of 1, 2, and 3 is consistent with a common mechanism being followed in each case. Whatever the nature of the mechanism, a quinone methide intermediate cannot be formed from 2 because of the meta relationship of its substituents.

Activation Parameters. The activation parameters for 1 by method III should be ignored because, as discussed earlier, the value of k determined by method III is too large due to the appreciable contribution of the self-condensation reaction. The remaining values of $\Delta H^{\ddagger}$ and $\Delta S^{\ddagger}$ for both 1 and 2 are the same within experimental error. The large negative values of $\Delta S^{\ddagger}$ indicate the presence of an ordered transition state in the slow step of this oxidation and are consistent with the homolytic oxidative-cleavage mechanism postulated earlier[4] for this oxidation with the first step being the slow step. The $\Delta H^{\ddagger}$ values of 3 are 4-5 kcal/mol larger than those of 1 and 2, and the $\Delta S^{\ddagger}$ values are less negative. The rate similarities of 1 and 3 are partly due to a favorable $\Delta S^{\ddagger}$ change balancing the unfavorable $\Delta H^{\ddagger}$ change.

Summary. The fact that the oxidation of both 1 and 2 give good yields of aldehydes at rates that differ by less than a factor of 2.5 and with activation parameters that are the same within experimental error is consistent with both oxidations going through a common mechanism. This mechanism cannot involve a quinone methide intermediate because such an intermediate is not physically possible from 2. To the extent that our compounds are adequate models of the lignin structure, the presence of a quinone methide intermediate in the nitrobenzene oxidation of lignin is also seriously questioned.

Experimental Section

Benzyl alcohols 1-3 were obtained commercially and purified by recrystallization.

The general reaction conditions used here were similar to those used in the nitrobenzene oxidation of lignin.[16] Typically a reaction mixture consisted of 0.484 mmol of benzyl alcohol, 7.8 mmol of nitrobenzene, and 10 mL of 2 N sodium hydroxide. For a kinetic run a series of eight identical mixtures of the same benzyl alcohol solution was sealed in eight 22-mL mini Parr reactors and heated in a fluidized sand bath. Analysis of each sample consisted of the addition of the internal standard benzophenone, continuous chloroform extraction to remove the excess nitrobenzene, acidification, another chloroform extraction to remove the phenols, acylation, and analysis on a PE 900 gas chromatograph with FID detector using a $^1/_8$ in. × 6 ft OV-17 column.[17] The products of one kinetic run on 2 were also analyzed on a HP-1090A liquid chromatograph using a 5-μm C-18 column with a programmed mix of methanol/water.

An iterative computer model method[14,15] was used to estimate the best values of the pseudo-first-order oxidation rate constants and the second-order rate constants for the side reactions shown in Scheme I. The average values of the correlation coefficients (r) for the determinations of the pseudo-first-order rate constants for 1 and 3 were 0.986 (14 runs) by method II and 0.990 (14 runs) by method III. The average r values for the determinations of the k_1's of 2 were 0.983 (6 runs) by method II and 0.943 (6 runs) by method III. No error estimation was possible for method I.

Acknowledgment. We gratefully acknowledge the funding for this project provided by the National Science Foundation and the U.S. Department of Agriculture-Wood Utilization Research Program.

Registry No. 1, 623-05-2; 2, 620-24-6; 3, 498-00-0; nitrobenzene, 98-95-3; lignin, 9005-53-2.

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A Cerium(III) Modification of the Peterson Reaction: Methylenation of Readily Enolizable Carbonyl Compounds

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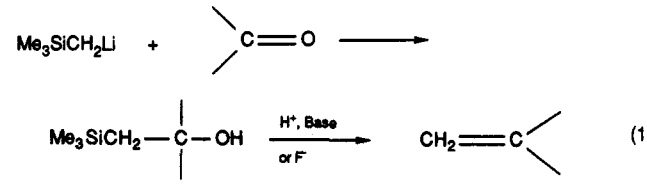
Received August 11, 1986

The Peterson methylenation procedure[1] (e.g., eq 1) has many redeeming points, yet its utility in synthesis is often limited by high basicity and lack of chemoselectivity of the lithium reagent. We envisioned circumventing these problems by using Imamoto's cerium trichloride methodology. Imamoto has fond that alkyllithium reagents interact with anhydrous cerium trichloride presumably to form a "$RCeCl_2$" species.[2] These cerium reagents show remarkable nucleophilic properties in additions to aldehydes and ketones and can be selectively added to these groups in the presence of esters, amides, and halides.[2]



(1)

[(Trimethylsilyl)methyl]lithium in tetrahydrofuran (prepared from (chloromethyl)trimethylsilane) or in pentane (purchased)[3] was added to anhydrous $CeCl_3$ at -78 °C. Addition of aldehydes and ketones to the reagent solution followed by aqueous workup under various acidic or basic conditions resulted in complex mixtures largely of allylic silanes and alkenes. This situation was markedly improved by the addition of 1 equiv of *N,N,N',N'*-tetramethylethylenediamine (TMEDA) per equiv of $CeCl_3$ just prior to workup with aqueous $NaHCO_3$. The procedure resulted in excellent yields of the desired 2-hydroxy silanes. In all cases involving enolizable aldehydes and ketones the Li/Ce reagents gave yields of addition products superior to those obtained by use of Mg/Ce reagents, Mg reagents, or Li reagents. A comparison of the yields of adducts obtained from $(CH_3)_3SiCH_2Li$ with and without $CeCl_3$ is given in Table I.

The 2-hydroxy silanes were converted to the corresponding methylene compounds[4] by treatment with aqueous HF (with or without pyridine) or potassium hydride (see table). The latter was found to cause double-bond isomerization in sensitive cases.

Experimental Section

Procedure B: Addition of [(Trimethylsilyl)methyl]lithium/Cerium Trichloride. Anhydrous cerium trichloride[2] was prepared as follows: To a 25-mL flask was added (0.652 g, 1.75 mmol) cerium trichloride heptahydrate. The temperature was raised to 140 °C over 1 h under high vacuum (0.10 >mm Hg). After 1 h at 140 °C, a spin bar was added, and the cerium tri-

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(3) [(Trimethylsilyl)methyl]lithium in pentane is available from Aldrich Chemical Company.
(4) For a review of reagents useful for the conversion of 2-hydroxy silanes into alkenes, see ref 1d.

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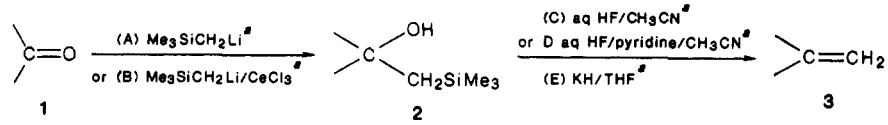
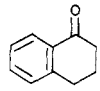
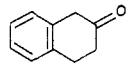
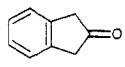
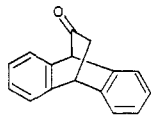
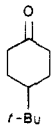
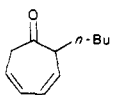
Table I. Cerium-Based Peterson Methylenations



1 2 3

carbonyl compound 1	reaction A		reaction B		elimination reaction	
	2, %	1 recovered, %	2, %	1 recovered, %	method	3, %
$PhCOCH_3$	78	0	93		C	84
					E	polymer
	37	50	95		D	91[b]
					E	85
	0	12	82	15	C	80[c]
					E	isomer[d] 83
	31	46	96		D	75[e]
					E	65
	6	26	83		C	87
					E	isomer[f] 86
	42	53	88		C	98
					E	*g*
	78	8	91		C	94
					E	96
	20	46	39	22		
$n\text{-}C_7H_{15}CHO$	56		86		C	93
					E	61
$MeO_2C(CH_2)_5CHO$	36	28	72			

[a] The details of reactions A–E are given in the Experimental Section under procedures A–E. [b] Plus 4-[(trimethylsily)methyl]-1,2-dihydronaphthalene (3%). [c] Plus 3-[(trimethylsilyl)methyl]-1,2-dihydronaphthalene (2%). [d] 3-Methyl-1,2-dihydronaphthalene. [e] Plus 3-[(trimethylsilyl)methyl]-1*H*-indene (11%). [f] 2-Methyl-1*H*-indene. [g] 1-(9,10-Dihydroanthracen-9-yl)-2-propanone (90%).

chloride was stirred for an additional hour at 140 °C under high vacuum. The reaction was cooled to room temperature and 5 mL of anhydrous THF was added using a syringe. After being mixed for 2 h at room temperature, the slurry was cooled to −78 °C and Me_3SiCH_2Li (1.5 mmol) in THF or pentane[3] was added dropwise slowly and with vigorous stirring. After 30 min of stirring at −78 °C, the ketone (1 mmol) was added in 1 mL of dry THF. The reaction was stirred for 2 to 5 h. Workup was effected by adding *N,N,N',N'*-tetramethylethylenediamine (TMEDA, 0.26 mL, 1.75 mmol) and allowing the mixture to stir for 15 min. The solution was poured into saturated aqueous $NaHCO_3$ (15 mL) and dichloromethane (50 mL). Extraction with three 50-mL portions of dichloromethane followed by washing with brine (50 mL) completed the workup. The extracts were dried over $MgSO_4$ and concentrated, and diethyl ether (40 mL) was added. Any precipitate was filtered off and discarded. The filtrate was concentrated. The resulting hydroxy silanes were isolated by flash chromatography.

Procedure A: Addition of [(Trimethylsilyl)methyl]lithium. To a 10-mL oven-dried reaction flask containing argon was added 5 mL of dry THF. After cooling to −78 °C, Me_3SiCH_2Li (1.1 mmol) in THF or pentane was added and the solution was stirred 5 min at −78 °C. The ketone (1 mmol) in 1 mL of anhydrous THF was added to the solution. After 2 h at −78 °C, the reaction mixture was poured into aqueous NH_4Cl (10 mL) and diethyl ether (50 mL). The aqueous layer was extracted with three 75-mL portions of diethyl ether. The combined organic extracts were washed with saturated aqueous NaCl (25 mL), dried ($MgSO_4$), and concentrated under vacuum. Purification of the products was carried out as in procedure B.

Procedure C: HF Elimination of Hydroxy Silanes. To a premixed solution of 50% aqueous HF (4 drops/mmol substrate) and acetonitrile (8 mL/mmol substrate) at room temperature was added the 2-hydroxy silane in acetonitrile (2 mL). The reaction was followed by TLC until completion, usually 5 min to 2 h at room temperature. Workup was effected by pouring the reaction mixture into aqueous $NaHCO_3$ (10 mL) and pentane (50 mL). The aqueous layer was extracted three times with 50-mL portions of pentane and the combined organic extracts were washed with saturated, aqueous NaCl (50 mL) and then dried over $MgSO_4$. Concentration and chromatography yielded the alkenes.

Procedure D: HF/Pyridine Elimination of Hydroxy Silanes. To a premixed solution of 50% aqueous HF (4 drops/mmol substrate), pyridine (0.5 mL/1 mmol substrate), and acetonitrile (8 mL/mmol substrate) was added the 2-hydroxy silane in acetonitrile (2 mL). The reactions were followed by TLC until completion, usually 0.5 h to 2 h at room temperature. Workup was carried out as in procedure C.

Procedure E: KH Elimination of Hydroxy Silanes. KH (50% oil dispersion, 3 mmol) was washed with anhydrous hexane (3 × 25 mL). The 2-hydroxysilane (1 mmol) was added in 5 mL of dry THF and the mixture stirred for 0.5 h to 24 h at room temperature. When TLC analysis showed no starting material the reaction was poured into saturated aqueous NH_4Cl (10 mL) and pentane (50 mL). Extraction with three 50-mL portions of pentane, washing with saturated aqueous NaCl (10 mL), followed by concentration, and chromatography produced the purified alkenes.

Acknowledgment. This work was supported by a grant from the National Science Foundation. We thank Professor Tsuneo Imamoto of Chiba University for valuable discussions.

Supplementary Material Available: Details of purification and characterization of hydroxy silanes, alkenes, and other products shown in Table I (8 pages). Ordering information given on any current masthead page.

Synthesis of Cholanthrene and 6-Methylcholanthrene, Biologically Active Analogues of the Potent Carcinogen 3-Methylcholanthrene

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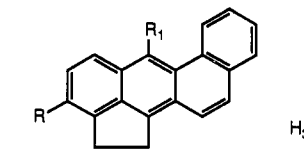
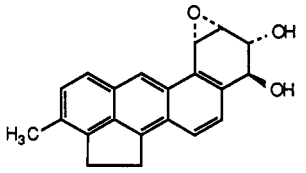
Received August 4, 1986

Although the biogenetic origin of 3-methylcholanthrene (3-MC) (**1a**) from steroids postulated by early investigators[1,2] has not been supported by subsequent studies,[3] 3-MC retains an important role in carcinogenesis research because of its exceptional carcinogenic potency.



1a: R = CH_3; R_1 = H. **b**: R = H; R_1 = CH_3. **c**: R = R_1 = H. **d**: R = R_1 = CH_3.

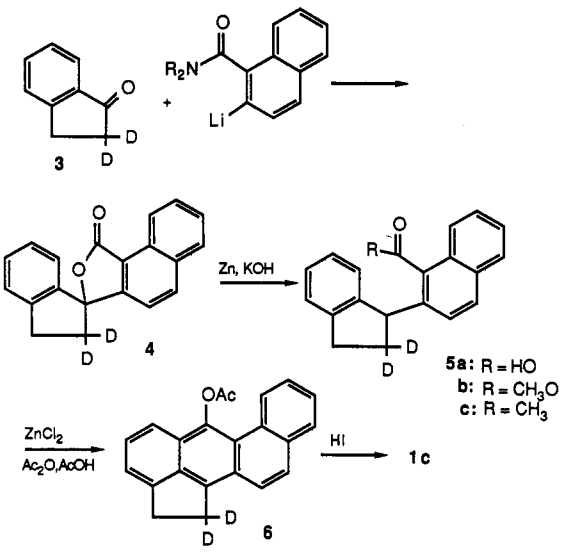


2

Bay region diol epoxide metabolites have been implicated recently as the active forms of other carcinogenic PAHs.[4,5] These intermediates bind covalently to DNA, leading to mutation, and ultimately to tumor induction. Investigations of the metabolic activation of 3-MC indicate that the bay region diol epoxide derivative, **2**,[6] accounts for only a small percentage of the oxidized metabolites of 3-MC which bind to nucleic acids in cells.[7] The majority of the 3-MC–DNA adducts arise from triol epoxides containing a third hydroxyl group in the 1-, 2-, and/or 3-positions.[7-9] In view of the complexity of the metabolism of 3-MC, we have initiated investigations on the parent hydrocarbon, cholanthrene (**1c**), which lacks a methyl group.

We now report convenient syntheses of **1c** and 6-methylcholanthrene (**1b**). The latter is predicted to be a more potent carcinogen than **1a** or **1c** because of the presence of a methyl group in the bay region.[10]

Scheme I



Results and Discussion

Synthesis of cholanthrene (**1c**) was accomplished via the reaction sequence in Scheme I which is based on the general method for the annelation of polycyclic ring systems previously reported.[11] This synthetic approach takes advantage of the availability of *o*-lithioarylamides from the ortho-metalation of *N,N*-diethylarylamides with alkyllithium–amine reagents by the method of Beak.[12] Condensation of 2,2-dideuterioindan-1-one (**3**) with 2-lithio-*N,N*-diethyl-1-naphthamide in ether at −78 °C furnished the addition product which on treatment with *p*-toluenesulfonic acid in refluxing benzene yielded the lactone **4**. The dideuterio analogue of indanone was employed to inhibit enolization of the carbonyl function, known to be a significant competing pathway in reactions of this type.[13] Reduction of **4** with zinc and alkali by the usual method[11] furnished the free acid **5a** in 70% yield. Reduction of **4** with zinc and acetic acid was more satisfactory, affording **5a** in essentially quantitative yield. Treatment of **5a** with $ZnCl_2$ in acetic acid–acetic anhydride yielded 6-acetoxycholanthrene (**6**). Removal of the 6-acetoxy group of **6** took place smoothly on reduction with hydriodic acid in the presence of hypophosphorus acid in refluxing acetic acid to yield cholanthrene.[11,14] Reaction time was short (90 s) to avoid further reduction of **1c** in the meso ring 6,12b-positions.[14] The deuterium isotope is lost in this step through HI-catalyzed exchange of the benzylic hydrogens.

6-Methylcholanthrene was readily synthesized by appropriate modification of the reaction sequence in Scheme I. For this purpose the carboxylic acid intermediate **5a** was esterified by treatment with KOH in hexamethylphosphoramide and methyl iodide to yield the methyl ester **5b**. The latter was converted to the corresponding methyl ketone **5c** by reaction with methyllithium in hexamethylphosphoramide and cyclized in liquid HF to yield the 1,1-dideuterio derivative of **1b**. Exchange of the deuterium atoms for hydrogen was effected by heating **1b** with *p*-toluenesulfonic acid in refluxing benzene.

The syntheses of **1b** and **1c** provide convenient methods for the preparation of these hydrocarbons on any desired

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