

Development of Pi-Conjugated Molecular Assemblies towards Chiral Amine Sensing

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Abstract:

Due to the functional implications of an amine's chirality, there is significant interest in methods for sensing amine chirality. Current methods of chiral amine sensing typically involve large, high-cost instruments whose operation can be time consuming. Our previous work has demonstrated the catalyst-free click reaction between alkynyl-substituted π -extended electron acceptors such as perylene diimide and amines [1]. In this work, the capability to perform chiral amine sensing using supramolecular assemblies of such alkynyl-substituted π -extended electron acceptors was investigated. Herein, the synthesis of a novel perylene diimide compound and characterization of its supramolecular assembly process is reported. Further, preliminary kinetic studies of click reactions between the developed assemblies and chiral amines indicates its potential use for chiral amine sensing.

Summary of Research:

An amine's chirality can have dramatic impacts on its functionality; for example, one enantiomer of a chiral amine may have useful medical applications, while the other may be biologically inactive. Thus, chiral amine sensing is important for verifying whether only the desired enantiomer is present in a sample. Methods such as high-performance liquid chromatography with a chiral column, circular dichroism, and nuclear magnetic resonance with chiral reagents are the major current methods that are currently used to perform such sensing; however, these methods rely on large, expensive machinery and can be time consuming. Thus, an inexpensive, facile method of chiral amine sensing is highly desired.

A potential method of achieving this relies on the reactivity of amines. Amines have been shown to undergo a catalyst-free click reaction with alkynyl-substituted π -extended electron acceptors such as naphthalene diimide (NDI) and perylene diimide (PDI) [1]. Such alkynyl-substituted NDI and PDI compounds can be formed into supramolecular assemblies whose conformation is dictated by "assembling units" that are side chains at the imide positions [2]. Through

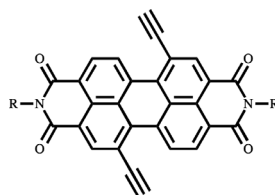


Figure 1: Structure of R-PDI2.

selection of a chiral assembling unit, a chiral supramolecular assembly can be produced that may potentially demonstrate enantioselectivity in reactions with chiral amines. Such chiral supramolecular assemblies can then be used as chiral amine sensors based on the differing kinetics that result from the enantioselectivity of the reaction.

In this work, a novel alkynyl-substituted PDI compound with chiral side chains (R-PDI2) was synthesized. The particular side chains used and synthetic scheme will not be reported here, but the general structure of the compound can be found in Figure 1. After synthesis of R-PDI2, the supramolecular assembly process was characterized using temperature-dependent ultraviolet-visible (UV-vis) absorption spectroscopy to optimize the solvent conditions for formation of supramolecular assemblies. To visualize the morphology of these assemblies, atomic force microscopy (AFM) images were taken of the compound after the assembling process. Finally, kinetic studies of the reactions of these supramolecular assemblies with enantiomers of a chiral amine were performed using time-dependent UV-vis absorption spectroscopy.

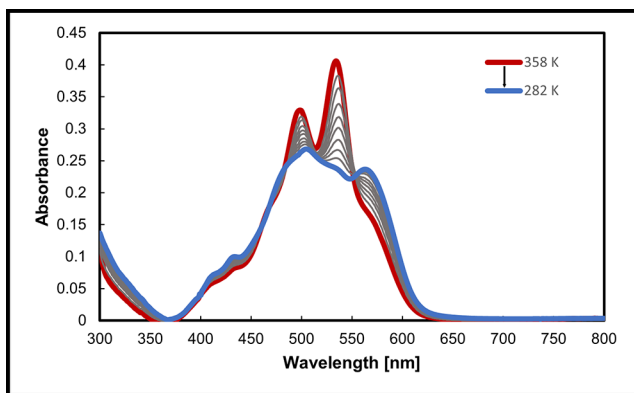


Figure 2: Temperature-dependent UV-vis absorption spectral changes for R-PDI2 (20 μm) in MCH/*p*-xylene (1:1 v/v) during cooling from 358 K to 282 K at a rate of 1 K/min.

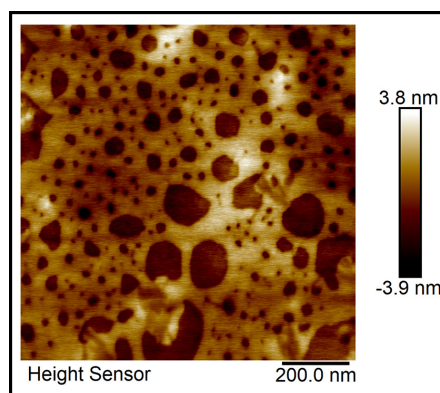


Figure 3: AFM image of a spin-coated sample prepared by cooling R-PDI2 (20 μm) from 358 K to 283 K at 1K/min in MCH/*p*-xylene (1:1 v/v).

Results:

Assembly Characterization. To optimize the solvent system for the supramolecular assembly process, UV-vis absorption spectroscopy measurements were taken over a range of temperatures in different solvent mixtures. The goal was to find a solvent in which 1) a significant change in the UV-vis absorption spectra could be observed across the range of temperatures and 2) the assemblies did not precipitate from solution up to a monomer concentration of 25 μM . This was achieved in a 1:1 v/v mixture of methylcyclohexane (MCH) and *p*-xylene. The UV-vis absorption spectra demonstrating this assembly process can be seen in Figure 2.

Visualization of the assembly structure was achieved through AFM measurement of a sample spin-coated from 1:1 v/v MCH/*p*-xylene. A resulting AFM image can be seen in Figure 3. The AFM image reveals the formation of thick fibers in a porous sheet, indicating that the monomers are assembling into stacked monomer chains.

Reactions with Chiral Amines. To determine whether supramolecular assemblies of R-PDI2 could be used to differentiate between amine enantiomers, preliminary kinetic studies were performed using time-dependent UV-vis absorption spectroscopy. R-PDI2 assemblies (18.75 μm) were reacted with (R)- and (S)-1-phenylethylamine (0.49 μM) over the course of 24 hours. Changes in the absorbance at 512 and 700 nm were used to qualitatively demonstrate differences in reaction kinetics between the (R)- and (S)-enantiomers of 1-phenylethylamine. Plots of the absorbance at 512 and 700 nm can be found in Figure 4. The spectral analysis indicates that the reaction kinetics of R-PDI2 are slightly different depending on the enantiomers.

Conclusions and Future Steps:

This work demonstrates the potential application of supramolecular polymers of an alkynyl-substituted PDI for chiral amine sensing. The novel compound R-PDI2 was successfully synthesized, assembled, and characterized, allowing for its use in future work.

Further, preliminary kinetic studies revealed that there is some degree of stereoselectivity involved in reactions between R-PDI2 assemblies and chiral amines. However, further work must be done to improve the application of these materials, with the ultimate goal of being able to react such an assembly with chiral amines and observe a color change that requires no instrumentation to detect. Finally, another promising direction of this work is to investigate R-PDI2's application for sensing chiral diamines, which would likely experience greater stereoselectivity due to crosslinking between R-PDI2 monomers.

References:

- [1] Takai and M. Takeuchi, Bulletin of the Chemical Society of Japan, vol. 91, no. 1, pp. 44-51, 2018.
- [2] M. Tan, M. Takeuchi and A. Takai, Chemical Science, vol. 13, no. 15, pp. 4413-4423, 2022.

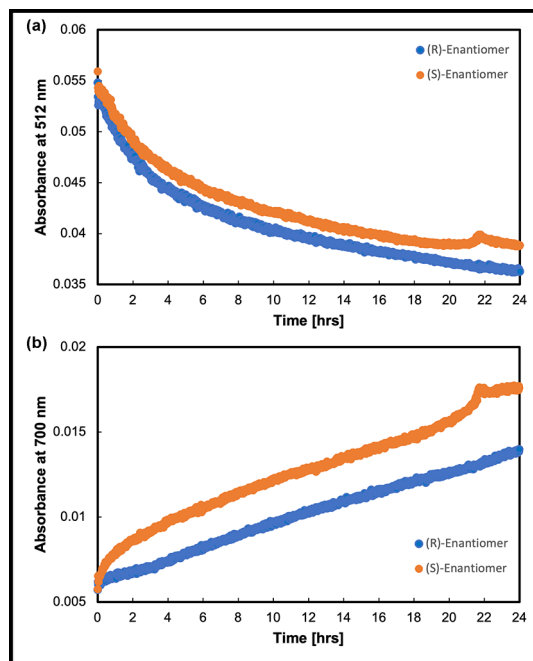


Figure 4: Absorbance values at (a) 512 nm and (b) 700 nm over the course of 24 hours for the reaction of R-PDI2 assemblies with the two enantiomers of 1-phenylethylamine.