

中国科学院感光化学研究所博士学位论文

疏水作用、疏脂作用在有机 合成中的应用

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专业 有机化学

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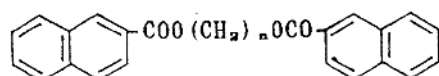
于北京，中国科学院感光化学研究所

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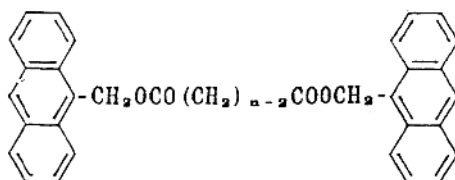
化合物结构式

双-2-萘甲酸多亚甲基二醇酯(缩写为N-Mn-N),



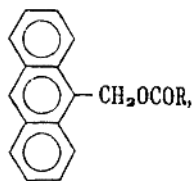
$$n = 2, 3, 5, 8, 10$$

α, ω -烷基二酸-9-蒽甲醇酯(缩写为A-Mn-A),



$$n = 3, 6, 10$$

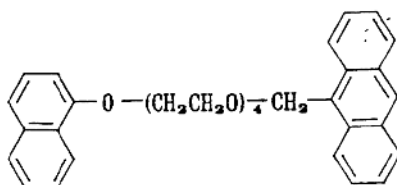
脂肪酸-9-蒽甲醇酯



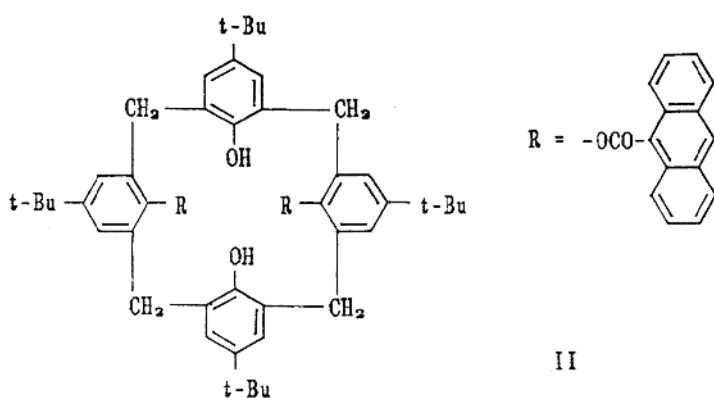
$R = \text{CH}_3, \text{AA};$

$R = (\text{CH}_2)_{10}\text{CH}_3, \text{AD}.$

1-(1-萘基)-14-(9-萘基)-1,4,7,10,13-五氧杂十四烷(N-P₄-A)



对称双萘甲酸酯化的对-叔丁基杯[4]芳烃(II):



摘 要

一. 疏水作用引起的分子自绕曲对大环化合物合成的促进作用.

本文合成了一系列不同链长的双-2-萘甲酸多亚甲基二醇酯 ($N-M_n$ -N, $n = 2, 3, 5, 8, 10$), 和不同链长的 α, ω -脂肪二酸二9-萘甲醇酯 ($A-M_n-A$, $n = 3, 6, 10$), 研究了它们在不同溶剂中的光物理行为, 发现疏水作用使带有非极性长链的化合物发生自绕曲, 利用自绕曲促进大环化合物的合成.

1. 研究了双-2-萘甲酸多亚甲基二醇酯 ($N-M_n$ -N) 在不良溶剂乙二醇-水 ($EG-H_2O$)、二甲基亚砜-水 ($DMSO-H_2O$) 和 1,4-二氧六环-水 ($DX-H_2O$) 中的稳态荧光光谱. 实验表明在不良溶剂中, 分子受疏水作用发生自绕曲, 两末端基相互靠拢, 有利于激基缔合物的生成. 糖淀粉对 $N-M_n$ -N 分子的包结作用也对分子的自绕曲给出了进一步的证据. 实验中测定了 $N-M_n$ -N 分子自绕曲形成的条件. 在 $DX-H_2O$ ($\Phi=0.6$), $5.0 \times 10^{-5} M$ 浓度的 $N-M_n$ -N 分子处于自绕曲状态.

2. 在 $DX-H_2O$ ($\Phi=0.6$) 中, 以 $\lambda > 280 nm$ 的光照射 $N-M_n$ -N 的稀溶液 ($5.0 \times 10^{-5} M$), 以 100% 的产率得到类立方烷结构 (Cubane-like) 的分子内光二聚产物, 合成了最大环为 17 员环的脂肪族大环化合物.

3. 测量了不同溶剂中 $N-M_n$ -N 分子内光二聚的光量子产率, 在有机-水混合溶剂中的光量子产率远大于在极性和非极性有机溶剂中的光量子产率, 它们之间可相差几倍或几十倍. 说明疏水作用引起的分子自绕曲对大环化合物的合成有促进作用.

4. 测量了不同光强下 $N-M_n$ -N 的光二聚反应速率. 实验结果表明, $N-M_n$ -N 的光二聚反应速率与光强的平方成正比, 说明该光二聚反应过程是吸收两个光子的过程.

5. 研究了 α, ω -脂肪二酸二9-萘甲醇酯 ($A-M_n-A$) 在不良溶剂 DX

-H₂O中的稳态荧光光谱. 测定了A-M_n-A分子自绕曲形成的条件.

6. 在DX-H₂O ($\Phi=0.6$) 中, 以 $\lambda > 300\text{nm}$ 的光照射A-M_n-A的稀溶液 ($2.0 \times 10^{-5}\text{M}$), 得到分子内光二聚产物, 合成了最大环为17 员环的脂肪族大环化合物.

7. 测量了不同溶剂中A-M_n-A分子内光二聚的光反应动力学. 动力学结果表明, 在有机-水混合溶剂中的光二聚反应速率均大于在极性和非极性有机溶剂中的光二聚反应速率. 再一次证实了疏水作用引起的分子自绕曲对大环化合物合成的促进作用.

二. 簇集对9-取代蒽化合物分子间光二聚立体选择性的影响.

合成了不同链长的脂肪酸-9-蒽甲醇酯. 研究了它们在良溶剂和不良溶剂中的光物理行为, 实验结果表明疏水作用使带有烷基长链的分子发生簇集. 利用簇集体的形成, 首次合成了以头-头构型为主的长链9-取代蒽分子间光二聚产物.

1. 研究了月桂酸-9-蒽甲醇酯 (AD) 和乙酸-9-蒽甲醇酯 (AA) 在不同溶剂中的荧光光谱. 实验结果表明, 在有机-水混合溶剂中, 疏水作用使带有长链的9-取代蒽分子发生簇集, 有利于分子间激基缔合物的形成. 实验中测定了AD在不同有机-水混合溶剂中的发生簇集的临界溶剂组成 ($C\Phi$) 和一定 Φ 下的临界簇集浓度 (CAC).

2. 研究了添加剂--长链饱和烷烃 (C_n) 和糖淀粉--对AD 荧光光谱的影响. 添加C_n引起激基缔合物荧光强度减弱, 同时伴随单体荧光的增强, 表明C_n和AD发生了共簇集. 加入糖淀粉, 由于糖淀粉与AD分子中的长的烷基链形成了包络络合物, 引起AD荧光光谱中激基缔合物荧光强度减弱, 同时伴随单体荧光的增强. 加入添加剂后AD荧光光谱的变化情况对AD分子间簇集体的形成给出了进一步的证据.

3. 在DX-H₂O ($\Phi=0.7$) 中, 以 $\lambda > 300\text{nm}$ 的光照射AD的稀溶液 (5.0

$\times 10^{-6}\text{M}$), 首次得到了以头-头构型为主的9-取代蒽分子间光二聚产物, 头-头构型和头-尾构型的比例为6:1, 而在有机溶剂中9-取代蒽分子间光二聚产物头-头和头-尾构型的比例为1:4. 说明簇集改变了9-取代蒽光二聚反应的立体选择性.

4. 测量了不同溶剂中AD分子间光二聚的光量子产率. 在DX-H₂O ($\Phi=0.7$) 光照AD的稀溶液 ($5 \times 10^{-6}\text{M}$) 的光量子产率比在有机溶剂苯中照射AD的浓溶液 ($5 \times 10^{-6}\text{M}$) 的光量子产率要高得多. 在苯的稀溶液 ($<10^{-6}\text{M}$) 中照射AD不发生反应. 以上结果表明簇集可以使9-取代蒽的光二聚反应高效快速的进行.

三. 疏脂作用对蒽和蒹之间的不对称加成的促进作用

合成了两端分别用蒽和蒹标记的聚乙二醇化合物N-P₄-A, 结构如下:



研究了它在良溶剂和不良溶剂中分子内蒽和蒹之间的能量传递, 实验结果表明, 在不良溶剂环己烷中N-P₄-A分子受疏脂作用驱动发生自绕曲, 而使末端基蒽和蒹相互靠拢, 利用N-P₄-A分子的自绕曲, 我们得到了蒽和蒹之间的不对称加成产物.

1. 研究了N-P₄-A分子在四氢呋喃、甲醇和环己烷中的能量传递. 实验结果表明, 在环己烷中具有较强的能量传递, 甲醇中次之, 四氢呋喃中最低. 这是由于在环己烷中N-P₄-A分子受疏脂作用发生自绕曲, 使末端基蒽和蒹相互靠拢, 增加了能量传递效率, 在甲醇和四氢呋喃中聚乙二醇链处于伸展状态, 两末端基相隔较远, 能量传递效率较低.

2. 在环己烷中以 $\lambda > 280\text{nm}$ 的光照射N-P₄-A溶液 ($1.0 \times 10^{-6}\text{M}$), 产物主要为蒽和蒹的不对称加成物. 其它条件不变, 当改用 $\lambda > 300\text{nm}$

的光照射反应, 只得到分子间蒽和蒽加成的产物. 说明蒽和蒽之间的不对称加成是通过蒽的激发态与蒽进行反应, 而不是蒽的激发态与蒽的反应. 同样条件下在四氢呋喃中以 $\lambda > 280\text{nm}$ 的光照射 N-P₄-A ($1.0 \times 10^{-4}\text{M}$), 只得到分子间蒽的加成产物. 说明蒽和蒽之间不对称加成的实现是依赖于疏脂作用使 N-P₄-A 分子发生的自绕曲现象.

四. 杯芳烃的模板效应以及和铕离子之间的能量传递.

合成了对称二蒽甲酸酯化的对-叔丁基杯[4]芳烃化合物, 利用杯芳烃的模板效应, 首次以100%的产率实现了头-头构型产物为唯一产物的9-取代蒽的光二聚. 研究了一系列杯芳烃衍生物与铕离子之间的能量传递, 对杯芳烃和铕离子之间络合物的生成进行了讨论.

1. 合成对称二蒽甲酸酯化的对-叔丁基杯[4]芳烃化合物, 核磁结果表明两个蒽相间处于杯芳烃底边上, 杯芳烃为锥型构象. 以 $\lambda > 300\text{nm}$ 的光照射该化合物的乙醚溶液 ($1.0 \times 10^{-5}\text{M}$), 蒽100%地发生了反应, 产物核磁结果显示, 产物中9-取代蒽全部为头-头构型.

2. 研究了一系列杯芳烃及其衍生物和铕离子这间的能量传递. 实验结果显示, 底边均为羟基的杯芳烃与铕离子可以比较好地形成络合物, 而且杯[8]芳烃较杯[4]和杯[6]芳烃与铕离子有更好的络合性能. 对于杯[4]芳烃, 当底边上的羟基部分被酯基所取代后, 不能看到杯芳烃向铕离子有效的能量传递. 说明此时的杯芳烃不能有效地和铕离子形成络合物. 而杯[8]芳烃, 即使底边上的八个羟基全部被较大的酯基所取代, 铕离子的荧光虽然很弱, 但仍可被观察到. 综合这部分的实验结果, 我们认为杯芳烃底边空间的大小直接影响着络合物的形成, 同时底边上与苯环相连氧上的负电性对络合物的形成也起着很大作用.

APPLICATIONS OF HYDROPHOBIC AND LIPOPHOBIC INTERACTIONS IN ORGANIC SYNTHESIS

Abstract

1. Enhancement of large-ring compounds formation via molecules self-coiling induced by hydrophobic interactions.

A series of polymethylene bis(2-naphthoates) (N-Mn-N, $n=2, 3, 5, 8, 10$) and 9-anthrylmethyl α, ω -alkanedioates (A-Mn-A, $n=3, 6, 10$) were synthesized. The photophysical and photochemical properties of these compounds have been studied. In aqueous organic mixed solvents, hydrophobic interactions force the molecules with long non-polar chains to self-coil. This phenomenon has been successfully used to promote the syntheses of large-ring compounds.

1. The fluorescence spectra of N-Mn-N in aqueous organic solvents, such as ethylene glycol-water (EG-H₂O), dimethyl sulfoxide-water (DMSO-H₂O) and 1,4-dioxane-water (DX-H₂O), have been investigated. Strong intramolecular force polymethylene chains to self-coil. Addition of amylose resulted in the enhancement of monomer fluorescence and reduction of the excimer emission, indicating that amylose forms inclusion complex with N-Mn-N.

2. Photoirradiation of the dilute solution of N-Mn-N ($5.0 \times 10^{-5} \text{M}$) in DX-H₂O ($\phi = 0.6$, represents the fraction of water in the mixed solvents) by using $\lambda > 280 \text{nm}$ light leads to intramolecular dimerization of 2-naphthoate groups to give ring-closure products. The yield of the product is 100% based

on the consumption of starting material. The largest ring synthesized is 17-membered-ring.

3. The quantum yields of the photodimerization of N-Mn-N have been measured in different solvents. The quantum yield in aqueous organic solvents are much greater than those in polar or non-polar organic solvents. This suggests that the self-coiling induced by hydrophobic interactions enhances the formation of large-ring compounds.

4. The rate of photodimerization at different light intensities has been measured. The linear relationship between the rate and the square of the light intensity has been obtained. This result indicates that the photodimerization is a two photons absorption process.

5. The fluorescence property of A-Mn-A in aqueous organic solvents has been studied and the evidence for self-coiling of A-Mn-A in the solvents have be obtained detected.

6. Irradiation of the dilute solution of A-Mn-A ($2.0 \times 10^{-5} \text{ M}$) in DX-H₂O), with $\lambda > 300 \text{ nm}$ light results in intramolecular photodimerization of the anthracene groups, thus giving macrocyclic compounds. The largest ring synthesized is 17-membered-ring.

7. In aqueous organic solvents the rate of photodimerization of A-Mn-A is much greater than those in polar or non-polar solvents. These results prove further that self-coiling induced by hydrophobic interactions may be used to promote formation of large-ring compounds.

II. The effect of aggregation on the stereoselectivity of

intermolecular photodimerization of 9-substituted anthracene derivatives

A series of 9-anthrylmethyl alkanoates have been synthesized. The photophysical behavior of these compounds in different solvents have been studied. The results indicate that compounds with long alkyl chains form aggregates in aqueous organic solvents due to hydrophobic interactions. Photoirradiation of these solution results in the dimerization of the anthracene nucleus at 9,10-positions to form almost exclusively the head-to-head(H-H) dimer.

1. Fluorescence property of 9-anthrylmethyl dodecanoate (AD) and acetate (AA) has been studied in different solvents. The results indicate that hydrophobic interaction force the molecules with long chains to form aggregates in aqueous organic solvents. This enhances the formation of intermolecular excimer. The critical solvent composition (C_0) for aggregate formation and the critical aggregation concentration (CAC) of AD in different aqueous organic solvents have been measured.

2. The effects of long chain alkanes and amylose on the fluorescence of AD in aqueous organic solvents have been studied. The excimer emissions decreased and the monomer fluorescence is increased as long chain alkane was added to the solution. This result suggests that AD and long chain alkane form co-aggregate. Addition of amylose to the solution results in the enhancement of monomer emission and reduction in the excimer emission. This is due to the fact that amylose forms an inclusion complex with AD and prevents the two

anthryl groups from approaching each other.

3. Photoirradiation of the dilute solution of AD ($5.0 \times 10^{-5} \text{M}$) in DX- H_2O ($\phi = 0.7$) with $\lambda > 300 \text{nm}$ light leads to the intermolecular photodimerization of the anthryls to give a H-H dimer as the main product. The ratio of H-H photodimer to the head-to-tail photodimer (H-T) is 6:1. This is contrary to that in organic solvents (H-H:H-T = 1:4). This result illustrated that aggregation changed the stereoselectivity of the photodimerization of 9-substituted anthracene.

4. The quantum yields of the intermolecular photodimerization of AD in different solvents have been measured. The quantum yield in DX- H_2O ($\phi = 0.7$) at low concentration ($5.0 \times 10^{-5} \text{M}$) is much greater than that in benzene even the later solution has a greater concentration ($3.0 \times 10^{-5} \text{M}$). When the dilute solution in benzene ($< 10^{-4} \text{M}$) was irradiated, no reaction could be detected. These results illustrate that aggregation can promote the photodimerization of 9-substituted anthracene with high efficiency.

III. Enhancement of cross photoaddition between anthryl and naphthyl via lipophobic interactions.

The compound of 1-(1-naphthyl)-14-(9-anthryl) 1,4,7,10,13-pentaoxotetradecane (N- P_4 -A) had been synthesized. The intramolecular energy transfer from naphthyl group to anthryl group in different solvents were studied. In non-polar solvents (cyclohexane) the molecules were self-coiling due to the lipophobic interactions and the end groups were approached each other. The cross photoaddition product

was obtained via the self-coiling of the molecules.

1. The intramolecular energy transfer from naphthyl to anthryl of N-P₄-A in THF, methanol and cyclohexane has been detected. The efficiency of the energy transfer in cyclohexane is higher than that in THF and methanol. This indicates that in cyclohexane the long polar chains self-coil, driven by lipophobic interactions, thus the end groups approach each other.

2. Photoirradiation of the dilute solution of N-P₄-A ($1.0 \times 10^{-4} \text{M}$) in cyclohexane with $\lambda > 280 \text{nm}$ light gives the intramolecular cross photoaddition product of naphthyl and anthryl in addition to the intermolecular photodimer of the anthryl groups. On the other hand, when the solution is irradiated with $\lambda > 300 \text{nm}$, no cross photoaddition is detected, instead, the product of intermolecular photoaddition of anthryl groups is obtained. This suggests that the cross photoaddition reaction is via the excited naphthyl with ground state anthryl group, not via excited anthryl with ground naphthyl group. In THF we irradiated the solution with $\lambda > 280 \text{nm}$ light, only intermolecular addition product of anthryl groups was detected. Thus, the intramolecular cross photoaddition in cyclohexane is attributed to self-coiling induced by lipophobic interactions.

IV. Orientation effect of calixane on photodimerization of anthryls and the energy transfer from calixane to Eu^{3+} .

p-(t-Butyl calix[4]ane)-1,3-alternate di-9-anthranate has been synthesized. Photoirradiation of this compound gives

exclusively the H-H dimer of the anthracene nucleus. The energy transfer from a series of calixane to Eu^{3+} has been studied and the complex formation between calixane and Eu^{3+} was discussed.

1. p-(t-butyl calix[4]ane)-1,3-alternate di-9-anthranate has been synthesized. The ^1H NMR shows the two anthryl groups are connected at lower rim symmetrically and the molecule is in a cone conformation. The solution of this compound ($1.0 \times 10^{-5}\text{M}$) in diethyl ether were irradiated by $\lambda > 300\text{nm}$ light. The photodimerization of anthryl groups gives only H-H photodimer with 100% yield.

2. The energy transfer from a series of calixane to Eu^{3+} has been studied. The results indicate that the calixane with hydroxyl groups at lower rim could complex Eu^{3+} efficiently. The complexation of calix[8]ane is more efficient than calix[4]ane and calix[6]ane. When the hydroxyl groups at lower rim were substituted by ester groups in calix[4]ane, there was no energy transfer from calixane to Eu^{3+} . For calix[8]ane, although eight hydroxyl groups at lower rim were substituted by esters, the luminescence of Eu^{3+} can still be detected. This suggests that the space size of the lower rim and the electric negative of the oxygen atom are important factors for the formation the complex of calixane with Eu^{3+} .

第一部分 引 言

1. 疏水作用

疏水作用影响着许多生物化学过程,如在生物大分子构型的变化、底物与生物酶的结合、亚单位形成多聚酶、膜的形成以及生物分子的高级组合而形成生命体系中的功能单元等过程中,疏水作用都起着十分重要的作用¹⁻³。而所有这些生物化学过程通常都具有两个特点:1、它们都涉及到许多非极性分子的缔合体或大分子中基团的堆集体;2、这些过程的发生都是在水介质中进行的。因此,要了解生命过程,首先必须了解疏水作用及分子的组合。胶束被认为是模拟生物体系的最简单的模型,然而近期的研究结果表明,在有机-水混合溶剂中,电中性分子趋向缔合,由此而形成的簇集体的结构比胶束更为简单⁴⁻⁵,疏水作用几乎是簇集体形成的唯一推动力。

簇集可以影响一些有机化合物的反应性能,例如:在某些情况下取代基效应的性质将由疏水作用代替电子效应⁶;发生反应的两个长链分子在疏水作用的影响下彼此靠近而导致速度增加的所谓“邻近效应”⁷⁻¹⁴。同时,象胶束溶液一样,簇集体溶液也可作为化学反应的介质。簇集体可以增溶疏水分子,由于簇集体具有较小的尺寸,增溶过程允许溶质处于单分子状态,从而可以改变化学反应的进行,使产物或(和)产物的相对产率相对于在均相溶液中的反应有所改变,因此在合成化学中它有着很好的应用前景。另外,簇集在催化反应中也是十分有效的。