unreactive and demonstrates an effect already observed when a polar substrate must react at a catalytic site in the nonpolar environment of the polystyrene surfaces.[10]

Catalyst activity depends strongly on the degree of cross-linking in the divinylbenzene–styrene copolymer from which it was prepared. For example, catalyst from 1%, 8%, and 20% (XAD-2) cross-linked polystyrene gave conversions of 2.6%, 7.6%, and over 50%, respectively. On the other hand, the amount of tellurium which can be introduced into these catalyst is inversely proportional to the cross-linking, being 28%, 24%, and 4.3% by weight. Catalysts prepared from, XAD-4, the most highly cross-linked resin commercially available, are the most active[11] and are preferred for synthetic work since they may give rates up to 10 times faster than catalysts prepared from XAD-2. The physical properties of catalysts closely resemble the resin from which they were made and change little with use.

The lack of catalytic activity of soluble tellurinic acids was confirmed by the preparation of phenethyl tellurinic acid and anisyl tellurinic acid.[12] They were found to be inactive under typical epoxidation conditions. Dimethyl ditelluride and diphenyl ditelluride, which may be regarded as precursors for tellurinic acids assuming that H_2O_2 acts upon them as it does upon diselenides,[13] also were tested and found to be inactive. Two obvious explanations for the activity of the tellurated resin are proposed:

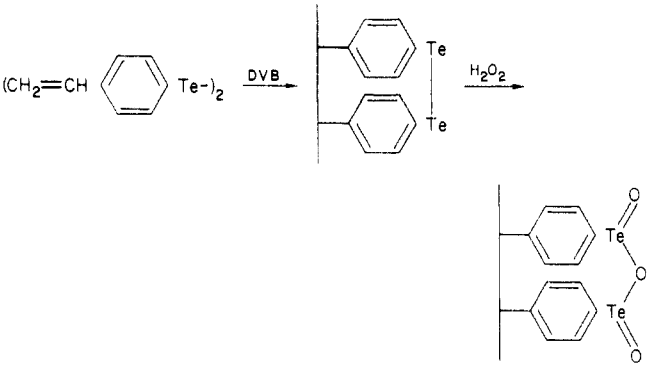
1. Various tellurium derivatives, formed in the preparation of the catalyst and present as bonded groups or absorbed byproducts, possibly may be very active epoxidation catalysts. These can form, for example, by reaction at the free vinyl group in the resin or by condensations involving adjacent phenyl groups.

2. Tellurinic acids may be active epoxdation catalysts but exist largely as anhydrides even in aqueous solutions as may be inferred from the reported[14,15] preparation of either acid or anhydride by careful acidification of solutions of their sodium salts. Equilibration would be influenced by the polymer matrix.

For evaluation of the first supposition, the following reference compounds were tested for catalytic activity under typical epoxidation conditions: TeO_2, diphenyl telluride, phenyltelluropolystyrene,[16] and diphenylenetellurone.[17] Tellurides are precursors for telluroxides[7] which conceivably may be oxidizing agents by analogy to selenoxides. Since the heavy cross-linking of the polymeric catalyst is a requirement for activity, the rigid telluroxide, diphenylenetellurone was used as a model. None of the compounds demonstrated any activity, making it improbable that the active catalytic site involves a functional group other than an aromatic tellurinic acid or a derivative.

Additional experiments cast some doubt on the assumption that the prevention of anhydride formation is responsible for the activity of the polymer. When oxidations are conducted with the polymeric catalyst in the presence of added excess anisyl tellurinic acid, no diminution of the epoxidation rate occurs. Formation of a mixed anhydride could occur under these conditions.

Polymers are now being prepared in which the tellurinic acid groups are placed in the polymer matrix by a template technique so that interaction of two groups is sterically favored. This was accomplished by copolymerizing bis(*p*-vinylphenyl) ditelluride[18] with divinylbenzene and treating the polymer with H_2O_2 to oxidize the ditelluride linkage to form fixed neighboring tellurinic acid groups.



Initial work produced a polymer with catalytic activity comparable to a tellurated XAD-2 resin. On the other hand, copolymerization of *p*-vinylbenzenetellurinic acid with divinylbenzene produced a polymer with randomly placed acid groups. It displayed little activity. In view of this, it may be postulated that anhydride formation is in fact required and sufficiently favored only in the solid catalyst. This may represent an example where the steric effect of a rigid support lowers the entropy of activation and enhances the formation of what would in solution be the less favored active form of the catalyst. Epoxidation of olefins may occur through reaction of peroxy intermediates formed from H_2O_2 and tellurinic anhydride in a manner similar to that demonstrated for carboxylic peracids.

Registry No. $TeCl_4$, 10026-07-0; XAD-2, 37380-42-0; XAD-4, 9060-05-3; bis(4-vinylphenyl)ditelluride, 100351-42-6; (bis(*p*-vinylphenyl)ditelluride)-(divinylbenzene)copolymer, 100351-43-7; 1-methylcyclohexene, 591-49-1; cyclohexene, 110-83-8; *cis*-2-octene, 7642-04-8; *trans*-2-octene, 13389-42-9; 1-octene, 111-66-0; 3-methylcyclohexene, 591-48-0; *trans*-2-butene, 624-64-6; styrene, 100-42-5; allyl chloride, 107-05-1; allyl alcohol, 107-18-6; cyclohexene oxide, 286-20-4; divinylbenzene, 1321-74-0.

(10) Hartley, F. R.; Vezey, P. N. *Adv. Organomet. Chem.* **1975**, *15*, 211.
(11) Some rate constants ($k_2 \times 10^5$ l mol^{-1} s^{-1}) for this catalyst (50 g/L) are dioxane, 60 °C 12; 40 °C 2.8; *tert*-butyl alcohol 60 °C 36; dioxane, 60 °C, 3rd use, 4.6.
(12) Reichel, L.; Kirschbaum, E. *Liebigs Ann. Chem.* **1936**, *523*, 211.
(13) Klayman, D. L. In "Organic Selenium Compounds: Their Chemistry and Biology"; Klayman, R. L., Gunther, H. H. Eds.; Wiley-Interscience: New York, 1973; p 125.
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(17) 9-Tellurafluorene 9-oxide, prepared from diphenyl and $TeCl_4$ by procedure of Cowrtot, C.; Bastani, G. *C.R. Acad. Sci.* **1936**, *203*, 197.
(18) Prepared from the *p*-vinylphenyl-Grignard reagent by reaction with Te in the presence of O_2. Haller, A. S.; Irgolic, K. J. *J. Organomet. Chem.* **1972**, *38*, 97.

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Stereochemical Transcription via the Intramolecular Diels–Alder Reaction. Enantioselective Synthesis of the Nucleus of (+)-Pillaromycinone

Summary: Synthesis of a tetracyclic structure containing functionality and stereochemistry similar to that of (+)-pillaromycinone has been accomplished from L-(+)-rhamnose, using an intramolecular Diels–Alder reaction

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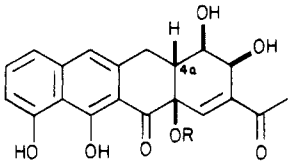
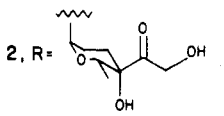
to elaborate the A ring and a Staunton–Weinreb annulation to assemble the anthracycline skeleton.

Sir: The transmission of stereochemical information from an existing asymmetric center to other atoms within the molecule by a process that preserves the originating configuration is a valuable means for augmenting the chiral content of a synthetic intermediate. This type of stereodifferentiation is likely to be most efficient when an asymmetric reaction possesses a compact transition state.[1] The intramolecular Diels–Alder reaction epitomizes such a process,[2] and exploratory studies have already demonstrated that stereochemical transcription can be achieved with good fidelity in this cycloaddition using a chiral center in the chain linking the diene and dienophile.[3] We now illustrate this principle in a chiral synthesis of the tetracycle **25** containing the nucleus of (+)-pillaromycinone (**1**).[4] The latter represents the aglycone of the novel anthracycline antibiotic (−)-pillaromycin A (**2**), an effective antineoplastic agent with low cardiotoxicity.[5]



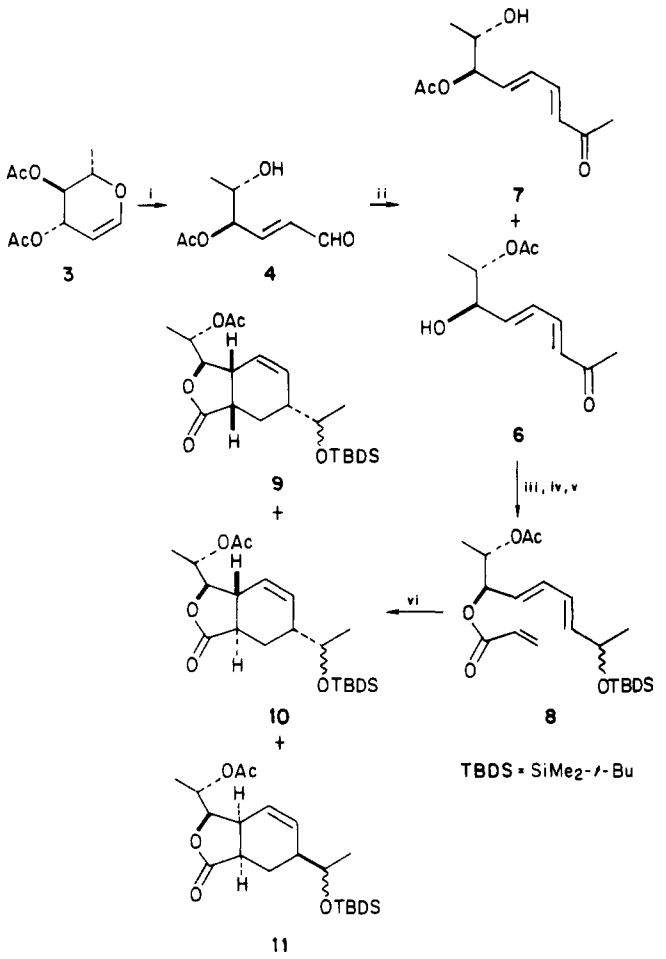
1, R = H



The diacetate **3**, available in three steps from L-rhamnose,[6] was converted to the *E*-hexenal derivative **4** ($[\alpha]^{23}_D$ −5.2°)[7] via a Perlin transformation,[8] and the latter underwent a Wittig reaction with the phosphorane **5** to give a 2:1 mixture of **6** ($[\alpha]^{23}_D$ −43.1°) and **7** (the minor isomer **7** could be converted to a 3.5:1 mixture of **6**–**7** with 0.5 equiv of Et_3N in DMF at 90 °C) (Scheme I). Esterification of **6** with acryloyl chloride, followed by reduction of the ketone function and protection of the resulting alcohol, gave **8** as a mixture of epimeric *tert*-butyldimethylsiloxy ethers.

A careful scrutiny of the transition states for the intramolecular Diels–Alder reaction of **8** leads to the prediction that the major cycloadduct should possess 4a*R* configuration as required for natural pillaromycinone. In the event, pyrolysis of **8** at 210 °C gave **9**, **10**, and **11** in the ratio 2.5:2.5:1, respectively, in good overall yield. Thus, stereochemical transcription from C-7 of **8** to the adjacent ring fusion site of the cycloadducts is accurate even though there is no endo/exo discrimination between the major

Scheme I[a]



[a] (i) $HgSO_4$ (catalyst), 0.05 M H_2SO_4/dioxane/acetone (7:1:1.2); 25 °C, 3 h, 93%; (ii) $Ph_3PCHCOCH_3$ (**5**), C_6H_6, reflux, 4.5 h, 88%; (iii) CH_2=CHCOCl, *i*-Pr_2EtN (4 equiv), CH_2Cl_2, −78 °C, 3 h; (iv) $NaBH_4$, $CeCl_3 \cdot 6H_2O$, MeOH, 0 °C, 25 min; (v) *t*-$BuMe_2SiCl$, lutidine (2.5 equiv), DMF, 0 °C, 1 h, 53% from **6**; (vi) toluene, BHT (0.25 equiv), 210 °C, 3 days, 68–73%.

stereoisomers **9** and **10**. As expected, the trans-fused γ-lactone **10** was isomerized (87%) to the more stable cis isomer **9** by treatment with lithium diisopropylamide (THF, 25 °C, 18 h),[9,10] thereby enhancing the chiral efficiency of the sequence.

Hydroxylation of **9** proceeded with high stereoselectivity to give the diol **12**, which was protected as its cyclohexylidene derivative **13** (Scheme II). Saponification of the acetate of **13**, followed by oxidation, furnished **14**. Numerous methods were investigated for the reduction of this substance to keto acid **15**, but all gave low yields or cleavage of the silyl ether. In contrast, samarium diiodide[11]

(1) Izumi, Y.; Tai, A. "Stereo-Differentiating Reactions"; Academic Press: New York, 1977; p 142. Stereochemical transcription would be codified as "intramolecular diastereoface-differentiation" in the Izumi–Tai lexicon. This term is to be distinguished from chirality transfer, in which chirality is removed from one site and installed at another (as, for example, in a Claisen rearrangement).

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(4) Kamiya, K.; Asai, M.; Nishikawa, M.; Mizuno, K.; Tomiie, Y.; Nitta, I. *Chem. Pharm. Bull.* **1970**, *18*, 1724. For a different approach to **1**, see: Trost, B. M., Caldwell, C. G.; Murayama, E.; Heissler, D. *J. Org. Chem.* **1983**, *48*, 3252.

(5) Shibata, M.; Asai, M.; Mizuno, K.; Miyake, A.; Tatsuoka, S. *Proc. Jpn. Acad.* **1964**, *40*, 296. Asai, M. *Chem. Pharm. Bull.* **1970**, *18*, 1699.

(6) Roth, W.; Pigman, W. *Methods Carbohydr. Chem.* **1963**, *2*, 405.

(7) Satisfactory analytical data for new compounds were obtained by either elemental analysis or high-resolution mass spectrometry.

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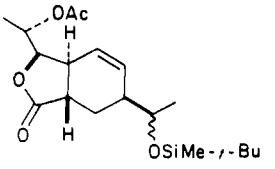
(9) White, J. D.; Sheldon, B. G. *J. Org. Chem.* **1981**, *46*, 2273.

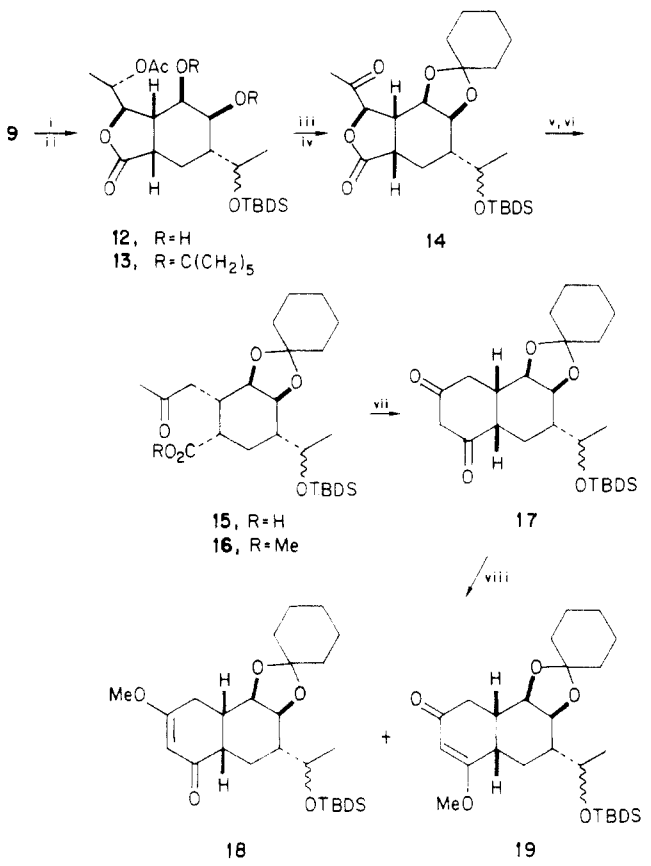
(10) Analogous isomerization of **11** afforded a minor quantity of the trans-fused γ-lactone **i**, the endo adduct missing from the Diels–Alder reaction of **8**. A detailed ^1H NMR analysis of these adducts, which corroborates the stereochemical assignments, will be reported in a full paper.



i

(11) Girard, P.; Namy, J. L.; Kagan, H. B. *J. Am. Chem. Soc.* **1980**, *102*, 2693.

Scheme II[a]

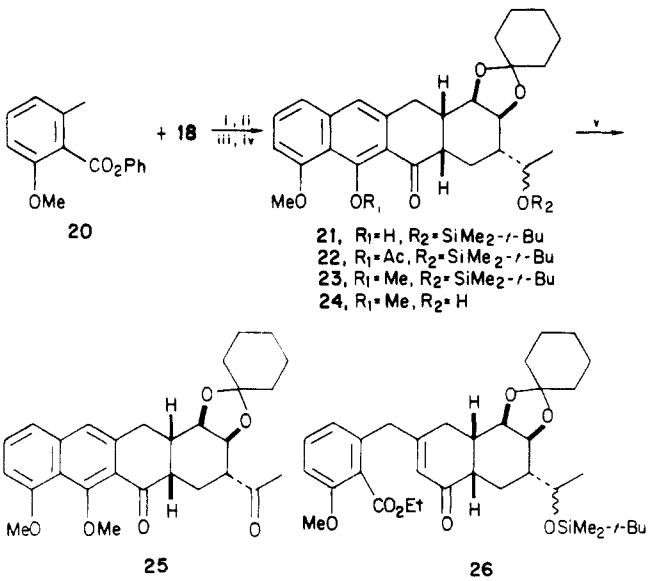


[a] (i) OsO_4 (catalyst), *N*-methylmorpholine *N*-oxide (3.3 equiv), THF/H_2O (3:1), 25 °C, 3 days; (ii) $(MeO)_2C(CH_2)_5$ (25 equiv), camphorsulfonic acid (catalyst), 25 °C, 4 h, 65% from **10**; (iii) K_2CO_3, MeOH, 25 °C, 2 h; (iv) PCC (5 equiv), CH_2Cl_2, 25 °C, 10 h, 61% from **13**; (v) SmI_2 (2 equiv), $FeCl_3$ (catalyst) THF, 25 °C, 0.25 h; (vi) CH_2N_2, Et_2O, 25 °C, 10 min, 84% from **14**; (vii) *t*-BuOK (3.3 equiv), C_6H_6, 25 °C, 20 min; (viii) CH_2N_2, Et_2O, 0 °C, 10 min, 89% from **16**.

in the presence of ferric chloride proved to be a highly effective reagent for this transformation and, after treatment of the reduction product with diazomethane, keto ester **16** was acquired in excellent yield. The latter underwent a smooth, intramolecular Claisen condensation[12] to dione **17**, which, upon methylation, afforded the enol ether **18** (ν 1645, 1610 cm^{-1}), accompanied by its readily separated isomer **19** (2.5:1, respectively).[13]

Assembly of the tetracyclic skeleton of **1** was carried out via the Staunton–Weinreb protocol.[14] Thus, the *o*-toluate anion from **20**[15] was condensed with **18** in the presence of anhydrous cerium trichloride to afford the intensely fluorescent naphthacenone **21** ($\lambda_{max}^{CHCl_3}$ 269, 398 nm), which was characterized as both its acetate **22** and dimethyl ether **23** (Scheme III). Finally, in order to converge the epimeric pair of silyl ethers at a single substance, **23** was transformed to alcohol **24**, and the latter was oxidized to ketone **25** ($\lambda_{max}^{CHCl_3}$ 264, 341 nm). A detailed examination of the reaction of **18** with **20** has revealed new insights into the mechanism of this interesting annulation,[16]

Scheme III[a]



[a] (i) $LiN(i\text{-}Pr)_2$, $CeCl_3$ (2.5 equiv), THF, −78 °C → 26 °C, 0.5 h, 62%; (ii) Ac_2O, DMAP, Et_3N, CH_2Cl_2, 25 °C, 3 h; (iii) Me_2SO_4, K_2CO_3, Me_2CO, Δ, 8 h; (iv) *n*-Bu_4NF, THF, 25 °C, 6 h; (v) PCC, CH_2Cl_2, 25 °C, 3 h, 70% from **21**.

including the fact that **26** is not an intermediate en route to **21**. These details, together with further transformations of **25**, will be reported subsequently.

Acknowledgment. This work was supported by the National Science Foundation through Grant CHE-8101223. Funds for the purchase of a Bruker AM 400 NMR spectrometer were provided by the National Science Foundation through Grant CHE-8216190.

Supplementary Material Available: ^1H NMR data for **13** and the cyclohexylidene ketal of the diol derived from hydroxylation of **11** and a 2D-COSY spectrum of the latter that establish the configurations of **9–11** (2 pages). Ordering information is given on any current masthead page.

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Auxiliary-Directed Diastereoselectivity in the Claisen Rearrangement of Glycolate Esters

Summary: Examples are presented in which the stereochemical course of the Claisen rearrangement of allylic glycolates is controlled by a chiral substituent appended to the glycolate hydroxyl (eq 1).

Sir: Recent studies[1,2] have focused on synthetic and mechanistic aspects of the highly diastereoselective enolate Claisen rearrangment[3] of acyclic α-alkoxy esters. Herein

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