  Bull. Chem. Soc. Jpn., 61, 1225—1230 (1988)

Cycloaddition Reactions of 2-Hydroxy-, 2-Amino-, and 2-Mercapto-1-azaazulenes with Reactive Acetylenes

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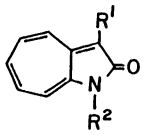
(Received August 28, 1987)

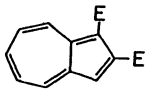
The reaction of 1-methyl-1-azaazulen-2(1*H*)-one (**1a**) with dimethyl acetylenedicarboxylate (DMAD) or dibenzoylacetylene (DBA) in refluxing acetonitrile gave 1,2-disubstituted azulene (**2**), 2-methylcyclopent[*de*]isoquinolin-3(2*H*)-ones, 1-methyl-1-azacyclopent[*cd*]azulen-2(1*H*)-ones, and 3-substituted 1-methyl-1-azaazulen-2(1*H*)-ones, whereas in refluxing *t*-butylbenzene, compound **2** and 6,8-etheno-1-methylcyclohepta[*b*]pyrrol-2(1*H*)-one were obtained as major products. The reactions proceeded periselectively depending on the temperature. 2-Hydroxy-1-azaazulene behaved as 1-azaazulen-2(1*H*)-one and the reaction with DMAD gave similar result as for **1a**. The reaction of 2-amino-1-azaazulene with DMAD gave methyl 2,4a-dihydro-2-oxo-1,4a-diazabenz[*a*]azulene-4-carboxylate and tetramethyl 4,5-dihydro-1*H*-1,11-diazacyclohept[*a*]azulene-2,3,4,5-tetracarboxylate. The reaction of 2-mercapto-1-azaazulene with DMAD gave tetramethyl 4,4a-dihydro-4a-azabenz[*a*]azulene-1,2,3,4-tetracarboxylate in moderate yield. The reaction mechanisms of these reactions are discussed.

We have studied the cycloadditions of 1-azaazulenes with reactive acetylenes and found that the acetylenes first attaked the N-1 position of 1-azaazulenes and give dipolar intermediates.[1,2] As a continuation of our work, we have advanced the reaction to 2-hydroxy-, 2-amino-, and 2-mercapto-1-azaazulenes. It is known that 2-hydroxy-1-azaazulene is a tautomer of 1-azaazulen-2(1*H*)-one and reacts toward electrophile at the C-3 position as well as the N-1 position.[3-9] Therefore, it is expected that 2-hydroxy-1-azaazulene with reactive acetylenes undergoes another type of cycloaddition reaction. Therefore, we first investigated the reaction of 1-methyl-1-azaazulen-2(1*H*)-one[9] in order to understand the reaction of the keto-form.[10] We then investigated the reaction of 2-hydroxy-, 2-amino-, and 2-mercapto-1-azaazulenes.

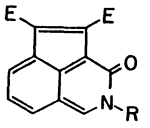
A treatment of **1a** with dimethyl acetylenedicarboxylate (DMAD) in refluxing acetonitrile for 120 h gave dimethyl 1,2-azulenedicarboxylate[11,12] (**2a**) (9%), dimethyl 2-methyl-2,3-dihydro-3-oxocyclopent[*de*]-



1a: R^1=H, R^2=Me
1b: R^1=CO_2Et, R^2=Me
1c: R^1=R^2=H
1d: R^1=CO_2Et, R^2=H
1e: R^1=CO_2Et, R^2=(*E*)-CCO_2Me=$CHCO_2Me$



2a: E=CO_2Me
2b: E=COPh

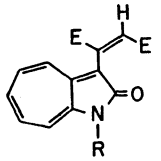


3a: R=Me, E=CO_2Me
3b: R=Me, E=COPh
3c: R=H, E=CO_2Me

4a: R=Me, E=CO_2Me
4b: R=Me, E=COPh
4c: R=H, E=CO_2Me

5a: R=Me, E=CO_2Me
5b: R=Me, E=COPh
5c: R=H, E=CO_2Me

6a: R=Me, E=CO_2Me
6b: R=Me, E=COPh
6c: R=H, E=CO_2Me



7a: R=Me, E=CO_2Me
7b: R=Me, E=COPh
7c: R=H, E=CO_2Me

8a: R^1=H, R^2=Me, E=CO_2Me
8b: R^1=CO_2Et, R^2=Me, E=CO_2Me
8c: R^1=H, R^2=Me, E=COPh

isoquinoline-4,5-dicarboxylate (**3a**) (11%), dimethyl 1-methyl-1,2,2a,3-tetrahydro-2-oxo-1-azacyclopent[*cd*]-azulene-3,4-dicarboxylate (**4a**) (11%), dimethyl 1-methyl-1,2-dihydro-2-oxo-1-azacyclopent[*cd*]azulene-3,4-dicarboxylate (**5a**) (7%), dimethyl 1-methyl-1,2-dihydro-2-oxo-1-azaazulene-3-maleate (**6a**) (17%), and dimethyl 1-methyl-1,2-dihydro-2-oxo-1-azaazulene-3-fumarate (**7a**) (21%). These structures were determined on the basis of the spectroscopic data as well as on elemental analyses. Compound **3a** was a stable fused 3(2*H*)-isoquinolinone derivative. In its ^{1}H NMR spectrum, a signal of the 1H singlet assignable to H-1 can be seen at δ 8.73 , which is a reasonable value as 3(2*H*)-isoquinolinone.[13] In the ^{1}H NMR spectrum of **4a**, AB doublets can be seen at δ 3.10 and 4.32 (J=9.2 Hz), and in the ^{13}C NMR spectrum, two methine signals at δ 43.14 and 50.09. The dehydrogenation of **4a** by tetrachloro-*o*-benzoquinone (TCQ) gave **5a** in 47% yield. The result assists with the structure.

When the above reaction was carried out in refluxing *t*-butylbenzene for 3 h, compounds **2a** (21%), **3a** (5%), **5a** (0.8%), and dimethyl 6,8a-etheno-1-methyl-1,2-dihydro-2-oxocyclohepta[*b*]pyrrole-7,8-dicarboxylate (**8a**) (49%) were isolated. In the ^{13}C NMR spectrum of **8a**, signals assignable to sp^3 carbons can be seen at δ 38.70 (d, C-6) and 71.55 (s, C-8a), and in its ^{1}H NMR spectrum, methine proton can be observed at δ 4.46 (ddd, J=8.5, 6.7, and 1.2 Hz, H-6). Further evidence supporting the structure of **8a** is provided by its mass spectrum which displays an intense peak at m/z 159 (98%) associated with the loss of DMAD.

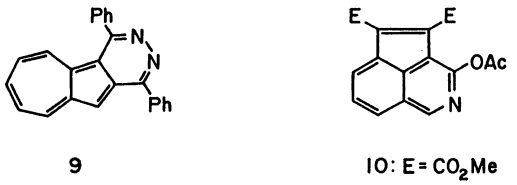
Ethyl 1-methyl-1,2-dihydro-2-oxo-1-azaazulene-3-carboxylate (**1b**) did not react with DMAD in refluxing benzene or acetonitrile, but gave **8b** (66%) in refluxing *t*-butylbenzene.

In a similar treatment, the reaction of **1a** with dibenzoylacetylene (DBA) in refluxing acetonitrile gave **2b** (9%), **3b** (3%), **4b** (50%), **5b** (6%), and **7b** (6%), and in refluxing *t*-butylbenzene **2b** (60%), **3b** (19%), and **8c** (15%). Dehydrogenation of **4b** with TCQ gave **5b** in a 70% yield.

The reaction of 1,2-dibenzoylazulene **2b** with hydrazine hydrate gave the corresponding pyridazino derivative **9**.

The reaction of 2-hydroxy-1-azaazulene with DMAD in refluxing acetonitrile gave **2a** (7%), **3c** (35%), **5c** (5%), **6c** (21%), and **7c** (30%). The result was similar to that of **1a**; it is therefore considered that 2-hydroxy-1-azaazulene behaved as 1-azaazulen-2(1*H*)-one (**1c**). The observation that compound **1b** exists in exactly the keto form in the ^{1}H NMR spectrum in $CDCl_3$ is in agreement with the above consideration. The structures obtained from the above reaction were assigned on the basis of spectroscopic data as well as on elemental analyses.

Compound **3c** was acetylated with acetic anhydride to give **10**. In the IR spectrum of **10**, three ester carbonyl signals were observed at 1756, 1730, and 1700 cm^{-1}, whereas the amide carbonyl signal was not. We therefore assigned **10** as an *O*-acetylated compound. In the ^{1}H NMR spectrum of **10**, an H-1 proton was observed at δ 8.92. The ^{1}H NMR spectrum of **3c** in DMSO-d_6 shows a signal of H-1 at δ 8.91, which is



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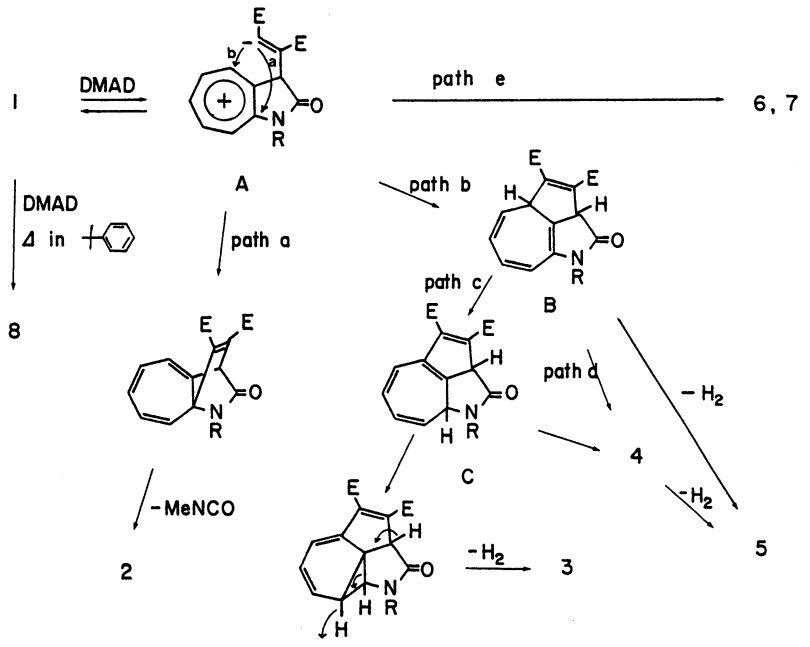
10: E = CO_2Me



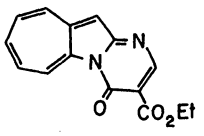
Scheme 1.

comparable with that of **10**. Therefore, we considered that compound **3c** would exist in an enol form in DMSO-d_6.

Previously, we reported that ethyl 1,2-dihydro-2-oxo-1-azaazulene-3-carboxylate (**1d**) reacted with DMAD to give **1e**.[2] Different from this, the corresponding fumarate was not obtained upon the reaction of **1c**. This result suggested that the C-3 position of **1c** is more reactive than the N-1 position.

A plausible mechanism is shown in Scheme 1. When DMAD attacks the C-3 position of **1**, which is a reactive site towards electrophile, a dipolar species **A** should be produced. A cyclization on the C-8a position of **A** and a successive elimination of MeNCO furnishes **2** (path a). A cyclization on the C-4 position of **A** gives **B** (path b), and several successive 1,5-hydrogen shifts of **B** produces **C** (path c) and **4** (path d). Dehydrogenation of **B** and/or **4** affords **5**. A tautomerization of **C** and a subsequent dehydrogenation leads to **3** (path c). A protonation and aromatization of **A** gave Michael adducts **6** and **7** (path e). Through a reaction at a higher temperature a Diels-Alder reaction occurs on a seven-membered ring and **8** is produced, in addition to the cycloaddition-cycloreversion product **2**. It is considered that the activation energy of the formation of **8** is higher than that of **A**. Consequently, compound **A** is favorably produced at lower temperatures. A similar periselectivity dependence on the temperature is known regarding the reaction of 5-azaazulene with reactive acetylenes.[14]

The treatment of 2-amino-1-azaazulene (**11**) with DMAD in refluxing acetonitrile for 5 h gave methyl 2,4a-dihydro-2-oxo-1,4a-diazabenz[*a*]azulene-4-carboxylate (**12**) and tetramethyl 4,5-dihydro-1*H*-1,11-diazacyclohept[*a*]azulene-2,3,4,5-tetracarboxylate (**13**) in 18.5% and 19% yield, respectively. These structures were assigned on the basis of the spectroscopic data as well as elemental analyses. The ^{1}H NMR spectrum of **12** shows protons at δ 4.04 (s, Me), 7.09 (s, H-10), 7.19 (s, H-3), 7.25—7.45 (m, H-6, 7, and 8), 7.94 (d, J=10.4 Hz, H-9), and 9.84—9.96 (H-5). In the ^{1}H NMR of 4-oxo compound **14**,[15] proton at C-5 was observed at δ 10.05—10.30. Different from the 4-oxo compound, deesterification of **12** gave no distinct compound. We therefore assigned **12** as being a 2-oxo compound. The ^{1}H NMR spectrum of **13** showed a pair of AB doublets (J=4.9 Hz) at δ 4.97 and 5.21. In its ^{13}C NMR spectrum, sp^3 carbon appeared at δ 43.47 (d) and 45.43 (d).



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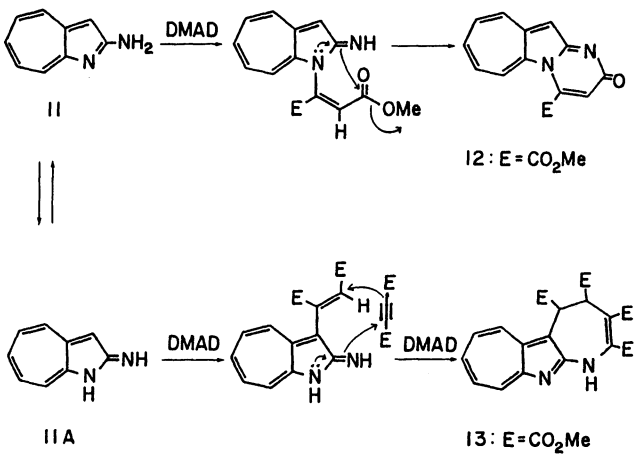
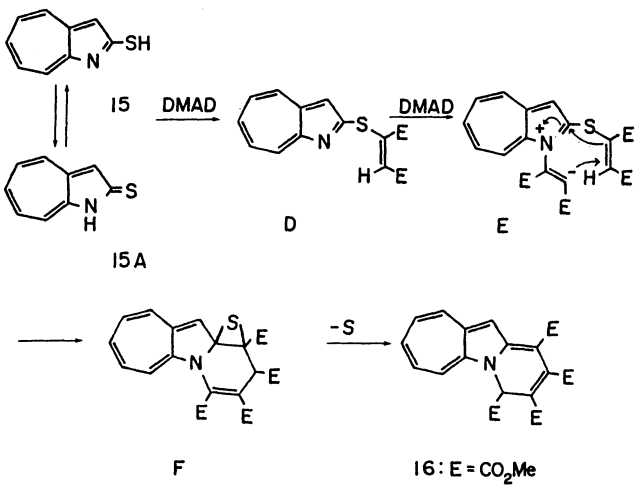
A plausible mechanism is shown in Scheme 2. When DMAD attacks the N-1 position of amino-form **11**, compound **12** should be produced. An attack of DMAD at the C-3 position of imino-form **11A** and a successive reaction of another molecule of DMAD furnishes **13**. In the ^{1}H NMR spectrum of **11** in $CDCl_3$, equilibrium (80% of **11**, 20% of **11A**) was observed.

The treatment of 2-mercapto-1-azaazulene (**15**) with DMAD in refluxing acetonitrile for 17 h gave a complex mixture and only **16** was isolated in 38% yield. Compound **16** was analyzed as $C_{21}H_{19}NO_8$ from HRMS and elemental analysis, and assigned as tetramethyl 4,4a-dihydro-4a-azabenz[*a*]azulene-1,2,3,4-tetracarboxylate. The ^{1}H NMR spectrum of **16** shows protons at δ 6.41 (s, H-4), 7.10—7.20 (m, H-6, 7, 8, and 9), 7.45 (s, H-10), and 7.63 (d, J=11.0 Hz, H-5), in addition of four methyl singlets. In its ^{13}C NMR spectrum, one sp^3 carbon was observed at δ 54.74 (d).

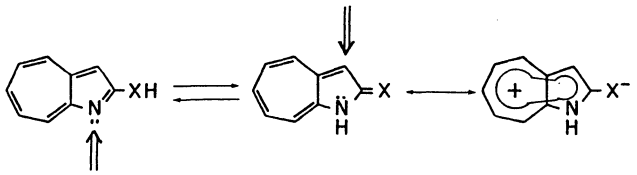
A plausible mechanism is shown in Scheme 3. In the ^{1}H NMR spectrum of **15** in $CDCl_3$, a predominant existance of the thione form **15A** (over 95%) was observed. This suggests that the reaction of **15A** with DMAD (considered as soft electrophile) would first occur on sulfur, which is a most soft atom, and gives 1-azaazulene **D**. A second molecule of DMAD attacks



Scheme 2.



Scheme 3.



G H I

the N-1 position of **D** and gives a dipolar intermediate **E**. A cyclization of **E** affords **F**, and a desulfurization of **F** furnishes **16**.

All these results show that DMAD first attacks the N-1 position of the 1-azaazulene form **G**, whereas DMAD first attacks the C-3 position or soft atom of 1,2-dihydro-1-azaazulen-2-ylidene form **H**. The reason for the difference in the reaction is considered to be as follows. In form **G**, the N-1 atom is most electron rich,[16] and a lone pair on nitrogen would have more nucleophilicity than C-3 carbon. On the other hand, in form **H**, the nucleophilicity of a lone pair on nitrogen would decrease owing to the contribution to the 10-π aromatic resonance as form **I**. The observation that the reaction occures on the N-1 position (**1d**) or not at all (**1b**) at lower temperatures, whereas the Diels-Alder reaction on seven membered ring is predominant at higher temperature (**1b**), when 3-position is blocked in form **H**, assists in the above consideration.

Experimental

Melting points are uncorrected. ^{1}H NMR sapctra (250 MHz) and ^{13}C NMR spectra (62.87 MHz) were recorded on a Hitachi R-250H spectrometer using deuteriochloroform as a solvent with tetramethylsilane as an internal standard, unless otherwise stated. IR spectra were recorded on a Hitachi 270-50 infrared spectrophotometer for Nujol mulls. Mass spectra were determined with a JEOL JMS-01SG-2 spectrometer (70 eV). Kieselgel 60 was used for column chromatography unless otherwise stated.

Reaction of 1 with DMAD. a) A solution of **1a** (0.510 g) and DMAD (1.367 g) in dry acetonitrile (30 ml) was refluxed for 120 h and evaporated. The residue was chromatographed. Elution with benzene gave **2a** (0.072 g, 9%), which was recrystallized from hexane to give violet needles, mp 53—54 °C (lit,[12] mp 45 °C, lit,[11] oil); ^{1}H NMR δ=3.96 (3H, s, OMe), 3.99 (3H, s, OMe), 7.48 (1H, s, H-3), 7.48 (1H, t, J=9.8 Hz, H-5), 7.57 (1H, t, J=9.8 Hz, H-7), 7.87 (1H, t, J=9.8 Hz, H-6), 8.50 (1H, d, J=9.8 Hz, H-4), and 9.44 (1H, d, J=9.8 Hz, H-8); IR 1732 and 1698 cm^{-1} (ester C=O); MS m/z (rel intensity) 244 (M$^+$; 81), 213 (100), 186 (11), 183 (14), 127 (14), and 126 (10); Anal. ($C_{14}H_{12}O_4$) C, H. Elution with benzene-chloroform (4 : 1) gave a 1 : 1-mixture (from the integration of the ^{1}H NMR) of **3a** and **4a** (0.216 g, 22%). Fractional recrystallization of the mixture from cyclohexane gave **3a** [0.055 g, yellow needles, mp 168—169 °C, ^{1}H NMR δ=3.40 (3H, s, NMe), 3.99 (3H, s, OMe), 4.11 (3H, s, OMe), 6.95 (1H, dd, J=6.1 and 1.2 Hz, H-6), 7.45—7.60 (2H, m, H-7 and 8), and 8.73 (1H, s, H-1); ^{13}C NMR δ=26.36 (q), 52.84 (q), 53.08 (q), 106.85 (d), 120.59 (d), 123.86 (s), 126.08 (s), 127.81 (s), 127.99 (s), 130.21 (d), 130.50 (s), 134.04 (d), 139.85 (s), 165.30 (s), 165.38 (s), and 166.64 (s); IR 1738 , 1722, and 1700 (ester C=O), 1638 (amide C=O), and 795 cm^{-1} (1,2,3-trisubstituted benzene); MS m/z (rel intensity) 299 (M$^+$; 100), 268 (62), 196 (16), 183 (39), 182 (21), 181 (26), 127 (13); Anal. ($C_{16}H_{13}NO_5$) C, H, N.] and **4a** [0.030 g, yellow prisms, mp 151—152 °C, ^{1}H NMR δ=3.08 (3H, s, NMe), 3.10 (1H, d, J=9.2 Hz, H-2a), 3.86 (3H, s, OMe), 3.88 (3H, s, OMe), 4.32 (1H, d, J=9.2 Hz, H-3), 5.66 (1H, d, J=6.1 Hz, H-8), 6.40—6.50 (2H, m, H-5 and 6), and 6.65—6.75 (1H, m, H-7); ^{13}C NMR δ=27.14 (q), 43.14 (d), 50.09 (d), 52.33 (q), 52.55 (q), 98.33 (d), 122.19 (d), 124.69 (d), 124.75 (s), 130.83 (s), 131.29 (d), 134.43 (s), 134.68 (s), 162.86 (s), 164.40 (s), and 170.73 (s); MS m/z (rel intensity) 301 (M$^+$; 100), 241 (26), 210 (26), 200 (26), 154 (11), 140 (13), 127 (12), 115 (10), and 114 (11); IR 1720 and 1706 (ester C=O), and 1628 cm^{-1} (amide C=O); Anal. ($C_{16}H_{15}NO_5$) C, H, N.]. Elution with chloroform gave **5a** (0.065 g, 7%), which was recrystallized from cyclohexane-dichloromethane to give red needles, mp 190—191 °C, ^{1}H NMR δ=3.52 (3H, s, NMe), 3.94 (3H, s, OMe), 4.05 (3H, s, OMe), 7.48 (1H, d, J=9.8 Hz, H-8), 7.72 (1H, t, J=9.8 Hz, H-6), 8.15 (1H, t, J=9.8 Hz, H-7), and 9.16 (1H, d, J=9.8 Hz, H-5); ^{13}C NMR δ=26.55 (q), 51.67 (q), 52.72 (q), 113.74 (d), 114.03 (s), 115.22 (s), 128.29 (d), 135.17 (s), 137.11 (s), 138.93 (s), 140.87 (d), 141.40 (d), 149.96 (s), 162.79 (s), 164.23 (s), and 167.63 (s); IR 1734, 1708, and 1700 (ester C=O), and 1620 cm^{-1} (amide C=O); MS m/z (rel intensity) 299 (M$^+$; 35), 268 (76), 240 (22), 238 (22), 210 (36), 209 (39), 196 (47), 182 (40), 153 (51), 152 (50), 126 (100), 114 (75). Anal. ($C_{16}H_{13}NO_5$) C, H, N. Further elution gave **6a** (0.164 g, 17%), which was recrystallized from cyclohexane-dichloromethane to give red prisms, mp 123.5—124 °C, ^{1}H NMR δ=3.58 (3H, s, NMe), 3.79 (3H, s, OMe), 3.96 (3H, s, OMe), 7.00 (1H, s, H-vinyl), 7.05—7.40 (4H, m, H-5, 6, 7, and 8), and 7.76 (1H, d, J=11.0 Hz, H-4); IR 1715 and 1656 (ester C=O), and 1620 cm^{-1} (amide C=O); Anal. ($C_{16}H_{13}NO_5$) C, H, N. Elution with chloroform-ethyl acetate (1 : 1) gave **7a** (0.206 g, 21%), which was recrystallized from cyclohexane-dichloromethane to give red prisms, mp 150—151 °C, ^{1}H NMR δ=3.58 (3H, s, NMe), 3.68 (3H, s, OMe), 3.81 (3H, s, OMe), 6.90—7.30 (5H, m, H-4, 5, 6, 7, and 8), and 7.15 (1H, s, H-vinyl), IR 1728 and 1672 (ester C=O), and 1630 cm^{-1} (amide C=O); Anal. ($C_{16}H_{15}NO_5$) C, H, N.

b) A solution of **1a** (0.200 g), and DMAD (0.536 g) in t-butylbenzene (6 ml) was refluxed for 3 h and evaporated. The residue was chromatographed. Elution with benzene gave **2a** (0.064 g, 21%). Elution with benzene-chloroform (1 : 1) gave **3a** (0.019 g, 5%) and **5a** (0.003 g, 0.8%), successively. Elution with chloroform gave **8a** (0.185 g, 49%), which was recrystallized from cyclohexane to give colorless scales, mp 156—158 °C, ^{1}H NMR δ=3.05 (3H, s, NMe), 3.77 (3H, s, OMe), 3.78 (3H, s, OMe), 4.46 (1H, ddd, J=8.5, 6.7, and 1.2 Hz, H-6), 5.95 (1H, s, H-3), 6.06 (1H, d, J=10.4 Hz, H-4), 6.21 (1H, dd, J=7.9 and 1.2 Hz, H-9), 6.41 (1H, dd, J=10.4 and 8.5 Hz, H-5), and 6.66 (1H, dd, J=7.9 and 6.7 Hz, H-10); ^{13}C NMR δ=26.47 (q), 38.70 (d), 52.64 (q×2), 71.55 (s), 120.57 (d), 121.16 (d), 129.47 (d), 132.62 (d), 133.26 (d), 134.23 (s), 145.64 (s), 147.03 (s), 163.07 (s), 164.95 (s), and 171.28 (s); IR 1735, 1720, and 1688 (ester C=O), and 1622 (amide C=O); MS m/z (rel intensity) 301 (M$^+$; 100), 270 (19), 269 (13), 242 (88), 241 (35), 210 (45), 198 (16), 183 (47), 159 (98), 154 (26), 130 (16), and 127 (12); Anal. ($C_{16}H_{15}NO_5$) C, H, N.

c) A mixture of **1b** (0.075 g) and DMAD (0.1 g) in t-butylbenzene (5 ml) was refuxed for 7 h and evaporated. The

residue was chromatographed with chloroform to give **8b** (0.08 g, 66%), which was recrystallized from hexane to give colorless prisms, mp 99—101 °C, ^{1}H NMR δ=1.36 (3H, t, J=7.0 Hz, Me), 3.06 (3H, s, NMe), 3.77 (3H, s, OMe), 3.78 (3H, s, OMe), 4.34 (2H, q, J=7.0 Hz, OCH_2), 4.57 (1H, ddd, J=7.9, 6.7, and 1.2 Hz, H-6), 6.23 (1H, dd, J=7.9 and 1.2 Hz, H-9), 6.69 (1H, dd, J=11.0 and 7.9 Hz, H-5), 6.78 (1H, dd, J=7.9 and 6.7 Hz, H-10), and 6.84 (1H, d, J=11.0 HZ, H-4); IR 1748, 1720, and 1710 (ester C=O), and 1688 cm^{-1} (amide C=O); Anal. ($C_{19}H_{19}NO_7$) C, H, N.

d) A solution of **1c** (0.250 g) and DMAD (0.75 g) in dry acetonitrile (30 ml) was refluxed for 45 h and evaporated. The residue was chromatographed. Elution with benzene gave **2a** (0.029 g, 7%). Elution with chloroform gave **3c** (0.180 g, 35%), which was recrystallized from cyclohexane-dichloromethane to give orange prisms, mp 176—178 °C, ^{1}H NMR δ=4.00 (3H, s, OMe), 4.12 (3H, s, OMe), 7.11 (1H, d, J=6.7 Hz, H-6), 7.56 (1H, dd, J=7.9 and 6.7 Hz, H-7), 7.63 (1H, d, J=7.9 Hz, H-8), 8.59 (1H, bs, exch., OH), and 8.81 (1H, s, H-1). δ (DMSO-d_6)=3.93 (6H, s, OMe×2), 7.15 (1H, d, J=6.7 Hz, H-6), 7.64 (1H, dd, J=8.5 and 6.7 Hz, H-7), 7.79 (1H, d, J=8.5 Hz, H-8), 8.91 (1H, s, H-1), and 11.13 (1H, s, exch., OH); IR 3188 (OH), 1750, 1722, and 1702 (ester C=O), 1638 (amide C=O), and 795 cm^{-1} (1,2,3-trisubstituted benzene); Anal. ($C_{15}H_{11}NO_5$) C, H, N. Further elution gave **5c** (0.026 g, 5%), which was recrystallized from cyclohexane-dichloromethane to give orange needles, mp 250—251 °C, ^{1}H NMR δ (DMSO-d_6)=3.86 (3H, s, OMe), 3.90 (3H, s, OMe), 7.72 (1H, d, J=9.8 Hz, H-8), 7.90 (1H, t, J=9.8 Hz, H-6), 8.37 (1H, t, J=9.8 Hz, H-7), 9.08 (1H, d, J=9.8 HZ, H-5), and 11.48 (1H, s, exch., NH); IR 3284 (NH), 1730, 1704, and 1684 (ester C=O), and 1625 cm^{-1} (amide C=O); MS Found: m/z 285.0617. Calcd for $C_{15}H_{11}NO_5$: M, 285.0638. Elution with chloroform-ethyl acetate gave **6c** (0.106 g, 21%), which was recrystallized from cyclohexane-dichloromethane to give red micro needles, mp 248—249 °C, ^{1}H NMR δ=3.80 (3H, s, OMe), 3.98 (3H, s, OMe), 7.05 (1H, s, H-vinyl), 7.10 (1H, dd, J=11.5 and 9.5 Hz, H-5), 7.30—7.42 (3H, m, H-6, 7, and 8), 7.80 (1H, d, J=11.5 Hz, H-4), and 11.27 (1H, s, exch., NH), δ (DMSO-d_6)=3.70 (3H, s, OMe), 3.86 (3H, s, OMe), 7.03 (1H, s, H-vinyl), 7.22 (1H, dd, J=11.6 and 9.8 Hz, H-5), 7.30—7.50 (3H, m, H-6, 7, and 8), 7.60 (1H, d, J=11.6 Hz, H-4), and 12.20 (1H, s, exch., NH); IR 3100—2600 (broad, NH), 1736 and 1704 (ester C=O), and 1652 cm^{-1} (amide C=O); Anal. ($C_{15}H_{13}NO_5$) C, H, N. Elution with ethyl acetate gave **7c** (0.150 g, 30%), which was recrystallized from cyclohexane-dichloromethane to give orange needles, mp 165—167 °C, ^{1}H NMR δ=3.67 (3H, s, OMe), 3.82 (3H, s, OMe), 7.03 (1H, dd, J=9.16 and 9.14 Hz, H-5), 7.10—7.32 (3H, m, H-6, 7, and 8), 7.19 (1H, s, H-vinyl), 7.35 (1H, d, J=9.16 Hz, H-4), and 12.43 (1H, s, exch., NH); IR 3150—2600 (broad, NH), 1730 (ester C=O), and 1644 cm^{-1} (amide C=O); Anal. ($C_{15}H_{13}NO_5$) C, H, N.

Reaction of 1 with DBA. a) A solution of **1a** (0.461 g) and DBA (1.357 g) in dry acetonitrile (30 ml) was refluxed for 72 h and evaporated. The residue was chromatographed. Elution with benzene gave **2b** (0.083 g, 8.5%), which was recrystallized from hexane to give blue prisms, mp 133—134 °C, ^{1}H NMR δ=7.10—7.52 (11H, m, H-5 and phenyl×2), 7.54 (1H, dd, J=10.4 and 9.8 Hz, H-7), 7.63 (1H, s, H-3), 7.89 (1H, dd, J=10.4 and 9.8 Hz, H-6), 8.60 (1H, d, J=9.8 Hz, H-4), and 9.19 (1H, d, J=10.4 Hz, H-8); IR 1670 cm^{-1} (C=O); Anal. ($C_{24}H_{16}O_2$) C, H. Elution with benzene-chloroform (1 : 1) gave **3b** (0.037 g, 3%), which was recrystallized from cyclohexane-dichloromethane to give yellow prisms, mp 204—205 °C, ^{1}H NMR δ=3.67 (3H, s, NMe), 7.03 (1H, dd, J=5.5 and 2.5 Hz, H-6), 7.4—7.7 (8H, m, H-7, 8, and m,p-phenyl×2), 7.83 (2H, d, J=7.3 Hz, H-o-phenyl), 7.88 (2H, d, J=7.3 Hz, H-o-phenyl), and 8.30 (1H, s, H-1); IR 1700, 1672, and 1652 (C=O), and 1632 cm^{-1} (amide C=O); Anal ($C_{26}H_{17}NO_3$) C, H, N. Further elution gave **4b** (0.568 g, 50%), which was recrystallized from cyclohexane to give orange micro needles, mp 100—102 °C, ^{1}H NMR δ=3.13 (3H, s, NMe), 3.32 (1H, bd, J=9.2 Hz, H-2a), 4.92 (1H, d, J=9.2 Hz, H-3), 5.73 (1H, bd, J=6.1 Hz, H-8), 6.35—6.45 (2H, m, H-5 and 6), 6.72 (1H, dd, J=9.8 and 6.1 Hz, H-7), 7.05—7.52 (10 H, m, phenyl×2); IR 1716 and 1662 (C=O), and 1638 cm^{-1} (amide C=O); Anal. ($C_{26}H_{19}NO_3$) C, H, N. Elution with chloroform gave **5b** (0.063 g, 6%), which was recrystallized from cyclohexane-dichloromethane to give red needles, mp 246—247 °C, ^{1}H NMR δ=3.55 (3H, s, NMe), 7.05—7.52 (8H, m, phenyl), 7.53 (1H, d, J=9.8 Hz, H-8), 7.61 (2H, d, J=7.3 Hz, H-o-phenyl), 7.74 (1H, t, J=9.8 Hz, H-6), 8.20 (1H, t, J=9.8 Hz, H-7), and 8.96 (1H, d, J=9.8 Hz, H-5); IR 1718 and 1654 (C=O) and 1624 cm^{-1} (amide C=O); Anal. ($C_{26}H_{17}NO_3$) C, H, N. Further elution gave **7b** (0.064 g, 6%), which was recrystallized from cyclohexane-dichloromethane to give red prisms, mp 201—203 °C, ^{1}H NMR δ=3.66 (3H, s, NMe), 7.00—7.20 (3H, m, H-5, 6, and 7), 7.30—7.60 (7H, m, H-8 and m,p-phenyl ×2), 7.88 (1H, d, J=11.0 Hz, H-4), 8.04 (2H, d, J=6.7 Hz, H-o-phenyl), 8.07 (2H, d, J=6.7 Hz, H-o-phenyl), and 8.59 (1H, s, H-vinyl); IR 1664 (C=O) and 1638 cm^{-1} (amide C=O); Anal. ($C_{26}H_{19}NO_3$) C, H, N.

b) A solution of **1a** (0.200 g) and DBA (1.472 g) in t-butylbenzene (10 ml) was refluxed for 1 h and evaporated. The residue was chromatographed. Elution with benzene gave recovered DBA (0.884 g) and **2b** (0.638 g, 60%). Elution with benzene-chloroform (1 : 1) gave **3b** (0.231 g, 19%). Elution with chloroform gave **8c** (0.188 g, 15%), which recrystallized from cyclohexane to give colorless prisms, mp 174—174.5 °C, ^{1}H NMR δ=2.88 (3H, s, NMe), 4.42 (1H, ddd, J=8.5, 6.7, and 1.2 Hz, H-6), 6.02 (1H, s, H-3), 6.29 (1H, d, J=10.4 Hz, H-4), 6.36 (1H, dd, J=7.9 and 1.2 Hz, H-9), 6.48 (1H, dd, J=10.4 and 8.5 Hz, H-5), 6.86 (1H, dd, J=7.9 and 6.7 Hz, H-10), and 7.14—7.50 (10H, m, phenyl ×2); IR 1688 and 1662 (C=O), and 1646 cm^{-1} (amide C=O); Anal. ($C_{26}H_{19}NO_3$) C, H, N.

Dehydrogenation of 4. a) A mixture of **4a** (0.030 g) and TCQ (0.080 g) in dry benzene (20 ml) was refluxed for 2 h and evaporated. The residue was chromatographed on alumina. Elution with chloroform gave **5a** (0.014 g, 47%).

b) A mixture of **4b** (0.440 g) and TCQ (1.200 g) in dry benzene (50 ml) was refluxed for 1 h and evaporated. The residue was chromatographed on alumina with chloroform to give **5b** (0.308 g, 70%).

Synthesis of 9. A solution of **2b** (0.184 g) and 80% hydrazine hydrate (1 ml) in ethanol (20 ml) was refluxed for 30 min and evaporated. The residue was chromatographed with chloroform to give **9** (0.081 g, 45%), which was recrystallized from cyclohexane-dichloromethane to give blue prisms, mp >300 °C, ^{1}H NMR δ=7.14 (1H, dd, J=1.0 and 7.9 Hz, H-6), 7.31 (1H, dd, J=9.8 and 8.6 Hz, H-8), 7.55—7.70 (7H, m, H-7 and m,p-phenyl ×2), 7.74 (1H, s, H-10), 7.80—7.88 (2H, m, H-o-phenyl), 8.15—8.21 (2H, m, H-o-phenyl), 8.40 (1H, d, J=9.8 Hz, H-9), and 8.44 (1H, d, J=7.9 Hz, H-5); IR no carbonyl absorption; MS m/z (rel intensity) 332 (M^+; 100), 331 (64), 302 (91), 300 (50), 276 (52), 226 (52), 202 (24), 200

(25), 151 (57), 150 (50), 138 (41), 126 (28), and 77 (71); Anal. ($C_{24}H_{16}N_2$) C, H, N.

Acetylation of 3c. A mixture of **3c** (0.080 g), acetic anhydride (10 ml), and conc. sulfuric acid (1 drop) was refluxed for 1 h and poured into water (100 ml). The mixture was neutralized with sodium hydrogencarbonate, extracted with chloroform, washed with water, dried over sodium sulfate, and evaporated. The residue was recrystallized from cyclohexane to give **10** (0.035 g, 38%) as yellow prisms, mp 174—176 °C, ^{1}H NMR δ=2.80 (3H, s, Me), 4.01 (3H, s, OMe), 4.13 (3H, s, OMe), 7.71 (1H, dd, J=8.6 and 6.7 Hz, H-7), 7.83 (1H, d, J=8.6 Hz, H-8), 8.32 (1H, d, J=6.7 Hz, H-6), and 8.92 (1H, s, H-1); IR 1756, 1730, and 1700 cm^{-1} (ester C=O). HRMS Found: m/z 327.0750. Calcd for $C_{17}H_{13}NO_6$: M, 327.0744.

Reaction of 2-Amino-1-azaazulene with DMAD. A solution of **11** (0.577 g) and DMAD (0.85 g) in acetonitrile (50 ml) was refluxed for 5 h and evaporated. The residue was chromatographed. Elution with chloroform gave **12** (0.188 g, 18.5%), which was recrystallized from cyclohexane-dichloromethane to give violet needles, mp 223—225 °C, ^{1}H NMR δ=4.04 (3H, s, OMe), 7.09 (1H, s, H-10), 7.19 (1H, s, H-3), 7.25—7.45 (3H, m, H-6, 7, and 8), 7.94 (1H, d, J=10.4 Hz, H-9), and 9.84—9.96 (1H, m, H-5); Anal. ($C_{14}H_{10}N_2O_3$) C, H, N. Elution with chloroform-ethyl acetate (1 : 1) gave **13** (0.325 g, 19%), which was recrystallized from ethyl acetate to give orange prisms, mp 182—183 °C, ^{1}H NMR δ=3.45, 3.61, 3.63, and 3.79 (each 3H, s, OMe), 4.97 (1H, d, J=4.9 Hz, H-4), 5.21 (1H, d, J=4.9 Hz, H-5), 7.60—7.80 (3H, m, H-7, 8, and 9), 8.12 (1H, bs, NH, exch.), and 8.20—8.38 (2H, m, H-6 and 10); ^{13}C NMR δ=43.47 (d), 45.43 (d), 52.38 (q), 52.49 (q×2), 52.75 (q), 105.64 (s), 106.37 (s), 128.74 (d), 129.83 (d), 130.85 (d), 131.77 (d), 134.04 (d), 139.79 (s), 145.84 (s), 156.02 (s), 159.08 (s), 165.20 (s), 167.71 (s), 169.81 (s), and 170.84 (s); IR 3230 (NH), 1750, 1740, 1730, and 1704 cm^{-1} (ester C=O); Anal. ($C_{21}H_{20}N_2O_8$) C, H, N.

Reaction of 2-Mercapto-1-azaazulene with DMAD. A mixture of **15** (0.350 g), DMAD (0.82 g), and acetonitrile (50 ml) was refluxed for 5 h, then evaporated. The residue was chromatographed. Elution with chloroform gave **16** (0.347 g, 35%), which was recrystallized from cyclohexane to give violet needles, mp 188—189 °C, ^{1}H NMR δ=3.64, 3.81, 3.83, 3.96 (each 3H, s, OMe), 6.41 (1H, s, H-4), 7.10—7.20 (4H, m, H-6, 7, 8, and 9), 7.45 (1H, s, H-10), and 7.63 (1H, d, J=11.0 Hz, H-5); ^{13}C NMR δ=51.16 (q), 52.03 (q), 52.38 (q), 53.03 (q), 54.74 (d), 91.40 (s), 101.02 (s), 110.71 (d), 115.76 (d), 131.50 (d), 132.13 (d), 132.60 (d), 133.04 (d), 142.73 (s), 143.65 (s), 146.39 (s), 152.22 (s), 164.23 (s), 164.94 (s), 167.52 (s), and 168.53 (s); IR 1740, 1690, 1676, and 1665 cm^{-1} (ester C=O); MS m/z (rel intensity) 413 (M^+; 2), 412 (7), 382 (5), 354 (100), and 178 (6). Found: C, 60.53; H, 4.58; N, 3.16%. Calcd for $C_{21}H_{19}NO_8$: C, 61.02; H, 4.63; N, 3.39%. HRMS Found: m/z 413.1109. Calcd for $C_{21}H_{19}NO_8$: M, 413.1109.

We thank Dr. Masafumi Yasunami (Tohoku University) and Dr. Akira Mori (Kyushu University) for the measurements of the mass spectra and elemental analyses.

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