A Novel [2 + 3] Cycloaddition Reaction: Singlet Oxygen Mediated Formation of 1,3-Dipole from Iminodiacetic Acid Dimethyl Ester and Its Addition to Maleimides

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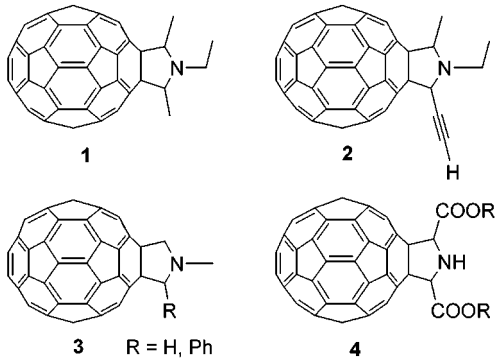
Sensitized photolysis of iminodiacetic acid methyl ester and maleimides follows a [2 + 3] cycloaddition pathway yielding pyrrolidine derivatives. This is similar to the photochemical reaction between C_{60} and amines. A series of pyrrolidine derivatives are prepared by the method including multipyrrolidines from bis- and tris-maleimide starting materials. The yields range from 13% to 85%. The reaction is highly stereoselective. All the isolated products have the 1,3-dimethoxycarbonyl groups in the cis configuration. Various sensitizers may be used with slightly different yields. A plausible mechanism is proposed that involves the singlet oxygen abstraction of two α hydrogen atoms from the iminodiacetate and formation of a 1,3-dipole with a structure similar to the classical thermally generated 1,3-dipole.

Various methods have been developed for the synthesis of five-membered heterocycles. Among them, [2 + 3] is probably the most versatile reaction.[1] In the presence of certain catalysts, highly stereoselective cycloaddition can be achieved.[2] Because of the wide application of such cycloaddition reactions, exploration of new strategies continues to be an active field and attracts the attention of organic chemists.[3] In the past few years, fullerene chemistry has exhibited many interesting reactions including some unusual [2 + 3] cycloaddition pathways. For example, triethylamine adds photochemically to a double bond of C_{60} through two methylene carbons to form a fullerene-fused pyrrolidine derivative **1**.[4] Similarly, 3-diethylamino-1-propyne,[5] dimethylaniline,[6] and other tertiary amines[7] react with C_{60} yielding pyrrolidinofullerene derivatives such as **2** and **3** (Scheme 1). We have found that amino acid esters such as iminodiacetic methyl ester add to a double bond of C_{60} to form the pyrrolidinofullerene **4**.[8]

The above cycloaddition reactions of C_{60} are unprecedented for nonfullerene systems. It is well established in the literature that conventional aromatic systems are reduced photochemically by amines to yield hydrogenated aminoadducts.[9] It is of interest to find out whether this fullerene type [2 + 3] cycloaddition can be applied to classical organic compound. Here, we report the sensitized photochemical reaction between iminodiacetic methyl ester and various maleimides.[10]

Scheme 1



Results and Discussion

Iminodiacetic methyl ester and its α-methyl-, and α-phenyl-substituted derivatives react similarly with phenyl maleimide (Scheme 2). Various light sources may be used for the photolysis. All commercial household light bulbs and tubes are effective, indicating that visible light can initiate the reaction. A TLC lamp giving 254 nm light was also tested as the light source, the yield of which reaction is much lower compared to the visible light irradiation. So the high absorption coefficient of fullerenes in the UV region does not improve the present reaction.

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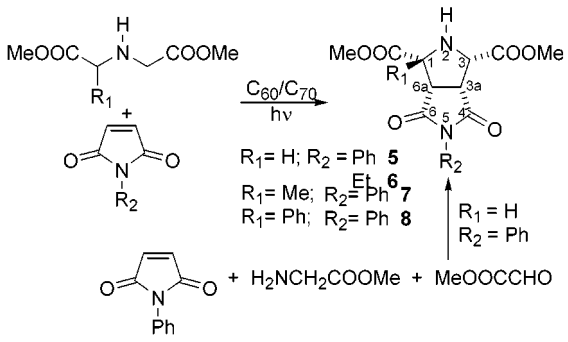
Scheme 2



A 250 W overhead project light bulb inside a water jacket was employed in most reactions because of its small size and relatively strong light intensity. During the irradiation, the temperature of the solution was kept at around 60 °C by adjusting the flow of the cooling water. The ratios of the starting materials are essentially stoichiometric. Less than 1 mol % of C_{60} or a mixture of C_{60}/C_{70} is added as the sensitizer. The reaction time depends on the scale of the reactants and the intensity of the irradiation. With a 0.5 mmol scale, usually 1 h is required. With a 5 mmol scale, 5−10 h are required. Progress of the reaction is monitored by TLC. Effective contact of the reaction solution with the atmosphere is necessary, but bubbling oxygen into the solution does not improve the yield.

For comparison, compound **5** was also prepared by the classical [2 + 3] thermal reaction (Scheme 2). Heating a mixture of *N*-phenylmaleimide, glycine methyl ester, and methyl glyoxylate gave **5**. The yield of this thermal reaction is 56% in our hands. Both the ^{1}H and ^{13}C NMR spectra of the sample from this thermal reaction are exactly the same as those from the fullerene-sensitized photoreaction.

Other sensitizers can also be applied to the above photochemical [2 + 3]-cycloaddition reaction. Under similar conditions, hypocrellin A (HA) gave the highest yield (10 h, 85%), followed by tetraphenylporphyrin (TPP, 12 h, 80%) and phthalocyanin (Pc, 8 h, 78%). Methylene blue (MB) gave the lowest yield (5 h, 27%). Because of the low solubility of MB in toluene, 1 mL of methanol was added to dissolve the MB. Fullerenes are relatively stable under the photochemical conditions. The other four sensitizers undergo photobleaching and slowly decompose during the photolysis. Fullerenes react with iminodiacetic methyl ester themselves, but the resulting fulleropyrrolidine can still act as a sensitizer. Given the unique inertness of the fullerenes toward singlet oxygen and the low price of the C_{60}/C_{70} mixture, fullerenes are the best sensitizer for the above reaction.

The effect of solvents was investigated. Freshly distilled toluene over sodium proves to be the most suitable. Impurities in the commercial toluene quench the photochemical reaction. Other solvents all gave poor yields: 12% in pyridine (20 h), 5% in methanol (7 h), and no detectable product in DMSO (24 h). TPP was used as the sensitizer in all these solvents except methanol, in which HA was used due to the low solubility of TPP. The shorter lifetime of singlet oxygen in methanol may be partly responsible for the lower yield as compared to other solvents. The only isomer of the reaction has the 1,3-cis configuration when toluene is the solvent. A 3:1 ratio between 1,3-cis and 1,3-trans stereoisomers is obtained when pyridine is used as the solvent. The same mixture of isomers is observed in methanol.

Compounds with multimaleimide moieties can also be applied to the photochemical cycloaddition reaction (Scheme 3). The yields tend to decrease as the number of cycloadditions increase in the same molecule. For the tris addition product **13** the isolated yield is 15%, whereas for the monoaddition product **5** the yield can reach 85%. The steric hindrance is probably responsible for the decreased yield. Similarly, the ortho isomer of the bismaleimide derivative gave compound **10** in 32% yield as compared to 67% and 63% yields for the meta (**11**) and para isomers (**12**), respectively.

The structures of the products are derived from their NMR data and X-ray single-crystal analysis. Stereoisomers such as the 1,3-cis and 1,3-trans isomers could be envisioned for the compounds. Both ^{1}H and ^{13}C NMR of **5** indicate that just one stereoisomer is present. But these data cannot distinguish whether it has C_2 or C_s symmetry, both of which should have the same NMR pattern. In other words, relative stereopositions of the two carboxylates and the four pyrrolidine ring protons cannot be assigned from these data alone.

To obtain a conclusive assignment of the structure of **5**, we obtained single crystals of **5** by slow evaporation from a $CHCl_3$ solution and determined its crystal structure by X-ray analysis. The X-ray molecular structure indicates the C_s symmetry for **5**. All four protons on the pyrrolidine ring are shown to be on the same side, and the two methoxycarbonyl groups at the 1,3-positions are in the cis-relative position. This stereo arrangement is similar to that of the pyrrolidine derivatives reported by Cossion and co-workers, who used metalating reagents in their 1,3-dipole cycloadditions.[11] Trans-dicarboxylated pyrrolidine derivatives have been reported by Harwood[12] and Risch[13] also via controlled diastereoselective 1,3-dipole cycloadditions.

The stereochemistry of the substituted iminodiacetic methyl esters **7** is the same as that of **5** with the two carboxyl groups on the same side and opposite to the 3a,-6a-ring protons. The isolated product shows just one set of NMR signals, indicating the formation of just one stereoisomer. D_2O exchange indicates the doublet at 3.57 ppm as the NH proton. Decoupling experiments helped to attribute the doublet at 3.40 ppm to the 6a-H, the triplet at 3.78 ppm to the 3a-H, and the doublet of doublets at 4.27 ppm to the 3-H. The relative positions of the substituents on the pyrrolidine ring are established by NOE experiment. The clear NOE signals between the methyl group on the ring and among the ring protons strongly support the structure of **7** as depicted. Similarly, the phenyl analogue **8** shows the same NMR pattern, and its NOE indicates the same stereoarrangment as that of **7**.

The bisadducts **9**, **11**, and **12** and the tris adduct **13** all showed one set of NMR signals. The pyrrolidine fragments are equivalent in these compounds. This is in agreement with the above 1,3-cis assignment. For the 1,3-trans isomer diastereomers would be formed in the multiadducts, which should exhibit different NMR chemical shifts. The ortho derivative **10** showed a more

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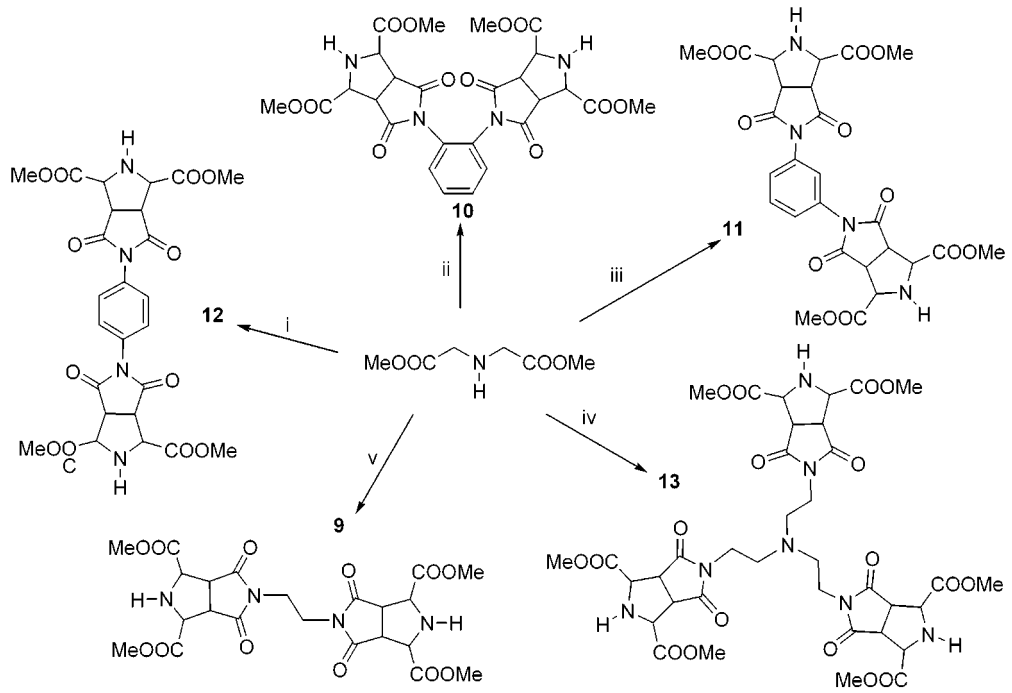
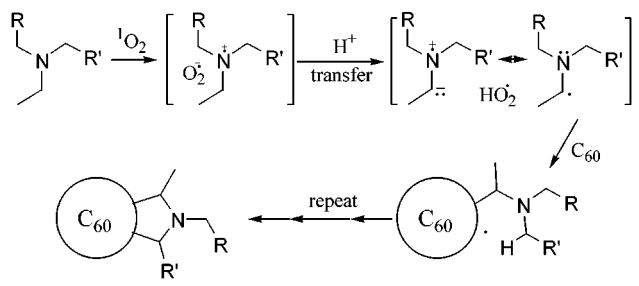
Scheme 3[a]



[a] Key: (i) *p*-phenylenedimaleimide, 63%; (ii) *o*-phenylenedimaleimide, 32%; (iii) *m*-phenylenedimaleimide, 67%; (iv) tris(2-maleimidoethyl)amine, 15%; (v) ethylenedimaleimide, 55%.

Scheme 4



complicated NMR pattern. There are two sets of signals for the two pyrrolidine groups at room temperature. For example, the four methoxy groups appear as two singlets at 3.81 and 3.83 ppm instead of one. At 50 °C, the two signals coalesce as a singlet at 3.80 ppm. The other protons behaved similarly. The steric hindrance between the two pyrrolidine groups is responsible for this phenomenon. As mentioned previously, the yield of **10** is much lower than those of the meta and para analogues **11** and **12** as a result of steric hindrance.

Foote et al. have recently established that singlet oxygen is involved in the photochemical reaction between C_{60} and amines.[5] According to their mechanism (Scheme 4), C_{60} sensitizes the formation of singlet oxygen in the first step; this singlet oxygen then interacts with the amine to form an α-carbon-centered radical, which adds to fullerene and opens a double bond on the spherical surface. Repeating the same set of steps, a second α carbon of the already attached amine is added to the other fullerene carbon of the opened double bond, yielding a pyrrolidinofullerene derivative. Their study of the involvement of singlet oxygen is extensive and well supported.

Our previous proposal about the mechanism of the reaction between C_{60} and iminodiacetic methyl ester suggested the involvement of oxygen on the basis of control experiments.[8] But the suggestion did not indicate specifically how it was involved. Later, we adapted the Foote mechanism to explain the reaction between maleimide and iminodiacetic methyl ester in our preliminary account of this work.[10] In light of the present data, the mechanism is still not perfect and needs modification. First, the high stereoselectivity of all the products here cannot be explained by that mechanism. Should the α-carbon-centered radicals form and also add stepwise to the electron-deficient alkene, both 1,3-cis and 1,3-trans stereoisomers should be present. In addition, the pyrrolidine ring-closing process of the above mechanism requires a long-lived carbon radical intermediate, which reacts with another singlet oxygen molecule at another methylene carbon α to the N (not the already formed more reactive radical carbon) to form a diradical species. The diradical then couples intramolecularly to form the pyrrolidine ring. This second C−C bond-formation step lacks experimental evidence and does not fully comply with the present data.

Scheme 5 shows a more likely pathway. The singlet oxygen initially oxidizes the nitrogen and then abstracts two protons from the methylene carbons α to the N atom. The net result is the formation of a 1,3-dipole intermediate and H_2O_2. A positive potassium iodide test of the reaction mixture after irradiation supports the presence of H_2O_2. In the singlet oxygen oxidation of pyrroles, Wasserman et al. have proposed the formation of an imino hydroperoxide intermediate, which reacts with a nucleophile further giving off H_2O_2.[14] The net result of this pyrrole reaction also involves the abstraction of two H atoms by singlet oxygen in the form of H_2O_2. The composition of the 1,3-diople intermediate generated here by singlet oxygen is exactly the same as that from glycine methyl ester and methyl glyoxylate. The present revised

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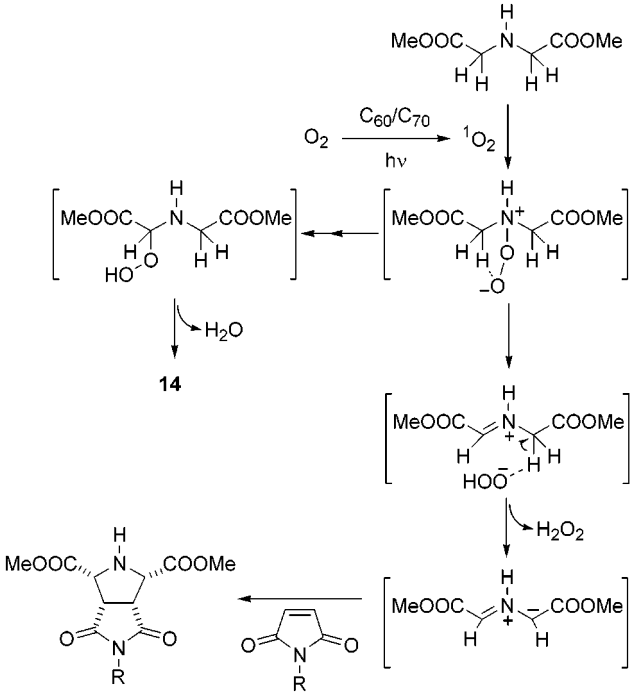
Scheme 5

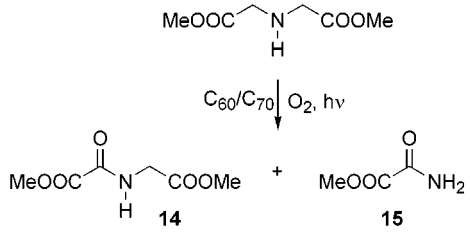


mechanism thus well explains the same stereochemistry of the product from both the photochemical and thermo reactions in Scheme 2.

The present mechanism can also readily rationalize the different effects of solvents mentioned earlier. In the less polar solvent toluene, the kinetically favored *syn*-azomethine ylide in Scheme 5 adds to maleimide rapidly once it was formed, giving the 1,3-cis isomer. Polar solvents such as pyridine and methanol facilitate the transformation of the *syn*-azomethine ylide to the thermodynamically more stable *anti*-azomethine ylide, which adds to maleimides and yields 1,3-trans isomer. The stereochemistry of 1,3-dipole cycloadditions has been well documented.[1]

The involvement of singlet oxygen in the mechanism is in agreement with other related observations. We have previously reported that the photochemical reaction between C_{60} and glycine methyl ester or sarcosine methyl ester results in complicated C−N bond breaking and formation processes and yields compound **4**, which is the same as the product from the iminodiacetic dimethyl ester C_{60} reaction.[8a] These unusual reactions can now be attributed to singlet oxygen involvement. Due to its high energy, singlet oxygen usually reacts with amine without specificity.[15] Deamination and formation of carbonyl derivatives are the most common pathways.[16] Considering the singlet oxygen induced fragmentation of amino acids and possible recombination processes of the fragments, it is not surprising that compound **4** can be produced from glycine or sarcosine methyl ester. Compound **4** is very stable and has been isolated as a byproduct from similar photochemical reactions such as the reaction of C_{60} with EDTA tetramethyl ester and nitrilotriacetic methyl ester.[8b] The much higher yield of

Scheme 6



the α-phenyl derivative **8** (51%) than the analogous α-methyl derivative **7** (13%) provides more evidence supporting the above mechanism. The electron-withdrawing α-phenyl group apparently stabilizes the radical formed in the first step of H abstraction, whereas the electron-donating methyl group just increases the steric hindrance.

The oxalic acid derivative **14** was detected occasionally from the fullerene-sensitized reaction from different runs. The isolated yield of **14** is less than 5%. It does not contain the maleimide moiety, and corresponds to the oxygenation of a methylene carbon in the iminodiacetic ester. When cyclohexene is used in the place of maleimide, **14** is the only isolated product. So the cycloaddition reaction does not take place with this relatively electron-rich alkene.

Compound **14** can also be prepared by photolysis of iminodiacetic methyl ester alone in the presence of C_{60}/C_{70} (Scheme 6). Prolonged irradiation results in fragmentation of the product and formation of compound **15**. Compound **14** has been shown to be an effective inhibitor of prolyl 4-hydroxylase.[17] The reaction in Scheme 6 agrees well with the classical reaction between singlet oxygen and amine.[18,19] These results further confirm the singlet oxygen involvement in the photochemical reaction.

Wasserman and co-workers have shown that when both electron-releasing and electron-attracting groups are substituted on the pyrrole ring, its reaction with singlet oxygen may take place under more control.[20] Some useful pyrrole derivatives have been prepared by the singlet oxygen−pyrrole reaction.[21] The present iminodicetate is also an electron-donating and electron-withdrawing system, the imino group being the donor and the ester being the acceptor. The combined effect of the "push−pull" groups stabilizes the radical intermediates[22] and facilitates the singlet abstraction of protons and formation of the 1,3-dipole.

In conclusion, the fullerene type [2 + 3] cycloaddition of amines can be applied to other electron-deficient nonfullerene alkenes such as maleimides. The reaction is promoted by singlet oxygen. Besides fullerenes, various other classical sensitizers may also be used to mediate the reaction. In contrast to the photobleaching of classical sensitizers, fullerenes are relatively inert toward singlet oxygen and serve as the best sensitizer for the present

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reactions. The role of singlet oxygen is probably the abstraction of two hydrogen atoms α to the nitrogen, thus resulting the formation of a 1,3-dipole and hydrogen peroxide. The reactivity of this singlet oxygen-generated 1,3-dipole is virtually the same as the thermally produced one in terms of both stereoselectivity and yields of the products.

Experimental Section

The maleimides were prepared according to literature methods.[23] Other reagents are commercials. All the photoreactions were carried out in a similar way under atmosphere. The following describes the photochemical cycloaddition between dimethyliminodiacetate and *N*-phenylmaleimide as an example.

4,6-Dioxo-5-phenyloctahydropyrrolo[3,4-*c*]pyrrole-1,3-dicarboxylic Acid Dimethyl Ester (5). Iminodiacetic dimethyl ester (320 mg, 2.0 mmol), *N*-phenylmaleimide (350 mg, 2.1 mmol), and C_{60}/C_{70} (5 mg) were added to 80 mL of toluene. An overhead project light bulb was used as the light source, which was cooled by a water jacket and emerged into the reaction container. The solution was irradiated with continuous stirring. During the photolysis, toluene was added occasionally to compensate for its slow evaporation. The progress of the reaction was monitored by TLC. After the starting material almost completely disappeared (about 8 h) or when there was no noticeable further change in other cases, the irradiation was stopped and the solution was evaporated on a rotatory evaporator. The residue was purified by chromatography on silica column. $CHCl_3$ first eluted unreacted starting material *N*-phenylmaleimide, and then ethyl acetate eluted the desired compound **5** as white powder (428 mg, 65% yield): mp 222−224 °C; IR (microscope, cm^{-1}) 1708, 1740; ^1H NMR δ (ppm) (200 MHz, $CDCl_3$) 3.72 (m, 2H), 3.84 (s, 6H), 4.11 (m, 2H), 7.21 (m, 2H), 7.43 (m, 3H); ^{13}C NMR δ (ppm) (50 MHz) 49.9, 52.8, 63.4, 126.4, 129.0, 129.3, 169.4, 174.1 (the phenyl C attached to the N is too weak to be assigned unambiguously); FABMS 333 ($M^+ + 1$). Anal. Calcd for $C_{16}H_{16}N_2O_6$: C, 57.81; H, 4.86; N,8.43. Found: C, 57.68; H, 4.62; N, 8.45.

The X-ray diffraction experiment for **5** was performed on a CAD4 Mach3 diffaractometer with graphite-monochromatized Mo Kα radiation (n = 0.710 73 Å). A total of 4220 reflection data, in which 3420 are unique (R_{int} = 0.023), were collected in a θ range of 2.25−26.970°. The data were corrected by Lp factors and decay (1.0%) but not absorption. The structure was solved by direct methods and refined anisotropicly for all nonhydrogen atoms by full-matrix least-squares methods. All hydrogen atoms were located by difference Fourier synthesis and refined isotropically. All calculations were carried out with Shelex97 on a 586 PC. Crystal data: Space group $P2_1/c$, a = 8.7139(4) Å, b = 16.7814(8) Å, c = 1.7419(7) Å, β = 90.406(5)°, V = 1570.76(15) Å^3, Z = 4, D_c = 1.405 g cm^{-3}, $F(000)$ = 696, size 0.40 × 0.35 × 0.24 mm, μ = 0.109 mm^{-1}, R1 = 0.053 (wR2 = 0.113) for 2614 observed reflections with $I = 2\sigma(I)$, GOF = 1.192, max/min $\Delta\rho$ = 0.22/−0.17 eÅ^{-3}. Details of the diffraction data can be found in the Supporting Information of ref 10.

4,6-Dioxo-5-ethyloctahydropyrrolo[3,4-*c*]pyrrole-1,3-dicarboxylic Acid Dimethyl Ester (6). Iminodiacetic methyl ester (160 mg), *N*-ethylmaleimide (374 mg), and C_{60}/C_{70} (5 mg) in 100 mL of toluene were irradiated for 2 h. The product was isolated as in the general procedure: yield 115 mg (40%); mp 160−162 °C; IR (microscope, cm^{-1}) 1695, 1753; ^1H NMR δ (ppm) (400 MHz, $CDCl_3$) 1.13 (t, 3H), 3.49 (q, 2H), 3.55 (m, 2H), 3.85 (s, 6H), 4.02 (m, 2H), 4.16 (d, 1H); ^{13}C NMR δ (ppm) (50 MHz, $CDCl_3$) 12.9, 34.2, 49.6, 52.5, 62.8, 169.3, 174.7; EIMS 285($M^+ + 1$); HRMS (EI) found, 284.1010 (M^+), $C_{12}H_{16}N_2O_6$ requires 284.1008. Anal. Calcd for $C_{12}H_{16}N_2O_6$: C, 50.69; H, 5.68; N, 9.86. Found: C, 50.53; H, 5.68; N, 9.90.

4,6-Dioxo-1-methyl-5-phenyloctahydropyrrolo[3,4-*c*]-pyrrole-1,3-dicarboxylic Acid Dimethyl Ester (7). α-Methyliminodiacetic methyl ester (900 mg), *N*-phenylmaleimide (700 mg), and C_{60}/C_{70} (5 mg) in 180 mL of toluene were irradiated for 10 h. The product was isolated as in the general procedure: yield 184 mg (13.2%); mp 138−139 °C; IR (microscope, cm^{-1}) 1713, 1736; ^1H NMR δ (ppm) (400 MHz, $CDCl_3$) 1.55 (s, 3H), 3.40 (d, 1H), 3.57 (d, 1H), 3.78 (t, 1H), 3.83 (s, 3H), 3.84 (s, 3H), 4.27 (dd, 1H), 7.20 (m, 2H), 7.40 (m, 1H), 7.45 (m, 2H); ^{13}C NMR δ (ppm) (100 MHz) 24.6, 50.5, 52.8, 53.1, 57.0, 62.3, 70.00, 126.5, 129.0, 129.3, 131.3, 169.9, 171.6, 174.2; FABMS 347 ($M^+ + 1$). Anal. Calcd for $C_{17}H_{18}N_2O_6$: C, 58.94; H, 5.24; N, 8.09. Found: C, 58.69; H, 5.26; N, 7.89.

1,5-Diphenyl-4,6-dioxooctahydropyrrolo[3,4-*c*]pyrrole-1,3-dicarboxylic Acid Dimethyl Ester (8). α-Phenyliminodiacetic methyl ester (2.37 g), *N*-phenylmaleimide (2 g), and C_{60}/C_{70} (5 mg) in 200 mL of toluene were irradiated for 16 h. The product was isolated as in the general procedure: yield 2.1 g (51%); mp 203−204 °C; IR (microscope, cm^{-1}) 1716, 1732; ^1H NMR δ (ppm) (400 MHz, $CDCl_3$) 3.58 (dd, 1H), 3.75 (S, 3H), 3.82 (s, 3H), 3.86 (d, 1H), 3.97 (t, 1H), 4.20 (d, 1H), 7.24 (m, 2H), 7.40 (m, 6H), 7.75 (d, 2H); ^{13}C NMR δ (ppm) (100 MHz, $CDCl_3$) 50.3, 52.8, 53.4, 56.7, 62.0, 75.4, 126.6, 127.3, 128.5, 128.6, 129.0, 129.3, 131.4, 138.0, 170.1, 174.3; 174.4; FABMS 409 ($M^+ + 1$). Anal. Calcd for $C_{22}H_{20}N_2O_6$: C, 64.68; H, 4.94; N, 6.86. Found: C, 64.87; H, 5.15; N, 6.53.

5-[2-[1,3-Dimethoxycarbonyl-4,6-dioxooctahydropyrrolo[3,4-*c*]pyrrol-5-yl]ethyl]-4,6-dioxooctahydropyrrolo-[3,4-*c*]pyrrole-1,3-dicarboxylic Acid Dimethyl Ester (9). Iminodiacetic methyl ester (600 mg), ethylenedimaleimide (350 mg), and C_{60}/C_{70} (5 mg) in 180 mL of toluene were irradiated for 11 h. The product was isolated as in the general procedure: yield 456 mg (55%); mp 262−264 °C; IR (microscope, cm^{-1}) 1708, 1744; ^1H NMR δ (ppm) (400 MHz, $CDCl_3$) 2.84 (m, 2H), 3.58 (m, 4H), 3.63 (s, 4H), 3.82 (s, 12H), 3.96 (m, 4H); ^{13}C NMR δ (ppm) (100 MHz) 37.3, 49.7, 52.6, 62.8, 169.1, 175.2; FABMS 539 ($M^+ + 1$). Anal. Calcd for $C_{22}H_{26}N_4O_{12}$: C, 49.06; H,4.87; N, 10.41. Found: C, 49.12; H, 4.93; N, 10.12.

5-[2-[1,3-Dimethoxycarbonyl-4,6-dioxooctahydropyrrolo[3,4-*c*]pyrrol-5-yl]phenyl]-4,6-dioxooctahydropyrrolo-[3,4-*c*]pyrrole-1,3-dicarboxylic Acid Dimethyl Ester (10). Iminodiacetic methyl ester (600 mg), *N*,*N*′-*o*-phenylenedimaleimide (400 mg), and C_{60}/C_{70} (5 mg) in 180 mL of toluene were irradiated for 10 h. The product was isolated as in the general procedure: yield 280 mg (32%); mp 168−169 °C; IR (microscope, cm^{-1}) 1724 (broad); ^1H NMR δ (ppm) (400 MHz, $CDCl_3$) rt 2.71 (b, 2H), 3.65 (m, 2H), 3.79 (s, 6H), 3.81 (s, 6H), 3.99 (m, 2H), 4.06 (m, 2H), 4.10 (m, 2H), 7.16 (d, 1H), 7.28 (d, 1H), 7.48 (m, 2H); at 323K: 2.50 (b, 2H), 3.62 (b, 2H), 3.80 (s, 12H), 4.02 (b, 6H), 7.24 (b, 2H), 7.46 (b, 2H); ^{13}C NMR δ (ppm) 49.3, 51.1, 52.8, 60.4, 62.8, 63.3, 128.7, 129.0, 129.4, 130.2, 130.7, 168.9, 170.0, 173.0, 173.7; FABMS 587 ($M^+ + 1$). Anal. Calcd for $C_{26}H_{26}N_4O_{12}$: C, 53.23; H, 4.47; N, 9.56. Found: C, 52.97; H, 4.42; N, 9.29.

5-[3-[1,3-Dimethoxycarbonyl-4,6-dioxooctahydropyrrolo[3,4-*c*]pyrrol-5-yl]phenyl]-4,6-dioxooctahydropyrrolo-[3,4-*c*]pyrrole-1,3-dicarboxylic Acid Dimethyl Ester (11). Iminodiacetic methyl ester (350 mg), *N*,*N*′-*m*-phenylenedimaleimide (200 mg), and C_{60}/C_{70} (5 mg) in 180 mL of toluene were irradiated for 12 h. The product was isolated as in the general procedure: yield 296 mg (67%); mp 230−232 °C; IR (microscope, cm^{-1}) 1717, 1743; ^1H NMR δ (ppm) (400 MHz, $CDCl_3$) 3.00 (t, 2H), 3.72 (m, 4H), 3.84 (s, 12H), 4.11 (m, 4H), 7.23 (m, 1H), 7.31 (m, 2H), 7.54 (t, 1H); ^{13}C NMR δ (ppm) (100 MHz) 49.8, 52.9, 63.4, 123.7, 126.7, 129.7, 131.8, 169.3, 173.6; FABMS 587 ($M^+ + 1$). Anal. Calcd for $C_{26}H_{26}N_4O_{12}$: C, 53.23; H, 4.47; N, 9.56. Found: C, 53.02; H, 4.41; N, 9.31.

5-[4-[1,3-Dimethoxycarbonyl-4,6-dioxooctahydropyrrolo[3,4-*c*]pyrrol-5-yl]phenyl]-4,6-dioxooctahydropyrrolo-[3,4-*c*]pyrrole-1,3-dicarboxylic Acid Dimethyl Ester (12). Iminodiacetic methyl ester (200 mg), *N*,*N*′-*p*-phenylenedimaleimide (134 mg), and C_{60}/C_{70} (5 mg) in 180 mL of toluene were irradiated for 8 h. The product was isolated as in the general procedure: yield 185 mg (63%); mp 214−216 °C; IR (microscope, cm^{-1}) 1713, 1739; ^1H NMR δ (ppm) (200 MHz, $CDCl_3$)

(23) (a) Bismaleimides: Patel, H. S.; Mathur, A. B.; Bhardwaj, I. S. *Pure. Appl. Chem*. **1995**, *A32*(12), 2025. Trismaleimide: (b) Kossmehl, G.; Nagel, H.-I, Pahl, A. *Angew. Makromol. Chem*. **1995**, *227*, 139.

3.01 (m, 2H), 3.74 (m, 4H), 3.81 (s, 12H), 4.10 (m, 4H), 7.15 (m, 1H), 7.39 (m, 1H), 7.56 (m, 2H); ^{13}C NMR δ (ppm) (50 MHz, $CDCl_3$) 49.9, 52.8, 63.4, 120.1, 127.1, 169.5, 174.2; FABMS: 587 ($M^+ + 1$). Anal. Calcd for $C_{26}H_{26}N_4O_{12}$: C, 53.23; H, 4.47; N, 9.56. Found: C, 52.99; H, 4.46; N, 9.05.

Tris[2-[1,3-Dimethoxycarbonyl-4,6-dioxooctahydropyrrolo[3,4-*c*]pyrrol-5-yl]ethyl]amine (13). Iminodiacetic methyl ester (410 mg), tris(2-maleimidoethyl)amine (267 mg), and C_{60}/C_{70} (5 mg) in 180 mL of toluene were irradiated for 10 h. The product was isolated as in the general procedure: yield 90 mg (15%); mp 107−109 °C; IR (microscope, cm^{-1}) 1705, 1746; ^{1}H NMR δ (ppm) (400 MHz, $CDCl_3$) 2.39 (m, 6H), 2.73 (bs, 3H), 3.31 (m, 6H), 3.65 (m, 6H), 3.81 (s, 18H), 3.96 (m, 6H); ^{13}C NMR δ (ppm) (100 MHz) 36.5, 50.2, 52.0, 52.5, 62.5, 169.4, 175.7; FABMS 864 ($M^+ + 1$). Anal. Calcd for $C_{36}H_{45}N_7O_{18}\cdot 1.5H_2O$: C, 48.52; H, 5.43; N, 11.01. Found: C, 48.60; H, 5.36; N, 10.55.

***N*-Methoxycarbonylmethyloxalamic Acid Methyl Ester (14) and Oxalamic Acid Methyl Ester (15).** The two compounds were prepared in a procedure similar to the general procedure but in the absence of maleimides. They are characterized by comparing their NMR data with those of authentic samples. Conditions of these reactions were not optimized. Single crystals of **15** were obtained upon slow evaporation of a $CHCl_3$ solution, and its molecular structure was determined using the same method as for compound **5**. Details of the structure analysis can be found in the Supporting Information.

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Supporting Information Available: ^{1}H and ^{13}C NMR, IR, and MS spectra for compounds **7**−**13** and details of X-ray diffraction analysis for compound **15**. This material is available free of charge via the Internet at http://pubs.acs.org.

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