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High-pressure Cycloaddition Reaction of Tropone with Furans

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Thermal reactions of tropone with furan and 2-methoxyfuran gave mainly the endo-[4+2] cycloadducts at 3000 bar. In the latter case, the products further reacted with tropone to yield 2:1-adducts. The NMR spectral data defined their stereochemistry; predominant formation of endo-adduct is rare in the Diels-Alder reaction of furans. This must be due to the conditions employed, under which the cycloreversion is prevented.

We have recently reinvestigated the high-pressure kinetics of the electrocyclic reactions of tropone (**1**) to show the normal volume profiles for the cycloadditions of **1**.[1,2] And, the ordinary pressure effect should apply to **1**. Accordingly, hitherto unsuccessful Diels-Alder reaction of **1** with furans,[3] which has a disadvantageous tendency of cycloreversion, seems to be promising under the high-pressure conditions. Herein, we will describe the reaction of **1** with furan (**2**) and 2-methoxyfuran (**3**).

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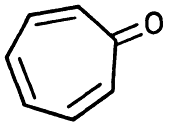

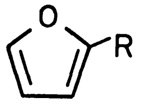

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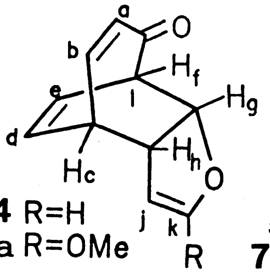

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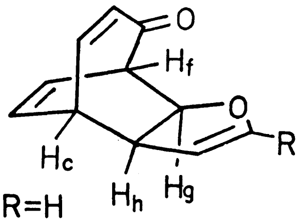

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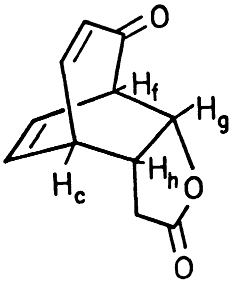

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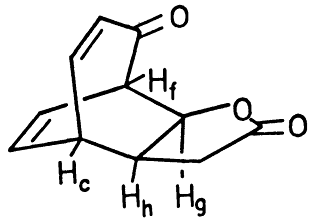

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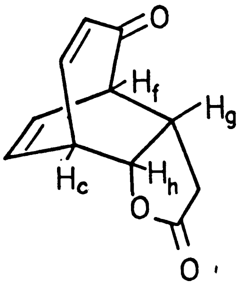
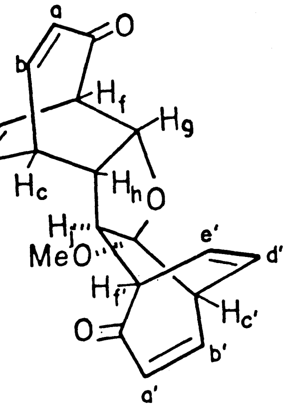


Heating of a cumene solution of **1** and **2** in a Teflon ampule placed in a pressure vessel (3000 bar)[4] at 130 °C for 10 h yielded, after silica-gel column chromatography, two 1:1-adducts, **4** (colorless oil, 6%) and **5** (colorless needles, mp 70–72 °C, 5%). A similar treatment of **1** and **3** yielded three 1:1-adducts, **6** (colorless needles, mp 138–140 °C, 35%), **7** (colorless needles, mp 137–139 °C, 13%), and **8** (colorless crystals, mp 103–105 °C, 1%).



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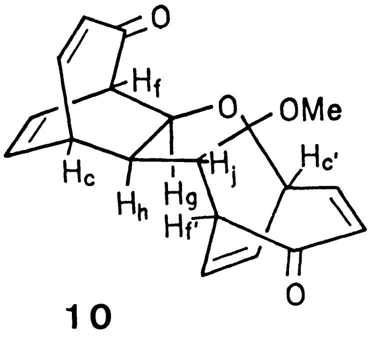

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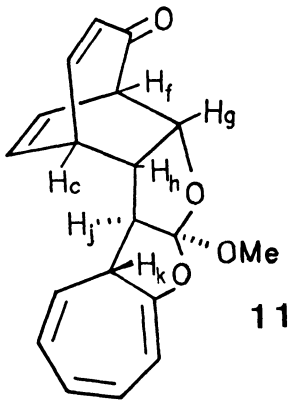

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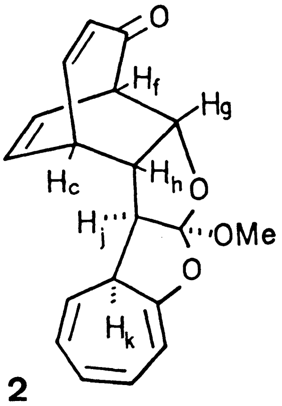

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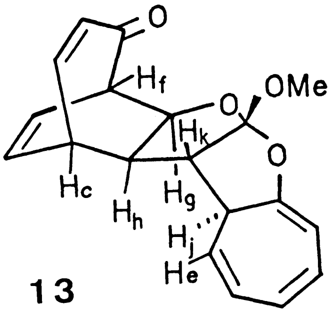

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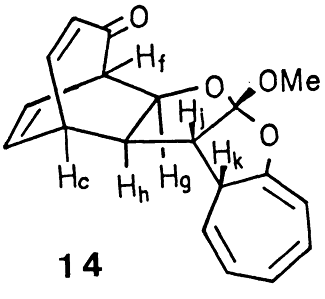

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In the latter case, there were six secondary products, **9** (colorless needles, mp 192–194 °C, 3%), **10** (colorless crystals, mp 180–182 °C, 0.5%), **11** (yellow oil, 4%), **12** (yellow oil, 3%), **13** (yellow oil, 3%), and **14** (yellow oil, 2%), which were derived from further cycloaddition of **1** to **6a** or **7a**, precursor of **6** or **7**.

The 1:1-adducts from **3** (**6**, **7**, and **8**) all possessed the lactonic carbonyl carbon signals in the ^{13}C NMR spectra (Table 1) to indicate a splitting-off of the methoxyl group under the chromatographic conditions. Structure determinations of these 1:1-adducts were straightforward from the ^{1}H NMR analysis;5) i.e., the ^{1}H NMR spectrum6) of **4** [δ=3.28(H_c,7) tdm, J=8.5, 2.5 Hz), 3.67(H_h, dtd, J=10, 2.5, 2 Hz), 3.95(H_f, dm, J=7 Hz), 4.70(H_j, td, J=2.5, 1 Hz), 5.00(H_g, ddd, J=10, 2.5, 1 Hz), 5.72(H_a, ddd, J=11, 2, 1 Hz), 6.07(H_e, ddt, J=8.5, 7, 1 Hz), 6.27(H_k, dd, J=2.5, 2 Hz), 6.40(H_d, tm, J=8.5 Hz), and 7.10(H_b, dd, J=11, 8.5 Hz)] exhibited J_{gh}=10 and J_{fg}=2.5 Hz, while that of **5** [δ=3.3–3.5(H_c and H_h, m), 4.07(H_f, tm, J=7 Hz), 4.82(H_j, t, J=2.5 Hz), 5.11(H_g, dd, J=11, 7 Hz), 5.88(H_a, dd, J=11, 2 Hz), 5.99(H_e, ddd, J=8.5, 7, 1 Hz), 6.29(H_k, dd, J=2.5, 1.5 Hz), 6.53(H_d, ddd, J=8.5, 6.5, 1 Hz), and 6.81(H_b, dd, J=11, 9 Hz)] did J_{gh}=11 and J_{fg}=7 Hz, from which the structures, endo-[4+2]8) for **4** and exo-[4+2] for **5**, were deduced.9) As far as the above coupling patterns concern, **4** and **6** [J_{gh}=8 and J_{fg}=2 Hz] were very similar, and so were **5** and **7** [J_{gh}=8 and J_{fg}=7.5 Hz].

The remaining **8** [J_{gh}=7.5 and J_{fg}=2.5 Hz] was another endo-[4+2] cycloadduct. Thus, the absence of [2+4] or [6+4] adducts should be worthy of note. In the same time, a predominant formation of endo-[4+2] cycloadducts, which must be the kinetically favored products, can be explained in terms of an inhibition of the cycloreversion process under the conditions.

Table 1. ^{13}C NMR spectra of the cycloadducts (δ)

4: 40.7, 50.4, 59.9, 81.5, 102.9, 125.2, 129.8, 136.7, 148.5, 154.2, 194.4.
5: 40.9, 49.9, 56.7, 81.9, 102.2, 125.3, 131.6, 139.5, 148.2, 151.4, 193.9.
6: 34.7, 38.9, 39.7, 59.1, 79.7, 127.2, 130.4, 136.2, 152.7, 175.9, 192.7.
7: 32.6, 39.7, 40.4, 56.3, 78.5, 124.5, 133.5, 140.2, 148.6, 176.0, 192.7.
8: 34.1, 35.1, 41.4, 57.2, 80.7, 126.2, 132.2, 136.7, 147.2, 175.8, 194.5.
9: 39.3, 43.1, 49.1, 52.2, 54.9, 58.7, 60.8, 84.8, 118.1, 125.5, 127.1, 129.7, 130.4, 136.0, 138.1, 148.5, 152.2, 194.8, 195.2.
10: 40.4, 43.7, 49.5, 52.4, 54.0, 59.4, 59.5, 85.0, 119.1, 125.9, 126.2, 130.4, 133.0, 137.8, 139.5, 148.6, 149.6, 195.2, 195.4.
11: 38.6, 47.4, 51.3, 51.8, 54.0, 59.1, 80.0, 97.1, 121.4, 124.7, 126.8, 128.1, 129.5, 130.1, 134.1, 135.7, 149.3, 152.6, 193.8.
12: 39.1, 42.6, 45.5, 50.2, 51.7, 58.8, 80.1, 99.9, 118.3, 123.9, 128.2, 128.3, 129.4, 130.2, 131.6, 135.5, 152.4, 152.7, 193.8.
13: 39.9, 48.0, 51.9, 52.1(2C), 56.8, 78.8, 96.5, 121.4, 124.6, 125.2, 126.7, 128.4, 129.5, 132.9, 134.5, 139.8, 149.4, 194.2.
14: 40.4, 42.7, 45.8, 48.5, 51.8, 56.9, 78.8, 99.6, 119.1, 123.8, 125.3, 128.2, 129.2, 131.7, 132.7, 139.7, 150.0, 153.1, 194.5.

Structures of 2:1-adducts were determined by detailed 400 MHz-decoupled NMR analyses or measurements of the nuclear Overhauser effect (NOE). The **9** and **10**, having two carbonyl carbon signals in the ^{13}C NMR spectra, were [4+2] [4+2] cycloadducts. The ^{1}H NMR spectra of **9** [δ=2.46(H_j, d, J=4.5 Hz), 2.67(H_h, ddd, J=8.5, 4.5, 2 Hz), 3.19(3H, s), 3.2–3.5(H_c and $H_{f'}$, m), 3.58(H_f, dm, J=7 Hz), 3.66($H_{c'}$, ddt, J=8.5, 7.5, 1 Hz), 4.74(H_g, dt, J=8.5, 1.5 Hz), 5.62(H_a, ddd, J=11, 2, 0.5 Hz), 5.76($H_{a'}$, ddd, J=11, 2, 1 Hz), 6.11($H_{e'}$, tm, J=7.5 Hz), 6.16(H_e, ddt, J=8.5, 7, 1 Hz), 6.50(H_d, ddd, J=8.5, 7.5, 1.5 Hz), 6.51($H_{d'}$, tm, J=7.5 Hz), 6.84($H_{b'}$, dd, J=11, 8.5 Hz), 7.02(H_b, dd, J=11, 8.5 Hz)] and **10** [δ=2.4(H_h, br m), 2.58(H_j, d, J=4 Hz), 3.10(3H, s), 3.43($H_{f'}$, dm, J=6.5 Hz), 3.4(H_c, br m), 3.75($H_{c'}$, ddt, J= 8.5, 7.5, 1 Hz), 3.87(H_f, m), 4.65(H_g, dd, J=8.5, 6.5 Hz), 5.79(H_a or $H_{a'}$, ddd, J=11, 2, 1 Hz), 5.93($H_{a'}$ or H_a, ddd, J=11, 2, 1 Hz), 5.94(H_e, ddd, J=8.5, 7.5, 1 Hz), 6.18($H_{e'}$, tm, J=7.5 Hz), 6.50(H_d or $H_{d'}$, ddd, J=8.5, 7.5, 1 Hz), 6.52($H_{d'}$ or H_d, ddd, J=8.5, 7.5, 1 Hz), 6.85(H_b, dd, J=11, 8.5 Hz), 6.91($H_{b'}$, dd, J=11, 8.5 Hz)] revealed J_{gh}=8.5, J_{fg}=1.5, and $J_{jf'}$=0 Hz for **9** and J_{gh}=8.5, J_{fg}=6.5 and $J_{jf'}$= 0 Hz for **10**, and clarified their structures to be endo-[4+2] endo-[4+2] and exo-[4+2] endo-[4+2] adducts, respectively. On the other hand, **11**–**14** each revealed only one carbonyl carbon signal in the ^{13}C NMR spectrum and thus are [4+2] [8+2] cycloadducts. Their coupling sequence of the methine protons determined the stereochemistry;10) e.g., **11** [J_{fg}=2, J_{gh}=8.5, J_{jk}=0, J_{hj}=7, and J_{ch}=2 Hz] and **12** [J_{fg}=2, J_{gh}=8.5, J_{jk}=7.5, and J_{hj}=7.5 Hz] are derived from **6a**, while **13** [J_{fg}=7, J_{gh}=8.5, J_{jk}=1, and J_{hj}=5 Hz] and **14** [J_{fg}=7, J_{gh}=8.5, J_{jk}=7.5, J_{hj}=6, and J_{ch}=5 Hz] are from **7a**. The assignments were supported by NOE observations; i.e., an irradiation with the frequency of H_h-signal of **11** enhanced its H_g- and H_k-signals, and similar irradiations with the frequencies of H_h and H_j of **13** enhanced the H_g- and H_e-signals, respectively. The ^{13}C NMR data were compiled in Table 1.11)

The ordinary reaction of **1** with **2** in a glass tube, sealed under atmospheric pressure, at 130 °C gave no adduct, while **1** with **3** yielded only **6** (13%) and **7** (3%). Although, the present pressure, 3000 bar, being a limit of our apparatus, is not high compared with the ones employed in other preparative works, the observed pressure effect was significant, and under higher pressures, the yields and the endo/exo-selectivity of the reaction would be improved.

Consequently, the high-pressure cycloadditions of the troponoids will be of synthetic value.

References

1) H. Takeshita, S. Sugiyama, and T. Hatsui, Chem. Lett., 1984, 1855; Bull. Chem. Soc. Jpn., 58, 2490 (1985).

2) H. Takeshita, S. Sugiyama, and T. Hatsui, J. Chem. Soc., Perkin Trans. 2, 1986, in press.

3) I. Saito (D. Sc. Thesis, Tohoku University, 1975) observed a formation of cycloadducts in the reaction of **1** with **2** in a methanolic $HClO_4$. This could be, however, the reaction of **1** with 5-methoxyoxolene formed in situ.

4) In this study, the same apparatus was used as that of the previous study.

5) S. Itô, H. Takeshita, and Y. Shoji, Tetrahedron Lett., 1969, 1815.

6) The NMR spectra were recorded either by JEOL GX 400 Model or by FX 100 Model spectrometers in $CDCl_3$ solutions, and the chemical shifts were expressed in units from the internal Me_4Si.

7) To specify the protons, the Roman characters were used as depicted.

8) For a convenience, we adopted the expression, [m+n], as the cycloadducts with mπ system of **1** to nπ system of furans.

9) A high-field shift of H_b-signals in the exo-[4+2] adducts is parallel to the cyclopentadiene adducts of **1**. See S. Itô, K. Sakan, and Y. Fujise, Tetrahedron Lett., 1970, 2873.

10) For analyses of stereochemistry of [8+2] adducts, there are good model compounds already investigated. See R. Gomper, A. Studeneer, and W. Elser, Tetrahedron Lett., 1968, 1019; T. S. Cantrell, ibid., 1975, 907.

11) The ^{1}H NMR spectra of the products other than recorded in this text showed pertinent figures, and the full data will be reported elsewhere.

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