ORGANIC LETTERS

1999
Vol. 1, No. 12
1881−1883

Novel Cyclic Molecules: Selective Synthesis of Cyclic Phenylazomethines

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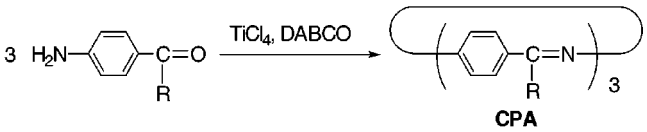
Received August 21, 1999

ABSTRACT



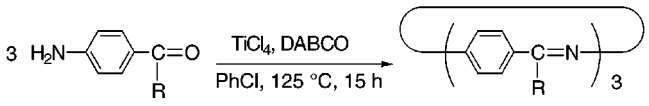
CPA

Novel cyclic molecules, the cyclic phenylazomethine trimers (CPAs), were synthesized via the dehydration of the 4-aminobenzophenone derivatives. The yields of the CPAs were enhanced to over 90% by induction of the bulky α-substituent to the substrate. The UV–vis spectra of the CPAs show a nonconjugated structure and *Z* conformation compared to the linear oligophenylazomethines (OPAs).

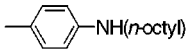
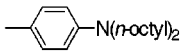
There has been considerable interest in aromatic macrocyclic oligomers that can be utilized as reactive monomers in the ring-opening polymerization for high molecular weight linear polyaromatics with high purity.[1] Most of the preparative methods for these aromatics result in not only low yields but also the formation of a mixture of cyclics with different numbers of repeating units.[2] Until now, cyclic compounds were synthesized under hyperdiluted conditions, and there have been few reports of a highly selective preparation of a discrete cyclic aromatic by a one-step reaction. We herein report the synthesis of novel cyclic molecules with a phenylazomethine backbone, cyclic phenylazomethines (CPAs), which have an alternate structure of phenylene and a C═N double bond as compared to the structure of the linear oligophenylazomethines (OPAs). The polyphenylazomethine chain with an alternating structure of a phenyl ring and C═N double bond should be noted as electronic functional molecules because the structure is analogous to poly(phenylene vinylene) which is an important conductive polymer.[3] We succeeded in the selective synthesis of cyclic tris[(α-phenyl)phenylazomethine] derivatives with a high yield using $TiCl_4$. Our results reveal that 4-aminobenzophenone with a bulky group facilitates the predominant formation of the cyclic structure.

The formation of the novel cyclic (α-phenyl)phenylazomethine trimer (CPA-a) was carried out by dehydration of 4-aminobenzophenone using $TiCl_4$ (Scheme 1, run 1).[4] In general, the dehydration of amines with aldehydes efficiently takes place in the presence of *p*-toluenesulfonic acid (PTS) as catalyst, while the dehydration of aromatic amines with aromatic ketones proceeds slowly. Instead of

Scheme 1



1 **CPA**

Run	R	Yield of **CPA**, %
1	Ph	20 (**CPA-a**)
2		49 (**CPA-b**)
3		92 (**CPA-c**)
4	Me	0

(1) (a) Wang, Y.-F.; Hay, A. S. *Macromolecules* **1996**, *29*, 5050. (b) Chan, K. P.; Wang, Y.-F.; Hay, A. S. *Macromolecules* **1995**, *28*, 653. (c) Teasley. M. F.; Wu, D. Q.; Harlow, R. L. *Macromolecules* **1998**, *31*, 2064. (d) Brunelle, D. J.; Krabbenhoft, H. O.; Bonauto, D. K. *Macromol. Symp.* **1994**, *77*, 117. (e) Memeger, W., Jr.; Lazar, J.; Ovenall, D.; Leach, R. A. *Macromolecules* **1993**, *26*, 3476.

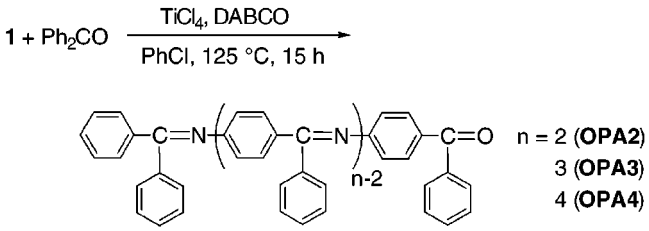
(2) (a) Ding, Y.; Hay, A. S. *Macromolecules* **1996**, *29*, 6386. (b) Chan, K. P.; Wang, Y.-F.; Hay, A. S.; Hronowski, X. L.; Cotter, R. J. *Macromolecules* **1995**, *28*, 6705. (c) Wang, J.; Chen, C.; Xun, X.; Wang, S.; Wu, Z. *J. Polym. Sci. A: Polym. Chem.* **1999**, *37*, 1957. (d) Colquhoun, H. M.; Lewis, D. F.; Fairman, R. A.; Baxter, I.; Williams, D. J. *J. Mater. Chem.* **1997**, *7*, 1.

10.1021/ol990975s CCC: $18.00
Published on Web 11/19/1999

PTS, using titanium(IV) tetrachloride as a Lewis acid acts as an effective dehydration agent. Only the CPA trimer was obtained with a 20% yield despite nondilute conditions, in which the yield is considerably higher than in the previously reported cyclization such as carbonate[5] and thiophenylene compounds,[6] and only the cyclic trimer of phenylazomethine was isolated. The high yield and the selectivity are caused by the steric effect of the bulky α-phenyl ring of the monomer, which is supported by the results of the reaction of the benzophenones with a bulky group at the α-position. The selectivity and yield were emphasized by the bulkiness of the monomer. The dehydration of 4-amino-4′-octylaminobenzophenone resulted in the formation of the corresponding cyclic trimer (CPA-b) in 49% yield (run 2). The dehydration of 4-amino-4′-dioctylaminobenzophenone gave the corresponding trimer (CPA-c) with a 92% isolated yield (run 3). However, the dehydration of 4′-aminoacetophenone did not provide the formation of the corresponding cyclic trimer (run 4) due to the small size of the group. These results indicate that bulky substituents at the α-position of the phenylazomethine facilitate the formation of the cyclic phenylazomethine trimers.

CPAs are formed by the intramolecular coupling of linear phenylazomethine trimers via dehydration. The yield of CPA depends on the *E*/*Z* conformation in the azomethine moieties of the linear trimer. The dehydration of only the *Z*,*Z* isomer of the linear trimer results in the formation of CPA. The linear oligophenylazomethines (OPAs) as model compounds were synthesized by the oligomerization of 4-aminobenzophenone in the presence of benzophenone (Scheme 2).[7]

Scheme 2



OPA

Run	[Ph_2CO] / [**1**]	Yield, %[a]		
		OPA2	**OPA3**	**OPA4**
1	2	28	27	12
2	5	52	29	10

[a] Yields were calculated for [**1**]

The ^{13}C NMR spectra revealed that OPA3 and OPA4 have two and four isomers on the basis of the *E*/*Z* conformation of the azomethine moiety, respectively. Two peaks attributed to the carbonyl carbon and four peaks attributed to the azomethine one were observed in the ^{13}C NMR spectrum of OPA3, even though OPA3 has only one carbonyl and two azomethines (Figure 1b). The ^{13}C NMR spectrum of OPA4 that has one carbonyl and three azomethines shows four peaks attributed to the carbonyl carbon and multiple peaks

(3) (a) Brabec, C. J.; Padinger, F.; Sariciftci, N. S.; Hummelen, J. C. *J. Appl. Phys.* **1999**, *85*, 6866. (b) Gurge, R. M.; Sarker, A.; Lahti, P. M.; Hu, B.; Karasz, F. E. *Macromolecules* **1996**, *29*, 4287. (c) Jin, J.-I.; Park, C.-K.; Shim, H.-K. *Macromolecules* **1993**, *26*, 1799. (d) Jin, J.-I.; Lee, Y.-H.; Shim, H.-K. *Macromolecules* **1993**, *26*, 1805.

(4) (a) Boone, H. W.; Bryce, J.; Lindgren, T.; Padias, A. B.; Hall, H. K., Jr. *Macromolecules* **1997**, *30*, 2797. (b) Boone, H. W. and Hall, H. K., Jr. *Macromolecules* **1996**, *29*, 5835. **Synthesis of CPA-a**: 4-Aminobenzophenone (4.93 g, 25.0 mmol) and 1,4-diazabicyclo[2.2.2]octane (DABCO) (8.41 g, 75.0 mmol) were dissolved in chlorobenzene (150 mL). Titanium(IV) tetrachloride (3.56 g, 18.8 mmol) was added dropwisely over 5 min. The additional funnel was rinsed with chlorobenzene (5 mL). The reaction mixture was heated in an oil bath at 125 °C for 15 h. The precipitate was isolated by filtration. The filter cake was added in α-chloronaphtharene (200 mL), and the heterogeneous solution was stirred at 190 °C for 3 h. The α-chloronaphtharene solution including OPA-a and DABCO was separated by hot filtration. CPA-a (0.890 g, 4.96 mmol, 20% yield) was isolated by precipitaion from methanol. **CPA-a**: ^1H NMR (400 MHz, CF_3COOD, TMS standard, 30 °C, ppm) δ 8.11 (t, J = 7.2 Hz, 3H), 8.03 (d, J = 7.6 Hz, 6H), 7.82 (dd, J = 7.2, 7.6 Hz, 6H), 7.69 (s, 12H); ^{13}C NMR (100 MHz, CF_3COOD, TMS standard, 30 °C, ppm) δ 187.39, 142.96, 141.96, 135.17, 134.07, 133.74, 132.85, 131.19, 129.79; IR (KBr) 1617 (C═N), 1599 (phenyl), 701 (phenyl); FAB-MS 538 $[M + 1]^+$. Anal. Calcd for $C_{39}H_{27}N_3$: C, 87.12; H, 5.06; N, 7.82. Found: C, 87.27, H, 4.78; N, 7.59. **Synthesis of CPA-b**: 4-Amino-4′-octylaminobenzophenone (0.195 g, 0.60 mmol) and 1,4-diazabicyclo[2.2.2]octane (DABCO) (0.202 g, 1.80 mmol) were dissolved in chlorobenzene (6 mL). Titanium(IV) tetrachloride (0.085 g, 0.45 mmol) was added dropwisely. The additional funnel was rinsed with chlorobenzene (1 mL). The reaction mixture was heated in an oil bath at 125 °C for 15 h. The precipitate was removed by filtration. The filtrate was concentrated, and CPA-b (0.090 g, 49%) was isolated by silica gel column chlomatography (ethyl acetate:hexane = 1:10, including 2% Et_3N, R_f = 0.1). **CPA-b**: ^1H NMR (400 MHz, $CDCl_3$, TMS standard, 30 °C, ppm) δ 7.67 (d, J = 8.8 Hz, 6H), 6.73 (d, J = 8.4 Hz, 6H), 6.55 (d, J = 8.8 Hz, 6H), 6.47 (d, J = 8.4 Hz, 6H), 4.00 (s, 3H), 3.15 (t, J = 6.8 Hz, 6H), 1.62 (m, 6H), 1.44−1.20 (m, 30H), 0.89 (t, J = 7.2 Hz, 9H); ^{13}C NMR (100 MHz, $CDCl_3$, TMS standard, 30 °C, ppm) δ 170.70, 153.00, 150.87, 130.93, 128.30, 128.14, 127.23, 120.07, 111.67, 43.52, 31.78, 29.38, 29.35, 29.22, 27.06, 22.62, 14.06; IR (KBr) 1613 (C═N), 1587 (phenyl), 1316 (C_{arom}−N), 1146 (C_{aliph}−N), 828 (phenyl); FAB-MS 919 $[M + 1]^+$. Anal. Calcd for $C_{63}H_{78}N_6$: C, 82.31; H, 8.55; N, 9.14. Found: C, 82.35, H, 8.32; N, 9.02. **Synthesis of CPA-c**: 4-Amino-4′-dioctylaminobenzophenone (0.10 g, 0.23 mmol) and 1,4-diazabicyclo[2.2.2]octane (DABCO) (0.077 g, 0.69 mmol) were dissolved in chlorobenzene (5 mL). Titanium(IV) tetrachloride (0.033 g, 0.17 mmol) was added dropwisely. The additional funnel was rinsed with chlorobenzene (1 mL). The reaction mixture was heated in an oil bath at 125 °C for 15 h. The precipitate was removed by filtration. The filtrate was concentrated, and CPA-c (0.089 g, 92%) was isolated by silica gel column chlomatography (ethyl acetate: hexane = 1:10, including 2% Et_3N, R_f = 0.2). **CPA-c**: ^1H NMR (400 MHz, $CDCl_3$, TMS standard, 30 °C, ppm) δ 7.69 (t, J = 8.8 Hz, 6H), 6.73 (d, J = 8.4 Hz, 6H), 6.59 (d, J = 8.8 Hz, 6H), 6.47 (d, J = 8.4 Hz, 6H), 3.30 (t, J = 7.6 Hz, 12H), 1.60 (m, 12H), 1.30 (m, 60H), 0.89 (t, J = 7.2 Hz, 18H); ^{13}C NMR (100 MHz, $CDCl_3$, TMS standard, 30 °C, ppm) δ 170.63, 153.09, 150.17, 130.80, 128.80, 128.14, 125.25, 120.13, 110.65, 51.03, 31.80, 29.45, 29.26, 28.92, 27.26, 22.62, 14.06; IR (KBr) 1613 (C═N), 1583 (phenyl), 1321 (C_{arom}−N), 1146 (C_{aliph}−N), 823 (phenyl). FAB-MS 1256 $[M + 1]^+$. Anal. Calcd for $C_{87}H_{126}N_6$: C, 83.20; H, 10.11; N, 6.69. Found: C, 83.39, H, 9.97; N, 6.63.

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(6) (a) Tsuchida, E.; Miyatake, K.; Yamamoto, K.; Hay, A. S. *Macromolecules* **1998**, *31*, 6469. (b) Miyatake, K.; Yokoi, Y.; Yamamoto, K.; Tsuchida, E.; Hay, A. S. *Macromolecules* **1997**, *30*, 4502.

(7) **Synthesis of OPAs**: 4-Aminobenzophenone (0.986 g, 5.00 mmol), benzophenone (4.56 g, 25.0 mmol), and 1,4-diazabicyclo[2.2.2]octane (DABCO) (1.68 g, 15.0 mmol) were dissolved in chlorobenzene (40 mL). Titanium(IV) tetrachloride (0.711 g, 3.75 mmol) was added dropwise over 5 min. The addition funnel was rinsed with chlorobenzene (5 mL). The reaction mixture was heated in an oil bath at 125 °C for 15 h. The precipitate was removed by filtration. The filtrare was concentrated, and OPA2 (0.946 g, 52%), OPA3 (0.713 g, 29%), and OPA4 (0.121 g, 10%) were isolated by silica gel column chlomatography (ethyl acetate:hexane = 1:10, including 2% Et_3N, R_f = 0.2, 0.15, and 0.1, respectively). **OPA2**: ^1H NMR ($CDCl_3$, 400 MHz, TMS standard, 30 °C, ppm) δ 7.77 (br, 2H), 7.71 (d, 2H, J = 7.0 Hz), 7.66 (d, 2H, J = 8.4 Hz), 7.54 (t, 1H, J = 7.0 Hz), 7.44 (dd, 2H, J = 7.0, 7.0 Hz), 7.50−7.40 (br, 3H), 7.29 (br, 3H), 7.14 (br, 2H), 6.80 (d,

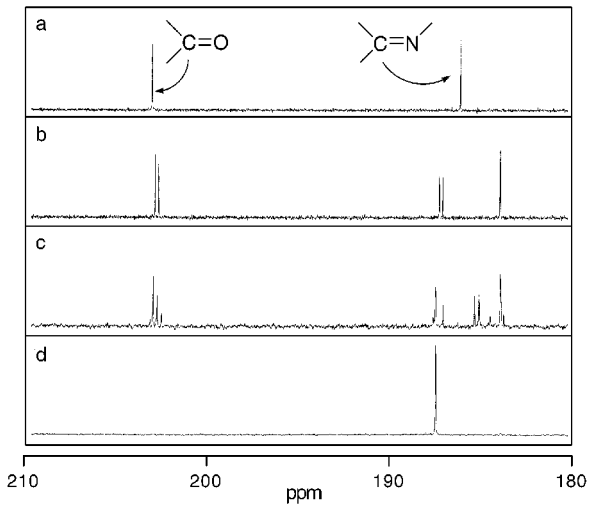

Figure 1. The ^{13}C NMR spectra (only 210−180 ppm) of (a) OPA2, (b) OPA3, (c) OPA4, and (d) CPA-a in CF_3COOD.

attributed to the azomethine one (Figure 1c). The ^{13}C NMR spectrum of OPA2 was simple because OPA2 does not have any *E*/*Z* isomers (Figure 1a). In the case of the cyclic compounds, the ^{13}C NMR spectrum of CPA that has three azomethines shows only one peak attributed to the azomethine carbon because CPA has only one conformation (Figure 1d).

The formation ratio of the *E*-type isomers to the *Z*-type one was estimated to be 1:1 on the basis of the area ratio of the corresponding peaks attributed to the carbonyl carbon. This result indicates that the *Z*-type isomer can be formed in about a 50% yield through dehydration coupling of the 4-aminobenzophenone in the presence of titanium(IV) tetrachloride. According to this speculation, CPA-a is theoretically formed in 25% (0.5^2) yield, which agrees with the experimental value of 20%. Integration of ^{13}C NMR spectrum (the pulse sequence is NNE) reveals that the formation ratio of the four isomers of OPA4 was approximately estimated to be 9:6:3:1.

UV−vis spectroscopy often gives important information about the conformation of molecules. The UV−vis spectrum of CPA shows the shortest λ_{max} absorbed $\pi-\pi^*$ transition of 318 nm of the OPAs (Figure 2). For the OPAs, the

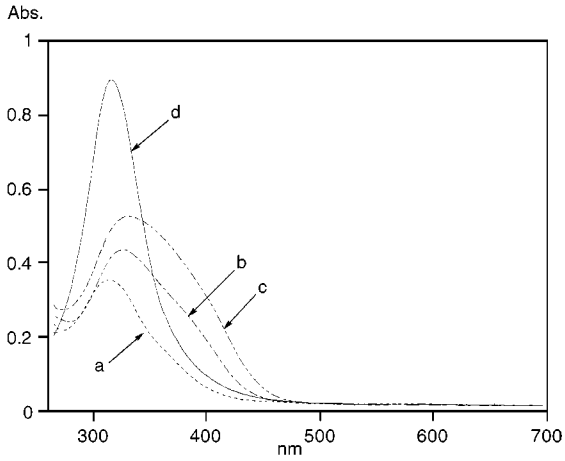

Figure 2. UV−vis spectra of (a) OPA2 (1.0×10^{-5} M), (b) OPA3 (1.0×10^{-5} M), (c) OPA4 (1.0×10^{-5} M), and (d) CPA-a (1.3×10^{-5} M) in CF_3COOH.

absorption based on the $\pi-\pi^*$ transition of azomethine shifts to the longer wavelength according to the conformation. The *E* and *Z* isomers show different absorptions, of which the absorption of the *E* isomer is shifted by about 20−50 nm to a longer wavelength than that of the *Z* isomer. The single conformation of CPA is supported by NMR, and molecular modeling of the *E* isomer of CPA is very difficult to build. These results support the idea that CPA has only the *Z* conformation.

In conclusion, as a novel class of cyclic molecules, the cyclic phenylazomethine trimers, which have three nitrogen atoms as the coordination and protonation sites, were synthesized with high yield. The selectivity for the cyclization was emphasized by the bulkiness of the group at the α-position of the phenylazomethine compounds.

Acknowledgment. This work was partially supported by a Grant-in-Aid for priority area (Nos. 11136245 and 11167273) and for Scientific Research from the Ministry of Education Science Foundation Culture (No. 11555253), a Kanagawa Academy Science and Technology Research Grant, and the Kawakami foundation.

OL990975S

2H, $J = 8.4$ Hz); ^{13}C NMR ($CDCl_3$, 100 MHz, TMS standard, 30 °C, ppm) δ 197.18, 169.96, 162.73, 156.59, 139.08, 132.95, 132.74, 132.11, 131.99, 130.58, 130.32, 130.19, 129.84, 129.11, 128.95, 121.24; IR (KBr) 1655 (C═O), 1623 (C═N), 1588 (phenyl), 698 (phenyl); EI-MS 361 $[M]^+$. Anal. Calcd for $C_{26}H_{19}NO$: C, 86.40; H, 5.30; N, 3.88. Found: C, 86.66; H, 5.11; N, 3.89. **OPA3**: ^1H NMR (CF_3COOD, 400 MHz, TMS standard, 30 °C, ppm) as mixture of two *E*/*Z* isomers, δ 8.12−7.52 (m, 28H); ^{13}C NMR (CF_3COOD, 100 MHz, TMS standard, 30 °C, ppm) as mixture of two *E*/*Z* isomers, δ 203.04, 202.85, 187.20, 187.00, 183.83, 145.90, 143.96, 142.09, 141.68, 141.48, 141.45, 141.01, 140.92, 138.98, 138.89, 138.49, 137.21, 137.18, 137.04, 136.40, 136.32, 135.76, 135.19, 135.07, 134.84, 134.61, 134.43, 134.33, 134.23, 134.05, 133.84, 133.36, 132.97, 132.75, 132.49, 132.46, 132.41, 132.24, 131.87, 131.65, 130.96, 130.93, 130.80, 130.55, 128.32, 128.13, 127.20, 126.85 [For OPA3, which is a mixture of the two isomers, 54 peaks are observed theoretically in ^{13}C NMR, even though 48 peaks were found]; IR (KBr) 1652 (C═O), 1618 (C═N), 1583 (phenyl), 697 (phenyl); EI-MS 540 $[M]^+$. Anal. Calcd for $C_{39}H_{28}N_2O$: C, 86.40; H, 5.30; N, 3.88. Found: C, 86.66; H, 5.11; N, 3.89. **OPA4**: ^1H NMR (CF_3COOD, 400 MHz, TMS standard, 30 °C, ppm) as mixture of four *E*/*Z* isomers, δ 8.14−7.50 (m, 37H); ^{13}C NMR (CF_3COOD, 100 MHz, TMS standard, 30 °C, ppm) as mixture of four *E*/*Z* isomers, δ 203.29, 203.11, 202.89, 202.65, 187.54, 187.41, 186.98, 186.14, 185.24, 185.01, 184.35, 183.81, 183.76, 183.63, 146.46, 146.43, 145.67, 145.23, 144.65, 144.42, 143.77, 143.18, 142.39, 142.19, 142.14, 142.01, 141.79, 141.76, 141.70, 141.63, 141.37, 141.14, 141.10, 141.07, 140.87, 140.58, 139.62, 139.13, 139.00, 138.77, 138.67, 138.41, 137.44, 137.24, 137.16, 136.96, 136.85, 136.70, 136.60, 136.52, 136.42, 136.30, 135.61, 135.38, 135.33, 135.22, 135.14, 134.94, 134.81, 134.66, 134.56, 134.48, 134.41, 134.32, 134.12, 134.00, 133.95, 133.74, 133.64, 133.53, 133.39, 133.36, 133.25, 132.85, 132.77, 132.70, 132.59, 132.52, 132.34, 132.24, 131.98, 131.80, 131.65, 131.14, 130.99, 130.88, 130.58, 130.45, 128.59, 128.45, 128.36, 128.22, 128.15, 127.41, 127.30, 127.18, 126.97, 126.90, 126.82 [For OPA4, which is a mixture of the four isomers, 144 peaks are observed theoretically in ^{13}C NMR, even though 99 peaks were found]; IR (KBr) 1651 (C═O), 1615 (C═N), 1582 (phenyl), 698 (phenyl); EI-MS 719 $[M]^+$. Anal. Calcd for $C_{52}H_{37}N_3O$: C, 86.76; H, 5.18; N, 5.84. Found: C, 86.62; H, 5.00; N, 5.97.