

## Stereochemical Aspects of R<sub>2</sub>O-3 Participation. Lithium Aluminum Hydride Reduction of 9-Oxabicyclononan-2-yl Iodides

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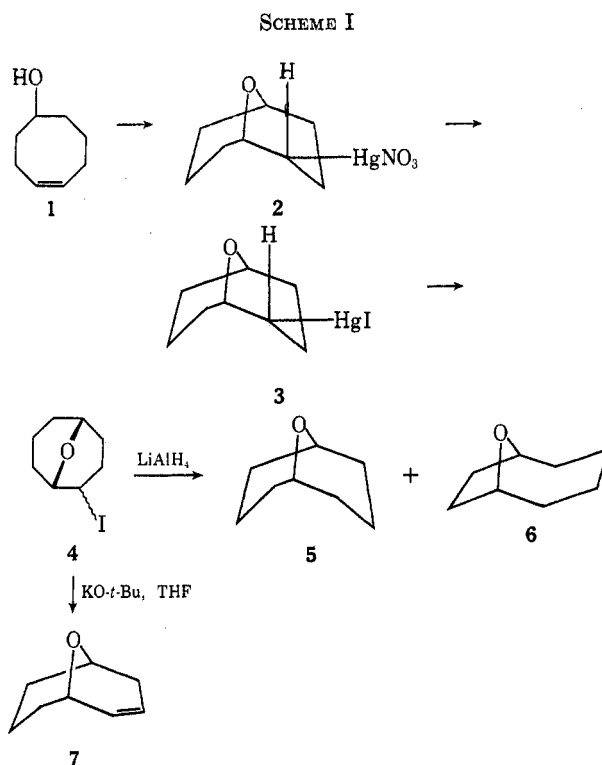
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Iododemercuration of *endo*-2,6-epoxycyclooctylmercuric iodide with iodine in carbon tetrachloride solution affords chiefly 2-iodo-9-oxabicyclo[3.3.1]nonane, probably as a statistical mixture of the two possible isomers. Lithium aluminum hydride reduction of this mixture in ether solution results in the formation of equal parts of 9-oxabicyclo[3.3.1]nonane and 9-oxabicyclo[4.2.1]nonane. In contrast, 2-iodo-9-oxabicyclo[4.2.1]nonane, similarly obtained as a mixture of isomers from *endo*-2,5-epoxycyclooctylmercuric iodide, affords exclusively 9-oxabicyclo[4.2.1]nonane upon hydride reduction. The mechanistic implications of these transformations are discussed.

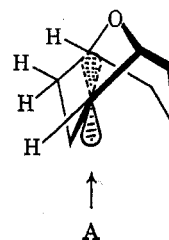
In an earlier paper from this laboratory,<sup>1</sup> it was shown that acetolysis of *endo*-9-oxabicyclo[4.2.1]nonan-2-yl brosylate proceeds with anchimeric assistance involving R<sub>2</sub>O-3 participation by the oxygen bridge. Also, although the geometry of the related *exo* isomer prohibits such direct neighboring-group participation, a similar oxonium ion does intervene later in the mechanistic scheme. In neither case was carbon-carbon bond migration noted. In the present work, the solvolytic behavior of 9-oxabicyclononan-2-yl iodides under conditions of lithium aluminum hydride reduction was examined to obtain further information on the stereochemical aspects of R<sub>2</sub>O-3 participation. This study was prompted by a number of isolated earlier reports which indicated that metal hydride reductions of certain aralkyl and alkyl arenesulfonate and halide systems result in the formation of appreciable quantities of rearranged hydrocarbons as a consequence of anchimerically assisted ionization.<sup>2</sup> The oxygen-bridged molecules **4** and **11** represent interesting substrates with which to probe further into the structural requirements of such transformations; an assessment of their reactivity is herein presented together with the mechanistic implications.

### Results

Oxymercuration of 4-cycloocten-1-ol (**1**) with mercuric nitrate in aqueous potassium nitrate solution according to the procedure of Bordwell and Douglass<sup>3</sup> led rapidly to the precipitation of *endo*-2,6-epoxycyclooctylmercuric nitrate (**2**). Conversion of **2** to the corresponding mercuric iodide (**3**) was achieved by means of potassium iodide in dilute sodium hydroxide solution (Scheme I). Iododemercuration of **3** with iodine in carbon tetrachloride solution afforded in good yield a colorless liquid. Considerable evidence attests to the fact that the cleavage of mercurials with halogens involve free-radical intermediates.<sup>4</sup> In the particular case of free radical A, considerations of product control and accessibility to the reactive site both favor preferred



attack from the "equatorial" direction to give the thermodynamically favored *endo* isomer of **4**. Analo-



gous factors appear to control the preferred *exo* bonding of various halogen donors to the 2-norbornyl free radical; in particular, the dominant *exo* selectivity is significantly overwhelming as the steric demands of the

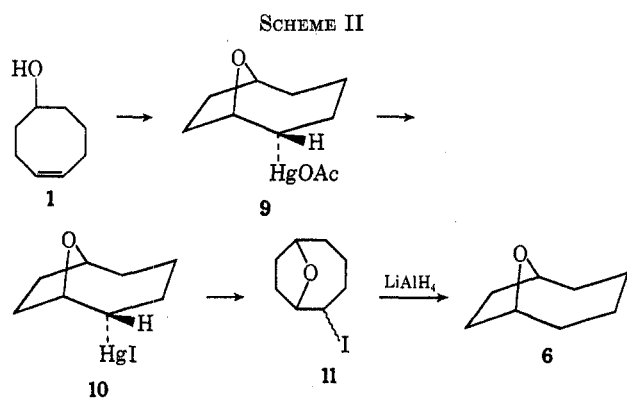
(1) L. A. Paquette and P. C. Storm, *J. Amer. Chem. Soc.*, **92**, 4295 (1970).  
 (2) (a) H. Schmid and P. Karrer, *Helv. Chim. Acta*, **32**, 1371 (1949);  
 (b) D. J. Cram, *J. Amer. Chem. Soc.*, **74**, 2149, 2152 (1952); (c) E. J. Corey,  
 M. G. Howell, A. Boston, R. L. Young, and R. A. Snee, *ibid.*, **78**, 5036  
 (1956); (d) P. R. Story, *ibid.*, **83**, 3347 (1961); (e) P. R. Story and M.  
 Saunders, *ibid.*, **84**, 4876 (1962); (f) H. C. Brown and H. M. Bell, *ibid.*,  
**85**, 2324 (1963); (g) S. Winstein, A. H. Lewin, and K. C. Pande, *ibid.*, **85**,  
 2324 (1963); (h) E. L. Allred and S. Winstein, *ibid.*, **89**, 4008 (1967).  
 (3) F. G. Bordwell and M. L. Douglass, *ibid.*, **88**, 993 (1966).  
 (4) For a review of this subject, consult F. R. Jensen and B. Rickborn,  
 "Electrophilic Substitution of Organomercurials," McGraw-Hill, New York,  
 N. Y., 1968, Chapter 4.

halogen source are increased.<sup>5</sup> Notwithstanding, Jensen<sup>6</sup> has shown that bromodemercuration of *cis*- and *trans*-4-alkylcyclohexylmercuric bromides in carbon tetrachloride proceeds *via* a free-radical pathway to give approximately 1:1 mixtures of *cis*- and *trans*-4-alkylcyclohexylbromides. On this basis, the reaction of **3** with iodine would not be expected to be stereospecific.

The nmr spectrum of **4** (see Experimental Section) was too complex for quantitative purposes. However, thin layer and vapor phase chromatographic techniques indicated the substance to be inhomogeneous. Preparative vpc and column chromatographic separation of the components was not possible because of partial decomposition and/or rearrangement under the conditions employed. In order to establish whether any skeletal rearrangement had transpired during the iododemercuration, distilled **4** was dehydrohalogenated with potassium *t*-butoxide in tetrahydrofuran under mild conditions. Since the product distribution from this reaction (after 8 hr) consisted of a maximum amount of 6% **8** (vpc and nmr analyses), **4** is composed chiefly of 9-oxabicyclo[3.3.1]nonan-2-yl iodides. Further comment on the probable configurational composition of this mixture is deferred to the Discussion section.

After being heated at reflux for 2 hr, a diethyl ether solution of **4** and lithium aluminum hydride was allowed to stand at room temperature overnight and worked up by addition of water and 25% aqueous sodium hydroxide solution. After filtration and careful evaporation of the ether, the concentrate was analyzed by vpc prior to, and after, distillation [crystalline distillate, bp 70–76° (20 mm)]. Two products were formed in *equal* amounts and these were identified as 9-oxabicyclo[3.3.1]nonane (**5**) and 9-oxabicyclo[4.2.1]nonane (**6**) by comparison with authentic samples.

Oxymercuration of **1** in buffered aqueous mercuric acetate solution under conditions of kinetic control<sup>8</sup> led to the formation of mercurial acetate **9** (Scheme II).



Exposure of **9** to potassium iodide solution gave **10** which was converted in 91% yield to a mixture of iodides when treated with iodine in carbon tetrachloride solution. As in the case of **4**, **11** was a nonseparable mixture of epimeric iodides; demonstration of the fact

(5) See, for example, (a) E. C. Kooyman and G. C. Vegter, *Tetrahedron*, **4**, 382 (1958); (b) S. J. Cristol, J. R. Douglass, W. C. Firth, Jr., and R. E. Krall, *J. Org. Chem.*, **27**, 2711 (1962); (c) S. J. Cristol, L. K. Gaston, and T. Tiedeman, *ibid.*, **29**, 1279 (1964).

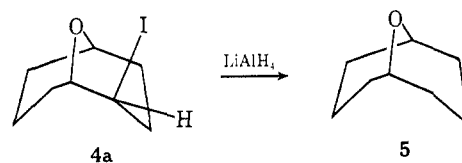
(6) (a) F. R. Jensen and L. H. Gale, *J. Amer. Chem. Soc.*, **82**, 148 (1960); (b) F. R. Jensen, L. H. Gale, and J. E. Rodgers, *ibid.*, **90**, 5793 (1968).

that the unpurified iodide was not purely of the 9-oxabicyclo[4.2.1]nonanyl series was gained by dehydrohalogenation to a mixture of **7** (15%) and **8** (85%). Nevertheless, lithium aluminum hydride reduction of unpurified **11** results exclusively in the formation of 9-oxabicyclo[4.2.1]nonane (**6**). No 9-oxabicyclo[3.3.1]nonane (**5**) was detected by vpc or nmr methods.

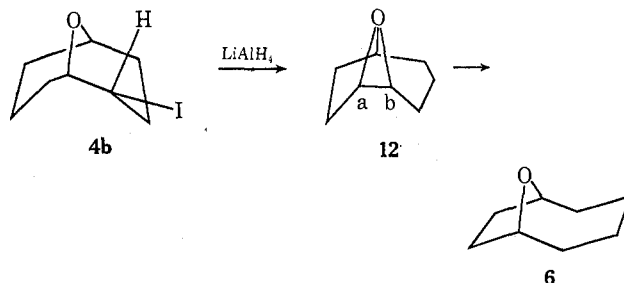
## Discussion

Although complex metal hydride reductions of arenesulfonates and halides are generally considered to proceed by the S<sub>N</sub>2 displacement pathway,<sup>7</sup> it is clear that certain systems do undergo reduction by processes which involve prior ionization. Perhaps the three most well-studied examples of this phenomenon are cholesteryl tosylate (LiAlH<sub>4</sub>),<sup>2a,c</sup> 7-norbornadienyl chloride (LiAlH<sub>4</sub><sup>2d,e</sup> and NaBH<sub>4</sub><sup>2f,g</sup>), and 4-methoxy-1-pentyl brosylate (LiAlH<sub>4</sub>).<sup>2h</sup> Each of these molecules is capable of ionization to a particularly stable cationic species. Apparently, the salt effect produced upon dissolution of a metal hydride in a solvent such as ether is quite capable of promoting anchimerically assisted ionization<sup>8</sup> when this is energetically feasible.

With such considerations in mind, it follows logically that the *exo* epimer of **4** (*i.e.*, **4a**) should undergo hydride reduction by direct S<sub>N</sub>2 displacement of iodide ion, due to geometric constraints which deter anchimeri-



cally assisted ionization.<sup>1</sup> The reduction of **4a** therefore would not eventuate in skeletal rearrangement. In contrast, the *trans*-disposed iodine substituent in *endo* isomer **4b** is ideally positioned for facile initial salt-promoted R<sub>2</sub>O-3 participation to give oxonium ion **12**. Although no definitive information is available as to the number of intermediate ion and ion-pair species which may be involved, it is entirely plausible that lithium aluminum hydride reduction of this isomer does not result in direct hydride displacement of iodide ion. Rather,



a slow ionization step to afford **12** is logically involved, this oxonium ion then suffering rapid kinetically controlled reduction to **6**. The high degree of selectivity formulated for the reduction of **12** is founded on earlier

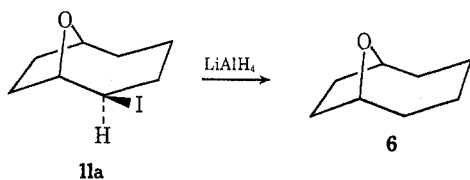
(7) L. W. Trevoy and W. G. Brown, *ibid.*, **71**, 1675 (1949). However, see also M. S. Newman, J. R. Le Blanc, H. A. Karnes, and G. Axelrod, *ibid.*, **86**, 868 (1964).

(8) A close analogy is seen in the fact that ether solutions which are at least 0.036 M in lithium perchlorate become better ionizing media than acetic acid [S. Winstein, E. C. Friedrich, and S. Smith, *ibid.*, **86**, 305 (1964); S. Winstein, S. Smith, and D. Darwish, *ibid.*, **81**, 5511 (1959)].

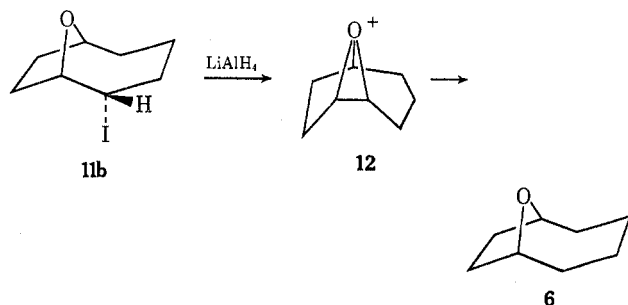
observations that the 9-oxabicyclo[4.2.1]nonyl system is strongly favored under conditions of kinetic control.<sup>3</sup>

A most salient feature of this interpretation resides in the requirement that an approximate 1:1 distribution of **4a** and **4b** be realized in the iododemercuration step.<sup>9</sup> In agreement with this conclusion of a statistical product distribution are the results derived from several related halogen atom transfer reactions which tend to have only small structure development in their transition states because of their low heats of reaction.<sup>6,10</sup> There exists little doubt that iodine will function like bromine and chlorine in having less bonding in the transition state and as a result be unselective (in the stereochemical sense) in its reactions.<sup>6,11</sup>

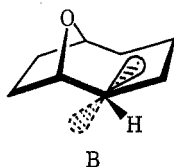
Similar arguments can be advanced in the case of **11**. Clearly, *exo* isomer **11a** is not subject to reductive rearrangement and therefore this isomer can be expected



to lead cleanly to **6**. The *endo* isomer **11b** would, however, again involve **12** which, as discussed above, is likewise a precursor of **6**. In actual fact, therefore, either isomer of **11** is predicted to afford only **6** and this



is observed. As in the case of intermediate A, free radical B is not expected to exert torsional effects which



would cause deviation from a statistical distribution of epimers.

Finally, some comment should be made on the intervention of crossover products during the iododemercuration reaction. Since leakage from free radical A to free radical B and *vice versa* are highly unlikely transpositions, the source of the rearrangements was considered to be mercuric iodide catalyzed skeletal rearrangement of the resulting iodides. Because **4b** and **11b** are expected to be the more reactive isomers of

(9) Refer to the ensuing discussion for comments on the fate of the small amount of 9-oxabicyclo[4.2.1]nonyl impurity present in the various samples of **4**.

(10) Reactions which have more bond formation in their transition states (*e.g.*, *exo*-norbornyl) would naturally tend to give chiefly those products which arise from pathways involving less torsional strain complications.

(11) F. D. Greene, M. L. Savitz, F. D. Osterholtz, H. H. Lau, W. N. Smith, and P. M. Zanet, *J. Org. Chem.*, **28**, 55 (1963).

each structural pair,<sup>1</sup> HgI<sub>2</sub>-induced interconversion of these products was implicated. In a limited number of control experiments, it was demonstrated that an increase in crossover product resulted<sup>12</sup> as the duration of the iododemercuration was extended from 4 to 12 hr. Since oxonium ion **12** is the very likely intermediate in these rearrangements, the crossover products must accordingly be *trans* disposed to the oxygen bridge and therefore ultimately give rise exclusively to 9-oxabicyclo[4.2.1]nonane upon lithium aluminum hydride reduction. As a result, the proportion of **6** in the final product should not be dependent on the extent of isomerization since all structural elements involved lead to **6** upon reduction. This conclusion was supported by several reduction experiments.

### Experimental Section

**2,6-Epoxyoctylmercuric Iodide (3).**—A solution of 66.0 g (0.4 mol) of potassium iodide dissolved in 100 ml of 10% sodium hydroxide solution was added dropwise to a solution of 17.5 g (0.045 mol) of **2**<sup>3</sup> in 175 ml of 10% sodium hydroxide. The precipitated product was collected on a filter and washed with 75 ml of cold 95% ethanol. Recrystallization of this solid from methanol afforded 20.0 g (98%) of **3** as white crystals, mp 143–144°.

*Anal.* Calcd for C<sub>8</sub>H<sub>12</sub>HgIO: C, 21.22; H, 2.89. Found: C, 21.66; H, 2.97.

**2-Iodo-9-oxabicyclo[3.3.1]nonane (4).**—To a solution of 4.5 g (0.01 mol) of **3** in 300 ml of carbon tetrachloride cooled to 0° under a nitrogen atmosphere was added 2.5 g (0.01 g-atom) of iodine. After the mixture had been stirred for 8 hr at room temperature, the salts were removed by filtration. The filtrate was decolorized with aqueous sodium thiosulfate, dried, and evaporated to afford 2.2 g of **4**. The nmr spectrum of **4** was characterized by a one-proton multiplet at δ 4.45–4.70, a two-proton multiplet at 3.75–4.15, and a ten-proton multiplet at 1.1–2.8.

**Hydride Reduction of 4.**—To a slurry of 0.4 g (0.01 mol) of lithium aluminum hydride in 25 ml of ether was added dropwise a solution of 2.5 g (0.01 mol) of **4** in 10 ml of anhydrous ether. The mixture was heated at reflux for 2 hr. After being stirred at ambient temperature overnight, the solution was cooled and treated successively with 0.4 ml of water, 0.4 ml of 25% sodium hydroxide solution, and 1.2 ml of water. After the addition of some anhydrous magnesium sulfate, the solids were separated by filtration and rinsed well with ether. The combined filtrates were evaporated and distilled to give 0.7 g (55%) of a crystalline distillate, bp 70–76° (20 mm). Vpc and nmr analysis demonstrated the presence in this solid of equal parts of **5** and **6**.

Authentic samples of **5** and **6** were prepared by the method of Bordwell and Douglass<sup>3</sup> and shown to be identical with the hydride reduction products.

**Dehydrohalogenation of 4.**—A solution of 2.1 g (8.33 mmol) of **4** in 25 ml of anhydrous tetrahydrofuran was cooled in ice while 1.03 g (9.2 mmol) of powdered potassium *t*-butoxide was added. The ice bath was removed after 30 min, and the mixture was stirred at room temperature for an additional 3.5 hr. The contents were poured into 300 ml of ice cold water and extracted with ether. Distillation of the dried ether solution gave 0.76 g (74%) of colorless oil. Vpc analysis (12 ft × 0.25 in. Al column packed with 15% FFAP on Chromosorb W at 130°) of this liquid indicated the presence of 6% **8** and 94% **7**. This was confirmed by nmr analysis.

• Preparative scale vpc separation on the above column gave pure **7**: δ<sub>TMS</sub><sup>CDCl<sub>3</sub></sup> 5.47–6.11 (m, 2, vinyl), 3.92–4.30 (br m, 2, CHO–), 2.30–2.88 (m, 1, allyl), 1.15–2.17 (m, 7, one allyl and methylene).

*Anal.* Calcd for C<sub>8</sub>H<sub>12</sub>O: C, 77.37; H, 9.74. Found: C, 77.21; H, 9.97.

The collected sample of **8** was identical in all respects with an authentic sample.<sup>1,13</sup>

(12) Determined by potassium *t*-butoxide induced dehydrohalogenation and vpc analysis of the mixture of **7** and **8**.

(13) A. C. Cope, M. A. McKervey, and N. M. Weinschenker, *ibid.*, **34**, 2229 (1969).

**Hydrogenation of 7.**—A solution of 50 mg of 7 in ~20 ml of ether was catalytically hydrogenated over Adams catalyst at room temperature. The catalyst was filtered and the product was isolated by preparative scale gas chromatography (32 mg). The substance was identical with 9-oxabicyclo[3.3.1]nonane (5).

**Iododemercuration of 3 for Various Time Periods.**—To determine the extent of isomerization of 4 as a function of time, 3 was treated as above with iodine for varying periods. The reaction mixture was divided in half; one half was dehydrohalogenated in the prescribed manner, and the second half was reduced with lithium aluminum hydride as outlined above. The product distribution results are tabulated in Table I.

TABLE I

Time, hr	Per cent composition <sup>a</sup>			
	Dehydrohalogenation		Reduction	
	7	8	5	6
4	96	4	50	50
8	92	8	50	50
10	86	14	50	50
12	82	18	50	50

<sup>a</sup> Vpc analyses.

**2-Iodo-9-oxabicyclo[4.2.1]nonane (11).**—A solution of 4.5 g (0.01 mol) of mercurial iodide 10 and 2.5 g (0.01 g-atom) of iodine in 300 ml of carbon tetrachloride at 0° under a nitrogen atmosphere was stirred for 8 hr while slowly being allowed to come

to room temperature. The salts were removed by filtration, and the filtrate was decolorized with aqueous sodium thiosulfate, dried, and concentrated to give 2.3 g (91%) of 11. The nmr spectrum of 11 was characterized by a one-proton multiplet at  $\delta$  4.6–4.85, a two-proton multiplet at 3.95–4.55, and a ten-proton multiplet at 1.0–2.5.

**Hydride Reduction of 11.**—A solution containing 2.5 g (0.01 mol) of 11 in 10 ml of anhydrous ether was reduced with lithium aluminum hydride as described above to give 0.9 g (72%) of a single product, bp 74–76° (24 mm), mp 31°, which was identical in all respects with authentic 1,4-epoxycyclooctane.<sup>3</sup>

**Dehydrohalogenation of 1.**—A 2.0-g (7.95 mmol) sample of 11 was dehydrohalogenated as above with 1.02 g (9.0 mmol) of potassium *t*-butoxide in 25 ml of anhydrous tetrahydrofuran. There was obtained 750 mg (76%) of a colorless liquid, vpc analysis of which indicated the presence of 7 (15%) and 8 (85%).

**Registry No.**—3, 25662-59-3; 4a, 25662-60-6; 4b, 25662-61-7; 5, 281-05-0; 6, 284-20-8; 7, 25665-25-2; 11a, 25716-05-6; 11b, 25662-62-8; lithium aluminum hydride, 16853-85-3.

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## Synthesis and Kinetics of Decomposition of Di-*t*-butyl Tricarbonate, Di-*t*-butyl Dithioltricarboxylate, and the Related Dicarboxylates<sup>1</sup>

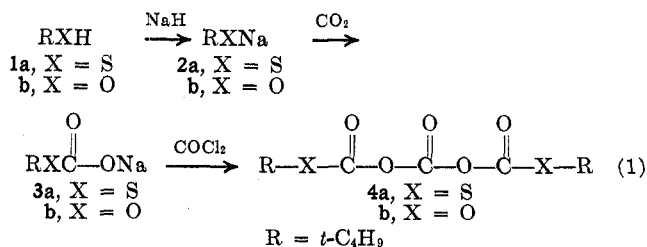
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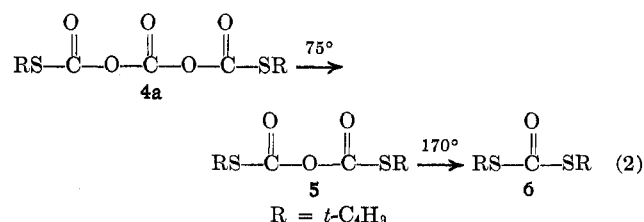
Details of the preparation of di-*t*-butyl dithioltricarboxylate,  $[(CH_3)_3C-S-CO_2-]_2CO$ , and di-*t*-butyl tricarbonate by the action of phosgene on sodium *t*-butyl thiolcarbonate and potassium *t*-butyl carbonate are given. Both tricarbonates decompose when heated above their melting points, the former producing di-*t*-butyl dithioltricarboxylate and carbon dioxide, and the latter fragmenting into isobutene, *t*-butyl alcohol, and three molecules of carbon dioxide. The decomposition of the di-*t*-butyl tricarbonate can be arrested at the dicarbonate stage by refluxing the tricarbonate in carbon tetrachloride in the presence of a trace of triethylamine. When heated di-*t*-butyl dicarbonate fragments into isobutene, *t*-butyl alcohol, and two molecules of carbon dioxide, whereas di-*t*-butyl dithioltricarboxylate gives the corresponding monocarbonate. Kinetic studies on all of these decompositions in both decalin and chlorobenzene, following the reactions by infrared spectroscopy, have shown them all to be strictly first order, and activation parameters have been determined. The mechanisms of the processes have been discussed.

The action of phosgene on sodium *t*-butyl thiolcarbonate 3a has been found to give di-*t*-butyl dithioltricarboxylate<sup>2</sup> (eq 1) 4a and by a similar procedure<sup>3</sup> di-*t*-butyl tricarbonate 4b has been made from potassium *t*-butyl carbonate 3b; both are crystalline compounds.



Several other oxygen tricarbonates 4b, where R is isopropyl or other, were prepared but could not be obtained pure.<sup>3</sup> When heated above its melting point (71–72°)

di-*t*-butyl dithioltricarboxylate 4a decomposes very rapidly with the loss of one molecule of carbon dioxide to give di-*t*-butyl dithioltricarboxylate 5 which, if heated at 170° for 45 min, similarly loses carbon dioxide to yield di-*t*-butyl dithiolmonocarbonate<sup>4</sup> 6 (eq 2). The same results were observed when the decomposition was effected in decalin and chlorobenzene as solvents.



In contrast to the behavior of the dithiol tricarbonate 4a, di-*t*-butyl tricarbonate 4b when heated above its melting point (64.5–65°), fragments into three molecules of carbon dioxide, one molecule of isobutene, and

(1) Aided by Grant GP-7874 from the National Science Foundation.

(2) A. W. Friederang and D. S. Tarbell, *Tetrahedron Lett.*, 5535 (1968).

(3) C. S. Dean and D. S. Tarbell, *Chem. Commun.*, 728 (1969).

(4) D. S. Tarbell and L. Wei, *J. Org. Chem.*, **33**, 1884 (1968).