OXIDATION OF TRI(O-TOLYL)ANTIMONY BY TERT-BUTYL HYDROPEROXIDE. MOLECULAR STRUCTURES OF BIS[µ₂-OXO- TRI(O-TOLYL)ANTIMONY] AND µ₂-OXO-BIS[(TERT-BUTYLPEROXY)TRI(O-TOLYL)ANTIMONY]

V.V. Sharutin, vvsharutin@rambler.ru
O.K. Sharutina, sharutinac@mail.ru
E.V. Artem'eva, katriona_dr@mail.ru
M.S. Makerova, marina.mms74@mail.ru
South Ural State University, Chelyabinsk, Russian Federation

Tr(o-tolyl)antimony oxidation by equimolar amount of tert-butyl hydroperoxide in diethyl ether led to the formation of bis[µ₂-oxo-tri(o-tolyl)antimony] (1). At the molar ratio of reactants 1:2 or 1:4 µ₂-oxo-bis[(tert-butylperoxy)tri(o-tolyl)antimony] (2) has been formed. According to the X-ray analysis data, antimony atoms are in the trigonal bipyramidal coordination in molecules 1 and 2. The bond lengths Sb–O vary within the ranges 1.937(2)–2.078(2) Å (1) and 1.975(17)–2.216(15) Å (2).

Keywords: tri(ortho-tolyl)antimony, tert-butyl hydroperoxide, oxidation, bis[µ₂-oxo-tri(o-tolyl)antimony], µ₂-oxo-bis[(tert-butylperoxy)tri(o-tolyl)antimony], molecular structures, X-ray analysis.

The interactions between triarylantimony and inorganic and organic oxidizing agents were investigated by many authors, for example [1–4]. The studies of reactions of triarylantimony with hydroperoxides are of great importance, as the products are useful precursors of derivatives with general formula Ar₃SbX₂ (X = acid radical HX) [5–10]. It has been found that hydrogen peroxide oxidizes triarylantimony to produce oxide Ar₃SbO (Ar = Ph, p-Tol) or dihydroxide Ar₃Sb(OH)₂ (Ar = 2,4,6-Me₃C₆H₂), depending on the volume of organic radical bonded with antimony atom, it is believed [10, 11]. The interaction of triarylantimony with tert-butyl hydroperoxide was studied on the example of triphenylantimony only. The molecular structure of the reaction product was found to depend on the amount of an oxidizing agent. Triphenylantimony oxide was formed at stoichiometric ratio of reactants and may be dimerized or polymerized [12–14]. Stable antimony peroxides Ph₃Sb(OOBu-t)₂ and (Ph₃SbOOBu-t)₂O are formed in the presence of the excess of tert-butyl hydroperoxide [15].

The reactions of tri(o-tolyl)antimony with tert-butyl hydroperoxide at various molar ratios of the reactants have been investigated and crystal and molecular structures of the products have been determined in the present paper.

Experimental

Synthesis of bis[µ₂-oxo-tri(o-tolyl)antimony] (1). Tri(o-tolyl)antimony (200 mg, 0.50 mmol) was dissolved in diethyl ether (20 mL). Then tert-butyl hydroperoxide (66 mg of 70 % aqueous solution, 0.50 mmol) was added. The solution was left to stand for 24 hours at temperature 20 °C. When the solvent evaporated, colourless crystalline substance 1 was obtained; the product yield was 199 mg (95 %), MP: 216 °C.

IR spectrum (ν, cm⁻¹): 3048, 2921, 2854, 1584, 1446,1280, 1202, 1160, 1120, 1031,935, 918, 890,764, 750, 740, 655, 636, 491, 471, 435.

Synthesis of µ₂-oxo-bis[(tert-butylperoxy)tri(o-tolyl)antimony] 2. Tri(o-tolyl)antimony (200 mg, 0.50 mmol) was dissolved in diethyl ether (20 mL). Then tert-butyl hydroperoxide (132 mg of 70 % aqueous solution, 1.00 mmol) was added. The solution was left to stand for 24 hours at temperature 20 °C. Colorless crystals 2 were obtained; yield 230 mg (92 %), MP: 162 °C.

The reaction with the molar ratio 1:4 was carried out at the same conditions. The product yield of substance 2 was 87 %.
Organometallic chemistry

**IR spectrum** of the substance 1 was recorded on the Bruker Tensor 27 FT-IR (KBr pellets; 4000–400 cm⁻¹).

**The X-ray diffraction analyses** of crystalline substances 1 and 2 were made on the Bruker D8 QUEST automatic four-circle diffractometer (Mo Kα-emission, λ = 0.71073 Å, graphite monochromator). The data were collected and analyzed, the unit cell parameters were refined, and the absorption correction was applied using the SMART and SAIN'T-Plus programs [16]. All calculations for structure determination and refinement were performed using the SHELXL/PC programs [17]. The structures 1 and 2 were determined by the direct method and refined by the least-squares method in the anisotropic approximation for non-hydrogen atoms.

The main crystallographic data and refinement results for structures 1 and 2 are listed in Table 1. The selected bond lengths and bond angles are given in Table 2.

**Table 1**

| Parameter                                      | Value | 2 |
|------------------------------------------------|-------|---|
| **Empirical formula**                          | C₆H₆O₂Sb₂ | C₆H₆O₂Sb₂ |
| **Formula weight**                             | 822.26 | 984.48 |
| **Temperature, K**                             | 296(2) | 296(2) |
| **Crystal system**                              | Triclinic | Triclinic |
| **Space group**                                 | P-1   | P1 |
| **a, Å**                                       | 11.0684(3) | 10.3355(4) |
| **b, Å**                                       | 11.1721(3) | 11.0049(5) |
| **c, Å**                                       | 17.0248(5) | 11.0848(4) |
| **α, deg**                                      | 80.7820(10) | 69.771(2) |
| **β, deg**                                      | 86.0600(10) | 84.636(2) |
| **γ, deg**                                      | 61.0370(10) | 81.907(2) |
| **V, Å³**                                       | 1818.06(9) | 1169.88(8) |
| **Z**                                          | 2     | 1 |
| **ρ(calcd.), g/cm³**                           | 1.502 | 1.397 |
| **μ, mm⁻¹**                                     | 1.520 | 1.198 |
| **F(000)**                                      | 824.0 | 502.0 |
| **Crystal size, mm**                           | 0.17×0.09×0.08 | 0.55×0.38×0.21 |
| **Range of data collection, deg**              | 7.38–58.28° | 3.98–47.5° |
| **Range of refraction indices**                | −15 ≤ h ≤ 15, −15 ≤ k ≤ 15, −23 ≤ l ≤ 23 | −11 ≤ h ≤ 11, −12 ≤ k ≤ 12, −12 ≤ l ≤ 12 |
| **Measured reflections**                       | 32558 | 14775 |
| **Independent reflections**                    | 9014  | 6981 |
| **R_{int}**                                     | 0.0480 | 0.0245 |
| **Refinement variables**                       | 421   | 521 |
| **GOOF**                                       | 1.030 | 1.159 |
| **R factors for F² > 2σ(F²)**                  | R₁ = 0.0314, wR₂ = 0.0551 | R₁ = 0.0511, wR₂ = 0.1274 |
| **R factors for all reflections**               | R₁ = 0.0564, wR₂ = 0.0611 | R₁ = 0.0589, wR₂ = 0.1361 |
| **Residual electron density (min/max), e/Å³**   | 0.49/−0.33 | 1.04/−2.17 |

**Table 2**

| Bond            | d, Å  | Angle | ω, deg | Bond            | d, Å  | Angle | ω, deg |
|-----------------|-------|-------|--------|-----------------|-------|-------|--------|
| Sb(1)–Sb(1a)   | 3.1409(4) |       |        | Sb(1)–O(1)     | 1.997(17) | 165.14(10) | 93.7(9) |
| Sb(1)–O(1)     | 1.9372(18) |       |        | O(1a)Sb(1)C(1) | 114.54(10) | 1.194(14) | 167.6(6) |
| Sb(1)–O(1a)    | 2.0784(18) |       |        | Sb(1)–O(2)     | 89.40(9)  | 2.143(18) | 86.7(7)  |
| Sb(1)–C(1)     | 2.1803(3)  |       |        | Sb(1)–C(2)     | 130.04(10)| 2.166(17) | 95.3(8)  |
| Sb(1)–C(11)    | 2.135(3)   |       |        | C(11)Sb(1)C(1) | 103.30(11)| 2.182(1)  | 116.3(10) |

24 Bulletin of the South Ural State University. Ser. Chemistry. 2015, vol. 7, no. 4, pp. 23–29
### Results and Discussion

It has been found that the oxidation of tri(o-tolyl)antimony by tert-butylhydroperoxide at the molar ratio 1:1 in diethyl ether goes with the formation of tri(o-tolyl)antimony oxide with dimeric structure: bis[μ₂-oxo-tri(o-tolyl)antimony] (I):

\[
2 \text{(o-Tol)}_3\text{Sb} + 2 \text{t-BuOOH} \rightarrow [(\text{o-Tol})_3\text{SbO}]_2 + 2 \text{t-BuOH}
\]

According to X-ray diffraction data the crystal of compound 1 contains two types of crystallographically independent molecules (A, B). The antimony atoms have intermediate coordination between trigonal-bipyramidal and square-pyramidal coordination (Fig. 1).

![The structure of compound 1A (hydrogen atoms aren't shown)](image)

The full tables of atomic coordinates, bond lengths, and bond angles for the substance 1 was deposited with the Cambridge Crystallographic Data Centre (№ 1052677; deposit@ccdc.cam.ac.uk; http://www.ccdc.cam.ac.uk).

| Bond          | \(d, \text{Å}\) | Angle, \(\omega, \text{deg}\) | Bond          | \(d, \text{Å}\) | Angle, \(\omega, \text{deg}\) |
|---------------|-----------------|-----------------|---------------|-----------------|-----------------|
| Sb(1)–C(21)   | 2.150(3)        | 111.93(11)      | Sb(2)–O(1)    | 1.951(18)       | 124.4(12)       |
| Sb(2)–Sb(2b)  | 3.1441(3)       | 110.58(8)       | O(2)Sb(1)C(11)| 87.2(9)         |                 |
| Sb(2)–O(2)    | 2.0585(17)      | 96.05(11)       | Sb(2)–C(61)   | 81.9(7)         |                 |
| Sb(2)–O(2b)   | 1.9473(17)      | 89.87(9)        | Sb(2)–C(31)   | 94.3(8)         |                 |
| Sb(2)–C(31)   | 2.186(3)        | 163.65(9)       | O(2)Sb(1)C(21)| 87.2(9)         |                 |
| Sb(2)–C(41)   | 2.131(3)        | 108.70(10)      | O(2)Sb(1)C(21)| 94.3(8)         |                 |
| Sb(2)–C(51)   | 2.151(3)        | 103.20(8)       | O(2)Sb(1)C(21)| 94.3(8)         |                 |
| Sb(2)–O(4)    | 2.129(17)       | 118.9(10)       | O(2)Sb(1)C(21)| 94.3(8)         |                 |
| Sb(2)–C(61)   | 2.114(12)       | 169.2(6)        | O(2)Sb(1)C(21)| 94.3(8)         |                 |
| O(1)–Sb(1a)   | 2.0784(18)      | 127.0(19)       | O(2)Sb(1)C(21)| 94.3(8)         |                 |
| O(2)–Sb(2b)   | 1.9473(17)      | 114.2(15)       | O(2)Sb(1)C(21)| 94.3(8)         |                 |

Symmetry relation: a) 1–x, –y, 2–z; b) 2–x, 1–y, 1–z

The sum of equatorial OSbC and CSbC angles is 356.57(10)° for A and 350.83(10)° for B. The axial OSbC angles are significantly distorted, they are equal to 165.14(10)° and 163.65(9)°. The OSbO and SbOSb angles in the flat cyclic fragment [Sb₂O₂] equal 77.14(8)°, 102.86(8)° (A) and 76.62(8)°, 103.13(7)° (B). The Sb–C_{eq} bond...
Organometallic chemistry

lengths (2.135(3), 2.150(3) Å; 2.131(3), 2151(3) Å B) and Sb–Oeq (1.937(2) Å A; 1.943(2) Å B) are less than Sb–Ceq (2.180(3) Å A; 2.186(3) Å B) and Sb–Oax (2.078(2) Å A; 2.058(2) Å B). The distances between antimony atoms in the cycle (3.149(5) A, 3.144(3) Å B) are considerably less than the double Van der Waals radius of antimony atom (4.4 Å [18]). The o-Tol3Sb fragments in compound 1 are in staggered conformation with respect to each other. Geometrical parameters of complex 1 are close to geometrical parameters of such compounds as (Ph3SbO)2 [19] and [(2-MeOC6H4)3SbO]2 [20].

When the concentration of tert-butylhydroperoxide has increased (1:2 or 1:4) the single organoantimony product in the reaction mixture is μ2-oxo-bis[(tert-butylperoxo)triphenylantimony] (2), the product yield is 92%:

\[
2 \text{ (o-Tol)3Sb} + 4 \text{ t-BuOOH} \rightarrow [(\text{o-Tol})3\text{SbOOBu-t}2]\text{O} + 2 \text{ t-BuOH} + \text{H}_2\text{O}
\]

The coordination polyhedron of antimony atoms in binuclear molecule 2 is an insignificantly distorted trigonal bipyramid (Fig. 2). The bipyramid distortion is characterized by deflection of Sb(1) and Sb(2) atoms from their respective equatorial planes by 0.02 Å and 0.08 Å to the direction of the bridging oxygen atom O(1), which leads to angle deviation between axial and equatorial bonds from the theoretical value 90°. The axial OSb(1,2)O angles are equal to 167.6(6)° and 159.5(5)°.

The equatorial CSb(1,2)C angles are changed in the range of 116.3(8)–124.4(12)°. The Sb(1)O(1)Sb(2) angle is 169.2(6)°. The SbOSb fragment has linear structure in the centrosymmetric molecule of μ2-oxo-bis[(tert-butylperoxo)triphenylantimony] [21].

Conclusions

Thus, tert-butylhydroperoxide oxidizes tri(o-tolyl)antimony at the molar ratio of the reactants 1:1 into tri(o-tolyl)antimony oxide, which dimerizes into bis[μ2-oxo-tri(o-tolyl)antimony]. With tert-butylhydroperoxide in excess (1:2 and 1:4) the reaction proceeds with the formation of the single organoantimony compound: μ2-oxo-bis[(tert-butylperoxo)tri(o-tolyl) antimony].

Fig. 2. The structure of compound 2 (hydrogen atoms aren’t shown)
References

1. Bhattacharya S.N., Singh M. Oxidative Addition Reactions of Triarylsarnes and Triarylstibines with Copper (II) and Mercury(II) Salts. Indian J. Chem., 1979, vol. 18A, no. 6, pp. 515–516.

2. Sharma H.K., Singh S., Dubey S.N., Puri D.M. Metal Derivatives of Organoantimony Compounds; Reactions of Anhydrous Ferric Chloride with Arylantimony Compounds. Indian J. Chem., 1982, vol. 21A, no. 6, pp. 619–621.

3. Alberola A., Gonzaleer A.M., Pulido F.G. The Reaction of p-Quinones with Triphenylstibine. Rev. Roum. Chim. 1984, vol. 5, no. 441–446.

4. Cherkasov V.K., Grunova E.V., Poddel’sky A.I., Fukan G.K., Kurskii Y.A., Abakumova L.G., Abakumov G.A. Oxidative Addition Reaction of o-Quinones to Triphenylanitmony. Novel Triphenylantimony Catecholate Complexes. J. Organomet. Chem. 2005, vol. 690, no. 5, pp. 1273–1281.

5. Goel R.G., Ridlej D.R. Organoantimony Compounds. J. Organomet. Chem. 1979, vol. 182, no. 2, pp. 207–212.

6. Bajpai K., Srivastava R.S. Synthesis and Reactions of o-Triorganooantimony Dioximates. Inorg. Met.-Org. Chem., 1981, vol. 11, no. 1, pp. 7–13.

7. Chang M.-M.Y., Kai S., Mushur J.I. Some New Organooantimony (V) Compounds. Isr. J. Chem., 1974, vol. 12, no. 5, pp. 967–970.

8. Domagala M., Huber F., Preut H. Triorganoolantimon- und Triorganobismutderivate von Carbon- sauren funfgliedriger Heterocyclen Kristall- und Molekulstruktur von (C6H5)3Sb(O2C-2-C6H5)2 und (C6H5)3Sb(O2C-2-C6H5)2. Z. Anorg. Allg. Chem., 1989, Bd. 574, ss. 130–142.

9. Domagala M., Huber F., Preut H. Triorganoolantimon- und Triorganobismutderivate von 2-Pyridincarbonsaure und 2-Pyridinlessigsaure. Kristall- und Molekulstrukturen von Ph3Sb(O2C-2- C6H5)2 und Me3Sb(O2CCH2-2-C6H5)2. Z. Anorg. Allg. Chem., 1990, Bd. 582, ss. 37–50.

10. Ruther R., Huber F., Preut H. Triorganoolantimon- und Triorganobismutdisulfonate Kristall- und Molekulstrukturen von (C6H5)3M(O2SC6H5)2 (M=Sb, Bi). Z. Anorg. Allg. Chem. 1986, Bd. 539, ss. 110–126.

11. Westhoff T., Huber F., Preut H. Syntesis of Tris(2,4,6-trimethylphenyl)hydroxooantimony Carboxylates. Crystall Structure of Tris(2,4,6-trimethylphenyl)hydroxooantimony 1-Adamantylcarboxylate. J. Organomet. Chem., 1988, vol. 348, no. 2, pp. 185–191.

12. Hiatt R., McCooleman C., Howe G.R. The Reaction of Hydroperoxides with Triphenylarsine and Triphenylstibine. Canad. J. Chem., 1975, vol. 53, no. 4, pp. 559–563.

13. Cvetkov V.G., Aleksandrov Ju.A., Glushakova V.N., Skorodumova N.A., Kol’jakova G.M. Thermochemistry of Reaction Triphenylphosphorusarsenic and -antimony with tert-butyl hydroperoxide. [Termohimija reakcii trifilenfosfora, -mysh’jaka i -sur’my s gidrolerekis’ju tretichnogo butila] Zhurn. obshh. Himii [Russian Journal of General Chemistry], 1980, vol. 50, no. 2, pp. 256–258. (in Russ.)

14. Razuvaev G.A., Shushunov V.A., Dodonov V.A., Brilkina T.G. Reactions of Organometallic Compounds with Organic peroxides. In: Organic Peroxides. N.Y.: J. Willey and Sons., 1972, vol. 3, pp. 141–270.

15. Pokrovskaja I.E., Dodonov V.A., Starikova Z.A., Kanunnikova E.N., Shhegoleva T.M., Lebedev G.P. The Peroxide Compounds of Triphenylantimony: Their Synthesis and Structure. [Peroksidnye soedinenija trifilenisur’my, ih sintez i strotenee]. Zhurn. obshh. Himii [Russian Journal of General Chemistry], 1981, vol. 51, no. 6, pp. 1247–1253. (in Russ.)

16. Bruker (2000) SMART. Bruker Molecular Analysis Research Tool, Versions 5.625 Bruker AXS, Madison, Wisconsin, USA.

17. Bruker (2000) SAINTPlus Data Reduction and Correction Program Versions 6.02a, Bruker AXS, Madison, Wisconsin, USA.

18. Bacanov S.S. Atomic Radii of the Elements [Atomnye radiusy jelementov]. Zhurn. Neorgan. Himii [Russian Journal of Inorganic Chemistry], 1991, vol. 36, no. 12, pp. 3015–3037. (in Russ.)

19. Bordner J., Doak G.O., Everett T. S. Crystal Structure of 2,2,2,4,4,4-Tetrahydro-2,2,2,4,4,4-hexaphenyl-1,3,2,4-dioxadistibetane (Triphenylstibine Oxide Dimer) and Related Compounds. J. Am. Chem. Soc., 1986, vol. 108, no. 14, pp. 4206–4213.

20. Matano Y., Nomura H., Hisanaga T., Nakano H., Shiro M., Imahori H. Diverse Structures and Remarkable Oxidizing Ability of Triarylбismuthane Oxides. Comparative Study on the Structure and Reactivity of a Series of Triarylпнictogen Oxides. Organometallics, 2004, vol. 23, no. 23, pp. 5471–5480.
ОКИСЛЕНИЕ ТРИ(О-ТОЛИЛ)СУРЬМЫ ТРЕТБУТИЛГИДРОПЕРОКСИДОМ. МОЛЕКУЛЯРНЫЕ СТРУКТУРЫ БИС[μ₂-ОКО-ТРИ(О-ТОЛИЛ)СУРЬМЫ] И μ₂-ОКО-БИС[(ТРЕТБУТИЛПЕРОКСО)ТРИ(О-ТОЛИЛ)СУРЬМЫ]

В.В. Шарутин, О.К. Шарутина, Е.В. Артемьева, М.С. Макерова
Южно-Уральский государственный университет, г. Челябинск

Окисление три(o-толил)сульфидов кислородом третбутилгидропероксида в этаноле приводит к образованию бис[μ₂-оксо-три(о-толил)сульфиды] (1). При соотношении реагентов 1:2 или 1:4 (мольн.) продуктом реакции является μ₂-оксо-[три(o-толил)(третбутилпероксисульфид)]-сульфид (2). По данным РСА, в молекулах 1 и 2 атомы Sb имеют исказенную трigoнально-бипирамидальную координацию. Длина связи Sb–O изменяется в интервалах 1.937(2)–2.078(2) Å (1) и 1.975(17)–2.216(15) Å (2).

Ключевые слова: три(o-толил)сульфид, третбутилгидропероксид, окисление, бис[μ₂-оксо-тр(о-толил)]сульфиды, μ₂-оксо-бис[(третбутилпероксисульфид)три(o-толил)]-сульфиды, молекулярные структуры, рентгеноструктурный анализ.

Литература

1. Bhattacharya, S.N. Oxidative Addition Reactions of Triarylsamines and Triarylstibines with Copper(II) and Mercury(II) Salts / S.N. Bhattacharya, M. Singh // Indian J. Chem. – 1979. – V. 18A, N. 6. – P. 515–516.
2. Metal Derivatives of Organotin Compounds; Reactions of Anhydrous Ferric Chloride with Arylanthimony Compounds / H.K. Sharma, S. Singh, S.N. Dubey, D.M. Puri // Indian J. Chem. – 1982. – V. 21A, N. 6. – P. 619–621.
3. Alberola, A. The Reaction of p-Quinones with Triphenylstibine / A. Alberola, A.M. Gonzalez, F.G. Pulido // Rev.Roum. Chim. – 1984. – V. 29, N. 5. – P. 441–446.
4. Oxidative Addition Reaction of o-Quinones to Triphenylantimony. Novel Triphenylantimony Catacholate Complexes / V.K. Cherkasov, E.V. Grunova, A.I. Poddel’sky et al. // J. Organomet. Chem. – 2005. – V. 690. – N. 5. – P. 1273–1281.
5. Goel, R.G. Organosammonium Compounds / R.G. Goel, D.R. Ridlej // J. Organomet. Chem. – 1979. – V. 182. – N. 2. – P. 207–212.
6. Bajpai, K. Synthesis and Reactions of o-Triorganoantimony Dioximates / K. Bajpai, R.S. Srivastava // Synth. Inorg. Met.-Org. Chem. – 1981. – V. 11, N. 1. – P. 7–13.
7. Chang, M.-M.Y. Some New Organosammonium Compounds / M.-M.Y. Chang, S. Kai, J.J. Musher // Isr. J. Chem. – 1974. – V. 12, N. 5. – P. 967–970.
8. Domagala, M. Triorganoantimonim- und Triorganobismutderivate von Carbonsauren unfangreifriger Heterocyclus Katalysator und Molekulstrukturen von (C₆H₅)₃Sb(O₂C=O–C₆H₅)₂ und (C₆H₅)₃Sb(O₂C=O–C₆H₅)₂ / M. Domagala, F. Huber, H. Preut // Z. Anorg. Allg. Chem. – 1989. – Bd. 574. – S. 130–142.
9. Domagala, M. Triorganoantimonim- und Triorganobismutderivate von 2-Pyrindincarbonsaure und 2-Pyridinlessigsäure. Kristall- und Molekulstrukturen von Ph₃Sb(O₂C=O–C₆H₅)₂ und Me₃Sb(O₂C=O–C₆H₅)₂ / M. Domagala, F. Huber, H. Preut // Z. Anorg. Allg. Chem. – 1990. – Bd. 582. – S. 37–50.
10. Ruther, R. Triorganooantimon- und Triorganobismutdisulfonate Kristall- und Molekulstrukturen von \((\text{C}_3\text{H}_7)_3\text{SbO}_2\text{Cl}_2\) (\(M=\text{Sb, Bi}\)) / R. Ruther, F. Huber, H. Preut // Z. Anorg. Allg. Chem. – 1986. – Bd. 539. – S. 110–126.

11. Westhoff, T. Synthesis of Tris(2,4,6-trimethylphenyl)hydroxoaantimonony Carboxylates. Crystall Structure of Tris(2,4,6-trimethylphenyl)hydroxoaantimonony 1-Adamantylcarboxylate / T. Westhoff, F. Huber, H. Preut // J. Organomet. Chem. – 1988. – V. 348, N. 2. – P. 185–191.

12. Hiatt, R. The Effect of Hydroxodioxides with Tripheynlarsine and Tripheynlstibine / R. Hiatt, C. McCoelman, G.R. Howe // Canad. J. Chem. – 1975. – V. 53, N. 4. – P. 559–563.

13. Термохимия реакция трифенилфосфора, -мыссяка и -сурымы с гидроперекисью третичного бутила / В.Г. Цветков, Ю.А. Александров, В.Н. Глушакова и др. // Журн. общ. химии. – 1980. – T. 50. – № 2. – C. 256–258.

14. Reactions of Organometallonic Compounds with Organic peroxides / G.A. Razuvaev, V.A. Shushunov, V.A. Dodonov, T.G. Brilkina // Organic Peroxides. – N.Y.: J. Willey and Sons. – 1972. – V. 3. – P. 141–270.

15. Perokсидные соединения трифенилсурымы, их синтез и строение / И.Е. Покровская, В.А. Додонов, З.А. Старикова и др. // Журн. общ. химии. – 1981. – T. 51, № 6. – C. 1247–1253.

16. Bruker (2000) SMART. Bruker Molecular Analysis Research Tool, Versions 5.625 Bruker AXS, Madison, Wisconsin, USA.

17. Bruker (2000) SAINTPlus Data Reduction and Correction Program Versions 6.02a, Bruker AXS, Madison, Wisconsin, USA.

18. Бацаевов, С.С. Атомные радиусы элементов / С.С. Бацаевов // Журн. неорган. химии. – 1991. – T. 36, № 12. – C. 3015–3037.

19. Bordner, J. Crystal Structure of 2,2,2,4,4,4-Tetrahydro-2,2,2,4,4,4-hexaphenyl-1,3,2,4-dioxidistibetane (Triphensiblutm Xyde Dimer) and Related Compounds / J. Bordner, G.O. Doak, T.S. Everett // J. Am. Chem. Soc. – 1986. – V. 108, N. 14. – P. 4206–4213.

20. Diverse Structures and Remarkable Oxidizing Ability of Triarylbismuthane Oxides. Comparative Study on the Structure and Reactivity of a Series of Triarylptectogen Oxides / Y. Matano, H. Nomura, T. Hisanaga et al. // Organometallics. – 2004. – V. 23, N. 23. – P. 5471–5480.

21. Кристаллическая и молекулярная структура окса-бис(трет.бутилперокси трифенилсурыма) / З.А. Старикова, Т.М. Щеголева, В.К. Трунов и др. // Кристаллография. – 1978. – T. 23, № 5. – C. 969–973.