

A Note on the Sodium Reduction of Hexamethylacetone and the Structure of a Supposed Tetra-(*t*-butyl)-ethylene Glycol

LENNART EBERSON

Department of Organic Chemistry, University of Lund, Lund, Sweden

By sodium reduction of hexamethylacetone in diethyl ether solution, no tetra-(*t*-butyl)-ethylene glycol could be isolated. The solid compound with m.p. 115–118°, previously assigned this structure, was found to be 1,1,4,4-tetra-(*t*-butyl)-butane-1,4-diol, and furthermore di-(*t*-butyl)-ethylcarbinol could be isolated. This was probably due to participation of diethyl ether in the reaction, since these products were not formed when the reduction was run in the absence of solvent.

The fact that the sodium reduction of hexamethylacetone has been claimed to give two compounds with a composition corresponding to tetra-(*t*-butyl)-ethylene glycol is of considerable interest, since it indicates that this compound might exist in two stable conformations with *gauche* and *trans* hydroxyl groups, respectively, due to restricted rotation about the central C—C bond.

A compound with m.p. 85–86°, assigned the structure of tetra-(*t*-butyl)-ethylene glycol, was isolated by Favorsky and Nazarov¹ in 35 % yield by treating hexamethylacetone with sodium at 100–120° for 5–6 h and then adding absolute ether, allowing the resultant mixture to stand for a week at room temperature before working it up. In the hands of Stevens and Mowat² this modification did not yield any solid product; instead they carried out the reaction in ether solution at a temperature below 30° and obtained a compound with m.p. 116–117° in 5 % yield (major products were recovered starting material and di-(*t*-butyl)-carbinol), which was assigned the structure of tetra-(*t*-butyl)-ethylene glycol on the basis of its chemical behavior and elemental analyses. No compound with m.p. 85–86° could be isolated, but Stevens and Mowat accepted the existence of two isomers, the isomerism being considered due to restricted rotation.

Later on, Kuhn,³ in a study of intramolecular hydrogen bonding in diols, reported the preparation of the tetra-(*t*-butyl)-ethylene glycol with m.p. 85–86° in very low yield, following the directions given by Favorsky and Nazarov. In dilute carbon tetrachloride solution this compound had a very large separation between the position of the free and intramolecularly hydrogen

bonded O—H stretching frequency ($\Delta\nu$ 170 cm^{-1}) as compared with other diols. Since this large $\Delta\nu$ value was in line with the expected trend in the series tetramethyl-, tetraethyl-, tetraisopropyl-, and tetra-(*t*-butyl)-ethylene glycol the structure of the compound was not questioned. A further reference to the isolation of tetra-(*t*-butyl)-ethylene glycol is found in the work of Bartlett and Swain,⁴ who obtained it as a by-product in the preparation of tri-(*t*-butyl)-carbinol from *t*-butyl chloride, hexamethylacetone or methyl pivalate, and sodium, but did not give the m.p. of the compound. They stated that it had O—H stretching frequencies at 2.75 and 2.84 μ (probably in the solid state).*

In order to investigate if tetra-(*t*-butyl)-ethylene glycol actually can exist in two stable conformations, some of the above-mentioned work on the reduction of hexamethylacetone has been repeated. The results indicate that the sodium reduction of hexamethylacetone is a rather complex reaction. No compound with the tetra-(*t*-butyl)-ethylene glycol structure could be isolated but instead it was possible to isolate products which point to participation of the solvent diethyl ether in the reaction.

RESULT AND DISCUSSION

When carefully purified hexamethylacetone was added to a sodium dispersion in ether at a temperature below 30° the deep red color of the ketyl immediately developed. This color persisted for about a week, after which time the mixture was worked up. The procedure followed the directions given by Stevens and Mowat in all essential details.

The products isolated were unreacted hexamethylacetone (19 %), di-(*t*-butyl)-carbinol (42 %), a solid with m.p. 115—118°, a solid with m.p. 94—98°, and a liquid with slightly longer retention time than di-(*t*-butyl)-carbinol. The solid, m.p. 115—118°, had the chemical and physical characteristics of the compound with m.p. 115—116°, isolated by Stevens and Mowat,² and no doubt was identical with it. In the solid state its infrared spectrum had O—H stretching frequency bands at 3610 and 3560 cm^{-1} , indicating a diol structure. It was found difficult to obtain satisfactorily reproducible elemental analyses of the recrystallized (from methanol) compound. Only after sublimation *in vacuo* were analyses reproducible, which is a frequently observed situation for solid diols.⁵ Apparently solvent molecules are included in the crystals during recrystallization. However, after sublimation, elemental analyses were not in accordance with the empirical formula of tetra-(*t*-butyl)-ethylene glycol, $\text{C}_9\text{H}_{19}\text{O}$, but instead with the formula $\text{C}_{10}\text{H}_{21}\text{O}$. Thus, for a diol the molecular formula would be $\text{C}_{20}\text{H}_{42}\text{O}_2$.

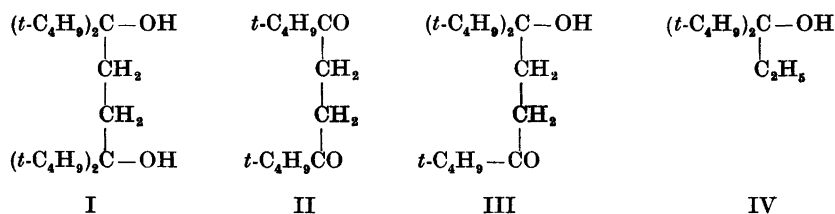
* *Note added in proof*: A private communication from Prof. Bartlett gives strong indications that the compound isolated as a by-product in the reaction between *t*-butyl chloride, hexamethylacetone and sodium is the same as that isolated by Stevens and Mowat and by the present author. It had m.p. 115—117° and the NMR spectrum had singlets at 8.27, 8.52, and 8.95 τ , one of them disappearing upon shaking the sample with deuterium oxide. Also, T. R. Steadman (Thesis, Harvard University, 1940) obtained a compound of m.p. 120.5—121° (corr., recrystallized from 95 % ethanol) in 3.5 % yield by sodium reduction of hexamethylacetone. The NMR spectrum of this sample was indistinguishable from the above-mentioned one.

The author is very grateful to Prof. Bartlett for communicating these data about his samples.

A study of its infrared spectrum under high resolution in dilute carbon tetrachloride solution in the 3700–3300 cm^{-1} region showed a free O—H stretching frequency band at 3620 cm^{-1} (this position is characteristic for tertiary alcohols) and an intramolecularly hydrogen bonded one at 3480 cm^{-1} . The $\Delta\nu$ value, 140 cm^{-1} , was of a magnitude compatible with a 1,4-diol structure, since $\Delta\nu$ for a large number of 1,4-diols falls in the 120–160 cm^{-1} region,⁶ whereas for 1,3-diols⁷ and most 1,2-diols³ $\Delta\nu$ falls in the 75–95 cm^{-1} and 30–100 cm^{-1} region, respectively. The NMR spectrum unambiguously ruled out the tetra-(*t*-butyl)-ethylene glycol structure, since it had signals at $\tau = 8.32$, 8.48, and 8.98 with integrated band areas in the proportions 2:1:18, with no spin-spin couplings. By addition of a trace of trifluoroacetic acid it could be shown that the signal at $\tau = 8.48$ originated from hydroxyl hydrogens. The signal at $\tau = 8.32$ was assigned to methylene hydrogens with the methylene group β to an oxygen atom and the third signal to methyl hydrogens. On the basis of these data the compound of m.p. 115–118° was assigned the structure of 1,1,4,4-tetra-(*t*-butyl)-butane-1,4-diol (I), which was further supported by a study of its mass spectrum. This had a peak of highest mass at m/e 239, corresponding to a loss of two water molecules and one *t*-butyl group from the molecular ion (314 – 2 × 18 – 57). The yield of I was 5 %, the same as that obtained by Stevens and Mowat.

Attempts to prepare I from diethyl succinate and an excess of *t*-butyllithium have been described by other investigators^{8,9} but were unsuccessful. In this reaction 2,2,7,7-tetramethyloctane-3,6-dione (II) and 3-(*t*-butyl)-2,2,7,7-tetramethyloctane-3-ol-6-one (III) were formed, whereas III apparently did not react further with *t*-butyllithium. In this investigation, II was allowed to react with *t*-butyllithium under different conditions but no I could be isolated.

The liquid compound was identified as di-(*t*-butyl)-ethylcarbinol (IV) by its infrared, NMR, and mass spectrum and also by comparison with an authentic specimen, synthesized from ethyllithium and hexamethylacetone.



The solid with m.p. 94–98° had elemental analyses consistent with the formula $\text{C}_{25}\text{H}_{44}\text{O}_2$. The mass spectrum had its peak of highest mass at m/e 259 with strong peaks at m/e 189, 173, 87, and 57. The NMR spectrum had signals at $\tau = 2.76$, 2.92, 7.07, 8.70, and 8.92 with band areas in the approximate proportions 1:2:3:2:30, with no spin-spin couplings. The signal at $\tau = 8.70$ originated from hydroxyl hydrogens. The infrared spectrum in dilute carbon tetrachloride solution had an O—H stretching frequency band at 3595 cm^{-1} .

EXPERIMENTAL

Reduction of hexamethylacetone with sodium in ether. (Stevens and Mowat procedure²). Dispersed sodium (12.5 g, 0.54 mole, particle size less than 20 μ) was covered with absolute ether (50 ml) in a 500 ml flask under nitrogen. Then hexamethylacetone (64.0 g, 0.45 mole, prepared as described by Whitmore and Stahly,¹⁰ distilled twice through a 15-plate column, purity better than 99 % as estimated by v.p.c. analyses) was added dropwise with stirring at such a rate that the temperature of the reaction mixture was kept below 35°. The mixture immediately acquired a deep red color due to the formation of the ketyl. It was then stirred in a nitrogen atmosphere for about a week, after which time the color had faded. Two 25 ml portions of absolute ether were added on the second day.

The reaction mixture was then poured on a mixture of ice and excess of dilute acetic acid, the organic layer taken up in ether, the ether solution dried with magnesium sulphate, the ether distilled off and finally a fraction with b.p. 60–70°/15 mm (39.5 g) was collected. By v.p.c. analysis it was found to consist of hexamethylacetone (31 %) and di-(*t*-butyl)-carbinol (69 %). To the distillation residue was added methanol (10 ml), the mixture slightly warmed and then kept in the refrigerator over night. The crystals (3.6 g) were filtered, m.p. 112–116°, m.p. 115–118° after one further recrystallization from methanol and a subsequent sublimation *in vacuo*. Found: C 76.5; H 13.5; O 10.2. Calc. for C₂₀H₄₂O₂: C 76.4; H 13.5; O 10.2). The substance was assigned the structure of 1,1,4,4-tetra-(*t*-butyl)-butane-1,4-diol on the basis of the infrared, NMR, and mass spectral data discussed above. The yield was 5 %.

The mother liquor was freed from methanol and distilled *in vacuo*. A fraction with b.p. up to 75°/0.3 mm was collected. By v.p.c. analysis (UCON-Oil-LB-550-X, temp. 180°) it was found to contain small amounts of hexamethylacetone and di-(*t*-butyl)-carbinol and at least twelve components with retention times longer than that of di-(*t*-butyl)-carbinol. One of the major components, coming next to di-(*t*-butyl)-carbinol, could be isolated by preparative gas chromatography (stationary phase Carbowax 20 M, temp. 180°). On the basis of its infrared, NMR, and mass spectrum it was assigned the structure of di-(*t*-butyl)-ethylcarbinol. This structure was confirmed by comparison with an authentic specimen, prepared from ethyllithium and hexamethylacetone.

The distillation residue was treated with acetone (10 ml) and the solution after standing over night at 0° had deposited crystals (1.2 g), which after one recrystallization from acetone and a subsequent sublimation melted at 94–98°. The elemental analyses were best in agreement with the formula C₂₅H₄₄O₂. (Found: C 79.6; H 11.9; O 8.5. Calc. for C₂₅H₄₄O₂: C 79.7; H 11.8; O 8.5). Infrared, NMR, and mass spectral data have been given above. From the mother liquor no further solid products could be isolated.

Reduction of hexamethylacetone with sodium. (Favorsky and Nazarow procedure¹). Sodium (9.0 g, 0.39 mole) was dispersed in xylene under nitrogen. After four washings with absolute ether, it was dried in a stream of nitrogen at 35°. Hexamethylacetone (30.0 g, 0.21 mole) was added in one portion, whereby a red color immediately developed and the temperature of the mixture rose to about 100°. The flask was stoppered and heated in an oil-bath at 115° for 14 h. After cooling, absolute ether (100 ml) was added and the mixture allowed to stand until the red color had disappeared (about a week). Working up according to the procedure given above gave hexamethylacetone (22 %), di-(*t*-butyl)-carbinol (35 %), I (3.5 %) and III (traces). No other solid products were isolated.

Reduction of hexamethylacetone with sodium in the absence of solvent. The foregoing description was followed, except that the heating time was 48 h and that the reaction mixture was worked up directly after the heating period. Hexamethylacetone (25 %) and di-(*t*-butyl)-carbinol (32 %) were isolated but no solid products. The gas chromatographic analysis of the distillation fractions unambiguously showed that III had not been formed in the reaction.

Acknowledgement. The author is grateful to *Mindre Akademiska Konsistoriet*, University of Lund, for financial support, to Drs. Göran Bergson and Sture Forsén for recording the NMR spectra and to Dr. Ragnar Ryhage for recording the mass spectra.

REFERENCES

1. Favorsky, A. E. and Nazarow, I. N. *Bull. Soc. Chim. France Ser. 5*, 1 (1934) 46.
2. Stevens, P. G. and Mowat, J. H. *J. Am. Chem. Soc.* **64** (1942) 554.
3. Kuhn, L. P. *J. Am. Chem. Soc.* **80** (1958) 5950.
4. Bartlett, P. D. and Swain, M. S. *J. Am. Chem. Soc.* **77** (1955) 2801.
5. Ebersson, L. *Unpublished work*.
6. Kuhn, L. P., von R. Schleyer, P., Baitinger, W. F. and Ebersson, L. *J. Am. Chem. Soc.* **86** (1964) 650.
7. von R. Schleyer, P. *J. Am. Chem. Soc.* **83** (1961) 1369.
8. Petrow, A., Sokolowa, E. and Gao-Chin-Lan *Bull. Soc. Chim. France* **1958** 1369.
9. Petrow, A. D., Sokolowa, E. B. and Kao-Ching-lang *J. Gen. Chem. USSR (Eng. Transl.)* **30** (1960) 1124.
10. Whitmore, F. C. and Stahly, E. E. *J. Am. Chem. Soc.* **55** (1933) 4153.

Received March 21, 1964.