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The association of 4-(*N*,*N*-dimethylamino)benzonitrile and β-cyclodextrin in dimethyl sulfoxide and *N*,*N*-dimethylformamide

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Abstract

Fluorescence and absorption studies indicate the association between β-cyclodextrin (CD) and 4-(*N*,*N*-dimethylamino)benzonitrile (DMABN) in dimethyl sulfoxide (DMSO) and in *N*,*N*-dimethylformamide (DMF). In DMSO, the fluorescence emission maximum of the host–guest (HG) complex is at 335 nm, and the values of the equilibrium constant and the ΔG^0 at 298 K are $6.0 \pm 0.6\ M^{-1}$ and -4.4 ± 0.2 kJ mol^{-1}, respectively. The process shows a weak favorable enthalpy change, although a reliable entropy measurement was not possible. The DMABN excimer is formed in DMSO at concentrations above 5×10^{-7} M, which presents a broad fluorescence band with maximum around 510 nm. A large increase in the molar absorptivity of DMABN in DMF is observed upon addition of CD. The equilibrium constant in DMF at 298 K equals $10.2 \pm 0.7\ M^{-1}$ and conforms with a 1 : 1 model for complexation.

Keywords: 4-(*N*,*N*-dimethylamino)benzonitrile; β-cyclodextrin; Dimethyl sulfoxide; *N*,*N*-dimethylformamide

1. Introduction:

The mode of interaction between a substrate and a host cannot be known without direct spectroscopic evidence and thermodynamic data [1–14]. In particular, the binding properties of substrates to cyclodextrins can involve processes other than the formation of inclusion complexes. Komiyama and Bender showed, using cyclodextrins with different cavity sizes, that 1-carboxyadamantane binds to the rim of the cavity of α-CD as it does not fit inside its cavity, while the same substrate fits tightly into the cavity of β-CD forming a HG complex [15]. Furthermore, El Baraka et al. found that the binding of the first singlet excited state (the B* state) of DMABN to β-CD is enthalpy driven with a modest unfavorable entropy factor, while the binding of the charge-transfer state (the A* state) is entropy driven and isoenthalpic [16]. Their results tend to indicate that the A* state of DMABN forms a surface complex with β-CD, while the B* state a HG complex. It follows that the formation of a HG complex is not the only possible binding mode between a substrate and a CD. The DMABN–CD system in aqueous solution reflects the importance of solvation effects as well as the charge distribution of the substrate with respect to the nature of the binding interactions. The DMABN–CD binding properties were first examined by Turro and coworkers [17] and Nag et al. [18], whereas the aggregation of two inclusion complexes was studied by Nakamura et al. [19].

Although the literature about substrate–CD binding in water is extensive [20–35], indicating that CD inclusion complex formation in aqueous solutions is generally enthalpy driven, studies in non-aqueous media are scarce even though they represent an important direction in trying to understand solvation effects [36–38]. To this end, in this work we present a study of the DMABN–CD equilibrium in DMSO and in DMF.

2. Experimental methods

β-Cyclodextrin (Aldrich) was used as received, and fluorescence spectra were recorded in DMSO and DMF, 99.9% HPLC grade (Aldrich) to confirm its purity. DMABN (Aldrich) was recrystallized from a 75% ethanol–water solution. DMABN solutions were diluted in order to avoid aggregate formation during fluorescence and absorption studies; this was possible at DMABN concentrations around 3×10^{-7} M. Appearance of an emission band from a DMABN TICT state reported previously in water [16] was not seen with increasing β-CD concentration, indicating that the hydrate content of the CD cavity was not a problem.

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Corrected emission spectra were taken with a SPF-4800 (SLM Aminco) spectrofluorometer. Slit widths of 4 nm were used in both the emission and the excitation monochromators. A water circulator (Brinkman model RM6) was adapted to the spectrofluorometer to keep the temperature of the solutions constant. This device was also used in temperature variation experiments. Absorption spectra were recorded with a Cary 1E UV–Vis (Varian) spectrophotometer.

3. Results and discussion

3.1. Determination of association constants using fluorescence spectroscopy

The formation of a weak complex between DMABN and CD can be represented as:

$$\text{DMABN} + \text{CD} \leftrightarrow \text{DMABN·CD} \quad (1)$$

where DMABN·CD denotes an association complex, which may be a surface or an inclusion complex in aqueous or non-aqueous media. The expression for the association constant is given by

$$K_{eq} = \frac{[\text{DMABN·CD}]}{[\text{DMABN}][\text{CD}]} \quad (2)$$

The formation constants for binary complexes between CD and DMABN can be evaluated using the Benesi–Hildebrand equation [24,16]

$$\frac{1}{F - F^S} = \frac{1}{K_{eq}(F^{CD} - F^S)[\text{CD}]_0} + \frac{1}{F^{CD} - F^S} \quad (3)$$

where F, F^S and F^{CD} denote the fluorescence intensity as function of CD concentration, the fluorescence intensity with no CD, and the fluorescence intensity when a large amount of CD has been added to shift the equilibrium represented by Eq. (1) completely to the right, respectively. In this study a linearization procedure using the Benesi–Hildebrand equation is permitted since one of the two species (CD) is present in large excess and the guest concentration is very low (see Appendix A).

3.2. DMABN–CD association in DMSO

Cyclodextrins are soluble in a few solvents, three of which are water, DMSO and DMF. In this paper we show that DMSO and DMF are amenable for absorption and fluorescence studies of the DMABN–CD equilibrium. Fig. 1 displays fluorescence spectra of DMABN 4×10^{-7} M in DMSO in the 300–570 nm region as a function of CD concentration. The inset of Fig. 1 displays the increase in the fluorescence intensity from the HG complex monitored at 345 nm as a function of concentration of CD. On the other hand, a DMABN excimer emission maximum is observed at 510 nm in DMSO. The onset concentration for the observation of the DMABN excimer is around 5×10^{-7} M, and it is highly dependent on DMABN changes in concentration since the monomer emission remains essentially constant while the excimer emission changes drastically in the concentration interval examined. Thus, to minimize errors in the determination of the DMABN HG constants one should work at DMABN concentrations of the order of 4×10^{-7} M (vide supra). It should be mentioned that DMABN shows a charge-transfer band (the A* state) around 520 nm in water and acetonitrile. Unlike excimer emissions, the fluorescence intensity from a charge-transfer band increases linearly with respect to the fluorescence intensity from the first singlet excited state as these states are interconverted through a large amplitude intramolecular motion [39,40].

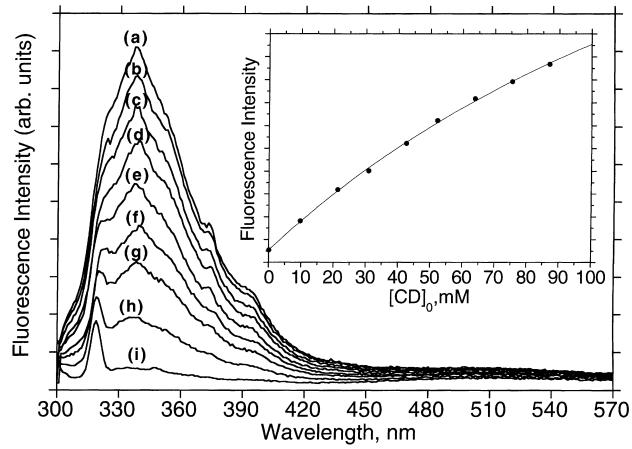

Fig. 1. The fluorescence yield of DMABN increases upon adding CD in DMSO. Fluorescence spectra of DMABN are presented as function of CD concentration: (a) 0.0869, (b) 0.0753, (c) 0.0637, (d) 0.0524, (e) 0.0425, (f) 0.0309, (g) 0.0212, (h) 0.00967 and (i) 0.0 M. In the inset the fluorescence intensities around 345 nm as a function of CD concentration are plotted.

DMABN fluorescence excitation spectra at different concentrations, exciting in the 250–350 nm spectral range while monitoring the excimer emission at 510 nm, show that the shape of the excimer band does not change, and that its intensity changes proportionately. This suggests that the excimer is formed through the reaction between an electronically excited molecule (DMABN*) and a ground state one: $\text{DMABN}^* + \text{DMABN} \rightarrow (\text{DMABN})_2^*$. Specifically, this indicates the absence of an aggregate absorption band in the wavelength interval examined, and that we can rule out the process: $(\text{DMABN})_2 + h\nu \rightarrow (\text{DMABN})_2^*$.

Benesi–Hildebrand plots were constructed at different temperatures for the determination of the DMABN–CD binding constants. Data sets similar to that presented in Fig. 1 were employed to construct these plots. The magnitudes of the binding constants (in units of M^{-1}) were determined for 12 different temperatures, which have been specified in parenthesis: 4.57 (293.3 K), 2.96 (298.0 K), 4.13 (301.5 K), 5.55 (304.3 K), 3.47 (307.0 K), 4.88 (310.0 K), 3.50 (313.0 K), 5.00 (316.0 K), 5.50 (320.0 K), 4.02 (324.7 K), 2.94 (329.3 K) and 3.55 (334.3 K). Using these binding constants we calculated the free energies for the

DMABN–CD formation as a function of temperature which average -3.7 ± 0.5 kJ mol^{-1}. An entropy of approximately zero was estimated from the slope of the plot of the free energies against temperature, although this is arguable since the magnitudes of the constants were small and the relative errors high, giving scatter plots showing weak dependence on temperature and offering no conclusive data regarding the entropy of the process. While in the formation of inclusion complexes a negative contribution to the entropy comes from the loss in the translational degrees of freedom of the substrate, a positive contribution arises from the remotion of solvent molecules from the cavity of the CD as well as from the remotion of the solvation shell of the substrate [13]. In the present system these factors might cancel out giving $\Delta S \approx 0$. In spite of its small magnitude, the negative enthalpy suggests the formation of an inclusion complex. El Baraka et al. [16] studied the DMABN–CD equilibrium in water and determined $K_{eq} = 1025 \pm 250$ M^{-1} at 298 K. This constant is two-orders of magnitude larger than in DMSO. These authors also found that the complexation of the B* state is enthalpy driven with an unfavorable entropy contribution, as expected for the formation of HG complex [16]. On the other hand, in their study of the temperature dependence of the equilibrium involving the DMABN CT state, El Baraka et al. determined that the process was entropy driven but isoenthalpic, and its thermodynamic parameters were characteristic of a surface or lid type complex. These findings indicate that the substrate–CD binding is more complex than it is usually thought of and that the strength of the solvation shell around the guest, as well as the enthalpy of solvation of both species, are determinant factors. Significant differences exist between complexation free energy values for the DMABN/β-CD system in water, DMSO and DMF. For instance, ΔG^0 in water is approximately two-orders of magnitude larger than in DMSO and DMF. In DMSO and DMF the high enthalpies of solution of DMABN and CD increase the thermodynamic stability of both free species, reducing the solvophobicity and the complexation driving force (low ΔG^0). Several substrates are known to form surface complexes between guest molecules and cyclodextrins in DMF [41–43]. Spencer et. al. showed that primary and secondary aliphatic amines form surface complexes with α-CD, whereas neither tertiary amines nor aniline react with the CD, the former because the nitrogen does not act as a proton acceptor for the CD external –OH and the latter because of the negative enthalpy of solution. We could infer that the DMABN tertiary amine character and its high solubility in DMF would also render it incapable of forming a surface complex with β-CD in DMF. Since we report a complexation reaction and DMABN fits inside the β-CD cavity (6.0–6.4 Å in diameter), this tend to indicate the formation of an inclusion complex and that the energy requirements for exclusion of DMF from the CD cavity are satisfied [41,44].

We should emphasize that the presence of the DMABN excimer affects the procedure previously described for the determination of equilibrium constants using fluorescence measurements. The magnitude of the constants obtained under such conditions are smaller than the real ones obtained working at low concentrations of DMABN. At different DMABN concentrations the relative concentration between free DMABN and the excimer are different. Furthermore, from Fig. 2 it is observed that the addition of CD to the system shifts the equilibrium: DMABN* + DMABN ↔ $(DMABN)_2$*, to the left since the fluorescence of the excimer decreases upon adding CD. This is because the DMABN + CD ↔ DMABN–CD equilibrium is also established. The presence of the iso-emissive point around 420 nm in Fig. 2 and the increase in the fluorescence intensity around 345 nm due to the formation of the DMABN–CD inclusion complex, support this explanation.

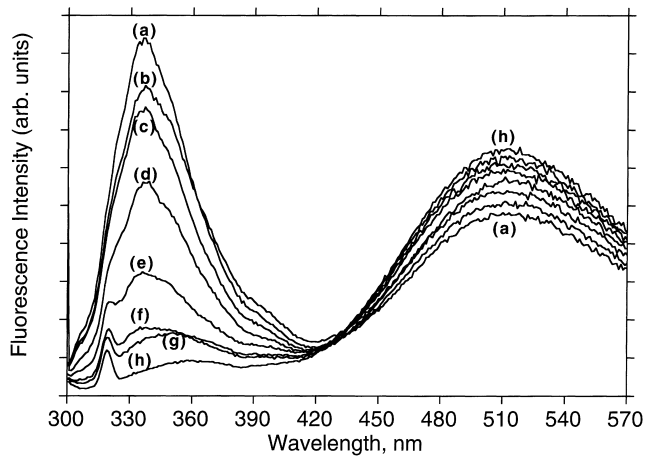

Fig. 2. Fluorescence variation from DMABN with increase in CD concentration in DMSO. The lower energy emission band corresponds to an excimer whose presence reduces the emission intensity expected for the DMABN excited monomer. This gives erroneous results while estimating binding constants using emission data. The DMABN concentration was 3×10^{-5} M. The following CD concentrations were employed: (a) 8.8×10^{-2}, (b) 7.6×10^{-1}, (c) 6.6×10^{-2}, (d) 4.4×10^{-2}, (e) 2.1 x 10^{-2}, (f) 9.7 x 10^{-3}, (g) 4.8×10^{-3} and (h) 0.0 M.

3.3. DMABN–CD association in DMF

In DMF, the determination of binding constants using fluorescence spectroscopy is impractical as an excimer is formed and the absorbance of the solution drastically increases upon adding CD. However, we estimated the association constant using absorption spectroscopy, keeping constant the DMABN concentration at 4×10^{-7} M, as shown in Fig. 3. As in the case of DMSO, dilute conditions were attained to prevent excimer formation and this was confirmed recording a fluorescence spectrum at a DMABN 4×10^{-7} M concentration (data not shown).

The association constant may be calculated from absorbance measurements using the following expression

$$K_{eq} = \frac{(A_{DMF} - A_T)}{(A_T - A_{CD})[CD]} \approx \frac{(A_{DMF} - A_T)}{(A_T - A_{CD})[CD]_0} \quad (4)$$

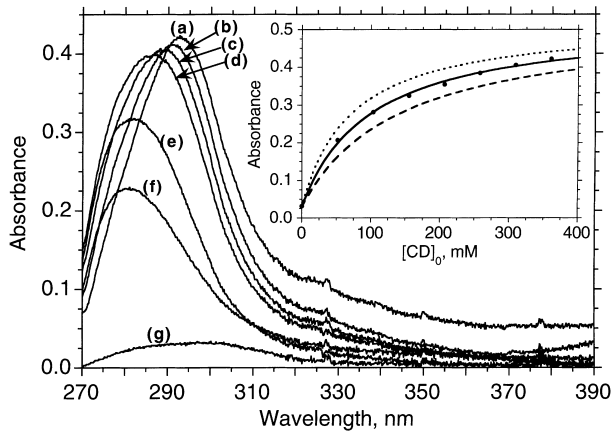

Fig. 3. Absorption spectra of DMABN increasing the CD concentration in DMF. The shifting of the higher energy band is noted as complexation occurs, but at higher CD concentrations the absorption maxima shifts towards lower energies, which suggests formation of another type of complex such as a homodimer. The DMABN concentration was 4×10^{-7} M. The corresponding CD concentrations were: (a) 3.61×10^{-1}, (b) 3.09×10^{-1}, (c) 2.58×10^{-1}, (d) 2.06×10^{-1}, (e) 1.03×10^{-1}, (f) 5.15×10^{-2} and (g) 0.0 M. Inset shows least squares analysis of DMABN–CD system absorption data in DMF at 298 K. The absorption data were taken at their corresponding wavelength maxima. The solid line represents the regression equation used in estimating A_{CD} and the binding constant. The dashed line regressions represent the same equation with different values for the binding constant demonstrating that there is only one correct fit for the experimental data.

where A_{CD} is the absorbance when the equilibrium is shifted completely towards the complex, A_{DMF} is the absorbance when no CD has been added, and $[CD]_0$ is the CD analytic concentration [16]. Solving for the total absorbance we obtain

$$A_T = \frac{(A_{DMF} + K_{eq}[CD]_0 A_{CD})}{1 + K_{eq}[CD]_0} \quad (5)$$

A least squares analysis of the absorption data against CD analytical concentration serves to approximate the K_{eq} and A_{CD} values and the results are displayed in the Fig. 3 inset. This plot confirms that there is a unique fit to the experimental data, which gives $K_{eq} = 10.2 \pm 0.7\ M^{-1}$ for the binding constant and 0.52 ± 0.01 for A_{CD}. It is noted from Fig. 3(g) ($[CD] = 0.0$) and Fig. 3(f) ($[CD] = 0.0515$ M) that the band shifts towards a shorter wavelength due to the formation of the DMABN–CD complex. However, the absorption maximum shifts gradually towards longer wavelengths at the higher CD concentrations as shown in Fig. 3(a)–(e), which may be due to the formation of a different complex. For example, Nakamura et al. demonstrated that the shift of the CT band of DMABN in water is due to the formation of a dimer comprised of two DMABN–CD HG complexes bound together, which they denoted a homodimer [19]. In the analysis presented below we have assumed that the molar absorptivity does not change due to the new interactions, and that their sole effect is to shift the absorption maxima. The fact that the model based on a 1 : 1 stoichiometry represents an appropriate fit for the experimental data inspite of band displacement, and that a Benesi–Hildebrand plot of the same data set assuming 1 : 2 stoichiometry does not yield a line, suggests a homodimer, whose empirical formula is still 1 : 1.

Qualitatively, we observed that the molar absorptivities for the free DMABN and for the DMABN–CD complex do not change appreciably with temperature, while the fluorescence intensity of the complex is weakly reduced with temperature increase, and this suggests that the process has a favorable enthalpy contribution.

Danil de Namor et al. found that negative enthalpy values are associated to the transfer of CDs from water to DMF establishing that CDs are more stable in DMF than in water [41]. Although in water it is known that 2, 8, and 12 molecules are included in α-, β-, and γ-CDs, respectively, it is still unknown whether DMF molecules are hosted inside the CD cavities [11]. However, this is suggested by increase in the magnitude of the solution enthalpy observed in DMF as the CD cavity size increases [41]. It follows that the energy required for the exclusion of solvent molecules from the cavity of the CD must be supplied to form a DMABN–CD inclusion complex in DMF. If this is not the case, the formation of surface or lid type complexes could occur, in which the ligand interaction sites are the exterior hydroxy groups.

4. Concluding remarks

The DMABN–CD binding in DMSO and water is enthalpy driven, suggesting the formation of a HG complex. The process in water has an unfavorable entropy contribution which is compensated by the enthalpy contribution [16]. In DMSO, although nothing can be inferred about the entropy contribution, the negative enthalpy change observed indicates enthalpic control. Excimer formation in DMSO affects the correct determination of DMABN–CD binding constants at high DMABN concentrations. No concluding remarks can be made about the driving force or the binding mechanism in the DMABN–CD–DMF system with the data presented. However, reduction in the fluorescence intensity with increase in temperature suggests a favorable enthalpy contribution. The DMABN–CD binding constants in DMSO and DMF at 298 K are two-orders of magnitudes smaller than in water. This is ascribed to the differences in the enthalpies of solvation of the species involved, and points to the importance of the solvophobic effect in establishing the final thermodynamic state of a given host–guest system.

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Appendix A

We adapted to fluorescence spectroscopy one of Loukas' non-linear models for accurate determination of 1 : 1 binding constants [42]. Let $\tilde{n}$ be the average number of CD molecules bound per guest (DMABN) molecule, which we denote by D

$$\tilde{n} = \frac{\sum(\text{D·CD})}{\sum(\text{D})} \tag{A.1}$$

where, D·CD stands for the DMABN bound to CD. In addition, the equilibrium CD concentration can be expressed as

$$[\text{CD}] = [\text{CD}]_0 - \tilde{n}[\text{D}]_0 \tag{A.2}$$

according to mass action, where $[\text{CD}]_0$ and $[\text{D}]_0$ stand for analytical concentrations of CD and D, respectively. Since the change in fluorescence (ΔF), keeping $[\text{D}]_0$ and the excitation intensity constant, can be related to the molar fraction of the complex

$$\Delta F = (X_{\text{D·CD}})(\Delta F_{\max}) \tag{A.3}$$

where the molar fraction of the complex is given below in terms of K_{eq} and [CD]

$$X_{\text{D·CD}} = \frac{K_{\text{eq}}[\text{CD}]}{1 + K_{\text{eq}}[\text{CD}]} \tag{A.4}$$

and $\Delta F_{\max} = F_{\text{CD·D}} - F_{\text{D}}$, with $F_{\text{CD·D}}$ and F_{D} representing the fluorescence intensities emanating from D when all the molecules are bound to CD and when D is free, respectively. Combining Eqs. (A.3) and (A.4), and substituting Eq. (A.2) for [CD] we obtain the equation of interest

$$\Delta F = \left(\frac{K_{\text{eq}}([\text{CD}]_0 - \tilde{n}[\text{D}]_0)}{1 + K_{\text{eq}}([\text{CD}]_0 - \tilde{n}[\text{D}]_0)}\right)\Delta F_{\max} \tag{A.5}$$

No approximations are involved in Eq. (A.5) and it relates the CD and DMABN analytical concentrations with the observed changes in fluorescence. The term $\tilde{n}$, which is larger than zero and less than 1 for 1 : 1 complexes, represents the extent of complexation. K_{eq} and $\tilde{n}$ are calculated iteratively. In our system, where the condition $[\text{DMABN}]_0 \ll [\text{CD}]_0$ holds, $\tilde{n}$ does not yield reliable values since the term $\tilde{n}\ [\text{D}]_0$ in Eq. (A.5) is of negligible weight relative to the $[\text{CD}]_0$ term. It follows that in our case the K_{eq} values estimated with the method outlined above and two other models given by Loukas yield the same results as the Benesi–Hildebrand equation.

References

[1] J.H. Fendler, Membrane Mimetic Chemistry, Wiley/Interscience, New York, 1982.
[2] K. Kalyanasundaram, Photochemistry in Microheterogeneous Systems, Academic Press, New York, 1987.
[3] M.L. Bender, M. Komiyama, Cyclodextrin Chemistry, Springer, New York, 1978.
[4] J.R. Lakowicz, Principle of Fluorescence Spectroscopy, Plenum Press, New York, 1983.
[5] G.R. Fleming, Chemical Applications of Ultrafast Spectroscopy, Oxford, New York, 1986.
[6] J. Klafter, J.M. Drake, Molecular Dynamics in Restricted Geometries, Wiley, New York, 1989.
[7] N.J. Turro, Modern Molecular Photochemistry, Benjamin/Cummings, CA, 1978.
[8] K.A. Dill, Biochemistry 29 (1990) 7133.
[9] J. Seelig, P. Ganz, Biochemistry 30 (1994) 9354.
[10] R.I. Gelb, L.M. Schwartz, B. Cardelino, H.S. Fuhrman, R.F. Johnson, D.A. Laufer, J. Am. Chem. Soc. 103 (1981) 1750.
[11] J. Szejtli, Cyclodextrin Technology, Kluwer Academic Publishers, Boston, 1988.
[12] R.J. Bergeron, in: J.L. Atwood, J.E.D. Davies, D.D. MacNicol (Eds.), Inclusion Compounds, vol. 3, Academic Press, London, 1984, p. 391.
[13] I. Tabushi, Y. Kiyosuke, T. Sugimoto, K. Yamamura, J. Am. Chem. Soc. 100 (1978) 916.
[14] I. Tabushi, Acc. Chem. Res. 15 (1982) 66.
[15] M. Komiyama, M.L. Bender, J. Am. Chem. Soc. 100 (1978) 2259.
[16] M. El Baraka, R. García, E. Quiñones, J. Photochem. Photobiol. Chem. 79 (1994) 181.
[17] G.S. Cox, P.J. Hauptman, N.J. Turro, Photochem. Photobiol. 39 (1984) 597.
[18] A. Nag, R. Dutta, N. Chattopadhyay, K. Bhattacharyya, Chem. Phys. Lett. 157 (1989) 83.
[19] A. Nakamura, S. Sato, K. Hamasaki, A. Ueno, F. Toda, J. Phys. Chem. 99 (1995) 10952.
[20] S.T. Roberts (Ed.), Molecular Recognition: Chemical and Biochemical Problems, The Royal Society of Chemistry, 1989.
[21] M.I. Page, A. Williams (Eds.), Enzyme Mechanisms, The Royal Society of Chemistry, Cambridge, Great Britain, 1987.
[22] B.J. Whitlock, H.W. Whitlock, J. Am. Chem. Soc. 116 (1994) 2301.
[23] M.A. Petti, T.J. Shepodd, R.E. Barrans, D.A. Dougherty, J. Am. Chem. Soc. 110 (1988) 6825.
[24] A.M. Muñoz, T. Ndou, J.B. Zung, I.M. Warner, J. Phys. Chem. 95 (1991) 3330.
[25] D.B. Smithrud, T.B. Wyman, F. Diederich, J. Am. Chem. Soc. 113 (1991) 5420.
[26] J.M. Coterón, C. Vicent, C. Bosso, S. Penadés, J. Am. Chem. Soc. 115 (1993) 10066.
[27] A.R. Bernardo, J.F. Stoddart, A.E. Kaifer, J. Am. Chem. Soc. 114 (1992) 10624.
[28] C.N. Sanramé, R.H. de Rossi, G.A. ArgŸello, J. Phys. Chem. 110 (1996) 8156.
[29] M.V. Encinas, E.A. Lissi, A.M. Ruffs, Photochem. Photobiol. 57 (1993) 603.
[30] S. Monti, G. Kšhler, G. Grabner, J. Phys. Chem. 97 (1993) 13011.
[31] C.H. Evans, S. De Feyter, L. Viaene, J. van Stam, F.C. De Schryver, J. Phys. Chem. 100 (1996) 2129.
[32] T. Yorozu, M. Hoshino, M. Imamura, H. Shizuka, J. Phys. Chem. 86 (1982) 4422.
[33] M. Barra, C. Bohne, J.C. Scaiano, J. Am. Chem. Soc. 112 (1990) 8079.
[34] D.W. Cho, Y.H. Kim, S.G. Kang, M. Yoon, D. Kim, J. Phys. Chem. 98 (1994) 558.
[35] V. Ramamurthy, D.F. Eaton, Acc. Chem. Res. 21 (1988) 300.
[36] D.B. Smithrud, T.B. Wyman, F. Diederich, J. Am. Soc. 113 (1991) 5420.
[37] I. Tabushi, K. Yamamura, H. Nonoguchi, K. Hirotsu, T. Higuchi, J. Am. Chem. Soc. 106 (1984) 2625.

[38] J. Canceill, M. Cesario, A. Collet, J. Guilhem, L. Lacombe, B. Lozach, C. Pascard, Angew. Chem. Int. Ed. Engl. 28 (1989) 1246.
[39] K. Rotkiewicz, K.H. Grellmann, Z.R. Grabowski, Chem. Phys. Lett. 19 (1973) 315.
[40] M. Van der Auweraer, Z.R. Grabowski, W. Rettig, J. Phys. Chem. 95 (1991) 2083.
[41] A.F. Danil de Namor, R. Traboulssi, D.F.V. Lewis, J. Am. Chem. Soc. 112 (1990) 8442.
[42] Y.L. Loukas, J. Pharm. Pharmacol. 49 (1997) 944.
[43] J.N. Spencer, J.E. Mihalick, I.M. Paul, B. Petigara, Z. Wu, S. Chen, C.H. Yoder, J. Solution Chem. 25 (1996) 747.
[44] R.J. Clarke, J.H. Coates, S.F. Lincoln, Adv. Carbohydr. Res. 46 (1986) 205.