The transmission of chiral information between the molecular, meso and microscopic scales is a facet of biology that remains challenging to understand mechanistically and to mimic with artificial systems. Here we demonstrate that the dynamic change in the expression of the chirality of a rotaxane can be transduced into a change in pitch of a soft matter system. Shuttling the position of the macrocycle from far-away-from to close-to a point-chiral center on the rotaxane axle changes the expression of the chiral information that is transmitted across length scales; from nanometer scale constitutional chirality that affects the conformation of the macrocycle, to the centimeter scale chirality of the liquid crystal phase, significantly changing the pitch length of the chiral nematic structure. The work extends the potential of mechanically interlocked molecules to dynamically modulate the properties of soft materials.

6.1 Introduction

Control over the transmission of asymmetry across length scales imparts structure and function in both biological and synthetic materials.\(^1\) Artificial molecular machines offer the potential to not only transfer the effects of molecular chirality to larger assemblies,\(^2\) but also to dynamically regulate the effects produced by external stimuli.\(^3\) For example, the ratios between the conformational and configurational states of the Feringa motors\(^4\) and the tying of a linear molecular strand into an overhand knot of single entanglement handedness have both been found to alter the pitch length of a liquid crystal medium.\(^5\) Here, we show that the translocation\(^6\) of a macrocycle from far-away-from to close-to a point chiral center on the axle of a rotaxane can amplify the macroscopic expression of the molecular chirality\(^7\) in a soft matter system\(^8\) (Figure 1). This adds to the growing number of examples that exploit the particular dynamics and stereochemistry of rotaxanes and catenanes to bring about unusual functional consequences.\(^9\)

![Diagram showing the decrease in macroscopic pitch length of a liquid crystal phase resulting from switching of a benzylic amide macrocycle from far-away-from to close-to a point chiral center on a rotaxane axle.](image)

**Figure 1.** Decrease in macroscopic pitch length of a liquid crystal phase resulting from switching of a benzylic amide macrocycle from far-away-from to close-to a point-chiral center on a rotaxane axle.

6.2 Results and discussions

6.2.1 Chirality expression of rotaxanes and thread in organic solvent

The rotaxane used in this work is a bistable molecular shuttle \(E/Z-1\), featuring two principal binding sites on the axle for the benzylic amide macrocycle: a pyridyl-acyl hydrazone unit (PH) and a glycyll-\(L\)-leucine unit (GL) (Scheme 1).\(^10\) An ethylene glycol spacer between the axle binding sites was chosen to improve the poor solubility of related rotaxanes (e.g. with longer alkyl chain spacers) we studied in ZLI-1083, a mesogenic mixture of three phenylcyclohexanes. The design of the rotaxane is such that, in the \(E\)-form, the macrocycle should reside primarily over the pyridyl-acyl \(E\)-hydrazone group (E-PH).\(^{10e}\) In this position the macrocycle is far from the asymmetric leucine unit on the axle, so the macrocycle conformation should not be substantially affected by the point-chiral center. Photochemical isomerization to the \(Z\)-
hydrazone should then result in the formation of a six-membered hydrogen bonded ring. This should substantially reduce the binding affinity of the macrocycle for the pyridine-hydrazone site causing the macrocycle to translocate to the peptide unit. We anticipated that the stereochemistry of the L-leucine should then significantly influence the conformation of the macrocycle. We envisaged that this change could potentially affect the ordering of the mesogens that would solvate the rotaxane in ZLI-1083.

Scheme 1. Synthesis of E/Z-1 and Configurational and Co-Conformational Switching between E-1 and Z-1. Reaction conditions: (i) p-xylylenediamine (8-fold excess), isophthaloyl dichloride (8-fold excess), Et$_3$N (16-fold excess), CH$_2$Cl$_2$, RT, 18 h, 71%; (ii) CD$_2$Cl$_2$, 312 nm UV light, RT, 45 min, >90%; (iii) CF$_3$CO$_2$H (20 mol%), CD$_2$Cl$_2$, 40 °C, 2 h, then K$_2$CO$_3$, 79%; (iv) CD$_2$Cl$_2$, 312 nm UV light, RT, 2 h, 80%; (v) CF$_3$CO$_2$H (20 mol%), CD$_2$Cl$_2$, 40 °C, 2 h, then K$_2$CO$_3$, >97%.

The pyridyl-acyl E-hydrazone-glycyl-L-leucine thread (E-2) was prepared in six steps from commercially available starting materials (Scheme S1). Thread E-2 was smoothly into Z-2 by irradiation at 312 nm (>90%, step ii, Scheme 1 and Figure 2a and d) and could be switched back to the E-state through thermal isomerization in the presence of a catalytic amount of CF$_3$CO$_2$H (79%, step iii, Scheme 1). Rotaxane formation was accomplished using a multicomponent clipping reaction, giving molecular shuttle E-1 in 71% yield (step i, Scheme 1).

Comparison of the $^1$H NMR spectra of the E-rotaxane 1 and thread 2 (Figure 2a and b) shows the excellent positional discrimination of the macrocycle between the different axle binding sites. The pyridyl-acyl hydrazone protons are shielded by the xyylene rings in the rotaxane (H$_5$ and H$_6$ are shifted substantially upfield; $\Delta \delta$ = -0.44 and -1.47 ppm), confirming that the macrocycle resides over the PH unit in the major translational co-conformer of E-1. In contrast, in Z-1 the pyridyl-acyl hydrazone proton (H$_8$) signals occur at similar shifts in the rotaxane and non-interlocked thread, while there is substantial shielding of the H$_{13}$ and H$_{14}$ protons of the GlyLeu group ($\Delta \delta$ = -1.1 and -1.2 ppm; Figure 2c and d). From these shifts we estimate that the macrocycle spends up to 95% of the time on the PH site in E-1 and up to 90% of the time on the GL site in Z-1. Rotaxane E-1 could be converted to Z-1 upon irradiation at 312 nm UV light (80%, Scheme 1, step (iv)) and subsequently restored to the E-form by treatment with CF$_3$CO$_2$H in CD$_2$Cl$_2$ at 40 °C followed by neutralization with K$_2$CO$_3$ (>97%, Scheme 1, step (v)). Alternatively, the Z-to-E thermal isomerization could be achieved with
HCl vapor (Figure S4). The results indicate excellent positional integrity (>90%) and switching fidelity (>80%) in both states of the molecular shuttle. In addition to $^1$H NMR, the position of the macrocycle on the rotaxane axle could be probed through circular dichroism (CD) spectroscopy.\textsuperscript{11}

**Figure 2.** Partial $^1$H NMR spectra (500 MHz, CD$_2$Cl$_2$, 298 K) of (a) thread $E$-2 ($E/Z = 77:23$); (b) rotaxane $E$-1; (c) rotaxane $Z$-1 obtained from irradiation of $E$-1 with 312 nm UV light for 45 min; (d) thread $Z$-2 obtained from irradiation of $E$-2 with 312 nm UV light for 1 h. The lettering and color coding of the signals corresponds to those shown in Scheme 1.

In addition to $^1$H NMR, the position of the macrocycle on the rotaxane axle could be probed through circular dichroism (CD) spectroscopy.\textsuperscript{11} Of the two rotaxanes ($E$-1 and $Z$-1) and two threads ($E$-2 and $Z$-2), only rotaxane $Z$-1, in which the macrocycle is bound close to the leucine residue, elicits a strong and negative CD response, a consequence of the macrocycle aromatic rings experiencing a well-expressed chiral environment (Figure 3). The absence of a significant CD response for $E$-1 confirms that the magnitude of the CD signal depends on whether the macrocycle is far away from, or in close proximity to, the point-chiral center on the axle. The chiral response can be selectively switched “on” or “off” through shuttling of the macrocycle between the two different binding sites.
Figure 3. CD spectra of operation cycle of (a) rotaxane 1 and (b) thread 2, measured in acetonitrile at room temperature. PSS = photostationary state.

6.2.2 Controlling liquid crystal chirality by rotaxanes and thread

We next investigated whether the asymmetry induced in the conformation of the macrocycle bound close to the leucine residue, could be transferred to the surroundings within a liquid crystal matrix. Thread E-2 and rotaxane E-1 were each dissolved in small quantities into (achiral) nematic liquid crystal ZLI-1083. The modest solubility of the rotaxane and thread prevented measurement of the helical twisting power (HTP) via Grandjean-Cano wedge cells, therefore we used an alternative approach based on θ-cells (Figure S7) which we have used in the past to track modest variations in helical chirality.

The HTP values for E-2 and E-1 are given in Table S1. Both E-2 and E-1 induce a left-handed helical structure of the liquid crystal, indicated by the defect line rotating counter-clockwise under polarized light microscopy (Figure 4 and S9). The HTP values scale linearly with the dopant concentration (Figure S9 and S10), confirming that both thread and rotaxane are homogenously dispersed throughout the liquid crystal, and that no unwanted aggregation has taken place.

The difference in liquid crystal pitch length induced by the two states of rotaxane 1 as dopant is substantial. Using E-1 as the dopant gives a HTP value of $-7.2 \pm 0.4 \mu m^{-1}$, whereas using the
20:80 \( E-1:Z-1 \) photostationary state (PSS) as dopant gives a HTP value of \(-10.6 \pm 0.2 \, \mu\text{m}^{-1}\) (Figure 4; Table S1). This represents an \(~32\%\) tightening of the supramolecular helical pitch when the macrocycle is located on GL binding site. In contrast, using the thread \( E-2 \) as dopant gave a \(-5.1 \pm 0.6 \, \mu\text{m}^{-1}\) HTP value which only changes to \(-4.5 \pm 0.5 \, \mu\text{m}^{-1}\) with the \( >10:90 \, E-2:Z-2 \) PSS (Table S1), which represents a \(~13\%\) unwinding of the liquid crystal pitch, suggesting slightly poorer transfer of chirality from the point-chiral center to the surrounding mesogens in the \( \text{Z}\)-form of the thread, possibly as a result of a change in conformation of the molecule. The substantially larger helical twisting power of the \( \text{Z}\)-rotaxane is consistent with the asymmetric conformation of the macrocycle enhancing the twist of the supramolecular helical structure (Figure 4).

In situ irradiation at 312 nm of \( E-1 \) in \( \text{ZLI-1083} \) generated a substantial proportion of \( Z-1 \), resulting in tightening of the helix to \(~23\%\) of its original length (HTP value of \(-9.3 \pm 0.4 \, \mu\text{m}^{-1}\); Figure 4 and Table S1). Irradiation of thread \( E-2 \) in \( \text{ZLI-1083} \) resulted in a slight decrease in the HTP value to \(-3.9 \pm 0.3 \, \mu\text{m}^{-1}\) which may reflect some photodegradation or the poor solubility of \( Z-2 \) (Figure 4; Table S1). The transformation of \( Z-1 \) back to \( E-1 \) in \( \text{ZLI-1083} \) could also be accomplished in situ, by subjecting the sample to HCl vapor, followed by neutralization with \( \text{Et}_3\text{N} \) vapor. The HTP values before operation and after one shuttling cycle suggests that the \( Z-1\)-to \( E-1 \) conversion is \(~77\%\) in the liquid crystal (Figure 4), again lower than the near-quantitative conversion in solution, although the HTP value may also be affected by the presence of \( \text{Et}_3\text{NHCl} \) and residual \( \text{Et}_3\text{N} \).

**Figure 4.** Polarized optical images of \( \theta \)-cells filled with nematic host \( \text{ZLI-1083} \) containing 0.1 wt\% of rotaxane. Images were taken at each step of the operational cycle of the rotaxane (in-situ). Schematic representations of the resulting supramolecular helix of mesogens are shown to the right of each image. The horizontal dashed line corresponds to the rubbing direction of the top substrate of the \( \theta \)-cells. The red arrow shows the rotation of the disclination line, while the dashed white arrow traces the initial angle for \( E-1 \).

### 6.3 Conclusion

In conclusion, switching the position of a macrocycle on the axle of a rotaxane so that it comes into the sphere of influence of a point-chiral center can change the structure of a liquid crystal at a length scale orders of magnitude larger than the translocation event. When the macrocycle is remote from the source of asymmetry, its conformation is symmetrical and does not elicit a circular dichroism response in an organic solvent nor affect the organization
of a liquid crystal phase. However, once the macrocycle binds close to the point-chiral center, the conformation of the macrocycle becomes asymmetric, resulting in both a strong circular dichroism response and substantial tightening of the pitch length of the liquid crystal. This adds to the effects possible through the dynamics and stereochemistry brought about by the chemistry of the mechanical bond.

6.4 Experimental section

6.4.1 General information

Unless stated otherwise, all starting materials and anhydrous solvents were obtained from commercial sources and were used without further purification. All moisture- or air-sensitive reactions were performed using oven-dried glassware under an inert atmosphere of dry argon. Air- or moisture-sensitive liquids and solutions were transferred via syringe. ¹H NMR and ¹³C NMR were measured on Bruker 300 MHz Spectrometer, Bruker 400 MHz Spectrometer and Bruker 500 MHz Spectrometer. Chemical shifts were reported in parts per million (ppm) downfield from high to low frequency using the residual solvent peak as the internal reference (CDCl₃ = 7.26 ppm, CD₂Cl₂ = 5.32 ppm and (CD₃)₂SO = 2.50 ppm). The multiplicity of ¹H signals are indicated as: s = singlet; d = doublet; t = triplet; q = quartet; m = multiplet; br = broad; app = apparent; or combinations thereof. COSY, HSQC and HMBC experiments were used to aid structural determination and spectral assignment. Flash column chromatography was carried out using Silica 60 Å (particle size 40–63 µm) as the stationary phase. Visualized using both short and long wave ultraviolet light in combination with standard laboratory stains (basic potassium permanganate, acidic ammonium molybdate and ninhydrin).
6.4.2. Synthesis

\[
\begin{align*}
S7 & \rightarrow \text{(Boc)}_2O, \text{MeOH, } 35^\circ C, 95\% \quad \text{a)} \\
S6 & \rightarrow \text{2-Bromoethanol, } K_2CO_3, \text{DMF, } 80^\circ C, 16\ h, 48\% \quad \text{b)} \\
S5 & \rightarrow \text{Succinimide, } Et_3N, \text{CH}_2Cl_2, \text{RT, } 18\ h, 53\% \quad \text{c)} \\
S4 & \rightarrow \text{4-DMAP, EDCI HCl, } \text{CH}_2Cl_2, \text{RT, } 12\ h, 77\% \quad \text{d)} \\
S3 & \rightarrow \text{TFA, } \text{CH}_2Cl_2, \text{RT, } 1\ h, \text{catalytic Acetic Acid, EtOH, RT, } 12\ h, \text{two steps 55 \%} \quad \text{e, f)} \\
S9 & \rightarrow \text{p-xylylenediamine, isophthaloyl dichloride, NEt}_3, \text{CH}_2Cl_2, 0^\circ C \text{ to RT, } 18\ h, 70\% \quad \text{g)}
\end{align*}
\]

Figure S1. Synthesis of rotaxane 1 and thread 2. S9\textsuperscript{11}, S8\textsuperscript{12} and S7\textsuperscript{11} were prepared as described previously. Reagents and conditions: a) \((\text{Boc})_2\text{O, MeOH, } 35^\circ C, 95\%\); b) \text{2-Bromoethanol, } K_2CO_3, \text{DMF, } 80^\circ C, 16\ h, 48\%; c) \text{Succinimide, } Et_3N, \text{CH}_2Cl_2, \text{RT, } 18\ h, 53\%; d) \text{4-DMAP, EDCI HCl, } \text{CH}_2Cl_2, \text{RT, } 12\ h, 77\%; e, f) \text{TFA, } \text{CH}_2Cl_2, \text{RT, } 1\ h; \text{catalytic Acetic Acid, EtOH, RT, } 12\ h, \text{two steps 55 \%}; g) \text{p-xylylenediamine, isophthaloyl dichloride, NEt}_3, \text{CH}_2Cl_2, 0^\circ C \text{ to RT, } 18\ h, 70\%.

6.4.2. Isomerization of rotaxane 1 and thread 2 in solution

Irradiations were carried out in a photoreactor fitted with 3 × 1.8 W LED (emission centered at 312 nm). The samples were irradiated in quartz NMR tubes and NMR spectra were recorded immediately after irradiation. The photochemical isomerizations were followed by \(^1\text{H NMR}.

Thermal isomerization with TFA: To heat a solution of the thread Z-2 or rotaxane Z-1 (1.5 mg) in degassed CD\textsubscript{2}Cl\textsubscript{2} (0.5 mL) at 40 ℃ with catalytic amount of trifluoroacetic acid (TFA) for 2 hours in a NMR tube, followed by neutralization with K\textsubscript{2}CO\textsubscript{3}. The thermal isomerizations were followed by \(^1\text{H NMR}.

Thermal isomerization with HCl: In a closed chamber, an opened vial of E-1 was placed with an opened vial of concentrated hydrochloric acid for 5 minutes at room temperature, followed by neutralization with K\textsubscript{2}CO\textsubscript{3}. The thermal isomerizations were followed by \(^1\text{H NMR}.

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Figure S2. Partial $^1$H NMR spectra (500 MHz, CD$_2$Cl$_2$, 298 K) of: (a) Thread $E$-2; (b) Thread $Z$-2 obtained from irradiation of $E$-2 with 312 nm UV light for 45 min; (c) Solution of (b) after 2 h heating at 40 °C with catalytic amount of TFA (20 mol%), followed by a neutralization with K$_2$CO$_3$.

Figure S3. Partial $^1$H NMR spectra (500 MHz, CD$_2$Cl$_2$, 298 K) of: (a) Rotaxane $E$-1; (b) Rotaxane $Z$-1 obtained from irradiation of $E$-1 with 312 nm UV light for 1 h; (c) Solution of (b) after 2 h heating at 40 °C with catalytic amount of TFA (20 mol%), followed by a neutralization with K$_2$CO$_3$. 
Figure S4. Partial $^1$H NMR spectra (400 MHz, CD$_2$Cl$_2$, 298 K) of: (a) Rotaxane E-1; (b) Rotaxane Z-1 obtained from irradiation of E-1 with 312 nm UV light for 1 h; (c) Solution of (b) after 5 min at room temperature with HCl vapor, followed by a neutralization with K$_2$CO$_3$.

Figure S5. Absorbance spectra change of the rotaxane 1 upon one E-Z-E isomerization cycle. Spectra were measured in acetonitrile at room temperature.

Figure S6. Absorbance spectra change of the thread 2 upon one E-Z-E isomerization cycle. Spectra were measured in acetonitrile at room temperature.
6.4.3 Liquid crystal preparation

Liquid crystal mixture ZLI-1083 (Figure. S7a) was produced by mixing PCH3 (ABCR), PCH5 (Synthon) and PCH7 (ABCR) in a 30/30/40 proportion (by weight). ZLI-1083 forms nematic liquid crystalline phase up to 51°C.

The molecular thread and rotaxane were dissolved in liquid crystal by using a common solvent, dichloromethane. The solvent was slowly evaporated and the residue mixture was dried under vacuum at 50°C for several hours. Due to the relatively low solubility, the concentrations of rotaxane in the liquid crystals were set as 0.1 wt%.

6.4.4 θ-cells fabrication

Cut edges glass slides (Thermo Fischer Scientific) were cut in 10x10 mm squares. The glass squares were immersed in ethanol and sonicated for 30 min at room temperature. The slides were air-dried and spin-coated with a Sunever 150 alignment layer polyimide (Nissan Chemical Industries) using a Laurell WS-650 spin coater. The slides were heated on a hot plate at 180°C for an hour.

Two kinds of aligning substrates were prepared. Unidirectional planar alignment was applied by unidirectional rubbing the slide with a velvet cloth. Circular planar alignment was achieved by rubbing of the rotating substrate. The thickness of the cells was defined by Teflon spacers of 50 µm placed on both edges of the slides. The cells were assembled with NOA68 UV-curable glue from the substrates promoting the different alignments. As the last step, the liquid crystal mixture was introduced into the cell by capillary forces at room temperature.

6.4.5 Helical Twisting Power and Screw-sense Measurements

In order to determine the screw sense and HTP values of the rotaxane in liquid crystals, so called θ-cells have been used. The method allows precise and reliable measurement of extremely large cholesteric helix pitch even in the centimeter range. In θ-cells, the liquid crystal material is confined between two glass substrates promoting unidirectional and circular molecular alignment (Figure S7b). The liquid crystal experiences twist deformation inhomogeneously in the plane of the layer so that areas with left and right twists can be distinguished. When the areas of opposite twist meet each other, they collide and yield a disclination line lying in the plane of the layer. If cholesteric material is introduced into the θ-cell, the equilibrium configuration of the director field will be changed in the way of rotation of disclination line (Figure S7c). The direction of such rotation determines the handedness of the used cholesteric liquid crystal as follow: i) clockwise rotation corresponds to right-handed cholesteric; ii) counter clockwise rotation corresponds to left-handed cholesteric. The angle between disclination line and rubbing direction on top substrate (δ+) mirrors the twist angle of the cholesteric helix over the cell thickness according to Equation 1 (valid for p>d):

\[ \delta_{+,−} = 2\pi d / p_{+,−} \]  

(1)

where \( d \) is cell thickness, \( p \) is cholesteric pitch and (+,−) indicates the sign of chirality.

Knowing the cholesteric pitch and concentration of chiral molecules (c), the HTP value can be calculated by following Equation 2:
\[ \text{HTP} = \delta_{+} \times (2\pi d \times c)^{-1} \]  

Optical imaging and measurements were performed using polarized optical microscope BX51 (Olympus) and Cell software (Olympus).

The absorbance and CD spectra were measured using a spectrometer HR2000+ (Ocean Optics) and JASCO 810 (Jasco), respectively. CD spectra of compounds in acetonitrile (0.2-0.5 mM) were recorded using 2 mm quartz cuvette. Protonated and deprotonated states were achieved by adding 1.1 equivalents of HCl and TEA, respectively.

As light sources for photo-optical studies, a mercury lamp (Spectroline) with a \( \lambda = 312 \text{ nm} \) filter (I \( \sim \) 2.5 mW/cm\(^2\)). The intensity of the light has been measured using a power meter PM-100D (Thorlabs).

![Figure S7](image)

**Figure S7.** (a) Chemical structures of the nematic liquid crystals that we screened for their suitability as hosts. (b) Schematic representation of the \( \Theta \)-cell. (c) Top view of liquid crystal molecules twist in the case of chiral materials introduced in \( \Theta \)-cell. For clarity, liquid crystal molecules at the top and bottom interfaces are shown in different colors.

### 6.4.6 Operation of rotaxane in liquid crystals

Typical operation cycle of rotaxane consisted of three steps: i) exposure to UV light (312 nm) which induced \( E \)-to-\( Z \) isomerization of hydrazone unit of the rotaxane thread; ii) protonation with HCl which breaks intramolecular H-bonds and facilitates back \( Z \)-to-\( E \) isomerization; iii) deprotonation with trimethylamine (TEA) recovering initial state of the rotaxane.

The first step was performed directly in \( \Theta \)-cell. The second and the third steps were performed in a vial by exposing liquid crystalline mixture to either HCl (vapor) or TEA (vapor) at room temperature for 10 minutes. Then open vials were kept at 50°C for 1 hour followed by filling the \( \Theta \)-cell and HTP measurements. Protonation and deprotonation steps were monitored by UV-Vis spectroscopy.
Figure S8. Absorbance spectra of the rotaxane (0.1wt%) in the liquid crystal measured in 60 µm-gap home-made quartz cell.

Figure S9. (a-c) Polarized optical images of the θ-cells filled with nematic host containing 0.2 wt% of threads E-2, Z-2 obtained in situ, and Z-2 obtained ex situ, respectively. (b) Concentration dependence of cholesteric pitch induced in ZLI-1083 by molecular thread 2. The thickness of the θ-cell is 50 µm. Scale bar in images is 200 µm. p is the pitch of cholesteric helix.
Figure S10. Concentration dependence of cholesteric pitch induced in ZLI-1083 by the rotaxane (a) in situ operation, (b) ex situ operation. Polarized optical images of the θ-cells filled with nematic host containing 0.05 wt.% (c) and 0.1 wt% (d) of threads E-1 ex situ operation. Thickness of θ-cell is 50 µm. Scale bar in images is 200 µm. \( p \) is the pitch of the cholesteric helix.
Table S1. Helical twisting power (HTP) values of the molecular strand 2 and rotaxane 1 measured in \( \theta \)-cells. HTPs are provided for the concentrations in mol.%. The nematic liquid crystal ZLI-1083 was used as a host.

<table>
<thead>
<tr>
<th>HTP, ( \mu \text{m}^{-1} )</th>
<th>Initial</th>
<th>312 nm PSS in-situ*</th>
<th>312 nm PSS ex-situ**</th>
<th>After HCl treatment</th>
<th>After TEA treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>( E-2 )</td>
<td>−5.1±0.6</td>
<td>−3.9±0.3</td>
<td>−4.5±0.5</td>
<td>−</td>
<td>−</td>
</tr>
<tr>
<td>( E-1 )</td>
<td>−7.2±0.4</td>
<td>−9.3±0.4</td>
<td>−10.6±0.2</td>
<td>−8.0±0.4</td>
<td>−6.5±0.8</td>
</tr>
</tbody>
</table>

* \( \theta \)-cell was exposed to 312 nm UV light.

** DCM solution containing liquid crystal and rotaxane was exposed to 312 nm UV light followed by solvent evaporation, and filling \( \theta \)-cell.

6.5 Acknowledgements

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6.6 References


