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(8) Commercially prepared t-C_4H_9Li (Aldrich) may be used, but purer compounds are obtained by use of freshly prepared (adapted from L. J. Tyler, L. H. Sommer, and F. C. Whitmore, *J. Am. Chem. Soc.*, **70**, 2876 (1948)) and titrated (C. Watson and J. F. Eastham, *J. Organomet. Chem.*, **9**, 165 (1967)) reagent. Typically, t-C_4H_9Li (25 mM in 30 mL of pentane) is added over 15–30 min to a slurry of $LnCl_3$ (6 mM) in 30 mL of THF. All reactions were conducted in an inert atmosphere using standard techniques (D. F. Shriver, "Manipulation of Air Sensitive Compounds", McGraw-Hill, New York, 1969).
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(10) The lighter lanthanides do not give similar complexes. For example, with Ln = Pr, a compound is isolated which differs markedly from the title complexes. The identity and properties of this compound and related light lanthanide analogues are under investigation.
(11) Decomposition is accompanied by a distinctive color change to dark orange. The decomposition product is insoluble in all common organic solvents and exhibits a featureless IR spectrum.
(12) Anal. Calcd for $LiErC_{32}H_{68}O_4$: Er, 24.20; Li, 1.00; C, 55.62; H, 9.92; O, 9.26. Found: Er, 24.42; Li, 1.12; C, 55.35; H, 9.70; Cl, 0.00; O, 9.41 (by difference) (Bernhardt).
(13) Anal. Calcd for $LiYbC_{28}H_{60}O_3$: Yb, 27.70. Found: Yb, 26.8. Calcd. for $LiSmC_{32}H_{68}O_4$: Sm, 22.30. Found: Sm, 23.4. (Determined by hydrolysis of a weighed sample followed by direct titration with 0.01 M $Na_2EDTA \cdot 2H_2O$ with xylenol orange as indicator.) The instability of the samarium and ytterbium compounds precludes normal commercial analyses. However, data from Bernhardt on the complexes is supportive though not complete.
(14) Hydrolysis is accomplished by addition of excess H_2O to a sample of the complex under a layer of deuteriobenzene. The organic products extracted into the deuteriobenzene were identified by NMR.
(15) $LiEr(t\text{-}C_4H_9)_4(THF)_4$: IR (Nujol, cm^{-1}) 2760 (s), 2730 (s), 2670 (s), 2620 (m) 1455 (s, discernible from Nujol), 1297 (w), 1250 (w, br), 1180 (w, br), 1135 (s), 1045 (s), 990 (m), 940 (m), 920 (m), 890 (s), 780 (s), 730 (w), 720 (sh, w), 675 (w).
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(18) Near-IR–visible (in THF) (λ_{max}, nm (ϵ)): $LiEr(C_4H_9)_4(THF)_4$, 997, 979, 668, 656, 536 (40), 532 (sh), 529 (65), 526 (120), 490, 451, 444, 406, 388 (75), 385 (sh), 383 (260); $LiSm(C_4H_9)_4(THF)_4$, 1551 (sh), 1499, 1392, 1271 (sh), 1242 (9), 1091 (9), 955; $LiYb(C_4H_9)_4(THF)_3$, 993 (35), 949 (sh), 500 (shoulder on charge-transfer band).
(19) (a) R. D. Peacock, *Struct. Bonding (Berlin)*, **22**, 83 (1975). (b) R. Pappalardo, *J. Chem. Phys.*, **49**, 1545 (1968). (c) N. M. Ely and M. Tsutsui, *Inorg. Chem.*, **14**, 2680 (1975). (d) Analysis of the $^4I_{15/2} \rightarrow {}^2H_{11/2}$ transition by Karraker's arguments correlating hypersensitive band shape with coordination number[20] would suggest that the Er^{3+} ion is eight coordinate in the complex, implying that the Er^{3+} coordination environment consists of four *tert*-butyl groups and four THF ligands with the unsolvated lithium cation interacting only with the methyl groups of the *tert*-butyl ligands. Although this is consistent with the infrared evidence, this argument suggests an unreasonably crowded coordination sphere for Er^{3+}. A crystallographic investigation will be required to determine if Karraker's arguments for oxygen donor atom ligands can be extended to alkyl ligands.
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(21) Susceptibilities were measured using the Evans' method[22] with the modified equation,[23] $\chi = 3\Delta f/4\pi fm + \chi_0$, appropriate for a Bruker 270-MHz NMR spectrometer. A Faraday measurement on the erbium sample of 9.37 μ_B was consistent with the solution measurement.
(22) D. F. Evans, *J. Chem. Soc.*, 2003 (1959).
(23) J. K. Becconsall, *Mol. Phys.*, **15**, 129 (1968).
(24) Subsequently identified by GC–mass spectrometry.
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(26) Formed by exchanging $LiSm(t\text{-}C_4H_9)_4(C_4H_8O)_4$ with C_4D_8O until C_4H_8O incorporation was <1%. The completeness of the exchange was confirmed by decomposition in $CDCl_3$.
(27) After decomposition, a brown soluble samarium complex remains. Since this product exhibits no NMR signals in the diamagnetic region, it is presumably not a complex of the alkoxides formed from the decomposition of THF.
(28) In contrast, the oil which forms when $LiSm(t\text{-}C_4H_9)_4(THF)_4$ is placed in benzene decomposes by a different route. 2-Methylpropane is still the primary product, but the decomposition is incomplete and some 2-methylpropene is observed. The effect of solvent on these decompositions and the identity of the samarium products remaining after decomposition are currently under investigation.
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(30) For example, in oxides Er^{3+} has an effective ionic radius of 0.88 Å compared with 0.44 Å for four-coordinate Cr^{4+}.[31]
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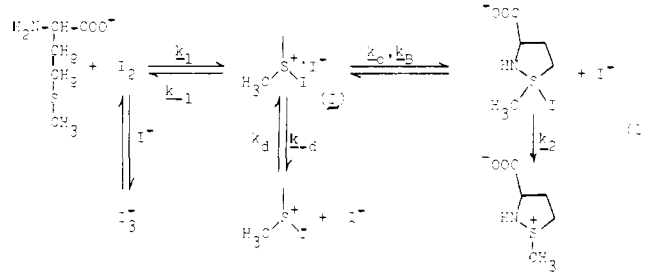
General Base Catalysis and Evidence for a Sulfurane Intermediate in the Iodine Oxidation of Methionine

Sir:

The oxidation of methionine by iodine to give the cyclic sulfimine dehydromethionine (*S*-methylisothiazolidine-3-carboxylic acid) is catalyzed by general bases and gives a nonlinear Brønsted plot which breaks from a slope of ~1.0 to a slope of zero at approximately $pK_a = 2$. This is interpreted as evidence for a mechanism involving stepwise proton transfer through a preassociation mechanism. At low concentration of buffer, the reaction is inversely dependent on the concentration of iodide ion. At high buffer concentration, the reaction rates exhibit a nonlinear dependence on iodide concentration which approaches an inverse-squared dependence. The observation of a simple inverse dependence at low buffer requires that diffusion apart of the iodosulfonium ion–iodide encounter complex (I) must be slow with respect to reduction of the complex through k_{-1} and ring closure through k_0 (eq 1). The



changeover to an inverse-squared dependence at high buffer requires a kinetically significant intermediate *after* the ring closure step. It is suggested that this intermediate is a tetracoordinate sulfurane.

The iodine oxidation of sulfides proceeds through the initial formation of an iodosulfonium ion.[1] Typically, this intermediate can be attacked by iodide ion, reversing the reaction, or by water to give the sulfoxide. A major unanswered question in nucleophilic reactions of these types is whether the attack occurs through an S_N2-like transition state or if a tetracoordinate sulfurane is involved as an obligatory intermediate.[2] In the iodine oxidation of methionine, the proximal amino group apparently traps the iodosulfonium ion intermediate faster than that intermediate is attacked by the solvent to give sulfoxide. In its simplest form, this mechanism predicts an inverse-squared dependence on the concentration of iodide ion: one inverse dependence as a result of the equilibrium to give triiodode ion and the second due to reversal of the oxidation process by attack of iodide on the iodosulfonium ion. The observation by us and others[3] that this reaction shows a simple inverse dependence at low buffer concentrations requires that either attack be rate limiting or that free iodide in solution does not reduce the iodosulfonium ion intermediate. Since buffer catalysis is observed, it is unlikely that attack of iodine is rate limiting. Therefore, the rate constants for reversion of the iodosulfonium ion–iodide encounter pair back to starting materials (k_{-1}) and the rate constant for ring closure (k_0) must be faster than the rate constant for diffusion apart of the ion pair. Since the ion pair is not expected to be extraordinarily stable, this suggests that k_{-1} and k_0 will also be faster than the rate constant for diffusion of 1 M buffer base up to the encounter pair. This requires that the buffer preassociate with the methionine–iodine complex *before* the oxidation step occurs and that the catalysis occur through either a concerted or a stepwise-preassociation mechanism.[4] While those two mechanisms can theoretically be distinguished based on their Brønsted behavior, the data do not rigorously exclude a linear

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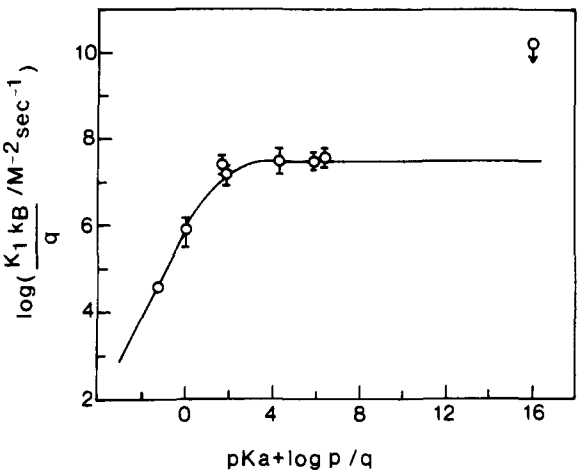

Figure 1. Brønsted plot for general base catalysis of the iodine oxidation of methionine: aqueous solution, 25 °C, ionic strength 1.0 with KCl. The buffers shown are H_2O, CF_3COO^-, $(CH_3)_2AsOOH$, $H_2PO_4^-$, CH_3SOO^-, $(CH_3)_2AsOO^-$, and HPO_4^{2-}. The arrow indicates the upper limit for catalysis by HO^-. Values of K_1k_B were calculated from the nonlinear buffer plots using the method described by H. F. Gilbert and W. P. Jencks, *J. Am. Chem. Soc.*, **99**, 7931 (1977).

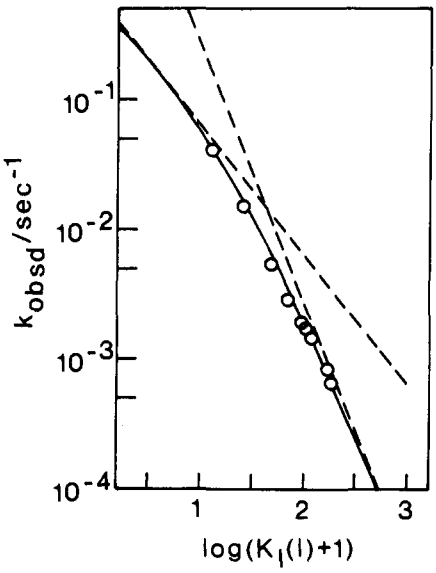

Figure 2. Dependence of log k_{obsd} for iodine oxidation of methionine on the quantity log $(K_1[I] + 1)$ where K_1 is the equilibrium constant for the formation of triiodide ion: aqueous solution, 25 °C, ionic strength 1.0 with KCl, pH 4.85, acetic acid buffer at a total concentration of 0.7 M. The solid line was calculated for a break from a slope of −1 to −2.

Brønsted plot diagnostic of a concerted mechanism; however, they are *most* consistent with the curved Brønsted plot expected for the stepwise-preassociation mechanism (Figure 1).

At high concentrations of buffer, the rates of reaction no longer show a simple inverse dependence on iodide concentration and approach a curve of slope −2.0 (Figure 2). This means that the breakdown of an intermediate coming *after* the buffer-mediated step has become rate limiting. This intermediate must contain the elements of dehydromethionine and iodide ion. Since the reaction goes to completion rather than to an equilibrium, the simplest explanation is that a tetracoordinate sulfurane is involved as an intermediate and that the breakdown of this sulfurane has become rate limiting. This is the first kinetic evidence that requires a sulfurane as an obligatory intermediate in a nucleophilic substitution reaction of this type.[5]

If a sulfurane intermediate is involved, then the proton transfer in the buffer-mediated step must be transfer to and from this sulfurane. If the assignment of a stepwise mechanism is correct, then the break in the Brønsted plot at about pK_a = 2 reflects an upper limit for the pK_a of this species. The driving force for the catalysis that is observed is the generation of an intermediate with a lifetime sufficiently short so that it is not at proton or diffusional equilibrium with the solvent. This is consistent with the rules defined for "enforced" mechanisms of catalysis as described by Jencks[4] and this work represents the first extension of these rules to systems outside of the framework of carbonyl addition-elimination reactions, and as such supports the generality of the concept.

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References and Notes

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(2) J. G. Tillett, *Chem. Rev.*, **76**, 747 (1976); T. L. Gilchrest and C. J. Moody, *ibid.*, **77**, 409 (1977).
(3) Gensch and Higuchi report that the rates of oxidation of methionine by iodine are inversely dependent on iodide concentration up to 2 M iodide at pH 7.2, 0.02 M phosphate buffer: K.-H. Gensch and T. Higuchi, *J. Pharm. Sci.*, **56**, 177 (1967).
(4) W. P. Jencks, *Acc. Chem. Res.*, **9**, 425 (1976). It is argued that the catalysis that is observed is not nucleophilic based on the zero slope observed in the Brønsted plot over the pK_a range 2–6, the very similar catalytic constants that are observed for buffers of widely differing structure but similar pK_a (phosphate and cacodylate), and the fact that water is included in the (nonlinear) Brønsted plot; nucleophilic catalysis by water would produce sulfoxide which is not observed.
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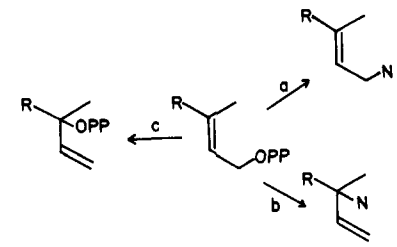
Cyclonerodiol Biosynthesis and the Stereochemistry of the Conversion of Farnesyl to Nerolidyl Pyrophosphate

Sir:

Allylic pyrophosphates play a central role in the biosynthesis of isoprenoid metabolites. These substances may undergo a variety of transformations (Scheme I), including direct displacements (S_N2 type, pathway a), allylic displacements (S_N2' type, pathway b), and allylic transpositions (allylic rearrangement, pathway c). The class of direct displacements has been the most thoroughly studied, and is represented by the prenyl transferase catalyzed chain elongation reactions whereby successive units of isopentenyl pyrophosphate are added to the primary allylic pyrophosphates dimethallyl, geranyl, or farnesyl pyrophosphate.[1] These processes have been shown to involve inversion of configuration at C-1 of the allylic

Scheme I



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