X-Ray Structure Determination of Stereoisomers with Respect to Cyclobutene Ring of 10,10-Ethylenedioxy-1-methoxycarbonyl-2-methyl-7-oxatricyclo[6.4.0.0^{2,5}]dodec-3-en-6-one

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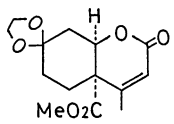
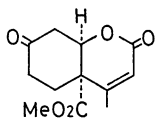
Synopsis. The structures of the title compounds were determined by X-ray crystallographic analysis. The results lead to a revision of the previously proposed structure for photochemical cycloadduct of 9,9-ethylenedioxy-6-methoxycarbonyl-5-methyl-2-oxabicyclo[4.4.0]dec-4-en-3-one with acetylene.

Cyclobutene compounds provide unique reactions assisted by the inherent strain in the four-membered ring. The characteristic reactions such as electrocyclic ring opening and oxa-di-π-methane rearrangement of cyclobutene derivatives have enormous potential for applications in organic synthesis[1] and it becomes of interest to investigate the ground- and excited-state reactions of cyclobutene compounds and their valence isomers.[2] In a previous paper, we reported that the [2+2]-photochemical cycloaddition of 9,9-ethylenedioxy-6-methoxycarbonyl-5-methyl-2-oxabicyclo[4.4.0]dec-4-en-3-one (**1**) with acetylene gave adduct (**2**), mp 130—131 °C, as a single compound in 62% yield, which was used as a key intermediate for the sesquiterpenoid synthesis.[3] At the moment, an α-*cis*-fused cyclobutene moiety of the photochemical adduct was tentatively proposed on the basis of the steric consideration that the stereoselectivity of this reaction derives from the steric influence of the ethylenedioxy group which blocks approach of acetylene from the β-face of the molecule.[4] In addition, the other stereoisomer of **2**, mp 154—156 °C, was prepared by the irradiation of 6-methoxycarbonyl-5-methyl-2-oxabicyclo[4.4.0]dec-4-ene-3,9-dione (**3**) in acetone solution in



1



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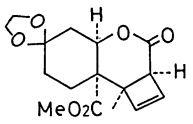
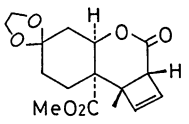


2a



2b

the presence of acetylene followed by acetalization of the keto cyclobutene product with ethylene glycol. In this paper, we describe on the crystal structures of the stereoisomers, and the structural revision of the previously reported cyclobutene adduct obtained from **1**.[3]

Experimental

Melting points are uncorrected. IR spectra were measured in $CHCl_3$ with a Hitachi 270-30 spectrophotometer. ^{1}H NMR spectra were obtained in $CDCl_3$ with a Hitachi R-1500 spectrometer. Chemical shifts are given in δ values (ppm) downfield from the internal TMS reference. Column chromatography was carried out with Fuji-Davison BW-300 silica gel.

Materials. *cis-cisoid-cis-* and *cis-transoid-cis*-10,10-Ethylenedioxy-1-methoxycarbonyl-2-methyl-7-oxatricyclo-[6.4.0.0^{2,5}]dodec-3-en-6-ones (**2a** and **2b**) were synthesized by the following methods.

2a: An acetonitrile solution (600 cm^3) of **1** (200 mg) was irradiated with a 500-W high-pressure mercury lamp through a Vycor filter under a continuous introduction of acetylene at 10—15 °C for 40 min. After removing the solvent under reduced pressure, the residue was subjected to column chromatography on silica gel using ethyl acetate-benzene as eluent to give **2a** as a single compound in 65% yield; mp 130—131 °C (ethyl acetate-hexane); IR 1740 cm^{-1}; ^{1}H NMR δ=1.27 (3H, s, -CH_3), 1.5—2.1 (4H, m, -CH_2- ×2), 2.27 (2H, d, J=4.0 Hz, -CH_2-), 3.23 (1H, t, J=1.2 Hz, -CH=CH-CH), 3.77 (3H, s, -CO_2CH_3), 3.8—4.0 (4H, m, -OCH_2CH_2O-), 4.91 (1H, t, J=4.0 Hz, -CH-O-), 6.19 and 6.32 (each 1H, dd, J=1.2 and 2.9 Hz, -CH=CH-); MS m/z 308 (M$^+$); Found: C, 62.60; H, 6.68%. Calcd for $C_{16}H_{20}O_6$: C, 62.33; H, 6.54%.

2b: An acetone solution (600 cm^3) of **3** (370 mg) was irradiated with a 500-W high-pressure mercury lamp through a Vycor filter under a continuous introduction of acetylene at 10—15 °C for 30 min. After removing the solvent followed by column chromatography on silica gel using ethyl acetate-hexane as eluent, two kinds of keto cyclobutene adducts (200 mg) were obtained. Acetalization of a mixture of the inseparable adducts (370 mg) obtained was performed in a benzene solution (30 cm^3) with ethylene glycol (1.5 cm^3) in the presence of *p*-toluenesulfonic acid (10 mg) under reflux for 30 min. After the usual workup, the crude product was column chromatographed on silica gel using ethyl acetate-benzene as eluent followed by recrystallization from acetone-hexane to give **2b** (ca. 300 mg) along with a small amount of **2a**. Mp 154—156 °C; IR 1740 cm^{-1}; ^{1}H NMR δ=1.31 (3H, s, -CH_3), 1.4—2.3 (6H, m, -CH_2- ×3), 3.23 (1H, d, J=0.9 Hz, -CH=CH-CH), 3.78 (3H, s, -CO_2CH_3), 3.8—4.1 (4H, m, -OCH_2CH_2O-), 5.21 (1H, dd, J=2.6 and 4.7 Hz, -CH-O-), 6.11 and 6.21 (each 1H, dd, J=0.9 and 2.6 Hz, and d, J=2.6 Hz, -CH=CH-); MS m/z 308 (M$^+$); Found: C, 62.31; H, 6.63%. Calcd for $C_{16}H_{20}O_6$: C, 62.33; H, 6.54%.

X-Ray Analysis. The single crystals were obtained by recrystallization from acetone-hexane for **2a** and from ethyl

Table 1. Crystal Data for **2a** and **2b**

Compound	**2a**	**2b**
Formula	$C_{16}H_{20}O_6$	$C_{16}H_{20}O_6$
Molecular weight	308.32	308.32
Crystal system	Monoclinic	Triclinic
Space group	$P2_1/c$	$P\bar{1}$
a/Å	6.913(1)	11.719(3)
b/Å	24.226(1)	10.253(3)
c/Å	9.198(1)	6.707(2)
α/°	90.0	107.88(3)
β/°	101.39(1)	95.58(4)
γ/°	90.0	94.45(6)
V/Å^3	1510.0(2)	758.4(4)
Z	4	2
D_x	1.36	1.35
Final R	0.052	0.074

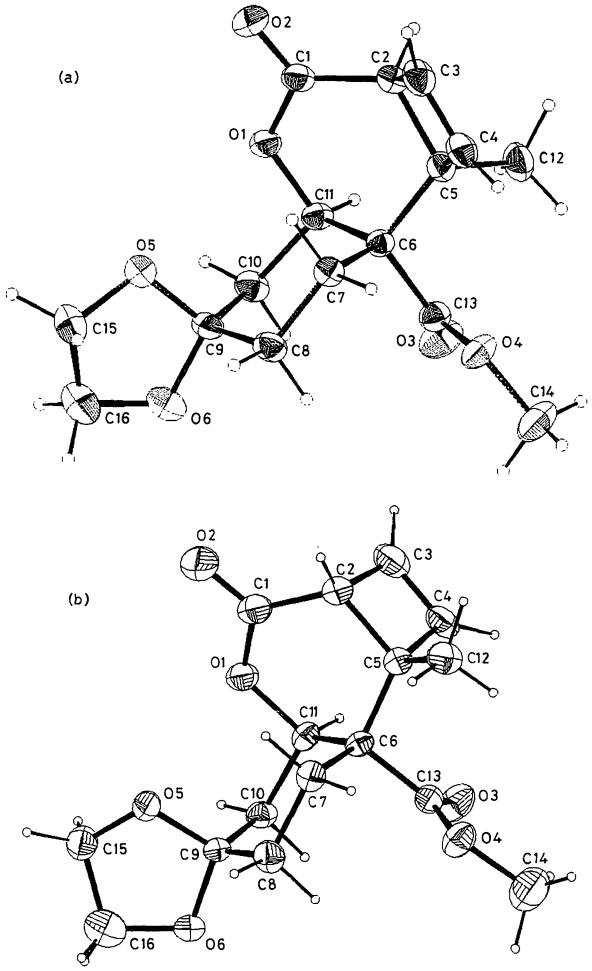


Fig. 1. ORTEP[6] views of **2a** (a) and **2b** (b) with the atom-numbering.

acetate-hexane for **2b**. Crystal data are summarized in Table 1. All unique diffraction intensities with $2\theta<130°$ for **2a** and $2\theta<50°$ for **2b** were collected in the variable speed ω-scan mode on a Rigaku AFC-5UD four-circle diffractometer with graphite monochromated Cu K_α (λ=1.5418 Å) and Mo K_α (λ=0.7107 Å) radiations, respectively. A total of 2193 and 1636 reflections ($|F_o|\geqq 3\sigma(F_o)$) for **2a** and **2b**, respectively, were judged to be observed after correction for Lorentz, polarization, and background effects. A phasing models

Table 2. Atomic Coordinates and Equivalent Isotropic Thermal Parameters of **2a** and **2b** with Estimated Standard Deviations in Parentheses

$$B_{eq}=\frac{4}{3}\sum_i\sum_j B_{ij}(\boldsymbol{a}_i\cdot\boldsymbol{a}_j)$$

Atom	x	y	z	B_{eq}/Å^2
2a				
O(1)	0.2911(3)	0.11820(8)	0.4856(2)	3.4
O(2)	0.2231(3)	0.04360(9)	0.6012(2)	4.9
O(3)	0.3002(4)	0.18602(9)	0.0638(2)	4.9
O(4)	0.4726(3)	0.11382(8)	0.0075(2)	4.1
O(5)	0.6939(3)	0.15712(9)	0.5966(2)	4.3
O(6)	0.7791(3)	0.22796(9)	0.4584(3)	5.1
C(1)	0.2257(4)	0.0655(1)	0.4846(3)	3.4
C(2)	0.1547(4)	0.0382(1)	0.3370(3)	3.4
C(3)	0.2547(5)	−0.0147(1)	0.3037(4)	4.2
C(4)	0.3093(4)	0.0051(1)	0.1839(3)	3.7
C(5)	0.2230(4)	0.0620(1)	0.1963(3)	3.1
C(6)	0.3758(4)	0.1098(1)	0.2379(3)	2.6
C(7)	0.5851(4)	0.0896(1)	0.3062(3)	2.9
C(8)	0.7260(4)	0.1385(1)	0.3437(3)	3.5
C(9)	0.6591(4)	0.1793(1)	0.4502(3)	3.4
C(10)	0.4449(4)	0.1963(1)	0.4017(3)	3.5
C(11)	0.3039(4)	0.1484(1)	0.3501(3)	3.0
C(12)	0.0470(5)	0.0769(1)	0.0730(3)	4.5
C(13)	0.3774(4)	0.1421(1)	0.0956(3)	3.3
C(14)	0.4792(6)	0.1392(2)	−0.1359(4)	5.6
C(15)	0.8831(5)	0.1758(2)	0.6714(4)	5.9
C(16)	0.9136(6)	0.2280(2)	0.5951(5)	6.6
2b				
O(1)	0.7393(3)	0.1399(4)	0.9133(6)	3.9
O(2)	0.8014(4)	−0.0634(4)	0.8317(8)	6.5
O(3)	0.8191(4)	0.5256(4)	0.8416(6)	5.1
O(4)	0.7420(3)	0.4532(4)	0.5063(6)	4.6
O(5)	0.4960(3)	0.1123(4)	0.7979(6)	4.2
O(6)	0.4226(3)	0.3171(4)	0.8563(7)	4.7
C(1)	0.8083(5)	0.0504(6)	0.8143(9)	4.5
C(2)	0.8954(5)	0.0957(6)	0.6928(9)	4.3
C(3)	0.9996(5)	0.1845(7)	0.8374(10)	5.7
C(4)	0.9823(5)	0.2975(7)	0.7855(9)	4.7
C(5)	0.8766(4)	0.2264(5)	0.6234(8)	3.6
C(6)	0.7596(4)	0.2816(5)	0.6765(8)	3.0
C(7)	0.6574(4)	0.1976(5)	0.5167(8)	3.4
C(8)	0.5412(5)	0.2498(6)	0.5789(9)	4.1
C(9)	0.5229(4)	0.2498(5)	0.7974(8)	3.5
C(10)	0.6243(4)	0.3265(5)	0.9606(8)	3.4
C(11)	0.7405(4)	0.2802(5)	0.8999(8)	3.3
C(12)	0.8983(5)	0.2044(6)	0.3933(9)	4.7
C(13)	0.7760(4)	0.4345(5)	0.6890(8)	3.6
C(14)	0.7622(7)	0.5942(7)	0.4997(12)	7.1
C(15)	0.4102(5)	0.1147(6)	0.9336(10)	4.7
C(16)	0.3428(6)	0.2245(8)	0.9046(15)	8.3

obtained by MULTAN 78[5] were refined using the Rigaku program system. Block-diagonal least-squares refinement with anisotropic thermal parameters for the non-hydrogen atoms and isotropic ones for the hydrogen atoms converged to the final R=0.052 for **2a** and R=0.074 for **2b**, respectively. Unit weight was used for all reflections.

Results and Discussion

By using the IR, ^{1}H, and ^{13}C NMR spectroscopic data of both products **2**, we could not identify the stereochemistry with respect to the cyclobutene ring junction as **2a** or **2b**. Single-crystal X-ray analyses were employed in order to confirm the stereostructures

of these crystalline compounds. Each complete structure and stereochemistry was unequivocally established; one product, mp 130—131 °C, has β-cis-fused cyclobutene ring as **2a** and the other, mp 154—156 °C has α-cis form as **2b** depicted, respectively. The X-ray analysis suggested that the photochemical cycloaddition of **1** with acetylene occurs from the β-side to yield **2a**. Thus, a predictable conformation with the α-axial methoxycarbonyl group of the dihydro-2-pyrone ring seems to derive the steric influence on the α-face of the molecule instead.[4] The final atomic parameters are listed in Table 2.[7] Views of the structures of **2a** and **2b** are shown in Fig. 1. In **2a** and **2b**, the cyclohexane ring has a chair form and the δ-lactone ring has a distored boat form.

References

1) For examples, see: T. Kametani, K. Suzuki, H. Nemoto, and K. Fukumoto, *J. Org. Chem.*, **44**, 1036 (1979); S. R. Wilson, L. R. Phillips, and K. J. Natalie, Jr., *J. Am. Chem. Soc.*, **101**, 3340 (1979).

2) For examples, see: Y. Sugihara, T. Sugimura, and I. Murata, *J. Am. Chem. Soc.*, **103**, 6738 (1981); M. Cavazza, *J. Chem. Soc., Perkin Trans. 1*, **1985**, 2283.

3) J. D. White, T. Matsui, and J. A. Thomas, *J. Org. Chem.*, **46**, 3376 (1981).

4) One of the structural features of **1** based on the molecular models and the ^{1}H NMR spectral data indicated that the ethylenedioxy group is directed towards the double bond of the dihydro-2-pyrone ring, resulting a big steric influence on the β-face.

5) P. Main, S. E. Hull, L. Lessinger, G. Germain, J. P. Declercq, and M. M. Woolfson, "MULTAN 78, A System of Computer Programs for the Automatic Solution of Crystal Structures from X-ray Diffraction Data," University of York, England (1978).

6) C. K. Johnson, ORTEP II, Report ORNL-3794, Oak Ridge National Laboratory, Tennessee (1976).

7) The complete tables of observed and calculated structure factors, isotropic thermal parameters and the atomic coordinates of hydrogen atoms, anisotropic thermal parameters of non-hydrogen atoms, and bond lengths and angles are deposited as Document No. 8919 at the Office of the Editor of Bull. Chem. Soc. Jpn.