use of zinc chloride as a catalyst in methylene chloride as solvent led to complete reaction within 6 h). Processing the initial cycloadduct **10** sequentially with 2 N hydrochloric acid and sodium dichromate–sulfuric acid gave in 92% overall yield a morpholinonaphthoquinone (dihydronaphthoxazinedione, **11**) which by 300-MHz $^1$H NMR analysis proved to be nearly a single regioisomer (isomer ratio for thermal reaction = 13:1, for $ZnCl_2$-catalyzed reaction = 39:1): mp 221–223 °C; 300-MHz $^1$H NMR ($CDCl_3$) $\delta$ 8.28 (br s, 1 H), 7.83 (s, 1 H), 7.37 (s, 1 H), 4.90 (br s, 1 H), 3.72 (s, 3 H), 3.00 (br s, 1 H), 2.31 (s, 3 H), 2.14 (s, 3 H), 1.76 (s, 3 H). Since the assignment of structure could not be made securely by NMR analysis, we resorted to an X-ray structural determination. The cycloadduct generated and pictured in Figure 1 was indeed the *incorrect isomer*.[13]

It thus became essential to modify the diene unit such that it would still carry the requisite methyl and alkoxy groups at C-2 and C-3 of **2** but would bear at the diene terminus C-4 an eliminatable functional group (Y) which could provide the proper sort of electronic releasing effect to steer the cycloaddition in the desired sense (Scheme II). Several possible candidates were envisioned. Of course, with the pioneering work of Cohen[14] and Trost[15] in the area of sulfur-substituted dienes, the most obvious choice for the new diene **2** was that with Y = SPh. The zinc chloride catalyzed reaction between dienophile **1c** and diene **2b**[16] was examined and found to be complete within 6 h at room temperature. Processing the crude cycloadduct **13** sequentially with potassium bicarbonate in methanol[17] and then with Fremy's salt gave a fully aromatic A-ring compound **14** which again proved to be almost a single regioisomer by 300-MHz $^1$H NMR (isomer ratio 48:1): mp 222–224 °C; 300-MHz $^1$H NMR ($CDCl_3$) $\delta$ 7.83 (s, 1 H), 7.49 (s, 1 H), 4.97 (br s, 1 H), 4.00 (s, 3 H), 3.90 (s, 3 H), 2.87 (br s, 1 H), 2.32 (s, 3 H), 2.08 (s, 3 H), 1.75 (s, 3 H).

For comparison purposes, the wrong isomer, **11**, was methylated, and the 300-MHz $^1$H NMR spectra of the two compounds **12** and **14** were compared; **12**: mp 242–244 °C; 300-MHz $^1$H NMR ($CDCl_3$) $\delta$ 7.97 (s, 1 H), 7.44 (s, 1 H), 4.97 (br s, 1 H), 3.99 (s, 3 H), 3.70 (s, 3 H), 2.92 (br s, 1 H), 2.32 (s, 3 H), 2.10 (s, 3 H), 1.75 (s, 3 H). These compounds exhibited significant chemical shift differences for the aromatic A-ring protons, thus leading us to assign structure **14**, the desired isomer, to the new morpholinonaphthoquinone.

In summary, a high-yield route for the regiospecific construction of morpholinonaphthoquinone **14** has been developed (50% overall yield via a 13-step reaction sequence from the monoprotected resorcinol **3**!), and a dramatic example of regiochemical steering in the Diels–Alder reaction through diene substituent selection has been discovered. These efforts complete the construction of a goodly portion of the ansamycin unit of the rubradirins. Studies are now in progress to construct the bridging aliphatic chain in chiral form and to attach it to the quinone **14**.[18]

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**Registry No. 1c**, 77270-56-5; **2a** (X = OMe; Y = H; R = $Si(Me)_3$), 77228-16-1; **2b** (X = H; Y = SPh; R = Me), 77270-57-6; **3**, 77270-58-7; **4**, 77270-59-8; **5a**, 77270-60-1; **6a**, 77270-61-2; **6b**, 77270-62-3; **7**, 77270-63-4; **8**, 77270-64-5; **9**, 77270-65-6; **10**, 77270-66-7; **11**, 77270-67-8; **12**, 77270-68-9; **13**, 77270-69-0; **14**, 77270-70-3; methyl 2,3-dibromopropionate, 1729-67-5.

**Supplementary Material Available:** Tables of the fractional coordinates and temperature parameters, bond distances, and bond angles for **11** (5 pages). Ordering information is given on any current masthead page.

(13) Preliminary X-ray diffraction photographs indicated that the symmetry of the crystals of **11** was $P2_1/n$ with $a$ = 16.021 (2) Å, $b$ = 7.352 (1) Å, $c$ = 19.423 (1) Å and $\beta$ = 109.40 (1)°; 2346 unique reflections were observed ($I \geq 3\sigma I$) from the 2896 measured with $2\theta \leq 114°$. Standard direct-methods techniques provided initial coordinates which were refined by using full-matrix least-squares techniques. The function $\Sigma w(|F_o| - |F_c|)^2$ with $w = (1/\sigma F_o)^2$ was minimized to give an unweighted residual of 0.054. A molecule of ethyl acetate was found cocrystallized in the asymmetric unit. A strong hydrogen bond of 2.70 Å links the solvent's ester carbonyl to the phenolic oxygen of **11**. Figure 1 is a computer-generated perspective drawing of **11** from the X-ray coordinates. The following library of crystallographic programs was used: "MULTAN 78, A System of Computer Programs for the Automatic Solution of Crystal Structures from X-Ray Diffraction Data"; University of York: England, 1978; "The X-Ray System, Version of June 1972"; Report TR-192; Computer Science Center, University of Maryland: College Park, MD, 1972; "ORTEP-II: A FORTRAN Thermal Ellipsoid Plot Program for Crystal Structure Illustrations"; U.S. Atomic Energy Commission Report ORNL-3794 (2nd Rev, with Supplemental Instructions), Oak Ridge National Laboratory: Oak Ridge, TN, 1970.

(14) Cohen, T.; Mura, A. J.; Shull, D. W.; Fogel, E. R.; Ruffner, R. J.; Falck, J. R. *J. Org. Chem.* **1976**, *41*, 3218. Cohen, T.; Ruffner, R. J.; Shull, D. W.; Fogel, E. R.; Falck, J. R. *Org. Synth.* **1980**, *59*, 202.

(15) Trost, B. M.; Vladuchick, W. C.; Bridges, A. J. *J. Am. Chem. Soc.* **1980**, *102*, 3548, 3554.

(16) Cohen, T.; Kosarych, Z. *Tetrahedron Lett.* **1980**, 3955. We thank Professor Cohen for a generous sample of this diene. In carrying out the Diels–Alder reaction of **2b** + **1c**, the dienophile and zinc chloride were first stirred for 30 min at room temperature, and then the diene was added.

(17) Elimination of thiophenol occurs during the reaction with potassium bicarbonate. Formation of some of the quinone **14** by air oxidation during this step is also apparent.

(18) All new compounds reported had spectral properties and high-resolution mass spectra for the molecular ion fully compatible with the assigned structures.

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## Concurrent Strong Acid and Base Catalysis. Synthesis of Cyclopentenones

*Summary:* 2-Alkyl-2-cyclopenten-1-ones were prepared in one operation from $\gamma$-keto aldehyde acetals by acid-catalyzed hydrolysis of the acetal and base-catalyzed aldol cyclization using mixed ion-exchange resins.

*Sir:* There are numerous reversible reactions which are not directly useable in preparative schemes owing to an unfavorable equilibrium constant. Other reactions are inefficient because polymerization is faster than the desired intramolecular processes. The two-step synthesis shown in Scheme I is burdened with both of these problems. When the steps are carried out separately, the acid-catalyzed hydrolysis of the dioxane ring is so unfavorable that a large excess of water gives only a small conversion.[1]

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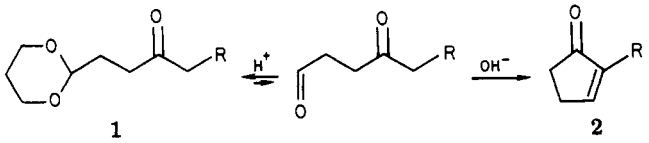
Scheme I



1 2

Furthermore, the base-catalyzed cyclization of γ-keto aldehydes gives much polymer, particularly where R is small.[3] Indeed where R is a methyl group, the cyclization could not be done in solution at all.[4]

Considered together, the characteristics of these two reactions would complement each other. To avoid polymerization in the aldol step, the concentration of keto aldehyde should be kept low. The acetal hydrolysis provides a very low concentration of keto aldehyde if little water is present. The second step is irreversible so it should ultimately drain the equilibrium step to completion if both steps are run concurrently. The dilemma is that the first step requires strong acid catalysis and the second requires a hydroxide base. Simple forms of these catalysts would of course neutralize each other, but we have found that R-276 Rexyn 300 (H-OH) ion-exchange resin,[5] which is a mixture of sulfonic acid beads and quaternary ammonium hydroxide beads, does catalyze both steps concurrently.

We have converted 2-(3-oxopentyl)-1,3-dioxane[6] (1, R = $CH_3$) to 2-methyl-2-cyclopenten-1-one[7] in 48% distilled yield in one operation by stirring with the mixed resin in hot methanol. In the same way, we have converted 2-(3-oxononyl)-1,3-dioxane[8] (1, R = $n$-$C_5H_{11}$) to 2-$n$-pentyl-2-cyclopenten-1-one[9] in 87% crude (56% distilled) yield.

In a typical procedure, 50 mmol of keto acetal, 55 g (34 mequiv) of resin, and 100 mL of methanol were heated at reflux with magnetic stirring for 1–2 h. This was cooled, filtered, and distilled to give the colorless cyclopentenone.

The thermal instability of the basic resin is a limitation in this process, so we are investigating other resins. We are also examining other reaction sequences which may be uniquely facilitated by this mixed catalysis.[10]

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(1) A dioxolane would be more readily removed but the dioxane is preferred because of the superior characteristics of the Grignard reagent used to prepare the keto acetal.[2]

(2) Stowell, J. C. *J. Org. Chem.* **1976**, *41*, 560.

(3) This cyclization is considered extremely delicate and the methods described in the literature are rarely satisfactory: Larcheveque, M.; Valette, G.; Cuvigny, Th. *Tetrahedron* **1979**, *35*, 1745.

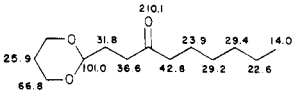
(4) Cavill, G. W.; Goodrich, B. S.; Laing, D. G. *Aust. J. Chem.* **1970**, *23*, 83. These authors did obtain some of the methylcyclopentenone at 370 °C in the gas phase.

(5) The mixed resin was obtained from Fisher Scientific Co.

(6) This keto acetal was prepared from propionyl chloride and the Grignard reagent from 2-(2-bromoethyl)-1,3-dioxane:[2] bp 97–99 °C (1.1 mmHg); $^1H$ NMR ($CDCl_3$) δ 1.05 (t, 3), 1.80 (m, 4), 2.45 (m, 4), 3.90 (m, 4), 4.58 (t, 1).

(7) The spectral characteristics of this compound are in accord with published values: Fischli, A.; Klaus, M.; Mayer, H.; Schonholzer, P.; Ruegg, R. *Helv. Chim. Acta* **1975**, *58*, 564.

(8) Prepared as in ref 2; $^{13}C$ NMR ($CDCl_3$):




(9) The spectral characteristics of this product are in accord with published values: Ravid, U.; Ikan, R. *J. Org. Chem.* **1974**, *39*, 2637.

(10) While this work was in progress, another example of sequential catalytic reactions appeared: Pittman, C. U., Jr.; Liang, Y. F. *J. Org. Chem.* **1980**, *45*, 5048.

**Registry No.** 1 (R = $CH_3$), 70710-36-0; 1 (R = $C_5H_{11}$), 57345-99-0; 2 (R = $CH_3$), 1120-73-6; 2 (R = $C_5H_{11}$), 25564-22-1; propionyl chloride, 79-03-8; 2-(2-bromoethyl)-1,3-dioxane, 33884-43-4.

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## Evidence for Single Electron Transfer in the Reactions of Alkali Metal Amides and Alkoxides with Alkyl Halides and Polynuclear Hydrocarbons

*Summary:* Evidence for single electron transfer as the major pathway in reactions previously considered to be classic $S_N1$ and $S_N2$ pathways has been obtained. In this connection, the reaction of KOBu-*t* with trityl bromide has been shown to proceed through the trityl radical, and the reaction of LiN(*i*-Pr)$_2$ with a primary alkyl iodide probe gave evidence of proceeding by single electron transfer, as indicated by the cyclized nature of the product as a result of a radical intermediate.

*Sir:* Recently we reported that the reactions of various main group metal hydrides with alkyl halides, polynuclear hydrocarbons, and dimesityl ketone proceed mechanistically via a single electron transfer (SET) pathway.[1-3] Although metal hydrides in general have been regarded previously as nucleophilic sources of hydride ion in reactions with the above organic substrates,[4-6] the occurrence of SET has been clearly established by spectroscopic (visible and EPR) studies as well as by product-formation studies using cyclizable probes. In view of these results, we have decided to extend our studies to include nucleophiles other than hydride ion and to involve reactions previously thought to proceed by classic $S_N1$ or $S_N2$ pathways, e.g., reactions involving alkali metal amides and alkoxides with alkyl halides. In this study we report the observation of radical intermediates in reactions involving typical nucleophiles such as alkoxides and dialkylamides, not only with alkyl halides but also with polynuclear hydrocarbons.

Lithium diisopropylamide (LiN-*i*-Pr$_2$), lithium *tert*-butoxide (LiOBu-*t*), and potassium *tert*-butoxide (KOBu-*t*) react rapidly with trityl chloride or bromide ($Ph_3CX$, when X = Cl or Br) in THF to give an orange-red solution. These solutions have been found to be EPR active and show an EPR spectrum consistent with that previously reported for the trityl radical ($Ph_3C\cdot$, Figure 1). The concentration of this radical increases with time over a period of 24 h (estimated intensity 10–20%), beyond which the intensity of the radical decreases. The product of the reaction of trityl bromide with LiN-*i*-Pr$_2$ is triphenylmethane which is consistent with the formation of a radical

(1) E. C. Ashby, A. B. Goel, and R. N. DePriest, *J. Am. Chem. Soc.*, **102**, 7779 (1980).

(2) E. C. Ashby, A. B. Goel, R. N. DePriest, and H. S. Prasad, *J. Am. Chem. Soc.*, **103**, 973 (1981).

(3) E. C. Ashby, R. N. DePriest, and A. B. Goel, *Tetrahedron Lett.*, submitted for publication.

(4) H. O. House, "Modern Synthetic Reactions", 2nd ed., W. A. Benjamin, Menlo Park, CA, 1972.

(5) H. C. Brown and S. Krishnamurthy, *J. Org. Chem.*, **45**, 849 (1980).

(6) C. W. Jefford, D. Kirkpatrick, and F. Deloy, *J. Am. Chem. Soc.*, **94**, 8905 (1972).

(7) F. C. Adam and S. I. Wieseman, *J. Am. Chem. Soc.*, **80**, 2057 (1958).

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