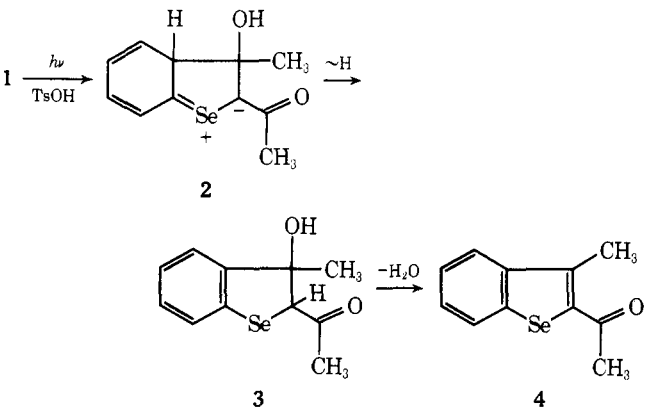
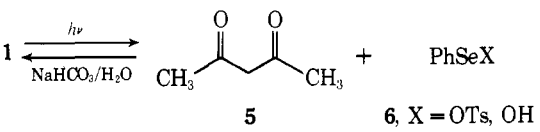
to β-hydroxy ketone 3; acid-catalyzed dehydration of 3 would give benzoselenophene (4).



That 3 actually is an intermediate in the conversion of 1 → 4 was demonstrated by photolysis of 1 in benzene-d_6 containing acetic acid (1 equiv) in a degassed[11] NMR tube; extended irradiation led to a mixture of products (vide supra), a major component (~30%) of which gave NMR singlets at δ 1.92 (3 protons), 2.31 (3 protons), and 4.86 (1 proton) and has been assigned structure 3 on the basis of chemical reactivity. Thus, treatment of the photolysis mixture with a catalytic amount of *p*-toluenesulfonic acid resulted in rapid disappearance of the three NMR singlets attributable to 3 together with an enhancement of absorptions due to the methyl resonances of benzoselenophene 4 (δ 2.60 and 2.73).

The photochemistry of 1 also includes cleavage of carbon–selenium bonds. Photoreaction of 1 in benzene-d_6 with *p*-toluenesulfonic acid was carefully monitored by NMR spectroscopy;[11] after brief irradiation, NMR analysis above δ 6.00 revealed that 1 (19%), benzoselenophene (4, 54%), and acetylacetone (5, 27%) were present. Interestingly, treatment of the crude photoreaction with aqueous sodium bicarbonate solution resulted in the disappearance of acetylacetone with concomitant formation of selenide 1. Thus, a portion of photoexcited 1 must undergo carbon–selenium bond cleavage to generate acetylacetone (5) and PhSeX (6); on treatment with base, 1 is regenerated from 5 and 6.[12] Formation of considerable acetylacetone occurred when 1 was irradiated in benzene–acetic acid solution, and in pure benzene photocleavage was the predominant reaction.



The high yield obtained in the conversion of 1 → 4 suggests that analogous photoreactions may be useful for synthesis of a variety of aryl annelated selenophenes. Perhaps more importantly, it is clear that appropriately structured organoselenium compounds may undergo interesting and synthetically useful photoreactions. Work in this area will continue.

Acknowledgment. This work was supported by the National Institutes of Health (Grant No. GM 21159-01).

References and Notes

(1) T. Do-Minh, A. M. Trozzolo, and G. W. Griffin, *J. Am. Chem. Soc.*, **92**, 1402 (1970); D. R. Arnold and L. A. Karnischky, *ibid.*, **92**, 1404 (1970); J. Buter, S. Wassenaar, and R. M. Kellogg, *J. Org. Chem.*, **37**, 4045 (1972).
(2) Preparation of highly stabilized selenonium ylides (three substituents attached to selenium) has been reported. For example, see R. D. Hughes and K. I. Kuriyan, *J. Chem. Soc.*, 1609 (1935); D. Lloyd and M. I. C. Singer, *Chem. Commun.*, 390 (1967); and J. Stackhouse, G. H. Senkler, B. E. Maryanoff, and K. Mislow, *J. Am. Chem. Soc.*, **96**, 7835 (1974).
(3) Previous reports of solution-phase photochemistry of organoselenium compounds are W. Stanley, M. R. VanDeMark, and P. L. Kumler, *Chem. Commun.*, 700 (1974) and D. L. Ross, J. Blanc, and F. J. Matticoli, *J. Am. Chem. Soc.*, **92**, 5750 (1970).
(4) A. G. Schultz and R. D. Lucci, *J. Org. Chem.*, **40**, 1371 (1975).
(5) A. G. Schultz, *J. Org. Chem.*, **39**, 3185 (1974).
(6) "Organic Selenium Compounds: Their Chemistry and Biology", D. L. Klayman and W. H. H. Günther, Ed., Wiley-Interscience, New York, N.Y., 1973, Chapter 6.
(7) K. B. Sharpless, R. F. Lauer, and A. Y. Teranishi, *J. Am. Chem. Soc.*, **95**, 6137 (1973).
(8) H. J. Reich, J. M. Renga, and I. L. Reich, *J. Org. Chem.*, **39**, 2133 (1974).
(9) L. Christiaens and M. Renson, *Bull. Soc. Chim. Belg.*, **77**, 153 (1968).
(10) A. G. Schultz and M. B. DeTar, *J. Am. Chem. Soc.*, **96**, 296 (1974).
(11) These photoreactions were performed in clear Pyrex NMR tubes degassed by four freeze–pump–thaw cycles with an oil-diffusion-pump vacuum and were examined periodically with a Varian a-60A NMR spectrometer (TMS external standard).
(12) It is of interest to note that ketones undergo an efficient acid-catalyzed selenenylation with ArSeX in ethyl acetate solution; see ref 7. With β diketones, however, the equilibrium is reversed and acid-catalyzed selenenylation is not possible: private communication, K. B. Sharpless.

Department of Chemistry **Arthur G. Schultz**
Cornell University
Ithaca, New York 14853

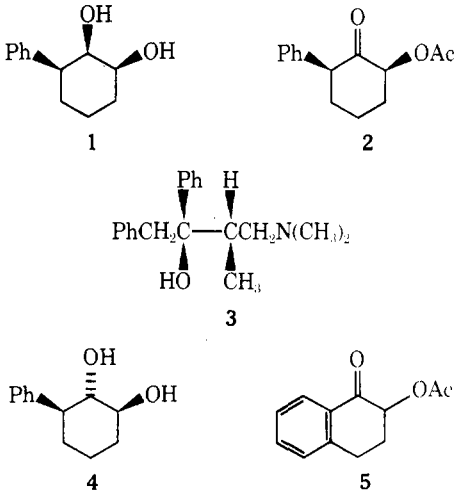
Received September 23, 1975

Asymmetric Synthesis and Absolute Stereochemistry of Some Cis and Trans Diols

Summary: A general method for the preparation of optically active cis and trans diols by asymmetric reduction of α-acetoxy ketones using a 2:1 Darvon–lithium aluminum hydride complex, is described. The absolute stereochemistry of these diols has been established by chemical methods.

Sir: In the course of some studies on the absolute stereochemistry of a variety of metabolites, cis dihydrodiols[1a] obtained from the microbial metabolism of aromatic substrates and trans dihydrodiols prepared by enzymatic hydration of arene oxides,[1b] we encountered difficulties in obtaining sufficient quantities of these compounds. Therefore, we have developed chemical methods for preparing optically active dihydro derivatives of several metabolites. The absolute stereochemistry of these compounds has been determined by chemical transformations to substances of known absolute stereochemistry.

We first chose the asymmetric synthesis of 1, a dihydro derivative of a metabolite of biphenyl[2] by a species of *Beijerinckia*. Our approach focused on the chiral reduction of



the appropriate cis α-acetoxy ketone **2** which was prepared by mercuric acetate oxidation of 2-phenyl cyclohexanone;[3] it was reduced under conditions in which the molar ratios of ketone:$LiAlH_4$:*l*-Darvon (**3**) were 1:1.5:3, at 0°C for 16 hr in diethyl ether as described by Yamaguchi and Mosher,[4] to yield a mixture of cis,cis and trans,trans diols (38, 21%, respectively) **1** and **4**, which were separated by thick layer chromatography on silica gel using 40% ethyl acetate–hexane. An examination of the NMR spectrum (220 MHz) of **1** {$[\alpha]^{25}D$ +33.8° (*c* 2.16, methanol)} in the presence of the chiral shift reagent tris(3-heptafluorobutyryl-*d*-camphorato)europium(III) showed the enantiomeric excess to be 64% (Δ 0.23 ppm, Eu/S 0.16, $CDCl_3$). This enantiomeric excess was confirmed, and the absolute stereochemistry determined as (1*S*,2*R*)-dihydroxy-3(*S*)-phenylcyclohexane, by oxidizing **1** (sodium periodate in 70% aqueous ethanol, followed by bromine water in the presence of calcium carbonate), to (+)-2(*S*)-phenyladipic acid of known absolute stereochemistry.[5] Attempts to determine the enantiomeric excess present in the trans,trans diol **4** {$[\alpha]^{25}D$ +23.1° (*c* 3.21, methanol)} using $Eu(hfbc)_3$ and $Eu(hfc)_3$ were unsuccessful. A minimum value of 77% for the enantiomeric excess, as well as its absolute stereochemistry [(1*R*,2*R*)-dihydroxy-3(*R*)-phenylcyclohexane], was determined by oxidation to (−)-2(*R*)-phenyladipic acid.

The large enantiomeric excess present in the above compounds and our interest in the absolute stereochemistry of a variety of aromatic metabolites prompted us to examine this route for the preparation of the dihydro derivatives of the cis and trans 1,2-dihydro diols from naphthalene.[6] The intermediate **5**[7,8] was reduced with a 2:1 Darvon–lithium aluminum hydride complex to yield primarily (~30%) (−)-cis diol, **6** {$[\alpha]^{25}D$ −15.0° (*c* 2.43, methanol)}. Examination of its NMR spectrum in the presence of the above-mentioned chiral shift reagent showed a 20% enantiomeric excess (Δ 0.18 ppm, Eu/S 0.3, $CDCl_3$). The enantiomeric excess of the minor product [5%, (+)-trans diol **7**] was 62% {$[\alpha]^{25}D$ +70° (*c* 0.39, $CHCl_3$)} based on the value reported by Nakazaki et al.,[6b] who has established its absolute stereochemistry as (1*R*,2*R*)-dihydroxytetrahydronaphthalene. The absolute stereochemistry of **6** was established as *cis*-(1*R*,2*S*)-dihydroxy-1,2,3,4-tetrahydronaphthalene by conversion (acetylation and hydrogenolysis) to the known (−) - 2(*S*) - acetoxy - 1,2,3,4 - tetrahydronaphthalene.[9] Although the absolute stereochemistry of the metabolite was previously reported,[6a] that of the dihydro derivative was not.[11]

Work is currently in progress on extending this approach toward the synthesis of a variety of dihydro derivatives of metabolites from polycyclic hydrocarbons.

References and Notes

(1) (a) H. Ziffer, D. M. Jerina, D. T. Gibson, and V. M. Kobal, *J. Am. Chem. Soc.*, **95**, 4048 (1973); (b) D. M. Jerina, H. Ziffer, and J. W. Daly, *ibid.*, **92**, 1056 (1970).
(2) D. T. Gibson, R. L. Roberts, M. C. Wells, and V. M. Kobal, *Biochem. Biophys. Res. Commun.*, **50**, 211 (1973).
(3) (a) E. Vedejs, *J. Am. Chem. Soc.*, **96**, 5944 (1974); (b) W. Treibs and M. Weissenfels, *Chem. Ber.*, **93**, 1374 (1960).
(4) S. Yamaguchi and H. S. Mosher, *J. Org. Chem.*, **38**, 1870 (1973).
(5) L. Westman, *Arkiv Kemi*, **12**, 167 (1957).
(6) (a) D. M. Jerina, J. W. Daly, A. M. Jeffrey, and D. T. Gibson, *Archiv. Biochem. Biophys.*, **142**, 394 (1971); (b) R. Miura, S. Honmaru, and M. Nakazaki, *Tetrahedron Lett.*, 5271 (1968).
(7) K. Hanaya, *Bull. Chem. Soc. Jap.*, **40**, 1884 (1967).
(8) P. D. Gardner, *J. Am. Chem. Soc.*, **78**, 3421 (1956).
(9) H. Arakawa, N. Torimoto, and Y. Masui, *Tetrahedron Lett.*, 4115 (1968).
(10) Visiting Scientist from College of General Education, Tohoku University, Sendai, Japan.
(11) After completion of this manuscript a report on the absolute stereochemistry of the dihydro derivative appeared in agreement with our assignment: A. M. Jeffrey, H. Y. C. Yeh, D. M. Jerina, T. R. Patel, J. F. Davey, and D. T. Gibson, *Biochemistry*, **14**, 575 (1975).

Laboratory of Chemical Physics
National Institute of Arthritis, Metabolism and Digestive Diseases
National Institutes of Health
Bethesda, Maryland 20014

Kuninobu Kabuto[10]
Herman Ziffer*

Received August 18, 1975