A novel light-gated sugar receptor, which shows high glucose selectivity

Hideyuki Shinmori, Masayuki Takeuchi and Seiji Shinkai *

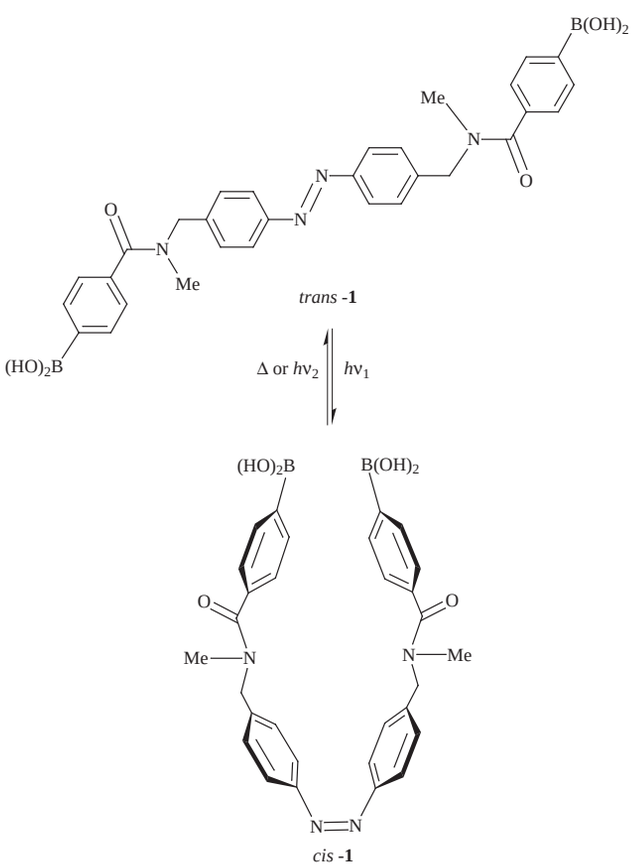
Department of Chemical Science & Technology, Faculty of Engineering, Kyushu University, Fukuoka 812, Japan

A bis(boronic acid)-based saccharide receptor (1) bearing a photoresponsive azobenzene moiety has been synthesised, aiming at the photocontrol of the saccharide-binding properties by the distance change between the two boronic acids. *trans*-1 is wholly CD-silent in the presence of various saccharides whereas *cis*-1 yielded CD-active species with D-glucose and D-allose in aqueous pH 10.5 solution and with D-glucose in methanol. The findings indicate that the two boronic acids in *cis*-1 can act cooperatively to selectively recognise these saccharides by the formation of the cyclic 1 : 1 complexes. *cis*-to-*trans* thermal isomerisation slowly takes place in methanol ($k_o = 2.1 \times 10^{-6}$ s^{-1}) but the rate is extremely slow in aqueous pH 10.5 solution (half-life 8.7 days). In methanol the rate is retarded only by D-glucose which forms a macrocyclic 1 : 1 complex with *cis*-1. In aqueous pH 10.5 solution the *cis*-to-*trans* isomerisation could be induced virtually only by visible-light irradiation, indicating that this system is useful as a light-gated saccharide receptor.

Introduction

The specific interaction between phenylboronic acids and saccharides or related compounds has been attracting increasing attention as a novel force for sugar recognition in aqueous systems.[1–8] Since one phenylboronic acid reacts with two OH groups to form a cyclic boronate ester, monosaccharides usually bearing five OH groups tend to form 1 : 2 monosaccharide–phenylboronic acid complexes.[1,9–13] However, the stability order of these complexes is always the same, which is governed by the inherent structure of monosaccharides.[2–4,14,15] Of such monosaccharides, fructose has a high association constant whereas glucose has a low association constant.[14,15] In contrast, diboronic acids which can react with four of the five OH groups to form intramolecular 1 : 1 complexes show a different stability order, which is related to the specific spatial position of two boronic acid groups. This implies that one can recognise a specific monosaccharide by appropriate manipulation of two boronic acids in the same molecule. This idea was first realised with 3,3′-methylenediphenylboronic acid which showed the highest affinity towards glucose.[9] The finding offers a new potential working-hypothesis that the desired monosaccharide may be selectively captured by adjusting the spatial position of two boronic acids to the distance complementary to that of the OH groups in the monosaccharide of concern.[1]

In the 1980s we were very much interested in the design and functions of various 'photoresponsive crown ethers'.[16] The basic idea of this research was to manipulate the shape of monocrown ethers or the distance of two crown ethers by light-triggered *cis–trans* interconversion of the integrated azobenzene moiety. For example, *trans*-azobis(benzocrown ether)s tend to form one metal–one crown complexes whereas *cis*-azobis(benzocrown ether)s tend to form one metal–two crowns sandwich complexes due to the shortened crown–crown distance.[17,18] As a result, metal selectivity was successfully interconverted by a light switch.[17,18] It thus occurred to us that if the distance between two boronic acid groups could be changed by a photofunctional azobenzene segment, saccharide selectivity should also be changeable in response to photoirradiation. Furthermore, saccharide recognition is favourably carried out in aqueous media: therein, *cis–trans* thermal isomerisation is virtually inhibited[19] but *cis–trans* photoisomerisation can be induced by irradiation with visible light.[16–19] One may thus consider that two forms can be interconverted only through a light-triggered gate. With these objects in mind we designed and synthesised compound **1**. We have found that *cis*-**1** generated



through the light gate can bind glucose and allose with very high selectivity.[20]

Results and discussion

Molecular design

It is known that the distance between 4,4′-carbons in *trans*-

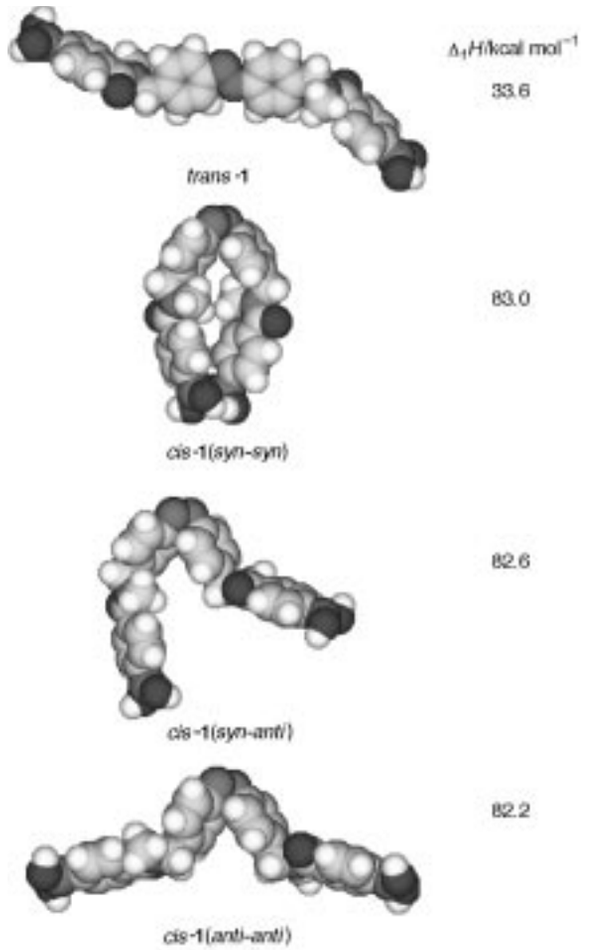


Fig. 1 Structures of *trans*-**1** and *cis*-**1** energy-minimised with MM3

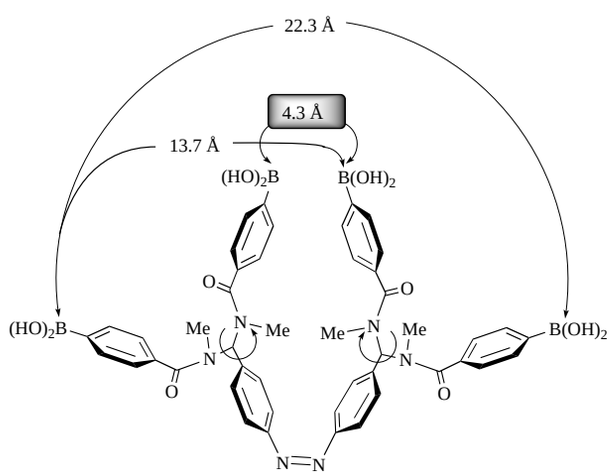


Fig. 2 Distance between two boronic acid groups

azobenzene is 9.0 Å whereas that in *cis*-azobenzene is shortened to 5.5 Å.[21] In *trans*-**1** two boronic acid groups cannot get close enough to act cooperatively to form intramolecular 1 : 1 complexes with monosaccharides (the size is *ca.* 4 Å). Computational studies on *cis*-**1** with MM3 suggested that this compound can adopt three different conformations (*syn–syn*, *syn–anti* and *anti–anti*: Fig. 1), the distance between these two boronic acid groups being 4.3, 13.7 and 22.3 Å, respectively (Fig. 2). Since the total heat of formation ($\Delta_f H$) is not much different among three conformers (83.0 kcal mol^{-1} for *syn–syn*, 82.6 kcal mol^{-1} for *syn–anti* and 82.2 kcal mol^{-1} for *anti–anti*), one can consider that these three conformers freely interconvert

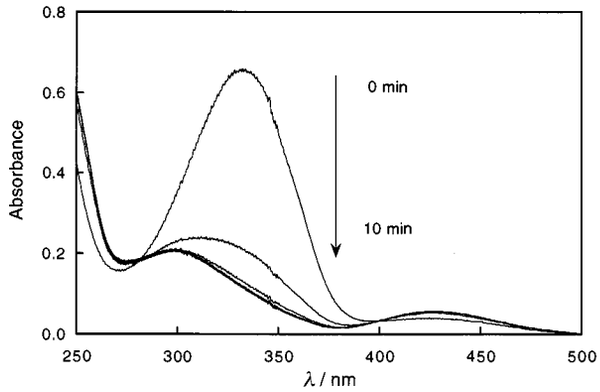


Fig. 3 Photochemical *trans–cis* isomerisation: [*trans*-**1**] = 2.50 × 10^{-5} mol dm^{-3}, pH 10.5 with 50 mmol dm^{-3} carbonate buffer, water : DMSO = 100 : 1 v/v, 25 °C

at room temperature. Judging from the agreement between the size of monosaccharides and the distance between the two boronic acid groups, it is expected that only the *syn–syn* form of *cis*-**1** can form intramolecular 1 : 1 complexes with selected monosaccharides.

Photo and thermal isomerisation in aqueous media

The absorption spectra of *trans*-**1** were measured in water–DMSO (0 : 100–120 : 1 v/v) mixed solvents, but the spectral shape was scarcely affected by the solvent composition variation (λ_{max} 335 ± 1 nm). Here, the effect of the *trans*-**1** concentration on the absorption spectrum was estimated in water–DMSO (100 : 1, v/v). The ε_{334} increased linearly with increasing *trans*-**1** concentration (up to 3.0 × 10^{-5} mol dm^{-3} : ε_{334} = 26 300 dm^3 mol^{-1} cm^{-1}), indicating that this system satisfies the Beer–Lambert law. These results support the view that *trans*-**1** is discretely dissolved in this medium under the measurement conditions. Thus, we decided to choose [*trans*-**1**] = 2.50 × 10^{-5} mol dm^{-3} and water : DMSO = 100 : 1 v/v as standard measurement conditions.

As shown in Fig. 3, *trans*-**1** was photoisomerised to *cis*-**1** by irradiation with a high-pressure Hg-lamp (400 W) through a visible filter (300 < λ < 400 nm). The photostationary state was reached in 3 min, where the *cis* concentration was estimated to be 83%.† *cis–trans* thermal isomerisation was so slow that we could not determine the absorbance at infinite time. If one can assume that the absorbance at infinite time is equal to that of *trans*-**1**, the half-life is computed to be 8.7 days. One can thus regard the *cis–trans* thermal isomerisation as being virtually inhibited in this medium. In contrast, *cis–trans* photoisomerisation was induced very easily by irradiation with a high-pressure Hg-lamp (400 W) through a UV filter (λ > 450 nm: Fig. 4). One may thus consider that both *trans–cis* and *cis–trans* transformations are mediated only by light irradiation and the direction can be determined by the wavelength.

Saccharide sensing using CD spectroscopy in aqueous media

The computational studies with MM3 predict that the distance between two boronic acid groups in *cis*-**1** with a *syn–syn* conformation is 4.3 Å, which is comparable with the size of monosaccharides. This molecular design offers an idea that the two boronic acid groups in *cis*-**1** would tweeze one monosaccharide, forming a macrocyclic 1 : 1 *cis*-**1**–monosaccharide complex.[1–16]

The CD spectra of *trans*-**1** were measured in the presence of the eight saccharides illustrated. In an aqueous medium, however, *trans*-**1** did not exhibit any CD-activity. In contrast, *cis*-**1** became CD-active with D-glucose and D-allose [Fig. 5(A)]. It has firmly been established that in these diboronic acid recep-

† This *cis* percentage was calculated from the absorbance at the absorption maximum of *trans*-**1**, assuming that the *A* of *cis*-**1** is negligible in comparison with that of *trans*-**1**.

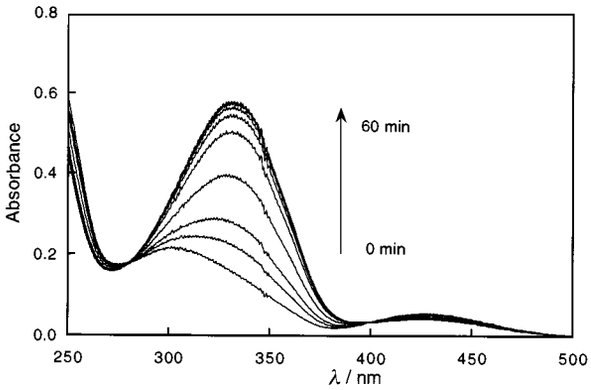
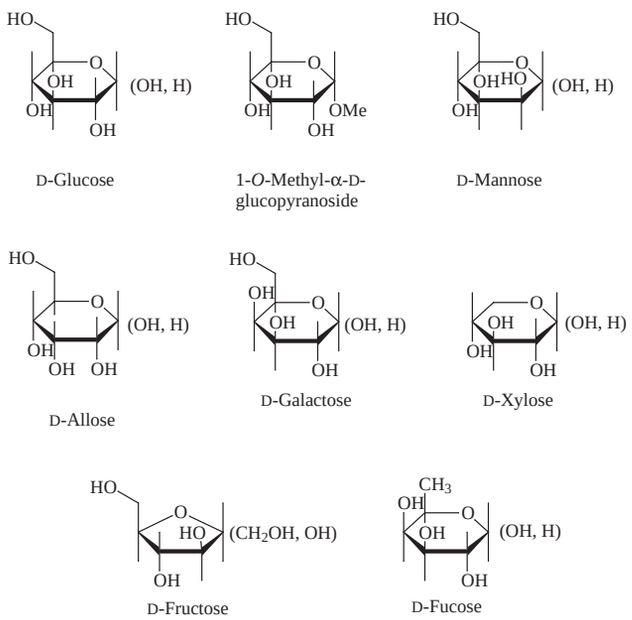


Fig. 4 Photochemical *cis*-to-*trans* isomerisation: [*cis*-**1** (83%) + *trans*-**1** (17%)] = 2.50×10^{-5} mol dm^{-3}. Other measurement conditions are recorded in the caption to Fig. 3.



tors the CD-activity appears only when two boronic acid groups form a macrocyclic complex with the saccharide and the molecular motion of the chromophoric moiety in the resultant macrocycle is suppressed.[1,6,8,9,11–13] One may thus consider that these two saccharides form macrocyclic 1 : 1 complexes with *cis*-**1**. In an aqueous medium the CD bands appeared at λ_{max} 249 and 427 nm: the 427 nm band coincides with the absorption maximum of *cis*-**1** (427 nm: n–π* transition band). The CD spectrum for D-glucose is the mirror image of that of L-glucose and stronger than that for D-allose. Careful comparison of the structure of the eight saccharides reveals that only D-glucose and D-allose have 1,2-*cis*-diol and 4,6-*trans*-diol groups which are indispensable to the formation of macrocyclic complexes.[1,12,13] D-Mannose, D-allose and D-galactose are epimers of D-glucose with a single difference in configuration at C-2, C-3 and C-4, respectively, but only D-allose retains 1,2-*cis*-diol and 4,6-*trans*-diol groups. Furthermore, 1-*O*-methyl-α-D-glucopyranoside, in which 1-OH is protected by a methyl group, cannot form an intramolecular 1 : 1 complex with *cis*-**1** and therefore is CD-silent. The CD-silence for D-xylose and D-fucose without 6-OH is explicable on the same basis. These results consistently support the view that two boronic acid groups in *cis*-**1** bind to 1,2-*cis*-diol and 4,6-*trans*-diol moieties to form CD-active macrocyclic complexes (Fig. 6).

Fig. 7 shows plots of the CD intensity *vs.* saccharide concentration. It is clearly seen from Fig. 7 that the concentration dependence is biphasic. A similar concentration dependence is frequently seen for many diboronic acid receptors, which indicates that the major species changes from a CD-active macro-

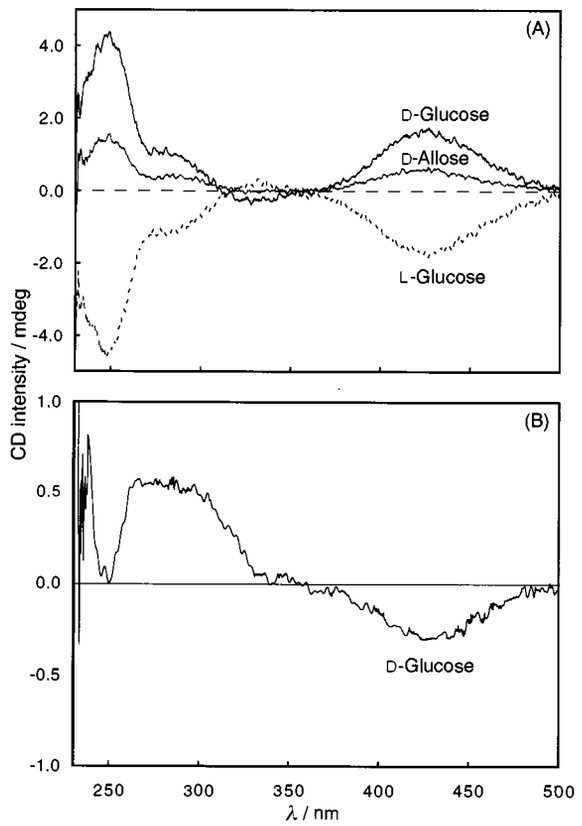
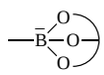


Fig. 5 CD spectra of **1** (2.50×10^{-5} mol dm^{-3}) in (A) water : DMSO = 100 : 1 v/v (pH 10.5 with 50 mmol dm^{-3} carbonate buffer, 83% *cis*-**1**) and (B) methanol : DMSO = 100 : 1 v/v (86% *cis*-**1**) : [saccharide] = 0.010 mol dm^{-3}, 25 °C

cyclic 1 : 1 complex in the low concentration region into a CD-silent noncyclic 1 : 2 complex in the high concentration regions (as shown in Fig. 6).[1,6,8,9,11–13,22,23] In Fig. 7, the CD maximum appears at 0.03 mol dm^{-3} for D-glucose and at 0.004 mol dm^{-3} for D-allose. This difference indicates that the relative stability of the macrocyclic 1 : 1 complex with respect to the noncyclic 1 : 2 complex is higher in D-glucose than in D-allose. The plots in Fig. 7 were analysed using a non-linear least-squares method[24] to estimate K_1 (= [*cis*-**1**·saccharide]/[*cis*-**1**][saccharide]) and K_2 (= [*cis*-**1**·(saccharide)$_2$]/[*cis*-**1**·saccharide][saccharide]). The concentration of *cis*-**1** was corrected for that at the photostationary state (*vide supra*). Thus, $K_1 = 4.6 \times 10^2$ and $K_2 = 10$ for D-glucose and $K_1 = 2.0 \times 10^3$ and $K_2 = 48$ for D-allose (in dm^3 mol^{-1}) were obtained in aqueous pH 10.5 solution. It is known that there is a specific affinity order for the complexation between monoboronic acids and monosaccharides[14] and the affinity with D-allose is generally greater than that with D-glucose.[13,25] As the K_2 values should reflect this affinity order, it is reasonable that the K_2 for D-allose is greater than that for D-glucose (by 4.8-fold). On the other hand, it is difficult to reasonably explain why the K_1 for D-allose is greater than that for D-glucose (by 4.3-fold). In these macrocyclic 1 : 1 complexes the lower side of the pyranose ring (*i.e.* the direction of 2-OH and 4-OH) faces the azobenzene moiety. The difference between D-glucose and D-allose is that in regard to the azobenzene moiety, 3-OH in the D-glucose complex is directed in the opposite direction whereas that in the D-allose complex is directed in the same direction. This steric configuration may allow 3-OH in D-allose to contribute to the complexation with the boronic acid groups by forming a tripodal linkage (**X**).[26] We consider that this contri-



X

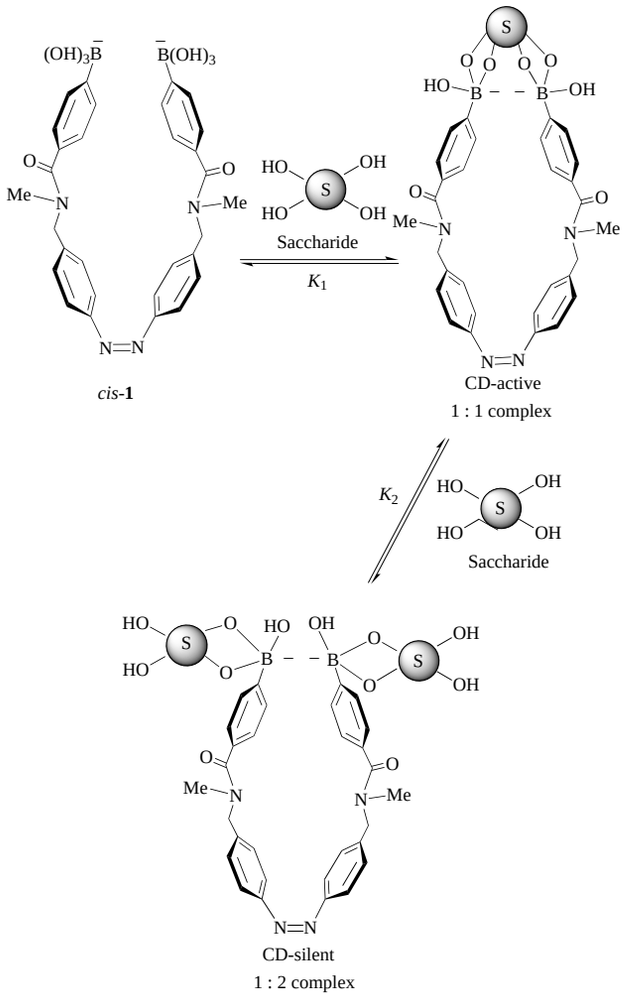


Fig. 6 Saccharide-binding processes in *trans*-**1** and *cis*-**1**. In methanol boronic acids form sp^2-hybridised neutral boronate esters whereas in aqueous pH 10.5 solution they form sp^3-hybridised OH^- adducts (as illustrated here). The furanose *vs.* pyranose selectivity[12,13] is not specified in this study.

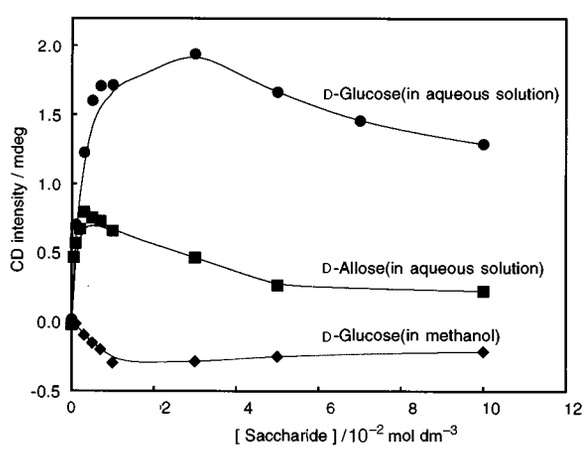


Fig. 7 Plots of the CD maximum (at 427 nm) in the aqueous medium and the CD minimum (at 424 nm) in methanol. The measurement conditions are recorded in the caption to Fig. 5.

bution is responsible for the K_1 enhancement observed for the D-allose complex. As seen in Fig. 7, however, the maximum CD intensity for D-allose is weaker than that for D-glucose and the competitive formation of the CD-silent 1:2 complex starts at the lower concentration region.

Saccharide binding and *cis–trans* thermal isomerisation in methanol

In methanol (λ_{max} 328 nm, $\varepsilon_{328} = 27\,700$ dm^3 mol^{-1} cm^{-1} for

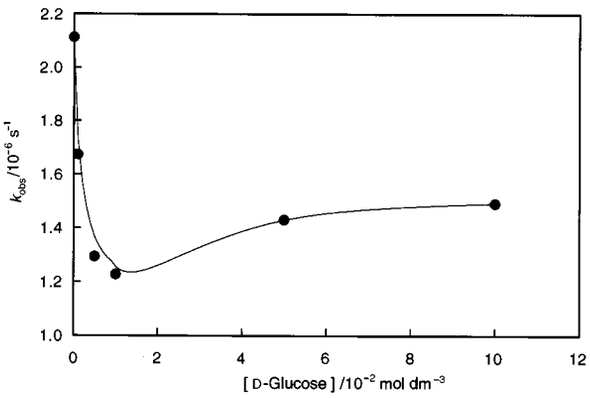
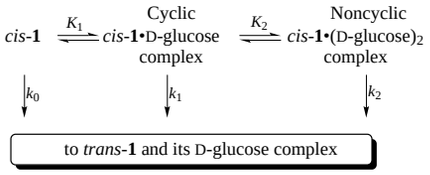


Fig. 8 Plot of k_{obs} (first-order rate constant for thermal *cis–trans* isomerisation of *cis*-**1**) *vs.* [D-glucose]:[*trans*-**1** + *cis*-**1**] = 2.50×10^{-5} mol dm^{-3}, methanol:DMSO = 100:1 v/v, 25 °C

trans-**1**), the photostationary state with 86% *cis*-**1** was attained in 4 min by irradiation with a high-pressure Hg-lamp (400 W) through a visible filter ($300 < \lambda < 400$ nm). As expected from previous work,[16–19] *cis–trans* thermal isomerisation occurred according to first-order kinetics at an appreciable rate. The first-order rate constant (k_o) was estimated to be 2.1×10^{-6} s^{-1} at 25 °C. *trans*-**1** was wholly CD-silent in the absence of any of the eight saccharides. For *cis*-**1** appreciable CD bands were observed only for D-glucose and the intensity was much weaker than that in the aqueous medium [Fig. 5(B)]. Furthermore, the CD sign at n–π* transition region (424 nm) was negative in contrast to the positive sign in the aqueous medium. These results are all associated with the difference in the complexation mode in organic media: in contrast to the formation of sp^3-hybridised anionic boronates in aqueous media, sp^2-hybridised neutral boronates are formed in organic media. Taking this difference into account, one can reasonably elucidate the results obtained in methanol. Firstly, the linkage with the sp^2-hybridised one is more rigid than that with the sp^3-hybridised one.[1,9,22,23] This situation destabilises the D-glucose complex (weak CD intensity) in methanol and changes the structure around the chromophoric azobenzene moiety (negative CD sign). Secondly, in the D-allose complex the formation of a tripodal sp^3-hybridised linkage becomes impossible in methanol. This situation should particularly destabilise the D-allose complex. In fact, *cis*-**1** was CD-silent even in the presence of D-allose (0–0.1 mol dm^{-3}). In Fig. 7, the CD minimum value (at 424 nm) is plotted against the D-glucose concentration. The analysis of this plot using a non-linear least-squares method[24] gave $K_1 = 1.2 \times 10^2$ and $K_2 = 14$ (in dm^3 mol^{-1}) for D-glucose in methanol. The K_1 value which sensitively reflects the ring strain is smaller by 3.8-fold than that in the aqueous medium (4.6×10^2 dm^3 mol^{-1}) whereas the K_2 value which mainly reflects the affinity with monoboronic acids is not much different (10 dm^3 mol^{-1}).

In azobis(benzocrown ether)s, it is known that the presence of certain alkali metal cations which intramolecularly interact with two crown rings to form a sandwich complex tends to suppress the rate of thermal *cis–trans* isomerisation in organic solvents.[17] In the present system, the rate should be also retarded if *cis*-**1** forms an intramolecular complex with the saccharide. Among the eight monosaccharides tested herein, only D-glucose suppressed the thermal isomerisation rate. A plot of k_{obs} *vs.* [D-glucose] showed a biphasic dependence with a rate minimum at 1.2×10^{-2} mol dm^{-3} (Fig. 8). As already established in several related systems,[1,6,8,9,11–13,22,23] this dependence is also explicable by the formation of a cyclic 1:1 complex at low D-glucose concentration followed by the formation of a non-cyclic 1:2 *cis*-**1**–saccharide complex. This kinetic pattern can be expressed as in Scheme 1.

In Scheme 1, the K_1, K_2 and k_0 values have already been determined. Thus, one can estimate k_1 and k_2 using a non-linear



Scheme 1

least-squares computation method.[24] The plot in Fig. 8 was best simulated with $k_1 = 6.7 \times 10^{-8}$ s^{-1} and $k_2 = 2.8 \times 10^{-6}$ s^{-1}. The results indicate that the rate of *cis–trans* thermal isomerisation for the macrocyclic *cis*-**1**·D-glucose complex is slower by 31 times whereas that for the acyclic *cis*-**1**·(D-glucose)$_2$ complex is almost comparable with that for *cis*-**1** ($k_0 = 2.1 \times 10^{-6}$ s^{-1}).

Conclusion

The present study has demonstrated that utilising the *cis–trans* transformation of azobenzene, a D-glucose (or D-allose) selective diboronic acid receptor can be generated through a light gate. Furthermore, reverse *cis–trans* isomerisation can be also controlled photochemically by light irradiation or thermally by D-glucose. Thus, the present system is classified as a novel sugar receptor with a photoresponsive function. We believe that further elaboration of the present system would be useful in designing novel photofunctionalised systems such as light-triggered release or capture of sugars, retention of unstable structures by sugar bridging, light-mediated selective extraction of sugars, *etc.*

Experimental

4,4′-Bis[(*N*-methyl)aminomethyl]azobenzene 2

Methylamine was continuously introduced into a DMF solution (100 ml) containing 4,4′-bis(chloromethyl)azobenzene[27] (1.80 g, 6.45 mmol) for 10 h. The evaporation of this solution resulted in an orange powder, which was recrystallised from chloroform–hexane: yield 59%, mp 78.1–81.1 °C; ν_{max}/cm^{-1} (KBr disk) 3250 (NH), 1590 (N=N); δ_H(250 MHz, $CDCl_3$, 27 °C) 2.48 (6H, s, NCH_3), 3.83 (4H, s, NCH_2), 7.46 and 7.88 (4H each, d each, *J* 8.26 Hz, ArH) (Found: C, 71.4; H, 7.3; N, 20.2. $C_{16}H_{20}N_4$·0.1H_2O requires C, 71.1; H, 7.5; N, 20.7%).

4,4′-Bis[(4-dihydroxyboryl)benzoyl-(*N*-methyl)aminomethyl]-azobenzene (*trans*-1)

4-Carboxyphenylboronic acid (445 mg, 2.68 mmol) was converted to 4-chlorocarbonylphenylboronic acid by treatment with thionyl chloride in the presence of a few drops of DMF.[28] This compound was dissolved in dry THF (20 ml) and to this solution cooled in an ice-bath was added dropwise a THF solution (20 ml) containing **2** (300 mg, 1.12 mmol) and pyridine (0.26 ml, 3.22 mmol). After the addition, the reaction mixture was stirred at room temp. for 17 h. The precipitate was removed by filtration, the filtrate being evaporated to dryness. The resultant orange solid was recrystallised from methanol–water: yield 32%, mp 241.1–243.3 °C; ν_{max}/cm^{-1} (KBr disk) 3100–3650 (OH), 1620 (C=O), 1580 (N=N), 1340 (B–O); δ_H(400 MHz, [$^2H_6$]-DMSO, 100 °C) 2.97 (6H, s, NCH_3), 4.69 (4H, s, NCH_2), 7.39 and 7.89 (4H each, d each, *J* 8.39 Hz, ArH of azobenzene), 7.48 and 7.83 (4H each, d each, *J* 8.09 Hz, ArH of phenylboronic acid), 7.68 [4H, br s, $B(OH)_2$] (Found: C, 62.9; H, 5.5; N, 9.7. $C_{30}H_{30}B_2N_4O_6$·0.5H_2O requires C, 62.9; H, 5.5; N, 9.8%).

Miscellaneous

trans–cis photoisomerisation was conducted by UV light obtained from a 400 W high-pressure Hg-lamp through a glass filter (Toshiba UV-D35). *cis–trans* photoisomerisation was conducted by visible light obtained from the same Hg-lamp through a glass filter (Toshiba No. 45). To avoid the temperature rise caused by light illumination, the cuvette was immersed in a water bath (at 25 °C) of a glass vessel. In *cis–trans* thermal isomerisation in methanol the absorbance was measured for a few seconds per 1.0 h to obviate *trans–cis* photoisomerisation by light (328 nm) from the spectrometer. The energy minimisation of *trans*-**1** and *cis*-**1** was carried out with AccuModel version 1.0 on a Macintosh computer.

Acknowledgements

This work was supported by a Grant-in-Aid for COE Research 'Design and Control of Advanced Molecular Assembly Systems' from the Ministry of Education, Science and Culture, Japan (No. 08CE2005). We thank Professor M. Irie for helpful discussions on photoisomerisation of azobenzene.

References

1 For recent comprehensive reviews see T. D. James, K. R. A. S. Sandanayake and S. Shinkai, *Supramol. Chem.*, 1995, **6**, 141; T. D. James, P. Linnane and S. Shinkai, *Chem. Commun.*, 1996, 281; T. D. James, K. R. A. S. Sandanayake and S. Shinkai, *Angew. Chem., Int. Ed. Engl.*, 1996, **35**, 1910.
2 J. Yoon and A. W. Czarnik, *J. Am. Chem. Soc.*, 1992, **114**, 5874; L. K. Mohler and A. W. Czarnik, *J. Am. Chem. Soc.*, 1993, **115**, 2998.
3 M. F. Paugan and B. D. Smith, *Tetrahedron Lett.*, 1993, **34**, 3723; G. T. Morin, M. P. Hughes, M.-F. Paugam and B. D. Smith, *J. Am. Chem. Soc.*, 1994, **116**, 8895; P. R. Westmark and B. D. Smith, *J. Am. Chem. Soc.*, 1994, **116**, 9343.
4 Y. Nagai, K. Kobayashi, H. Toi and Y. Aoyama, *Bull. Chem. Soc. Jpn.*, 1993, **66**, 2965.
5 G. Wulff, B. Heide and G. Helfmeier, *J. Am. Chem. Soc.*, 1986, **108**, 1089; G. Wulff and H.-G. Poll, *Makromol. Chem.*, 1987, **188**, 741.
6 C. R. Cooper and T. D. James, *Chem. Commun.*, 1997, 1419.
7 M. Takeuchi, M. Yamamoto and S. Shinkai, *Chem. Commun.*, 1997, 1731.
8 T. Mizuno, M. Takeuchi, I. Hamachi, K. Nakashima and S. Shinkai, *Chem. Commun.*, 1997, 1793.
9 K. Tsukagoshi and S. Shinkai, *J. Org. Chem.*, 1991, **56**, 4089; Y. Shiomi, M. Saisho, K. Tsukagoshi and S. Shinkai, *J. Chem. Soc., Perkin Trans. 1*, 1993, 2111.
10 T. D. James, T. Harada and S. Shinkai, *J. Chem. Soc., Chem. Commun.*, 1993, 857.
11 K. Nakashima and S. Shinkai, *Chem. Lett.*, 1995, 443; K. R. A. S. Sandanayake, T. D. James and S. Shinkai, *Chem. Lett.*, 1995, 503.
12 J. C. Norrild and H. Eggert, *J. Am. Chem. Soc.*, 1995, **117**, 1479.
13 T. D. James, K. R. A. S. Sandanayake, R. Iguchi and S. Shinkai, *J. Am. Chem. Soc.*, 1995, **117**, 8982 and references cited therein.
14 J. P. Lorand and J. O. Edwards, *J. Org. Chem.*, 1959, **24**, 769.
15 H. Murakami, T. Nagasaki, I. Hamachi and S. Shinkai, *Tetrahedron Lett.*, 1993, **34**, 6273; *J. Chem. Soc., Perkin Trans. 2*, 1994, 975; T. Imada, H. Murakami and S. Shinkai, *J. Chem. Soc., Chem. Commun.*, 1994, 1557; S. Arimori, H. Murakami, M. Takeuchi and S. Shinkai, *J. Chem. Soc., Chem. Commun.*, 1995, 961; S. Arimori, M. Takeuchi and S. Shinkai, *Chem. Lett.*, 1996, 77; *J. Am. Chem. Soc.*, 1996, **118**, 245.
16 For comprehensive reviews see S. Shinkai and O. Manabe, *Top. Curr. Chem.*, 1984, **121**, 67; S. Shinkai, *Cation Binding by Macrocycles*, ed. Y. Inoue and G. W. Gokel, Marcel Dekker, New York, 1990, p. 397.
17 S. Shinkai, T. Nakaji, T. Ogawa, K. Shigematsu and O. Manabe, *J. Am. Chem. Soc.*, 1981, **103**, 111; S. Shinkai, T. Ogawa, Y. Kusano, O. Manabe, K. Kikukawa, T. Goto and T. Matsuda, *J. Am. Chem. Soc.*, 1982, **104**, 1960.
18 S. Shinkai, K. Shigematsu, Y. Kusano and O. Manabe, *J. Chem. Soc., Perkin Trans. 1*, 1981, 3279.
19 T. Asano, T. Okada, S. Shinkai, K. Shigematsu, Y. Kusano and O. Manabe, *J. Am. Chem. Soc.*, 1981, **103**, 5161 and references cited therein.
20 The similar idea was recently reported by M. Takeshita, K. Uchida and M. Irie, *Chem. Commun.*, 1996, 1807. In their system, the saccharide addition is effective to suppress the photochemical ring closure of a diarylethene derivative. In our system, the saccharide addition is effective to suppress the *cis–trans* thermal isomerisation of the high-energy *cis*-form. Furthermore, the *cis*-form is applicable to selective saccharide sensing.
21 J. J. DeLange, J. M. Robertson and I. Woodward, *Proc. Roy. Soc. Ser. A*, 1939, **171**, 398; G. C. Hampson and J. M. Robertson, *J. Chem. Soc.*, 1941, 409.

22 Y. Kondo, Y. Shiomi, M. Saisho, T. Harada and S. Shinkai, *Tetrahedron*, 1992, **48**, 8239; Y. Shiomi, M. Saisho, K. Tsukagoshi and S. Shinkai, *J. Chem. Soc.*, *Perkin Trans. 1*, 1993, 2111.
23 M. Takeuchi, T. Mizuno, H. Shinmori, M. Nakashima and S. Shinkai, *Tetrahedron*, 1996, **52**, 1195; M. Takeuchi, S. Yoda, T. Imada and S. Shinkai, *Tetrahedron*, 1997, **53**, 8335.
24 J. A. Nelder and R. Mead, *Comput. J.*, 1965, **7**, 308; S. L. Morgan and S. N. Deming, *Anal. Chem.*, 1974, **46**, 1170.
25 G. Deng, T. D. James and S. Shinkai, *J. Am. Chem. Soc.*, 1994, **116**, 4567.
26 H. Suenaga, K. Nakashima, M. Mikami and S. Shinkai, *Chem. Lett.*, 1995, 73 and references cited therein.
27 S. Shinkai, S. Nakamura, M. Nakashima, O. Manabe and M. Iwamoto, *Bull. Chem. Soc. Jpn.*, 1985, **58**, 2340.
28 T. Kimura, S. Arimori, M. Takeuchi, T. Nagasaki and S. Shinkai, *J. Chem. Soc.*, *Perkin Trans. 2*, 1995, 1889.

Paper 7/08212F
Received 14*th November* 1997
Accepted 22*nd December* 1997