Hz), 1.45 (d, 3 H, $J = 5.9$ Hz), and 1.21 (s, 3 H); IR (KBr) 1750 and 1650 cm^{-1}; mass spectrum (EI), m/z 288 (M$^+$, 37.5), 260 (31.7), 244 (41.7), 215 (21.7), and 82 (100); HRMS calcd for $C_{18}H_{24}O_3$ 288.1725, found 288.1732.

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Registry No. **1**, 126724-79-6; **2**, 126786-76-3; **3**, 126724-80-9; **4**, 126724-81-0; **5**, 27428-41-7; **6**, 126724-82-1; **7**, 126724-83-2; **8**, 126724-84-3; **9**, 126724-85-4; **10**, 126724-86-5; **11**, 126724-87-6; **12**, 126724-88-7; **13**, 126724-89-8; vinylmagnesium bromide, 1826-67-1; formaldehyde, 50-00-0; ethyl acetoacetate, 141-97-9; 1-bromo-3,3-(ethylenedioxy)butane, 37865-96-6.

Supplementary Material Available: ^{1}H NMR spectra of compounds **2**, **4**, **5**, **8**, **9**, **11**–**13** (12 pages). Ordering information is given on any current masthead page.

[2 + 2 + 2] Cycloaddition Reaction of 1-Methylpyrrole with Diethyl Azodicarboxylate

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Reactions of bimolecular [2 + 2 + 2] cycloaddition are of interest since they serve as examples of orbital interactions that can be explained by the Woodward–Hoffmann rules.[1] However, concerted [2 + 2 + 2] cycloadditions involving three molecules are rare. For example, trimerization of acetylene to benzene needs a catalyst such as $AlCl_3$ and a 1:1 adduct is involved in the course of formation, indicating a stepwise process.[2] Although few reports are found in the literature, termolecular [2 + 2 + 2] cycloaddition reactions seem to be useful synthetic processes if a suitable catalyst is employed.[3-7] We report an example of an uncatalyzed cycloaddition reaction that appears to involve 6 π electrons from three double bonds in three molecules.

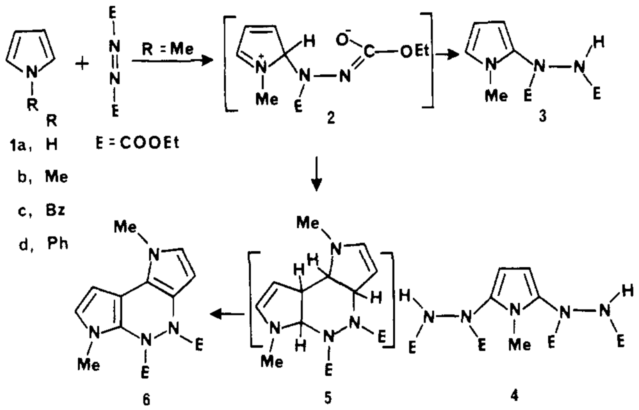
In the course of our investigation of reactions of five-membered heteroaromatic compounds with dienophiles, we repeated the reaction of 1-methylpyrrole (**1b**) with diethyl azodicarboxylate (DADC). In ethanol, the Michael-type 1:2 adduct 4 formed as reported previously.[8] However, when the reaction was carried out in thoroughly dried ether, new compound 8 precipitated out in ca. 4% yield together with 3 (32%) and 4 (53%). The use of anhydrous ether was critical since the yield of 8 was variable, depending on the quality of the solvent employed. Furthermore, the yield could not be improved by using other solvents than ether. Michael-type adduct 4 was always the major product (Table I).

Table I. Yields of 4 and 8 in Various Solvents[a]

	40 °C		80 °C	
solvent	4, %	8, %	4, %	8, %
diethyl ether	53[b]	4	40[c]	0
tetrahydrofuran	17	5	*d*	*d*
benzene	37	0	40	0
carbon tetrachloride	40	3	60	0
dioxane	23	3	60	0
dimethyl sulfoxide	86	0	80	0

[a] Molar ratio of **1b** and DADC was 1:2. [b] 1:1 Michael-type adduct 3 was also isolated in 32% yield. [c] Heated in a sealed stainless steel tube (inner volume = 40 mL). [d] Not tried.

Scheme I



Reaction temperature was also critical: that is, the yield of 8 was maximum when the reaction was carried out at 40 °C in various aprotic solvents. At higher temperature (80 °C) only the Michael-type adduct (4) was formed. When excess amounts of **1b** (10 molar equiv) were used, only the Michael-type adduct was isolated. The optimum ratio for the formation of 8 was a 1:2 molar ratio of **1b** and DADC.

1*H*-Pyrrole (**1a**) and other N-substituted pyrroles (**1c**,**d**) did not give adducts similar to 8. Only the Michael-type adducts similar to 4 were obtained regardless of solvents or reaction temperature.

The structure of 8 was established by IR, UV, ^{1}H NMR, ^{13}C NMR (DEPT), and EI- and CI-mass spectra together with elemental analysis. It has a new type of dipyrrolopyridazine skeleton. A structure such as 6 would be logical if the reaction is stepwise and 2 is the intermediate leading to 3, 4, 5, or 6 (Scheme I) because C_2 in pyrrole is much more nucleophilic than C_3.[9] But the ^{13}C NMR spectrum clearly indicated the presence of only eight carbon atoms, in spite of the molecular formula of $C_{16}H_{20}N_4O_4$ (from high resolution mass spectrum), which is consistent with the elemental analysis. Therefore, the molecule must be symmetric. Two other structures, 9 and 10, which have C_2 symmetry, may also be considered. An AB pattern at δ 7.33 and 7.50 with $J = 6.0$ Hz was the only signal that appeared in the aromatic region. The coupling constants of 6.0 Hz is unusually large compared to 2.6–3.1 Hz for $J_{2,3}$ of pyrrole or indole.[10] This large value may be due to the electronic and field effects of the ethoxycarbonyl group on the nitrogen atom of the ring. In fact, $J_{2,3}$ of dimethyl 1-methylindole-4,6-dicarboxylate is 8.0 Hz.[11] This data

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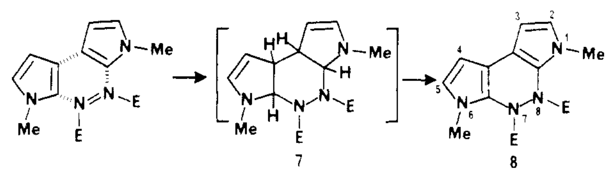
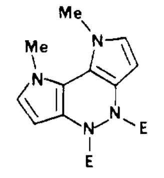
Scheme II

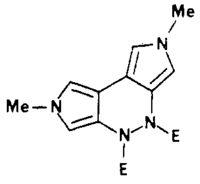


is inconsistent with structure **10**, which was ruled out at this stage.

Most of the ^{13}C NMR spectrum was assigned in conjunction with DEPT experiments. However, the two peaks at 162.28 and 165.94 ppm provided a clue in distinguishing between the structures **8** and **9**. One of the peaks is due to the carbonyl carbon atom and the other results from a carbon atom in the ring. Such a low field shift of an sp^2 carbon atom may be explained in structure **8** due to bonding to two nitrogen atoms. Similar low field shifts were observed with the pyrrolo[2,3-*d*]pyrimidine system.[12]



9



10

The orientation of the pyrroles and DADC in **8** and the low yield may be explained by a concerted $[{}_{2}\pi_{s} + {}_{2}\pi_{s} + {}_{2}\pi_{s}]$ cycloaddition (Scheme II). DADC has been widely used as a component in various types of addition reactions.[13] However, to our knowledge, a termolecular cycloaddition with DADC has not been reported in the literature. Although the intermediate **7** was not isolated, it seems reasonable to assume that dehydrogenation leading to aromatized pyrrole rings takes place readily. An independent, yet unsuccessful, attempt of preparation of **8** from **3** and **1** in various solvents readily ruled out the possibility of the initial formation of the 1:1 adduct. The yield of **8** from **1b** and DADC in the presence of **3** in ethereal solution did not change appreciably. Similar attempts failed in the presence of either a strong base (*t*-BuOK) or an acid ($AlCl_3$).

The dipyrrolopyridazine **8** can be considered as a carbamate. But unlike to the easy reduction of carbamates to *N*-methyl compounds by $LiAlH_4$,[14] **8** was not reduced under various reaction conditions.

Experimental Section

Melting points were determined on a Fisher Mel-Temp apparatus and are uncorrected. Infrared spectra were recorded on a Perkin-Elmer Model 1430 spectrophotometer, and the ultraviolet-visible spectrum was recorded on a Hitachi U-3200 double-beam spectrophotometer. NMR spectra were recorded on a IBM NR/300 NMR spectrometer. Mass spectra were determined on an AEI MS-30 spectrometer at 70 eV and 200 °C. Elemental analyses were performed by M-H-W Laboratories.

Preparation of 2-[*N*,*N'*-Bis(ethoxycarbonyl)hydrazino]-1-methylpyrrole (3), 2,5-Bis[*N*,*N'*-bis(ethoxycarbonyl)hydrazino]-1-methylpyrrole (4), and Diethyl 1,6-Dimethyl-1,6,7,8-tetrahydrodipyrrolo[2,3-*c*:3',2'-*e*]pyridazine-7,8-dicarboxylate (8). A solution of **1** (dried over molecular sieves and distilled prior to use, 2.00 g, 24.7 mmol) and DADC (8.60 g, 49.4 mmol) in anhydrous ether (dried over $LiAlH_4$ prior to use, 20 mL) was refluxed under N_2 for 10 h. The deep violet precipitate was collected by filteration and was recrystallized from ethanol to give pure **8** (0.36 g, 4%): mp 194 °C dec; IR (KBr) 3180, 2900, 1660 (C=O), 1580, 1235, 1205, 1120, 1090, 1055, 810 cm^{-1}; UV (ethanol) λ_{max} 479 nm infl (ϵ 45400), 458 (57500), 326 (6200); ^{1}H NMR ($CDCl_3$) δ 1.33 (t, 6 H, CH_2CH_3, $J = 6.00$ Hz), 3.59 (s, 6 H, NCH_3), 4.22 (q, 4 H, OCH_2, $J = 6$ Hz), an AB pattern centered at 7.33 (2 H, H_3 of pyrrole, $J = 6.00$ Hz), and 7.50 (2 H, H_2 of pyrrole, $J = 6.00$ Hz); ^{13}C NMR ($CDCl_3$) ppm 14.46 (CH_3CH_2), 32.39 (NCH_3), 62.13 (OCH_2), 122.65 (C_3), 131.39 (C_2), 131.60 (C_{3a}), 162.28 (C_{8a} or C=O), 165.94 (C=O or C_{8a}); CI-mass spectrum, *m/z* (rel intensity) 333 (8, M + H^+), 287 (9, $M^+ - OC_2H_5$), 260 (11), 214 (100, $M^+ - COOC_2H_5$, OC_2H_5).

Anal. Calcd for $C_{16}H_{20}N_4O_4$: C, 57.82; H, 6.06; N, 16.85. Found: C, 57.76; H, 6.09; N, 16.70.

The filtrate was evaporated to dryness to give a dark brown residue, which was dissolved in ethanol, decolarized with charcoal, and then left in a refrigerator (4 °C) overnight, giving white precipitate **4** (5.62 g, 53%), mp 170 °C (lit.[8] mp 172–173 °C).

The filtrate after **4** showed three spots on a silica gel TLC plate ($CHCl_3$–MeOH = 4:1, R_f 0.77, **8**; R_f 0.62, **4**; R_f 0.57, **3**). The mixture was chromatographed on a column of silica gel (2.5 cm × 30 cm), collecting ca. 100-mL portion of elutes separately. Each fraction was evaporated and examined by TLC: (1) benzene, 0.5 L; (2) benzene, 0.2 L; (3) benzene–chloroform (9:1), 0.5 L; (4) benzene–chloroform (9:1), 0.5 L; (5) benzene–chloroform (4:1), 0.5 L; (6) benzene–chloroform (1:1), 0.5 L; (7) chloroform, 0.5 L. Fraction 1 gave no organic material. Fractions 2, 3, and 4 gave a trace amount of a mixture of **4** and **8**. Fraction 5 was a trace amount of a mixture of **3** and **4**. Fractions 6 and 7 gave **3** as a gummy solid mass, 2.02 g (32%). It was unsuccessful to obtain crystalline solid from either ethanol or chloroform solution: IR (neat) 3290 (vs, NH), 3100, 2990, 2930, 2850, 1720 (vs, C=O), 1560, 1495, 1400, 1370, 1335, 1230, 1182, 1089, 1050, 980, 910, 760, 715 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 1.15 (t, 6 H, CH_2CH_3, $J = 7.00$ Hz), 3.52 (s, 3 H, NCH_3), 4.16 and 4.18 (two overlapping quartets, 4 H, OCH_2, $J = 7.00$ Hz), 6.05 (m, 2 H, H_3 and H_4 of pyrrole), 6.48 (m, 1 H, H_5 of pyrrole), 7.68 (s, 1 H, NH); EI-mass spectrum, *m/z* (rel intensity) 255 (30, M^+), 196 (82, $M^+ - C_2H_5OCO$), 150 (100, $M^+ - C_2H_5OCO$, C_2H_5OH).

Anal. Calcd for $C_{11}H_{17}N_3O_4$: C, 51.76; H, 6.71; N, 16.46. Found: C, 51.66; H, 6.70; N, 16.82.

Reactions of 1b with DADC in Various Solvents. A solution of **1b** (1.00 g, 12.3 mmol) and DADC (4.37 g, 24.7 mmol) in a solvent (15 mL, Table I) was heated in an oil bath at 40 °C (or at 80 °C) for 10 h. The progress of the reaction was examined by TLC and the reaction mixture was chromatographed on a column of silica gel for isolation of **4** and **8**.

Reaction of 1a, 1c, and 1d with DADC in Diethyl Ether. A solution of **1** (10.0 mmol) and DADC (20 mmol) in anhydrous ether (15 mL) was heated at reflux for 10 h. The reaction was monitored by TLC, but only the adduct similar to **4** was isolated as reported previously.[8]

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An Endo-Selective Ionic Diels–Alder Reaction of α,β-Enone and α,β-Enal Acetals Catalyzed by Electrogenerated Acid

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A variety of modified methods have been proposed for the Diels–Alder cycloaddition to avoid problems such as polymerization and isomerization encountered in these thermal reactions. Lewis acids[1] and certain lanthanide

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