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LARGE INDUCED CIRCULAR DICHROISM OF METHYL ORANGE BOUND TO CHIRAL BILAYER MEMBRANES. ITS EXTREME SENSITIVITY TO THE PHASE TRANSITION AND THE CHEMICAL STRUCTURE OF THE MEMBRANE[1]

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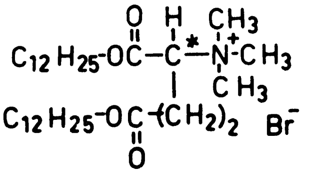
Large circular dichroism is induced when Methyl Orange is bound to the bilayer membrane of chiral dialkyl amphiphiles and the magnitude of the induced circular dichroism is changed drastically by the gel-to-liquid crystal phase transition and the chemical structure of the membrane.

Well-developed bilayer membranes are formed by dispersion in water of amino acid-derived dialkylammonium amphiphiles such as **1**. When a dodecylamide derivative of Methyl Orange was bound to some of these chiral membranes, small induced circular dichroism(ICD) was observed.[2] However, no ICD was detected at room temperature with Methyl Orange itself. More recently, we prepared the bilayer membrane of chromophore-containing chiral amphiphiles **2** and **3**, and found that their optical activities were enhanced remarkably at temperatures below the phase transition.[3,4] For instance, $[\theta]_{max}$ of L-**2**(n = 4) due to the π-π^* transition of the benzene chromophore jumped in magnitude from +6,000 to -400,000 by lowering the temperature of measurement across the phase transition temperature(T_c). This result prompted us to conduct careful ICD study for Methyl Orange bound to chiral bilayer membranes of **1** to **4**.



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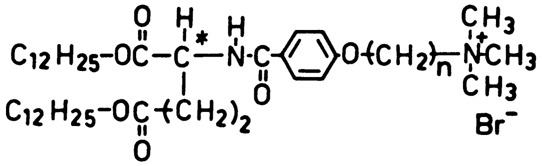
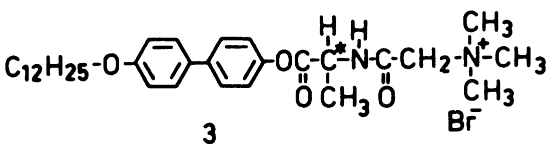


2 n= 2,4,6 (L-)
n=4 (D-,DL-)



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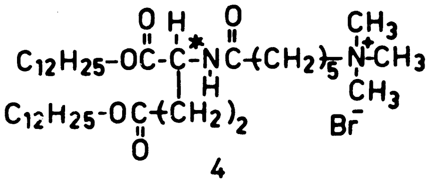

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Dilute aqueous solutions(10 mM) of these amphiphiles contain the bilayer aggregate(vesicles, lamellae and disks) as shown by electron microscopy and by differential scanning calorimetry.5) When Methyl Orange is added to aqueous dispersions6) of 2, strong ICD spectra are observed. Figure 1 shows CD spectra of aqueous solutions containing Methyl Orange and the bilayer membrane of 2(n = 4). The CD spectrum with the D-2(n = 4) membrane obtained at low temperatures(Fig. 1a) possesses a maximum at 495 nm with a shoulder at 440 - 450 nm. A mirror-image spectrum is obtained with the L-2(n = 4) membrane(Fig. 1b). An absorption spectrum measured under the same conditions shows λ_{max} at 488 nm,7) in accord with the location of $[\theta]_{max}$ in the CD spectrum. The observed CD spectrum can be thus attributed to the ICD spectrum of Methyl Orange.9)

An interesting feature of the ICD spectrum is its extreme sensitivity to the temperature of measurement. As shown in Fig. 1, the spectrum is invariable up to 26 - 27°C with large $[\theta]_{max}$ values of 200,000. A further rise in temperature suppresses the spectral intensity and no ICD spectrum is detected at 29.5°C: $[\theta] < 10^3$. Figure 2 summarizes the temperature dependence of $[\theta]$ at the maximum or minimum position. By elevating temperature, the $[\theta]_{max}$ value is diminished drastically in narrow temperature ranges(2 - 3°C). In particular, the $[\theta]_{max}$ value changes by three orders of magnitude in the case of L-2(n = 2). This drastic change in ICD is unprecedented. These temperature ranges agree well with T_c estimated by differential scanning calorimetry.5) Therefore, it is suggested that large ICD spectra are derived from Methyl Orange bound specifically to the rigid(below T_c) chiral membrane.

Another feature worthy of emphasis is observation of large spectral changes induced by small variations of the amphiphile structure. When the length of the methylene spacer(n) of L-2 is changed by two carbons, the ICD spectral pattern (maximum and minimum $[\theta]$ values) changes extensively: $[\theta]_{375} = +260,000$ and $[\theta]_{362} = -760,000$ for L-2(n = 2); $[\theta]_{495} = -200,000$ for L-2(n = 4); $[\theta]_{440} = -214,000$ for L-2(n = 6). When the ammonium amphiphile does not contain the benzene ring, $[\theta]_{max}$ becomes smaller by at least an order of magnitude, though the sharp change at T_c is still observed: for L-1, $[\theta]_{416} = -20,000$ at 8°C and no ICD detected at 14°C; for L-4, $[\theta]_{420} = -20,000$ at 7°C and no ICD detected at 13°C. On the other hand, the ICD spectrum with L-3 does not show a drastic change at T_c.12)

The extent of orientational fixation of guest molecules is estimated by the dissymmetry factor g. Mason13) made a theoretical predication that g is $10^{-5} - 10^{-6}$ for the random mutual orientation of an achiral chromophore and a chiral matrix molecule and $10^{-2} - 10^{-3}$ for the fixed mutual orientation. The g value obtained for L-2(n = 2), 1.4×10^{-2}, is one of the highest values ever observed for dye molecules embedded in chiral environments.

The ICD of achiral molecules in the chiral microenvironment has been reported by several groups.14-24) Among the examples in the aggregate systems(polymers and liquid crystals), Hatano et al.22) reported ICD for Methyl Orange bound to poly(L-lysine) with a large $[\theta]_{max}$ value(100,000 - 380,000). The change in the magnitude of ICD with temperature was reported for guest molecules embedded in liquid crystals.15,23,24) However, these ICD spectra do not show extraordinary sensitivities to temperature and to the amphiphile structure such as observed in the present system.

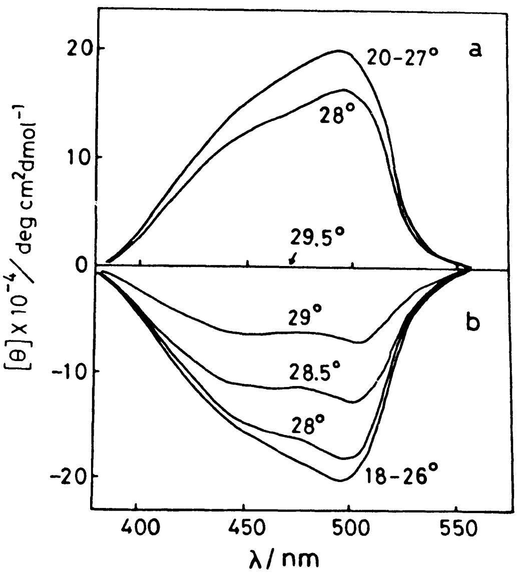

Fig. 1. ICD spectra of Methyl Orange bound to the chiral membrane. Methyl Orange, 2.5 × 10^{-5} M.

(a) membrane D-**2**(n = 4), 2.5 × 10^{-4} M;

(b) membrane L-**2**(n = 4), 2.5 × 10^{-4} M.

D-**2** and L-**2** are enantiomeric.

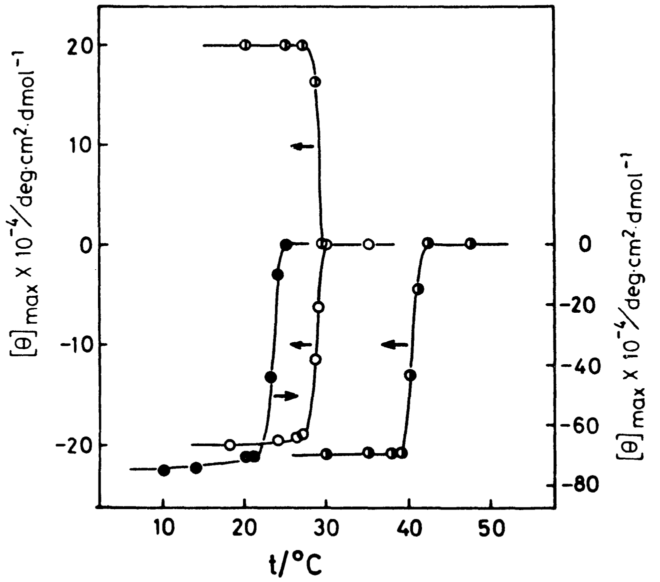

Fig. 2. Temperature dependence of $[\theta]_{max}$. Methyl Orange, 2.5 × 10^{-5} M; **2**, 2.5 × 10^{-4} M. Aqueous dispersions of **2** were kept in an ice bath for 30 min and aqueous Methyl Orange was added. The measurement was started from the low temperature side.

◐ , for D-**2**(n = 4) at 495 nm;
○ , for L-**2**(n = 4) at 495 nm;
● , for L-**2**(n = 2) at 362 nm;
◑ , for L-**2**(n = 6) at 440 nm.

In conclusion, the chiral bilayer membrane provides exceptionally strong and specific chiral microenvironments. The observed red shift, large ICD, and its extreme sensitivity to the membrane fluidity and to the amphiphile structure imply that Methyl Orange is bound at or near the membrane surface in highly specific manners. These data suggest that the bilayer membrane matrix is useful for chiral recognition of guest molecules.

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5) The T_c value(the peak top temperature in the DSC thermogram) and the transition range(given in the parenthesis) are as follows: 13°C(10 - 17°C) for L-**1** and D-**1**; 27°C(24 - 33°C) for L-**2**(n = 2); 31°C(27 - 36°C) for L-**2** (n = 4) and D-**2**(n = 4); 26°C(22 - 30°C) for DL-**2**(n = 4); 42°C(37 - 48°C) for L-**2**(n = 6); 35°C(33 - 38°C) for L-**3**; 11.5°C(9.5 - 16°C) for L-**4**.

6) An aqueous suspension of **1** was sonicated using a Branson cell disruptor 185(probe type) for 0.5 min and clear solutions were obtained from **2** to **4** by sonication with a Branson ultrasonic cleaner 12(bath type) for 3 - 5 min.

7) The absorption maximum of monomeric Methyl Orange is positioned at 420 to 464 nm, depending on the medium polarity. The observed red shift is outside of this range and is explained in terms of the specific aggregation on the chiral membrane.[8]

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9) The contribution of the CD spectrum of the chiral membranes to the ICD spectrum is small(ca. 5 % at 500 nm)[3] for **2**(n = 4) and not detectable for **2**(n = 2 and 6). The involvement of the linear dichroism[10,11] must be also small if at all, because of several reasons including the extreme sensitivity of the ICD spectrum to the membrane phase transition, lack of the CD spectrum with the DL-**2**(n = 4)-Methyl Orange system, etc.(see Ref. 3).

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