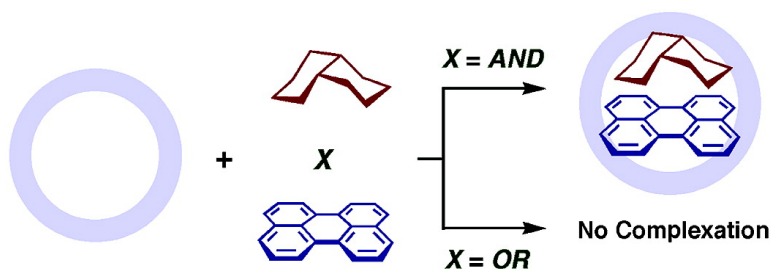


AND/OR Bimolecular Recognition

Michito Yoshizawa, Masazumi Tamura, and Makoto Fujita

J. Am. Chem. Soc., **2004**, 126 (22), 6846-6847 • DOI: 10.1021/ja048860t • Publication Date (Web): 14 May 2004

Downloaded from <http://pubs.acs.org> on March 31, 2009



More About This Article

Additional resources and features associated with this article are available within the HTML version:

- Supporting Information
- Links to the 10 articles that cite this article, as of the time of this article download
- Access to high resolution figures
- Links to articles and content related to this article
- Copyright permission to reproduce figures and/or text from this article

[View the Full Text HTML](#)

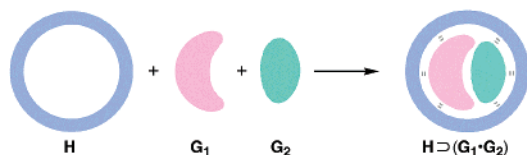
AND/OR Bimolecular Recognition

Michito Yoshizawa, Masazumi Tamura, and Makoto Fujita*

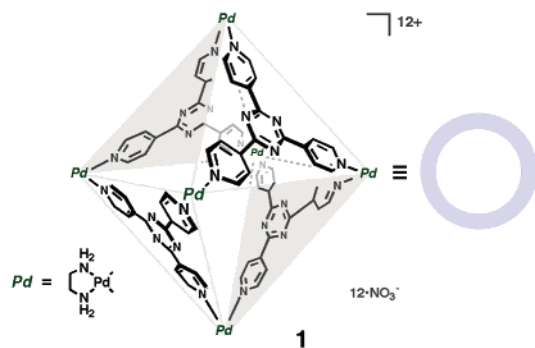
School of Engineering, The University of Tokyo, and CREST, Japan Science and Technology Corporation (JST), Hongo, Bunkyo-ku, Tokyo 113-8656, Japan

Received February 29, 2004; E-mail: mfujita@appchem.t.u-tokyo.ac.jp

Bimolecular recognition is termed for host–guest interaction where a host recognizes two different guests in a single binding pocket. The two guests may or may not interact with each other, but their spatial orientation and the binding ratio are restricted by the host. Such a recognition process¹ is essential to heterotropic allosteric binding and potentially applicable to, for example, simultaneous sensing of two substrates^{2,3} and chemical reactions^{4–6} between two different substrates. Previous examples of bimolecular recognition are in most cases limited to the binding of small molecules because the recognition sites of artificial hosts are, in general, too small to bind two or more common organic guests at will.^{1–8}



Bimolecular recognition can be further classified into two cases depending on whether the host can bind *either or neither* of the guests individually. We term these two cases AND and OR bimolecular recognition by analogy with AND/OR logic gates.^{9,10} In the AND bimolecular recognition, host **H** cannot bind each of two guests, **G**₁ and **G**₂; nevertheless, it forms a stable **H**⊃(**G**₁·**G**₂) complex. Thus, the complexation takes place only if **G**₁ and **G**₂ exist (Table 1a). This rare event has been observed only for the coencapsulation of gaseous hydrocarbon.^{1b} In the OR bimolecular recognition, the host can bind either of two guests, and hence, complexation takes place if **G**₁ or **G**₂ exist (Table 1b). Here we demonstrate that a self-assembled M₆L₄-type coordination cage (**1**), which assembles from six (en)Pd²⁺ and four exo-tridentate ligands, with a large hydrophobic cavity, experiences both AND and OR bimolecular recognition. The unique and efficient binding of large neutral guests by cage **1** has been well-discussed previously.^{6,11}



A typical example of AND bimolecular recognition is given for a case: **G**₁ = *cis*-decalin (**2**) and **G**₂ = perylene (**3**). Each of them was not recognized by cage **1** at all, even at elevated temperature

Table 1. “Truth Tables” for AND and OR Bimolecular Recognitions

(a) AND			(b) OR		
G ₁ ^a	G ₂ ^a	recognition ^b	G ₁ ^a	G ₂ ^a	recognition ^b
Y	Y	Y	Y	Y	Y
Y	N	N	Y	N	Y
N	Y	N	N	Y	Y
N	N	N	N	N	N

^a Y/N denotes the presence/absence of the guest. ^b Y/N denotes that recognition occurs/does not occur.

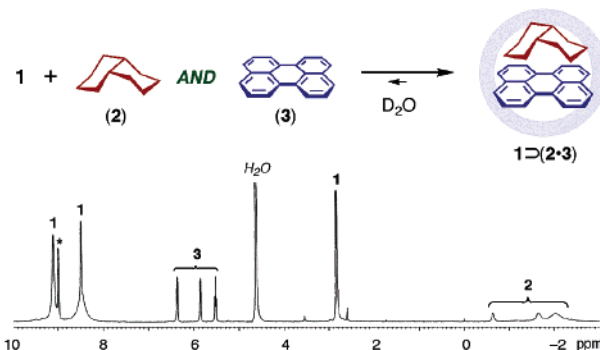


Figure 1. Schematic representation of AND bimolecular recognition of *cis*-decalin (**2**) and perylene (**3**) in cage **1**, and ¹H NMR spectrum (500 MHz) of **1**⊃(**2**·**3**) complex in D₂O at rt (*: free cage **1**).

(80 °C). However, when a suspension of **2** and **3** (~10-fold excess each) in a D₂O solution of cage **1** (5 mM) was stirred for 30 min at room temperature, the color of the solution turned red (as discussed later). ¹H NMR spectrum of the solution showed highly upfield-shifted signals for **2** (at –0.6 to –2.0 ppm) and **3** (at 5.5–6.4 ppm). The complex can be formulated as **1**⊃(**2**·**3**) because the ratio **1**:**2**:**3** in the inclusion complex was estimated to be 1:1:1 by NMR. The yield of **1**⊃(**2**·**3**) complex was 67% based on **1**, which was enhanced to be 92% when the complexation was carried out at 80 °C (Figure 1a). The co-enclathration of **2** and **3** was strongly supported by NOE correlation observed between them.

The formation of **1**⊃(**2**·**3**) complex was clearly indicated by the color change from colorless to red (Figure 2) and by the appearance of a new absorption band at λ_{max} = 437 nm (ε = 5500 M^{–1} cm^{–1}) and the shoulder in the UV–vis spectrum, which are attributed to charge transfer between **1** and **3**. Of course, no coloration and UV–vis change was observed when cage **1** was treated with **2** or **3** individually (Figure 2b).

The AND bimolecular recognition is commonly observed when one guest is a large aromatic compound and another is an appropriate aliphatic compound. For example, combination of **2** with pyrene (**4**), triphenylene (**5**), and coronene (**6**) afforded **1**⊃(**2**·**4**), **1**⊃(**2**·**5**), and **1**⊃(**2**·**6**) complexes in ~100, 85, and 32% yields, respectively (Figure 3a,b). A linear alkane, hexane (**7**), was also included with **4** in an AND fashion in 68% yield (Figure 3c).

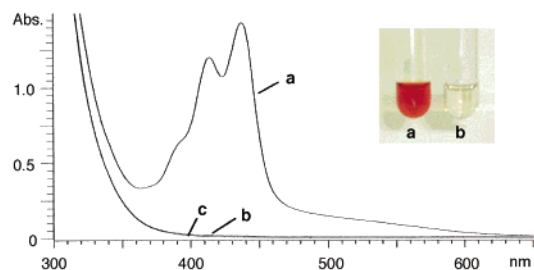


Figure 2. UV-vis spectra and coloration of AND bimolecular recognition (H_2O , rt): (a) $1 \supset (\text{cis-decalin } (2) \cdot \text{perylene } (3))$, (b) 1 after treated with 3 (suspension), and (c) untreated 1 .

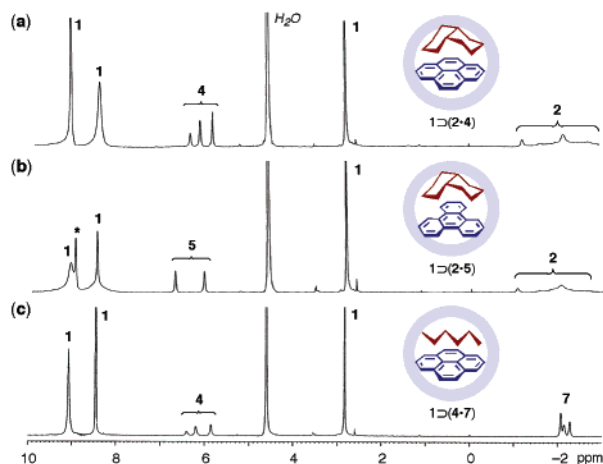


Figure 3. ^1H NMR spectra of AND bimolecular recognition (500 MHz, D_2O , rt): (a) $1 \supset (2 \cdot 4)$, (b) $1 \supset (2 \cdot 5)$, and (c) $1 \supset (4 \cdot 7)$ complexes (*: free cage 1).

Despite conformational freedom of **7**, the signals of the two guests in $1 \supset (4 \cdot 7)$ were correlated by NOESY, indicating a tight complexation in **1**.¹²

OR bimolecular recognition is also observed when two guests are relatively small aromatic molecules. For instance, azulene (**8**) and 1,4-naphthoquinone (**9**) are individually recognized by **1** to afford $1 \supset (8)_2$ and $1 \supset (9)_2$ complexes, respectively (Figure 4a,b). When **1** was treated with a mixture of **8** and **9**, neither $1 \supset (8)_2$ or $1 \supset (9)_2$ was observed, but a new inclusion complex was formed which included **8** and **9** in a 1:1 ratio (Figure 4c).⁶ This newly formed complex is assigned as $1 \supset (8 \cdot 9)$ because of the observation of clear NOE by NOESY.¹³

Indeed, AND/OR bimolecular recognition provides a prototypical molecular logic gate. Since previous logic gates work upon the action of two different ions (e.g., cation/proton or cation/anion), the output is derived from the physical property changes of hosts, which may be disturbed by other ionic stimuli.^{9,10} In contrast, the output in our system comes from the intrinsic nature of input molecules and, hence, is much less disturbed. More importantly, by combining with physical or chemical interactions between two input molecules, physical properties of reaction products can be generated as outputs of the bimolecular recognition. Development of such new properties and chemical reactions through bimolecular recognition is being actively studied in due course.

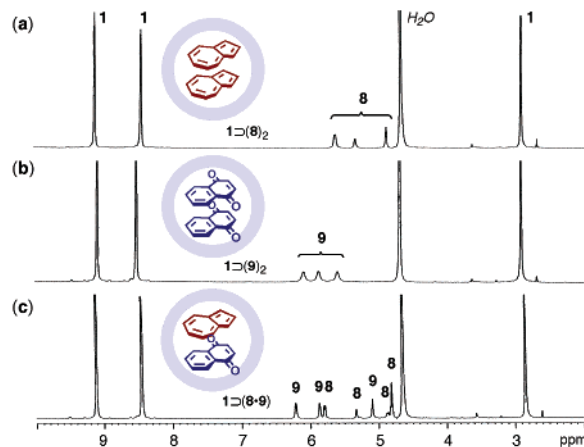


Figure 4. ^1H NMR spectra of OR bimolecular recognition (500 MHz, D_2O , rt): (a) $1 \supset (\text{azulene } (8))_2$, (b) $1 \supset (1,4\text{-naphthoquinone } (9))_2$, and (c) $1 \supset (8 \cdot 9)$ complexes.

Acknowledgment. This work was financially supported by a Grant-in-Aid for Scientific Research (S), No. 14103014 from the Ministry of Education, Culture, Sports, Science, and Technology of Japan.

Supporting Information Available: Experimental details and spectroscopic data. This material is available free of charge via the Internet at <http://pubs.acs.org>.

References

- (1) (a) Heinz, T.; Rudkevich, D. M.; Rebek, J., Jr. *Nature* **1998**, *394*, 764. (b) Shivanyuk, A.; Scarso, A.; Rebek, J., Jr. *Chem. Commun.* **2003**, 1230.
- (2) Kim, H.-J.; Heo, J.; Jeon, W. S.; Lee, E.; Kim, J.; Sakamoto, S.; Yamaguchi, K.; Kim, K. *Angew. Chem., Int. Ed.* **2001**, *40*, 1526.
- (3) Fenyvesi, E.; Szente, L.; Russell, N. R.; McNamara, M. *Comprehensive Supramolecular Chemistry*; Szejtli, J., Osa, T., Eds.; Pergamon: Oxford, UK, 1996; Vol. 3, Chapter 10.
- (4) (a) Mackay, L. G.; Wylie, R. S.; Sanders, J. K. M. *J. Am. Chem. Soc.* **1994**, *116*, 3141. (b) Walter, C. J.; Sanders, J. K. M. *Angew., Chem. Int. Ed. Engl.* **1995**, *34*, 217.
- (5) (a) Kang, J.; Rebek, J., Jr. *Nature* **1997**, *385*, 50. (b) Kang, J.; Hilmersson, G.; Santamaria, J.; Rebek, J., Jr. *J. Am. Chem. Soc.* **1998**, *120*, 3650.
- (6) Yoshizawa, M.; Takeyama, T.; Okano, T.; Fujita, M. *J. Am. Chem. Soc.* **2003**, *125*, 3243.
- (7) Ebbing, M. H. K.; Villa, M.-J.; Valpuesta, J.-M.; Prados, P.; de Mendoza, J. *Proc. Natl. Acad. Sci. U.S.A.* **2002**, *99*, 4962.
- (8) Atwood, J. L.; Szumna, A. *Chem. Commun.* **2003**, 940.
- (9) Molecular AND logic gates: (a) de Silva, A. P.; Gunaratne, H. Q. N.; McCoy, C. P. *Nature* **1993**, *364*, 42. (b) Iwata, S.; Tanaka, K. *Chem. Commun.* **1995**, 1491. (c) Inouye, M.; Akamatsu, K.; Nakazumi, H. *J. Am. Chem. Soc.* **1997**, *119*, 9160. (d) Cooper, C. R.; James, T. D. *Chem. Commun.* **1997**, 1419.
- (10) Molecular OR logic gates: (a) de Silva, A. P.; Gunaratne, H. Q. N.; Maguire, G. E. M. *Chem. Commun.* **1994**, 1213. (b) Ghosh, P.; Bharadwaj, P. K.; Mandal, S.; Ghosh, S. *J. Am. Chem. Soc.* **1996**, *118*, 1553.
- (11) Our recent reports: (a) Kusakawa, T.; Yoshizawa, M.; Fujita, M. *Angew. Chem., Int. Ed.* **2001**, *40*, 1879. (b) Yoshizawa, M.; Takeyama, T.; Kusakawa, T.; Fujita, M. *Angew. Chem., Int. Ed.* **2002**, *41*, 1347. (c) Kusakawa, T.; Fujita, M. *J. Am. Chem. Soc.* **2002**, *124*, 13576.
- (12) We suggest that a planar aromatic guest gains stabilization by stacking on the ligand while a flexible aliphatic guest enhances it by filling the void. Such cooperation of the two different guests can account for the AND bimolecular recognition.
- (13) Guests **3–5** are too large to self-associate in the cavity. Thus, only AND recognition takes place. In contrast, relatively small **8** or **9** can self-associate in the cavity and experience OR recognition, where donor–acceptor stacking between **8** and **9** may be important.

JA048860T