The Stereoselective Diels-Alder Reaction of Bicyclo[3.2.0]nona-3,6-dien-2-one with Several Dienes

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Synopsis. The *endo-cis* adducts were selectively obtained by the Diels-Alder reaction of several dienes with bicyclo[3.2.2]nona-3,6-dien-2-one, prepared from tropone and ethylene. This selective formation from the bicyclic dienophile, the isolated C=C and ethano C–C bonds of which are situated in similar sterical environments within the molecule, was supported by an Extended Hückel calculation.

Recently, we have prepared a series of Diels-Alder adducts (**A**) of tropones with spiro[2.4]hepta-4,6-diene (**1**)[1] in connection with studying the cyclopropane effect on the singlet-oxygen oxidation of dispiro[cyclopropane-1,3′-tricyclo[5.2.1.$0^{2,6}$]deca-4′,8′-diene-10′,1″-cyclopropane],[2] a Diels-Alder dimer of **1**. During the studies, we have noticed the formation of 1:2 adducts (**B** and **C**), in which the geometry of the adducts was always *endo-cis* form with respects to the isolated double bond of the intermediate 1:1 adducts. Although Alder's classical rule for the stereochemistry of the adducts predicts the *endo-cis* adduct formation due to a maximal overlapping of the π-electron systems of the reacting molecules,[3] the previous discussions were restricted to the conjugated system, and only a few examples of stereoselective Diels-Alder addition controlled by an unconjugated π-electron system have been known.[4,5] It is known that the two π-electron systems of **A** show a transannular conjugation effect in the UV spectroscopy,[6] and this delocalization in the **A** may be reflected in the HOMO–LUMO interaction to favor the observed selective reaction. Thus, we thought it might be worthwhile to evaluate the role of this delocalized π-system in the selective 1:2 adduct formation on the sterically unhindered dienophile. With this in mind, we have made a study with bicyclo[3.2.2]nona-3,6-dien-2-one (**2**), the Diels-Alder adduct of tropone (**3**) with ethylene (**4**).[7] The isolated C=C and the ethano C–C of 2 are located in the same geometrical position with found to the α,β-unsaturated keto group of the reaction site.

When a mixture of **2** and **1** was heated in a sealed tube at 130 °C for 180 h, only one adduct (**5**) was obtained after the silica-gel chromatography of the reaction mixture. The NMR spectrum[8] of **5** clearly indicated the stereochemistry of the adduct, *endo-cis*, on the basis of the high-field shift for particular proton signals on the isolated double bond in an order of 1 ppm upon suffering a strong anisotropic effect of the other double bond. Similarly, the reaction of **2** with cyclopentadiene (**6**) also gave a sole 1:1 product (**7**), a colorless oil, which revealed an NMR spectrum very similar with that of **5**, suggesting the same stereochemistry. In this case, a small amount of 1:2 adduct (**8**) was obtained. In addition, cyclohexadiene (**9**) also gave a single product (**10**) by the reaction with **2**. The NMR features of **10** confirmed it to be an analogue of the other adducts in this series.

Parallel with the other experiments, we have carried out Extended Hückel MO calculations of the electronic structure of the ground-state geometry of **2**, which was figured out by inspecting the Dreiding Stereomodel; the stabilization energies of the HOMO level of **6**, as a representative diene, and the LUMO level of **2** for both *cis-cisoid* and *cis-transoid* geometries were calculated by the method of Herndon and Hall,[9] but the figures, $\Delta E_{\mathrm{cis}}=7.7$ kJ/mol, and $\Delta E_{\mathrm{trans}}=4.6$ kJ/mol, are too small for any definite conclusion to be drawn therefrom. The index for each carbon was also small, as is depicted in Fig. 1, but the signs are in accord with the adducts actually isolated.

As a whole, the Diels-Alder reaction of **2** with dienes proceeded with complete stereospecificity, and there is no isomer in any detectable quantity. It is clear now that the norbornene-type C=C of **2**, which prohibits,

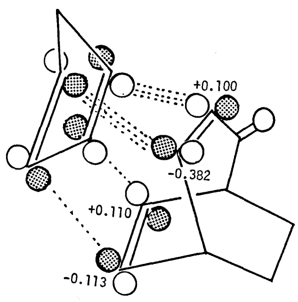
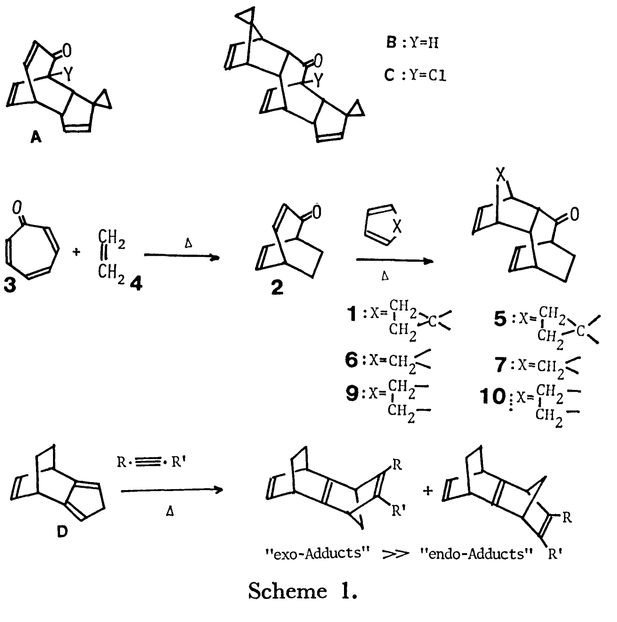


Fig. 1.



Scheme 1.

on structural grounds, full overlapping with the approaching diene, has determined the course of the product formation. On the contrary, a recent paper of Paquette *et al.*[4] described a somewhat inferior stereoselective adduct formation between a diene (**D**), with structural properties similar to those of **2**, and several acetylenic dienophiles. This seems to be attributable to the difference in the geometry of one component of the addends; linear acetylenic dienophiles can hardly interact with the isolated C=C of **D**.

Experimental

*Diels-Alder Reaction of **3** with **4**. Preparation of **2**:*[7] A toluene solution (100 cm^3) of **3** (3 g) was placed in an autoclave, gaseous ethylene was introduced under *ca.* 30 atm, and the mixture was heated for 1.5 h at 225 °C. Then, the mixture was worked up in an ordinary manner. The product, purified on a silica-gel column, was **2** (2.93 g, 77%), which showed NMR spectral data identical with those previously reported.

*Diels-Alder Reaction of **2** with **1**.* A mixture of benzene (1 cm^3), **2** (150 mg), **1** (1 cm^3), and hydroquinone (20 mg) was heated in a sealed tube for 180 h at 130 °C. The mixture was then purified on a silica-gel column with hexane–ethyl acetate (9:1) to give a colorless oil, **5** (45 mg, 58%) [Found: *m/e*, 226.1354 (M$^+$). Calcd for $C_{16}H_{18}O$: 226.1358. δ: 0.15—0.60 (4H, m), 1.35—2.75 (8H, m), 3.13 (2H, m), 5.32 (1H, t, *J*=8 Hz), 5.88 (1H, dd, *J*=6, 3 Hz), 6.09 (1H, dd, *J*=6, 3 Hz), and 6.12 (1H, t, *J*=8 Hz). $\nu_{C=O}$: 1685 cm^{-1}], together with the recovered **2** (102 mg, 68%).

*Addition Reaction of **2** with **6**.* A mixture of benzene (1 cm^3), **2** (150 mg), **6** (1 cm^3), and hydroquinone (50 mg) was heated similarly in a sealed tube at 180 °C for 20 h. The mixture was then purified on a silica-gel column and then further by high pressure liquid chromatography to give **7** (31 mg, 20%) as colorless needles (mp 64—66 °C) [Found: *m/e*, 200.1210 (M$^+$). Calcd for $C_{14}H_{16}O$: 200.1201. δ: 1.20 (1H, dm, *J*=9 Hz), 1.34 (1H, dm, *J*=9 Hz), 1.4—2.0 (4H, m), 2.45 (1H, dt, *J*=9.5, 3 Hz), 2.57 (1H, m), 2.72 (1H, m), 3.01 (1H, dd, *J*=9.5, 4 Hz), 3.11 (1H, ddm, *J*=7.5, 4 Hz), 3.33 (1H, m), 5.31 (1H, ddm, *J*=8.5, 7.5 Hz), 5.85 (1H, dd, *J*=6, 3 Hz), 5.95 (1H, dd, *J*=6, 3 Hz), and 6.08 (1H, ddm, *J*=8.5, 8 Hz). $\nu_{C=O}$: 1690 cm^{-1}], recovered **2** (46 mg, 31%), and a colorless oil (**8**) [Found: *m/e*, 266.1680 (M$^+$). Calcd for $C_{19}H_{22}O$: 266.1671. $\nu_{C=O}$: 1685 cm^{-1}], 29 mg (16%).

*Addition Reaction of **2** with **9**.* A mixture of benzene (2 cm^3), **2** (550 mg), **9** (2.2 g), and hydroquinone (5 mg) was heated in a sealed tube at 150 °C for 86 h. The mixture was then chromatographed on a silica-gel column with hexane–ethyl acetate (9:1) to give **10** (295 mg, 86%), colorless needles (mp 111—112 °C from benzene) [Found: C, 83.20; H, 8.62%. Calcd for $C_{15}H_{18}O$: C, 83.12; H, 8.97%. δ: 1.1—2.0 (8H, m), 2.24 (1H, dd, *J*=9.5, 3 Hz), 2.2—2.5 (2H, m), 2.79 (1H, dd, *J*=9.5, 3 Hz), 3.0—3.3 (2H, m), 5.49 (1H, ddd, *J*=8, 6, 1.5 Hz), 6.15 (1H, m), and 6.20 (1H, t, *J*=8 Hz). $\nu_{C=O}$: 1670 cm^{-1}].

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