Communication

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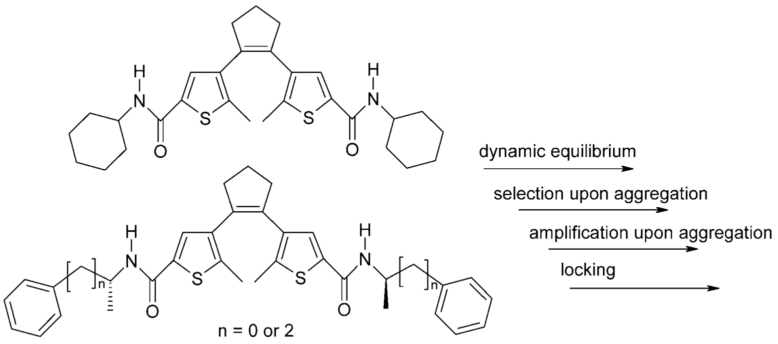

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Dynamic Chiral Selection and Amplification Using Photoresponsive Organogelators

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The origin of the homochirality of essential biomolecules remains an intriguing and, as yet, unresolved issue.[1] The amplification of a small stereochemical bias is widely accepted to be a central factor in biochirality.[2] Such chiral amplification is observed in many systems, such as crystal seeding, (auto)catalysis,[3] and the sergeant−soldier effect, which acts through the propagation of highly specific (inter)molecular interactions using small molecules, polymers,[4] and liquid crystalline phases.[5] Noncovalent interactions in combination with the sergeant−soldier effect can also lead to chiral supramolecular polymers[6] by coassembly of achiral and chiral monomers.[7] Unfortunately, the chiral amplification is transient and restricted to the supramolecular assembly, as there is no preference for a specific chiral conformation of the achiral monomer outside the assembly. Hence, the chiral information must be retained by covalent bond formation within the supramolecular structure.[8]

Here, we report the coassembly of achiral (soldier) with chiral (sergeant) diarylethene photochromic switches,[9] accompanied by a dynamic selection and amplification in a supramolecular system. We exploit the highly specific self-assembly features of low molecular weight gelators[10] (LMWG) bearing multiple hydrogen bonding groups, which can be addressed and controlled by incorporation of a diarylethene photoresponsive unit. Mixtures of isostructural chiral and achiral compounds, each showing dynamic helix inversion (*P* ↔ *M*), are capable of a coassembly process.[11] The coassembly enables the transfer and propagation of chirality in the coaggregate's supramolecular structure. Photochemical ring-closure can lock this chiral information at the molecular level (Figure 1).

Diarylethene switches are present in two, rapidly exchanging conformations (*P* and *M* helicity), which upon photochemical ring-closure lead to the *RR* or *SS* enantiomers in equal amounts. Recently, we demonstrated that aggregation of a chiral diarylethene switch in the open form **1o** (Figure 2) leads to selection of only one of the helical forms of **1o** in the gel state.[13,14] Subsequent photochemical ring-closure of **1o** to **1c** in the gel state proceeds with 96% diastereomeric excess (de) and a photostationary state (PSS)[13] of 40%, whereas in solution, no stereoselection is observed. Similar results are found for **2**. The related achiral switch **3o** (**3o**(*P*) ↔ **3o**(*M*)) forms gels in apolar organic solvents also, but as expected, photochemical ring-closure in the gel state leads to **3c** as a racemate (**3c***RR*/**3c***SS*, Figure 2).

For chiral amplification to take place as outlined in Figure 1, **3o** must be capable of coassembly with either **1o** or **2o**. Neither **1o**, **2o**, nor **3o** (0.6 mM in toluene) on their own form gels at 0 °C. However, for a sample containing 0.6 mM of **3o** and 0.6 mM of either **1o** or **2o**, a gel is obtained, indicating that in the mixed system at 0.6 mM cooperative assembly occurs. Indeed, the circular dichroism (CD) spectra reveal a dramatic increase of the helicity for mixtures of **3o** with **1o** or **2o** at low concentration (0.3 mM) at which **1o**−**3o** alone do not gelate (Figure 3). Even at concentrations at which **1o**−**3o** gelate (>1.2 mM), the mixtures of **3o** with **1o** or **2o** show markedly enhanced CD effects compared to that of **1o** or **2o** alone. The clear increase of the helicity in mixtures of **1o** or **2o** with **3o** can be explained by a similar preferred helical conformation for **3o** as chiral compounds **1o** or **2o**. Remarkably, the helicities observed for aggregates containing **1o** have opposite sign to those of **2o**, although both contain chiral (*R*) side groups. The coincidence of the CD bands with the UV−vis absorptions of the dithienyl moiety indicates that aggregate fibers of **3o** have opposite helicity when containing **1o** or **2o** (vide infra).

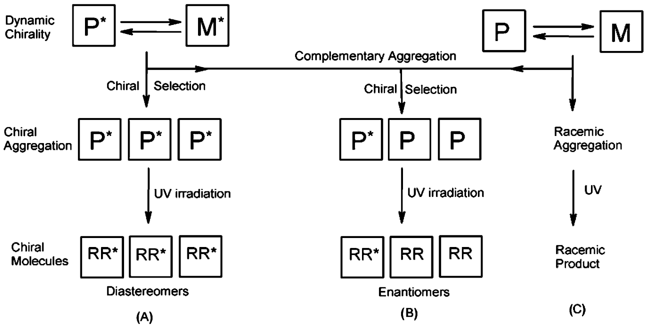

Figure 1. Schematic representation of the amplification of supramolecular chirality and subsequent transfer to molecular chirality. (A) In a dynamic equilibrium (*P** versus *M**), upon aggregation of one of the helical conformations, (*P**) is preferred due to chiral auxiliary groups involved in hydrogen bonding, leading to high diastereomeric excess after UV irradiation (*RR**).[13] (C) For achiral compounds, no selection during aggregation from the dynamic equilibrium (*P* versus *M*) occurs; hence, a racemic product is formed upon UV irradiation. (B) Coaggregation of both molecules leads to a selection process and preferential formation of single (*RR*) enantiomers after UV irradiation.[12]

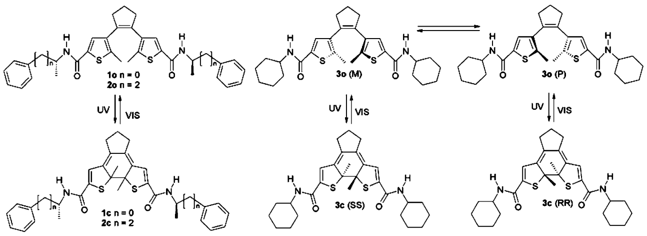

Figure 2. Chiral diarylethene switches **1**−**3** used for selection and amplification upon aggregation by hydrogen bond formation; **o** = open form, **c** = closed form, UV: $\lambda = 313$ nm, VIS: $\lambda > 420$ nm.

It is apparent, therefore, that coassembly of **3o** with **1o** or **2o** takes place and is accompanied by a preference for one of the helical conformations of **3o** (Figure 1b). It was anticipated that the chirality of **3o** induced by coaggregation could be locked by the photochemical ring-closure to **3c**. To confirm this, gels of **3o** in toluene with increasing amounts of **1o** or **2o** were prepared by heating−cooling cycles, followed by aging overnight at −18 °C.

The gels formed were irradiated with UV light ($\lambda = 313$ nm) at 0 °C to reach the PSS (60%), after which the solvent was removed and the remaining solid residue analyzed by chiral HPLC. The results are summarized in Figure 4.[15] At a 1:1 ratio of achiral **3o**/

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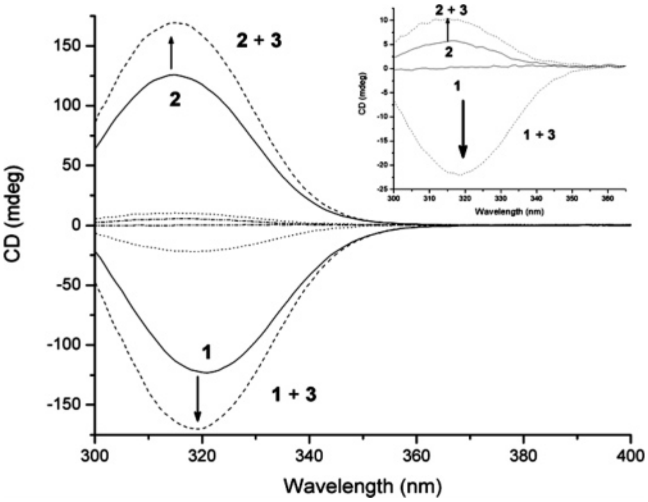

Figure 3. CD spectrum of a 0.3 mM solution (inset) and 1.2 mM gel of **1o** (—, negative CD signals) and a 0.3 mM solution (inset) and 1.3 mM gel of **2o** in toluene (—, positive CD signals). Upon addition of 1 equiv of **3o** the signal increases (- - -, change is marked by arrows).

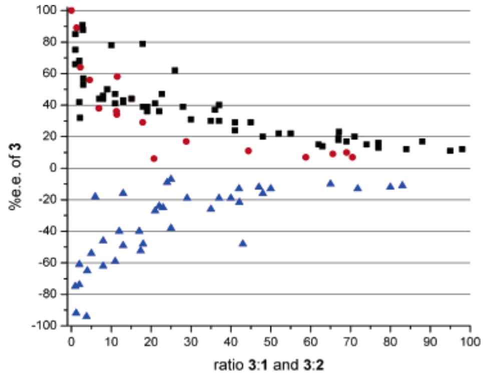

Figure 4. Observed enantiomeric excess (%)[11] of **3c** for different ratios of **3o** (soldier) over sergeants **1o** (■) or **2o** (▲) as determined by chiral HPLC. The CD signal (●) maximum is set at 100% at a ratio of 1:1. Each ▲, ■, and ● represents one individual measurement. See Supporting Information for control experiments.

chiral **1o**, the asymmetric induction amounts to 94% ee in **3c**, displaying almost the same stereoselectivity for the photochemical ring-closure of **1o** alone in gels (96% de). Although the enantiomeric excess drops gradually with an increase of **3o**/**1o**, the enantiomeric excess values remain much higher than expected for a 1:1 interaction between **3o** and **1o**. It is apparent that the presence of **1o** enforces several molecules of **3o** into a preferred helical conformation, that is, a sergeant−soldier effect. Assuming that the ratios of **1o** and **3o** in solution and gel are similar, the number of molecules of **3o** of which the stereochemistry is controlled by **1o** during coaggregation at a specific ratio can be determined directly from the enantiomeric excess of **3o** and points to a maximum value of eight achiral soldiers controlled by one chiral sergeant molecule.[16] Thus, both the transfer and amplification of molecular chirality to racemic switches are possible with near absolute stereocontrol upon aggregation into supramolecular structures. In support of these observations, CD spectroscopy was used to determine the degree of induction, as was shown previously for **1o**.[13] For mixtures of **3o** and **1o**, the decrease of the CD signal with increasing ratio of **3o**/**1o** is in accordance with the change in enantiomeric excess (Figure 4). This confirms that the induced supramolecular chirality and the resulting molecular chirality correlate very closely.

Similar chiral amplification effects are observed for mixtures of **3o** with sergeant **2o** (PSS from gel = 39%) with a maximum ee of 94%, however, of the opposite enantiomer (Figure 4). This is in excellent agreement with the CD spectra of mixtures of **3o** and **2o** in the open form, which are opposite in sign to the CD spectra of the **3o**−**1o** gel (Figure 3). The inversion of chirality is remarkable given the asymmetric induction originates from the stereogenic center next to the amide bond, which for **1** and **2** has the same absolute configuration (*R*). It is probable that the phenyl moieties are involved in the aggregation of **1**; however, the C2 spacer of **2** precludes such interaction during self-assembly.

In conclusion, it was possible to assemble cooperatively chiral and achiral amide substituted perhydro dithienyl switches **1o**−**3o** into supramolecular assemblies. The selection of only one of the photoactive conformers of the chiral switches **1o** (and **2o**) during aggregation controls the stereochemistry of achiral switch **3o**, resulting in chiral induction with up to 8-fold chiral amplification.

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Supporting Information Available: Experimental details, characterization, and spectroscopic data of **1**−**3**. This material is available free of charge via the Internet at http://pubs.acs.org.

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(15) LMWGs are easily disturbed; this explains some deviations in Figure 4.

(16) From **3o**/**1o** = 20 and 40% ee, it follows that out of every 20 soldiers, 8 are addressed by only 1 sergeant; see Supporting Information.

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