

## SYNTHESIS AND COMPLEXATION BEHAVIOR OF DIAZA-18-CROWN-6 HAVING TROPONYL AND ANTHRYL GROUPS

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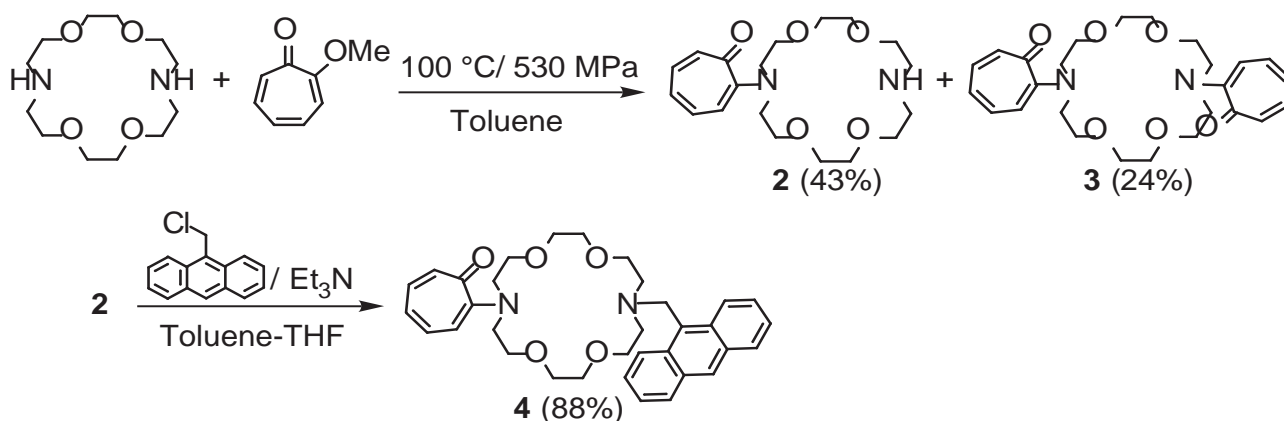
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**Abstract** — *N*-(9-anthrylmethyl)-*N'*-(tropon-2-yl)diaza-18-crown-6 (**4**) gave a weak emission, showing that the excited anthracene chromophore was quenched by the diazacrown nitrogen atoms and troponone unit. Diazacrown (**4**) was found to display unique photophysical properties in the presence of metal salts. Diazacrown (**4**) exhibited Cu<sup>2+</sup> selectivity and in the presence of this cation the host fluorescence intensity was increased by a factor of 7.8.

Photoresponsive supramolecular systems are of great significance particularly for their potential application to nanoscale devices for cation sensors and switches.<sup>1</sup> There are extensive investigations toward the characterization of fluoroionophores including podand, crown ether, calixarene, cyclophane, and cyclodextrin derivatives with fluorophore. Recently, a number of fluoroionophores have been designed for specific metal ions.<sup>1-3</sup> Some of them operate a quenching process by photoinduced electron transfer (PET) mechanism. In a classical example by de Silva group,<sup>3</sup> *N*-(9-anthrylmethyl)aza-18-crown-6 (**1**) is used as a PET fluoroionophore for Na<sup>+</sup> and K<sup>+</sup>. The uncomplexed fluoroionophore is weakly fluorescent, as the photoexcited fluorophore is quenched by electron transfer from amino group. Following metal incorporation (Na<sup>+</sup> and K<sup>+</sup>), the metal-ligand interaction decreases the amine oxidation potential drastically to prevent electron transfer. As a consequence, the intense and characteristic anthracene emission is largely

restored. We have also synthesized new fluoroionophores consisting of an azacrown or a diazacrown ether for guest cations using the same approach.<sup>4</sup> To design an effective PET fluoroionophore, important factors are that the PET fluoroionophores have low emission quantum yield by PET from amine donors to the excited chromophore, high emission quantum yield in complexation with guest molecules, selectivity, and stability. As an approach to the manipulation of PET fluoroionophore, we now report the synthesis, complexation, and fluorescence behavior of diazacrown ether having tropon-2-yl and 9-anthrylmethyl groups.



When a toluene solution of diaza-18-crown-6 and 2-methoxytroponone was heated at 100 °C under 530 MPa for 24 h, *N*-(tropon-2-yl)diaza-18-crown-6 (**2**, 43% yield) and *N,N'*-bis(tropon-2-yl)diaza-18-crown-6 (**3**,<sup>5,6</sup> 24% yield) were obtained. *N*-(9-Anthrylmethyl)-*N'*-(tropon-2-yl)diaza-18-crown-6 (**4**) was prepared by condensation of **2** with 9-chloromethylantracene (88% yield). The structure and purity of **4** were ascertained by  $^1\text{H}$ ,  $^{13}\text{C}$  NMR, and HR FAB MS spectroscopic data.

### Fluorescence Behavior of **4**

The UV absorption spectrum of the diaza-18-crown-6 (**4**) was typical as that of 9-methylantracene (9-MA) and 2-aminotroponone. On the other hand, the fluorescence spectrum of **4** ( $1.0 \times 10^{-5}$  M) gave weak emission bands at 399, 414, and 441 nm by excitation at 366 nm, which are similar to those<sup>4</sup> of *N*-(9-anthrylmethyl)aza-18-crown-6 (**1**) and *N,N'*-bis(9-anthrylmethyl)diaza-18-crown-6. As shown in Figure 1, the emission-band intensity of **4** was reduced to approximately a one-400 th of that (at 414 nm) of the standard substance (9-methylantracene:  $1.0 \times 10^{-5}$  M). This indicates that the quenching of the excited-state anthracene chromophore by the azacrown unit proceeds in a mechanism similar to that for the classical fluorescent-aliphatic system.<sup>7</sup> The quenching efficiency of an excited fluorescent molecule by PET from

donor atoms is expressed as a relative emission intensity ratio ( $I_H/I_{\text{standard}}$ ) of various host molecules and a standard substance. The  $I_H/I_{\text{standard}}$  value ( $I_4/I_{9\text{-MA}}: 2.4 \times 10^{-3}$ ) of **4** is smaller than that ( $I_1/I_{9\text{-MA}}: 2.6 \times 10^{-2}$ )<sup>4</sup> of *N*-(9-anthrylmethyl)aza-18-crown-6 (**1**) and that ( $I/I_{9\text{-MA}}: 5.6 \times 10^{-3}$ )<sup>4</sup> of *N,N'*-bis(9-anthrylmethyl)diaza-18-crown-6. The more efficient quenching of **4** means that the 2-aminotropone unit participates in PET in addition to diazacrown and anthracene chromophores. Indeed the emission intensity ( $I_{9\text{-MA}+2\text{-dimethylaminotropone}}/I_{9\text{-MA}}=0.8$ ) of 9-MA ( $1.0 \times 10^{-5}$  M) in the presence of 2-dimethylaminotropone ( $1.0 \times 10^{-5}$  M) is smaller than that ( $I_{9\text{-MA}+\text{triethylamine}}/I_{9\text{-MA}}=1.0$ ) in the presence of triethylamine ( $1.0 \times 10^{-5}$  M) as shown in Figure 2.

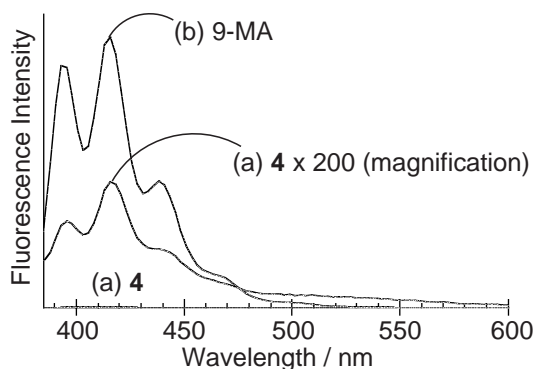


Figure 1. Fluorescence spectra of (a) **4** ( $1.0 \times 10^{-5}$  M) and (b) 9-MA ( $1.0 \times 10^{-5}$  M) in methanol at room temperature, as excited at 366 nm.

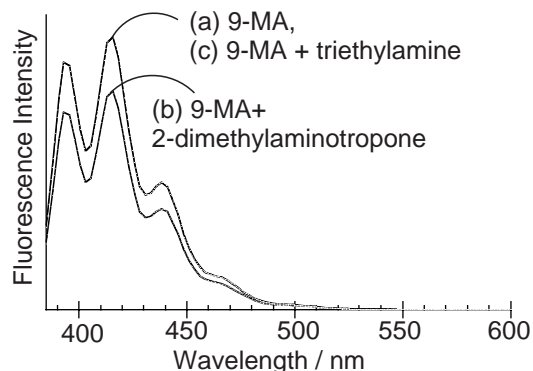


Figure 2. Fluorescence spectra of (a) 9-MA ( $1.0 \times 10^{-5}$  M) with (b) 2-dimethylaminotropone ( $1.0 \times 10^{-5}$  M) and (c) triethylamine ( $1.0 \times 10^{-5}$  M) in methanol at room temperature, as excited at 366 nm.

### Complexation Behavior of **4**

By additions of guest salts, the UV absorption spectra of **4** changed in  $\text{CH}_3\text{CN}$ . Addition of guest salts to **4** caused to disappear an original absorption band at 420 nm of **4** and a new absorption band around 330 nm appeared as shown in Figure 3.

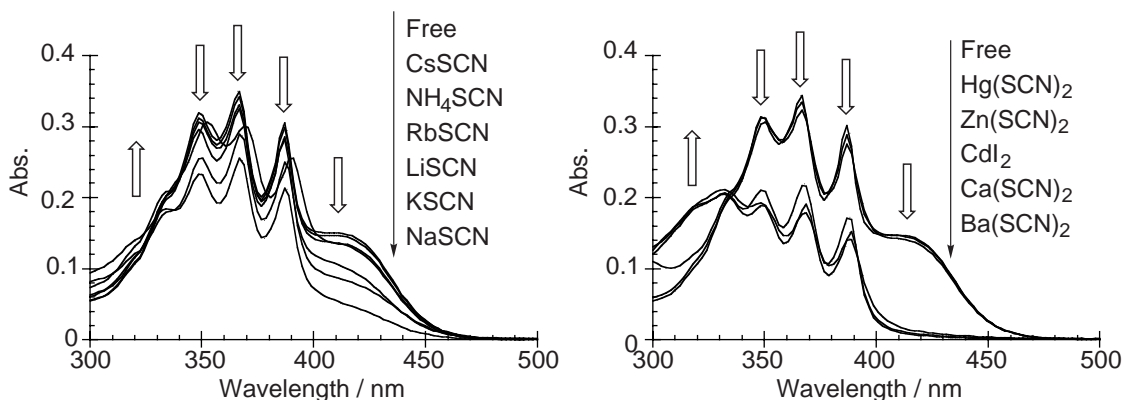


Figure 3. Absorption spectra of **4** ( $2.0 \times 10^{-5}$  M) with and without guest salts ( $3.0 \times 10^{-3}$  M) in acetonitrile.

The spectral changes of **4** in the presence of various metal salts were similar to those of *N,N'*-bis(tropon-2-yl)diaza-18-crown-6 (**3**).<sup>5,6</sup> By the molar ratio method (Figure 4) using absorption spectral changes, the stoichiometries of the complexes were determined as **4**·Ca(SCN)<sub>2</sub>, **4**·Ba(SCN)<sub>2</sub>, and **4**·CdI<sub>2</sub>, respectively. The metal-ion concentration dependence (Figure 5) of the absorption spectral changes allowed us to determine the association constants (Log *K* / M<sup>-1</sup>) by the non-linear curve-fitting method.<sup>8</sup>

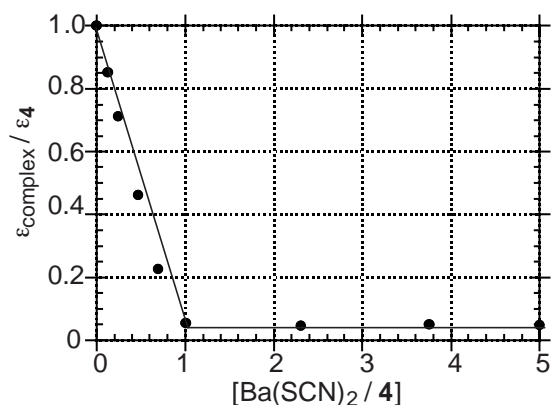


Figure 4. Molar ratio method of **4** for Ba(SCN)<sub>2</sub>.

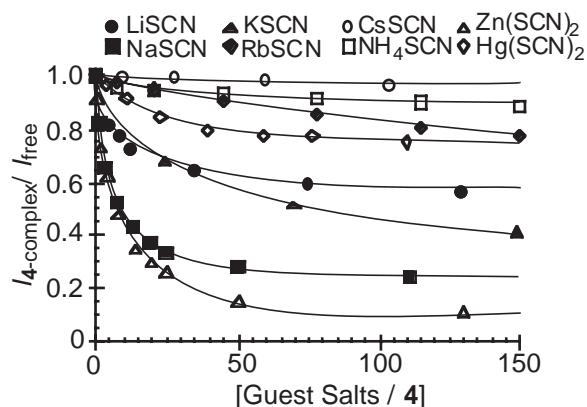


Figure 5. Dependence of absorbance of **4** ( $2.0 \times 10^{-5}$  M) on concentration of guest salts in acetonitrile.

The association constants of **4** were decreased in the following order: Na<sup>+</sup> ( $4.03 \pm 0.02$ ) > Zn<sup>2+</sup> ( $3.86 \pm 0.02$ ) > Li<sup>+</sup> ( $3.67 \pm 0.04$ ) > K<sup>+</sup> ( $3.09 \pm 0.02$ ) > NH<sub>4</sub><sup>+</sup> ( $3.02 \pm 0.06$ ) > Hg<sup>2+</sup> ( $2.81 \pm 0.07$ ) > Rb<sup>+</sup> ( $2.28 \pm 0.03$ ) > Cs<sup>+</sup> (< 1). To determine the association constant of **4** for Ca<sup>2+</sup>, Ba<sup>2+</sup>, and Cd<sup>2+</sup>, UV titration was carried out in a mixture solvent of chloroform and methanol (9:1 v/v). The order of the association constant decreased in the following order: Ba<sup>2+</sup> ( $5.37 \pm 0.08$ ) > Ca<sup>2+</sup> ( $3.37 \pm 0.03$ ) > Cd<sup>2+</sup> ( $3.07 \pm 0.03$ ) > Zn<sup>2+</sup> ( $2.26 \pm 0.05$ ). The order of **4** is similar to that (Ba<sup>2+</sup> > Ca<sup>2+</sup> > Cd<sup>2+</sup> > Zn<sup>2+</sup> > Na<sup>+</sup> > Li<sup>+</sup> > NH<sub>4</sub><sup>+</sup> > Hg<sup>2+</sup> > K<sup>+</sup> > Rb<sup>+</sup>, Cs<sup>+</sup>) of *N,N'*-bis(tropon-2-yl)diaza-18-crown-6 (**3**).<sup>5,6</sup>

In Figure 6 are illustrated the fluorescence spectra of **4** ( $1.0 \times 10^{-5}$  M) in methanol at room temperature. A dramatic change in the emission intensity of **4** (*I*<sub>4</sub>) was observed upon the addition of various kinds of guest cations (Ba<sup>2+</sup>, Ni<sup>2+</sup>, Cu<sup>2+</sup>, Cd<sup>2+</sup>, and Hg<sup>2+</sup>). When the metal salts were added (50 molar equivalent), the relative emission intensity (*I*<sub>complex</sub> / *I*<sub>4</sub>), being used as a measure of the molecular recognition sensing, changed from 1.3 to 7.8 depending on the nature of metal cations. Interestingly, the complexation of **4** with quenching metal cations<sup>2,9</sup> such as Ni<sup>2+</sup>, Cu<sup>2+</sup>, and Hg<sup>2+</sup> enhanced the emission intensity. This means that the complexation inhibited the PET from nitrogen atoms to the anthracene ring. Figure 7 illustrates the relative emission intensity of **4** against the metal salt concentration. Clearly, the emission intensity increases with an increase in the metal salt concentration. The intensity ratio (*I*<sub>metal salt complex</sub> / *I*<sub>4</sub>) was different

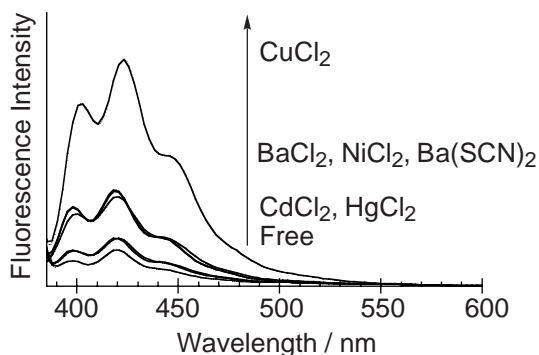


Figure 6. Fluorescence spectra of **4** ( $1.0 \times 10^{-5}$  M) with and without various guest salts ( $5.0 \times 10^{-4}$  M) in methanol, as excited at 369-372 nm.

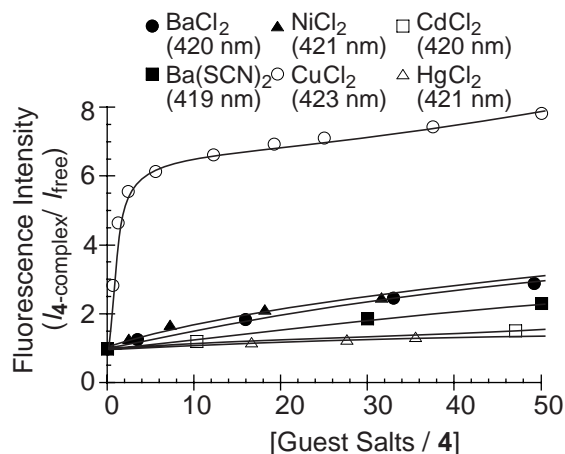


Figure 7. Dependence of fluorescence intensities of **4** ( $1.0 \times 10^{-5}$  M) at 418-423 nm on concentration of various guest salts in methanol.

among the bound metal salts and decreased in the following order:  $\text{CuCl}_2$  (7.8) >  $\text{BaCl}_2$  (2.9) >  $\text{NiCl}_2$  (2.8) >  $\text{Ba}(\text{SCN})_2$  (2.3) >  $\text{CdCl}_2$  (1.5) >  $\text{HgCl}_2$  (1.3). The emission recovery in the presence of  $\text{Ba}(\text{SCN})_2$  is smaller than that of  $\text{BaCl}_2$ . This suggests that the smaller emission recovery is due to quenching<sup>1,10</sup> by thiocyanate ion. The metal-ion concentration dependence (Figure 7) of the emission intensity allowed us to determine the association constants ( $\text{Log } K$ ) by the non-linear curve-fitting method.<sup>8</sup> The sensor (**4**) showed the following cation selectivity:  $\text{CuCl}_2$  ( $4.40 \pm 0.09$ ) >  $\text{NiCl}_2$  ( $3.51 \pm 0.03$ ) >  $\text{BaCl}_2$  ( $2.96 \pm 0.03$ ) >  $\text{HgCl}_2$  ( $2.94 \pm 0.05$ ) >  $\text{Ba}(\text{SCN})_2$  ( $2.71 \pm 0.04$ ) >  $\text{CdCl}_2$  ( $2.45 \pm 0.14$ ). In spite of the small association constant for **4** in  $\text{CH}_3\text{OH}$ , the emission intensity of this host was greatly enhanced in the presence of  $\text{Cu}^{2+}$ , establishing that **4** has a high fluorescence switch-on ability for complexation within a wide concentration range.

In conclusion, the PET fluoroionophore (**4**) could be utilized as not only a chromoionophore for  $\text{Ba}^{2+}$  and  $\text{Ca}^{2+}$  but also a fluoroionophore for  $\text{Cu}^{2+}$ .

## ACKNOULEDGMET

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## EXPERIMENTAL

The NMR spectra were measured on Alpha 400 Model spectrometer in  $\text{CDCl}_3$ ; the chemical shifts are expressed in  $\delta$  unit. The MS spectra were measured with JEOL 01SG-2 spectrometer. The IR spectra were

recorded on a JASCO IR-A102 spectrophotometer with liquid films inserted between NaCl plates for oily materials. The UV spectra were measured using Hitachi U-3410 spectrophotometer. Fluorescence spectra were measured with a JASCO Model FP-700 spectrofluorimeter. The stationary phase for the column chromatography was Wakogel C-300 and the elution solvents were mixtures of hexane and ethyl acetate.

***N*-(Tropon-2-yl)-1,4,10,13-tetraoxa-7,16-diazacyclooctadecane (2).**

A toluene solution (4 mL) of diaza-18-crown-6 (1,4,10,13-tetraoxa-7,16-diazacyclooctadecane, 172.8 mg, 0.66 mmol) and 2-methoxytropone (50.2 mg, 0.37 mmol) was heated at 100 °C under 530 MPa for 24 h. The mixture was evaporated and the residue was purified by column chromatography over silica gel using hexane and ethyl acetate (1:5 *v/v*) as the eluent to give **2** (57.9 mg, 43%) and **3**<sup>5,6</sup> (20.5 mg, 24%).

yellow crystals (Recrystallization from ethyl acetate), mp 92–94 °C; HR-MS (FAB): Found: *m/z*, 367.2230. Calcd for C<sub>19</sub>H<sub>30</sub>N<sub>2</sub>O<sub>5</sub>: (M+H<sup>+</sup>), 367.2233; <sup>1</sup>H-NMR (CDCl<sub>3</sub>) δ=2.80 (4H, t, *J*=4.6 Hz), 3.59–3.63 (13H, m), 3.78 (4H, dd, *J*=5.3, 5.6 Hz), 3.85 (4H, dd, *J*=5.3, 5.8 Hz), 6.53 (1H, dd, *J*=9.4, 8.9 Hz), 6.63 (1H, d, *J*=10.4 Hz), 6.87 (1H, d, *J*=11.4 Hz), 6.97–7.07 (2H, m); <sup>13</sup>C-NMR (CDCl<sub>3</sub>) δ=49.2 (2C), 52.3 (2C), 69.2 (2C), 70.1(2C), 70.2 (2C), 70.3 (2C), 113.3, 122.7, 131.8, 133.8, 135.1, 157.3, 181.0; IR (KBr) *ν*=582, 705, 781, 825, 861, 995, 1047, 1100, 1114, 1132, 1181, 1246, 1348, 1372, 1426, 1464, 1564, 1605, 2796, 2870, 3324 cm<sup>-1</sup>; UV (CH<sub>3</sub>OH) λ<sub>max</sub>=254.4 (ε=4300), 354.2 (2700), 417.3 (2100) nm.

***N*-(9-Anthrylmethyl)-*N*'-(tropon-2-yl)-1,4,10,13-tetraoxa-7,16-diazacyclooctadecane (4).**

A toluene-tetrahydrofuran solution (4 mL, 1:1 *v/v*) of **2** (57.9 mg, 0.16 mmol), triethylamine (0.5 mL, 3.6 mmol), and 9-chloromethylanthracene (119.5 mg, 0.53 mmol) was refluxed for 48 h. The mixture was evaporated and the residue was purified by column chromatography over silica gel using hexane and ethyl acetate (1:1 *v/v*) as the eluent.

yellow oil, HR-MS (FAB) : Found: *m/z*, 557.3015. Calcd for C<sub>34</sub>H<sub>40</sub>N<sub>2</sub>O<sub>5</sub> (M+H<sup>+</sup>), 557.3013; <sup>1</sup>H-NMR (CDCl<sub>3</sub>) δ=2.91 (4H, t, *J*=5.8 Hz), 3.52-3.60 (12H, m), 3.75-3.82 (8H, m), 4.59 (2H, s), 6.50 (1H, dd, *J*=9.2, 9.2 Hz), 6.62 (1H, d, *J*=10.4 Hz), 6.86 (1H, d, *J*=11.8 Hz), 6.93 (1H, dd, *J*=10.4, 10.1 Hz), 7.03 (1H, dd, *J*=11.8, 8.4 Hz), 7.43-7.52 (4H, m), 7.99 (2H, d, *J*=8.2 Hz), 8.40 (1H, s), 8.55 (2H, d, *J*=8.9 Hz); <sup>13</sup>C-NMR (CDCl<sub>3</sub>) δ=52.9 (2C), 53.8 (2C), 69.3 (2C), 70.3 (2C), 70.4 (2C), 71.0 (2C), 113.6, 122.8, 124.8 (2C), 125.2 (2C), 125.6 (2C), 127.5, 128.9 (2C), 130.4 (2C), 131.4 (2C), 131.4 (2C), 131.9, 133.8, 135.1, 157.4, 181.2; IR (KBr) *ν*=707, 732, 758, 847, 885, 927, 986, 1116, 1178,

1199, 1250, 1285, 1344, 1377, 1433, 1461, 1485, 1561, 1608, 1721, 2858, 2916, 3050  $\text{cm}^{-1}$ ; UV ( $\text{CHCl}_3$ )  $\lambda_{\text{max}}=334.9$  ( $\epsilon=10600$ , sh), 351.4 (17000), 368.6 (18300), 389.4 (15700), 418.6 (7840) nm.

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