Synthesis and structure of 2,4-di-*tert*-butyl-1-chloro-6-methyltricyclo[4.1.0.$0^{2,7}$]hept-4-en-3-one

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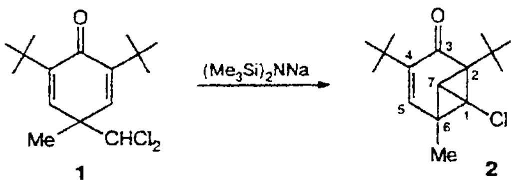
The reaction of 2,6-di-*tert*-butyl-4-dichloromethyl-4-methylcyclohexa-2,5-dien-1-one with $(Me_3Si)_2NNa$ yielded 2,4-di-*tert*-butyl-1-chloro-6-methyltricyclo[4.1.0.$0^{2,7}$]hept-4-en-3-one (substituted tropovalene). The structure of the title compound was established by ^1H and ^{13}C NMR spectroscopy and X-ray diffraction analysis.

Key words: tropovalene, synthesis, structure, mechanism of formation.

Previously, we have found that the reaction of 4-dibromomethyl-4-methylcyclohexa-2,5-dien-1-one with sodium bis(trimethylsilyl)amide, $(Me_3Si)_2NNa$, yielded a spiro compound.[1] As part of continuing studies of *gem*-halomethyl-substituted cyclohexadienones, we extended the range of dienones that can react with $(Me_3Si)_2NNa$. In this work, we demonstrated that the analogous reaction of 2,6-di-*tert*-butyl-4-dichloromethyl-4-methylcyclohexa-2,5-dien-1-one (**1**) (Scheme 1) afforded substituted tropovalene, 2,4-di-*tert*-butyl-1-chloro-6-methyltricyclo[4.1.0.$0^{2,7}$]hept-4-en-3-one (**2**), in a yield of 78%.

Scheme 1



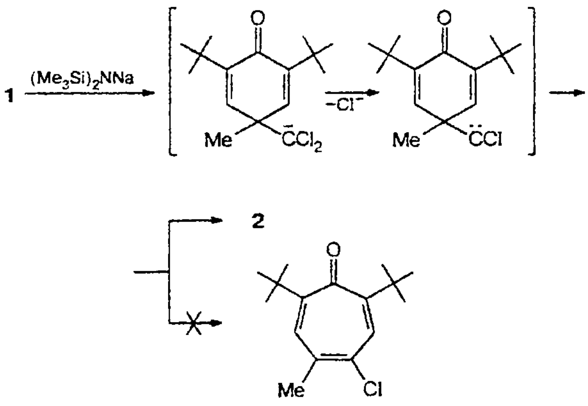
Tropovalene, a valence isomer of tropone, is of chemical interest as a starting compound in the synthesis of octabisvalene,[2] heptalvalene,[3] cross-conjugated polyenes,[4] and difficult to obtain 3-substituted tropones.[5] From the theoretical standpoint, tropovalene is a model compound in studies of the behavior of bicyclobutane, which is incorporated into its rigid framework, under the conditions of thermolysis.[6]

Tropovalene was prepared for the first time from quadricyclon-7-one (heating in C_5H_5N at 130 °C for 140 h).[7] A method has been reported[8] for the preparation of tropovalene by irradiation of the stereoisomeric cycloadducts that are the products of cycloaddition of acetylene to 4-acetoxycyclopent-2-en-1-one followed by β-elimination of MeCOOH on Al_2O_3 (see also Ref. 9). Substituted tropovalenes were synthesized by the photoreaction of 4-acetoxycyclopent-2-en-1-one with substituted acetylenes.[5,10] 4-Acetoxytropovalene was prepared from bicyclo[3.2.0]hept-6-en-2-one.[11] Analysis of the published data[5,6,8–11] demonstrated that the synthesis of the tropovalene skeleton is very complicated and elaborate. We developed a simple and efficient method for the preparation of tricycloheptenone. In addition, the tropovalene thus obtained contains a halogen atom at position 1, and we believe that it is a promising compound for further studies devoted to synthesis.

Results and Discussion

It has been suggested that the presence of two bulky *tert*-butyl groups in the molecule of initial dienone **1** should produce steric hindrances to attack of a carbanion on the carbonyl group, which can occur after deprotonation of the Cl_2CH group of another dienone molecule under the action of $(Me_3Si)_2NNa$ (see Ref. 1). In this case, the carbanion formed should lose the halide ion to form carbene, which can undergo rearrangement to form chlorine-substituted tropone (Scheme 2).

Scheme 2



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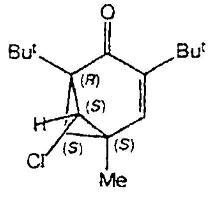
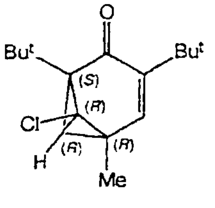
However, instead of the expected tropone, its valence isomer, tropovalene 2, was isolated from the reaction mixture in a high yield. The data of elemental analysis and mass spectrometry (see Experimental) are consistent with the molecular formula $C_{16}H_{23}ClO$, which corresponds to both possible isomers. Therefore, we used NMR spectroscopy and X-ray diffraction analysis to unambiguously determine the structure of the product.

The ^1H NMR spectrum of the compound under study has a singlet corresponding to the olefin proton and a singlet at δ 3.39 (which corresponds to the doublet at δ 41.01 with the spin-spin coupling constant $^1J_{C-H}$ = 214 Hz in the ^{13}C NMR spectrum) in addition to the signals of two nonequivalent Bu^t groups and one Me group. The order of magnitude of $^1J_{C-H}$ is typical of only a limited number of classes of compounds and agrees well with the presence of a bicyclobutane fragment with a bridgehead H atom in molecule 2. The complete assignment of the signals in the ^1H and ^{13}C NMR spectra (see Experimental) was made using selective heteronuclear decoupling and the homonuclear Overhauser effect. The ^1H and ^{13}C chemical shifts of the tropovalene framework are close to those reported previously[5,7,8,10,11] for related compounds. It should be noted that the proton and carbon signals of the Bu^t group at the C(2) atom are broadened even at −20 °C, which apparently is associated with hindered free rotation of the Bu^t group at the C(2) atom (compared to the Bu^t group at the C(4) atom) due to substantial steric hindrances.

The tropovalene structure of compound 2 was unambiguously established by X-ray structural analysis (Fig. 1). The centrosymmetric crystal structure consists of enantiomeric molecules, which have the (*S*)(*S*)(*S*)(*R*) and (*R*)(*R*)(*R*)(*S*) configurations:



(*S*)(*S*)(*S*)(*R*)



(*R*)(*R*)(*R*)(*S*)

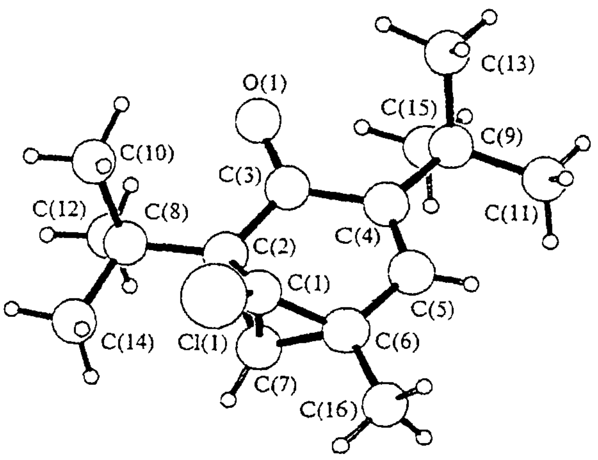


Fig. 1. Molecular structure of compound 2.

The atomic coordinates of molecule 2 are given in Table 1. In Table 2, the experimental geometric parameters of molecule 2 are compared with the bond lengths and bond angles that were calculated by the semiempirical PM3 method with geometry optimization. Both the experimental and calculated data demonstrate that in molecule 2, the carbonyl group and the double bond are in a single plane. The largest discrepancies between the X-ray structural data and the calculated characteristics are observed in the C—Cl and C(1)—C(7) bond lengths (see Table 2). The calculations underestimated the C—Cl bond length (by 0.084 Å) and overestimated the C(1)—C(7) bond length (by 0.034 Å). Taking into account the so-called typical values of the C—Cl bond lengths for the C atom with different hybridizations ($C(sp^3)$—Cl is 1.77 Å, $C(sp^2)$—Cl is 1.71 Å, and C(sp)—Cl is 1.64 Å), it can be concluded that the calculations overestimated the s-character of the bridgehead C atom of the bicyclobutane fragment of the molecule. According to the results of calculations, the character of the C(1) atom is close to sp, whereas the X-ray structural data indicate that the character of the C(1) atom is close to sp^2. The differences between the calculated and experimental lengths of the other bonds in molecule 2 are no more than 0.02 Å.

The energy of the highest occupied MO of tropovalene 2 calculated by the PM3 method is −9.65 eV. The shape of this MO is indicative of attractive interaction between the C(2)C(3)C(4)C(5)C(6) σ-system and the C(7)C(1)Cl π-system (Scheme 3).

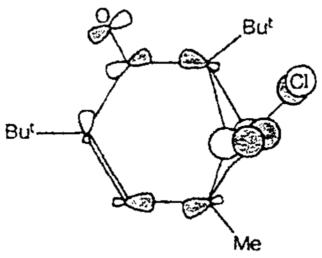
Table 1. Atomic coordinates (×10^4) in the structure of 2

Atom	*x*	*y*	*z*
Cl(1)	1425(1)	309(1)	6083(1)
O(1)	3536(1)	4077(2)	6991(2)
C(1)	1943(2)	1592(2)	5451(3)
C(2)	2964(2)	2212(2)	5786(2)
C(3)	2935(2)	3627(2)	6096(2)
C(4)	2152(2)	4441(2)	5321(2)
C(5)	1455(2)	3809(3)	4502(3)
C(6)	1473(2)	2403(3)	4335(3)
C(7)	2467(2)	1781(3)	4459(3)
C(8)	3867(2(	1420(2)	6463(3)
C(9)	2183(2)	5901(2)	5470(3)
C(10)	4819(2)	2063(4)	6273(4)
C(11)	1327(3)	6530(4)	4536(4)
C(12)	3884(3)	1330(4)	7878(3)
C(13)	3155(3)	6405(4)	5215(5)
C(14)	3860(3)	55(3)	5941(5)
C(15)	2099(3)	6278(3)	6806(3)
C(16)	627(3)	1822(4)	3389(4)

Table 2. Experimental (X-ray structural data) and calculated values of selected bond lengths (d) and bond angles (ω) in molecule 2

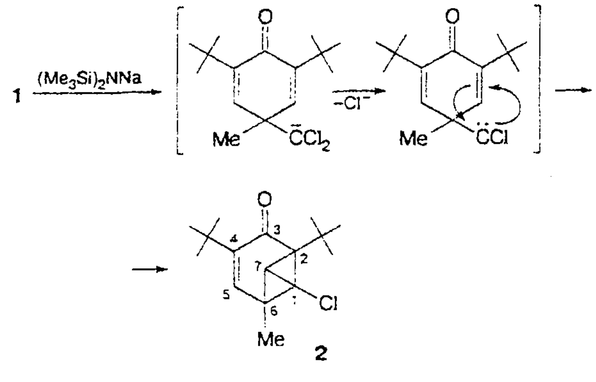
Bond	d/Å		Angle	ω/deg	
	X-ray	PM3		X-ray	PM3
Cl(1)—C(1)	1.729(3)	1.645	C(7)—C(1)—C(6)	61.0(2)	60.7
O(1)—C(3)	1.226(3)	1.216	C(7)—C(1)—C(2)	61.9(2)	60.9
C(1)—C(7)	1.443(4)	1.477	C(6)—C(1)—C(2)	99.7(2)	98.4
C(1)—C(6)	1.505(4)	1.522	C(7)—C(1)—Cl(1)	136.5(2)	142.3
C(1)—C(2)	1.522(4)	1.524	C(6)—C(1)—Cl(1)	127.8(2)	129.3
C(2)—C(3)	1.513(3)	1.527	C(2)—C(1)—Cl(1)	132.5(2)	132.0
C(2)—C(7)	1.526(4)	1.522	C(3)—C(2)—C(1)	113.4(2)	116.0
C(2)—C(8)	1.542(3)	1.542	C(3)—C(2)—C(7)	118.0(2)	116.0
C(3)—C(4)	1.483(4)	1.502	C(1)—C(2)—C(7)	56.2(2)	58.0
C(4)—C(5)	1.333(4)	1.343	C(5)—C(4)—C(3)	115.4(2)	117.6
C(4)—C(9)	1.527(3)	1.519	C(5)—C(4)—C(9)	124.1(2)	121.1
C(5)—C(6)	1.475(4)	1.472	C(3)—C(4)—C(9)	120.5(2)	121.2
C(5)—H(5)	0.92(3)	1.101	C(7)—C(6)—C(1)	57.5(2)	58.2
C(6)—C(7)	1.498(4)	1.516	C(1)—C(7)—C(6)	61.5(2)	61.1
C(6)—C(16)	1.504(4)	1.501	C(1)—C(7)—C(2)	61.6(2)	61.1
C(7)—H(7)	0.96(3)	1.086	C(6)—C(7)—C(2)	99.8(2)	98.8
			C(1)—C(7)—H(7)	132(2)	141.6

Scheme 3



It can be suggested that the formation of substituted tropovalene 2 proceeds as the intramolecular cycloaddition of carbene, which forms as a result of the reaction of the *gem*-dichloromethyl group of dienone 1 with $(Me_3Si)_2NNa$, at one of two double bonds of this homotopic molecule (Scheme 4) to yield an equimolar mixture of the (*S*)(*S*)(*S*)(*R*) and (*R*)(*R*)(*R*)(*S*) isomers.

Scheme 4



Experimental

The ^1H and ^{13}C NMR spectra were recorded on a Varian VXR-400 spectrometer in CD_2Cl_2 at 30 °C with $SiMe_4$ as the internal standard. The IR spectrum was obtained on a UR-20 instrument in CCl_4. The UV spectrum was recorded on a CARY-219 spectrophotometer in EtOH. The GLC-mass spectrum was measured on an MS-1303 spectrometer.

The X-ray data were collected on a four-circle CAD-4 diffractometer (graphite monochromator, Mo-Kα radiation). The monoclinic unit cell parameters were determined by automatic indexing using 22 reflections. The space group is $P2_1/c$. Intensities of 3161 reflections (θ_{max} = 26°, ω-scanning technique) were measured from a platelet-like crystal of dimensions of 0.45×0.20×0.08 mm (monoclinic crystal system). The structure was solved and refined using 2994 independent reflections of which 1688 reflections had $I > 2\sigma(I)$. The structure was solved by the direct methods using the SHELXS-96 program and refined using the SHELXL-93 program.

The geometry of the molecule was calculated by the semiempirical PM3 method[12] using the HyperChem Release 4 program package.

2,6-Di-*tert*-butyl-4-dichloromethyl-4-methylcyclohexa-2,5-dien-1-one (1) was prepared according to a procedure reported previously.[13]

2,4-Di-*tert*-butyl-1-chloro-6-methyltricyclo[4.1.0.0^{2,7}]hept-4-en-3-one (2). $(Me_3Si)_2NNa$ ($2.0 \cdot 10^{-3}$ mol) was added in three portions with intense stirring to a solution of compound 1 ($1.0 \cdot 10^{-3}$ mol) in a mixture of benzene (3 mL) and pentane (1 mL) under an atmosphere of argon at 5 °C. After 40 min, H_2O (5 mL) was added. The reaction mixture was extracted with ether (10 mL) and washed with H_2O (2×5 mL). The solution was passed rapidly (rough vacuum of a water-jet pump) through a silica gel layer (the height was 2 cm, the diameter was 0.5 cm). After evaporation of the solvent, product 2 was obtained in a yield of 204 mg (78%), m.p. 91—92 °C (from MeOH). Found (%): C, 71.73; H, 8.61; Cl, 13.56. $C_{16}H_{23}ClO$. Calculated (%): C, 72.04; H, 8.63; Cl, 13.32. IR (CCl_4), ν/cm^{-1}: 1690 (C=O). UV ($CHCl_3$), λ_{max}/nm (ε/L mol^{-1} cm^{-1}): 256 (4000), 365 (86). ^1H NMR (CD_2Cl_2), δ: 1.09 (s, 9 H, $Me_3C(4)$); 1.18 (s, 9 H, $Me_3C(2)$); 1.35 (s, 3 H, Me); 3.39 (s, 1 H, H(7)); 6.49 (s, 1 H, H(5)). ^{13}C NMR (CD_2Cl_2), δ: 17.72 (q, Me, ^1J = 126 Hz); 28.02 (q, $\underline{Me}_3C(2)$, ^1J = 126 Hz); 29.21 (q, $\underline{Me}_3C(4)$, ^1J = 126 Hz); 33.95 (s, $\underline{C}Me_3$); 34.02 (s, $\underline{C}Me_3$); 41.01 (d, C(7), ^1J = 214 Hz); 41.94 (s, C(6)); 63.44 (s, C(1)); 64.82 (s, C(2)); 142.21 (s, C(4)); 142.54 (d, C(5), ^1J = 157 Hz); 193.28 (s, C(3)). MS (50 eV), *m/z*: 268.266 [M^+].

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