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Solution-phase Assembly of a Rhodium Complex via Specific Hydrogen Bonding between Barbituric Acid and Triaminopyrimidine Moieties

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Solution-phase assembly of a Rh complex using specific hydrogen bonding between BA and TAP moieties was achieved by tuning the substituent on TAP to control the solubility of the assembly.

Great efforts have been devoted to developing novel methods for the assembly of transition-metal complexes, because of their intriguing electronic and photochemical properties[1] as well as unique catalytic activities.[2] Use of noncovalent bonds offers convenient strategies to form the assembly spontaneously by the components.[3] Hydrogen bonding has received particular attention, due to its relatively high strength and directionality[4] and has been applied for assembly of metal complexes both in solid and solution states.

Melamine (MEL) and 2,4,6-triaminopyrimidine (TAP) are known to self-assemble with barbituric acid (BA) and cyanuric acid (CA) in alternative fashion by specific hydrogen bonding to form cyclic rosette or linear tape structures,[5] and several studies of self-assembly of metal complexes covalently linked to these molecules have been reported. Solution-phase assembly of complexes have been achieved by using MEL and BA to form cyclic rosette.[6] To the best of our knowledge, however, TAP has not been used to assemble metal complexes, though the properties of TAP can be easily tuned without affecting the hydrogen-bonding scaffolds by introducing substituents at the 5-position.[7,8]

Herein we report that the solution-phase assembly of a Rh complex was achieved using specific hydrogen bonding between BA and TAP moieties (Figure 1). A new type of TAP derivative, which serves to solubilize a poorly-soluble assembly formed by hydrogen bonding, was designed, synthesized, and used for the assembly formation.

A Rh complex bearing a BA moiety was prepared as shown in Scheme 1. 2-Methyl-8-hydroxyquinoline (**1**) was converted to a ligand bearing a BA moiety (**2**) in five steps.[9] Reaction of ligand **2** with $Rh(acac)(CO)_2$ provided dicarbonyl complex **3** in 95% yield.[10] Because complex **3** has relatively low solubility in most of the common organic solvents, one of the CO ligands of **3** was exchanged with PPh_3 to form complex **4**, which is soluble in organic solvents.

Formation of solution-phase assembly of complex **4** with TAP derivatives was then examined. When TAP derivatives with a butyl (**5**) or decyl (**6**) group (Figure 2) was mixed with **4** in nonpolar solvents, the assembly precipitated out from the solution. Increase of the number of alkyl chains using a TAP derivative bearing a dialkoxyphenyl group (**7**) led to the formation of assembly with higher solubility in halogenated solvents. However, precipitation in dichloroethane started at 30 mM and vapor pressure osmometer (VPO) measurement to estimate the degree of assembly was difficult to perform.

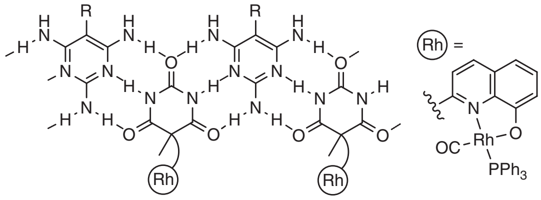
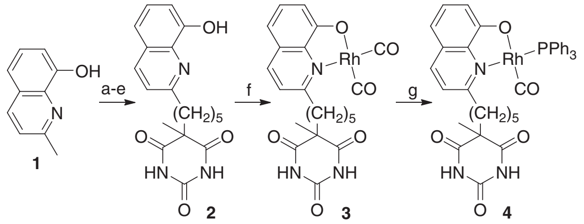


Figure 1. A possible structure of assembly of Rh complexes via hydrogen bonding between BA and TAP.[9]



Scheme 1. Preparation of Rh complexes bearing a BA moiety. Reagents and conditions: (a) MOMCl, NaH, DMF, quant; (b) LDA, $Br(CH_2)_4Br$, THF, 60%; (c) $CH_3CH(CO_2Et)_2$, NaH, DMF, 97%; (d) urea, NaH, DMF; (e) 0.9 M HCl in $H_2O/MeOH$, 75% (2 steps); (f) $Rh(acac)(CO)_2$, CH_2Cl_2, 95%; (g) PPh_3, CH_2Cl_2, 65%.

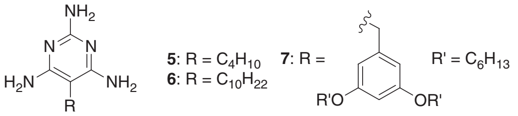
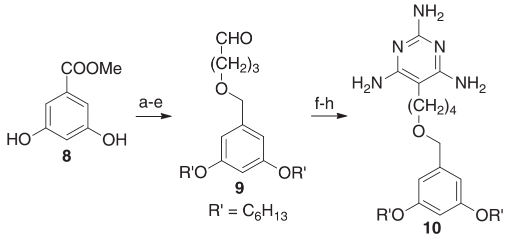


Figure 2. TAP derivatives with various substituents.

To further increase the solubility of the BA/TAP assembly, a TAP derivative with an extended alkyl tether (**10**) was prepared (Scheme 2). Methyl 3,5-dihydroxybenzoate (**8**) was transformed to aldehyde **9** in five steps.[9] Condensation with malononitrile, followed by reduction and reaction with guanidine hydrochloride provided TAP derivative **10**.[11] As expected, the assembly of **4** and **10** showed high solubility in halogenated solvents, and no precipitate was observed at 100 mM, which enabled the VPO measurements[12] to assess the molecular weight of the assembly.[13]

VPO measurements of complex **4**, TAP derivative **10**, and their equimolar mixture in dichloroethane were conducted at various concentrations to calculate M_n. Solutions of **4** (FW 748) and **10** (FW 488) showed gradual increase in M_n along with the concentration, which is thought to be caused by self-association of each compound ($M_n = 1200$ and 620 at 40 mM, respectively).



Scheme 2. Preparation of TAP derivative **10**. Reagents and conditions: (a) $C_6H_{13}Br$, K_2CO_3, CH_3CN, 87%; (b) $LiAlH_4$, THF, 93%; (c) CBr_4, PPh_3, CH_2Cl_2, quant; (d) 1,4-butanediol, Ag_2O, CH_2Cl_2, 69%; (e) $SO_3 \cdot py$, Et_3N, DMSO, CH_2Cl_2, 79%; (f) $CH_2(CN)_2$, basic Al_2O_3, toluene, 91%; (g) $NaBH_4$, *i*-PrOH, 71%; (h) guanidine hydrochloride, EtONa, EtOH, 94%.

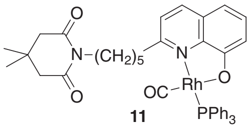


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Figure 3. A Rh complex bearing a dimethylglutarimide moiety.

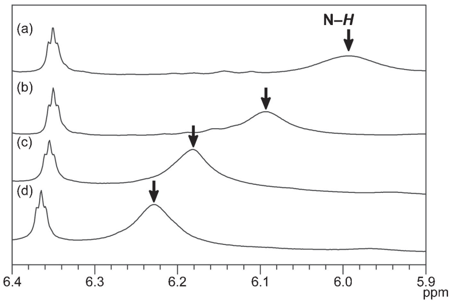

Figure 4. ^{1}H NMR spectra of 1:1 mixture of complex **4** and TAP derivative **10** at (a) 10, (b) 20, (c) 40, and (d) 67 mM.

On the other hand, an M_n of 2400 was observed for an equimolar solution of **4** and **10** at 40 mM, indicating ca. 2:2 assembly formation (FW 2470) in the dichloroethane solution.[9]

In order to examine the effect of the specific hydrogen bonding in assembly formation, a Rh complex bearing a 3,3-dimethylglutarimide moiety (**11**) was examined (Figure 3). VPO measurements showed that the M_n of complex **11** (FW 747) and the 1:1 mixture of **10** and **11** at 40 mM was 840 and 730, respectively and suggested that the assembly formation of **4** and **10** was mediated by the BA moiety.

NMR studies of the 1:1 mixture of **4** and **10** in CD_2Cl_2 were also performed at various concentrations (Figure 4). The chemical shift of the N–H protons of **10** was observed at 6.0 ppm at 10 mM, and the N–H signal shifted downfield as the concentration of the mixture increased. This suggests that the TAP moiety of **10** was involved in the assembly formation and hydrogen bonding between the BA of **4** and the TAP of **10** mediated the self-assembly.

The ability of TAP **10** to dissolve the assembly was also shown by dissolution of an equimolar mixture of **3** and **10** in dichloroethane to give a 10 mM solution upon heating and then cooling to rt, though without **10**, a significant amount of **3** remained as a precipitate after the same protocol.

In conclusion, solution-phase assembly of a Rh complex was achieved using specific hydrogen bonding between BA and TAP moieties. By tuning the substituent on TAP, the solubility of the formed assembly in organic solvents was greatly enhanced. The VPO measurement revealed that ca. 2:2 assembly of Rh complex **4** and TAP derivative **10** was formed in dichloroethane. Application of the strategy to self-assemble other transition-metal complexes and examination of their catalytic activities are in progress.

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