of 5; a white powder (72 mg, 78%) was obtained: mp >300 °C; IR (KBr) 3539, 3397, 3180, 3082, 1714, 1652, 1287, and 1050 cm^{-1}; NMR (500 MHz, DMSO-d_6) δ 10.94 (s, 2 H, NH, exch. with D_2O), 4.72 (s, 2 H, OH, exch. with D_2O), 3.62 (s, 2 H, methines), 3.44 (d, 4 H, H_A of AB, methylenes, J = 16.4 Hz), 3.40 (d, 4 H, H_B of AB, methylenes, J = 16.4 Hz), 3.00 (m, 2 H, methines), 1.63 (m, 2 H, methylenes), 1.55 (m, 2 H, methylenes). Anal. Calcd for $C_{14}H_{20}N_4O_6 \cdot 0.5H_2O$: C, 48.13; H, 6.06; N, 16.04. Found: C, 48.00; H, 6.12; N, 16.01.

(3aα,4aβ,8aβ,9aβ)-Diethyl Octahydro-2,2-dimethyl-6-oxo-1,3-dioxolo[4,5-*g*]quinoxaline-5,8-diacetic Acid Ester (45). Diamine 28 (1.1 g, 6.1 mmol) was treated with PMP (3.8 g, 25 mmol) and ethyl bromoacetate (16.2 g, 97 mmol) in DMF (25 mL) as described for the synthesis of 29. The yellow oily residue was purified by preparative TLC (silica gel, hexane–AcOEt (2:1)) to furnish a colorless oil (1.8 g), which was identified as **(3aα,5β,6β,7aβ)-ethyl *N*-(2-ethoxy-2-oxoethyl)-*N*-[6-[(2-ethoxy-2-oxoethyl)amino]hexahydro-2,2-dimethyl-1,3-benzodioxol-5-yl]glycine ester (43)** and spontaneously converted to 45 at room temperature. For 43: FAB/MS calcd for $C_{21}H_{37}N_2O_8$ $(M + H)^+$ 445.53, found 445.51; NMR (500 MHz, $CDCl_3$) δ 4.20 (m, 6 H, methylenes, overlap with equivalent methylene protons of 45), 3.89 (m, 1 H, methine), 3.69 (d, 3 H, H_A of AB, methylenes, J = 18.6 Hz), 3.60 (d, 3 H, H_B of AB, methylenes, J = 18.6 Hz), 3.34 (m, 1 H, methine), 3.20 (m, 1 H, methine), 3.16 (m, 1 H, methine), 2.75 (br. s, 1 H, NH, exch. with D_2O), 2.21 (m, 1 H, methylene), 2.08 (m, 1 H, methylene), 1.85 (m, 1 H, methylene), 1.32 (m, 1 H, methylene), 1.38 (s, 6 H, methyls, overlap with equivalent methyl protons of 45), 1.28 (m, 9 H, methyls, overlap with equivalent methyl protons of 45). For 45: IR (neat) 2990, 2935, 1775, 1650, and 1200 cm^{-1}; ^{13}C NMR (125 MHz, $CDCl_3$) δ 14.1, 26.7, and 26.8 (methyls), 23.2, 28.6, 43.3, 51.7, 55.2, 61.0, and 61.3 (methylenes), 54.4, 57.3, 74.7, 78.4 (methines), and 110.8 (quaternary C), 168.6, 168.7, 169.7 (C=O); ^1H NMR (500 MHz, $CDCl_3$) δ 4.70 (d, 1 H, methylene, J = 17.6 Hz), 4.26 (m, 1 H, methine), 4.20 (m, 4 H, methylenes), 3.88 (d, 1 H, methylene, J = 17.6 Hz), 3.59 (d, 1 H, H_A of AB, methylene, J = 18.2 Hz), 3.46 (d, 1 H, H_B of AB, methylene, J = 18.2 Hz), 3.45 (d, 1 H, $H_{A'}$ of A'B', methylene, J = 16.7 Hz), 3.43 (m, 1 H, methine), 3.37 (m, 1 H, methine), 3.33 (d, 1 H, $H_{B'}$ of A'B', methylene, J = 16.7 Hz), 3.28 (td, 1 H methine, J = 11.9 and 4.0 Hz), 2.35 (td, 1 H, methylene, J = 14.2 and 3.0 Hz), 2.20 (td, 1 H, methylene, J = 11.6 and 4.0 Hz), 1.91 (q, 1 H, methylene, J = 11.7 Hz), 1.63 (ddd, 1 H, methylene, J = 14.2, 12.4, and 3.5 Hz), 1.38 (s, 6 H, methyls), 1.28 (m, 6 H, methyls); FAB/MS, exact mass calcd for $C_{19}H_{31}N_2O_7$ $(M + H)^+$ 399.2131, found 399.2122.

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Aza- and Diazaannulenones. Influence of Nitrogen Position on Their Reactivity and Stability

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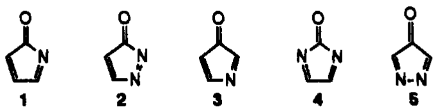
Three new elusive intermediates, 3-aza-2,4-cyclopentadienone, 2,5-diaza-2,4-cyclopentadienone, and 3,4-diaza-2,4-cyclopentadienone, are reported. The three species can act either as dienes or as dienophiles in Diels–Alder reactions. The influence of the number and position of nitrogen atoms on their stability is studied.

We have previously demonstrated the existence in solution of 2-aza-2,4-cyclopentadienone, 1, and 2,3-diaza-2,4-cyclopentadienone, 2, and studied their reactivity in Diels–Alder reactions.[1,2] In order to study the influence of nitrogen position on their stability and reactivity, we presently report the study of three new intermediates, 3-aza-2,4-cyclopentadienone, 3, 2,5-diaza-2,4-cyclopentadienone, 4, and 3,4-diaza-2,4-cyclopentadienone, 5 (Chart I).

The literature provides some information on 2,5-disubstituted 3,4-diaza-2,4-cyclopentadienones in Diels–Alder reactions, but the parent compound has not been studied to date. On the other hand, no experimental evidence for the existence of compounds related to 3 and 4 exists. To study this aspect, and the reactivity and stability of these intermediates, we have employed the three-phase test. Accordingly, the intermediate is generated from an insoluble polymer-bound precursor and trapped by a second solid phase by using Diels–Alder reactions.[3] Isolation of an adduct gives positive evidence for existence of the postulated intermediate. We used this test successfully to demonstrate the transient existence of several reactive intermediates.[4]

Chart I



We were interested in providing evidence for the existence of 3–5 and showing that they may behave either as dienes or as dienophiles in Diels–Alder reactions. Thus, we prepared a suitable polymer-bound precursor for each intermediate, as shown below. Polymer-bound monoester of acetylenedicarboxylic acid,[5] 17, and polymer-bound ester of 2-furoic acid,[5] 21, were used as dienophilic and dienic trapping agents in the three-phase test.

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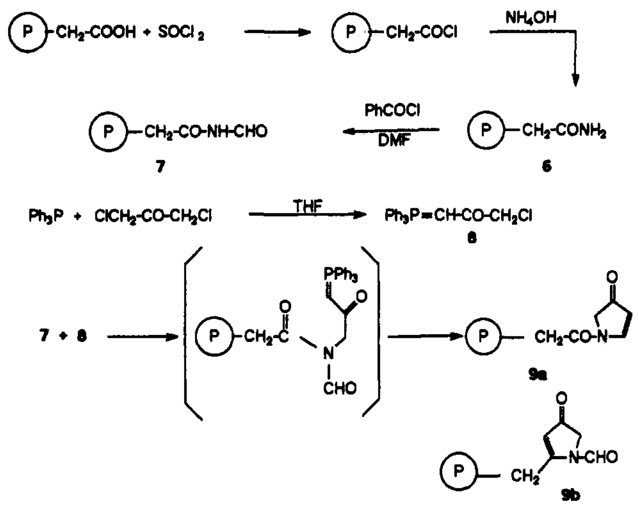
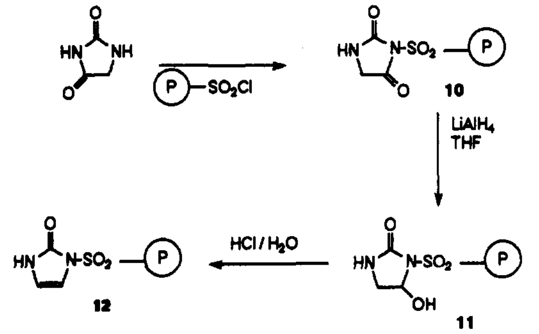
0022-3263/91/1956-5417$02.50/0

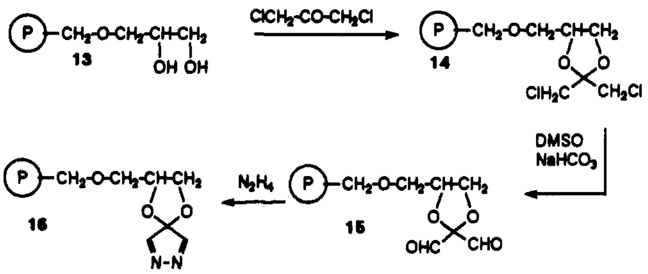
Scheme I



Scheme II



Scheme III

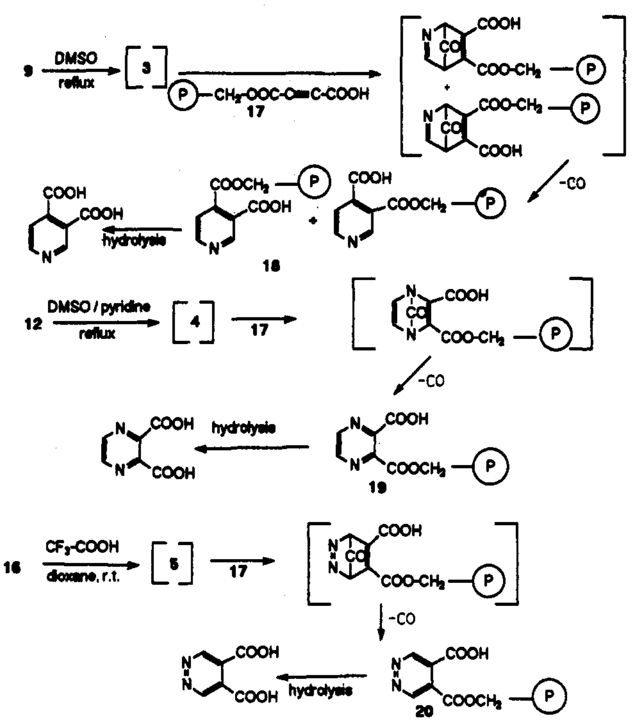


Results and Discussion

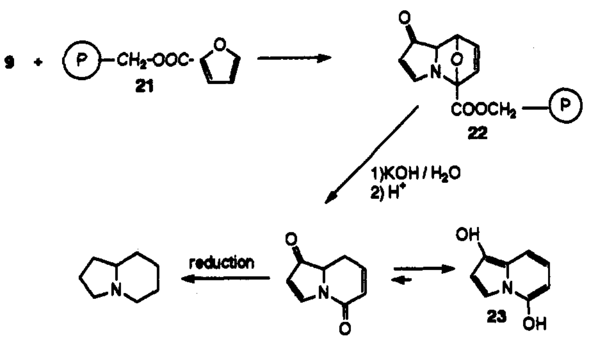
Synthesis of Precursors. The polymer-bound precursor of 3-aza-2,4-cyclopentadienone, 3, was synthesized by modifying the Flitsch method for *N*-acyl-3-hydroxypyrroles[6] (Scheme I). Reaction of polymer-bound *N*-formylamide 7 with 8[6] could give products 9a,b. To determine the structure of the resin and establish the linking between the polymer and heterocyclic moiety, we hydrolyzed the polymer. Isolation of the sodium salt of the acid resin showed that the product obtained was 9a. Reaction of 9a with several eliminating agents, such as Me_2SO or $LiNH_2$/HMPT, always led to polymer-bound acid and complex mixtures in solution. This behavior is also observed for 1[4a] and for nonnitrogenated 2,4-cyclopentadienones, which can only be isolated as dimers or as their decarbonylation[5,7] products.

Precursor 12 for 2,5-diaza-2,4-cyclopentadienone, 4, was prepared as shown in Scheme II. The 3-polymer-bound sulfamide of hydantoin was obtained by reaction between its potassium salt and chlorosulfonate macroreticular resin.[8] The resin 10 was reduced to 11 and converted into 12 according to the Kohn and Liao procedure.[9]

Scheme IV



Scheme V



The polymeric precursor 16 for 3,4-diaza-2,4-cyclopentadienone, 5, was obtained as shown in Scheme III. The reaction of polymer-bound 1,2-diol[10] 13 with 1,3-dichloroacetone gave 14. The subsequent step involved oxidation of 14 to a dialdehyde polymer[11] 15. Finally, 15 was converted to the precursor 16 by reaction with 80% hydrazine hydrate.

Compounds 3–5 as Dienes in the Diels–Alder Reaction. The reactions were carried out by using each precursor and 17 in the conditions indicated in Scheme IV. The resins were separated as usual, and trapping agents were shown to be polymer-bound monoesters of the following: 2,3-pyridinedicarboxylic acid, 18; 2,3-pyrazinedicarboxylic acid, 19; and 4,5-pyridazinedicarboxylic acid, 20. The acids were isolated by hydrolysis of polymer and preparative TLC. These acids were identified by comparing their physical and spectroscopic properties with authentic samples. The isolation of these

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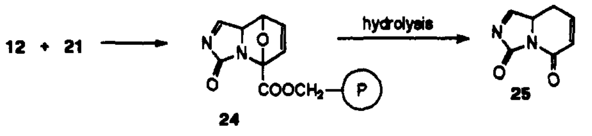
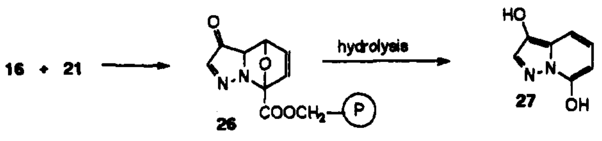
Scheme VI



Scheme VII



compounds supported the existence of each intermediate, as direct reaction between the two solid phases is unlikely.

18–20 should proceed from Diels–Alder adducts through a carbonyl extrusion and aromatization reaction. These reactions do not take place during hydrolysis as in cyclopentadienone reaction, but rather during the three-phase test.[5] This behavior was established by comparison of **18–20** with authentic samples synthesized as shown in the Experimental Section. Such comparison was carried out taking IR spectra for compounds obtained in each reaction and mixed samples as well.

Compounds 3–5 as Dienophiles in the Diels–Alder Reaction. The next step in our study was to demonstrate that the intermediates are able to act as dienophiles in Diels–Alder reactions. The polymer-bound ester of 2-furoic acid was used as a dienic trapping agent. Reaction of **9** with **21** in DMSO at 100 °C yielded the polymer-bound adduct **22** (Scheme V), from which **23** (8.3%) was obtained by basic hydrolysis followed by acidification and preparative TLC. Clemmensen reduction of **23** gave δ-coniceine identical with an authentic sample.

When **4** was generated from **12** in the presence of **21**, polymer **24** resulted (Scheme VI), from which **25** (15.5%) could be isolated by basic hydrolysis followed by acidification. Reaction between **16** and **21** gave **26** (Scheme VII). From this polymer, **27** (23.1%) was separated by basic hydrolysis and acidification.

The ability of **5** to react as a diene and as a dienophile was similar to that of its diphenyl derivative, 2,5-diphenyl-3,4-diaza-2,4-cyclopentadienone.[12] There are no references to the existence and reactivity in Diels–Alder reactions of **3** or **4** derivatives, but the behavior of the parent compounds has been as we expected.

Lifetime Determinations. The three-phase test modified by using the "polyphasic dynamic reactor" (PDR) has been applied to determine the lifetime of several intermediates.[13a,b] We recently used this method to determine the lifetimes of **1** and **2**. In the present study, the same procedure has been used to measure the lifetimes of intermediates **3–5**. Thus, the polymer precursor for each species and polymer-bound monoester of acetylenedicarboxylic acid was used. A flow of solvent was produced and adjusted by using a peristaltic pump. Results for intermediates **3–5** are given in Table I. Time of diffusion of the intermediates from the polymer beads to the surface and time of diffusion to the inside of the trapping polymer bead should be considered. Nevertheless, both timings are in the range of some tenths of a second[14] and can be included within method error.

Table I. Lifetime of Compounds 1–5[a]

intermediates	lifetimes (s)
1	2.0 ± 0.5
2	63.5 ± 0.5
3	11.5 ± 0.5
4	<1
5	16.0 ± 0.5

[a] Experimental conditions are indicated in the Experimental Section.

Clearly, these lifetime values depend on the ability to detect the trapped species. Under our experimental conditions, we may confirm that for those values, 97% of intermediate molecules were too reactive to reach the trapping agent. It is easy to calculate that under such conditions the relationship between intrinsic half-time ($t_{1/2}$) and observed lifetime (t) is $t_{1/2} = 0.2t$. Therefore, if we use the same experimental conditions in every case, this relationship is constant, and we may use lifetime values to compare reactivities.

Conclusions

For the first time, evidence for the existence in solution of the three aza- and diazacyclopentadienones **3–5** has been supplied. These intermediates are all able to act either as dienes or as dienophiles in the Diels–Alder reaction. Compound **4** needs stronger conditions to react as a dienophile with **21** than as a diene with **17**. Only 2,3-diaza-2,4-cyclopentadienone, **2**, among all azaannulenones studied in the present work, exhibits no detectable behavior as a diene.[2] When compounds **3–5** were generated in the absence of a trapping agent, complex mixtures in solution were always obtained. This behavior is also observed for **1**, **2**[1,2] and several related carbocyclic intermediates.

Lifetime values show that the position of the nitrogen atoms is more important than their actual number. Intermediates **1** and **4** have a very short lifetime. This seems to depend on the high reactivity of the *N*-acylimine group contained in their structures. **1** and **4** have a shorter lifetime than **3** and **5**; this could be due to the β position of the nitrogen atom in **3** and **5**. The stability of these last intermediates is similar to that of the homocyclic species, 2,4-cyclopentadienone. Intermediate **2** has a surprisingly long lifetime. This could be explained by taking into account that it does not react as a diene in the Diels–Alder reaction.

Experimental Section

Preparation of Polymer-Bound Precursor 9. The polymeric acid[15] (1 g) was heated at 80 °C for 25 h with 1 mL of $SOCl_2$ in 50 mL of dry benzene. After the reaction mixture was filtered and washed with dry benzene, CH_2Cl_2, and acetone, polymeric acid chloride was obtained.

A 1-g portion of this polymer was suspended in 20 mL of dioxane, and 6 mL of concentrated NH_4OH was added. The reaction mixture was stirred at room temperature for 24 h. The resin was filtered and washed with water–dioxane (1:1), dioxane, ethanol, dichloromethane, and acetone to give **6**: IR (KBr) 3450, 3327, 1654, 1589 cm^{-1}.

A 524-mg sample of **6** was suspended in 40 mL of freshly distillated DMF. Then, 1.5 mL of benzoyl chloride was added, and the mixture was stirred at room temperature overnight. Polymer-bound amidinium salt was hydrolyzed with 15 mL of DMF and 15 mL of water at room temperature overnight. The polymer was removed by filtration and washed with DMF, ethanol,

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dichloromethane, and acetone to give **7**: IR (KBr) 2843, 1738, 1683 cm^{-1}.

A suspension of 0.5 g of **7** and 0.036 g of NaH in 20 mL of dry dioxane was stirred at room temperature for 12 h. The polymer was separated and washed with dioxane–mater (1:1), dioxane, acetone, and ether: IR (KBr) 2880, 1727, 1667 cm^{-1}. A 265-mg portion of this polymer was allowed to react with 250 mg of phosphorane **8**[16] in 20 mL of DMF at 80 °C for 10 days. The polymer, washed with dioxane, acetone, and ether (IR (KBr) 2910, 1724, 1664, 1600, 1490 cm^{-1}), was cyclized in 50 mL of diethylbenzene at reflux for 20 h. The polymer was filtered and washed with dioxane, acetone, and ether: IR (KBr) 1717, 1703, 1661 cm^{-1}. Analysis (3.06% N) indicated 2.19 mequiv/g.

Preparation of Polymer-Bound Precursor 12. A 7.5-g portion of hydantoin was treated with 4.25 g of KOH in 600 mL of ethanol. The mixture was heated under reflux for 2 h, and the solid was then filtered and washed with ethanol and ether.

A 6.9-g portion of the potassium salt of hydantoin and 1 g of polymeric tosyl chloride were suspended in 380 mL of DMSO and 12 mL of pyridine. The reaction mixture was heated at 170–180 °C for 7 days, adding 12 mL of pyridine every day. The resin was washed with water–HCl (1:1), dioxane, benzene, acetone, and ether to give **10**: IR (KBr) 3300, 2910, 1755, 1685, 1630, 1215, 1160 cm^{-1}.

10 (0.5 g) was treated with $LiAlH_4$ (0.05 g) in 40 mL of THF under nitrogen at room temperature for 6 days. Afterwards, water was added and the polymer was filtered and washed with dioxane–water (1:1), dioxane, benzene, acetone, and ether. To this polymer were added 1 mL of water, followed by 1 mL of HCl (15%) and then 3 mL of water. The mixture was stirred for 20 min. The resin **12** was filtered and washed with water–dioxane (1:1), dioxane, benzene, acetone, and ether: IR (KBr) 3250, 1680, 1638, 1595 cm^{-1}. Analysis (1.08% N) indicated 0.38 mequiv/g.

Preparation of Polymer-Bound Ketal 14. To a solution of 1.37 g of anhydrous glycerol in 50 mL of dry DMF was added 0.31 g of Na. The mixture was heated under reflux until sodium was completely dissolved. A 3.99-g portion of Merrifield's resin was added to the cooled solution, and the reaction was kept under reflux for 23 h. The polymer **13** was separated by filtration and washed with DMF, DMF–water (1:1), water–dioxane (1:1), benzene, acetone, and ether: IR (KBr) 3440, 3020, 1590, 1120, 1030 cm^{-1}.

A suspension of polymer **13** (0.5 g), 1,3-dichloroacetone (0.26 g), and *p*-toluenesulfonic acid (90 mg) was heated in 25 mL of dry benzene for 50 h. Resin **14** was obtained after the reaction mixture was filtered and washed with benzene, acetone, and CH_2Cl_2: IR (KBr) 1590, 1220, 1115, 1026, 999 cm^{-1}; 0.62 mequiv/g.

Oxidation of 14. A 0.45-g portion of **14** was suspended in 30 mL of Me_2SO containing 1.9 g of sodium bicarbonate and heated under reflux for 6 h. The polymer **15** was filtered and washed with Me_2SO, hot water, dioxane–water (2:1), dioxane, ethanol, acetone, and ether: IR (KBr) 2760, 1699, 1590, 754 cm^{-1}.

Preparation of Precursor 16. A 0.385-g portion of **15** in 22 mL of CH_2Cl_2 was treated with 100 μL of 80% hydrazine hydrate. The mixture was stirred for 24 h at room temperature, and the polymer **16** was separated and washed with dichloromethane, ethanol–water (1:1), ethanol, and ether: IR (KBr) 1589, 1480, 1022, 754 cm^{-1}; 0.82% N, 0.3 mequiv/g.

Reaction of 3 as a Diene. A 1-g sample of **9** and 0.8 g of the polymer-bound monoester of acetylenedicarboxylic acid, **17**, were suspended in 500 mL of Me_2SO. The mixture was heated under reflux for 3 days. After the reaction was complete, **18** was obtained by filtration and washing (1.93% N, 1.38 mequiv/g): IR (KBr) 3050, 2990, 1710, 1670 cm^{-1}. Hydrolysis of **18** with 0.4 M NaOH (dioxane–water (1:1)) under reflux for 2 days followed by acidification and separation by preparative TLC (ether–hexane), gave 0.20 g (54.3%) of pyridine-3,4-dicarboxylic acid, identical (IR, NMR, TLC) with an authentic sample (Aldrich).

Reaction of 4 as a Diene. A 1.5-g portion of **12** and 2 g of the polymer-bound monoester of acetylenedicarboxylic acid, **17**, were suspended in 500 mL of Me_2SO and 30 mL of pyridine. The mixture was heated at 170 °C for 7 days, and 15 mL of pyridine was added every day. Resins were separated and washed with water–HCl (1:1), dioxane, ethanol, acetone, and ether. Polymeric trapping agent gave **19** (0.53% N, 0.19 mequiv/g): IR (KBr) 3010, 2910, 1700 cm^{-1}.

Hydrolysis of **19** with 0.4 M KOH (dioxane–water (1:1)) under stirring and reflux for 2 days yielded hydroxybenzylic resin, as well as a solution from which 2,3-pyrazinedicarboxylic acid could be isolated after neutralization and extraction with acetone. The product (54 mg, 56.3%) was identified by comparison (IR, NMR, TLC) with an authentic sample (Aldrich).

Reaction of 5 as a Diene. A 1.5-g portion of **16** and 1 g of polymer-bound monoester of acetylenedicarboxylic acid were stirred at room temperature for 1 day with 80 mL of dioxane containing 5.7 mL of trifluoroacetic acid. The trapping polymer was washed with water–dioxane, ethanol, and ether to give **20** (0.56% N, 0.2 mequiv/g): IR (KBr) 3010, 2900, 1670 cm^{-1}. Hydrolysis of **20** with KOH in dioxane–water gave a solution from which 4,5-pyridazinedicarboxylic acid could be isolated as white needles by crystallization. The product (32 mg, 42.2%) was identified by comparison (NMR, IR, TLC, mixed mp) with an authentic sample prepared by oxidation of phthalazine with $KMnO_4$.[17]

Alternative Preparation of 18–20. A 0.5-g portion of chloromethylated resin was suspended in 100 mL of dioxane–water (1:1) containing 0.3 g of 3,4-pyridinedicarboxylic acid, 2,3-pyrazinedicarboxylic acid, or 4,5-pyridazinedicarboxylic acid, respectively, and 10 mL of NEt_3. The resulting mixture was heated and stirred at 100–110 °C for 48 h. After being washed with dioxane–water (1:1), dioxane, ethanol, acetone, and ether, the resin was acidified (HCl in aqueous dioxane) and washed again with water, acetone, and ether to give **18**, **19**, or **20**.

Reaction of 3 as a Dienophile. A 2-g portion of **9** and 2 g of polymeric 2-furoic acid were heated under reflux in 500 mL of DMSO for 3 days. Filtration and washing of the resin gave **22**: IR (KBr) 1725, 1670, 1280, 1170, 1050 cm^{-1}. Hydrolysis of **22**, as described before, gave a mixture of compounds. Furoic acid (128 mg) and **23** (56 mg, 8.6%) could be isolated as major products by chromatography (acetone–ethanol (1:1)). **23** appears as a yellow oil: ^{1}H NMR (CD_3OD) δ 6.6 (dd, *J* = 6.5 Hz, *J'* = 2.9 Hz, 2 H, H-C(2), H-C(6)), 7.0 (dd, *J* = 8.7 Hz, *J'* = 1.2 Hz, 2 H, H-C(8), H-C(7)), 7.6 (d, *J* = 2.9 Hz, 1 H, H-C(3)), 8.5 (br s, 2 H, OH); ^{13}C NMR (CD_3OD) δ 101.5, 110.3, 110.5, 113.2, 114.4, 116.1, 132.9, 141.1. Anal. Calcd for $C_8H_7NO_2$: C, 64.43; H, 4.69; N, 9.39. Found: C, 64.38; H, 4.59; N, 9.41.

Reduction of **23** was carried out via the Clemmensen reduction conditions used by several authors in similar cases.[18] **23** (50 mg) was heated under reflux with amalgamated zinc wool and hydrochloric acid for 5 h. The mixture was neutralized with NaOH until pH 8 and then extracted with ether. Evaporation of the ethereal solution gave 42 mg of octahydroindolizine (δ-coniceine), identical (IR, NMR, TLC) with an authentic sample[19] (the picrate recrystallized from methanol had mp 225–227 °C).

Reaction of 4 as a Dienophile. A 2-g portion of **12** and 2 g of **21** were suspended in 350 mL of Me_2SO/30 mL of pyridine. The mixture was heated at 170 °C for 7 days, and 15 mL of pyridine was added each day. The trapping agent, after being washed with HCl–water (1:1), dioxane, ethanol, acetone, and ether gave **24**: IR (KBr) 1699, 1593, 1289 cm^{-1}. Hydrolysis of **24** in the usual way gave a solution from which **25** (17.8 mg, 15.5%) could be isolated by neutralization and TLC using acetone–ethanol 3:7 as eluent: IR (KBr) 1745, 1703, 1589, 1258 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 2.5 (dd, *J* = 2.0 Hz, *J'* = 2.4 Hz, 2 H, CH_2), 3.7 (m, 1 H, aliphatic CH)) 5.7 (m, 1 H, H-C=C), 6.8 (d, *J* = 9.3 Hz, 1 H, =CHCON—), 7.7 (d, *J* = 1.1 Hz, 1 H, HC=N—); ^{13}C NMR ($CDCl_3$) δ 25.6 (t), 59.8 (d), 112.3 (d), 141.6 (d), 150.2 (d), 153.8 (s), 169.7 (s). Anal. Calcd for $C_7H_6N_2O_2$: C, 56.00; H, 4.00; N, 18.66. Found: C, 56.18; H, 3.91; N, 18.61.

Reaction of 5 as a Dienophile. A 1-g portion of **16** and 1 g of the dienic trapping agent were suspended in 500 mL of dioxane containing 12 mL of trifluoroacetic acid and heated under reflux for 24 h. The adduct polymer **26** was separated by filtration and washed with dioxane, ethanol, acetone, and ether: IR (KBr) 1707,

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1583 cm^{-1}. **26** was hydrolyzed as usual giving the hydroxybenzylic polymer. From neutralized solution **27** (10.4 mg, 23.1%) was isolated by extraction with dichloromethane: mp 109–111 °C; IR (KBr) 3129, 2958, 1687, 1571, 1297, 1184, 1076 cm^{-1}; ^{1}H NMR (CDCl$_3$) δ 6.35 (dd, J = 8.5 Hz, J' = 6.7 Hz, 1 H), 7.05 (m, 2 H), 7.4 (s, 1 H), 7.65 (wide s, 2 H); ^{13}C NMR (CDCl$_3$) 100.6, 112.9, 120.5, 139.8, 144.1, 147.9, 163.7. Anal. Calcd for $C_7H_6N_2O_2$: C, 56.00; H, 4.00; N, 18.66. Found: C, 56.21; H, 4.16; N, 18.73.

Lifetime Determinations. In a series of experiments, suspensions of 6.5 mequiv of polymeric precursor (**9** or **12**) in Me$_2$SO at 170 °C were stirred in one of the PDR vessels. Trapping agent **17** (4.5 mequiv) was stirred in the other. A peristaltic pump was used to transfer the solvent carrying the intermediate from one vessel to the other. Previous peristaltic pump calibration allowed us to establish a relationship between flow rates and times the intermediate required to go from the precursor polymer to the trapping one. After each experiment (at a specific flow rate) was complete, the polymeric trapping agent was filtered, washed, and analyzed by hydrolysis and IR. The lifetime values are shown in Table I. The lifetimes for **1** and **2** were repeated under these conditions, and no changes were observed. For **5**, experimental conditions were as follows: 4.5 mequiv of **16**, 4.5 mequiv of **17**, and dioxane containing 3 mL of trifluoroacetic acid at room temperature.

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Molecular Orbital Estimation of the Activation Enthalpies for Intramolecular Hydrogen Transfer as Functions of Size of the Cyclic Transition State and C–H–C Angle

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The AM1 molecular orbital method was used to compute the activation enthalpies for H-transfer between carbons as a function of C–H–C angle and size of the cyclic transition state for intramolecular H-transfer. In the case of intramolecular H-transfer, reactions of a primary radical site with primary, secondary, and tertiary C–H's were considered for H-shifts to C_1 from C_3–C_8. The activation enthalpies are insensitive to C–H–C angle in the range 145–180°. Activation enthalpies are lowest for intramolecular H-transfers involving 1–5 and 1–6 H-shifts. The higher activation enthalpies for the other internal H-transfers are attributed to C–H–C strain for 1–3 and 1–4 H-transfers only, and conformational effects other than C–H–C angle in the transition states.

One expects the transition state for hydrogen atom transfer between carbons to prefer a linear arrangement of the carbons and the H-atom being transferred.[1] Molecular orbital calculations have confirmed this expectation.[2]

Recent developments in synthetic organic chemistry have generated new interest in the structure of the transition states for these reactions and the effects upon the activation energies of distortions from the ideal structures. In particular, the cyclization of the 1-hexenyl radical[3] has become a useful synthetic reaction.[4] Applications often occur with complete or high regio- and stereospecificity.[5] However, cyclizations of this type often have to compete with intramolecular abstraction reactions when appropriately situated hydrogens are in the starting material.[6] Clearly, the synthetic chemist needs to have a reasonable measure of when to expect an abstraction to compete with a cyclization.

In view of the interest in this problem, we have undertaken a molecular orbital study of the effects of C–H–C angle and ring size on intramolecular H-abstraction. We have chosen to study the effect of C–H–C angle by calculating the transition states for H-transfer between two methyl groups as a function of C–H–C angle. The effects of ring size on the transition states for intramolecular H-transfer were studied for transfer of a hydrogen atom from primary, secondary, and tertiary carbons to a primary radical center involving three to eight carbons in the cyclic part of the transition state (see Figure 1). Houk has recently reported the results of an ab initio study of the intermolecular abstraction of a terminal hydrogen by *n*-butoxyl radical (Barton reaction),[7] which is similar to the 1–5 shifts studied here except that abstraction is by oxygen. We are unaware of other theoretical work on this problem.

Methods

The AM1 approximation to molecular orbital theory[8] using the half-electron method[9] as implemented in the AMPAC computer

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