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## A FACILE FORMATION OF anti-BREDT'S COMPOUNDS FROM THE REACTION OF 1-AROYL-2-ARYL-3a,6a-DIAZAPENTALENES WITH ACETYLENE-DICARBOXYLATES<sup>1</sup>

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**Abstract** – The reaction of 1-aryloyl-2-aryl-3a,6a-diazapentalenes with acetylene-dicarboxylates affords surprisingly unusual anti-Bredt's adducts having 4,10-diazabicyclo[5.2.1]deca-1,3,5,8-tetraene structure. The structure was elucidated by making full uses of new MMR spectroscopies and finally an X-Ray crystallographic analysis. The plausible mechanism for the formation of the present compounds is described.

### INTRODUCTION

Carbon–carbon double bonds exhibit large strain effects when factors of molecular geometry do not allow all the bonds of the two sp<sup>2</sup>-hybridized carbons to be coplanar.<sup>2,3</sup> The geometry of bicyclic rings can also cause distortion of the coplanarity of olefinic system.<sup>4</sup> Attempt to construct a model of this

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**Dedicated to Dr. Pierre Potier, Emeritus Director of CNRS, on the occasion of his 70th birthday.**

molecule will show that the geometry of the bicyclic system does not permit coplanarity of the substituents bonded to the  $sp^2$ -carbons. As the result of the excessive strain, the molecule has at most transitory existence.<sup>5</sup> The absence of such bridgehead double bonds in organic compounds had been noted a long time ago and formulated as Bredt's rule.<sup>6</sup> However, as the structural basis for Bredt's rule has become clear, it became evident that the prohibition against bridgehead double bonds is not absolute.<sup>7</sup> When the bridges of the bicyclic system are large enough to permit planarity of the  $\pi$ -system, bridged olefins will be capable of existence. It has been proposed that the limit for unstable but isolable bridgehead olefins is reached when the largest ring containing the olefinic linkage contains eight atoms. Bridgehead C=C bonds in which the largest ring is of seven atoms are expected to be capable of only short existence.<sup>8</sup> These proposals have subsequently been tested and verified by the successful synthesis of the bridgehead olefins.<sup>9</sup> The strained C=C bonds in these molecules are exceptionally reactive, and undergo a variety of addition reactions. Hence, bridged olefins are unstable to isolate at room temperature. Thus, in spite of a large number of investigations that have been performed on the synthesis and properties of isocyclic systems of this structure variants<sup>6,10</sup> heterocyclic anti-Bredt compounds are little known, although anti-Bredt enamines and enol ethers have been reported.<sup>11</sup> In particular, stable examples of such systems that have been characterized by X-Ray crystallographic methods are very rare, with exception of metal-complexed derivatives.<sup>12</sup>

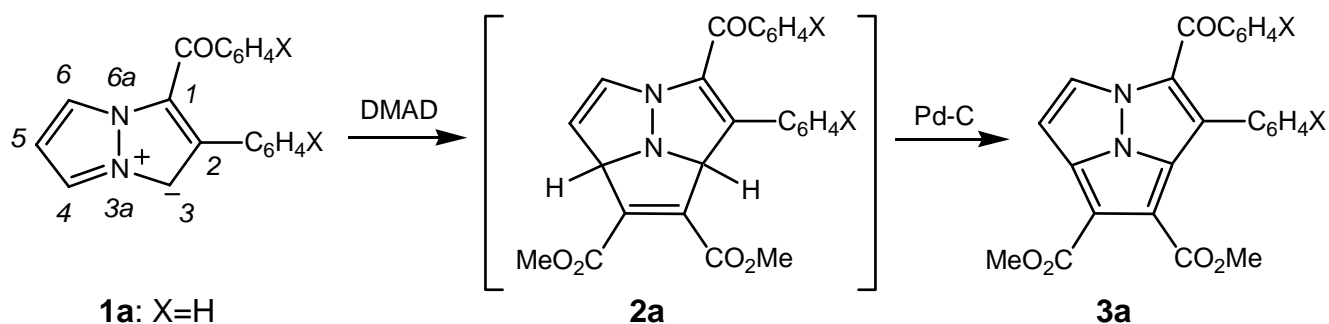
We report herein a novel and easy formation of strained C=C bonds in one-pot reaction, whose molecules exist as stable compounds with melting points higher than 100 °C.

## Results and Discussion

### Reactions of 1-aryl-2-aryl-3a,6a-Diazapentalenes **1** with Acetylenedicarboxylates.

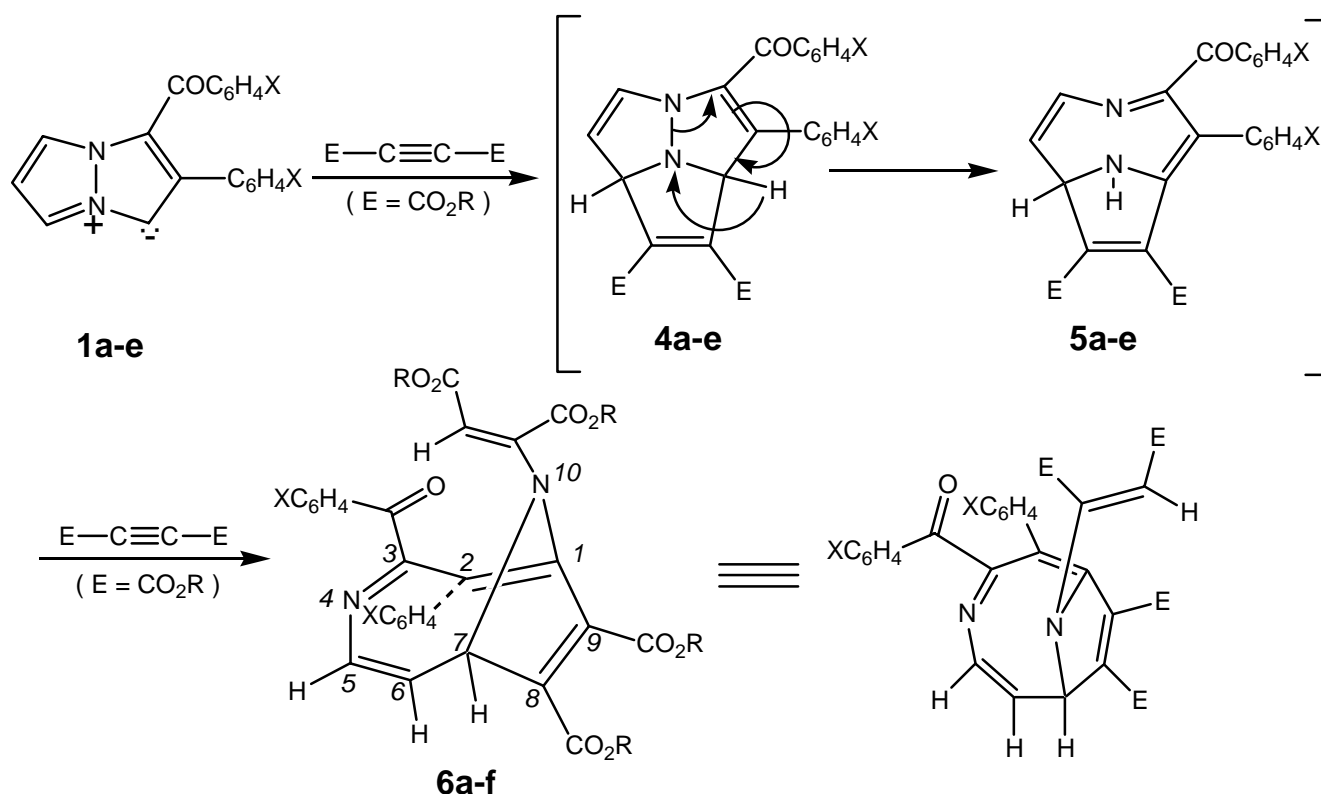
Boekelheide *et al.* reported a beautiful synthesis of diazacyclazine (**3a**)<sup>13</sup> from the reaction of 1-benzoyl-2-phenyl-3a,6a-diazapentalene (**1a**)<sup>14</sup> with dimethyl acetylenedicarboxylate (DMAD) in the presence of Pd-C albeit in very low yields. Scheme 1 illustrates that the reaction proceeds *via* a 1:1 cycloadduct (**2**) between **1** and DMAD. It occurred to us that they might had investigated side reactions because the yields were too low (lower than 3% yields), and therefore we carefully re-investigated the same reaction in the absence of Pd-C. The reaction of 1-benzoyl-2-phenyl-3a,6a-diazapentalene (**1a**) upon reaction with 2 equiv. of DMAD gave a 1:2 adduct as an orange solid.

Scheme 2 illustrates the reactions between 3a,6a-diazapentalenes (**1a-e**) and acetylenedicarboxylates leading to an easy formation of diazabicyclo[5.2.1]decatetraene structures. Thus, reaction of **1a-e** with



**Scheme 1.** Boekelheide's synthesis of diaza[2.2.2]cyclazine (**3a**) from the reaction of 3a,6a-diaza-pentalenes (**1a**) with DMAD under dehydrogenation conditions using 10% Pd-C.

DMAD or diethyl acetylenedicarboxylate (DEAD) in benzene at room temperature gave the sole products (**6a-f**) in moderate yields.



**Scheme 2.** A One-pot formation of anti-Bredt's adducts (**6a-f**) possessing 4,10-diazabicyclo[5.2.1]deca-1,3,5,8-tetraene structure from the reaction between 3a,6a-diaza-pentalenes (**1a-e**) with acetylenedicarboxylates.<sup>a</sup>

<sup>a</sup> Conditions. DMAD or DEAD (3 equiv), benzene, rt, 12 h; yield isolated, **6a** (X=H, R=Me), 65%, **6b** (X=*p*-Cl, R=Me), 54%, **6c** (X=*p*-Br, R=Me), 42%, **6d** (X=*m*-NO<sub>2</sub>, R=Me), 49%, **6e** (X=*p*-MeO, R=Me), 61%, **6f** (X=H, R=Et), 58%.

### Structural Identification.

Microanalytical and molecular weight data from mass spectrometry for **6** indicate that the product is clearly consistent with 1:2 adduct between the substrate (**1**) and DMAD or DEAD. The IR spectra of **6**

display very strong stretching vibrations of conjugated ester group at around  $1735\text{ cm}^{-1}$  and those of carbon–carbon double bonds appearing at  $1652$  and  $1590\text{ cm}^{-1}$  while bending vibrations at  $764\text{ cm}^{-1}$  indicating that the product is conjugated ester. MS spectra of the products (**6a**) have shown that the molecular ion ( $M^+$   $m/z$  570 for **6a**) appears as the base peaks.

Structural elucidation of the product (**6**) in Scheme 2 was a serious problem since  $^1\text{H}$  and ordinary  $^{13}\text{C}$  NMR information was severely less relative to the carbon frame of the molecule. Table 1 illustrates that

**Table 1.** Selected  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ ,  $\text{Me}_4\text{Si}$ ) spectral data for the product (**6a**).<sup>a,b</sup>

H(5)	H(6)	H(7)	H(2')
7.08 (d) [d] $\underline{J}_{5,6}$ 10.8	5.78 (dd) [dd] $\underline{J}_{5,6}$ 10.8, $\underline{J}_{6,7}$ 2.5	4.76 (d) [d] $\underline{J}_{6,7}$ 2.5	5.35 (s) [s]

<sup>a</sup> The numbering for hydrogens follows that for carbons in Scheme 2. Chemical shifts and selected coupling constants are in  $\delta$  scale and Hz unit, respectively. Multiplicities in parentheses and brackets are due to Lorentz-transformed  $^1\text{H}$  NMR spectrum and those resolution-enhanced with sine-bell wind function, respectively.

<sup>b</sup> Chemical shifts that are not shown in Table 1 are shown in experimental section.

the  $^1\text{H}$  NMR spectrum of **6a** gives us too less information to solve the structure since four protons other than those in two phenyl groups interpret two spin networks. One is three spin system indicating a simple ABX pattern and the other is single spin system exhibiting singlet. To accomplish a full assignment and accurate analysis we have used modern techniques of the following NMR ( $^1\text{H}$  and  $^{13}\text{C}$ ) spectroscopies. One-dimensional (1D) NMR: Resolution-enhanced spectra with Gaussian- and sine-bell wind functions,<sup>15</sup> separately. Two-dimensional (2D) NMR:  $^1\text{H}$ – $^1\text{H}$  shift-correlation spectroscopy (COSY),<sup>16</sup>  $^1\text{H}$ – $^1\text{H}$  shift-correlation spectroscopy by long-range couplings (COLOC),<sup>17</sup>  $^{13}\text{C}$ – $^1\text{H}$  COSY,<sup>18</sup>  $^{13}\text{C}$ – $^1\text{H}$  COLOC<sup>19</sup> with an aid of composite decoupling (CPD), gated decoupling,  $^{13}\text{C}$ – $^1\text{H}$  selective decoupling (SEL), and  $^{13}\text{C}$ – $^1\text{H}$  long-range selective decoupling (LSPD).<sup>20</sup> The results in Table 2 show that the  $^{13}\text{C}$ – $^1\text{H}$  long-range spin network through  $\underline{J}_{\text{C-H}}$  strongly suggests the structure for **6a**.<sup>21</sup>

It should be noted that a large ring strain is confirmed by both the methine bond through the  $^1\underline{J}_{\text{C}(7)\text{-H}(7)} = 154.0\text{ Hz}$  and an olefinic bond through the  $^1\underline{J}_{\text{C}(6)\text{-H}(6)} = 165.5\text{ Hz}$ . Surprisingly, the former value<sup>22</sup>

is close to that (155 Hz) of tetraprismane<sup>23</sup> (cubane) and is larger than that (148 Hz) of pentaprismane.<sup>23</sup> In addition, the olefinic carbon couplings— $^1J_{C(6)-H(6)} = 165.5$  Hz and  $^1J_{C(5)-H(5)} = 176.2$  Hz—are found to be larger than those of cyclopentene (161 Hz) and norbornene (165 Hz).<sup>24</sup>

**Table 2.** Selected  $^{13}C$  NMR (100.6 MHz,  $CDCl_3$ ,  $Me_4Si$ ) spectral data for the representative product (**6a**).<sup>a-c</sup>

C(1)	C(2)	C(3)	C(5)	C(6)
146.28 (s) [s]	135.81 (d) [td] $^3J_{CH(o')} 7.9$	161.44 (s) [dt] $^3J_{CH(5)} 1.5$	136.15 (d) [dd] $^1J_{CH(5)} 176.2$ $^3J_{CH(7)} 4.6$	117.81 (d) [ddd] $^1J_{CH(6)} 165.5$ $^2J_{CH(5)} 2.3$ $^2J_{CH(7)} 4.0$
C(7)	C(8)	C(9)	C(1')	C(2')
61.48 (d) [ddd] $^1J_{CH(7)} 154.0$ $^3J_{CH(5)} 9.2$ $^2J_{CH(6)} 6.9$	140.33 (s) [d] $^2J_{CH(7)} 4.6$	143.56 (s) [d] $^3J_{CH(7)} 5.5$	146.15 (s) [dm] $^2J_{CH(2')} 3.8$ $^3J_{CH(7)} 1.4$ $^4J_{CH(Me)} 1.4$	94.73 (d) [dm] $^1J_{CH(2')} 163.4$
$\underline{CO-Ph}$	$C(8)-\underline{CO_2Me}$	$C(9)-\underline{CO_2Me}$	$C(1')-\underline{CO_2Me}$	$C(2')-\underline{CO_2Me}$
189.25 (s) [td] $^3J_{CH(o)} 4.3$ $^3J_{CH(5)} < 1.0$	166.65 (s) [qd] $^3J_{CH(Me)} 4.2$ $^3J_{CH(7)} < 1.0$	161.38 (d) [qd] $^3J_{CH(Me)} 3.8$ $^3J_{CH(7)} 0.8$	163.27 (s) [q] $^3J_{CH(1')} 4.7$ $^3J_{CH(Me)} < 1.0$	161.52 (d) [dq] $^2J_{CH(2')} 7.5$ $^3J_{CH(Me)} 2.0$

<sup>a</sup> For the atomic numbering, see Scheme 2. Chemical shifts and coupling constants are in  $\delta$  and Hz unit, respectively. Multiplicities in parentheses and brackets are represented due to off-resonance spectra and those resolution-enhanced with Gaussian wind function, respectively.

<sup>b</sup> Signal and coupling assignment is confirmed by SEL, gated decoupling, 2D  $^{13}C$ - $^1H$  COSY and COLOC, and LSPD spectra. The magnitudes of  $J_{C-H}$  are determined by gated decoupling spectra resolution-enhanced with Gaussian wind function as well as LSPD experiments.

<sup>c</sup> Chemical shifts that are not shown in Table 2 are shown in experimental section. The numbering for

aromatic and ester carbons follows that in Scheme 2. Multiplicities described are due to resolution-enhanced with sine-bell wind function.

We finally established the structure of **6a** by an X-Ray crystallographic analysis.<sup>1</sup> An ORTEP plot of **6a** has been described before.<sup>1</sup> Table 3 illustrates selected bond lengths and angles of the molecule (**6a**). It is noteworthy that in the molecule the bridgehead bonds [1.360 (3) Å for C(1)=C(2) and 1.498 (4) Å for C(6)–C(7) and 1.614 (4) Å for C(7)–C(8)] are long, indicating the large strain imposed on the bonds. This anomalously large strain is also NMR spectroscopically confirmed by the <sup>1</sup>J<sub>C(7)–H(7)</sub> coupling constant (Table 2). Apparently bending of the formally trisected sp<sup>2</sup> system is not energetically prohibitive; thus, in the remarkable compound (**6a**), in-plane distortion (σ-strain) leads to reduced sp<sup>2</sup> endocyclic angles to be 116.0(2)° [C(1)–C(2)–C(3)] and 104.4(2)° [C(9)–C(1)–N(10)], while the exocyclic angle becomes large value of 130.6(2)° for C(2)–C(1)–C(9). Similarly, the bridgehead sp<sup>3</sup> carbon, C(7), has been shown to have a notably small angle of 99.6(2)°.

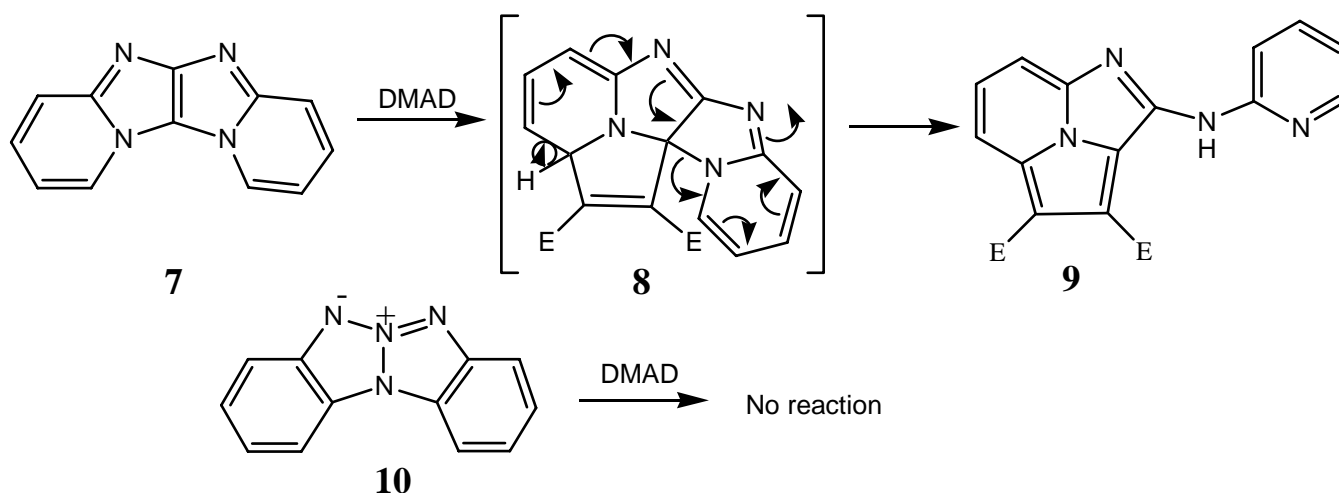
**Table 3.** Selected bond lengths and angles for **6a**.<sup>1</sup>

Bond distance (Å)			
atoms	distance	atoms	distance
C(1)–C(2)	1.360 (3)	C(7)–N(10)	1.465 (3)
C(6)–C(7)	1.498 (4)	C(9)–C(1)	1.466 (4)
C(7)–C(8)	1.514 (4)		
Bond angle (°)			
atoms	angle	atoms	angle
C(1)–C(2)–C(3)	116.0 (2)	C(7)–C(8)–C(9)	109.4 (2)
C(1)–C(2)–C(ipso)	120.7 (2)	C(8)–C(9)–C(1)	107.1 (2)
C(3)–C(2)–C(ipso)	122.7 (2)	C(8)–C(7)–N(10)	99.6 (2)
C(2)–C(1)–C(9)	130.6 (2)	C(9)–C(1)–N(10)	104.4 (2)
C(2)–C(1)–N(10)	120.9 (2)	C(8)–C(7)–N(10)	99.6 (2)
C(6)–C(7)–N(10)	107.3 (2)		

As depicted in Scheme 2, the facile formation of bridgehead olefins (**6**) can be explained by an initial [8 + 2] cycloaddition (1,3-dipolar reaction) of the 3a,6a-diazapentalenes (**1**) to DMAD (or DEAD) and a subsequent rearrangement of the 1:1 adducts (**4**) which undergo a Michael-type nucleophilic addition

with another molecule of DMAD. The driving force for the selective elimination of one of the two bridgehead protons would be relief of steric hindrance between the large groups on C(2A) and C(3A) as C(2A)-C(3A) becomes a single bond and twisting is permitted.<sup>25</sup> In contrast with this, an extremely unstable parent 3a, 6a-diazapentalene<sup>26</sup> has proven to proceed a slightly different reaction sequence, i.e. firstly, an [8 + 2] cycloaddition with DMAD and subsequent two intramolecular rearrangements followed by a Michael-type nucleophilic addition to give diethyl 3-[1,2-bis(methoxycarbonyl)ethenyl]pyrolo[1,5a]azepine-8,9-dicarboxylate in 30-36 % yields.<sup>27</sup>

In connection with this, 1,3,4,6-tetraazapentalene (**7**) also underwent an [8 + 2] cycloaddition with DMAD to give 1-azacyclo[3.2.2]azine (**9**), a stable 10 $\pi$  aromatic system, not an anti-Bredt's compound.<sup>28</sup> In contrary, an analogous tetraazapentalene, 2,3:4,5-dibenzo-1,3a,6,6a-tetraazapentalene (**10**) did not undergo the reaction with DMAD even under severe conditions including high pressure and the substrate remained unchanged as shown in Scheme 3.<sup>29</sup> This difference is speculated to be formation of the thermodynamically more stable product (**9**) rather than the initial adduct (**8**). This is not the case in the reaction of **10** with DMAD.



**Scheme 3.** 2,3:4,5-Dibenzo-1,3a,6,6a-tetraazapentalene (**6**) system did not take place reaction with DMAD.<sup>a</sup>

<sup>a</sup> Conditions. (i) DMAD (2 equiv), DMF, reflux, 12 h. (ii) DMAD (2 equiv), xylene, reflux, 24 h. (iii) DMAD (2 equiv), CH<sub>2</sub>Cl<sub>2</sub>, high pressure (1.0GPa), 10 days.

## EXPERIMENTAL

**Reagents and Starting Material.** The starting material, 1-benzoyl-2-phenyl-3a,6a-diazapentalene (**1a**) and 1-(4-chlorophenyl)-2-(4-chlorobenzoyl)-3a,6a-diazapentalene (**1b**), 1-(4-bromophenyl)-2-(4-bromobenzoyl)-3a,6a-diazapentalene (**1c**), 1-(3-nitrophenyl)-2-(3-nitrobenzoyl)-3a,6a-diazapentalene (**1d**), and

1-(*p*-methoxyphenyl)-2-(*p*-methoxybenzoyl)-3a,6a-diazapentalene (**1e**) were prepared according to a literature method.<sup>14</sup> DMAD and DEAD were freshly distilled before use. The solvents used for the reactions were freshly distilled under nitrogen from appropriate drying agents and were all degassed.

**Instrumentation/Analytical Procedures.** All reactions were performed under Argon or Nitrogen environment. Melting points were taken on a Yanagimoto micro melting point apparatus Yanaco-MP and were uncorrected. <sup>1</sup>H and <sup>13</sup>C NMR spectra were measured either on a JEOL JNM-EX270 (270 MHz for <sup>1</sup>H, 67.80 MHz for <sup>13</sup>C) or on a JNM-ALPHA500 (500 MHz for <sup>1</sup>H, 125.65 for <sup>13</sup>C) instrument in CDCl<sub>3</sub> or a Bruker AM-400 (100.6 MHz for <sup>13</sup>C, 400 MHz for <sup>1</sup>H) instrument in CD<sub>2</sub>Cl<sub>2</sub>, unless otherwise specified, with Me<sub>4</sub>Si as the internal standard. The assignments of NMR spectra are based on <sup>1</sup>H{<sup>1</sup>H} homonuclear decoupling, <sup>13</sup>C{<sup>1</sup>H} heteronuclear one and 2D NMR experiments. IR spectra were recorded on a JASCO IR-G. UV and visible absorption spectra were recorded on a Shimadzu UV-3101PC UV-VIS-NIR scanning spectrophotometer. Electron impact (EI) mass measurement was performed on a Kratos MS 50 high-resolution mass spectrometer, while fast atom bombardment mass measurement was carried out with AEI MS-9 and MS-50 mass spectrometers using 1,4-dithiothreol as the matrix. Elemental analysis was performed by the department services at the laboratory for organic elemental microanalysis, faculty of pharmaceutical sciences, Kyoto University on Yanaco CHN-CORDER MT-2 or MT-3 or MT-5. All solvents were distilled before use, and where necessary dried according to literature procedures. Column chromatography on silica gel was carried out using Merck Silica Gel 60 (70-200 mesh).

#### A typical experimental procedure for synthesis of 6a-e.

**Tetramethyl 3-benzoyl-10-ethynyl-2-phenyl-4,10-diazabicyclo[5.2.1]dec-1,3,5,8-tetraene-8,9,10(1', 2')-tetracarboxylate (6a):** To a solution of 1-benzoyl-2-phenyl-3a,6a-diazapentalene (143 mg, 0.50 mmol) in benzene (10 mL) was added DMAD (0.19 mL, 1.5 mmol), and the mixture was stirred at rt overnight. The solvent was removed *in vacuo*, and then the residue was further purified by column chromatography on silica gel (30 g) with ethyl acetate and hexane (1:3, v/v) to afford 4,10-diazabicyclo[5.2.1]dodecatetraene (**6a**) (186 mg, 65.3 %) as red needles. The analytical sample was obtained from ethanol as red needles.

**6a** : 65%, mp 152-153 °C (ethanol); <sup>1</sup>H NMR (270 MHz, CDCl<sub>3</sub>) δ : 3.38 (3H, s), 3.62 (3H, s), 3.72 (3H, s), 3.76 (3H, s), 4.76 (1H, d, *J* = 3.0 Hz), 5.35 (1H, s), 5.77 (1H, dd, *J* = 10.2, 3.0 Hz), 7.10 (1H, d, *J* = 10.2 Hz), 7.02-8.03 (10H, m); <sup>13</sup>C NMR (67.8 MHz, CDCl<sub>3</sub>) δ : 51.4 (q), 52.6 (q), 52.7 (q), 52.9 (q),

61.6 (d), 94.8 (d), 117.9 (d), 127.5 (d), 127.8 (d), 128.6 (d), 129.2 (d), 130.8 (d), 132.6 (d), 133.9 (s), 135.8 (s), 135.9 (s), 136.2 (d), 140.4 (s), 143.6 (s), 146.2 (s), 146.4 (s), 161.4 (s), 161.5 (s), 163.2 (s), 163.4 (s), 166.6 (s), 189.2 (s); IR  $\nu_{\max}$  (KBr) : 2925 (m), 1735 (s), 1700 (s), 1652 (m), 1590 (s), 1435 (m), 1421 (m), 1371 (m), 1346 (m), 1275 (s), 1230 (m), 1190 (m), 1159 (s), 1124 (m), 1063 (m), 1015 (m), 883 (m), 820 (m), 764 (m), 746 (m), 706 (m), 696 (m), 672 (w)  $\text{cm}^{-1}$ ; UV-VIS  $\lambda_{\max}$  ( $\epsilon$ ) (ethanol) 427.5 (2215), 295.5 (20500), 257.0 (22100); *Anal.* Calcd for  $\text{C}_{31}\text{H}_{26}\text{N}_2\text{O}_9$  : H, 4.59; C, 65.26; N, 4.91. Found: H, 4.50; C, 65.05; N, 4.78.

**Tetramethyl 3-(*p*-chlorobenzoyl)-10-ethynyl-2-(*p*-chlorophenyl)-4,10-diazabicyclo[5.2.1]dec-1,3,5,8-tetraene-8,9,10(1',2')-tetracarboxylate (6b)**: 54%, mp 164-165 °C (ethanol);  $^1\text{H}$  NMR (270 MHz,  $\text{CDCl}_3$ )  $\delta$  : 3.42 (3H, s), 3.62 (3H, s), 3.67 (3H, s), 3.76 (3H, s), 4.76 (1H, d,  $J = 2.7$  Hz), 5.33 (1H, s), 5.82 (1H, dd,  $J = 10.5, 2.7$  Hz), 7.09 (1H, d,  $J = 10.5$  Hz), 6.98-7.98 (8H, m);  $^{13}\text{C}$  NMR (67.8 MHz,  $\text{CDCl}_3$ )  $\delta$  : 51.4 (q), 52.6 (q), 52.7 (q), 52.8 (q), 61.4 (d), 95.4 (d), 118.2 (d), 127.8 (d), 128.0 (d), 128.7 (d), 132.2 (d), 132.4 (s), 133.7 (s), 134.4 (s), 135.1 (s), 135.9 (d), 139.1 (s), 139.9 (s), 144.0 (s), 145.8 (s), 147.0 (s), 160.9 (s), 161.1(s), 163.0 (s), 163.1 (s), 166.3 (s), 187.9 (s); IR  $\nu_{\max}$  (KBr) : 2920 (m), 1743 (s), 1705 (s), 1677 (m), 1596 (s), 1491 (w), 1438 (m), 1425 (m), 1400(w), 1372 (m), 1355 (m), 1288 (s), 1236 (m), 1165 (s), 1123 (m), 1088 (m), 1068 (m), 1016 (m), 976 (w), 884 (m), 841 (w), 817 (w), 789 (w), 775 (w), 762 (w), 752 (w), 700 (w), 684 (w), 578 (w)  $\text{cm}^{-1}$ ; UV-VIS  $\lambda_{\max}$  ( $\epsilon$ ) (ethanol) 444.0 (2660), 299.5 (25400), 254.5 (26450); *Anal.* Calcd for  $\text{C}_{31}\text{H}_{24}\text{N}_2\text{O}_9\text{Cl}_2$  : H, 3.78; C, 58.23; N, 4.38. Found: H, 3.61; C, 58.19; N, 4.20.

**Tetramethyl 3-(*p*-bromobenzoyl)-10-ethynyl-2-(*p*-bromophenyl)-4,10-diazabicyclo[5.2.1]dec-1,3,5,8-tetraene-8,9,10(1',2')-tetracarboxylate (6c)**: 42%, mp 185-186 °C (ethanol);  $^1\text{H}$  NMR (270 MHz,  $\text{CDCl}_3$ )  $\delta$  : 3.42 (3H, s), 3.64 (3H, s), 3.67 (3H, s), 3.77 (3H, s), 4.76 (1H, d,  $J = 3.0$  Hz), 5.33 (1H, s), 5.84 (1H, dd,  $J = 10.8, 3.0$  Hz), 7.04 (1H, d,  $J = 10.8$  Hz), 6.91-7.90 (8H, m);  $^{13}\text{C}$  NMR (67.8 MHz,  $\text{CDCl}_3$ )  $\delta$  : 51.4 (q), 52.6 (q), 52.7 (q), 52.8 (q), 61.4 (d), 95.5 (d), 118.3 (d), 123.4 (s), 127.9 (s), 129.0 (d), 130.9 (d), 131.0 (d), 131.7 (d), 132.3 (s), 132.9 (s), 134.2(s), 135.9 (d), 140.0 (s), 144.0 (s), 145.7 (s), 147.1 (s), 160.8 (s), 161.1(s), 163.0 (s), 163.1 (s), 166.3 (s), 188.1 (s); IR  $\nu_{\max}$  (KBr) : 2960 (m), 1741 (s), 1706 (s), 1678 (m), 1595 (s), 1489 (m), 1438 (m), 1426 (m), 1396 (m), 1373 (s), 1356 (m), 1288 (s), 1238

(m), 1161 (s), 1124 (m), 1072 (m), 1012 (m), 978 (w), 924 (w), 884 (m), 868 (w), 839 (m), 816 (w), 789 (w), 775 (w), 762 (w), 752 (w), 702 (w), 676 (w), 589 (w)  $\text{cm}^{-1}$ ; UV-VIS  $\lambda_{\text{max}}$  ( $\epsilon$ ) (ethanol) 444.5 (2300), 299.0 (22200), 257.0 (23150); *Anal.* Calcd for  $\text{C}_{31}\text{H}_{24}\text{N}_2\text{O}_9\text{Br}_2$ : H, 3.32; C, 51.12; N, 3.85. Found: H, 3.45; C, 51.07; N, 3.69.

**Tetramethyl 3-(*m*-nitrobenzoyl)-10-ethynyl-2-(*m*-nitrophenyl)-4,10-diazabicyclo[5.2.1]dec-1,3,5,8-tetraene-8,9,10(1',2')-tetracarboxylate (6d):** 49%; mp 183-184 °C (ethanol);  $^1\text{H}$  NMR (270 MHz,  $\text{CDCl}_3$ )  $\delta$ : 3.45 (3H, s), 3.68 (3H, s), 3.70 (3H, s), 3.79 (3H, s), 4.84 (1H, d,  $J = 3.0$  Hz), 5.43 (1H, s), 5.73 (1H, dd,  $J = 10.8, 3.0$  Hz), 7.08 (1H, d,  $J = 10.8$  Hz), 7.37-8.90 (10H, m);  $^{13}\text{C}$  NMR (67.8 MHz,  $\text{CDCl}_3$ )  $\delta$ : 51.6 (q), 52.8 (q), 52.9 (q), 53.4 (q), 61.5 (d), 96.8 (d), 119.3 (d), 122.1 (d), 123.6 (d), 126.0 (d), 126.8 (d), 128.9 (d), 129.5 (d), 132.6 (s), 133.5 (d), 135.7 (s), 135.9 (s), 136.0 (d), 136.6 (s), 139.7 (s), 145.0 (s), 145.2 (s), 147.5 (s), 148.1 (s), 149.2 (s), 160.0 (s), 160.8 (s), 162.8 (s), 163.0 (s), 166.1 (s), 187.4 (s); IR  $\nu_{\text{max}}$  (KBr): 2945 (m), 1737 (s), 1712 (s), 1680 (m), 1600 (s), 1530 (s), 1485 (m), 1439 (m), 1423 (m), 1377 (m), 1357 (s), 1284 (s), 1263 (m), 1240 (m), 1215 (m), 1195 (m), 1165 (s), 1131 (m), 1102 (m), 1066 (m), 859 (m), 821 (w), 780 (w), 745 (w), 737 (w), 721 (w), 713 (w), 698 (w), 672 (w), 653 (w), 601 (w), 573 (w)  $\text{cm}^{-1}$ ; UV-VIS  $\lambda_{\text{max}}$  ( $\epsilon$ ) (ethanol) 429.5 (2470), 255.0 (32850); *Anal.* Calcd for  $\text{C}_{31}\text{H}_{24}\text{N}_4\text{O}_{13}$ : H, 3.66; C, 56.37; N, 8.48. Found: H, 3.46; C, 56.07; N, 8.26.

**Tetramethyl 3-(*p*-methoxybenzoyl)-10-ethynyl-2-(*p*-methoxyphenyl)-4,10-diazabicyclo[5.2.1]dec-1,3,5,8-tetraene-8,9,10(1',2')-tetracarboxylate (6e):** 61%, mp 150-151 °C (ethanol);  $^1\text{H}$  NMR (270 MHz,  $\text{CDCl}_3$ )  $\delta$ : 3.45 (3H, s), 3.60 (3H, s), 3.72 (3H, s), 3.76 (3H, s), 3.79 (3H, s), 3.85 (3H, s), 4.75 (1H, d,  $J = 2.7$  Hz), 5.34 (1H, s), 5.71 (1H, dd,  $J = 10.5, 2.7$  Hz), 6.83 (1H, d,  $J = 8.9$  Hz), 6.86 (1H, d,  $J = 9.2$  Hz), 7.03 (1H, d,  $J = 9.2$  Hz), 7.06 (1H, d,  $J = 10.5$  Hz), 8.08 (2H, d,  $J = 9.2$  Hz);  $^{13}\text{C}$  NMR (125 MHz,  $\text{CD}_2\text{Cl}_2$ )  $\delta$ : 51.3 (q), 52.6 (q), 52.6 (q), 52.8 (q), 55.3 (q), 55.4 (q), 61.6 (d), 94.0 (d), 113.1 (d), 114.0 (d), 117.1 (d), 126.3 (s), 128.5 (s), 128.9 (d), 133.3 (d), 136.2 (d), 140.4 (s), 143.1 (s), 146.8 (s), 160.4 (s), 161.5 (s), 161.9 (s), 163.3 (s), 163.4 (s), 163.5 (s), 166.7 (s), 187.4 (s); IR  $\nu_{\text{max}}$  (neat): 1742, 1717, 1599, 1251, 1160  $\text{cm}^{-1}$ ; UV-VIS  $\lambda_{\text{max}}$  ( $\epsilon$ ) (ethanol) 446.5 (1825), 306.5 (23800), 297.0 (24325), 266.5 (26500); *Anal.* Calcd for  $\text{C}_{33}\text{H}_{30}\text{N}_2\text{O}_{11}$ : H, 4.79; C, 62.85; N, 4.44. Found: H: 4.92, C: 62.62, N: 4.36.

**Tetraethyl 3-benzoyl-10-ethynyl-2-phenyl-4,10-diazabicyclo[5.2.1]dec-1,3,5,8-tetraene-8,9,10(1',2')-tetracarboxylate (6f):** 58%, mp 166-167 °C (ethanol); <sup>1</sup>H NMR (270 MHz, CDCl<sub>3</sub>) δ : 1.04 (3H, t, *J* = 7.2 Hz), 1.12 (3H, t, *J* = 6.5 Hz), 1.16 (3H, t, *J* = 7.2 Hz), 1.24 (3H, t, *J* = 7.2 Hz), 3.60-4.40 (8H, m), 4.76 (1H, d, *J* = 3.0 Hz), 5.35 (1H, s), 5.77 (1H, dd, *J* = 10.5, 3.0 Hz), 7.02-8.05 (11H, m); <sup>13</sup>C NMR (67.8 MHz, CDCl<sub>3</sub>) δ : 13.2 (q), 13.4 (q), 13.9 (q), 14.2 (q), 59.9 (t), 61.5 (d), 61.7 (t), 62.0 (t), 62.5 (t), 94.9 (d), 117.8 (d), 127.4 (d), 127.5 (d), 128.2 (d), 128.3 (d), 128.9 (d), 130.8 (d), 132.3 (s), 134.0 (s), 135.8 (s), 136.0 (d), 138.1 (s), 140.1 (s), 143.5 (s), 146.3 (s), 160.9 (s), 161.5 (s), 162.8 (s), 162.9 (s), 166.0 (s), 189.3 (s); IR ν<sub>max</sub> (KBr) : 2955 (m), 1735 (s), 1703 (s), 1667 (m), 1596 (s), 1467 (w), 1444 (m), 1426 (m), 1393 (m), 1376 (m), 1341 (m), 1283 (s), 1218 (m), 1196 (m), 1161 (s), 1116 (m), 1098 (m), 1080 (m), 1063 (m), 1020 (m), 863 (m), 826 (m), 814 (w), 806 (w), 764 (m), 744 (m), 706 (m), 694 (m), 667 (w), 654 (w), 582 (w) cm<sup>-1</sup>; UV-VIS λ<sub>max</sub> (ε) (ethanol) 438.0 (2060), 298.5 (19400), 258.0 (20050); *Anal.* Calcd for C<sub>35</sub>H<sub>34</sub>N<sub>2</sub>O<sub>9</sub> : H, 5.47; C, 67.08; N, 4.47. Found: H: 5.53, C: 67.09, N: 4.34.

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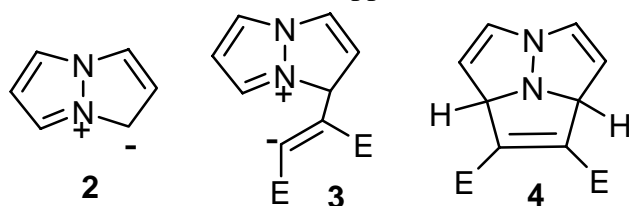
2. Examples that illustrate the twisting of an olefinic  $\pi$ -system can be found in *trans*-cycloheptene and *trans*-cyclooctene. Isolation of both the compounds has not been possible, but evidence for their formation has been obtained, being trapped as a transient species.<sup>3</sup> The olefins are generated in the presence of a reagent expected to react rapidly with it—in these cases, the very reactive Diels–Alder diene, i.e. 2,5-diphenyl-3,4-isobenzofuran. The adduct isolated has the structure anticipated for that derived from *trans*-cycloheptene. *trans*-Cyclooctene is significantly strained, but less so than *trans*-cycloheptene.
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  21. In the spectrum of **6a**, <sup>1</sup>H NMR resonance at δ 4.76 (d) is assigned to aliphatic methine proton which shifted to downfield by an influence of a nitrogen atom linked directly with the methine carbon. The methine signal corresponds to a <sup>13</sup>C NMR signal at δ 61.48 (d), which is assigned to methine carbon, C(7), according to off-resonance spectrum and its magnitude of <sup>1</sup>J<sub>CH</sub> coupling. The

methine bond, C(7)–H(7), has an anomalously large strain judging from the large coupling interaction of  $^1J_{\text{CH}}$ . Both the signals due to C(7) and H(7) are key atoms to decipher the  $^1\text{H}$  and  $^{13}\text{C}$  spectra, since the  $^1\text{H}$  signal is made X-part of ABX spin system. The H(7) couples with long-range  $^{13}\text{C}$ – $^1\text{H}$  interactions of  $^3J_{\text{C}(1)\text{--H}(7)}$ ,  $^3J_{\text{C}(5)\text{--H}(7)}$ ,  $^2J_{\text{C}(6)\text{--H}(7)}$ ,  $^2J_{\text{C}(8)\text{--H}(7)}$ ,  $^3J_{\text{C}(9)\text{--H}(7)}$ ,  $^3J_{\text{C}(1')\text{--H}(7)}$ , and  $^3J_{\text{C}(9)\text{COMe--H}(7)}$ . This relationship of heteronuclear long-range couplings builds up the carbon framework of the compound (**6a**). On the other hand,  $^1\text{H}$  NMR resonances at  $\delta$  7.08 (d), 5.78 (dd) and 5.35 (s) are due to olefinic protons, which link with olefinic carbons at  $\delta$  136.15 (d), 117.81 (d) and 94.73 (d), respectively, judging from 2D  $^{13}\text{C}$ – $^1\text{H}$  COSY and LSPD. The former two  $^1\text{H}$  signals are AB-part of the ABX system and the latter olefinic proton is isolated without any long-range  $^1\text{H}$ – $^1\text{H}$  couplings. In an olefinic carbon region, two signals shifted to downfield at  $\delta$  146.28 (s) and 146.15 (s) are assigned to C(1) and C(1'), respectively, which are directly linked with nitrogen atom.

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Furthermore, an initial step might be an [8 + 2] cycloaddition (1,3-dipolar cycloaddition) rather than Michael addition.

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