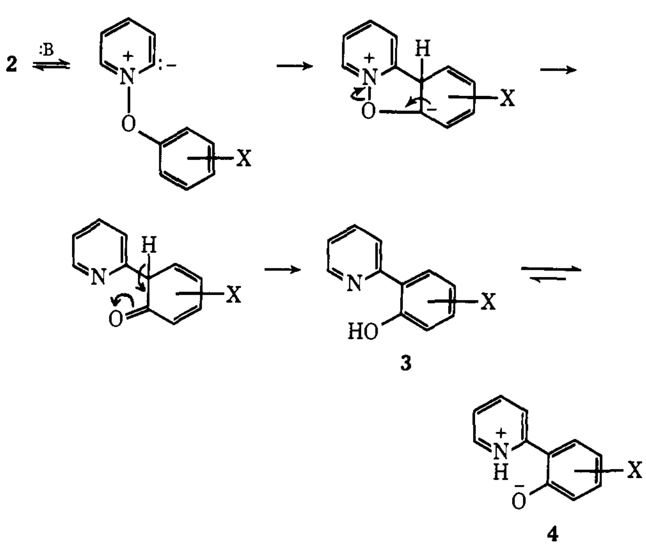
which, in turn, reacts with pyridine 1-oxide to give 2-acylaminopyridines.[3]

Heterocyclic tertiary amine *N*-oxides[4] and ylides[5] are known to undergo interesting photodecompositions and -rearrangements, and recently Mee, Heseltine, and Taylor[6] have reported that the photolysis of *N*-methoxyphenanthridinium perchlorate yields methoxyl radicals which can substitute into an aromatic nucleus. It was our hope that photolysis of **2** would take a different course and lead to pyridine and $XC_6H_4O^+$ which would be isoelectronic with the corresponding nitrene. To our surprise, **2a** proved to be stable to irradiation in acetonitrile using 2537- or 3000-Å light. Photolysis of **2a** in acetonitrile containing some 1,4-dimethoxybenzene at 2537 Å gave a trace of *p*-nitrophenol, the salt being recovered almost quantitatively. On the other hand, the *o*-CF_3 salt (**2d**) did undergo photolysis and the nature of the products formed from it and other salts will be described in a future paper. The salts are also thermally stable and may be recovered unchanged after boiling in acetonitrile for prolonged periods.

On the other hand, we have discovered a new base-catalyzed rearrangement of compounds **2**. Treatment of **2a** in hot acetonitrile solution either with potassium phenoxide or with triethylamine gave 2-(2-hydroxy-5-nitrophenyl)pyridine (**3a**): mp 216–217° (65%); ν_{max}^{KBr} 2600 ($-N^+H=$); λ_{max}^{MeCN} 249, 287, and 323 mμ; ϵ 14,000, 16,700, 12,000; *m/e* 216 (M^+), 200 ($M^+ - O$), 186 ($M^+ - NO$), 170 ($M^+ - NO_2$), 142 ($M^+ - NO_2 - CO$); $\delta_{TMS}^{CF_3CO_2H}$ 8.93–8.67 (m, 5 H), 8.0 (1 H, t, J = 7 Hz), 7.37 (1 H, d, J = 10 Hz). An authentic sample of **3a** was synthesized by the Gomberg–Hey arylation of pyridine with the diazonium salt from 2-amino-4-nitroanisole, fractional crystallization of the products to give 2-(2-methoxy-5-nitrophenyl)pyridine,[7] followed by demethylation with hot HBr to give **3a**, identical in all respects with the rearrangement product. Similarly, other 2-(2-hydroxyphenyl)pyridines were obtained in good yield from **2b–f**. Interestingly, **3a–e** exhibit no O–H stretching band in the infrared (or only a very weak broad band), but do show a broad $-N^+H=$ band at *ca.* 2600 cm^{-1}, indicating that, in the solid state at least, they exist in the zwitterionic form **4**.

A possible mechanism for the rearrangement involves base-catalyzed proton abstraction from the 2 position of the pyridine ring[8] followed by nucleophilic attack at the ortho position of the benzene ring, though other pathways are conceivable (see scheme).

The scope of this O-arylation, the chemical reactions and photochemistry of the salts **2**, the mechanism of the rearrangement, and the reactions of the novel phenols **3** are presently under study.



Acknowledgment. We wish to thank the National Institutes of Health for a grant (GM-16626).

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Received March 13, 1971

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(3) R. A. Abramovitch and G. M. Singer, *J. Amer. Chem. Soc.*, **91**, 5672 (1969).

(4) G. G. Spence, E. C. Taylor, and O. Buchardt, *Chem. Rev.*, **70**, 231 (1970).

(5) J. Streith, A. Blind, J.-M. Cassal, and C. Sigwalt, *Bull. Soc. Chim. Fr.*, 948 (1969); T. Sasaki, K. Kanematsu, A. Kakehi, I. Ichikawa, and K. Hayakawa, *J. Org. Chem.*, **35**, 427 (1970). A. Balasubramanian, J. M. McIntosh, and V. Snieckus, *ibid.*, **35**, 433 (1970).

(6) J. D. Mee, D. W. Heseltine, and E. C. Taylor, *J. Amer. Chem. Soc.*, **92**, 5814 (1970).

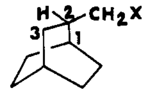
(7) J. W. Haworth, I. M. Heilbron, and D. H. Hey, *J. Chem. Soc.*, 358 (1940).

(8) R. A. Abramovitch, G. M. Singer, and A. R. Vinutha, *Chem. Commun.*, 55 (1967); J. A. Zoltewicz and L. S. Helmick, *J. Amer. Chem. Soc.*, **92**, 7547 (1970).

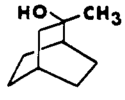
Carbonium Ion Rearrangements of Bicyclo[2.2.2]oct-2-ylcarbinyl Derivatives[1]

Sir:

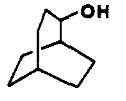
The products of carbonium ion rearrangements of the bicyclo[2.2.2]oct-2-ylcarbinyl system (**1**) include those resulting from hydride shift (tertiary alcohol or acetate **2**) and from rearrangement of C_3 (bicyclo[3.2.2]non-2-yl derivatives **3**).[2] The present stereochemical and tracer experiments on these processes reveal a new type of geometric restriction in multiple carbonium ion rearrangements. They also are relevant to the question whether ion-pairing effects may cause the special stereochemical properties characteristic of the first rearranged intermediates in these reactions and in related processes where "memory effects" are observed.[4]



(−)-**1**



(−)-**2**



(+)-**3**

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[1] We are grateful for the support of this work by grants from the National Science Foundation (GP-1608, GP-6212X, and GU-3282), the National Institute of Arthritis and Metabolic Diseases (AM-07505), the National Institute of General Medical Sciences (GM-16962), the Petroleum Research Fund, and the Hoffmann–La Roche Foundation.

(2) (a) Previous studies of these reactions have been reported by K. Alder and R. Reubke, *Chem. Ber.*, **91**, 1525 (1958). (b) The product distribution depends on conditions. Deamination in aqueous dioxane gives 40% of hydrocarbons, 7% of **2**, 27% of **3**, 7% of **1**, and 4% each of bicyclo[3.3.1]- and -[3.2.2]nonan-2-ol. Control experiments in deuterated media[3] show that in hydrolysis none of the alcohol products arises by hydration of hydrocarbon intermediates. In deamination, the conclusion is the same, the observed small amount of incorporation of deuterium being virtually *identical* in all the alcohol products, presumably because of partial exchange *via* the diazoalkane occurring in competition with rearrangement.

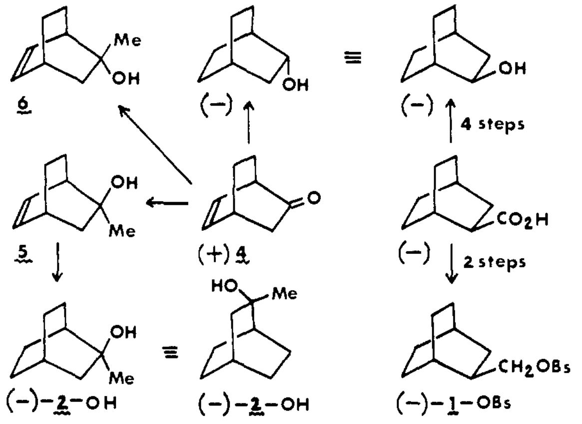
(3) R. T. Luibrand, Ph.D. Thesis, University of Wisconsin, 1971.

(4) (a) J. A. Berson, *Angew. Chem., Int. Ed. Engl.*, 7, 779 (1968); (b) J. A. Berson, J. J. Gajewski, and D. S. Donald, *J. Amer. Chem. Soc.*, **91**, (1969); (c) J. A. Berson, R. G. Bergman, G. M. Clarke, and D. Wege, *ibid.*, **91**, 5601 (1969).

The configurations shown correspond to the indicated signs of rotation for (−)-**1**-OBs and (−)-**1**-NH_2, (−)-**2**, and (+)-**3**.

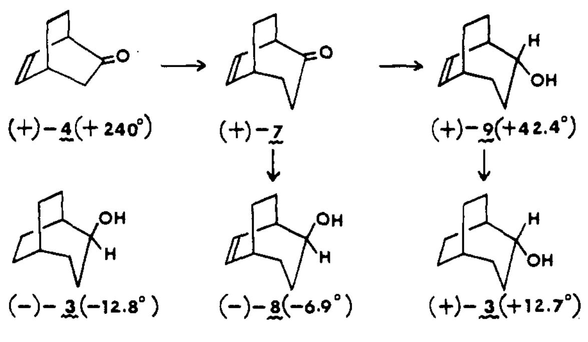
(+)-Bicyclo[2.2.2]oct-5-en-2-one (**4**)[5] serves as a relay compound for the configurational correlation of (−)-**1**-OBs and (−)-**2**-OH (Chart I, configurations absolute as shown). The key to the correlation lies in the conversion of the epimeric difference between **5** and **6** to an enantiomeric difference by hydrogenation to **2**. Assignment of the indicated epimeric configurations **5** and **6** to, respectively, the major and minor products of the action of methyl Grignard reagent on **4** rests on the nmr chemical shifts of these substances and a number of their derivatives and also upon the oxidations of **5** and **6**, which lead to a hydroxydibasic acid and a lactonic acid, respectively.

Chart I. Configurational Correlations



Similarly, Tiffeneau ring expansion[6] converts partially resolved (+)-**4**, [α] +240°, to (+)-bicyclo[3.2.2]non-6-en-2-one (**7**), which gives the unsaturated alcohols **8** and **9** upon reduction (Chart II). The epimeric configurations of **8** and **9** follow from the contact-shifted nmr spectra,[7] which show strong downfield shifts of four aliphatic and two olefinic proton resonances, respectively. Spin decoupling experiments confirm the chemical-shift assignments. Hydrogenations of the separated epimers give the enantiomers of bicyclo[3.2.2]nonan-2-ol (**3**, Chart II).

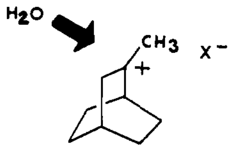
Chart II



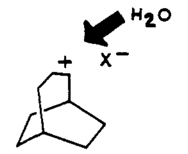
Hydrolyses of (−)-**1**-OBs in buffered 68.2% dioxane–water and in 74% ethanol–water (v:v) and deamination of **1**-$NH_3^+Cl^-$ from (−)-**1**-NH_2 in the former medium give the product of hydride shift **2**-OH with 28–30%, 20–24%, and 15% preservation of enantiomeric purity, respectively. In each case, the **2**-OH is (−), which according to Chart I, indicates that hydroxyl replaces the migrating hydrogen with *retention* of configuration.

Deamination of **1**-$NH_3^+Cl^-$ from (−)-**1**-NH_2 in dioxane–water gives ring-expanded product bicyclo[3.2.2]nonan-2-ol **3**-OH with complete[8] retention of enantiomeric purity. The **3**-OH is (+), which according to Chart II indicates that hydroxyl replaces migrating carbon with *inversion* of configuration.

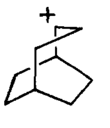
The simple carbonium ion precursors of **2**-OH and **3**-OH both are symmetrical and thus cannot account for the optical activity that survives in these products. Invocation of an asymmetrically placed counterion, *e.g.*, as in **2a** or **3a**, provides in principle a source of stereochemical preference but requires in detail most peculiar behavior in that attack on **3a** must occur preferentially on the same side as the counterion rather than on the side away from it. Moreover, even if this behavior is accepted for **3a**, the *opposite* behavior must be invoked for **2a**. It seems preferable to ascribe the stereochemical outcome to intrinsic asymmetry of at least one of the cations. In the precursor of **3**-OH, this could be caused either by slow interconversions of conformational isomers (*e.g.*, **3R**) or by nonclassical bonding (**3N**). Specific formulations for precursors of **2**-OH, although presently speculative, may involve hydrogen-bridged[9,10] or other nonclassical species. As in the past,[4] the asymmetric behavior of intermediates in the multiple rearrangements we have studied does not find a particularly helpful or natural interpretation in properties expected of ion pairs.



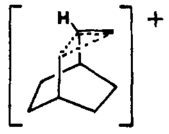
2a



3a



3R



3N

Deaminations of **1**-$NH_3^+Cl^-$-*methylene-t* in the above aqueous dioxane medium and in an aqueous acetic acid solvent system give **3**-OH in which 91.3 and 90.8%, respectively, of the tritium label is at C-3. Based on Chart III and the relationship $k_r/k_c = 2(\mathbf{3}\text{-}6\text{-}t)/[(\mathbf{3}\text{-}3\text{-}t) - (\mathbf{3}\text{-}6\text{-}t)]$, the above data give $k_r/k_c = 0.22$ and 0.22 for the ratio of rates of rearrangement *vs.* nucleophilic capture of the first intermediate. These results contrast sharply with that reported[11] for the next lower homologous cation **10R**, which in the same aqueous acetic acid medium used here shows a corresponding ratio $k_r'/k_c' = 6.5\text{-}13$. The insertion of a single ring methyl-

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[5] K. Mislow and J. G. Berger, *J. Amer. Chem. Soc.*, 84, 1956 (1962).

[6] *Cf.* P. A. S. Smith and D. R. Baer, *Org. React.*, 11, 157 (1960).

[7] Obtained upon samples treated with tris(dipivaloylmethanato)europium. *Cf.* (a) C. C. Hinckley, *J. Amer. Chem. Soc.*, **91**, 5160 (1969); (b) J. K. M. Sanders and D. H. Williams, *Chem. Commun.*, 422 (1970).

[8] The observed value, 102 ± 5%, depends upon the absence of racemization in the correlation of Chart I. Actually, there is good reason to suspect a small amount of racemization there,[3] which would make the above value too high.

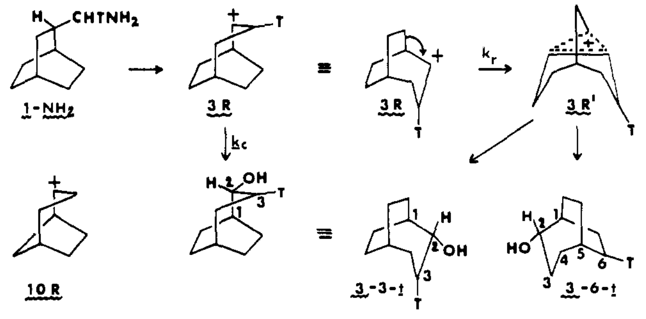
[9] D. J. Cram and J. Tadanier, *J. Amer. Chem. Soc.*, 81, 2737 (1959).

[10] S. Winstein and N. J. Holness, *ibid.*, 77, 5562 (1955).

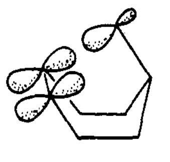
[11] J. A. Berson and P. Reynolds-Warnhoff, *ibid.*, 84, 682 (1962); **86**, 595 (1964).

ene group converting **10R** to **3R** thus produces a 30- to 60-fold decrease in the relative rates of rearrangement

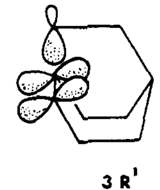
Chart III



to solvent capture. This extra ring member causes severe difficulties in achieving proper orbital overlap in a strain-free rearrangement transition state (or intermediate) **3R'**, whereas the lower homolog **10R'** encounters no such problems.



10R'



3R'

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[12] Supported by a National Institutes of Health Predoctoral Fellowship of the National Institute of General Medical Sciences: (a) Grant No. GM-37475, 1968–1970; (b) Grant No. GM 37920, 1967–1968.

[13] We acknowledge with thanks the collaboration of Mr. James Tear[12b] in the early stages of this work.

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Received March 8, 1971

Stereochemical Behavior of α-Lithio Sulfoxides (α-Sulfinyl Carbanions)[1]

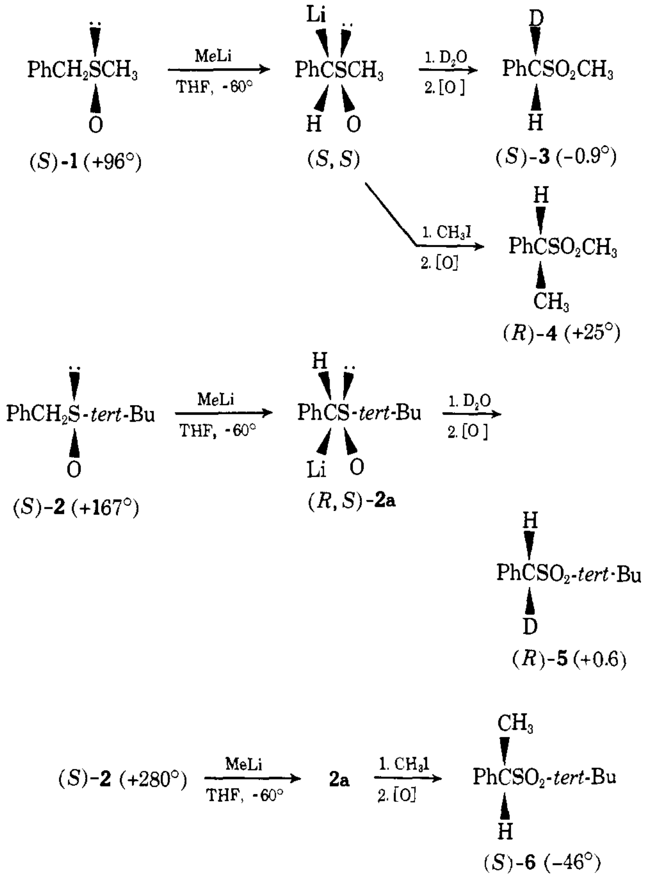
Sir:

Recent studies have shown that base-catalyzed hydrogen–deuterium exchange of the diastereotopic protons in sulfoxides of the type RCH$_2$S(O)R' (R and/or R' = aryl or alkyl) can occur at significantly different rates.[2] The importance of solvent on the relative rates of exchange of the two diastereotopic protons has also been reported.[2g,3] Exploitation of the selectivity observed in the H–D exchanges for synthetic purposes, especially the use of asymmetric sulfoxides for the synthesis of compounds having optical activity at carbon, has however received much less attention.[4,5]

In order to evaluate the synthetic possibilities we have studied the reactions of various α-lithio sulfoxides with alkylating agents and carbonyl compounds and compared the diastereomer ratios and stereochemical course in these reactions with those obtained in the H–D exchanges.

Benzyl methyl (**1**) and benzyl *tert*-butyl sulfoxide (**2**) have been studied in greatest detail. Reaction of **1** and **2** with methyllithium in THF at −60° rapidly generated the corresponding α-lithiobenzyl derivatives. These were quenched after 1 min with excess D$_2$O and gave mixtures of monodeuterated diastereomeric sulfoxides, the recovery being greater than 85%. The diastereomer ratios were 15:1 and >99:1, respectively. Variable-temperature studies[3] indicated that these ratios reflect the ratios of the lithio salts in solution, D$_2$O serving as a trapping agent. The respective lithio salts were also allowed to react with acetone, cyclohexanone, and methyl iodide (tenfold excess), for 1 min. In each case the resultant diastereomer ratio agreed within experimental error with that obtained on deuteration.[6] Thus these reagents also

Scheme I



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[1] Presented at the C.I.C. sponsored Heteroatom Symposium, London, Ontario, Sept 1970.

[2] (a) A. Rauk, E. Buncel, R. Y. Moir, and S. Wolfe, *J. Amer. Chem. Soc.*, **87**, 5498 (1965); (b) S. Wolfe and A. Rauk, *Chem. Commun.*, 778 (1966); (c) E. E. Bullock, J. M. W. Scott, and P. D. Golding, *ibid.*, 168 (1967); (d) M. Nishio, *ibid.*, 562 (1968); (e) R. R. Fraser and F. J. Schuber, *ibid.*, 397 (1969); (f) J. E. Baldwin, R. E. Hackler, and R. M. Scott, *ibid.*, 1415 (1969); (g) B. J. Hutchinson, K. K. Andersen, and A. R. Katritzky, *J. Amer. Chem. Soc.*, **91**, 3839 (1969).

[3] (a) T. Durst, R. R. Fraser, M. R. McClory, R. B. Swingle, R. Viau, and Y. Y. Wigfield, *Can. J. Chem.*, **48**, 2148 (1970); (b) R. R. Fraser and F. J. Schuber, private communications.

[4] T. Durst, *J. Amer. Chem. Soc.*, **91**, 1034 (1969).

[5] We have succeeded in preparing epoxides from β-hydroxy sulfoxides in a three-step sequence (reduction to sulfide, methylation to sulfonium salt followed by base-catalyzed cyclization). The sequence has been applied successfully to the production of optically pure epoxides; T. Durst and C.-H. Nguyen, unpublished observations.[1]

[6] The diastereomer ratios were obtained from integration of the nmr spectra of the total crudes. In the case of the deuteration and hydroxyalkylation reactions the remaining benzylic proton of each diastereomer was used to obtain the ratio;[3] for the methylations, com-