alkali metals[10] were much smaller than those involving $Hg(CF_3)_2$. Finally, we note that the rearrangement of eq 4 is reminiscent of the slow conformational transitions responsible for hysteretic behavior in enzymology.[11]

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Registry No. 1, 33100-27-5; **2**, 17455-13-9; **3**, 33089-36-0; **4**, 14187-32-7; **5**, 71638-20-5; **7**, 41051-91-6; **8**, 76453-08-2; $Hg(CN)_2$, 592-04-1; $Hg(CF_3)_2$, 371-76-6.

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Synthesis of Covalently Linked DNA/RNA Cross Sections

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The classical Watson-Crick double-helical model of DNA/RNA possesses well-defined hydrogen bonds that hold the two strands in complementarity (Figure 1a).[1] A covalently linked cross section (Figure 1b) with molecular architecture[2] similar to the hydrogen-bonded base pair would be a good mimic of the Watson-Crick cross section and hence a potential candidate for incorporation into various biological systems. In this paper we report the first syntheses of covalently linked DNA/RNA duplex cross sections starting from readily available *O*-acetylated deoxyribonucleosides and ribonucleosides.

The synthetic strategy is outlined in Scheme I. The reaction of 2′,3′,5′-tri-*O*-acetyladenosine (**1a**)[3] with chloroketene diethyl acetal (**2**)[4] in ethyl acetate in the presence of a catalytic amount of *p*-toluenesulfonic acid gave N^6-(1-ethoxy-2-chloroethylidene)-2′,3′,5′-tri-*O*-acetyladenosine (**3a**)[5] in quantitative yield. The subsequent condensation of **3a** with 2′,3′,5′-tri-*O*-acetylcytidine (**5a**)[6] was carried out in benzene/acetonitrile in the presence of a catalytic amount of *p*-toluenesulfonic acid under reflux to afford the bis(ribonucleoside) **7a** in 27% yield. Some of the loss in this reaction was accounted for by reversion of **3a** to **1a** and cyclization of **3a** to 8-ethoxy-3-(2′,3′,5′-tri-*O*-acetylribofuranosyl)imidazo-[2,1-*i*]purine (**4a**).[5] The decision as to the direction of ring closure of the putative transient intermediate **6a** was made on the basis of ^1H NMR guidelines.[5] It was evident from the shift to lower field of the original 2-proton on the purine nucleus in **7a** that ring closure had occurred on the adenosine side of **6a** to yield **7a**, as indicated. The structure of 8-N^4-(2′,3′,5′-tri-*O*-acetylcytidino)-3-(2′,3′,5′-tri-*O*-acetyl-β-D-ribofuranosyl)imidazo[2,1-*i*]purine (**7a**) was further confirmed by its ^{13}C NMR spectrum (75.2 MHz) and by high-resolution FAB mass spectral analysis. The bis(deoxyribonucleoside) **7b**, 8-N^4-(3′,5′-di-*O*-acetyl-2′-deoxycytidino)-3-(3′,5′-di-*O*-acetyl-2′-deoxy-β-D-ribofuranosyl)-imidazo[2,1-*i*]purine, was made in a similar manner from 3′,5′-di-*O*-acetyl-2′-deoxyadenosine (**1b**), **2**, and 3′,5′-di-*O*-acetyl-2′-deoxycytidine (**5b**). The mixed dinucleoside **7c**, 8-N^4-(2′,3′,5′-tri-*O*-acetylcytidino)-3-(3′,5′-di-*O*-acetyl-2′-deoxy-β-D-ribofuranosyl)imidazo[2,1-*i*]purine, was made from 3′,5′-di-*O*-acetyl-2′-deoxyadenosine (**1b**), **2**, and 2′,3′,5′-tri-*O*-acetylcytidine. In order to accomplish the oxidative ring closure of **7a-c**, iodobenzene diacetate[7] was first selected since it had been demonstrated to be effective for the construction of the related 1,3,4,6-tetraazapentalene ring system.[8] When the oxidative cyclization of **7a** was attempted in the high-dielectric, low-nucleophilic solvent

(1) Saenger, W. *Principles of Nucleic Acid Structure*; Springer-Verlag: New York, 1983; pp 116-158.
(2) The dimensions indicated have not yet been determined but have been calculated from a composite structure consisting of two separate entities in the formula, the 1,N^6-ethenoadenosine side and the 3,N^4-ethenocytidine side. The dimensions of these entities have been determined by single-crystal X-ray structure analysis. See: Leonard, N. J. *CRC Crit. Rev. Biochem.* **1984**, *15*, 125 and references therein. [Note: interchange pages 157 and 158.]
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