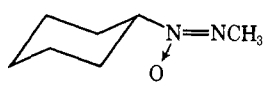
Table II. Results of 22° Thermolysis of 2

Solvent	$\sim t_{1/2}$, hr	1:3 ratio[a]
Neat	23	80:20
CCl_4	27	74:26
CD_3OD	14	70:30
DMSO-d_6	14	68:32

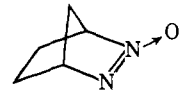
[a] Determined by nmr and corroborated by vpc.

established by alternate synthesis (in 72% yield) *via* peracid oxidation of *cis*-azoisopropane (**4**).[9] Elemental analysis and thermal isomerization (>100°) to **1** substantiated the assigned structure of **3**. Compound **3**, representing the first documented example of an acyclic *cis*-azoxyalkane, had the following absorption spectral features: uv, λ_{max} 232 (ϵ 7900), 280 nm (sh); ir_{CCl_4}, $\nu_{N=N}$ 1480 cm^{-1} plus ν_{NO} 1275 cm^{-1}, with intensity reduced relative to the ν_{NO} of the trans isomer **1**. The nmr of **3** (see Table I) shows the methine H signals downfield relative to those of the *cis*-azoalkane **4**, as predicted by Freeman.[10] In contrast, the methine H signals of cyclic *cis*-azoxyalkanes are superimposed, and upfield, relative to their azoalkane counterparts.[11] Finally, **3** can be photoisomerized completely to **1** (ratio, 97/3 at 9 hr) under conditions which yield no **2** (3500 Å, Pyrex filter, pentane).

The above results indicate that, despite the event of a highly unfavorable cis–trans photoequilibrium, *cis*-azoxyalkanes should be synthesizable, if not by direct photoisomerization,[3] then by the photolysis–thermolysis sequence which converted **1** to **3**. The extension of the results of Scheme I to the synthesis of the unsymmetrical *cis*-azoxyalkane **6**[12] (35% yield, mp 98–98.5°; uv, λ_{max} 232 nm (ϵ 6000); elemental analysis, within limits) from



6, cis
7, trans



8 (λ_{max} 228 nm)

7 give an indication of the generality of the approach. Incidentally, the uv spectra of **3**, **6**, and cyclic azoxy compounds such as **8**[13] indicate a λ_{max} range of about 230 ± 3 mμ for *cis*-azoxyalkanes (trans range, 220 ± 3 mμ) which permits the assignment of cis geometry to the azoxy compound (λ_{max} 237) isolated by Hortmann and Youngstrom.[14]

The formation of **3** from the ring opening of **2** finds analogy in the reported formation of *cis* (as well as *trans*) nitrones from the thermolysis of *trans*-oxaziridines.[15] As can be seen from Table II both the rate of isomerization of **2** and the yield of *cis*-azoxyalkane show a modest increase with increasing dielectric constant of the reaction solvent. Thus, it would seem that the developing higher dipole moment of the cis isomer is, as would be expected, more stabilized in the transition state by highly polar solvents.

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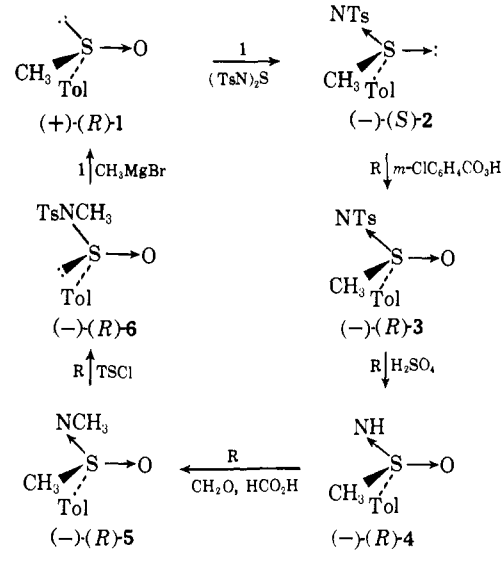
Three New Organosulfur Reactions and the First Example of a Monoligostatic Stereochemical Cycle[1]

Sir:

Recently the properties of stereochemical reaction cycles were described[2] and a literature search revealed no example of a stereochemical reaction cycle in which only a single ligand of a chiral tetrahedron was common to all chiromers (optically active compounds of the cycle). We now wish to report completion of such a *monoligostatic* cycle which contains two new reactions (Chart I). In addition we report a third new reaction

Chart I



Tol = p-$CH_3C_6H_4$; Ts = p-$CH_3C_6H_4SO_2$

which completes a new four-reaction diligostatic cycle.

In the cycle of Chart I the single ligand common to all chiromers is the *p*-tolyl group, and the chiral center is sulfur. Replaceable ligands are O, electron pair, NTs, NH, CH_3, NCH_3, and $TsNCH_3$. The cycle involves six reactions and six chiromers, none of which are enantiomerically related (podal). Two of its reactions occur with inversion, four with retention of configuration, and the cycle contains no ligand metathesis.

The stereochemical courses of the reactions (+)-(*R*)-**1** → (−)-(*S*)-**2** → (−)-(*R*)-**3** → (−)-(*R*)-**4** have been es-

(9) I. I. Abram, G. S. Milne, B. S. Solomon, and C. Steel (*J. Amer. Chem. Soc.*, **91**, 1220 (1969)) report the preparation of **4** by photoisomerization of **5**. Interestingly, mercuric oxide oxidation of symmetrical diisopropylhydrazine affords **4** (4%) as well as **5** (96%) and the cis compound can be isolated by distillation of large-scale oxidations.
(10) J. P. Freeman, *J. Org. Chem.*, **28**, 2508 (1963).
(11) J. P. Snyder, L. Lee, and D. G. Farnum, *J. Amer. Chem. Soc.*, **93**, 3816 (1971).
(12) K. G. Taylor and S. Isaac, unpublished results.
(13) F. D. Greene and S. S. Hecht, *Tetrahedron Lett.*, 575 (1969).
(14) A. G. Hortman and R. E. Youngstrom, *J. Org. Chem.*, **34**, 3392 (1969).
(15) J. S. Splitter, T-M. Su, H. Ono, and M. Calvin, *J. Amer. Chem. Soc.*, **93**, 4075 (1971).

(1) This investigation was supported by the U.S. Public Health Service, Research Grant No. GM 12640-07 from the Department of Health, Education, and Welfare.
(2) D. C. Garwood and D. J. Cram, *J. Amer. Chem. Soc.*, **92**, 4575 (1970).

tablished.[3] Johnson and coworkers[4] have reported the methylation of sulfoximides in 70% yield with trimethyloxonium fluoroborate. We report here a more convenient method for alkylation of sulfoximides (60–90%). This new method is an adaptation of the Eschweiler-Clarke reductive alkylation of amines. Treatment of optically pure (−)-(*R*)-**4** ($[\alpha]^{25}_{436}$ −70.6° (*c* 1.21, acetone))[3] with excess formaldehyde (37% solution in water) and 98% formic acid at 100° for 24 hr gave a 90–95% yield of (−)-(*R*)-**5**[5] as a colorless hygroscopic oil, $[\alpha]^{25}_{589}$ −102° (*c* 1.06, acetone), bp 135° (0.7 mm). This reaction is assumed to proceed with retention at chiral sulfur since no bonds were made or broken to sulfur. Similar alkylations were performed to give the corresponding *N*-benzyl, *N*-isobutyryl, *N*-carbomethoxymethylene, and *N*-(α-carbomethoxyethyl) derivatives.[5] We presume the mechanism of this alkylation reaction parallels that for the alkylation of ordinary amines.[6]

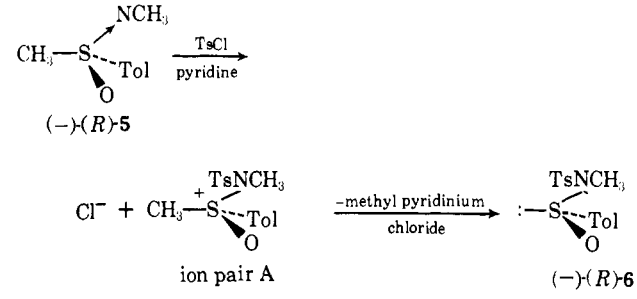
Conversion of (−)-(*R*)-**5** to (−)-(*R*)-**6** occurred at 25° (2.5 hr) in pyridine containing 2 equiv of tosyl chloride. The product was isolated at 0° and proved to be extremely sensitive to both heat and moisture. The material was obtained by extraction and chromatography on silica gel (ether–pentane) in 30–35% yield as a gummy solid, $[\alpha]^{25}_{436}$ −469° (*c* 1.13, chloroform). This material was recrystallized to constant rotation and melting point from ether–pentane to give **6**, $[\alpha]^{25}_{436}$ −533° and $[\alpha]^{25}_{589}$ −225° (*c* 1.14, chloroform), mp 70.5–73°.[5] If one assumes this recrystallized sulfinamide to be optically pure (see below), the conversion of (−)-**5** to (−)-**6** proceeded with at least 94% stereospecificity. The stereochemical course and mechanism of this unusual conversion is discussed in the final paragraphs.

The stereochemical reaction cycle was closed by conversion of (−)-(*R*)-**6** to (+)-(*R*)-**1** by treatment with methylmagnesium bromide in ether at −78° for 4 hr. The product was chromatographed to give a 38.3% yield of (+)-(*R*)-**1** of 95% optical purity. Recrystallization of this material from ether–pentane gave (+)-(*R*)-**1**, mp 75–76.5° (lit.[7a] 73–74.5°), mmp 41–43°, with an equal amount of (−)-(*S*)-**1** (lit.[7b] mp 42–43°). The sample of (+)-(*R*)-**1** was further characterized by its spectral properties.

Conversion of **6** to **1** resembles the reaction of *N*-alkyl- or *N*-arylsulfinamides with methyllithium to give methyl sulfoxides.[8] Although ordinary sulfinamides are inert to Grignard reagents, **6** is a sulfinamide with the *N*-methyl-*p*-toluenesulfonamide anion as a particularly good potential leaving group. The conversion of **6** to **1** with high probability went with inversion of configuration as did the other conversions of sulfinamides to sulfoxides.[8]

The absolute configurations of all of the chiromers of Chart I are known except that of **6**. The stereochemical courses of all of the six reactions of Chart I are known with the exception of (−)-**5** → (−)-**6**. These facts allow the absolute configuration of (−)-**6** to be assigned as *R* and the stereochemical *course* of (−)-**5** → (−)-**6** to be retention. The reasoning is as follows. Since (−)-**6** gives (+)-(*R*)-**1** with inversion then (−)-**6** must have the *R* configuration. If (−)-(*R*)-**6** is produced from (−)-(*R*)-**5** this reaction must have gone with retention. The alternative that **6** → **1** with retention and **5** → **6** with inversion is very highly improbable. We have noted earlier[2] that six reaction monoligostatic podal cycles must have the property that the number of inversions plus the number of ligand metatheses must be an even number. The stereochemical cycle of Chart I contains two inversions and no ligand metathesis.

The reaction of (−)-(*R*)-**5** with tosyl chloride in pyridine to give (−)-(*R*)-**6** is interesting mechanistically. Tosylation of nitrogen undoubtedly turns sulfur into a positively charged leaving group for the attached methyl group (see ion pair A). In a second stage pyridine attacks methyl displacing sulfur (*N*-methylpyridine formation was observed in the nmr). The electron pair of the methyl–sulfur bond remains with the sulfur atom without perturbing the configuration at sulfur. We conclude that this reaction represents an example of a nucleophilic substitution reaction at carbon in which the configuration of the leaving group has been preserved. This reaction is the only known source of *N*-tosyl-*N*-alkylsulfinamides. Attempts to produce this class of compound by more classical means have failed.



Earlier[3] we reported the deimidation reaction of (−)-(*R*)-**4** to give (+)-(*R*)-**1** with nitrosyl hexafluorophosphate as reagent. The reaction proceeded with complete retention of configuration in yields that varied between 20 and 90%. We now report a superior method. Optically pure (−)-(*R*)-**4**, when treated with aqueous nitrous acid (sodium nitrite and 2 *N* sulfuric acid) for 1 hr at 25°, gave a 99% yield of (+)-(*R*)-**1** (99% optically pure). Recrystallization from hexane gave optically pure (+)-(*R*)-**1**, $[\alpha]^{25}_{546}$ +181° (*c* 1.12, acetone) (lit.[3] $[\alpha]^{25}_{546}$ +180.5° (*c* 0.795, acetone)), mp 74.7–76.3°, mmp 41.5–44°, with an equal amount of (−)-(*S*)-**1**. Others have reported that sulfoximides react with nitrous acid more slowly than do aromatic amines[9] at 0°. Whitehead and Bentley claimed[10] that treatment of dimethyl sulfoximide with nitrous acid at 74–80° gave dimethyl sulfone.

This new deimidation reaction, coupled with our other two new reactions, completes the following new

(3) D. J. Cram, J. Day, D. R. Rayner, D. M. von Schriltz, D. J. Duchamp, and D. C. Garwood, *J. Amer. Chem. Soc.*, **92**, 7369 (1970).

(4) C. R. Johnson, M. Haake, and C. W. Schroeck, *ibid.*, **92**, 6594 (1970).

(5) All new compounds reported here gave elementary analysis within 0.3% of theory and ir and nmr spectra in agreement with their assigned structures.

(6) M. L. Moore, *Org. React.*, **5**, 301 (1949).

(7) (a) K. Mislow, M. M. Green, P. Laur, J. T. Melillo, T. Simmons, and A. L. Ternay, Jr., *J. Amer. Chem. Soc.*, **87**, 1958 (1965); (b) A. Cerniani and G. Modena, *Gazz. Chim. Ital.*, **89**, 843 (1959).

(8) (a) J. Jacobus and K. Mislow, *Chem. Commun.*, 253 (1968); (b) D. J. Cram, A. Nudelman, R. E. Booms, and T. R. Williams, manuscript in preparation; (c) S. Colonna, R. Giovini, and F. Montanari, *Chem. Commun.*, 865 (1968).

(9) F. Misani, T. W. Fair, and L. Reiner, *J. Amer. Chem. Soc.*, 73, 459 (1951).

(10) J. K. Whitehead and H. R. Bentley, *J. Chem. Soc.*, 1572 (1952).

stereochemical reaction cycle

$$(+)\text{-}(R)\text{-}\mathbf{1} \xleftarrow{R} (-)\text{-}(R)\text{-}\mathbf{4} \xrightarrow{R} (-)\text{-}(R)\text{-}\mathbf{5} \xrightarrow{R} (-)\text{-}(R)\text{-}\mathbf{6} \xrightarrow{I} (+)\text{-}(R)\text{-}\mathbf{1}$$

This four-reaction cycle contains four chiromers, three retentions, and one inversion. Unlike the cycle of Chart I, the presence of a ligand metathesis and one inversion makes this reaction cycle podal. All chiromers contain tolyl and oxygen as common ligands and therefore the cycle is diligostatic.[2]

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The Isotopic Rearrangement of *n*-Propyl-α-^{13}C-benzene

Sir:

In 1964 Roberts, Khalaf, and Greene[1] proposed that the isotopic rearrangement of α or β ^{14}C-labeled *n*-propylbenzene in the presence of aluminum chloride involves diphenylpropanes as key intermediates. Later in the same year, Farcasiu[2] suggested that the isotopic rearrangement and the small amount of isomerization of isopropylbenzene that also occur result from a mechanism in which diphenylhexyl cations ($C_{18}H_{21}^+$) are produced, rearrange, and undergo fission in a way similar to the "bimolecular mechanism" proposed by Karabatsos for the isotopic rearrangements of ^{13}C- and ^{14}C-labeled *tert*-pentyl cations.[3,4]

Both of these mechanisms provide explanations for an important aspect of the *n*-propylbenzene isotopic rearrangement; the lack of rearrangement of the isotopic carbon to the γ position. In both of them the intermediate carbonium ions which lead to equilibration of the isotope between the α and β positions can be secondary, whereas primary carbonium ions are required to put the isotope into the γ position.[5]

An obvious and elegant test to distinguish between these two mechanisms would be to use ^{13}C as the labeling isotope. The diphenylhexyl cation mechanism would allow the formation of dilabeled and unlabeled as well as monolabeled molecules of *n*-propylbenzene, whereas only monolabeled isotopic isomers could result from rearrangement *via* diphenylpropane intermediates. Analysis of the reaction products by mass spectroscopy should thus allow an assessment of the extent of rearrangement *via* bimolecular processes.

n-Propyl-α-^{13}C-benzene was synthesized from Ba-$^{13}CO_3$ by a procedure analogous to the one described previously for *n*-propyl-α-^{14}C-benzene.[6] The isotopic analysis of ^{13}C-labeled molecules was obtained by mass spectrometry through comparison of the intensities of the p and p + 1 ions. The spectrum of unenriched *n*-propylbenzene at 70 eV exhibits a strong parent peak, p (*m/e* 120), and a small p + 1 peak (*m/e* 121) which corresponds to the expected distribution of molecules containing ^{13}C from natural abundance. The enriched *n*-propyl-α-^{13}C-benzene exhibited a much higher ratio of *m/e* 121:120 peaks, of course (Table I). The formation of dilabeled and unlabeled molecules from monolabeled molecules of *n*-propylbenzene upon reaction with $AlCl_3$ could be detected easily by a significant change in the ratio of the *m/e* 121:120 peaks.

Table I. Mass Spectroscopic Analysis of *n*-Propyl-^{13}C-benzene before and after Reaction with Aluminum Chloride

	m/e 120 ($C_9H_{12}^+$), %	*m/e* 121 ($C_8{}^{13}CH_{12}^+$), %	*m/e* 91 ($C_7H_7^+$), %	*m/e* 92 ($C_6{}^{13}CH_7^+$), %
		Before Reaction		
Expt 1	67.7	32.3	67.7	32.3
Expt 2	83.1	16.9	82.1	17.9
		After Reaction		
Expt 1	67.7	32.3	82.5	17.5
Expt 2	83.3	16.7	90.8	9.2

The distribution of the label in the fragment ions of the mass spectrum could be used to locate the position of the label within the parent molecule, if there were no scrambling of carbon atoms preceding the primary fragmentation. Cleavage of the bond between the α and β carbon atoms does indeed produce the tropylium ion ($C_7H_7^+$, *m/e* 91, and $C_6{}^{13}CH_7^+$, *m/e* 92, base peak) without scrambling the label, thereby making possible determination of the amount of ^{13}C in the α position before and after the isotopic rearrangement.

Samples of *n*-propyl-α-^{13}C-benzene (500 mg, 32.3% monolabeled and 498 mg, 16.9% monolabeled) were treated with aluminum chloride in the presence of benzene and a trace of water (1.0:0.5:6.0:0.1 molar ratios, respectively) at reflux for 7 hr, duplicating the conditions previously reported[1] to give equilibration of the isotope between the α and β positions. The work-up, involving decomposition of the reaction mixture with water, was carried out as before. Preparative glpc resulted in 60–67% recovery of *n*-propylbenzene.

The quantitative mass spectral data were obtained with a CEC 21-110 mass spectrometer with an ionizing voltage of 70 eV. Peak intensities were measured by means of a potentiometric recorder. The data are presented in Table I. The natural abundance of ^{13}C, 1.1% per carbon atom, was subtracted from each of the observed values.

As may be seen from the first two columns of Table I, there was no significant change in the ratio of the *m/e* 120:121 peaks before and after reaction, showing that no unlabeled or dilabeled *n*-propylbenzene molecules were produced. The change in the ratio of the *m/e* 91:92 peaks before and after reaction (columns three and four) was indicative of the expected isotopic rearrangement; in experiment 1, 54.3% (17.5/32.3 × 100) and in experiment 2, 51.4% (9.2/17.9 × 100) of the ^{13}C remained in the α position after reaction.

^{13}C and ^1H nmr spectroscopy was also used to confirm ^{13}C label position among the α, β, and λ positions,

(1) R. M. Roberts, A. A. Khalaf, and R. N. Greene, *J. Amer. Chem. Soc.*, 86, 2864 (1964).
(2) D. Farcasiu, *Rev. Chim. (Bucharest)*, 10, 457 (1965).
(3) G. J. Karabatsos, F. M. Vane, and S. Meyerson, *J. Amer. Chem. Soc.*, 83, 4297 (1961).
(4) G. J. Karabatsos and F. M. Vane, *ibid.*, 85, 79 (1963).
(5) One deficiency of the "bimolecular mechanism" is the fact that t predicts the rearrangement of *n*-propylbenzene to isopropylbenzene as easily (*i.e.*, *via* secondary and tertiary carbonium ions) as the isotopic rearrangement, in disagreement with experimental facts. The mechanism involving diphenylpropane intermediates allows for rearrangement to isopropylbenzene only *via* primary carbonium ions, which would not be expected to be facile, in accord with experimental facts.
(6) R. M. Roberts and J. E. Douglass, *J. Org. Chem.*, 28, 1225 (1963).