Adducts of Fulvene and 6-Acetoxyfulvene with Dimethyl Azodicarboxylate

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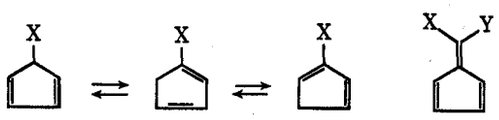
The syntheses of dimethyl 7-methylene- and 7-acetoxymethylene-2,3-diazabicyclo[2.2.1]hept-5-ene-2,3-dicarboxylate are described. All efforts to hydrolyze the enol acetate to the corresponding aldehyde were unsuccessful. Catalytic hydrogenation reduced the bridge double bond and then the enol acetate double bond sequentially in a highly stereoselective reaction to produce dimethyl 7-*syn*-acetoxymethyl-2,3-diazabicyclo[2.2.1]heptane-2,3-dicarboxylate. Nevertheless, a reversal of double bond reactivity is observed on bromination. Addition of bromine to the enol acetate generates stereoselectively dimethyl 7-*anti*-formyl-7-*syn*-bromo-2,3-diazabicyclo[2.2.1]-hept-5-ene-2,3-dicarboxylate. Rationalization of these stereoselectivities is presented. The adducts of 4-phenyl-1,2,4-triazoline-2,5-dione with the ethyl ketal of cyclopentadienone and the ethylene and dibenzyl ketals of tetrachlorocyclopentadienone are also described.

The preparation of 7-substituted 2,3-diazabicyclo-[2.2.1]hept-5-enes, important compounds both for physical chemical studies and as intermediates in the synthesis of theoretically interesting small rings, may be approached in several ways. Functionalization of 7-keto derivatives provides a direct and versatile approach to such compounds.[3] Alternatively, the utilization of substituted cyclopentadienes avoids such

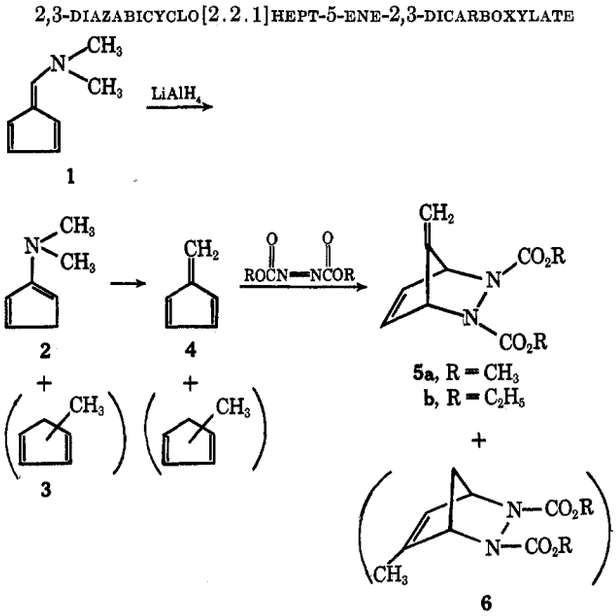


intermediates. Two types of substituted cyclopentadienes may be employed—5-alkylcyclopentadienes[4] or 5-alkylidenecyclopentadienes (fulvenes). Use of the latter class precludes the formation of isomeric adducts arising from the 1,5-hydrogen shift in the 5-alkylcyclopentadienes competing with condensation. Only 6,6-dimethyl- and 6,6-diphenylfulvene have been employed as dienes with azodienophiles.[3c-e,5] Fulvenes substituted with strong electron-releasing substituents (*e.g.*, dimethylamino) in the six position do not participate in normal Diels–Alder reactions;[6] nevertheless, such functionality was of particular interest to us since our goal was the synthesis of a 7-formyl derivative. We, therefore, examined the behavior of fulvene and 7-acetoxyfulvene toward dimethyl azodicarboxylate and the chemistry of the resultant adducts.

Fulvene **4** was prepared by the method of Sturm and Hafner.[7] Full details are included in the Experimental Section since these conditions are not available. Treatment of a solution of fulvene in ether with excess dimethyl or diethyl azodicarboxylate gave a 95% yield of the desired adduct **5** contaminated with a trace of the 2-methylcyclopentadiene adduct **6** (see Scheme I). The formation of methylcyclopentadiene **3** arises as a result of overreduction in the conversion of 6-dimethylaminofulvene **1** into 6-dimethylaminomethylcyclopentadiene **2**. An attempt to convert the 7-methylene into a 7-formyl substituent by epoxidation and rearrangement was made. Epoxidation with *m*-chloroperbenzoic acid led to production of *m*-chlorobenzoic acid; however, nmr examination of the remaining organic material indicated the presence of mostly recovered starting material. A singlet did appear at δ 3.17 which potentially could be assigned to the desired 7-epoxide. The lability of the reaction mixture precluded isolation of any pure compounds.

SCHEME I

SYNTHESIS OF DIMETHYL 7-METHYLENE-2,3-DIAZABICYCLO[2.2.1]HEPT-5-ENE-2,3-DICARBOXYLATE



This investigation subsequently centered upon the adduct derived from 6-acetoxyfulvene since this compound possesses the desired aldehyde masked as its enol acetate. 6-Acetoxyfulvene, readily available by the condensation of cyclopentadiene and ethyl formate followed by acetylation,[8] readily cycloadded in a variety of solvents with dimethyl azodicarboxylate to form a very labile adduct **7** (see Scheme II). A variety of mild reagents, including methanol, converted it into intractable tars. Its characterization by spectral means, however, fully confirms the assigned structure (see Experimental Section).

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(2) National Science Foundation and National Institutes of Health Predoctoral Fellow.

(3) (a) B. M. Trost, R. M. Cory, and P. D. Carpenter, submitted for publication; (b) E. L. Allred and C. Anderson, *J. Org. Chem.*, **32**, 1874 (1967); (c) N. P. Marullo and J. A. Alford, *ibid.*, **33**, 2368 (1968); (d) N. P. Marullo, A. Bodine, J. L. Eggers, and A. Sobti, *Tetrahedron Lett.*, 3939 (1969); (e) J. J. Tufariello and J. J. Spadaro, Jr., *ibid.*, 3935 (1969).

(4) B. M. Trost and R. M. Cory, *J. Amer. Chem. Soc.*, **93**, 5572 (1971).

(5) J. A. Berson, R. J. Bushby, J. M. McBride, and M. Tremelling, *J. Amer. Chem. Soc.*, **93**, 1544 (1971).

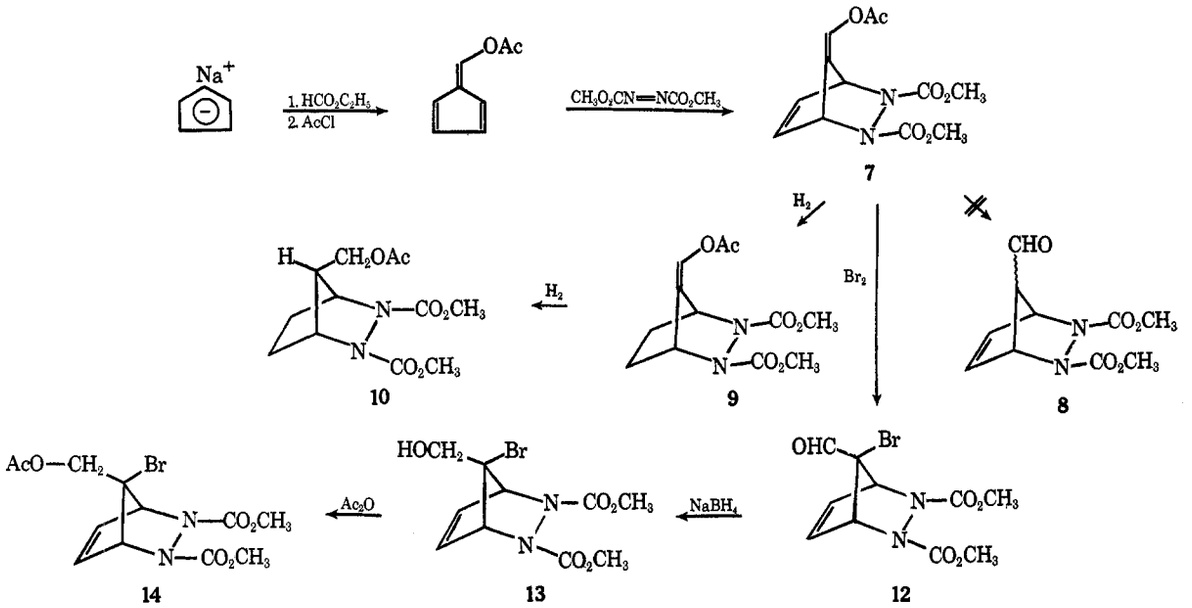
(6) K. Hafner, K. H. Vöpel, G. Ploss, and C. König, *Justus Liebigs Ann. Chem.*, **661**, 67 (1963). See, however, K. Hafner and W. Bauer, *Angew. Chem., Int. Ed. Engl.*, **7**, 297 (1968).

(7) E. Sturm and K. Hafner, *ibid.*, **3**, 749 (1964).

(8) K. Hafner, G. Schultz, and K. Wagner, *Justus Liebigs Ann. Chem.*, **678**, 49 (1964).

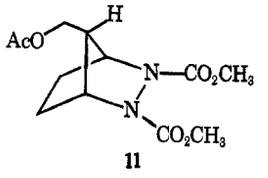
SCHEME II

SYNTHESIS AND CHEMISTRY OF DIMETHYL 7-ACETOXYMETHYLENE-2,3-DIAZABICYCLO[2.2.1]HEPT-5-ENE-2,3-DICARBOXYLATE



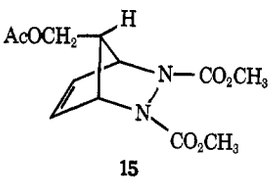
All attempts to convert **7** to the aldehyde, **8**, under many different conditions met with failure in that only tars and other intractable materials were produced. Reagents tried included dilute aqueous sulfuric acid in monoglyme, aqueous oxalic acid, aqueous sodium acetate, acidic ion-exchange resin in aqueous monoglyme, aqueous sodium bisulfite in monoglyme, hydrogen bromide in methylene chloride, and methyllithium in tetrahydrofuran. Although peaks were observed in some of the reaction mixtures in the nmr region of δ 9–10, the expected product and the compounds responsible for the peaks could not be isolated.

Catalytic hydrogenation of fulvene adducts normally leads to saturation of the 5,6 double bond.[3] The possibility that acetoxy substitution could reverse this selectivity to provide the acetate of the alcohol corresponding to **8** was briefly examined. Catalytic hydrogenation over palladium on carbon led after uptake of 1 equiv of hydrogen to the dihydro derivative **9** exclusively. Prolonged hydrogenation produced the fully saturated derivative **10**. Chromatographic and spectroscopic properties indicated that **10** was a homogeneous substance. None of the *anti*-7-acetoxymethyl compound **11**, available by an alternate sequence,[4] was



detectable. The high stereoselectivity observed in this hydrogenation can be attributed to the steric hindrance created by the carbamate groups to approach of the catalyst syn to these groups.

Whereas catalytic hydrogenation followed the traditional reactivity patterns of such fulvene adducts, bromination led to a reversal of the relative double-bond reactivities.[9] Treatment of **7** with 1 equiv of bromine in methylene chloride led directly to a compound $C_{10}H_{11}O_5N_2Br$ (high resolution mass spectroscopy). The ir spectrum indicated the presence of an aldehyde in addition to the carbamate groups (2725, 1754, and 1724 cm^{-1}). The nmr spectrum confirmed the presence of the aldehyde bound to a fully substituted carbon (δ 9.19, 1 H, singlet). The remaining absorptions indicated the presence of the 2,3-diazabicyclo[2.2.1]hept-5-ene system (see Experimental Section). This data requires the gross structure depicted in **12**. The stereochemistry was assigned on a consideration of the solvent-induced shifts of a derivative, **14**, compared to the related shifts for the bromine free compound **15** and the



saturated acetoxymethyl compounds **10** and **11**. Dimethyl 7-bromo-7-acetoxymethyl-2,3-diazabicyclo-[2.2.1]hept-5-ene-2,3-dicarboxylate (**14**) was obtained by sodium borohydride reduction of **12** to the hydroxymethyl compound **13** followed by acetylation.

Table I summarizes the solvent-induced shifts observed for **10**, **11**, **14** and **15**. The key differences arise in the magnitude of the ASIS for the 7-CH_2OAc and the 7-CH absorptions in **10** and **11**. Prior investigations of

TABLE I

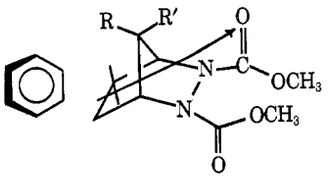
BENZENE-INDUCED SOLVENT SHIFTS[a] (ASIS[b])

Compd	CH_3CO	CH_2OAc	7-CH	CO_2CH_3	5,6-H	Bridgehead H
10	9	1	15	8	13	5
11	12	11	3	7	9	2
14	13	10		8	18	8
15	12	11	7	9	14	7

[a] All shifts are obtained from the equation $\Delta Hz = Hz_{CDCl_3} - Hz_{CDCl_3 + PhH}$. [b] ASIS = aromatic solvent-induced shift.

(9) T. J. Limasova, J. Ronayne, and D. H. Williams, *Zh. Org. Khim.*, **7**, 751 (1971).

such shifts established that benzene associates with the more positive end of a solute molecular dipole.[10] In any of the compounds under discussion, the predominant influence on the dipole moment is the highly polarized carbamate functions. Thus, the collision complex should mostly resemble **16**. Indeed, the 7-*syn*-acetoxy-



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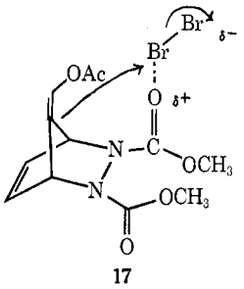
methyl compound **10** exhibits a large shift for the 7-methine hydrogen and only a small one for the methylene group of the 7-acetoxymethyl substituent. Exactly the reverse behavior is observed for the 7-*anti*-acetoxymethyl series. The presence of a double bond in the 5,6 position does not alter the magnitude of the shifts (*cf.* **15**). Comparing the ASIS for the protons of the bromo compound **14** to those of the related derivatives shows remarkably close shifts to those of **11** and **15**. This result suggests the 7-anti stereochemistry for **14** and thus for the aldehyde **12**. Attempts to confirm these assignments by cyclizing the bromohydrin failed.[11]

The high stereoselectivity of the bromination contrasts to that of the catalytic hydrogenation—bromine approaches from the more hindered side. Two reasons may be suggested. First, the urethane linkages may facilitate syn approach by complexing molecular bromine and delivering the reagent intramolecularly, *i.e.*, **17**. Second, the 5,6 double bond may stabilize the in-



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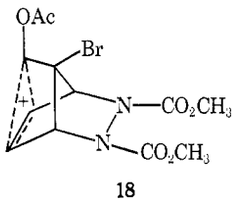
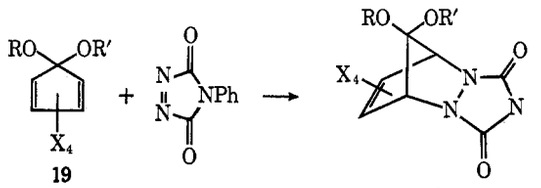


18

termediate cation **18**. This latter possibility, though attractive, appears less likely since it has been shown that, in the case of the bicyclo[2.2.1]hept-2-en-7-ylmethyl cation, the syn isomer is not stabilized relative to the anti isomer.[12] The fact that bromoaldehyde is a direct product of bromination indicates that deacylation of **18** by bromide addition to the carbonyl and elimination of acetyl bromide is the preferred mode of satisfying the positive charge. Such fulvene adducts and especially the bromoaldehyde should prove to be valuable synthetic intermediates.

In an ancillary investigation, obtention of 7-substituted 2,3-diazabicyclo[2.2.1]hept-5-enes from their 7-keto derivatives was examined. Utilizing the Diels–Alder reaction of 4-phenyl-1,2,4-triazoline-3,5-dione with ketals **19a**, **19b**, and **19c** generated the correspond-



19 **20**

a, R, R′ = CH_2CH_2; X = Cl
b, R = R′ = CH_2Ph; X = Cl
c, R = R′ = CH_2CH_3; X = H

ing Diels–Alder adducts **20a**, **20b**, and **20c**. Hydrolysis, hydrogenolysis, or dealkylation procedures failed to convert any of these ketals to their ketones or ketone hydrates.[3]

Experimental Section

Melting points were taken on a Thomas-Hoover melting point apparatus and are corrected. Ir spectra were determined on a Beckman IR-8 spectrophotometer, and uv spectra were recorded on Cary Model 11 and Model 15 spectrophotometers. Nmr spectra were determined on a Varian Associates Model A-60A spectrometer fitted with a variable-temperature probe. Chemical shifts are given in δ units, parts per million relative to TMS as an internal standard. Mass spectra were taken on a CEC 103 C or a MS-902 mass spectrometer at an ionizing current of 40 mA and ionizing voltage of 70 V. Analyses were performed by Spang Microanalytical Laboratory.

All reactions were carried out under nitrogen. Thick layer chromatography (tlc) was performed on 20 × 20 cm × 1.5 mm or 20 × 40 cm × 1.5 mm layers of silica gel PF-254 (E. Merck AG Darmstadt).

***N*,*N*-Dimethylaminomethylcyclopentadiene (2).**—The following operations were performed with the room lights off. To 10.08 g (83.3 mmol) of 6-(*N*,*N*-dimethylamino)fulvene (**1**),[6] with stirring, was added, by direct distillation from lithium aluminum hydride, sufficient ether (~250 ml) to just dissolve the yellow solid. The resulting yellow solution was transferred to a dropping funnel and added in 15 min to a stirred suspension of 3.12 g (82.3 mmol) of lithium aluminum hydride in 50 ml of ether (dried as above) kept between −5 and 0° by means of a methanol–ice bath. After the mixture had been stirred for another 75 min in that temperature range, it was cooled to −20°, and there were added very slowly with vigorous stirring *via* syringe 3.5 ml of water, 3.5 ml of 15% aqueous sodium hydroxide, and 9.5 ml of water. During these additions the temperature was not allowed to rise above −3°. The suspension was allowed to stir for 15 min thereafter and then filtered by suction. The white cake was washed with ether, and the filtrate was evaporated at −20° until the pressure had fallen to 15 mm. The concentrated solution was filtered through a short column of anhydrous sodium carbonate, which was then washed with ether, and the filtrate was cooled to −20° under nitrogen. The bulk of the remaining ether was distilled at −20° under aspirator pressure into a trap at −70° protected by a drying tower. The residue was shown by nmr, using benzene as internal standard, to contain 75% (8.0 g, 78% yield) amine **2** (mixture of isomers) in ether.

Nmr (CCl_4) showed δ 2.13 (s, 6 H, NCH_3), 2.90 (m, 2 H, divinyl CH_2), 3.12 (m, 2 H, vinyl amino CH_2), 5.95–6.55 (m, 3 H, vinyl H).

Fulvene (4).—A 2.7 × 32.7 cm column of 200 g of Woelm alumina (activity II) was prepared in pentane under nitrogen. To this was applied 2.02 g (16.4 mmol) of amine **2** in the crude solution described above. A yellow band was produced immediately and was eluted in ~70 ml of pentane. Using benzene as internal standard, this solution was shown by nmr and vpc to contain 0.40 g of fulvene with minor amounts of two other volatile products. Further fractions from the column, though a yellow coloration on the column could not be discerned, were found to contain almost pure fulvene and were eluted in ~600 ml of pentane. These were analyzed as before and found to contain a total of 0.58 g of fulene, bringing the combined yield to 0.98 g

(10) For a review, see J. Ronayne and D. H. Williams, *Annu. Rev. NMR. Spectrosc.*, **2**, 83 (1969).

(11) See R. K. Bly and R. S. Bly, *J. Org. Chem.*, **28**, 3165 (1963); J. C. J. MacKenzie, A. Rodgman, and G. F. Wright, *ibid.*, **17**, 1666 (1952).

(12) R. K. Bly and R. S. Bly, *ibid.*, **31**, 1577 (1966); J. A. Berson, M. S. Poonian, W. J. Libby, J. J. Gajewsky, and D. S. Donald, *J. Amer. Chem. Soc.*, **91**, 5550, 5567 (1969).

(77%). These dilute fractions were concentrated by flash distillation of the solvent through an efficient fractionating column.

Nmr[13] (pentane) showed δ 5.71 (s, 2 H, CH_2), 6.12 (m, 2 H, ring H), 6.43 (m, 2 H, ring H).

Fulvene Adduct 5 with Dimethyl Azodicarboxylate. Dimethyl 7-Methylene-2,3-diazabicyclo[2.2.1]-5-heptene-2,3-dicarboxylate.—To a solution of 63 mg (0.81 mmol) of the crude fulvene in 13 ml of ether was added 0.394 g (2.70 mmol) of dimethyl azodicarboxylate. The solution was refluxed for 44.5 hr, after which vpc showed that only 60% of the fulvene had reacted. An additional 0.233 g (1.57 mmol) of the azo compound was added bringing the total to 4.27 mmol. After a total of 70 hr of refluxing the mixture was allowed to stand at room temperature for 24 hr. The ether solution was decanted from the brown solids and evaporated to a reddish brown syrup. The excess azo compound was removed by distillation at 0.3 mm; the bath temperature was allowed to rise to 65°. The residue was chromatographed on 15 g of Woelm alumina (activity III), and elution with methylene chloride gave a mixture which was shown by nmr to consist of 0.17 g (95%) of the fulvene adduct, **5**, 0.07 g of the adduct of methylcyclopentadiene with the azo compound (**6**, dimethyl 5-methyl-2,3-diazabicyclo[2.2.1]-5-heptene-2,3-dicarboxylate), and ~0.02 g of an unidentified compound. Further elution with methylene chloride gave 42 mg of dimethyl hydrazodicarboxylate $CH_3O_2CNHNHCO_2CH_3$, mp 128–130° (chloroform).

Although the two adducts were difficult to separate, they could be purified by preparative tlc, eluting with ether or methylene chloride.

Nmr ($CDCl_3$) of the fulvene adduct showed δ 3.77 (s, 6 H, OCH_3), 4.56 (s, 2 H, 7-CH_2), 5.17 (unresolved m, 2 H, bridgehead CH), 6.74 (t, 2 H, J = 2 Hz, bridge vinyl H); ir ($CHCl_3$) 1712 (s, br) cm^{-1}; mass spectrum m/e (%) 59 (80, $^+CO_2CH_3$), 78 (100, fulvene), 106 (3, M − 2 × 59), 165 (2, M − 59), 224 (1.5, M); exact mass determination calcd for $C_{10}H_{12}N_2O_4$, 244.07970; found, 224.07751 ± 0.004.

Nmr[14] (CCl_4) for adduct **6** showed δ 1.65 (m, 2 H, bridge CH_2), 1.90 (d, 3 H, J = 1.5 Hz, vinyl CH_3), 3.68 (s, 6 H, OCH_3), 4.80 (unresolved m, 1 H, bridgehead CH), 4.96 (unresolved m, 1 H, bridgehead CH), 5.97 (unresolved m, 1 H, vinyl H).

Enol Acetate 7. Dimethyl 7-Acetoxymethylene-2,3-diazabicyclo[2.2.1]-5-heptene-2,3-dicarboxylate.—To 99.4 mg (0.73 mmol) of 6-acetoxyfulvene[8] in 0.5 ml of chloroform in an nmr tube was added 104.1 mg (0.71 mmol) of dimethyl azodicarboxylate. The reaction was followed by nmr, and at probe temperature (~40°) a rough plot of [adduct **7**]/[azo] *vs.* time gave a second-order rate constant of 5×10^{-3} l. mol^{-1} sec^{-1}. After 45 min the azo compound had been consumed, leaving about 10% of the starting fulvene. The solvent was evaporated to a yellowish gum which could not be purified without decomposition.

Nmr ($CDCl_3$) showed δ 2.14 (s, 3 H, CH_3CO), 3.79 (s, 6 H, OCH_3), 5.33 (unresolved m, 1 H, bridgehead CH), 5.62 (unresolved m, 1 H, bridgehead CH), 6.72 (t, 2 H, J = 2 Hz, bridge vinyl H), 6.86 (s, 1 H, vinyl HCOAc); ir (CCl_4) 1767 (s), 1721 (s) cm^{-1}; mass spectrum m/e (%), 43 (100, CH_3CO^+), 49 (37), 66 (28, 94 − CO, cyclopentadiene), 83 (30), 94 (61, 136-ketene), 136 (29, 94), 240 (0.4, M − ketene), 282 (0.4, M); exact mass determination calcd for $C_{12}H_{14}N_2O_6$, 282.08518; found, 282.08518 ± 0.001.

Saturated *syn*-Acetate 10. Dimethyl 7-*syn*-Acetoxymethyl-2,3-diazabicyclo[2.2.1]heptane-2,3-dicarboxylate.—To 24.6 mg of 10% palladium on charcoal in 2 ml of ethyl acetate which had been equilibrated under 1 atm of hydrogen for 10 hr was added 100 mg (0.36 mmol) of the crude enol acetate **7** in 0.8 ml of ethyl acetate. The first equivalent of hydrogen (~10 ml) was taken up in 15 min and the second in 5 hr. After a total of 11 hr, 0.54 mmol of hydrogen had been consumed, and the mixture was filtered. The filtrate was evaporated to a brown gum, which was purified by preparative tlc (ether elution, R_f 0.16) to give 42 mg (>41%) of the completely saturated acetate **10**. Molecular distillation at a bath temperature of 130° (0.02 mm) produced a colorless, gummy liquid.

Nmr (CCl_4) showed δ 1.79 (unresolved m, 4 H, ring CH_2), 2.02 (s, 3 H, CH_3CO), 2.21 (t of unresolved m's, J = 8 Hz, 1 H, 7-CH), 3.72 (s, 6 H, OCH_3), 3.92 (d, 2 H, J = 8 Hz, OCH_2), 4.37 (unresolved m, 2 H, bridgehead CH); ir (CCl_4) 1748 (s), 1715 (s) cm^{-1}; mass spectrum m/e (%) 43 (100, Ac^+), 59 (44, $^+CO_2CH_3$), 81 (34), 95 (82), 139 (53), 227 (12, M − 59), 286 (40, M); exact mass determination calcd for $C_{12}H_{18}N_2O_6$, 286.11648; found, 286.11120 ± 0.005.

Anal. Calcd for $C_{12}H_{18}N_2O_6$: C, 50.35; H, 6.34; N, 9.79. Found: C, 50.26; H, 6.29; N, 9.71.

Dihydro Enol Acetate 9. Dimethyl 7-Acetoxymethylene-2,3-diazabicyclo[2.2.1]heptane-2,3-dicarboxylate.—After 22.2 mg of 10% palladium on charcoal in 2 ml of ethyl acetate had been equilibrated under 1 atm of hydrogen for 6 hr, 0.118 g (<0.42 mmol) of the crude enol acetate **7** in 1 ml of ethyl acetate was added. After 18 min the hydrogen uptake began to slow down, and the hydrogen was replaced by nitrogen. At this point, 8.5 ml (0.30 mmol) of hydrogen had been consumed. The mixture was filtered, and the filtrate was evaporated to a brown gum. Preparative tlc (eluting with ethyl acetate) yielded 19 mg of the completely saturated *syn*-acetate **10** (R_f 0.45) and 63 mg (>53%) of enol acetate **9** (R_f 0.55).

Nmr (CCl_4) showed δ 1.85 (unresolved m, 4 H, ring CH_2), 2.14 (s, 3 H, CH_3CO), 3.70 (s, 6 H, OCH_3), 4.67 (unresolved m, 1 H, bridgehead CH), 4.96 (unresolved m, 1 H, bridgehead CH), 7.09 (s, 1 H, vinyl H); ir (CCl_4), 1767 (s), 1718 (s) cm^{-1}; mass spectrum m/e (%) 43 (99, Ac^+), 59 (29, $^+CO_2CH_3$), 67 (33), 79 (35), 95 (35), 116 (39), 117 (44), 119 (41), 148 (100, M − $MeO_2CNHNHCO_2Me$), 213 (2, 241 − CO), 225 (2, M − 59), 241 (6, M − Ac), 284 (10, M); exact mass determination calcd for $C_{12}H_{16}N_2O_6$, 284.10083; found, 284.09819 ± 0.003.

Bromo Aldehyde 12. Dimethyl 7-*anti*-Formyl-7-bromo-2,3-diazabicyclo[2.2.1]hept-5-ene-2,3-dicarboxylate.—To 67.4 mg (<0.24 mmol) of crude enol acetate **7** in 3 ml of methylene chloride at −78° was added 13 μl (0.24 mmol) of bromine in 0.5 ml of methylene chloride. The addition required 10 min. After it had stirred for 15 min at −78°, the mixture was allowed to warm to room temperature. The solvent was evaporated under aspirator pressure, and the resulting brown gum was redissolved in methylene chloride and extracted twice with 5% aqueous sodium bicarbonate, twice with water, and twice with saturated aqueous sodium chloride. The methylene chloride solution was dried over sodium sulfate and evaporated to a brown gum which was purified by preparative tlc, eluting with ethyl acetate. The major band (R_f 0.54) was shown to contain 42 mg (>55%) of the bromo aldehyde **12**.

Nmr ($CDCl_3$) showed δ 3.78 (s, 6 H, OCH_3), 5.23 (unresolved m, 2 H, bridgehead CH), 6.52 (t, 2 H, J = 2 Hz, vinyl H), 9.19 (s, 1 H, CHO); ir ($CHCl_3$) 1754 (s, sh), 1724 (s) cm^{-1}; mass spectrum m/e (%) 59 (100, $^+CO_2CH_3$), 163 (8, 239 − 76), 195 (12, 239 − 44), 239 (43, M − Br), 259 and 261 (1.5, M − 59), 318 and 320 (2, M), metastables at 111.3 (239 → 163), 159.2 (239 → 195), 179.1 (M → 239); exact mass determination calcd for $C_{10}H_{11}O_5N_2Br$, 317.98518; found, 317.98513 ± 0.003.

Bromohydrin 13. Dimethyl 7-*anti*-Hydroxymethyl-7-bromo-2,3-diazabicyclo[2.2.1]hept-5-ene-2,3-dicarboxylate.—To 101.5 mg (0.318 mmol) of bromo aldehyde **12** in 3 ml of absolute ethanol at 0° was added 31 mg (0.18 mmol) of the 1:1 complex of sodium borohydride and diglyme in 1.7 ml of ethanol. The addition required 10 min, and the solution was then allowed to warm to room temperature. After it had been stirred for 4.5 hr, the yellowish solution was squirted into 20 ml of water and stirred for 10 min. The mixture was treated with 10 ml of methylene chloride and 6.5 g of sodium chloride. The aqueous layer was washed with three 10-ml portions of methylene chloride, and the combined organic extracts were washed with 20 ml of saturated sodium chloride, dried over sodium sulfate, and evaporated. The resulting brown gum was purified by preparative tlc (ether elution) to give a single band (R_f 0.08) (in addition to diglyme) which contained 76 mg (74%) of the bromohydrin **13**.

Nmr ($CDCl_3$) showed δ 3.16 (position variable, br t, 1 H, J = 6.5 Hz, OH), 3.81 (s, 6 H, OCH_3), 3.98 (br d, 2 H, J = 6.5 Hz, CH_2OH), 5.07 (unresolved m, 2 H, bridgehead CH), 6.52 (t, 2 H, J = 2 Hz, vinyl H); ir ($CHCl_3$) 3584 (w), 3484 (wb), 1748 (s), 1709 (s) cm^{-1}; mass spectrum m/e (%) 39 (35), 41 (30), 42 (31), 49 (57), 59 (100, $^+CO_2CH_3$), 91 [91, $HOC(OCH_3)_2^+$], 92 (63), 241 (86, M − Br), 320 and 322 (5, M); exact mass determination calcd for $C_{10}H_{13}O_5N_2Br$, 320.00083; found, 320.00516 ± 0.005.

Bromo Acetate 14. Dimethyl 7-*anti*-Acetoxymethyl-7-bromo-2,3-diazabicyclo[2.2.1]hept-5-ene-2,3-dicarboxylate.—To 87 mg (0.27 mmol) of bromohydrin **13** in 0.3 ml of deuteriochloroform in an nmr tube was added 76 mg (0.75 mmol) of acetic anhydride. After a few milligrams of *p*-toluenesulfonic acid had been added,

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the rate of the reaction could be followed easily by nmr and was 75% complete in ~1 hr. The tube was then placed in the refrigerator (0°) for 12 hr, after which nmr showed only a trace of starting material. The mixture was transferred with methylene chloride to a flask containing a small amount of calcium carbonate, filtered, and evaporated to an off-white oil, which was purified by preparative tlc (ether elution) to give 74 mg (75%) of a colorless gum. On long standing, the latter crystallized to a white solid, mp 102–104°.

Nmr ($CDCl_3$) showed δ 2.17 (s, 3 H, CH_3CO), 3.88 (s, 6 H, OCH_3), 4.53 (s, 2 H, OCH_2), 5.11 (unresolved m, 2 H, bridgehead CH), 6.60 (t, 2 H, J = 2 Hz, vinyl H); ir (CCl_4) 1754 (s), 1724 (s) cm^{-1}; mass spectrum m/e (%) 43 (89, Ac^+), 49 (31), 59 (63, $^+CO_2CH_3$), 165 [41, 283 − (2 × 59)], 283 (100, M − Br), 362 and 364 (1, M), metastables at 96.2 (283 → 165) and 205.1; exact mass determination calcd for $C_{12}H_{15}O_6N_2Br$, 362.01140; found, 362.01140 ± 0.005.

1,4,5,6-Tetrachloro-2,3-diazabicyclo[2.2.1]hept-5-en-7-one-2,-3-phenyldicarboximide Ethylene Ketal (19a).—Into a suspension of 7.5 g (0.04 mol) of 4-phenylurazole[15] in 75 ml of reagent grade acetone under nitrogen cooled to −78° was added dropwise over a period of 45 min 4.45 g (0.04 mol) of *tert*-butyl hypochlorite.[16] Subsequent to this addition, a solution of 10.5 g (0.04 mol) of the ethylene ketal of tetrachlorocyclopentadienone in a minimum volume of acetone (~25 ml) was added at a rapid dropwise rate. The cooling bath was removed and stirring continued at room temperature until the red color of the triazoline disappeared (3–5 hr). The suspended solid was removed by filtration and the solvent evaporated *in vacuo* to yield more solid. Combined weight of crude material was 16.1 g (90% yield). Recrystallization from ethyl acetate–cyclohexane generated colorless crystals, mp 223°, weighing 13.4 g (75% yield).

Nmr (DMSO-d_6) showed apparent A_2B_2 with H_A at δ 4.35 and H_B at 4.30 (J_{AB} = 6 Hz), 7.38 (m, 5 H); ir ($CHCl_3$) 1790, 1740, 1590, 1555, 1500 cm^{-1}.

Anal. Calcd for $C_{15}H_9N_3O_4Cl_4$: C, 41.22; H, 2.08; N, 9.61; Cl, 32.45. Found: C, 41.41; H, 2.24; N, 9.89; Cl, 32.47.

1,4,5,6-Tetrachloro-2,3-diazabicyclo[2.2.1]hept-5-en-7-one-2,-3-phenyldicarboximide Dibenzyl Ketal (19b).—To a solution of 1.01 g (5.74 mmol) of 4-phenyl-1,2,4-triazoline-3,5-dione[2b] in 10.0 ml of methylene chloride was added 2.39 g (5.78 mmol) of tetrachlorocyclopentadienone dibenzyl ketal[17] in 10.0 ml of methylene chloride over 10 min. After an additional 15 min of stirring, the red color of the azo compound had been replaced by dark yellow. The solution was stirred for another 3.5 hr and evaporated to a gum which crystallized on standing for a few minutes. The gum was digested with refluxing cyclohexane, the suspension was filtered, and the filtrate was cooled, yielding 2.42 g (71%) of pale yellow crystals in three crops. The first crop was recrystallized from cyclohexane to give an analytical sample, mp 152.5–153.5°.

Nmr ($CDCl_3$) showed δ 7.36 (m, 15 H, Ar H), 5.17 (s, 2 H, OCH_2Ph), 4.95 (s, 2 H, OCH_2Ph); ir ($CHCl_3$) 1792 (w), 1752 (s) cm^{-1}; ir (Nujol mull) 748 (m) cm^{-1}; uv (ethanol) λ_{max} 2.51 nm (log ϵ 3.59), 257 (sh); mass spectrum m/e (%) 497 (8.7, M − CH_2Ph), 119 (25, PhNCO), 91 (100, C_7H_7).

Anal. Calcd for $C_{27}H_{19}Cl_4N_3O_4$ (mol wt, 590.98): C, 54.82; H, 3.25, Cl, 24.00; N, 7.11. Found: C, 54.87; H, 3.28; Cl, 23.93; N, 7.10.

2,3-Diazabicyclo[2.2.1]hept-5-en-7-one-2,3-phenyldicarboximide Diethyl Ketal.—To a solution of 1.00 g (6.32 mmol) of cyclopentanone diethyl ketal[18] in 16 ml of absolute ethanol at 5° was added, with stirring, 2.02 g (12.63 mmol) of bromine at such a rate that a small concentration of bromine was present at all times. The temperature was maintained below 20° by means of an ice bath. Anhydrous sodium carbonate (3.0 g) was then added, and the mixture was stirred for 10 min. After addition of 15 ml of pentane at 0° the mixture was poured into 8 ml of ice water. The pentane extract was separated, dried over anhydrous magnesium sulfate, and filtered, and the solvent was evaporated at 0°. The remaining colorless oil, crude 2,5-dibromocyclopentanone diethyl ketal, weighed 1.53 g (77%).

The above product was dissolved in 5 ml of dimethyl sulfoxide and added with vigorous stirring to 2.5 g (20.5 mmol) of potassium *tert*-butoxide in 15 ml of dimethyl sulfoxide. During the addition, which required 5 min, the temperature was kept just above 17° by cooling with a Dry Ice–acetone bath. To the resulting dark brown mixture was added 15 ml of cold pentane, and the mixture was poured into ~15 ml of ice, water, and salt. The pentane layer was separated and transferred to a dropping funnel jacketed with Dry Ice. The aqueous layer was extracted with four more 15-ml portions of pentane at 0°, each being combined with the first.

The combined extracts at −70° were added dropwise to 1.18 g (6.75 mmol) of 4-phenyl-1,2,4-triazoline-3,5-dione in 15 ml of methylene chloride at 25–30° during 1.5 hr. The mixture was refluxed for 0.5 hr after the addition was complete and then stirred at room temperature for 65 hr. The light brown solution was decanted and evaporated to a sticky solid. The latter was chromatographed on 100 g of alumina, eluting with methylene chloride. The product was recrystallized from benzene–petroleum ether (bp 60–68°) yielding 0.76 g (36%) of the ketal as white needles. An analytical sample was prepared by one more recrystallization, mp 144–145.5° (turned bright red while melting).

Nmr ($CDCl_3$) showed δ 1.17 (t, 6 H, J = 7.0, CH_3), 3.55 (pseudoquintet—superimposed doublet of quartets, 4 H, J = 6.9, OCH_2), 4.90 (A_2B_2 pattern, 2 H, bridgehead CH), 6.59 (A_2B_2 identical in appearance with that at 4.90, 2 H, vinyl H), 7.45 (m, 5 H, Ar H); ir ($CHCl_3$) 1767 (m), 1706 (s) cm^{-1}; uv (ethanol) λ_{max} 222 nm (log ϵ 4.15); mass spectrum m/e (%) 154 (4, cyclopentadienone diethyl ketal), 119 (100, PhNCO), 91 (58, C_6H_5N), 64 (48).

Anal. Calcd for $C_{17}H_{19}N_3O_4$ (mol wt, 329.33): C, 62.1; H, 5.82; N, 12.77. Found: C, 62.19; H, 5.88; N, 12.79.

Registry No.—**2,** 33608-32-1; **4,** 497-20-1; **5a,** 33527-33-2; **6** (R = CH_3), 22700-75-0; **7,** 33527-35-4; **9,** 33527-36-5; **10,** 33536-28-6; **12,** 33536-29-7; **13,** 33536-30-0; **14,** 33536-31-1; **19a,** 33527-37-6; **19b,** 33527-38-7; dimethyl hydrazodicarboxylate, 17643-54-8; 2,3-diazabicyclo[2.2.1]hept-5-en-7-one-2,3-phenyldicarboximide diethyl ketal, 33527-40-1.

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